

Plausibility and Recovery From Garden Paths: An Eye-Tracking Study

Martin J. Pickering
University of Glasgow

Matthew J. Traxler
Florida State University and University of Glasgow

Three eye-tracking experiments investigated plausibility effects on recovery from misanalysis in sentence comprehension. On the initially favored analysis, a noun phrase served as the object of the preceding verb. On the ultimately correct analysis, it served as the subject of a main clause in Experiments 1 and 3 and of a complement clause in Experiment 2. If the object analysis was implausible, disruption occurred during processing of the noun phrase. If it was plausible, disruption occurred after disambiguation. In Experiment 3, discourse context affected plausibility of the initial analysis and subsequent reanalysis. The authors argue that readers performed substantial semantic processing on the initial analysis and committed strongly when it was plausible. Experiment 3 showed that these effects were not due to selectional restrictions or word co-occurrences and that the interpretation of the target sentence was not computed in isolation.

Research in sentence processing has focused overwhelmingly on the resolution of syntactic ambiguity by considering syntactic misanalysis and reanalysis in “garden-path” sentences (Bever, 1970; Frazier, 1979; Frazier & Rayner, 1982). (In this article, syntactic misanalysis and reanalysis may refer to adopting and abandoning a single analysis or to favoring and subsequently disfavoring an analysis in comparison to others.) Much recent research has been concerned with the role of semantics in initial syntactic analysis (e.g., Altmann, Garnham, & Dennis, 1992; Altmann & Steedman, 1988; Ferreira & Clifton, 1986; Mitchell, Corley, & Garnham, 1992; Rayner, Carlson, & Frazier, 1983; Taraban & McClelland, 1988; Trueswell, Tanenhaus, & Garnsey, 1994). In this article, we address a related question: How do semantic factors affect the process of recovery from misanalysis when there is no doubt that initial misanalysis has

taken place? We also address the question of what kinds of information affect the computation of the plausibility of an analysis: Is the relevant assessment of plausibility based solely on sentence-internal factors, or is it affected by discourse context?

Incremental understanding rapidly affects processing. For example, resolution of a noun phrase with respect to discourse context rapidly affects syntactic analysis (Altmann et al., 1992; Altmann, Garnham, & Henstra, 1994; Altmann & Steedman, 1988; Britt, Perfetti, Garrod, & Rayner, 1992; Britt, 1994; Spivey-Knowlton, Trueswell, & Tanenhaus, 1993; Trueswell & Tanenhaus, 1991). Semantic context also rapidly affects processing of spoken and written language (e.g., Boland, Tanenhaus, Garnsey, & Carlson, 1995; Garrod, Freudenthal, & Boyle, 1994; Marslen-Wilson, 1973, 1975; Marslen-Wilson, Tyler, & Koster, 1994; Swinney, 1979; Traxler & Pickering, 1996; Trueswell et al., 1994; Tyler & Marslen-Wilson, 1977). Hence, it might be expected that semantics would rapidly affect syntactic reanalysis.

The fact that people interpret sentences incrementally allows us to make some general predictions about semantic influence on syntactic processing. We propose that people experience greater difficulty during the initial processing of syntactically ambiguous fragments when the analysis that they adopt (or foreground) is semantically implausible than when it is semantically plausible. Further, we propose that people experience greater difficulty during processing of syntactically disambiguating information (after misanalysis) when the initial analysis had a plausible interpretation than when it had an implausible interpretation. If people construct an analysis for a sentence fragment that has a plausible interpretation, they should strongly commit to that analysis, integrating its interpretation with general knowledge. They should then find reanalysis comparatively difficult. In contrast, if people construct an analysis for a sentence fragment that has an implausible interpretation, they should less strongly commit to that analysis. Either they reanalyze immediately or they retain the analysis but integrate it less strongly with general knowledge. However, it is also

Martin J. Pickering, Human Communication Research Centre, Department of Psychology, University of Glasgow, Glasgow, United Kingdom; Matthew J. Traxler, Department of Psychology, Florida State University, and Human Communication Research Centre, Department of Psychology, University of Glasgow, Glasgow, United Kingdom.

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Correspondence concerning this article should be addressed to Martin J. Pickering, Human Communication Research Centre, Department of Psychology, University of Glasgow, Florentine House, 53 Hillhead Street, Glasgow G12 8QF United Kingdom. Electronic mail may be sent to martin@psy.gla.ac.uk.

possible that people incrementally construct a syntactic analysis and interpret it, but their degree of commitment to the analysis does not depend on whether its interpretation is plausible or not. If so, degree of difficulty at the point of syntactic disambiguation would not be affected by the plausibility of the current analysis.

To investigate whether commitment to plausible and implausible analyses differs, we looked at temporarily ambiguous sentences that are likely to produce syntactic misanalysis. We compared sentences containing plausible misanalyses with sentences containing implausible misanalyses. In Experiments 1 and 2, within-sentence factors determined plausibility. So, for example, a misanalysis might be plausible if it involved interpreting *the magazine* as the thing edited in *the woman edited the magazine*, and it might be implausible if it involved interpreting *the magazine* as the thing sailed in *the woman sailed the magazine*. We examined processing of syntactically ambiguous fragments to investigate semantic influences while readers were constructing an initial analysis. We examined processing of the syntactically disambiguating region to investigate semantic influences on recovery from misanalysis.

In Experiment 3, preceding context determined plausibility. So, for example, it is normally implausible that *the professor* could be the thing polished in *the janitor polished the professor*. But if context made it clear that *the professor* referred to a statue of a professor, then this interpretation would be plausible. A contextual effect of this kind would demonstrate that context can affect interpretation during initial analysis and hence affect syntactic processing. It would also show that apparent semantic effects cannot be explained away as being due to differences in the likelihood of the co-occurrence of specific words on the different analyses and must therefore reflect genuine processes of interpretation with respect to general knowledge (see below).

We intended to manipulate plausibility at a point in the sentence after the processor had made an initial choice of analysis. Hence, we adopted sentences for which we had good grounds to believe that misanalysis would occur. We could therefore focus on the question of whether semantics affects reanalysis. We were not concerned with the question of what happens if semantic information becomes relevant at the same time as the initial ambiguity is encountered. We now review work on two types of locally ambiguous sentence that considers how the plausibility of a misanalysis affects processing.

Plausibility and Garden-Pathing in Subordinate-Clause Ambiguities

Consider Sentence 1a:

(1a) As the woman edited the magazine amused all the reporters.

Current parsing theories propose that readers initially assume that the noun phrase *the magazine* is the object of *edited*. Frazier (1979) predicted this as a result of *late closure*, because this analysis allows the noun phrase to be integrated into the current clause. Other syntactically driven

accounts also predict that readers initially adopt the object analysis (e.g., Abney, 1989; Crocker, 1996; Gorrell, 1995; Pickering, 1994; Pritchett, 1992). Constraint-based accounts also predict that the processor foregrounds this analysis (MacDonald, Pearlmuter, & Seidenberg, 1994; Spivey-Knowlton et al., 1993), under the assumptions that either the verb *edited*, or some larger class of verbs that includes *edited*, is preferentially transitive and that a new clause would often be signaled by a comma after *edited*.

The object analysis turns out to be wrong. The verb *amused* indicates that *the magazine* must be the subject of this verb, and not the object of *edited*. Readers should therefore experience processing difficulty at *amused*. Experimental studies have confirmed this prediction (Clifton, 1993; Ferreira & Henderson, 1991; Frazier & Rayner, 1982; Warner & Glass, 1987).

Now consider Sentence 1b:

(1b) As the woman sailed the magazine amused all the reporters.

This sentence is syntactically identical to Sentence 1a but semantically different on the misanalysis. In Sentence 1a, the fragment *as the woman edited the magazine* is plausible. But in Sentence 1b, the fragment *as the woman sailed the magazine* is implausible. If readers misanalyze Sentences 1a and 1b, as the research indicates, and if they interpret sentences incrementally, then they should experience difficulty around *magazine* with 1b but not 1a during initial analysis.

In Sentence 1a, readers should strongly commit to the object analysis of the fragment *as the woman edited the magazine* because it is plausible. They could perform extensive semantic processing on the fragment, easily integrating its interpretation with general knowledge. Hence, abandoning this analysis should be relatively hard. But in Sentence 1b, readers should less strongly commit to the object analysis of the fragment *as the woman sailed the magazine* because it is implausible. They would find extensive semantic processing on the fragment difficult. Hence, abandoning this analysis should be relatively easy. We therefore predict that reanalysis should be easier in 1b than in 1a. Readers might reanalyze as soon as they have interpreted the fragment *as the woman sailed the magazine*, in which case there should be no difficulty at all at *amused*. Alternatively, they might accept the object analysis for the time being but perform less semantic processing based on that analysis, in which case Sentence 1b should produce some difficulty at *amused*, though less than Sentence 1a.

Note that this discussion assumes that readers interpret *magazine* as the head of the object noun phrase. In fact, Sentence 1b could have continued *as the woman sailed the magazine owner's yacht*, which would be plausible, where *magazine* would not be the head noun. If readers show disruption while processing *the magazine* in 1b, then they must be interpreting *magazine* as the head of the object-noun-phrase argument of *sailed*.

Stowe (1989) suggested that plausibility of the object analysis affects processing. Readers read sentences like 2a

and 2b and incrementally evaluated whether the current fragment was grammatical:

- (2a) As the police stopped the driver became very frightened.
 (2b) As the police stopped the silence became very frightening.

Readers took longer to make judgments on the critical noun phrase *the driver/silence* when the object analysis was implausible, as in Sentence 2b, and longer at the disambiguating point when the object analysis was plausible, as in Sentence 2a. However, as Clifton (1993) noted, grammaticality judgment takes a long time and may not reflect normal language processing. Further, some of the manipulations in this experiment may not have had the intended effect. In two conditions, the inanimate noun *truck* (which does not readily allow *stopped* to take an object) replaced *police*. In these conditions, readers took less time to make judgments on the disambiguating word when the critical noun phrase was *the driver* than when it was *the silence*. This does not admit of any straightforward interpretation.

In two eye-tracking experiments, Clifton (1993) manipulated the plausibility of the object analysis in Sentences 3 and 4:

- (3) Before the police stopped the Datsun disappeared into the night.
 (4) Before the police stopped the moon had risen over the ocean.

The plausibility of the object analysis was not manipulated in either experiment alone, but we can examine the effects of plausibility across the two experiments. Compared with unambiguous control sentences containing commas after *stopped*, readers took 11 ms per character longer on first-pass reading time (i.e., the time spent in the region before leaving the region), and 19 ms per character longer on total time in the region *disappeared* in Sentence 3. A numerically smaller effect occurred on the comparable region *had risen* in Sentence 4. When there was no comma, readers took 5 ms per character longer on first pass and 12 ms per character longer on total time. This difference between the two experiments provides some evidence that a noun phrase that makes the initial analysis plausible may cause the processor more difficulty on the disambiguating words than a noun phrase that makes the initial analysis implausible. However, this difference reflects a post hoc experimental comparison using items that were not perfectly controlled, and the effects were not evaluated statistically. The effect is clearly of sufficient interest to merit direct investigation.

Plausibility and Garden-Pathing in Complement-Clause Ambiguities

Consider Sentence 5a:

- (5a) The criminal confessed his sins harmed too many people.

Sentences like 5a are locally ambiguous in that the critical noun phrase *his sins* could be the object of the verb *confessed* or the subject of an embedded sentence, as in fact turns out to be the case. We call these sentences *complement-clause ambiguities*. If readers treat the critical noun phrase as an object, then they will experience difficulty at *harmed*.

