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Grammatical Search and Reanalysis

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This paper investigates the extent to which existing structural commitments constrain the human parser's search for grammatical analyses of incoming material, specifically whether a *Reanalysis As a Last Resort* (RALR) strategy applies to sentence parsing. Two self-paced reading experiments investigate this issue using a structural ambiguity in which a local, easy reanalysis is pitted against a nonlocal attachment requiring no reanalysis. This ambiguity is created by embedding classic noun phrase/sentential complement ambiguities inside a relative clause modifying a subject NP. The results of both experiments indicate that readers' existing structural commitments do constrain their subsequent parsing decisions: nonlocal analyses which avoid reanalysis are consistently favored over local analyses which require an easy reanalysis. This conclusion is confirmed by the results of a subcategorization-bias manipulation in Experiment 2, which shows that readers show a consistent bias to avoid reanalysis, rather than a general bias for either local or matrix clause attachments.

Key Words: parsing; ambiguity; reanalysis; monotonic parsing; subcategorization.

The main objective of this paper is to investigate the degree to which commitments made at earlier stages in parsing a sentence constrain the choices that are made at later stages in parsing. Although it is clear that parsing a sentence involves many cycles of grammatical search followed by structural commitment, it is much less clear how the commitments made at one cycle constrain the grammatical search undertaken at the next cycle. One possibility is that existing commitments strongly constrain subsequent search, such that the parser only searches for analyses of incoming material which respect all existing structural commitments. If this is the case, then reanalysis would only be considered after all other options have failed. This approach amounts to the strategy sometimes known as *Reanalysis As a Last Resort* (RALR) (Fodor & Frazier, 1980; Frazier, 1990; Frazier & Clifton, 1998); it also appears under the heading of *monotonic parsing* (Gorrell, 1995; Marcus, Hindle, & Fleck, 1983; Weinberg, 1993), and it has been implemented in activation-based parallel models in the form of lateral inhibition mechanisms (Vosse & Kempen, 1999). Alternatively, the parser may always select the optimal analysis of the new material, with little regard to whether or not this requires reanalysis of existing structural commitments (Gibson, 1991; Stevenson, 1998). From a computational standpoint, it is generally more efficient to let existing commitments constrain subsequent parsing choices, because this narrows the search space. However, in the light of evidence that many reanalyses are relatively easy, many psycholinguists have assumed that existing commitments only weakly constrain subsequent search processes (see papers in Fodor & Ferreira, 1998). The experiments reported here attempt to distinguish these alternatives. Studies similar to ours have been conducted by Sturt, Pickering, Scheepers, and Crocker (2001). These studies were developed independently of our own, but they yielded compatible results and are discussed further below.

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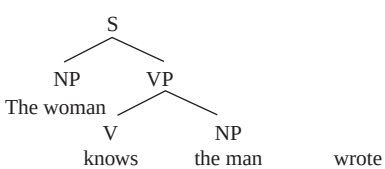
A good deal of recent work has attempted to characterize the structural differences between easier and more costly reanalyses (e.g., Fodor & Ferreira, 1998; Gibson, 1991; Pritchett 1988, 1992; Sturt & Crocker 1996), in order to explain why some parsing errors lead to comprehension breakdown (classic "garden path" sentences), whereas other parsing errors are easily recovered from. Our concern here is not to characterize the relative difficulty of different reanalyses. Rather, we are concerned with the logically prior question of how the parser searches for possible grammatical analyses of new material. If the parser always searches for new analyses that are consistent with existing commitments, then we make the following strong prediction: even the very easiest reanalyses should be avoided, because they are not part of the initial search space, and even globally preferred structures will be avoided, if reanalysis is required in order to build them.

An answer to our main question would lead us to a more detailed understanding of how sentences such as (1) are parsed. The sequence *The woman knows the man wrote* … is unambiguous, and the only possible analysis of the NP *the man* is as the subject of the embedded verb *wrote*, but it is less certain how the parser arrives at this conclusion when the verb *wrote* is first encountered. If grammatical search is constrained by existing commitments, then the parser will search for other analyses before determining that the NP *the man* must be reanalyzed as the subject of *wrote*. If search is not constrained by existing commitments, this reanalysis may be found immediately.

The woman knows the man *wrote* …



(1)

An answer to the question of how unambiguous sequences like (1) are parsed will shed light on general questions of how the parser rapidly determines the correct analysis of globally unambiguous sequences, which are probably more common than ambiguous sentences.

We will focus on structures similar to (1), because of two useful properties of these structures. First, the ambiguous NP (*the man* in (1)) is initially misanalyzed, and therefore reanalysis is necessary when the embedded verb is encountered (Ferreira & Henderson, 1990; Frazier & Rayner, 1982; Rayner & Frazier, 1987). Although this may not be the case in all contexts, it is certainly true when the NP is a plausible direct object of the main clause verb and when the main verb appears frequently with NP complements in corpora (Garnsey, Pearlmutter, Myers, & Lotocky, 1997; Juliano & Tanenhaus, 1994; Mitchell & Holmes, 1985; Trueswell, Tanenhaus, & Kello, 1993). Second, the reanalysis that is needed in (1) is known to be quite easy. Recent experiments by Sturt and colleagues (Sturt, Pickering, & Crocker, 1999) show that reanalysis in sentences like (1) is much easier than the related reanalysis required at the underlined verb in sentences like (2). These experiments confirm widely held intuitions (cf. Gibson, 1991; Pritchett, 1988, 1992; papers in Fodor & Ferreira, 1998). The fact that the reanalysis in (1) is so easy makes it a good candidate for testing the reality of the *Reanalysis As a Last Resort* (RALR) constraint.

While the woman was reading the magazine *fell* onto the floor. (2)

Since the reanalysis in (1) is mandatory, it is hard to test RALR using exactly this structure. However, we can test RALR by embedding structures like (1) inside a subject NP, as in (3a,3b). The effect of the manipulation in (3) is that the underlined verb *wrote* no longer forces reanalysis; this verb could be analyzed as the main clause verb, taking the sentence-initial NP *the creative woman* as its subject, as in (4a). In this case, no reanalysis of the NP *the funny man* would be required. Alternatively, the verb *wrote* could be locally attached as an embedded verb within the relative clause, with the NP *the funny man* reanalyzed as its subject, as in (4b). The addition of a gender-specific emphatic reflexive, which grammatically requires a local antecedent, allows the two alternative structures to

be distinguished. In effect, this ambiguity pits against one another (i) a reanalysis which is independently known to be quite easy and (ii) a structure which does not require reanalysis but which goes against an independently motivated bias, in this instance the *local attachment bias* (Altmann, van Nice, Garnham, & Henstra, 1998; Frazier, 1987; Gibson, Pearlmutter, Canseco-González & Hickok, 1996; Kimball, 1973; Phillips & Gibson, 1997; Stevenson, 1994a; Wanner, 1980).

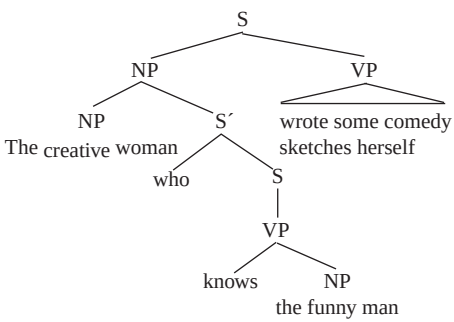
(3)

a. The creative woman who knows the funny man *wrote* some comedy sketches herself.

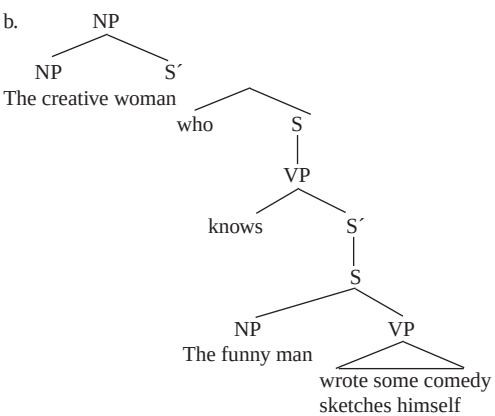
b. The creative woman who knows the funny man *wrote* some comedy sketches himself thinks he should publish the sketches.

(4)

a.



b.



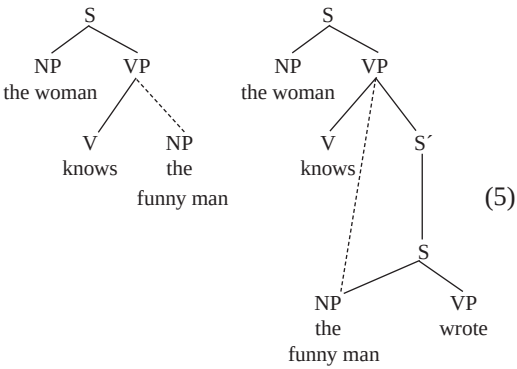
Predictions

If reanalysis is cost-free, we expect the parser to pursue the local attachment involving reanalysis, given the independently motivated locality bias. On the other hand, if the RALR constraint applies, then the nonlocal attachment of the verb *wrote* should be pursued, avoiding reanalysis but overriding the locality bias.

To our knowledge, examples like (3) above were first pointed out by Stevenson (1998, p.358), who presents them as modifications of examples in Sturt and Crocker (1996). Stevenson recognized these examples as key tests of RALR. In Stevenson's competitive attachment model, initial attachments and reanalyses directly compete with one another, and the locality preference built into Stevenson's parsing architecture therefore predicts that the local attachment will be chosen in (3), all other things being equal. Similar predictions apply to a number of other parallel parsing models (e.g., Gibson, 1991; Jurafsky, 1996). Working within a serial framework, Fodor and Inoue's model of reanalysis (1998, p.105) also predicts that local reanalysis will be chosen over nonlocal attachment in (3).

For an interestingly different reason, a preference for local attachment in (3) is also predicted by a number of proposals in the framework of D(escription)-theory (Marcus et al., 1983). In order to account for the ease of reanalysis in examples like (1), it has been suggested that attachment of the underlined verb *wrote* in direct object/embedded subject ambiguities like (1) does not require retraction of any existing structural commitments (e.g., Gorrell, 1995; Weinberg, 1993). Phrase-structure representations are assumed to be encoded in terms of dominance relations between pairs of nodes (and crucially not *immediate* dominance relations, in contrast to more standard syntactic approaches). Therefore, when the NP *the funny man* is changed from a direct object to an embedded subject, the only structural change is the addition of new dominance relations among nodes (e.g., the new S and S′ both now dominate the NP *the funny man*). This change requires no retraction of existing dominance relations (e.g., main clause VP still dominates NP *the funny man*), as illustrated in (5). Due to this nonstandard encoding of phrase-structure, the structural "change" in (1) no longer has the character of a reanalysis, and it is therefore predicted to be relatively easy. For the same reason, approaches

based on D-theory predict the same structural change to be cost-free when it is embedded inside a relative clause, as is the case in (3).



(5)

A number of models predict that reanalysis will be avoided in (3), and hence the nonlocal, main clause attachment of the underlined verb will be selected. This prediction is made by serial models which incorporate an explicit RALR principle (Fodor & Frazier, 1980: Frazier, 1978; Sturt & Crocker, 1996), and it is also made by Vosse and Kempen's Competitive Inhibition model (Vosse & Kempen, 2000). Vosse and Kempen's model is interesting in the present context, both because it is an implemented computational model and because it captures some similar effects to an RALR principle in an activation-based parallel model, without explicitly building in such a principle. The model contains a *lateral inhibition* mechanism that causes incompatible parses to inhibit one another. This results in a reinforcement of highly ranked candidates and causes reranking to be very costly. In this manner, Vosse and Kempen's model uses existing commitments to constrain the search for subsequent analyses, despite its lack of an explicit RALR constraint.

EXPERIMENT 1

This experiment was designed as an initial test of whether existing commitments constrain grammatical search. We tested structures like those in (3) and (4) above, but we also manipulated the probabilistic bias of the embedding verb to take an NP-complement. We included this manipulation because such probabilistic biases may affect the strength of the parser's commitment to an initial analysis, and hence may affect the parser's reluctance to give up this commitment.

Participants

Sixty-three members of the University of Delaware community participated in the study for payment. Seven participants (11%) were excluded from the analyses below because of low accuracy on the comprehension questions following each trial (less than 75% on experimental sentences or less than 80% on filler sentences), leaving a total of 56 participants.

Reading Span Test

All participants took part in a reading span task based on the test used by Daneman and Carpenter (1980). This test was run because of the complexity of the test sentences, because of the heterogeneity of the participant pool, and because of previous reports of differential sensitivity to probabilistic information in high- and low-span readers (Pearlmutter & MacDonald, 1995). Participants read sentences aloud from a computer screen and answered yes/no comprehension questions after each sentence. After reading and answering questions about a group of two sentences, their task was to recall the last word of each of the sentences that was read aloud. If at least four of the initial block of five pairs of sentences were answered correctly, a block of five three-sentence sets was tested. The procedure continued until a participant failed to successfully complete a block (maximum block size = 5). The reading-span score is equal to the size of the largest group successfully completed, plus 0.2 points per successful trial in the next group. In Experiment 1 the mean reading span score was 2.44 (s.d. = 0.88). Twenty-five participants who scored 2.6 or higher were classified as high-span readers; the remaining 31 participants were treated as low-span readers. In what follows we present the results for high-span and low-span readers together, only showing separate results where they differ. The inclusion of a comprehension question after each sentence in this task (following Roberts & Gibson, 1999, submitted manuscript) forces participants to interpret each sentence, and thus reinforces the in-

terference between on-line comprehension and rote memorization in this task. This may also explain why reading-span scores tend to be lower in this version of the task than in other versions of the task which do not include comprehension questions.

Materials

Forty-eight sets of four items were used in the experiment, in a 2 × 2 × 2 design, which manipulated the attachment-site (high vs low) of the ambiguous verb, the presence or absence of temporary ambiguity at the verb, and the complement bias of the embedding verb (strongly NP-biased vs weakly NP-biased). All conditions began with a subject NP which was modified by a subject relative clause. The relative clause contained a verb (henceforth the *embedding verb*) which allows both NP complements and sentential complements. The embedding verb was followed by an NP (the *ambiguous* NP) which could be analyzed as the object of the embedding verb or as the subject of a sentential complement. The ambiguous NP was followed by a transitive verb (the *ambiguous verb*), which could be attached either as a main clause verb (high attachment) or as an embedded verb (low attachment). Placed four words after the ambiguous verb was a gender-marked emphatic reflexive that disambiguated toward either a high or a low attachment.

The main clause subject NP and the ambiguous NP were always animate NPs with contrasting gender. This ensured that the disambiguating reflexive was an effective disambiguator, and it also ensured that both the main clause subject and the ambiguous NP were semantically good candidates to be the subject of the ambiguous verb. The four-word delay between the ambiguous verb and the disambiguation was included in order to be certain that commitments to the attachment of the ambiguous verb had been established. The reflexive was always followed by a four-word PP and additional material to ensure a grammatical and natural completion of the sentence. Emphatic (nonargumental) reflexives were used rather than argumental reflexives, in order to lengthen the delay between the ambiguous verb and the disambiguation, and in order to avoid anticipation of a reflexive at the ambiguous verb itself.

The low unambiguous control condition was created by addition of the complementizer *that*. The high unambiguous control condition was created by replacing the ambiguous NP with an accusative-marked pronoun (*him* or *her*). A sample set of stimuli is shown in (7), where the italicized words are the crucial manipulations, and a full list of materials is provided in Appendix B.

(7)

a. **low ambiguous**

The creative woman who knows *the funny man* wrote some comedy sketches *himself* about the amusing escapades thinks he should publish them.

b. **low unambiguous**

The creative woman who knows *that the funny man* wrote some comedy sketches *himself* about the amusing escapades thinks he should publish them.

c. **high ambiguous**

The creative woman who knows *the funny man* wrote some comedy sketches *herself* about the amusing escapades she had seen.

d. **high unambiguous**

The creative woman who knows *him* wrote some comedy sketches *herself* about the amusing escapades she had seen.

The embedding verbs were divided into two classes, based on sentence completion norms compiled by Susan Garnsey (p.c.). In 24 of the stimulus sets the embedding verb was strongly biased toward an NP complement (83%+ NP-completions as a proportion of all *that*-less complements). In the remaining 24 stimulus sets the embedding verb was either *neutral* or *weakly* biased toward an NP complement (52–78% NP-completions). Due to the small number of verbs in each class, all verbs appeared in a number of experimental items. Within each class, each verb was used in the same number of stimuli. No S-biased verbs were included in this experiment because of the possibility that NPs following strongly S-biased verbs might be initially attached as subjects of embedded clauses rather

than as direct objects (Garnsey et al., 1997; Juliano and Tanenhaus, 1994; Trueswell et al., 1993), thereby eliminating the trade-off between local attachment and reanalysis cost that the experiment is based upon. All verbs used in the experiment also satisfied the additional constraint that they allow animate NPs as direct objects. This constraint limited the number of verbs that could be used in the experiment, but it guaranteed that all candidate subjects of the ambiguous verb were plausible. If inanimate ambiguous NPs had been used, then this could have created a semantic bias for the verb to take the higher, animate NP as its subject, independent of any RALR constraint.

Procedure

Sentences were presented on a computer screen using a self-paced reading paradigm with a one-word moving-window display (Just, Carpenter, & Woolley, 1982), using the `mw-run` software for Macintosh developed at MIT. Each trial began with a series of dashes marking the length and position of the words in the sentences. Participants pressed the space bar to reveal each successive word of the sentence. As each new word appeared, the preceding word disappeared. The time spent on each word was recorded. All sentences were followed by a yes/no comprehension question. Feedback on accuracy was given immediately after each question. Most of the comprehension questions questioned the ambiguity itself, but with some variation to prevent participants from adopting experiment-specific strategies.