Frazier (1979) predicted that the processor misanalyzes Sentence 5a as a result of *minimal attachment*, because the object analysis requires postulation of fewer nodes in a phrase-structure tree than the complement analysis. Other syntactically driven accounts also predict that readers initially adopt the object analysis (e.g., Abney, 1989; Crocker, 1996; Gorrell, 1995; Pickering, 1994; Pritchett, 1992). Constraint-based models predict that readers foreground the object analysis, so long as verb preferences support this analysis (MacDonald et al., 1994; Spivey-Knowlton et al., 1993).

Complement-clause ambiguities have much in common with subordinate-clause ambiguities, but linguists and psycholinguists treat them as different kinds of ambiguities. For instance, Frazier (1979) assumed that the processor initially selects the object analysis in both cases, but for different reasons. In subordinate-clause ambiguities, the choice of object analysis follows from late closure; whereas in complement-clause ambiguities, it follows from minimal attachment. From the perspective of this article, perhaps the most interesting difference is that the critical noun phrase in subordinate-clause ambiguities (*the magazine* in Sentence 1a) changes clause after reanalysis; whereas the equivalent noun phrase in complement-clause ambiguities (*his sins* in Sentence 5a), although demoted to the subject of an embedded clause, remains part of the sentence's main clause (because the entire embedded clause serves as the complement of the sentence's main verb). In this case, it may be possible to perform reanalysis by revising the initial analysis rather than by wholesale reconstruction (e.g., Gorrell, 1995; Pritchett, 1992; Sturt & Crocker, 1996).

In fact, there is debate about whether complement-clause ambiguities ever cause syntactic misanalysis. Some studies showed no processing difficulty after the point of syntactic disambiguation for complement-clause ambiguities (Holmes, Kennedy, & Murray, 1987; Kennedy, Murray, Jennings, & Reid, 1989). Other studies showed misanalysis effects either generally (Ferreira & Henderson, 1990; Frazier & Rayner, 1982; Rayner & Frazier, 1987) or when the ambiguous sentences contained object-preference verbs (Trueswell, Tanenhaus, & Kello, 1993). Some theoretical accounts argue that the parser initially chooses the object analysis but that reanalysis produces no conscious difficulty (Gorrell, 1995; Pritchett, 1992). The weight of evidence suggests that complement-clause ambiguities do cause a garden-path effect with object-preference verbs, but a further demonstration of this effect would help resolve the conflicting data.

As with subordinate-clause ambiguities, it is possible to manipulate whether the misanalysis is plausible or not. For example, people can confess sins but cannot confess gangs. Hence, the object analysis is plausible in Sentence 5a above but implausible in Sentence 5b:

- (5b) The criminal confessed his gang harmed too many people.

If readers misanalyze Sentences 5a and 5b, and if they interpret sentences incrementally, then we predict that they should experience difficulty with 5b during processing of *his gang*, but no difficulty with 5a during processing of *his sins*. But after they reach *harmed*, we make the opposite predic-

tion: Readers should find 5a harder to recover from than 5b, so there should be more disruption around *harmed* in 5a than in 5b. For this to happen, readers must also interpret *sins* or *gang* as the head of the object-noun-phrase argument of *confessed*.

Holmes, Stowe, and Cupples (1989) examined the effect of manipulating the plausibility of the object analysis, using sentences like 6a and 6b in grammaticality-judgment and self-paced-reading experiments:

- (6a) The reporter saw her friend was not succeeding.
 (6b) The reporter saw her method was not succeeding.

Control conditions included the complementizer *that* immediately after *saw*. As with *confessed*, the verb *saw* can take either an object noun phrase or a complement clause. If readers adopt the object analysis, then they should have greater difficulty processing *was* in Sentences 6a and 6b than in the controls. In sentences containing object-preference verbs, readers experienced difficulty on *was* in a grammaticality-judgment experiment and on the next word *not* in a self-paced-reading experiment (with a nonsignificant tendency on *was*). In addition, Holmes et al. looked for a plausibility effect at the critical noun by comparing *friend* with *method*. The grammaticality-judgment experiment revealed longer judgment time on *method* than on *friend*. Holmes et al. reasoned that this would occur only if the parser had adopted a direct-object interpretation at this point, but they also found this effect when the complementizer was present. In addition, the self-paced-reading experiment showed no such effect. So plausibility effects were only detected by using a technique that is uncertainly related to normal reading, and plausibility effects also occurred in the control conditions.

More important, Holmes et al. (1989) did not find any evidence for an effect of plausibility at or after the disambiguating verb *was* in either experiment. Thus, it may be that plausibility has no effect on degree of commitment in complement-clause ambiguities, perhaps because reanalysis is due to fairly straightforward processes of revision. (In contrast, subordinate-clause reanalysis may require wholesale reconstruction, and therefore the processor may be more concerned to use plausibility to determine degree of commitment.) However, Holmes et al.'s null finding clearly does not disprove the hypothesis that plausibility influences recovery from misanalysis. In particular, the measures they used may not detect effects that more sensitive measures (e.g., eye-tracking) do.

Experiments

In Experiment 1, we investigated plausibility effects in subordinate-clause ambiguities. Using a similar design, in Experiment 2 we investigated plausibility effects in complement-clause ambiguities. Although the experiments address the same general question, we conducted two separate experiments because of the linguistic and psycholinguistic differences between the constructions (as discussed above). The central concern is whether the plausibility of the initial analysis affects subsequent reanalysis. More specifically, do

sentences with implausible initial analyses present difficulty in reanalysis, and, if so, are they less difficult to reanalyze than sentences with plausible initial analyses? Previous research is fairly unclear in these respects: For instance, there is some evidence that plausibility affects the difficulty of reanalysis with subordinate-clause ambiguities (see Clifton, 1993) but not with complement-clause ambiguities (see Holmes et al., 1989). In Experiment 3, we also used subordinate-clause ambiguities, but we embedded them within short discourse contexts. These contexts may affect the plausibility of the target sentences, which do not differ between conditions. If the process of analysis and reanalysis is affected by the context manipulation, it would demonstrate that contextual semantics affects sentence processing in ways that are similar to sentence-internal semantics. It would also demonstrate that our effects must be due to the manipulation of plausibility and could not be due to statistical or other low-level properties of the words in the target sentence.

Experiment 1

In Experiment 1, we investigated plausibility effects in subordinate-clause ambiguities and unambiguous controls, as in Sentences 7a–d:

- (7a) As the woman edited the magazine about fishing amused all the reporters.
 (7b) As the woman sailed the magazine about fishing amused all the reporters.
 (7c) As the woman edited, the magazine about fishing amused all the reporters.
 (7d) As the woman sailed, the magazine about fishing amused all the reporters.

Sentence 7a contains a plausible misanalysis, under which the woman edited the magazine, whereas 7b contains an implausible misanalysis, under which the woman sailed the magazine. These analyses make *the magazine about fishing* the object of *edited* or *sailed* (with *magazine* being the head noun). Sentences 7c and 7d are disambiguated by the comma, so no misanalysis should occur. If readers initially adopt the object analysis in 7a and 7b, then they should experience greater difficulty in the region *magazine about fishing* in 7b than in 7a, 7c, and 7d because this analysis is implausible in 7b. Readers should experience greater difficulty processing the syntactically disambiguating verb phrase in 7a than in 7b–d because the object analysis in 7a is plausible, and so readers will find it harder to switch to the correct analysis. Finally, the difficulty of Sentence 7b with respect to 7c and 7d as the verb phrase is processed may provide evidence about whether implausibility by itself can trigger reanalysis. We also conducted a replication, using sentences like 7a and 7b in short discourse contexts (see *Discussion*).

Method

Participants. Thirty-two normally sighted, native English-speaking students from the University of Glasgow were paid to participate. Some had taken part in other eye-tracking studies.

Stimuli. We constructed 24 sets of four sentences for Experiment 1 (similar to Sentences 7a–d above; see Appendix). We manipulated plausibility by pairing the second noun phrase in each sentence with two different verbs. According to the results of a norming study (see below), a given noun phrase made a plausible object of one of the verbs but not of the other. In any set of items, the conditions differed from one another only in the presence or absence of a comma and the verb in the subordinate clause. Each subordinate verb appeared in two sets of items, once in the plausible conditions and once in the implausible conditions. This ensured that irrelevant characteristics of particular verbs would not confound any effects of plausibility. Likewise, each critical noun phrase appeared in two sets of items, once in the plausible conditions and once in the implausible conditions. This method of constructing sentences produced identical critical regions (across conditions). We constructed four lists of items. Exactly one version of each item appeared in each list.

All target sentences in Experiment 1 (and in Experiment 2 and its replications) were displayed on two lines and were split one or two words after the syntactically disambiguating verb.

Norming. The plausibility manipulation depended on readers' interpretations of the subordinate clause. We therefore conducted a norming study based on these subordinate clauses. Twenty raters from the University of Glasgow read a typewritten list of 144 sentences (e.g., *The woman sailed the magazine*) and wrote down a number from 0 (*very implausible*) to 7 (*very plausible*) that indicated how much sense each sentence made. About half of the sentences related to this experiment and about half related to Experiment 2. None of these raters participated in any other phase of the study. We eliminated all pairs of items in which either item produced a mean rating between 2.0 and 5.0. Hence, raters perceived critical noun phrases in the plausible condition as plausible objects for the subordinate verb and critical noun phrases in the implausible condition as implausible objects for the subordinate verb. The subordinate clauses used in the experimental materials contained these sentences and postnominal modifiers (such as *about fishing*).

Procedure. An SRI Dual Purkinje Generation 5.5 eye-tracker monitored participants' eye movements. The tracker has angular resolution of 10' arc. It monitored only the right eye's gaze location. A PC displayed items on a VDU 70 cm from readers' eyes. The VDU displayed four characters per degree of visual angle. The tracker monitored readers' gaze location every millisecond, and the software sampled the tracker's output to establish the sequence of eye fixations and their start and finish times.

Before the experiment started, readers read an explanation of eye-tracking and a set of instructions. The instructions told them to read at their normal rate and to comprehend the sentences as well as they could. The experimenter then seated the reader at the eye-tracker and used individually molded bite bars and forehead restraints to minimize head movements. Next, readers completed a calibration procedure. Before each trial, a small "+" symbol appeared near the upper left-hand corner of the screen. Immediately after readers fixated the "+" symbol, the computer displayed a target sentence, with the first character of the sentence replacing the "+" on the screen. The "+" symbol also served as an automatic calibration check because the computer did not display the text until it detected stable fixation on the "+" symbol. If readers could not fixate the "+" symbol, the experimenter recalibrated the eye-tracker. When readers finished reading each sentence, they pressed a key, and the computer either displayed a comprehension question (e.g., *Did the reporters find the fishing magazine amusing?*) on about half of the trials, balanced across conditions, or proceeded to the next trial. Half of these questions had "yes" answers, and half had "no." Readers responded to the

questions by pressing a button and received no feedback on their answers. After readers completed each quarter of the experiment, the experimenter recalibrated the equipment, and readers had a short break. Thus, the eye-tracker was calibrated a minimum of four times during the experiment and usually more. Readers normally completed the experiment in about 40 min.

The computer displayed each experimental list in a fixed random order, together with the 24 experimental items from Experiment 2 and 50 filler sentences of various types. The first two sentences and the first two after each calibration were fillers. At least one sentence intervened between each sentence from Experiment 1.

Regions. We identified four regions for statistical analysis (see Table 1). The *noun* region comprised the head noun from the noun phrase of interest (e.g., *magazine*). We excluded the determiner from this region because it is only at the noun that the plausibility varies between conditions. (For all of the experiments, we performed a full set of analyses that included the determiner in the noun region. Analyses with and without the determiner produced nearly identical results.) The *postnoun* region comprised the text between the noun region and the verb region. The *verb* region comprised the syntactically disambiguating verb (e.g., *amused*). The *postverb* region comprised the text after the verb region up to the line break. We sometimes refer to the *critical noun phrase*; by this, we mean the noun and postnoun regions together.