Up to 100 characters could appear on each line of the display, which allowed all material up to and including the disambiguating reflexive to appear on a single line. Following a brief practice session, sentences were presented in pseudo-random order in a single block, consisting of 48 experimental sentences, 36 sentences from an unrelated experiment, and 65 filler sentences.

Results

Comprehension accuracy and residual reading times at each region were entered into a repeated-measures ANOVA, with ambiguity, attachment site (high/low), and verb-class (strongly vs weakly NP-biased) as within-subjects factors.

Comprehension Accuracy

The overall level of accuracy in responses to comprehension questions was 87%. Results for all conditions are shown in Table 1. There was no effect of reading span (High versus Low) in overall comprehension accuracy (all Fs < 1). Responses to the comprehension questions showed a main effect of attachment site (participant analysis, $F_1(1,55) = 26.61$, MSe $= 2.96$, $p < .0001$; item analysis, $F_2(1,42) = 29.52$, MSe $= 3.02$, $p < .0001$), due to greater accuracy in the high-attachment conditions than in the low-attachment conditions. There was a significant ambiguity $\times$ attachment site interaction ($F_1(1,55) = 9.72$, MSe $= 1.08$, $p < .01$; $F_2(1,42) = 10.44$, MSe $= 1.07$, $p < .01$), due to a cost of ambiguity in the low-attachment conditions ($F_1(1,55) = 7.23$, MSe $= .991$, $p < .01$; $F_2(1,42) = 7.36$, MSe $= .929$, $p < .01$), but not in the high-attachment conditions. The fact that comprehension accuracy was lowest in the low ambiguous conditions is consistent with the self-paced reading results (below), which show the greatest difficulty at the point of disambiguation in this condition. There were no main effects or interactions involving verb class in the comprehension questions.

Self-Paced Reading

A regression equation predicting reading time from word length was constructed for each subject, using all items (filler and experimental). At each word, the reading time predicted by the subject's regression equation was subtracted from the actual measured reading time, and all analyses were performed on these differences (residual reading times). This transformation removes ex-

TABLE 1

Comprehension Accuracy, Experiment 1

	Ambiguous	Unambiguous
Low	80%	86%
High	90%	88%

traneous variance by subtracting out a baseline for each subject, and by controlling for noise due to length effects (Ferreira & Clifton, 1986; Trueswell & Tanenhaus, 1991). All times reported here are based on the residual reading times for trials in which the comprehension question was answered correctly. Reading times greater than 4 standard deviations from the mean were trimmed to 4 s.d. (1108 ms), affecting less than 1% of words; reading times greater than 8000 ms were excluded, affecting less than 0.01% of trials. Trials for the verb *fear* were removed from the analysis due to an unusually flat reading-time profile. Additionally, the high unambiguous condition of item (5) was removed due to a presentation error that rendered the sentence ungrammatical.

There are two areas of particular interest in all conditions. First, reading times at the disambiguating region (region 8 and subsequent regions) can help determine which parsing commitments were made in the ambiguous region. Second, reading times in the ambiguous region (regions 3–7) provide information on the relative difficulty of making those commitments. Because the reading times in the ambiguous regions are more easily understood in the light of the results in the disambiguating regions, we take the unorthodox step of presenting the results from regions 8–11 before the results from regions 3–7. Strongly and weakly NP-biased embedding verbs are combined in all analyses, due to the absence of interactions involving verb class.

Residual reading times for all conditions and regions are shown in Fig. 1 (raw reading times can be found in Appendix A). At the word immediately following the disambiguating reflexive there was a main effect of ambiguity ($F_1(1,54) = 45.94$, MSe = 2340905, $p < .0001$; $F_2(1,42) = 45.19$, MSe = 2392136, $p < .0001$), a main effect of attachment site ($F_1(1,54) = 10.85$, MSe = 552687, $p = .001$; $F_2(1,42) = 10.83$, MSe = 572958, $p = .001$), and an ambiguity × attachment site interaction ($F_1(1,54) = 25.11$, MSe = 1279537, $p < .0001$; $F_2(1.42) = 25.21$, MSe = 1334320, $p < .0001$). Each of these effects, with the exception of the effect of attachment site, was already significant at the disambiguating reflexive itself (region 8), and all of the effects remained significant at regions 10–12.

Pairwise comparisons showed that the ambiguity × attachment site interaction at region 9 was due to a strong cost of ambiguity in the low-attachment conditions ($F_1(1,54) = 58.31$, MSe = 3407338, $p < .0001$; $F_2(1,42) = 57.41$, MSe = 3522229, $p < .0001$), but no cost of ambiguity in the high-attachment conditions ($p > .15$). This pattern of results clearly suggests that the disambiguating reflexive causes most difficulty in the low-attachment conditions. In other words, it sug-

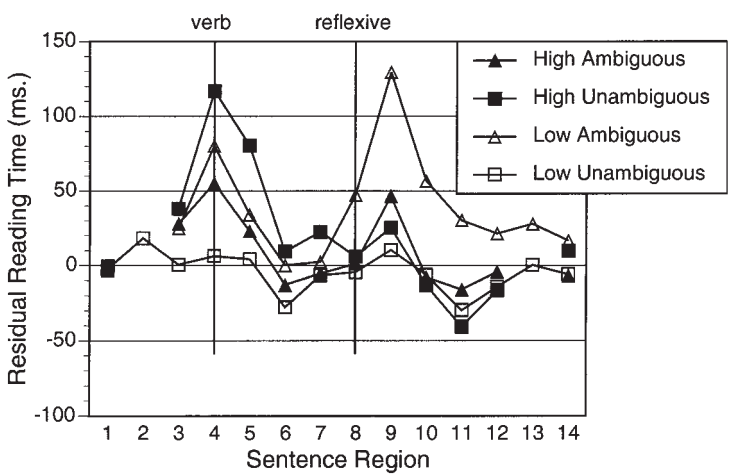


FIG. 1. Residual reading times for Experiment 1 (The creative woman who knows $_1$ / that $_2$ / the funny man $_3$ / wrote $_4$ / some $_5$ / comedy $_6$ / sketches $_7$ / himself $_8$ / about $_9$ / the $_{10}$ / amusing $_{11}$ / escapades $_{12}$ / thinks $_{13}$ / he should publish them $_{14}$ /).

gests that participants strongly favor a main clause analysis of the ambiguous verb.

Despite the evidence that high-attachment conditions were much easier than low-attachment conditions, analysis of the high-attachment conditions at region 9 reveals a significant interaction of ambiguity with reading-span group ($F_1(54) = 4.89$, MSe = 216234, $p < .05$; $F_2(1,42) = 5.41$, MSe = 247511, $p < .05$). This interaction was due to the fact that low-span readers also showed a cost of ambiguity in the high-attachment conditions (high attachment: $F_1(1,30) = 4.00$, MSe = 190916, $p < .05$; $F_2(1.42)=4.80$, MSe = 234637, $p < .05$), but high-span readers did not (all Fs < 1). However, even for the low-span readers, the magnitude of the slowdown due to ambiguity was much greater in the low-attachment conditions (ambig., 146 ms; unambig., 20 ms; slowdown, 126 ms) than in the high-attachment conditions (ambig., 56 ms; unambig., 25 ms; slowdown, 31 ms). This difference could indicate that incorrect low attachments are more difficult to revise than incorrect high attachments, or it could indicate that high attachments were more common, or a combination of the two. Whereas the cost of ambiguity in the low-attachment conditions persisted until region 12 and beyond, the cost of ambiguity in the high-attachment conditions was only observed at region 9. Among high-span readers, the magnitude of the slowdown due to ambiguity was large in the low-attachment conditions (ambig., 121 ms; unambig., 9 ms., slowdown, 113 ms), and very small in the high-attachment conditions (ambig., 44 ms., unambig., 42 ms; slowdown, 2 ms).

At the ambiguous verb in region 4 there was no main effect of ambiguity (all Fs < 1), but there was a main effect of attachment site ($F_1(1.54) = 12.34$, MSe = 877088, $p < .001$; $F_2(1.42) = 12.63$, MSe = 915345, $p < .001$), which persisted until region 5, and an ambiguity $\times$ attachment site interaction ($F_1(1,54) = 32.21$, MSe = 2288876, $p < .0001$; $F_2(1.42) = 28.95$, MSe = 2098477, $p < .0001$), which persisted until region 7. Pairwise comparisons reveal that this interaction was due to main effects of ambiguity for both attachment sites, but with opposite directions. The low ambiguous condition was read more slowly than its unambiguous counterpart ($F_1(1,54) = 22.31$, MSe = 1261511, $p < .0001$; $F_2(1,42) = 21.8$, MSe = 1287387, $p < .0001$), possibly because the NP is more strongly predicted after the complementizer, or because its attachment is unambiguous and local in this position. On the other hand, the high unambiguous condition was read more slowly than its ambiguous counterpart ($F_1(1,52) = 12.5$, MSe = 1051882, $p < .001$; $F_2(1,42) = 10.15$, MSe = 867926, $p < .01$). The high unambiguous condition remained slower than all other conditions until region 7, the word immediately preceding the reflexive. In light of the finding that high ambiguous conditions were relatively easy at the disambiguation point, we conclude that *both* ambiguous and unambiguous high-attachment conditions were given a high-attachment analysis starting at region 4. Therefore, we cannot attribute the slowdown in the high unambiguous conditions to the cost of finding the high attachment. A more likely cause is the unnaturalness of the unanchored pronoun used as a disambiguator. We address this issue further below in the discussion and in Experiment 2.

Discussion

The clearest finding of this experiment was that readers consistently chose the main clause analysis (i.e., high-attachment) of the ambiguous verb. This finding contrasts with a good deal of evidence for a local attachment bias in parsing ambiguities where reanalysis is not an issue, and therefore provides compelling evidence that parsing decisions are constrained by existing commitments, as the *Reanalysis As a Last Resort* principle predicts.

The preference for high attachments over low attachments was equally clear with both strongly and weakly NP-biased verbs. This could be taken to indicate that the effect of existing commitments is not graded, and that all existing commitments are respected, regardless of how well they are supported by probabilistic information. Alternatively, the lack of a verb class difference could simply reflect the fact that our manipulation was a relatively weak one, since both verb classes were to some extent NP-biased. Ferreira and Henderson (1990) failed to

find any evidence of verb bias effects in initial parsing decisions, but they did notice some differences in ease of recovery from error based on verb bias. Trueswell et al. (1993) found strong evidence of verb-class effects at the point of disambiguation. It should be noted, however, that the verb bias differences in the materials used in the Ferreira and Henderson and Trueswell et al. studies were greater than the verb bias differences in this experiment, and this might be the reason for the lack of findings here.

Inferences that can be drawn from reading times at the disambiguating regions allow us to constrain the possible interpretations of the reading times in the ambiguous region (3–7). The slower reading time for the low ambiguous condition relative to its control is expected, both because the disambiguating complementizer could facilitate the reading times for the subsequent words, and because the ambiguous verb is attached nonlocally as a main clause verb in the ambiguous condition, an attachment which may require extra time.

The fact that the high unambiguous condition was read more slowly than the high ambiguous condition is more surprising. Based on the results at the disambiguating region, we can be confident that participants give the same main clause analysis to the ambiguous verb in both high ambiguous and high unambiguous conditions. Therefore, we cannot attribute the slowdown in the unambiguous condition to any additional cost of the high attachment. We suggest that the slowdown reflects difficulty associated with the pronoun that is used as a disambiguator in this condition. In a string such as *The creative woman who knows him . . .* the pronoun is not anchored to any existing discourse referent. Although this is fully grammatical and natural in some English contexts (as in *The people who know him best think the President is a genius*), it is unnatural in this context and may trigger an ultimately fruitless search for an antecedent.

Although high-span readers and low-span readers showed similar results at most regions, the one striking difference was the evidence for a garden path in both high-attachment and low-attachment conditions for the low-span readers. This suggests that they did not always attach the ambiguous verb high, but they sometimes (probably infrequently) attached it low, in apparent violation of RALR. One possible explanation for the contrast between span groups relates to independent evidence that low-span readers are less constrained by probabilistic biases than are high-span readers (Pearlmutter & MacDonald, 1995). This could mean that our low-span readers sometimes initially analyzed the ambiguous NP as an embedded subject, even before the ambiguous verb was encountered. If this happened, then RALR would no longer block the low attachment of the ambiguous verb. However, the span group difference at region 9 should be treated with some caution. Although high-span readers showed no slowdown due to ambiguity in the high conditions at region 9, they showed a marginally significant effect of ambiguity at region 8 ($F_1(1,24) = 2.49$, MSe = 101172, $p < .12$; $F_2(1,42) = 3.14$, MSe = 119775, $p < .08$), due to slower reading times for the *un*ambiguous high-attachment condition. Therefore, we cannot exclude the possibility that a small cost of ambiguity at region 9 was masked by an independent slowdown in the high unambiguous condition.

There are a number of questions which need to be addressed by a further experiment. First, although we took care to make both animate NPs equally plausible subjects for the ambiguous verb, it might be objected that the high attachments were made because the main clause subject-verb dependency has special status (cf. Gibson, 1998). This can be addressed by embedding the test structures such that the nonlocal attachment site does not correspond to the main clause.

Second, the use of an unanchored pronoun as disambiguator in the high-attachment conditions may have introduced spurious differences between the high-attachment and low-attachment conditions. This problem can be addressed by providing an antecedent for the pronoun and by using matched disambiguators in high-attachment and low-attachment conditions.

Third, the lack of verb-class differences may be due to the weakness of our verb-class manipulation, and the anomalous behavior of low-span readers may have been due to their relative

insensitivity to probabilistic verb argument structure biases. These can be addressed by using a wider variety of verb classes.

The use of a stronger verb-bias manipulation also makes it possible to address a couple of other accounts of the high attachment bias observed in Experiment 1. The high attachments observed there may be due to a simple "avoid embedding" constraint, which attempts to minimize the degree of embedding at any choice point in a sentence (and thus necessarily competes against local attachment constraints), or they may be due to a constraint which places a cost on long subject NPs (the low attachment lengthens the subject NP). It has been observed that subject NPs tend to be shorter than NPs in other positions (e.g., Behagel, 1932; Hawkins, 1994). Attention to this statistical property of language may lead comprehenders to adopt an early closure strategy for subject NPs. If either of these alternatives is responsible for the high attachment effect, then we should expect an across-the-board high-attachment bias, independent of the bias of the embedding verb (NP-bias vs S-bias), and hence independent of the initial attachment of the ambiguous NP. On the other hand, if RALR is responsible for the high-attachment bias, then the effect should be highly sensitive to the initial attachment of the ambiguous NP. Experiment 2 was designed to address each of these issues.

EXPERIMENT 2

This experiment was designed to replicate and extend the results of Experiment 1, and to address the alternative accounts of the results found there. The basic structures tested were the same as in Experiment 1, but a number of changes were made in order to address issues arising from the first experiment. In this experiment we used a wider range of verb classes, we more closely matched the high and low unambiguous conditions, and we ensured that all pronouns had an antecedent in the existing discourse.

Participants

Sixty-four undergraduate students from the University of Delaware, none of whom participated in Experiment 1, participated in the study for payment. Eight participants (12.5%) were excluded from the analysis based on their low accuracy on the comprehension questions (less than 65% on experimental sentences, or less than 80% on the filler sentences), leaving a total of 56 participants. The exclusion criterion was slightly more liberal in this experiment than in Experiment 1, due to the increased length of the experimental stimuli, but the percentage of subjects excluded was almost identical to that in Experiment 1.

Materials

Materials for this experiment were identical in format to those used in Experiment 1, with the following exceptions. First, four classes of embedding verbs were used, instead of the two classes used in Experiment 1: strongly NP-biased, weakly NP-biased, S-biased, and verbs that only allow NP complements. See Appendix C for full details of the verbs used. The conditions with NP-only verbs were included in the experiment in order to provide a baseline measure of the difficulty of the high attachment, and in order to ensure that the use of pronouns as early disambiguators did not introduce spurious differences independent of ambiguity. Second, the unambiguous conditions were more closely matched across high-attachment and low-attachment conditions than in Experiment 1—an accusative pronoun was used in the high unambiguous condition, and a nominative pronoun in the low unambiguous condition. Third, in order to avoid any confounds due to the lack of an antecedent for the pronouns, all items were embedded as the right-branching complement of a higher clause which provided an antecedent for the pronouns in the unambiguous conditions. The antecedent for the disambiguating pronoun in the unambiguous conditions corresponded to the ambiguous NP in the ambiguous conditions (e.g., *the funny man* in example (8) below). The additional clause made the experimental items slightly longer, but more natural. The highest clause always contained a verb which unambiguously selects a finite sentential complement. Fourth, due to the large numbers of stimuli involved, only 20 sets of items were tested for

each verb class. A sample set of stimuli for this experiment is shown in (8). Note that there were no low-attachment conditions for the items in the NP-only conditions, since these would be ungrammatical.

a. **low ambiguous**

The talent agency thinks that the creative woman who knows *the funny man* wrote some comedy sketches *himself* about the amusing escapades wants to publish them.

b. **low unambiguous**

The funny man thinks that the creative woman who knows *he* wrote some comedy sketches *himself* about the amusing escapades wants to publish them.

c. **high ambiguous** (8)

The talent agency thinks that the creative woman who knows *the funny man* wrote some comedy sketches *herself* about the amusing escapades she had seen.

d. **high unambiguous**

The funny man thinks that the creative woman who knows *him* wrote some comedy sketches *herself* about the amusing escapades she had seen.