Table 1
Experiment 1 and Its Replication: Regressions, First Pass, and Total Time by Region and Condition

Condition	Region			
	Noun	Postnoun	Verb	Postverb
Experiment 1				
Regressions				
Plausible, no comma	0.15	0.08	0.20	0.37
Implausible, no comma	0.24	0.24	0.15	0.22
Plausible, comma	0.11	0.10	0.15	0.16
Implausible, comma	0.13	0.17	0.22	0.18
First pass (in ms)				
Plausible, no comma	247	427	277	271
Implausible, no comma	264	449	273	254
Plausible, comma	251	442	265	218
Implausible, comma	252	410	274	225
Total time (in ms)				
Plausible, no comma	477	873	512	502
Implausible, no comma	509	836	461	373
Plausible, comma	365	654	391	292
Implausible, comma	379	667	419	315
Replication				
Regressions				
Plausible	0.12	0.11	0.36	0.46
Implausible	0.17	0.33	0.29	0.29
First pass (in ms)				
Plausible	225	426	275	306
Implausible	243	396	242	308
Total time (in ms)				
Plausible	462	1052	672	628
Implausible	513	973	513	509

Analyses. An automatic procedure pooled short contiguous fixations. The procedure incorporated fixations of less than 80 ms into larger fixations within one character and then deleted fixations of less than 40 ms that fell within three characters of any other fixation. Following Rayner and Pollatsek (1989), we presumed that readers do not extract much information during such brief fixations. Before analyzing the eye-movement data, we eliminated the occasional trial when the reader failed to read the sentence or when the tracker lost track of the reader's gaze location. More specifically, we removed trials in which two or more adjacent regions had 0-ms first-pass reading time. If readers skipped both the noun and verb regions on first pass, then that trial was eliminated.

A *regression* is any eye movement that begins at the right-most point the reader has fixated and leaves the currently fixated region to the left. This definition is therefore only concerned with disruption occurring during initial processing. *First-pass time* is the sum of the fixations occurring within a region before the first fixation outside the region. If the eye fixates a point beyond the end of a region before fixating the region for the first time, then the first-pass time for that region is zero. (This measure is equivalent to the gaze-duration measure [e.g., Rayner & Duffy, 1986], when the region is a single word.) *Total time* is the sum of all fixations in a region.

Our main analyses excluded 0-ms fixations that occurred when readers skipped a region. For all of the experiments, we performed a second set of analyses that included 0-ms fixations. The results of these analyses matched the results of the main analyses almost exactly, so we do not report them. All independent variables in all of the experiments were treated as within-subjects and within-items variables in the statistical analyses.

Results

Effects were analyzed by subjects (F_1) and by items (F_2). Table 1 presents regressions, first-pass time, and total time by region and condition for Experiment 1 and its replication. Note that the regressions means are based on the total number of regressions per condition per subject, divided by the number of trials in each condition. To recover the raw number of regressions, multiply the means by 6. The error terms in the analysis of variance (ANOVA) tables are based on the raw scores. Table 2 summarizes results of the ANOVAs for Experiment 1 and its replication. Where simple effects are reported, the error terms and degrees of freedom are based on the appropriate Plausibility \times Punctuation interaction tests that appear in Table 2.

If readers find it easier to process a plausible analysis initially but easier to abandon an implausible analysis, and if the comma prevents readers from initially adopting such an analysis, then we should see three-way interactions of plausibility (plausible vs. implausible object analysis), punctuation (comma present vs. absent), and region (noun vs. verb). These interactions emerge in the regressions and total-time data (see the first block of analyses in Table 2) but not in the first-pass data. The interactions occurred because plausibility and region interacted in ambiguous sentences (i.e., sentences without a comma) and did not interact in unambiguous sentences. These effects suggest that when a comma was present readers adopted only the correct analysis. The regressions demonstrate that readers initially adopted

or foregrounded the ultimately incorrect object analysis when the comma did not appear. Figure 1 illustrates differences between the two types of ambiguous sentences (sentences without commas) and their unambiguous controls for Experiment 1, with regressions data on the left and first-pass data on the right. The two types of unambiguous sentences produced relatively few regressions, and they did not differ from one another. The sentences with implausible object analyses produced more regressions than did the sentences with plausible object analyses in the noun and postnoun regions, where readers first constructed the implausible interpretation, and fewer regressions in the verb and post-verb regions.

If implausible object analyses cause difficulty once adopted, then one should find interactions of plausibility and punctuation during processing of the critical noun phrase. The regressions and first-pass data produced trends toward this interaction, but none of the analyses attained the standard level of statistical significance (see the bottom of Table 2 for analyses on individual regions). However, tests for simple effects demonstrated that sentences with implausible object analyses evoked more regressions from the noun and postnoun regions than did their unambiguous controls, noun: $F_1 = 7.20, p < .02; F_2 = 8.62, p < .01$; postnoun: $F_1 = 4.55, p < .05; F_2 = 4.85, p < .05$, and than sentences with plausible object analyses, noun: $F_1 = 5.83, p < .05; F_2 = 7.12, p < .02$; postnoun: $F_1 = 22.6, p < .0001; F_2 = 19.5, p < .001$. Total-time data also demonstrated that readers had difficulty processing the critical noun phrase when it was part of an implausible object analysis. Total time on the critical noun phrase was longer for sentences with implausible object analyses than for their unambiguous controls, noun: $F_1 = 25.6, p < .0001; F_2 = 6.22, p < .02$; postnoun: $F_1 = 14.3, p < .001; F_2 = 30.7, p < .0001$. The pattern of regressions in the critical noun phrase suggests that readers rapidly constructed and interpreted the object analysis, even though it subsequently turned out to be a misanalysis. When this analysis had an implausible interpretation, readers were rapidly disrupted, but when it had a plausible interpretation, readers processed the critical noun phrase without difficulty.

Interactions of plausibility and punctuation in the verb region occurred in the total time analyses and in the subjects analysis of the regressions data, with a marginal result in the items analysis of the regressions data. The first-pass data showed no interaction of plausibility and punctuation in the verb region. The postverb region produced similar results, with statistically significant interactions of plausibility and punctuation in the regressions and total-time data but no such result in the first-pass data. Taken together, these results demonstrated that readers had greater difficulty abandoning plausible object analyses after syntactic disambiguation. Simple effects give further support to this assertion, by showing that sentences with plausible object analyses produced more disruption after syntactic disambiguation than did their unambiguous controls on all three measures. Regressions showed this effect in the postverb region, $F_1 = 23.0, p < .0001; F_2 = 26.0, p < .0001$, as did first pass, $F_1 = 7.96, p < .01; F_2 = 5.65, p < .03$. Total time showed the

Table 2
Experiment 1 and Its Replication: ANOVAs for Regressions, First-Pass, and Total-Time Data

Source	Within subjects		Within items	
	F_1	MSE	F_2	MSE
Experiment 1				
PL × R (noun vs. verb) × PU				
Regressions	6.97**	0.77	4.34*	2.10
First pass	<1	4,283	1.74	5,021
Total time	4.88*	7,961	8.58**	3,872
PL × R (noun vs. verb, sentences without commas)				
Regressions	6.64*	0.99	8.04**	1.48
First pass	<1	.064	1.37	6,964
Total time	7.96**	6,956	4.90*	8,751
PL × R (noun vs. verb, sentences with commas)				
Regressions	<1	0.69	<1	0.41
First pass	<1	3,041	<1	0.32
Total time	<1	7,701	<1	4,516
PL × PU (noun region)				
Regressions	1.52	0.87	2.00	1.17
First pass	<1	3,360	<1	2,771
Total time	<1	10,525	<1	6,219
PL × PU (postnoun region)				
Regressions	3.89	0.58	3.50	0.96
First pass	2.73	8,780	3.81	4,347
Total time	<1	31,663	1.11	12,716
PL × PU (verb region)				
Regressions	4.73*	0.95	3.94	1.89
First pass	<1	5,183	1.14	2,891
Total time	4.43*	11,677	5.22*	12,066
PL × PU (postverb region)				
Regressions	6.90**	1.09	8.38**	1.28
First pass	<1	5,634	<1	5,077
Total time	14.0**	13,095	11.3**	12,166
Replication				
PL × R (noun vs. verb)				
Regressions	3.17	1.44	3.77	1.87
First pass	5.36*	4,250	5.09*	3,067
Total time	29.0**	13,710	20.4**	12,963
PL × R (postnoun vs. postverb)				
Regressions	22.8**	2.14	25.8**	2.91
First pass	1.28	7,062	1.38	6,988
Total time	<1	31,152	1.34	13,504
PL (noun region)				
Regressions	4.65*	0.42	2.16	1.39
First pass	1.58	3,484	2.51	1,243
Total time	2.45	19,418	3.72	9,635
PL (postnoun region)				
Regressions	24.3**	1.34	23.7**	2.11
First pass	1.58	9,870	1.66	9,839
Total time	1.74	64,797	3.15	15,602
PL (verb region)				
Regressions	1.51	1.76	1.52	2.69
First pass	3.52	5,497	3.16	4,621
Total time	14.8**	30,691	14.4**	20,172
PL (postverb region)				
Regressions	7.38**	2.38	9.86**	2.74
First pass	<1	5,023	<1	5,543
Total time	7.14**	34,962	5.69*	29,839

Note. Degrees of freedom in Experiment 1 are 1 and 31 for subjects (F_1) and 1 and 23 for items (F_2). Degrees of freedom for the replication experiment are 1 and 35 for subjects and 1 and 23 for items. PL = plausibility; R = region; PU = punctuation.

* $p < .05$. ** $p < .01$.

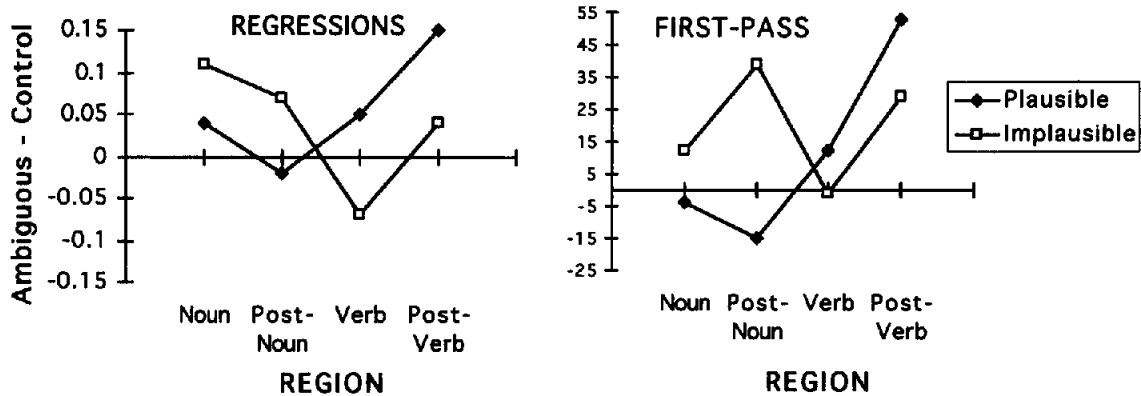


Figure 1. Experiment 1: The left-hand panel represents mean first-pass regressions in ambiguous control sentences minus the regressions in the unambiguous control sentences. The right-hand panel represents mean first-pass time (in milliseconds) in the ambiguous sentences minus first-pass times in unambiguous control sentences.

effect in both regions, verb: $F_1 = 20.3, p < .0001$; $F_2 = 19.6, p < .001$; postverb: $F_1 = 53.6, p < .0001$; $F_2 = 42.3, p < .0001$.

Regressions and total-time data demonstrated that sentences with plausible object analyses caused greater disruption after disambiguation than did sentences with implausible object analyses. The former produced more regressions than the latter in the postverb region, $F_1 = 10.5, p < .01$; $F_2 = 10.3, p < .01$, and led to longer total times in both regions, verb: $F_1 = 3.65, p < .07$; $F_2 = 3.73, p < .07$; postverb: $F_1 = 20.1, p < .0001$; $F_2 = 18.2, p < .001$.