Procedure

The procedure was identical to that in Experiment 1, except where noted here. Due to the large number of trials in this experiment, the self-paced reading task was divided into two blocks of trials each containing 100 sentences (35 experimental sentences, 36 sentences from unrelated experiments, 29 fillers). The length of the filler sentences was matched to the length of the experimental sentences. The order of the blocks was counterbalanced. In this experiment, all of the comprehension questions involved the ambiguity—the question could only be answered correctly if the ambiguity had been appropriately resolved.

Reading Span Task

All participants took part in a reading span task, as in Experiment 1. The mean reading span score was 2.21 (s.d. = 0.84). Twenty-nine participants who scored 2.4 or higher were classified as high-span readers; the remaining 27 participants were classified as low-span readers.

Results

Analysis procedures were identical to Experiment 1, except that the verb class factor included two additional levels in this experiment, S-bias and NP-only. Since the NP-only conditions were always unambiguous, even in the absence of unambiguously case-marked pronouns, these conditions are not included in the analyses unless specifically noted.

Comprehension Accuracy

Table 2 shows mean comprehension accuracy scores for Experiment 2. The overall accuracy level in this experiment was 80%. The slightly lower accuracy level in this experiment can be attributed both to the increased length of the test sentences and to the fact that all comprehension questions specifically tested the ambiguity. Overall comprehension accuracy was very similar for high-span (80.2%) and low-span readers (79.6%), and there were no main effects or interaction involving span group. There was a main effect of ambiguity on comprehension accuracy, due to higher accuracy scores on the unambiguous conditions ($F_1(1,54) = 15.62$, $p < .0001$; $F_2(1,57) = 16.42$, $p < .0001$). There was also a significant attachment site $\times$ verb class interaction ($F_1(2,54) = 12.21$, $p < .0001$; $F_2(2,57) = 12.41$, $p < .0001$). This interaction was due to the tendency for comprehension accuracy to increase as S-bias increased in the low attachment conditions, and for comprehension accuracy to decrease as S-bias increased in the high-attachment conditions. This pattern of difficulty parallels the patterns of difficulty seen below in the analysis of reading times.

TABLE 2

Comprehension Accuracy, Experiment 2

	Ambiguous	Unambiguous
Low, strong NP-bias	71%	83%
Low, weak NP-bias	74%	77%
Low, S-bias	78%	85%
High, NP-only	91%	86%
High, strong NP-bias	82%	87%
High, weak NP-bias	79%	84%
High, S-bias	71%	75%

Self-Paced Reading

As in Experiment 1, all times reported here are residual reading times for trials in which the comprehension question was answered correctly. Three trials (> 0.01%) were removed because of residual reading times greater than 8000 ms. Residual reading times greater than 4 standard deviations from the mean were trimmed to 4 s.d. (1194 ms); this affected less than 1% of words. Item (44) was removed from the analysis due to a missing region, with the consequence that only 19 weakly NP-biased items were analyzed, compared to 20 for other verb classes. As in Experiment 1, for ease of exposition we report reading times at the disambiguating region (regions 8 and following) before discussing reading times in the ambiguous region (regions 3–7). Region numbering matches the numbering used in Experiment 1. Because the complementizer *that* was no longer used as a disambiguator, there was no region 2 in this experiment. Raw reading times are reported in Appendix A.

The ANOVA revealed significant interactions involving verb class and attachment site, in both the ambiguous regions and following the disambiguation point. At the word immediately following the ambiguous verb (region 5) there was an ambiguity × verb class interaction ($F_1(2,54) = 4.95$, MSe = 265482, $p < .01$; $F_2(2,56) = 5.24$, MSe = 279262, $p < .01$) and an ambiguity × attachment site × verb class interaction ($F_1(2,54) = 4.36$, MSe = 233794, $p < .05$; $F_2(2,56) = 4.97$, MSe = 265307, $p < .01$). At the word immediately following the disambiguating reflexive (region 9) there was an attachment site × verb class interaction ($F_1(2,54) = 7.80$, MSe = 430588, $p < .001$; $F_2(2,56) = 8.64$, MSe = 487289, $p < .001$) and an ambiguity × attachment site × verb class interaction ($F_1(2,54) = 4.18$, MSe = 230867, $p < .05$; $F_2(2,56) = 3.25$, MSe = 183256, $p < .05$). Based on this evidence that the verb class manipulation modulates the effects of ambiguity and attachment site, all further analyses were conducted separately for each verb class. The analyses focus on the regions following the disambiguation point (regions 8–12), and on the ambiguous regions (regions 4–7). Reading time differences at the NP in region 3 are of less direct concern here, since there was a substantial length difference between the ambiguous conditions, in which the NP was three words long, and the unambiguous conditions, in which the NP was a pronoun. As in Experiment 1, we will only mention span-group differences where statistically justified. In all other cases, the results will be for all subjects.

NP-only verbs. Residual reading times in conditions with NP-only verbs are shown in Fig. 2. Very few differences between "ambiguous" and "unambiguous" NP-only conditions were observed. There were main effects of ambiguity at region 6 ($F_1(1,54) = 4.91$, MSe = 227988, $p < .05$; $F_2(1,9) = 5.00$, MSe = 239375, $p < .05$) and at regions 10–12 ($F_1(1,54) = 7.15$, MSe = 186538, $p < .01$; $F_2(1,9) = 7.08$, MSe = 198192, $p < 0.01$). At region 6 the "ambiguous" conditions were read more quickly, and at regions 10–12 the "unambiguous" conditions were read more quickly. Since there were no differences between "ambiguous" and "unambiguous" NP-only conditions immediately following the disambiguation (regions 8–9) or immediately following the onset of the ambiguous region (regions 4–5), we conclude that the use of pronouns as early disambiguators did not introduce spurious differences in this experiment.

Strongly NP-biased verbs. *Disambiguation*. Residual reading times in conditions with strongly NP-biased verbs are shown in Fig. 3. At the word immediately following the disambiguating reflexive (region 9) there was a main effect of ambiguity ($F_1(1,54) = 11.94$, MSe = 567068, $p < 001$; $F_2(1,19) = 10.15$, MSe = 504212, $p < .01$), a main effect of attachment site ($F_1(1,54) = 15.96$, MSe = 757975, $p < .0001$; $F_2(1,19) = 15.951$, MSe = 792529, $p < .0001$), and an ambiguity × attachment site interaction ($F_1(1,54) = 8.88$, MSe = 421673, $p < .01$; $F_2(1,19) = 7.25$, MSe = 360176, $p < .01$). However, pairwise comparisons showed tha the main effects are misleading, and that the cost of ambiguity was restricted to the low-attachment conditions (high-attachment, all Fs < 1; low-attachment, $F_1(1,54) = 14.25$, MSe = 879135, $p < .001$; $F_2(1,19) = 12.27$, MSe = 819816, $p < .001$). This pattern of results sug-

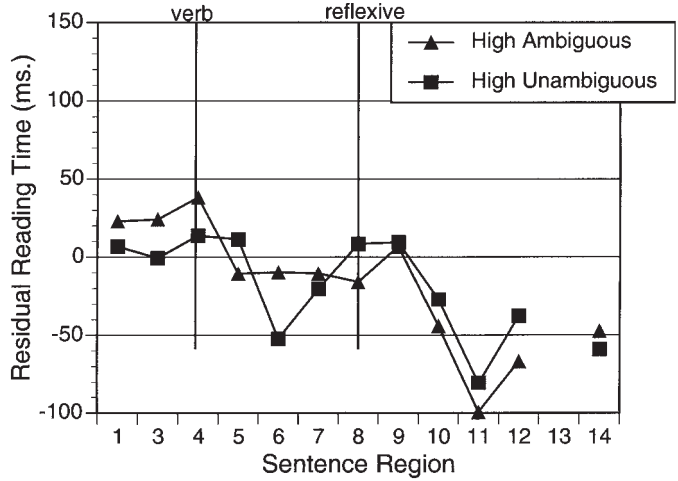


FIG. 2. Residual reading times for NP-only conditions in Experiment 2 (The homeless people think that the brilliant woman who supported $_1$ / the impoverished man $_3$ / called $_4$ / the $_5$ / large $_6$ / charity $_7$ / herself $_8$ / after $_9$ / the $_{10}$ / fund $_{11}$ / drive $_{12}$ / to see if he had applied for aid $_{14}$ /).

gests that readers commit to the high attachment before reaching the disambiguating reflexive, leading to significant slowdown when the reflexive disambiguates toward the low-attachment parse. For high-span readers this is the same pattern observed in Experiment 1. For low-span readers this pattern differs from Experiment 1: in Experiment 1 low-span readers showed a significant cost of ambiguity in both high-attachment and low-attachment conditions, whereas in this experiment there was no evidence of difficulty at the disambiguation in the high ambiguous condition.

Ambiguous region. At the ambiguous NP and the two following words (regions 3–5) main effects of ambiguity were observed, due to slower

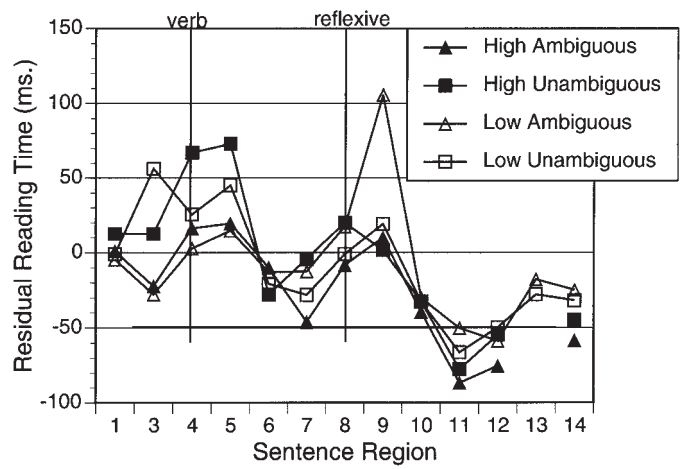


FIG. 3. Residual reading times for strongly NP-biased verbs in Experiment 2 (The faculty members were grateful that the generous benefactor who understood $_1$ / the persuasive woman $_3$ / bought $_4$ / the $_5$ / powerful $_6$ / telescope $_7$ / herself $_8$ / for $_9$ / the $_{10}$ / small $_{11}$ / college $_{12}$ / promised $_{13}$ / to fund a new observatory $_{14}$ /).

reading times for the *un*ambiguous conditions (region 3, $F_1(1,54) = 25.51$, MSe = 1245280, $p < .0001$; $F_2(1,19) = 27.83$, MSe = 1336473, $p < .0001$; region 4, $F_1(1,54) = 4.47$, MSe = 334924, $p < .05$; $F_2(1,19) = 4.57$, MSe = 351057, $p < .05$; region 5, $F_1(1,54) = 5.91$, MSe = 356067, $p < .05$; $F_2(1,19) = 6.60$, MSe = 404011, $p < .05$).

At the ambiguous NP (region 3) there was also an ambiguity × attachment site interaction ($F_1(1,54) = 4.87$, MSe = 237853, $p < .05$; $F_2(1,19) = 4.18$, MSe = 201106, $p < .05$). This interaction was due to a greater slowdown for the nominative pronoun in the low unambiguous condition than for the accusative pronoun in the high unambiguous condition, although pairwise comparisons revealed that the slowdown was significant for both high- and low-attachment conditions (high-attachment, $F_1(1,54) = 3.66$, MSe = 161920, $p = .055$; $F_2(1,19) = 5.02$, MSe = 218523, $p < .05$; low-attachment, $F_1(1,54) = 19.76$, MSe = 1067996, $p = .0001$; $F_2(1,19) = 24.08$, MSe = 1275771, $p < .0001$). The greater slowdown at the low unambiguous attachment condition may reflect the fact that a nominative pronoun is unexpected following a strongly NP-biased verb. The ambiguity × attachment site interaction did not reach significance at regions 4–5 (all Fs < 1). Note that this pattern of results contrasts with Experiment 1, where the low unambiguous conditions were read faster than all other conditions throughout the ambiguous region (see Fig. 1). The greater similarity between the two unambiguous conditions in this experiment may reflect the fact that the conditions were more closely matched.

At the ambiguous verb (region 4) there was an ambiguity × span-group interaction ($F_1(1,54) = 11.41$, MSe = 854597, $p < .001$; $F_2(1,19) = 1.19$, MSe = 781983, $p < .01$), due to the fact that the cost of ambiguity was greater among low-span readers. Pairwise comparisons revealed that the effect of ambiguity in this region was significant for low-span readers ($F_1(1,26) = 11.80$, MSe = 1109050, $p < 0.001$; $F_2(1,19) = 11.18$, MSe = 1079270, $p < .001$; ambig., −14 ms; unambig., 46 ms), but not for high-span readers (all Fs < 1; ambig., 32 ms; unambig., 9 ms). The interaction with span-group was not significant at any other region.

Weakly NP-biased verbs. *Disambiguation*. Results for weakly NP-biased verbs are shown in Fig. 4. At the disambiguating reflexive (region 8) and the following words (regions 9–12) there was a significant ambiguity × attachment site interaction, due to a cost of ambiguity in the low ambiguous condition, but not in the high ambiguous condition (region 8, $F_1(1,54) = 4.03$, MSe = 249324, $p < .05$; $F_2(1,18) = 4.42$, MSe = 279302, $p < .05$; region 9, $F_1(1,54) =$

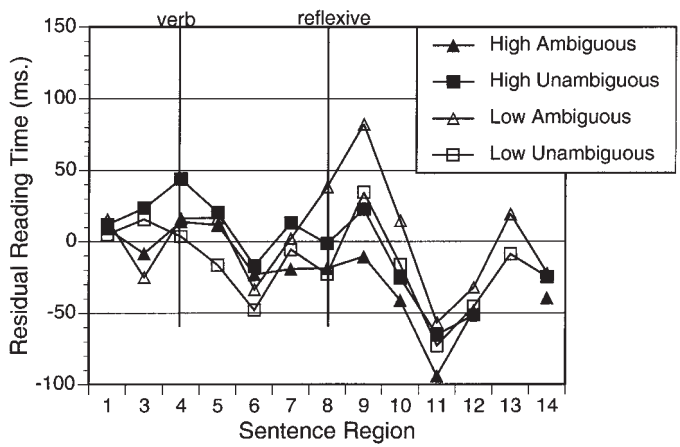


FIG. 4. Residual reading times for weakly NP-biased verbs in Experiment 2 (The talent agency thinks that the creative woman who knows $_1$ / the funny man $_3$ / wrote $_4$ / some $_5$ / comedy $_6$ / sketches $_7$ / himself $_8$ / about $_9$ / the $_{10}$ / amusing $_{11}$ / escapades $_{12}$ / thinks $_{13}$ / he should publish them $_{14}$ /).

4.29, MSe = 247247, $p < .05$; $F_2(1,18) = 6.30$, MSe = 358144, $p < .05$; regions 10–12: $F_1(1,54) = 3.31$, MSe = 106276, $p < .07$; $F_2(1,18) = 3.86$, MSe = 131936, $p < .05$). The main effect of attachment site was also significant, beginning at the word following the reflexive, and was due to slower reading times for low conditions (region 9, $F_1(1,54) = 8.97$, MSe = 516875, $p < .01$; $F_2(1,18) = 9.37$, MSe = 532526, $p < .01$; regions 10–12, $F_1(1,54) = 10.81$, MSe = 348488, $p = .001$; $F_2(1,18) = 8.10$, MSe = 276794, $p < .01$). No interactions involving reading span group were significant at any of these regions. At these regions, the results for weakly NP-biased verbs were similar to those for strongly NP-biased verbs. The only significant costs of ambiguity were observed in the low-attachment conditions, indicating that the ambiguous verb was consistently given a high-attachment analysis. Nevertheless, the magnitude of the slowdown in the low-attachment conditions was somewhat smaller with the weakly NP-biased verbs than with the strongly NP-biased verbs.

Ambiguous region. There was a main effect of ambiguity at the ambiguous NP (region 3), due to slower reading times for the unambiguous conditions ($F_1(1,54) = 7.79$, MSe = 316463, $p < .01$; $F_2(1,18) = 8.80$, MSe = 363749, $p < .01$). At regions 4–5 no main effects or interactions were significant or marginally significant. At region 6 the only significant effect was the ambiguity × attachment site × span group interaction ($F_1(1,54) = 4.26$, MSe = 216490, $p < .05$; $F_2(1,18) = 3.92$, MSe = 200702, $p < .05$).

S-biased verbs. Disambiguation. Results for conditions with S-biased verbs are shown in Fig. 5. Results with this verb class differed strikingly from the results with other verb classes. In particular, there was a substantial change in which conditions caused the greatest difficulty at the disambiguating regions.

At the disambiguating reflexive and the following word (regions 8–9) there were significant or marginally significant main effects of ambiguity (region 8, $F_1(1,54) = 3.49$, MSe = 249918, $p < .07$; $F_2(1,19) = 3.46$, MSe = 253565, $p < .07$; region 9, $F_1(1,54) = 9.14$, MSe = 556718, $p < .01$; $F_2(1,19) = 8.37$, MSe = 528453, $p < .01$). At region 8 there was also a marginally significant main effect of attachment site ($F_1(1,54) = 3.11$, MSe = 222662, $p < .08$; $F_2(1,19) = 2.75$, MSe = 201270, $p < .10$).