If implausibility always triggered reanalysis, then sentences with implausible object analyses should not differ from their unambiguous controls during the disambiguating verb phrase (assuming that our implausible sentences were implausible enough). Regressions and first-pass data produced no differences between these sentences in either the verb or postverb region, but there was a weak total-time effect in the postverb region, $F_1 = 4.11, p < .05$; $F_2 = 3.05, p < .10$. If this difference reflects reanalysis, then readers presumably do not always abandon the favored analysis on the basis of implausibility alone but at least sometimes retain that analysis until syntactic information makes that analysis impossible.

Discussion

The regressions and total-time data demonstrate that readers misanalyzed both types of ambiguous sentence, that sentences with implausible object analyses were harder to process during the critical noun phrase, and that sentences with plausible object analyses were harder to process during the syntactically disambiguating verb phrase. The regressions data demonstrate further that readers incrementally interpreted the sentences, because plausibility effects emerged before the point of syntactic disambiguation. Readers must have initially treated *the magazine about fishing* as the object of the subordinate verb (with *magazine* as the head noun).

To increase our confidence in these results and to determine whether similar effects occurred in short discourses, we conducted a two-condition replication using the ambiguous materials from Experiment 1 (e.g., 7a and 7b) preceded by a context sentence. (Unlike Experiment 3 below, this context did not have major theoretical significance, though it may have improved readability.) Hence, we were able to increase the number of ambiguous items and thereby increase the chance of finding differences between sentences with implausible misanalyses and sentences with plausible misanalyses. We paid 36 new participants to take part and presented the experimental items together with 81 other items. The results are included in Table 1 under the subheading "Replication."

The results from the replication are entirely compatible with the results from Experiment 1. Because we did not manipulate punctuation in the replication, our initial analyses explored the interaction of plausibility and region, noun versus verb region in the first case, and postnoun versus postverb region in the second. We examined the postnoun and postverb regions, as in Experiment 1, because effects triggered by one part of a sentence may appear slightly further along in the sentence (see, e.g., Ehrlich & Rayner, 1983; Rayner & Pollatsek, 1989). If readers find it easier to process a plausible analysis initially but easier to abandon an implausible analysis, then one should find interactions of region and plausibility. These first two tests produced the predicted interactions (see the first two sections of the replication in Table 2).

The next set of analyses tested for the effects of plausibility within individual regions (see the last four sections of the replication in Table 2). The strongest effects occurred in the verb and postverb regions on total time. But the pattern in the regressions and first-pass data closely resembles the pattern obtained in the comparable conditions in Experiment 1 (see Table 1). Thus, we can be confident that the pattern we observed in Experiment 1 accurately reflects processing of subordinate-clause ambiguities. Further, similar patterns

emerged whether readers processed sentences individually or as part of a more elaborate discourse.

The only surprising result in Experiment 1 and the replication was the scarcity of effects in the first-pass data. However, the regressions data demonstrated that readers in general responded to both implausibility and syntactic evidence for misanalysis by re-reading preceding text rather than by greatly slowing their reading. This pattern of processing may partially reflect the strength of the plausibility manipulation and the fact that readers never saw an experimental item in which the critical noun phrase was the syntactic object of the preceding verb. Had the implausibility been weaker, readers might have worked longer to come up with an acceptable interpretation instead of immediately beginning a regressive eye movement. Likewise, if the object analysis had been correct on some proportion of trials, readers might have fixated the critical noun phrase for longer (see also the *Discussion* to Experiment 3 below).

Experiment 2

In Experiment 2, we investigated plausibility effects in sentences with complement-clause ambiguities and unambiguous controls, like Sentences 8a–d:

- (8a) The criminal confessed his sins which upset kids harmed too many people.
- (8b) The criminal confessed his gang which upset kids harmed too many people.
- (8c) The criminal confessed that his sins which upset kids harmed too many people.
- (8d) The criminal confessed that his gang which upset kids harmed too many people.

Sentence 8a contains a plausible object analysis, under which the criminal confessed his sins, whereas 8b contains an implausible object analysis, under which the criminal confessed his gang. Sentences 8c and 8d are disambiguated by the complementizer *that*, so no misanalysis should occur. If readers misanalyze 8a and 8b, then they should experience greater difficulty while processing *his sins/gang which upset kids* in 8b than in 8a, 8c, and 8d because this object analysis has an implausible interpretation in 8b. Readers should experience greater difficulty processing the syntactically disambiguating verb phrase in 8a than in 8b–d, because the object analysis in 8a has a plausible interpretation that would make it more difficult for readers to switch to the correct analysis. As in Experiment 1, we were also interested in whether readers experienced greater disruption in 8b than in 8c and 8d in this region. We also conducted a replication, analogous to the replication to Experiment 1 (see *Discussion*).

Method

Participants and procedure. Experiment 2 was run in conjunction with Experiment 1, and the participants and procedure were identical to those in Experiment 1.

Stimuli. We constructed 24 sets of four sentences for Experiment 2 (similar to Sentences 8a–d above; see Appendix). We manipulated plausibility by pairing verbs with two different noun

phrases. According to the results of a norming study (see Experiment 1), half of the noun phrases made plausible objects for the verbs and half made implausible objects for the verbs. We equated the different noun phrases' length and frequency between the plausible and implausible versions of each sentence (Kucera & Francis, 1986). The ambiguity in this experiment, as in Experiment 1, involved a choice between treating a noun phrase as the object of a verb or as the subject of a new clause.

One factor we must consider is whether the critical noun phrases in the plausible and implausible versions of the sentences make equally good subjects for the complement clause. For instance, are *His sins harmed too many people* and *His gang harmed too many people* equally plausible? We might expect readers to have less difficulty processing plausible than implausible complement clauses, for reasons that have nothing to do with the initial misanalysis. Any differences in plausibility between the complement clauses in different conditions may accentuate or mask any disruption after syntactic disambiguation. We therefore asked 13 raters to rate sentences consisting of the complement clauses from the experimental items on a scale ranging from 0 to 7, as in previous norming. Sentences from the implausible conditions produced a mean rating of 4.7, whereas sentences from the plausible conditions produced a mean rating of 6.0. These means did indeed differ from one another, $F_1(1, 12) = 20.18, p < .001$; $F_2(1, 22) = 5.71, p < .05$. Note, however, that raters perceived that the complement clauses were less plausible in the implausible conditions than in the plausible conditions. If raters have less difficulty processing the disambiguating verb phrase in the implausible conditions than in the plausible conditions, this cannot be attributed to this plausibility difference.

Regions. We identified four regions for statistical analysis, just as in Experiment 1 (see Table 3). In Sentences 8a–d, the noun region comprised the word *sins* or *gang*. The verb region comprised the word *harmed*.

Results

Table 3 presents regressions, first-pass, and total-time data by region and condition for Experiment 2 and its replication. Note that the regressions means are based on the total number of regressions per condition per participant, divided by the number of trials in each condition. To recover the raw number of regressions, multiply the means by 6. The error terms in the ANOVA tables are based on the raw scores. Table 4 summarizes results of the ANOVAs for Experiment 2 and its replication. Where simple effects are reported, the error terms and degrees of freedom are based on the appropriate plausibility by complementizer interaction tests that appear in Table 4. As in Experiment 1, we analyzed the noun and postnoun regions separately on the assumption that effects that are triggered by one part of the text can appear slightly downstream.

If readers find it easier to process a plausible analysis initially but easier to abandon an implausible analysis, and if the complementizer prevents readers from initially adopting such an analysis, then we should see three-way interactions of plausibility (plausible vs. implausible object analysis), punctuation (complementizer present vs. absent), and region (in this case, noun vs. verb or postnoun vs. verb). Table 4 shows that analyses on the noun and verb regions produced only a weak three-way interaction in the total-time data. This interaction occurred because plausibility and region interacted in ambiguous sentences (without complementizers)

Table 3
Experiment 2 and Its Replication: Regressions, First Pass, and Total Time by Region and Condition

Condition	Region			
	Noun	Postnoun	Verb	Postverb
Experiment 2				
Regressions				
Plausible, no comp.	0.22	0.12	0.32	0.18
Implausible, no comp.	0.23	0.28	0.28	0.15
Plausible, comp.	0.18	0.12	0.21	0.11
Implausible, comp.	0.18	0.16	0.21	0.10
First pass (in ms)				
Plausible, no comp.	254	416	302	176
Implausible, no comp.	258	427	306	186
Plausible, comp.	218	439	284	158
Implausible, comp.	236	449	300	163
Total time (in ms)				
Plausible, no comp.	489	936	618	294
Implausible, no comp.	561	947	558	240
Plausible, comp.	365	731	439	274
Implausible, comp.	411	793	455	231
Replication				
Regressions				
Plausible	0.33	0.18	0.68	0.48
Implausible	0.33	0.55	0.68	0.36
First pass (in ms)				
Plausible	249	408	305	167
Implausible	234	428	320	179
Total time (in ms)				
Plausible	484	750	1105	346
Implausible	541	634	1120	284

Note. Comp. = complementizer.

but did not interact in unambiguous sentences. However, when we compared the postnoun and verb regions, the regressions data produced a three-way interaction of plausibility, complementizer, and region. As in the total-time data, the three-way interaction in the regressions data occurred because plausibility and region interacted in the ambiguous sentences but not in the unambiguous sentences. These results are thus compatible with the results from Experiment 1. Figure 2 illustrates differences between the two types of ambiguous sentences (sentences without complementizers) and their unambiguous controls for Experiment 2, with regressions data on the left and first-pass data on the right. The regressions data show a pattern like that obtained in Experiment 1 (see Figure 1).

Table 4 shows that we found an interaction of plausibility and complementizer in the regressions data from the postnoun region and an interaction in the total-time data from the verb region that attained statistical significance in the subjects analysis but not in the items analysis. None of the other plausibility by complementizer interaction tests, including those on the first-pass data, achieved the standard level of significance in both the subjects and items analyses.

As in Experiment 1 (and its replication), sentences with

implausible object analyses were difficult to process during the critical noun phrase. They evoked more regressions from the postnoun region than did their unambiguous controls, $F_1 = 9.45, p < .01$; $F_2 = 10.5, p < .01$, or sentences with plausible object analyses, $F_1 = 17.2, p < .001$; $F_2 = 19.0, p < .001$. Likewise, they produced longer total time in the noun region than did their unambiguous controls, $F_1 = 39.4, p < .0001$; $F_2 = 28.7, p < .0001$, or sentences with plausible object analyses, $F_1 = 9.24, p < .01$; $F_2 = 5.89, p < .03$.

Also as in Experiment 1 (and its replication), sentences with plausible object analyses were difficult to process during the syntactically disambiguating verb phrase. They evoked more regressions from the verb region than did their unambiguous controls, $F_1 = 8.85, p < .01$; $F_2 = 5.97, p < .05$. Likewise, they produced longer total time in the verb region than their unambiguous controls, $F_1 = 61.7, p < .0001$; $F_2 = 27.4, p < .0001$, or sentences with implausible object analyses, $F_1 = 7.29, p < .01$; $F_2 = 4.67, p < .05$.

If implausibility always triggers syntactic reanalysis, then sentences with implausible object analyses should not differ from their unambiguous controls during the disambiguating verb phrase (assuming that our implausible sentences were implausible enough). Regressions and first-pass data produced no differences between these sentences in either the verb or postverb region. However, total time in the verb region was greater for sentences with implausible object analyses than for their unambiguous controls, $F_1 = 20.4, p < .0001$; $F_2 = 8.63, p < .01$. Hence, readers presumably do not always abandon an analysis on the basis of implausibility alone.

Discussion

The regressions and total-time data demonstrate that readers misanalyzed both kinds of ambiguous sentences, that sentences with implausible object analyses were harder to process during the critical noun phrase, and that sentences with plausible object analyses were harder to process during the disambiguating verb phrase (contra Holmes et al., 1989). These results are directly comparable with those found in Experiment 1 and its replication.

As in Experiment 1, we conducted a two-condition replication using the ambiguous materials from Experiment 2 (e.g., Sentences 8a and 8b) preceded by a context sentence. We paid 20 new participants to take part and presented the experimental items together with 50 other items. The results are included in Table 2 under the subheading "Replication."

This replication produced results similar to those of Experiment 2 (see Table 3). The total-time data produced an interaction of plausibility and region between the noun and verb regions, and the regressions data produced an interaction of plausibility and region between the postnoun and verb regions. The difficulty associated with sentences containing implausible object analyses was reflected in greater numbers of regressions from the postnoun region; whereas the difficulty associated with abandoning plausible object analyses was reflected in longer reading times on the verb and postverb regions.

Experiment 2 and its replication produced no statistically

Table 4
 Experiment 2 and Its Replication: ANOVAs for Regressions, First Pass, and Total-Time Data

Source	Within subjects		Within items	
	F_1	<i>MSE</i>	F_2	<i>MSE</i>
Experiment 2				
PL × R (noun vs. verb) × C				
Regressions	<1	0.73	<1	1.85
First pass	<1	3,866	<1	3,176
Total time	5.87*	7,135	2.97	10,801
PL × R (noun vs. verb, sentences without a C)				
Total time	5.87*	7,135	10.2**	10,127
PL × R (noun vs. verb, sentences with a C)				
Total time	1.66	4,378	<1	9,893
PL × R (postnoun vs. verb) × C				
Regressions	4.54*	0.83	4.77*	1.05
First pass	<1	10,502	<1	5,339
Total time	<1	21,412	<1	12,264
PL × R (postnoun vs. verb, sentences without a C)				
Regressions	9.99**	1.19	6.68*	2.41
PL × R (postnoun vs. verb, sentences with a C)				
Regressions	<1	0.79	<1	1.12
PL × C (noun region)				
Regressions	<1	0.69	<1	1.05
First pass	<1	3,096	<1	2,407
Total time	<1	9,158	<1	9,442
PL × C (postnoun region)				
Regressions	4.73*	0.88	5.23*	1.05
First pass	<1	15,039	<1	7,960
Total time	<1	39,847	<1	29,578
PL × PU (verb region)				
Regressions	<1	0.86	<1	1.69
First pass	<1	3,949	<1	3,422
Total time	5.58*	8,272	2.65	15,230
PL × PU (postverb region)				
Regressions	<1	0.85	<1	0.75
First pass	<1	4,040	<1	3,340
Total time	<1	39,847	<1	29,579
Replication				
PL × R (noun vs. verb)				
Regressions	<1	1.97	<1	0.51
First pass	1.81	2,484	<1	1,890
Total time	11.9**	12,528	6.98*	30,085
PL × R (postnoun vs. postverb)				
Regressions	24.4**	1.67	20.9**	1.74
First pass	<1	3,481	<1	7,538
Total time	1.41	21,216	<1	29,418
PL (noun region)				
Regressions	<1	1.18	<1	0.44
First pass	1.17	1,827	<1	2,342
Total time	3.43	9,461	1.62	19,825
PL (postnoun region)				
Regressions	16.2**	2.73	12.4**	0.81
First pass	<1	5,150	<1	9,658
Total time	<1	53,833	<1	62,151
PL (verb region)				
Regressions	<1	3.92	<1	0.81
First pass	1.46	1,630	<1	2,157
Total time	5.20*	25,872	6.57*	33,465
PL (postverb region)				
Regressions	3.70	1.52	4.18*	0.28
First pass	<1	2,687	<1	3,016
Total time	8.91**	4,279	5.25*	9,120

Note. Degrees of freedom for Experiment 2 are 1 and 31 for subjects (F_1) and 1 and 23 for items (F_2). Degrees of freedom for the replication experiment are 1 and 19 for subjects and 1 and 23 for items. PL = plausibility; R = region; C = complementizer. * $p < .05$. ** $p < .01$.

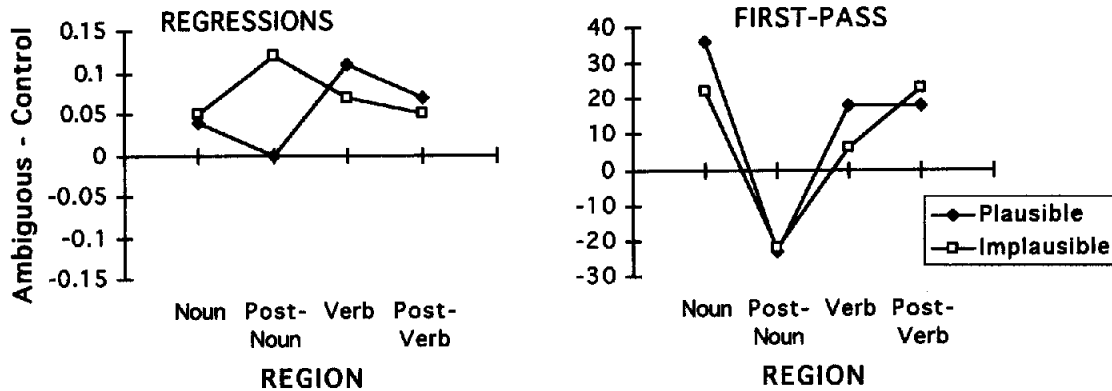


Figure 2. Experiment 2: The left-hand panel represents mean first-pass regressions in ambiguous control sentences minus the regressions in the unambiguous control sentences. The right-hand panel represents mean first-pass time (in milliseconds) in the ambiguous sentences minus first-pass times in unambiguous control sentences.

significant effects in the first-pass data. But as in Experiment 1 and its replication, implausibility rapidly evoked large numbers of regressions. Thus, the data suggest that readers dealt with implausibility, not by slowing down and then continuing further into the sentence, but rather by refixating prior text. Similar effects occurred during processing of the disambiguating verb phrase. We turn now to sentence-external influences on plausibility and recovery from misanalysis.

Experiment 3

We now explore further the question of whether the effects that we have observed are due to the plausibility of the events described by the initial analyses and ask whether discourse context can affect the computation of plausibility. In Experiments 1 and 2, we investigated the effects of plausibility by manipulating words within the target sentence. But it is conceivable that the findings are not due to readers' determining whether the described event is plausible but rather are due to their basing their parsing strategy on "low-level" factors concerned with the actual form of the words used in the different conditions. We have assumed that readers experience difficulty with a fragment like *as the woman sailed the magazine about fishing* because they adopt the object reading, and because it is implausible to sail a magazine. This assumes that readers have interpreted the fragment at a deep semantic level during initial processing.

But there are two kinds of explanation for why this fragment might cause processing difficulty, and for the results of Experiments 1 and 2 more generally, that do not invoke such deep semantic processing. First, readers might be assessing the meaning of the object analysis in isolation, without integrating this meaning into a discourse representation that also draws on the interpretation of prior context. If this is the case, then it should be impossible to affect the processing of such fragments by manipulating discourse context.

Second, readers might not even be basing their processing strategy on the meaning of the fragment at all. They might base their evaluation on properties of the words themselves. On one version of this account, readers were disrupted by fragments like *as the woman sailed the magazine about fishing* because accessing the verb *sailed* activated the restriction that its object must be something that can be sailed. Readers adopted the object analysis and accessed the head noun *magazine*, which cannot be sailed. Hence, the process of combining the words produced a clash, which might have caused the analysis to be abandoned. An interpretation for the fragment as a whole need not have been computed.

On another version of this account, readers are aware of the statistical likelihood for pairs or strings of words to occur on a particular analysis. For instance, readers might have encountered *edited the magazine* fairly frequently on both analyses. Likewise, they might have encountered *sailed the magazine* fairly frequently on the analysis where *the magazine* is the subject of a subsequent verb, but very rarely or never on the object analysis. If readers remembered this (quite detailed) information and used it during processing, they might have been disrupted by *sailed the magazine* but not by *edited the magazine* after having chosen the object analysis, without having determined that this analysis describes an implausible event.

Such explanations can be ruled out if the words in the target sentence remain the same between conditions and their interpretation is manipulated by discourse context. This was the case in Experiment 3, in which context could cause a critical noun phrase in the target sentence to be interpreted literally or nonliterally. If this manipulation is to be effective, discourse context must have rapid effects on parsing, and the processor must rapidly interpret expressions in a nonliteral manner.

Discourse context can rapidly affect parsing, as many recent studies have shown (e.g., Altmann et al., 1992; Altmann & Steedman, 1988; Britt, 1994; Britt et al., 1992),

although controversy remains about whether these effects occur during initial parsing (e.g., Mitchell et al., 1992; Rayner, Garrod, & Perfetti, 1992). In these studies, context affects the syntactic analysis of an ambiguous anaphoric noun phrase. Context can also rapidly affect the interpretation of a homonym like *bank* (e.g., Rayner & Duffy, 1986; Swinney, 1979), though again there is controversy about how context operates.

However, the process of determining whether an expression has a literal or nonliteral interpretation may be different from determining the appropriate syntactic analysis or the interpretation of a homonym. Whereas there are only finitely many unrelated meanings for a homonym, an expression can, in general, be interpreted in infinitely many nonliteral ways. For instance, *the professor* can refer to a statue, a painting, a sketch of the professor, or even an article by the professor (e.g., Gibbs, 1994). Thus, a simple lookup of nonliteral meaning cannot always be possible. Hence, some interpretation must occur during processing, which could be delayed. In accord with this, some evidence suggests that the processor sometimes delays determining whether an expression should be taken literally. Frazier and Rayner (1990) argued that readers need not determine whether *the newspaper* has a literal or institutional interpretation until disambiguating material becomes available (whereas lexical ambiguities are resolved immediately).

However, nonliteral processing need not be delayed. First, context can rapidly foreground contextually relevant aspects of the meaning of unambiguous expressions (e.g., Tabossi, 1988). Also, nonliteral processing does not appear to lag appreciably behind literal processing (e.g., Cacchiari & Glucksberg, 1994; Gibbs, 1994; Glucksberg, Gildea, & Bookin, 1982) and can be straightforward in appropriate contexts (e.g., Ortony, Schallert, Reynolds, & Antos, 1978). In conclusion, context might have rapid effects on the interpretation of nonliteral expressions, but its effects might also be delayed. Overall, there has been very little research into the effects of processing of nonliteral language on eye movements (though see Frazier & Rayner, 1990, and Inhoff, Lima, & Carroll, 1984).

In Experiment 3, we investigated the processing of literal and nonliteral expressions and how their interpretation may affect the interpretation of syntactically ambiguous sentences. We used subordinate-clause ambiguities, as in Sentence 9, in the context of sentences like 9a or 9b:

Context

- (9a) The janitor polished bronze statues of the old maths professor that the principal hated and the dean of the art school.
 (9b) The janitor polished bronze statues for the old maths professor that the principal hated and the dean of the art school.

Target

- (9) While the janitor was polishing(.) the professor that the principal hated reviewed the spring term teaching schedule.

In the absence of the comma, Sentence 9 has an implausible

misanalysis, under which the janitor is polishing the professor. However, this analysis is in fact only implausible if *the professor that the principal hated* refers literally to an actual professor. This interpretation is likely if 9 follows 9b. Thus readers may process Sentence 9 in the context of 9b in a way similar to Sentence 1b above.