The ambiguity × attachment site interaction did not reach significance at either of these regions (all Fs < 1). However, at both region 8 and region 9 there were marginally significant interactions with reading span group (ambiguity × span, region 8, $F_1(1,54) = 2.93$, MSe = 209725, $p < .09$; $F_2(1,19) = 3.02$, MSe =

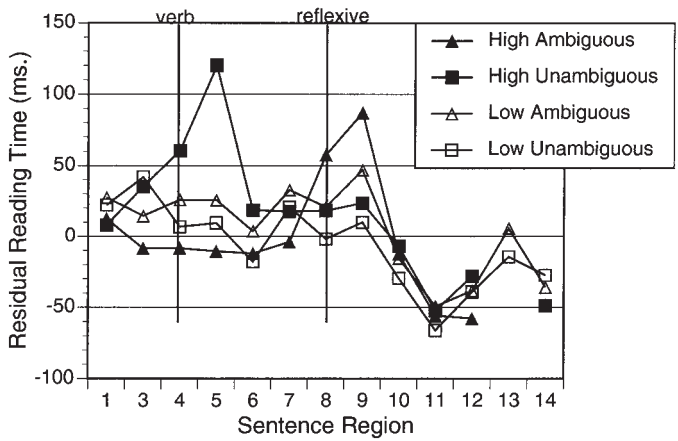


FIG. 5. Residual reading times for S-biased verbs in Experiment 2 (The family said that the aging uncle who claimed $_1$ / the teenage girl $_3$ / purchased $_4$ / the $_5$ / new $_6$ / car $_7$ / herself $_8$ / at $_9$ / the $_{10}$ / car $_{11}$ / dealership $_{12}$ / denied $_{13}$ / that he had anything to do with the purchase $_{14}$ /).

221071, $p < .09$; ambiguity × attachment site × span, region 8, $F_1(1,54) = 3.72$, MSe = 266697, $p < .06$; $F_2(1,19) = 2.66$, MSe = 194738, $p = .10$; ambiguity × attachment site × span, region 9, $F_1(1,54) = 1.96$, MSe = 119471, $p = .16$; $F_2(1,19) = 3.46$, MSe = 218130, $p < .07$). These interactions led us to examine the results separately for each reading span group.

At region 9 high-span readers showed significant main effects of ambiguity ($F_1(1,28) = 5.94$, MSe = 313812, $p < .05$; $F_2(1,19) = 5.45$, MSe = 297727, $p < .05$) and attachment site ($F_1(1,28) = 4.41$, MSe = 232766, $p < .05$; $F_2(1,19) = 5.68$, MSe = 309987, $p < .05$), and the ambiguity × attachment site interaction was significant in the item analysis and marginally significant in the participant analysis ($F_1(1,28) = 3.46$, MSe = 182733, $p < .07$; $F_2(1,19) = 4.09$, MSe = 223257, $p < .05$). However, the two main effects are misleading, since pairwise comparisons reveal that there was a significant cost of ambiguity in the high-attachment conditions only ($F_1(1,28) = 5.47$, MSe = 426260, $p < .05$; $F_2(1,19) = 7.33$, MSe = 534523, $p < .01$; ambig., 121 ms; unambig., 30 ms), and no corresponding effect in the low-attachment conditions (all Fs < 1; ambig., 28 ms; unambig., 16 ms). This is the opposite of the pattern observed above with strongly and weakly NP-biased verbs, and it indicates that the high-span readers were consistently adopting the low-attachment analysis for the ambiguous verb.

In contrast to the high-span readers, low-span readers showed clear evidence of difficulty in both high and low ambiguous conditions. There was a main effect of ambiguity (marginally significant at region 9, $F_1(1,26) = 3.63$, MSe = 252532, $p < .06$; $F_2(1,19) = 2.58$, MSe = 184748, $p < .11$; significant at the $p < .01$ level when regions 8–9 were combined) and no main effect of attachment site or interaction of ambiguity and attachment site (all Fs < 1). Pairwise comparisons showed a significant cost of ambiguity in the high-attachment conditions (regions 8–9, $F_1(1,26) = 4.17$, MSe = 395846, $p < .05$; $F_2(1,19) = 4.05$, MSe = 372347, $p < .05$; ambig., 72 ms; unambig., 30 ms) and a marginally significant cost of ambiguity in the low-attachment conditions (region 9, $F_1(1,26) = 2.98$, MSe = 187950, $p < .09$; $F_2(1,19) = 3.25$, MSe = 203705, $p < .08$; ambig., 70 ms; unambig., 4 ms). These results suggest that whereas high-span readers consistently adopt a low attachment for the ambiguous verb, low-span readers adopt a mix of high and low attachments.

Ambiguous region. At the ambiguous verb in region 4 and at the following word (region 5), there was a significant ambiguity × attachment site interaction (region 4, $F_1(1,54) = 4.84$, MSe = 357346, $p < .05$; $F_2(1,19) = 4.81$, MSe = 351480, $p < .05$; region 5, $F_1(1,54) = 20.29$, MSe = 1129924, $p < .0001$; $F_2(1,19) = 22.28$, MSe = 1228903, $p < .0001$), and at region 5 there were also significant main effects of ambiguity and attachment site (ambiguity, $F_1(1,54) = 11.45$, MSe = 637838, $p < .001$; $F_2(1,19) = 12.63$, MSe = 696474, $p < .001$; attachment site, $F_1(1,54) = 6.16$, MSe = 342958, $p < .05$; $F_2(1,19) = 6.68$, MSe = 368616, $p < .01$). Pairwise comparisons revealed that at both regions 4 and 5 the high unambiguous condition was read more slowly than the high ambiguous condition (region 4, $F_1(1,54) = 5.74$, MSe = 418207, $p < .05$; $F_2(1,19) = 4.65$, MSe = 355061, $p < .05$; region 5, $F_1(1,54) = 22.24$, MSe = 1486158, $p < .0001$; $F_2(1,19) = 25.803$, MSe = 1731943, $p < .0001$), with no corresponding slowdown in the low-attachment conditions (all Fs < 1).

Discussion

We will first discuss those findings which were consistent across reading-span groups before considering differences between the two groups. This experiment replicated the main result of Experiment 1, but it showed important variation due to the verb class manipulation, which was not seen in Experiment 1 due to the limited range of verb classes tested.

As in Experiment 1, this experiment showed that the ambiguous verb was consistently given a high-attachment analysis when it followed strongly NP-biased or weakly NP-biased embedding verbs. This again supports the notion that existing commitments constrain the parser's search for analyses of incoming material. Furthermore, the current experiment showed that the high attachments are not due to any spe-

cial status of the main clause subject-verb dependency, which was one concern about Experiment 1. In Experiment 2 the additional level of embedding had the effect that neither potential attachment site involved a main clause dependency.

By extending the range of embedding verb classes used in this experiment we were able to see clear effects of verb class on the parse assigned to the ambiguous verb. In conditions with S-biased verbs, both reading-span groups showed a tendency to analyze the ambiguous verb as an embedded verb. (Low-span readers did not choose this analysis exclusively—we discuss this further below.) This clear effect of verb class is not surprising if we assume that NPs following S-biased verbs are initially analyzed as embedded subjects (i.e., not "minimally attached"), as has been argued in a number of other studies (Garnsey et al., 1997; Juliano & Tanenhaus, 1994; Tabor, Juliano, & Tanenhaus, 1997; Trueswell et al., 1993). If the ambiguous NP is initially analyzed as an embedded subject, then there is every reason for the parser to analyze the ambiguous verb as belonging to the same clause, since high attachment of the ambiguous verb would require reanalysis. This verb class effect is predicted by RALR, but it is not predicted by an account which attributes the results of Experiment 1 to a bias to avoid long subjects or to avoid embedding. Such constraints would lead to an across-the-board high-attachment bias.

An important concern about Experiment 1 was the difference between the disambiguation used in high- and low-attachment control conditions. Two steps were taken in this experiment to address this concern: first, the two control conditions were more closely matched, by using a case-marked pronoun in both high and low unambiguous control conditions; second, an additional opening clause provided an antecedent for the pronouns. These changes appear to have been effective, since there was no across-the-board difficulty associated with the pronouns in Experiment 2. This is seen most clearly in the NP-only conditions, which provide a baseline measure of the difficulty of the high-attachment conditions, independent of ambiguity. However, the pronoun conditions were often read more slowly than their ambiguous counterparts, and there was considerable variability in this across verb classes. We discuss this variability below in the context of differences between reading-span groups.

Turning now to differences between reading-span groups, it was again true in this experiment that high-span readers showed a simpler pattern of results. Whereas high-span readers consistently analyzed the ambiguous verb in a manner compatible with the probabilistic bias of the embedding verb, low-span readers were more variable. In particular, in the S-bias conditions, low-span readers appear to have made a combination of both high and low attachments of the ambiguous verb, whereas high-span readers appear to have consistently made low attachments. This difference between span groups is again compatible with the notion that low-span readers may be less sensitive to probabilistic verb biases (cf. Pearlmutter & MacDonald, 1995).

However, it is important to point out that low-span readers did not show clear evidence of variability with the other verb classes. With strongly and weakly NP-biased verbs there was disruption following the disambiguation only in the low-attachment conditions, suggesting that the ambiguous verb was consistently given the high-attachment analysis. We did not find evidence of disruption in high ambiguous conditions, in contrast to Experiment 1.