But *the professor that the principal hated* can refer nonliterally (metonymically) to a statue of a professor. This is likely to be the case if Sentence 9 follows 9a. In this context, the misanalysis of 9 is plausible. To obtain this interpretation, readers must rapidly resolve the reference of *the professor that the principal hated* with respect to its discourse context. They will then commit to this analysis because it is plausible. But after reading *prepared*, readers will be forced to reanalyze. Moreover, they will probably have to reinterpret *the professor that the principal hated* literally because an actual professor can prepare something, but a statue of a professor is unlikely to prepare anything. Hence, readers may process Sentence 9 in the context of 9a in a way similar to Sentence 1a above. However, there may be an additional difficulty due to reverting from the nonliteral to the literal interpretation of the critical noun phrase.

If, on the other hand, the effects of context are delayed, or if the initial computation of plausibility depends on some set of default features stored along with the lexical entry of *professor*, or if plausibility effects are really caused by the likelihood of co-occurrence of lexical items under particular syntactic analyses, then the contextual manipulation should have no effect on initial processing of Sentence 9. Thus, this experiment may provide evidence about the information the processor uses in the computation of plausibility.

Method

Participants. Thirty-two normally sighted, native English-speaking students from the University of Glasgow were paid to participate. Some had participated in other eye-tracking experiments.

Stimuli. We constructed 28 sets of four passages for Experiment 3 similar to Sentence 9 (see Appendix). We constructed four lists of items. One version of each item appeared in each list. Equal numbers of items from each condition appeared in each list.

Plausibility norming. We normed the items to determine that the misanalysis was implausible in isolation in a way similar to Experiment 1. Twenty raters read 28 sentences like *The janitor polished the professor*, along with 116 fillers. We eliminated items that produced a mean rating above 2.0. The subordinate clauses used in the experimental items contained these sentences and postnominal modifiers (e.g., *that the principal hated*).

The computer displayed each experimental list in a fixed random order together with 34 additional passages. Line breaks occurred at slightly different positions in different items. Within each item, line breaks occurred in the same place across conditions.

Regions. We identified four regions for statistical analysis, just as in Experiment 1 (see Table 5). In Sentence 9 above, the noun region comprised the word *professor*. The verb region comprised the word *reviewed*.

Procedure. The experimental procedure was identical to that of Experiment 1.

Results

Table 5 presents regressions, first pass, and total time by region and condition for Experiment 3. Difficulty associated with adopting implausible object analyses and abandoning plausible object analyses, combined with the effects of punctuation, should produce three-way interactions of plausibility (plausible vs. implausible object analysis), punctuation (comma present vs. absent), and region (noun vs. verb). Such interactions occur on first pass (see the top of Table 6) but not on regressions or total time. As before, the three-way interactions occur because plausibility and region interact in ambiguous sentences but not in unambiguous sentences. Figure 3 illustrates differences between the two types of ambiguous sentences (sentences without commas) and their unambiguous controls, with regression data on the left and first-pass data on the right. Simple effects tests are based on appropriate plausibility by punctuation interactions.

The noun and verb regions both individually produced interactions of plausibility and punctuation in the first-pass data. The verb region produced the clearest result, providing strong evidence of difficulty in sentences with plausible object analyses. First-pass times on the verb were longer in sentences with plausible object analyses than in their unambiguous controls, $F_1 = 5.85, p < .05; F_2 = 6.50, p < .05$, and sentences with implausible object analyses, $F_1 = 4.06, p = .05; F_2 = 6.12, p < .05$; whereas the other three sentence types did not differ from one another.

Means comparisons for the noun region produced no reliable differences between condition means. When the noun region was extended to include the text up to the beginning of the verb region, the total-time data produced a main effect of punctuation in the noun region, $F_1 = 26.4,$

$p < .0001, MSE = 47,690; F_2 = 4.70, p < .05, MSE = 273,525$. This shows that readers misanalyzed both types of ambiguous sentence.

Discussion

The three-way interactions of plausibility, punctuation, and region demonstrated that the processing of the ambiguous sentences diverged rapidly from the processing of the unambiguous controls. The two-way interactions demonstrated that the ambiguous sentences showed the familiar "crossover" pattern, with plausible sentences being easier than implausible sentences before disambiguation but implausible sentences being easier than plausible sentences after disambiguation. However, the unambiguous control sentences did not show this pattern. Thus, the results are compatible with Experiments 1 and 2 and provide more evidence that readers commit to a plausible initial analysis more strongly than they commit to an implausible initial analysis. The experiment also demonstrates that readers accessed and used contextual information rapidly when parsing sentences in discourse.

However, two differences emerged between Experiment 3 and Experiments 1 and 2 (and their replications). First, Experiment 3 showed no residual difficulty in sentences with implausible object analyses during processing of the syntactically disambiguating verb phrase. Experiment 1 showed weak evidence for such difficulty, whereas Experiment 2 showed considerable difficulty. We return to this in the General Discussion.

Second, there were differences in the ways that the main experimental effects manifested themselves. In general, effects showed up on regressions and total time in Experiments 1 and 2 but on first-pass time in Experiment 3. Additionally, many of the effects of disambiguation in Experiments 1 and 2 were somewhat delayed, appearing as regressions from postverb region or as total-time effects. In contrast, there were clear first-pass effects at the disambiguating verb in Experiment 3.

Any explanation of these differences has to be tentative because they reflect general trends rather than absolute differences (e.g., the replication of Experiment 1 showed some sign of first-pass effects). Additionally, they could reflect differences between the participants in different experiments. But two important differences between the items in Experiment 3 and the earlier experiments may have caused the behavioral differences.

Experiment 3 demonstrates that our basic findings must reflect interpretative processes and cannot be entirely due to the strings of words used in the different conditions. However, the differences in the patterns of results between the experiments may suggest that readers are disrupted by unlikely strings of words (on a given analysis) in a qualitatively different manner from the way that they are disrupted by strings of words with unlikely interpretations. Thus, *the janitor was polishing the professor* (on the object analysis) is plausible if context makes it clear that *the professor* refers to a statue, and implausible otherwise, but the words themselves do not differ. In contrast, *the woman edited the*

Table 5
Experiment 3: First Fixation, First Pass, and Total Time
by Region and Condition

Condition	Region			
	Noun	Postnoun	Verb	Postverb
Regressions				
Plausible, no comma	0.15	0.09	0.14	0.09
Implausible, no comma	0.10	0.08	0.13	0.10
Plausible, comma	0.22	0.18	0.19	0.19
Implausible, comma	0.25	0.13	0.27	0.16
First pass (in ms)				
Plausible, no comma	290	715	370	369
Implausible, no comma	318	736	333	387
Plausible, comma	312	720	325	353
Implausible, comma	289	705	342	333
Total time (in ms)				
Plausible, no comma	484	1432	649	600
Implausible, no comma	497	1155	575	561
Plausible, comma	453	1301	466	516
Implausible, comma	420	1180	452	537

Table 6
Experiment 3: ANOVAs for Regressions, First-Pass, and Total-Time Data

Source	Within subjects		Within items	
	F_1	MSE	F_2	MSE
PL × R (noun vs. verb) × PU				
Regressions	<1	1.47	<1	1.12
First pass	8.71**	5,044	9.64**	6,158
Total time	1.70	27,796	1.22	29,934
PL × R (noun vs. verb, sentences without a comma)				
Regressions	<1	0.82	<1	1.12
First pass	5.78*	5,827	9.16**	5,527
Total time	2.05	23,191	1.36	36,252
PL × R (noun vs. verb, sentences with a comma)				
Regressions	<1	1.24	<1	1.47
First pass	2.76	5,990	3.44	4,147
Total time	<1	26,622	<1	16,365
PL × PU (noun region)				
Regressions	1.51	1.68	1.32	2.19
First pass	4.80*	4,457	8.47**	5,299
Total time	1.62	11,997	<1	19,890
PL × PU (postnoun region)				
Regressions	<1	0.68	<1	1.15
First pass	<1	104,310	<1	125,466
Total time	<1	207,455	<1	125,466
PL × PU (verb region)				
Regressions	3.55	1.17	3.64	1.30
First pass	4.23*	5,316	3.49	5,038
Total time	<1	46,140	<1	47,309
PL × PU (postverb region)				
Regressions	<1	1.18	<1	1.64
First pass	1.45	8,252	<1	9,760
Total time	<1	33,206	1.40	17,943

Note. Degrees of freedom are 1 and 31 for subjects (F_1) and 1 and 27 for items (F_2). PL = plausibility; R = region; PU = punctuation.
* $p < .05$. ** $p < .01$.

magazine is more plausible than *the woman sailed the magazine*, but, additionally, *the woman edited the magazine* is a much more likely string of words than *the woman sailed the magazine*. In the latter case, a selection restriction is violated, because magazines cannot be sailed. If the parser adopts the object analysis for the experimental sentences (as

assumed), then the differences in the string of words will affect processing in Experiments 1 and 2 but not in Experiment 3.

We hypothesize that the early regression effects found in Experiments 1 and 2 are at least in part a response to unlikely strings of words and selection-restriction violations. For

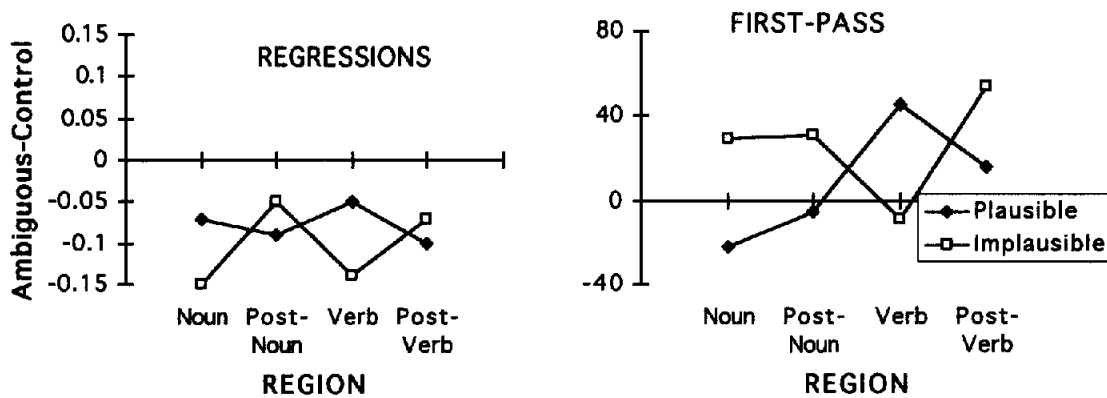


Figure 3. Experiment 3: The left-hand panel represents mean first-pass regressions in ambiguous control sentences minus the regressions in the unambiguous control sentences. The right-hand panel represents mean first-pass time (in milliseconds) in the ambiguous sentences minus first-pass times in unambiguous control sentences.

instance, it may be that the reader often decides to check whether a word has been misread and assumes that a low-level problem has a low-level solution, namely re-reading. In Experiment 3, however, the string of words does not differ between conditions, and the reader may respond to difficulty by changing the interpretation of words. For this, local re-reading is not useful, but additional processing time may be. If this explanation is right, it suggests that we cannot straightforwardly interpret an effect as being due to a difference in plausibility between conditions if there are also differences in the words used.

The other way in which the items in Experiment 3 differ from those in Experiments 1 and 2 has been mentioned earlier: Reanalysis of the plausible sentences requires changing the interpretation of the critical noun phrase. In Sentence 9a, after reading *While the janitor was polishing the professor* following a context sentence mentioning a statue of a professor, the reader will normally have assigned a nonliteral interpretation to *the professor*. But at the point of disambiguation, it rapidly becomes clear that *the professor* must be interpreted literally (in Sentence 9a, the professor reviews a term schedule). Hence, the reanalysis following the plausible nonliteral interpretation is more tricky than the reanalysis required in Experiments 1 and 2 because both the initial syntactic analysis and the nonliteral interpretation of the critical noun phrase have to be abandoned. This is not necessary in the other experimental conditions, in which the nonliteral interpretation of the critical noun phrase is never entertained.

General Discussion

All of the experiments demonstrate that readers had difficulty processing the critical noun phrase when the initial analysis was implausible and greater difficulty processing disambiguating information when the initial analysis was plausible. Both subordinate-clause and complement-clause ambiguities produced garden-path effects, with readers initially adopting or foregrounding the object analysis. All of the experiments provide evidence about when readers realized that they had misanalyzed. When the object analysis was plausible, readers realized this after reaching the syntactically disambiguating verb. When the object analysis was implausible, it is unclear whether readers reanalyzed while initially processing the critical noun phrase or whether they waited until the verb (see below). More generally, we conclude that readers semantically committed to the object analysis to a greater extent when it was plausible than when it was implausible.

In Experiment 3, we found that the effects of semantic interpretation on analysis and reanalysis did not take place in isolation from discourse context. Instead, degree of semantic commitment depended on whether context suggested that an expression had a literal or nonliteral interpretation. The experiment also indicated that the apparently semantic effects cannot be explained in terms of "low-level" factors based on the actual words used (e.g., selection restrictions or co-occurrence statistics). From these results, we conclude

that readers perform substantial rapid semantic interpretation during the early stages of sentence processing, in cases in which they have chosen an initial analysis, and that they can use this semantic processing to determine whether or when to abandon or disfavor this analysis.

Does Implausibility Trigger Reanalysis?

It is uncontroversial that syntactic information can cause readers to abandon an analysis. It is more uncertain whether semantic information by itself can have the same effect. Our experiments show that the manipulation of plausibility after readers have constructed an initial analysis can affect the degree of difficulty incurred at the point of syntactic disambiguation, but it is less clear whether implausibility can eliminate such difficulty. Total-time data from Experiment 2 demonstrated that sentences with implausible initial analyses caused difficulty while readers fixated the syntactically disambiguating verb. Experiment 1 provided weak evidence for difficulty in sentences with implausible initial analyses after syntactic disambiguation. Experiment 3 provided no evidence that sentences with implausible initial analyses produced difficulty during the disambiguating verb phrase.

The evidence strongly suggests that difficulty can occur after syntactic disambiguation in sentences where the initial analysis is highly implausible. The total-time effects in Experiment 2 were extremely strong, so a Type I error in this experiment is very unlikely. Every care was taken in pretesting our items to make the implausible conditions as implausible as possible, so it is also unlikely that our manipulations were insufficiently strong. It is just possible that readers always reanalyzed before the disambiguating verb phrase but that there was some spillover from reanalysis in earlier regions into the disambiguating region. But the most probable explanation is that sentences with very implausible misanalyses can still cause readers some difficulty when they are processing disambiguating material. If so, our results suggest that readers at least sometimes do not abandon their initial analysis when that analysis is extremely implausible. It is possible that the effect occurred in Experiment 2 because we used complement-clause ambiguities, for which reanalysis may be possible by means of revision rather than wholesale reconstruction (as discussed earlier). Because reanalysis may in general be more straightforward in such cases, readers may be less inclined to perform early reanalysis on the basis of uncertain semantic evidence.

It is possible that implausibility by itself never triggers reanalysis. On this account, the difference between sentences with plausible and implausible initial analyses is entirely due to differences in semantic processing. Readers syntactically commit to the object analysis in both conditions but conduct more extensive semantic processing if this analysis is plausible than if it is implausible and find it harder to abandon an analysis if it has been more extensively semantically processed. This account is compatible with our data but difficult to reconcile with findings that show

semantic effects on syntactic processing (e.g., Altmann & Steedman, 1988; MacDonald, 1994; Rayner et al., 1983; Taraban & McClelland, 1988; Trueswell et al., 1994).

Hence, we suggest that our readers sometimes reanalyze (or change the activation of competing analyses) before syntactic disambiguation. On this account, semantic factors can in principle cause the processor to reanalyze, but the processor makes use of probabilistic information to decide whether to reanalyze. Our experiments (most especially Experiment 3) suggest that this information includes the plausibility of the event described on the initial analysis. Readers implicitly rate the plausibility of a fragment like *as the woman sailed the magazine* on this analysis by determining how likely it is for the woman to sail a magazine. However, other semantic or pragmatic factors may also influence the decision. For example, readers might determine how likely it is that the meaning of the fragment would be expressed by a particular linguistic form. Also, syntactic factors may affect the decision. For instance, readers may be less likely to abandon an extremely frequent analysis than a less frequent one. Further research is needed to determine how these factors interact to trigger reanalysis.

Implications for Parsing Theories

Our findings are consistent with current theories of parsing. On the one hand, constraint-based theories, such as MacDonald's (1994), propose that ambiguity resolution is a continuous parallel process in which multiple analyses can be computed and evaluated together. According to this account, there is no initial stage during which the parser restricts itself to syntactic information. Rather, multiple probabilistic pre- and post-ambiguity syntactic and semantic constraints interact to determine the activation of alternative interpretations (Boland et al., 1995; MacDonald et al., 1994; Spivey-Knowlton et al., 1993; Trueswell et al., 1993, 1994). In our experiments, the object analysis is strongly activated and is therefore highly favored. Semantic plausibility is a post-ambiguity constraint because it is manipulated after the point of ambiguity (and before the point of disambiguation). According to MacDonald's model, information that is probabilistically associated with an analysis will boost the activation of the associated analysis and decrease the activation of competing analyses. For example, she demonstrated that constraints that make active transitive interpretations less probable facilitate comprehension of reduced-relative sentences when the constraints were introduced prior to the point of syntactic disambiguation:

- (10a) The management team believed that the workers transported to the polluted beaches would help clear up the oil spill.
- (10b) The management team believed that the workers transported almost two thousand miles would help clear up the oil spill.

The word *transported* can be either an active past-tense verb or a past participle in a reduced-relative construction. The sentences are not disambiguated until the verb *would*, when it becomes certain that *transported* is a past participle.

However, the active analysis becomes highly unlikely in Sentence 10a at the word *to*, early in the region *to the polluted beaches*. In contrast, the active analysis becomes highly unlikely in Sentence 10b only at *miles*, late in the region *almost two thousand miles*. Thus, information that makes the analysis unlikely is available well before syntactically disambiguating information in 10a, but only just before it in 10b. Readers experienced more difficulty at disambiguation in 10b than in 10a. In MacDonald's model, the active analysis becomes deactivated in 10a earlier than in 10b. More generally, a strong postambiguity constraint deactivates the initially favored analysis and promotes alternatives.

In our experiments, sentences with implausible initial analyses provide a strong post-ambiguity constraint against the object analysis, whereas sentences with plausible initial analyses provide a strong post-ambiguity constraint in favor of the object analysis. The important difference between MacDonald's (1994) work and ours is that she provides evidence for or against an analysis on the basis of probabilistic syntactic information, whereas we provide evidence for or against an analysis on the basis of probabilistic semantic information. The finding that sentences with implausible initial analyses produce more difficulty during the critical noun phrase than sentences with plausible initial analyses is what she calls a *reverse ambiguity effect*.

Our results are also straightforwardly compatible with two-stage serial parsing models (e.g., Ferreira & Clifton, 1986; Frazier, 1987; Mitchell, 1987; Rayner et al., 1983). The processor makes initial decisions about analyses on the basis of a restricted set of information sources, including major-category information, but specifically excluding semantic information. Readers respond to semantic information such as plausibility during a second stage on the basis of what is sometimes called a *thematic processor*. As in the constraint-based model, plausible interpretations are favored over implausible interpretations. Thus, plausible interpretations will resist revision more than implausible interpretations.

An interesting difference between the models concerns how they might decide to reanalyze or reorder analyses. In serial models, the decision to abandon an analysis must be based on the likelihood of that analysis alone. The decision to reanalyze would be based on the initial analysis falling below some threshold of acceptability. For example, the processor could pay attention to the plausibility of the event described, the frequency of the analysis, and the likelihood of using that analysis to describe the event. It could not pay attention to characteristics of alternative analyses, because those analyses would not have been computed.

In parallel constraint-based models, reordering analyses amounts to changing the activation levels of competing analyses, so that a highly active analysis is deactivated and the activation of competitors is enhanced. Because more than one analysis is computed together, the plausibility of currently disfavored analyses could affect the activation level of the currently favored analysis. A given sentence might be processed more rapidly when no alternative

analysis is supported but more slowly if the input boosts activation of competing analyses. Thus, in contrast with serial models, activation of the favored analysis would depend on characteristics of the favored and disfavored analyses together.

The data in the current study do not provide a means to choose between these competing views of the parsing process. In fact, we did not design these experiments as a test of constraint-based or serial two-stage parsers. Rather, the data represent a point of departure for discussing how post-ambiguity semantic information affects processing. One possible way to distinguish between the two classes of models on the basis of plausibility would be to manipulate the plausibility of disfavored analyses. Serial two-stage parsers should not be sensitive to such manipulations, so the plausibility of disfavored analyses should have no effect on readers' decisions to reanalyze. Thus, such models predict that manipulating the plausibility of disfavored analyses should have no effect on processing because those analyses are never actually computed. By contrast, parallel constraint-satisfaction mechanisms should be sensitive to the plausibility of disfavored analyses, and so manipulating this factor may produce changes in readers' behavior.

There is reason to believe that the manipulation of the plausibility of the initial analysis is a very good way to investigate syntactic misanalysis in general because the two sentences that are compared involve exactly the same construction. With respect to complement-clause ambiguities, Trueswell et al. (1993) pointed out that sentences with and without the complementizer *that* may differ in irrelevant ways (e.g., in their frequencies), there is an additional word in the sentence with the complementizer, and, in fact, they are different constructions. Related points can be made about the use of the comma in subordinate-clause ambiguities. Differences in item length, syntactic construction, and punctuation occur in many studies of syntactic misanalysis. The manipulation of plausibility in our experiments avoids these problems and therefore constitutes a valuable technique. In particular, the manipulation of plausibility in Experiment 2 provides confirmation that complement-clause ambiguities can produce processing difficulty due to syntactic misanalysis, in a manner roughly comparable to the subordinate-clause ambiguities in Experiments 1. This lends support to the proposals of Frazier and Rayner (1982), Rayner and Frazier (1987), Ferreira and Henderson (1990), and Trueswell et al. (1993), in contrast to Holmes et al. (1987) and Kennedy et al. (1989).

This plausibility manipulation can also address the question of whether pre-ambiguity constraints (e.g., verb bias) affect choice of analysis. For example, if such constraints render the object analysis unlikely, and if the processor serially adopts the most likely analysis, then the plausibility of the object analysis should not influence processing. Current work that addresses this question has produced conflicting results (Garnsey, Pearlmutter, Myers, & Lotocky, 1997; Pickering, Traxler, & Crocker, 1998). In general, the manipulation of plausibility provides interesting evidence about the process of syntactic analysis and reanalysis.

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Appendix

Experimental Stimuli

Words appearing immediately before “/” marks appeared in the plausible stimuli. Words appearing immediately after “/” marks appeared in the implausible stimuli. Commas appeared in the unambiguous control sentences in Experiments 1 and 3. Complementizers appeared in the unambiguous control sentences in Experiment 2. The context sentences appeared in the replications of Experiments 1 and 2. The line breaks in the target sentences appeared in the same place in Experiment 1 and its replication and in Experiment 2 and its replication. Line breaks are indicated by “|” marks. In Experiments 1 and 2, the line break between context and target sentences always occurred after the period at the end of the context sentence.

Stimuli for Experiment 1 and Its Replication

Sometimes the woman edited articles while she and her guests sailed her yacht. As the woman edited/sailed(,) the magazine about fishing amused all the| reporters.

The woman often sailed as she edited to get away from the pressurized atmosphere of the newspaper offices. She looked out her window and was surprised to see two boats collide. As the woman sailed/edited(,) the yacht that was damaged crossed the bay| rather slowly.

The judge couldn't stop thinking about the verdict in the murder trial as he packed several bags and prepared to go. After the judge decided/packed(,) the verdict of the trial caught the old| man's attention.

The judge had packed before he had decided where he was going to go. After the judge packed/decided(,) the suitcases that had tags burst| their locks.

Before the motorist writes, he parks in front of the cinema. While the motorist parks/writes(,) the lorry that was noisy rushes along| the high street.

The man parks behind the newspaper offices before he runs inside to write for the morning edition. As the motorist writes/parks(,) the story about animals remains on the| back seat.

Two of the scientists were breeding the large jungle cats, and the others were typing reports for the Royal Society. As the zoologists were breeding/typing(,) the tigers from India chewed on| a piece of meat.

Two of the handlers were typing letters to the board of directors in the office while the other two were breeding jungle cats in the veterinary surgery. As the zoologists were typing/breeding(,) the reports about apes fell off| the table.

The gardener eats his supper while he reads some things he picked up this morning. Whilst the man reads/eats(,) the books about gardening seemed somewhat| confusing.

The man saves time by reading and eating at the same time. Before the man eats/reads(,) the sandwich from the bakery looked really| appetising.

The cleaners were rubbing the spots after they were running the errands for the supervisor. When the cleaners were rubbing/running(,) the paint that dried stained the| new carpet.

The cleaners were running to the hardware store after they were rubbing out the stains on the lower landing. As the cleaners were running/rubbing(,) the errands that I set remained at| the end of the list.

The janitor followed us after he polished the tiles. Whilst the janitor polished/followed(,) the floor of the hall shone rather| brightly.

The janitor hated polishing things more than anything and he spent

most of his time following people around trying to eavesdrop on their conversations. As the janitor followed/polished(,) the professors of maths chatted about| the first year exam.

The cowboys were relaxing and practising their cowboy skills. Some of them were roping steers off to the side of the barn and some of them were drinking beer on the porch. As the cowboys roped/drank(,) the horses that had escaped charged across| the ranch.

Some of the cowboys were roping as the sun went down, but the ones in the bunk house were drinking. As the cowboys drank/roped(,) the whiskey that tasted bad disgusted the| saloon owner.

The young scientist was inventing new electrical equipment all the time, but he was still teaching us physics every day. As the scientist was inventing/teaching(,) the light that worked created an| enormous demand.

When the scientist wasn't teaching, he was almost certainly in his laboratory inventing. When the scientist was teaching/inventing(,) the student of botany took the| books away.

The young artist sings as he paints down at the art studio. As the artist paints/sings(,) the picture of the roses pleases all the| critics greatly.

Almost everyone likes the way the young artist paints, but everyone runs for cover when she sings. While the artist sings/paints(,) the song about young love annoys quite| a few people.

The carpenter always questions people before he builds anything, because he wants to do it right the first time. As the carpenter questions/builds(,) the actor that came in speaks very| quietly.

The carpenter builds things for people and he always questions them about what they want. As the carpenter builds/questions(,) the table that sloped breaks in the| middle.

The ambassador visited several places before he negotiated the agreement last October. When the ambassador negotiated/visited(,) the treaty about arms upset many| of the civilians.

The wise old ambassador negotiated the agreement before he visited the countryside. As the ambassador visited/negotiated(,) the village that burned asked the| government for help.

Stimuli for Experiment 2 and Its Replication

The chief criminal went to see his priest because his conscience started to nag at him and he was having trouble sleeping. The criminal confessed (that) his sins/gang which upset kids harmed too| many people.

The leader of the outlaws was pretty disgusted with their behaviour in the religious city during the past few months. The outlaw warned (that) his gang/sins which annoyed the nun would be a| great nuisance.

The dog catcher was trying to arrange things in his truck so that he wouldn't have any more accidents or mishaps. The dog catcher worried (that) the terrier/book which fell wouldn't fit| into the box.

The newspaper journalist got a lot of his inspiration just by watching and listening to events in his block of flats. The journalist wrote (that) the book/terrier from upstairs caused very| great interest.

The historian had been arguing with his senior colleagues in the college for months and months. The historian proves (that) the theory/geny from Oxford resolved a very| messy dispute.

The molecular biologist had finally finished reviewing all of the research on microbiology. The biologist proved (that) the theories/seminars about cells explained all| the unclear data.

The Swedish hotel owner dedicated much of his time to raising funds for international charities like OXFAM and Greenpeace. The Swede believed (that) the visitor/holiday that was fun helped raise| funds for charity.

The principal was talking to the visiting parents about the problems he had experienced in trying to maintain staff morale. The principal declared (that) the holiday/visitor that he liked seemed to| cheer up the staff.

The visitor to the university library takes out a couple of volumes on legal practices in the Irish Republic. The visitor reads (that) the adverts/companies from Ireland encouraged the| young people to smoke.

The government issued a report that illustrated the health hazards associated with excessive alcohol consumption. The government cautioned (that) the companies/adverts that lied promoted a| big increase in drinking.

The manager called the travel agent because he wanted to get some reassurance about the complicated travel plans. The travel agent confirms (that) the reservation/employee of his received a| stamp of approval from the boss.

The manager put a lot of his energy into organising the office and making sure people knew all of the right procedures. The manager taught (that) the employee/reservation that he chose required a| better filing system.

The sailor has been trying to decide how his ship will travel to the far east on its next cruise. The sailor reads (that) the chart/actor from London described new routes| around the world.

The prison guard likes to pay attention to events in town and has a lot of free time to read when the prisoners are asleep. The guard reads (that) the magazine/majority from the city created sympathy| for the homeless.

The crafty old solicitor was trying his best to make the witness admit that he had lied about his intentions. The witness swore (that) the oath/aide that he recalled described his| intentions exactly.

The ambassador's wife received a message that the ambassador had posted three months ago from his embassy in Berlin. The ambassador wrote (that) the article/ability which he used impressed an| old friend of his.

The lecturer spent most of his spare time lobbying about health policy on behalf of a political party. The lecturer wrote (that) the speech/sister that upset people annoyed all| of the politicians.

The United Nations mediator in charge of disarmament was having a lot of difficulty maintaining order at the negotiating table. The mediator resolved (that) the dispute/devices which erupted should be| discussed by the committee.

The lawyer presented a series of brilliant arguments and devastated the weak defence forwarded by the planners. The lawyer argued (that) the case/city which was described occupied too| much valuable time.

The music teacher knew all of the rules and really insisted that everything in the school should be up to the proper standard. The teacher believed (that) the pupil/piano in the cafeteria failed to| meet the requirements.

The karate master was travelling the world, and was making a living by teaching many people. The karate master instructs (that) the victim/valley that is lost lacks a| proper means of defence.

The cabinet minister considered that the energy problem could be solved by educating people about fossil fuel reserves. The cabinet minister proposed (that) the policy/school of mining would be| a great benefit.

The policeman came and talked to the council about new developments in traffic law enforcement in Europe. The policeman cautioned (that) the motorist/policy from abroad created an| enormous hazard.

After she heard all the testimony, the chairwoman had some ideas about how the military could improve training. The chairwoman decided (that) the issues/troops that she heard could be| ignored for now.

Stimuli for Experiment 3

Mary knitted little figures of| for the boy with the red hair and the| girl with the blue dress. While Mary was knitting(,) the| boy with the flaming red hair went outside to play in the tree.

The janitor polished the bronze statues of| for the old maths| professor that the principal hated and the dean of the art| school. While the janitor was polishing(,) the professor that the| principal hated reviewed the spring term teaching schedule.

The artists refurbished portraits of| for the bishop, the cardinal,| and the pope. While the artists were refurbishing(,) the| cardinal whom the bishop admired wrote an open letter to the congregation.

The artist was printing sketches of| by the river and the| mountain. While the artist was printing(,) the river with the| steep and treacherous banks gurgled and tripped over the stones.

The carpenter built life-sized, wooden cut-outs of| for the young| actor that the actress liked and the cheeky actor whom the| actress hated. While the carpenter was building(,) the actor whom| the actress liked a lot combed his hair and straightened his tie.

The toy maker manufactured dolls of| for the handsome prince, the| intelligent princess, and the young duke. While the toy maker| was manufacturing(,) the handsome prince with the big ears fished| for salmon in the fast-flowing river.

The protesters built flammable effigies of| for the communist| guerilla and the great dictator. While the protesters were building(,) the communist guerrilla who smoked big cigars spoke to the| assembled masses.

The photographer printed pictures of| for the footballer from| Aberdeen and the cricketer from Yorkshire. While the| photographer was printing(,) the footballer whom the cricketer knew| waited alone in the front room.

The graphic artist printed posters of| for the band that got reviewed| by the Times and the classical music trio that played on the BBC. While the graphic artist was printing(,) the band the Times| reviewed practised some new tunes in the upstairs flat.

The young assistant duplicated drawings of| for the Duke of Wellington| and Admiral Nelson. While the young assistant was duplicating(,) the Duke of Wellington planned a summer campaign with the Chief| of Staff.

The auctioneer sold paintings of| for the Duke of Edinburgh and the| King of Sweden. While the auctioneer was selling(,) the Duke of Edinburgh| watched a polo match on television.

Theresa drafted illustrations of| for the Kaiser of Germany and the| Czar of Russia. While Theresa was drafting(,) the Kaiser of Germany reviewed petitions from his loyal subjects.

The student composed abstract representations of| in confusion about| life and dismay about love. While the student was composing(,) confusion about life overwhelmed his senses and forced him to| stop working for a while.

The young woman sewed hand puppets of| for the clown with the orange| hair and the clown with the big smile. While the young woman| was sewing(,) the clown with the orange hair juggled bowling pins| to amuse the children.

The potter constructed clay figurines of| for the Japanese ambas-

- sador| and the Chinese minister of protocol. While the potter was| constructing(,) the ambassador from Japan toured the art school| campus.
- The artisan carved wooden statues of/for the baker, the shop keeper,| and the police constable. While the artisan was carving(,) the| baker who made excellent pastries put another loaf of bread in| the oven.
- The old woman carved stone reliefs of/for the general, the staff| officer and the sergeant major. While the old woman was carving(,) the general with a bright plume in his hat trotted by on a| black horse.
- The painter composed portraits of/for the philosopher, the| physicist, and the chemist. While the painter was composing(,) the| philosopher whom the physicist feared wrote long essays on truth| and beauty.
- The secretary duplicated photographs of/for the publicity officer,| the account manager, and the computer programmer. While the| secretary was duplicating(,) the publicity officer whom the| computer programmer envied ate lunch with the account manager.
- The editor sold illustrations of/for the Grand Old Duke of York and| the Brothers Grimm. While the editor was selling(,) the Grand Old| Duke of York marched ten thousand men up and down the hill.
- The young man printed drawings of/for the psychology student and the| maths student. While the young man was printing(,) the student| from the psychology department looked for journal articles in the| library.
- The school children drafted likenesses of/for the stern teacher and| the kind and gentle teacher. While the children were drafting(,) the stern teacher whom the soft and cuddly teacher pitied| prepared lessons in the room across the hall.
- The avant-garde artist painted abstract representations of/with pain| and of ecstasy. While the avant-garde artist was painting(,) pain in the eyes of children constituted a major theme in the| critical review.
- The sculptor constructed figures of/for the ballet dancer and the| young mother. While the sculptor was constructing(,) the ballet| dancer with the gracious expression practised leaping in one| corner of the room.
- The young man drafted sketches of/for the model and the art teacher. While the young man was drafting(,) the model from the South| of France read a book of poetry.
- The art student printed sketches of/for the little boy and the| teenage girl. While the art student was printing(,) the little boy| with the yellow jumper played with some stuffed toys.
- The printers duplicated posters of/for the folk singer, the poet,| and the playwright. While the printers were duplicating(,) the| folk singer with whom the playwright shared a flat composed a song about| lost love.
- The street vendor sold sketches of/for the football reporter and the| television news presenter. While the street vendor was selling(,) the reporter whom the news presenter interviewed wrote a story| about the FA Cup tie.

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