Turning to the ambiguous regions, starting at the ambiguous NP in region 3, we again find differences between reading-span groups in the effects of the verb class manipulation. Figure 6 shows the slowdown at regions 3–5 in the pronoun (unambiguous) conditions, relative to their ambiguous counterparts. The effect of ver class on the high-span readers is striking—the unambiguous conditions are read more slowly the more they conflict with the verb bias, leading to opposite trends for high- and low-attachment conditions. For the low-span readers, on the other hand, the trends for high- and low-attachment conditions are much more similar to one another, again suggesting a much weaker effect of verb bias.

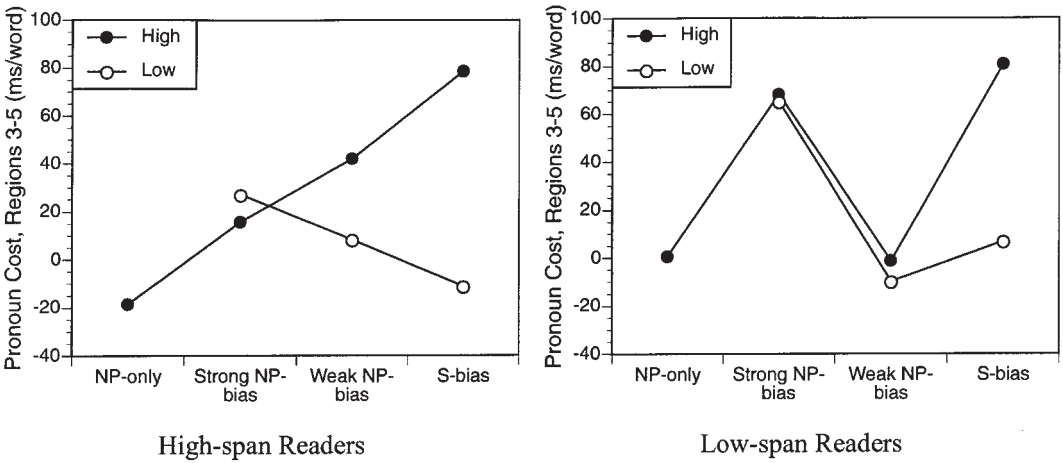


FIG. 6. Slowdown in unambiguous (pronoun) conditions at regions 3–5, relative to their ambiguous counterparts, Experiment 2.

GENERAL DISCUSSION

Comparison of Experiments

In both experiments we found support for the claim that existing parsing commitments constrain the search for analyses of subsequent incoming material. This confirms the existence of a *Reanalysis As a Last Resort* principle, or an activation-based analog of this principle such as Vosse and Kempen's lateral inhibition mechanism (Vosse & Kempen, 1999).

Experiment 2 showed that the parsing of the temporarily ambiguous structure was substantially affected by the probabilistic bias of the embedding verb. However, this finding is entirely compatible with RALR, if we assume that the verb bias had immediate effects on the parsing of the ambiguous NP. If the ambiguous NP was parsed as a direct object, then RALR predicts a high attachment of the ambiguous verb; if the ambiguous NP was parsed as an embedded clause subject, then RALR predicts a low attachment for the ambiguous verb.

The costs of ambiguity at the disambiguation point for each verb class and each reading-span group in the two experiments are summarized in Table 3.

Across the two experiments, there are five different ambiguous verb-class conditions (two in Experiment 1; three in Experiment 2). For all five of these verb-class conditions, high-span readers show disruption due to ambiguity in *either* the high-attachment *or* the low-attachment conditions, but never in both. In each instance,

TABLE 3

Summary of Cost of Ambiguity (Ambiguous Minus Unambiguous Residual Reading Times) at Region 9 in Experiments 1 and 2

	High-span readers				Low-span readers			
	High-attachment		Low-attachment		High-attachment		Low-attachment	
	Exp. 1	Exp. 2	Exp. 1	Exp. 2	Exp. 1	Exp. 2	Exp. 1	Exp. 2
NP-only		16				−22		
Strong NP-bias	2	22	107*	65*	49*	−13	168*	110*
Weak NP-bias	0	−44*	97*	53*[r9–10]	63*	−17	102*	55*[r8–9]
S-bias		92*		13		42*[r8–9]		66**

the verb bias straightforwardly predicts which attachment site will cause difficulty. On the other hand, in three of the five verb-class conditions, low-span readers show disruption due to ambiguity in *both* high-attachment *and* low-attachment conditions. This difference between the span-groups can be explained under the assumption that low-span readers are less sensitive to probabilistic verb biases, although this does not explain why low-span readers showed a slowdown in the high ambiguous conditions in Experiment 1 but did not show a parallel effect with the NP-biased conditions in Experiment 2.

Sturt et al. (2001) show results very similar to those shown here. In particular, their results for NP-biased sentences show the same preference for high attachments that we have shown. They also show that increasing the length of the matrix subject has no effect on high attachments, countering a possible objection that high attachment might only hold within a certain proximity. Likewise, our studies provide strong support for the result that the easy reanalysis is not made in NP-biased contexts. To that we add evidence involving a wider selection of verbs, which demonstrate that when the parser's initial commitments are reversed, its treatment of the ambiguous verb is reversed. This finding supports the existence of an RALR constraint and provides evidence that the results are not related to any bias toward making matrix attachments.

Relevance to Other Theoretical Assumptions

There is a tendency for advocates of serial parsing models to assume RALR, and for advocates of parallel parsing models to not assume RALR. It is true that it is more straightforward to implement RALR in a serial model (cf. Schneider, 1999), but we cannot claim that our results provide evidence in favor of a serial approach to parsing, as we have seen that there are parallel models which incorporate RALR (Vosse & Kempen, 1999) and serial models which do not (Fodor & Inoue, 1998).

However, our results are relevant to accounts of why reanalysis is so easy in sentences like (1), repeated below.

The woman knows the man *wrote*… (1)

An interesting proposal made in the context of D(escription)-theory (Marcus et al., 1983) is that the reanalysis in (1) is not really a reanalysis at all, since the change at the underlined verb in (1) only requires monotonic addition of new dominance relations. This approach elegantly predicts that the change in (1) is easy, because it does not involve reanalysis. However, if this is the correct analysis of (1), then the low attachment in our test sentences, which requires the same change, should not involve reanalysis either. But if the low attachment does not involve reanalysis, then it is unclear why readers should consistently avoid it. For this reason, our results cast doubt on the D-theory claim that sentences like (1) do not involve reanalysis.

Alternative Accounts of the Results

Our account of the results consists of two components. First, a parse is assigned to the ambiguous NP, either as a direct object or an embedded subject, according to the probabilistic bias of the embedding verb or any other constraints that may be relevant at this point. Second, once the ambiguous verb is encountered, it is attached in a manner that preserves the existing structure. Under this interpretation, the results follow from independently motivated properties of how noun phrases are parsed, plus a general architectural property of the parser that it respects existing commitments until forced to do otherwise (i.e., *Reanalysis As a Last Resort*).

Two alternative possibilities substitute the very general RALR constraint with more specific constraints that either restrict the length of subject NPs or restrict the depth of embedding that the parser will allow.

A number of studies of language production have noted that subject NPs tend to be shorter than NPs occurring later in a clause (e.g., Behagel, 1932; Hawkins, 1994). Therefore, it might be suggested that the parser is sensitive to this distributional generalization and therefore aims to complete subject NPs as soon as possible. In our experimental materials, the high attachment of the ambiguous verb allows completion of the subject NP, whereas the low attachment commits the parser to an even longer

subject NP. A constraint which restricts the length of subjects can account fairly well for the results of Experiment 1. However, the avoidance of long subjects should be an across-the-board effect, which applies regardless of the properties of the embedding verb. For this reason, the clear verb class differences which we observed in Experiment 2 pose a problem for an account based on subject length restrictions. The parser may be sensitive to subject length restrictions, but this cannot be the sole explanation of our results. In order to account for the effect of the verb-class manipulation, we must assume that revisions of existing structural commitments carry some nontrivial cost. The RALR constraint is one instance of such a constraint.

Similarly, the results of Experiment 1 are consistent with an account based on constraints on the depth of embedding that the parser can tolerate, but such a constraint does not explain the greater variability observed when additional verb classes were introduced in Experiment 2. Again, we do not wish to claim that the avoidance of embedding (or other kinds of syntactic complexity) is irrelevant to parsing decisions; we simply claim that it cannot substitute for a constraint on the avoidance of reanalysis.

A third alternative account is more promising. In a number of principle-based parsers, parsing decisions are driven by the need to complete grammatical dependencies involving thematic relations, case relations, and agreement relations (e.g., Abney, 1987, 1989; Crocker, 1996; Gibson, 1991; Pritchett, 1988, 1992). In these frameworks, our results could be attributed to a need to complete a subject-verb dependency for an existing subject NP, for reasons of thematic role assignment, case licensing, or both. If we assume that the ambiguous NP is parsed in a manner consistent with the probabilistic bias of the embedding verb, then in conditions with NP-biased verbs, the only incomplete subject-verb dependency involves the main clause subject. This dependency can be completed by parsing the ambiguous verb as a main clause verb. In conditions with S-biased verbs, where the ambiguous NP may have been parsed as an embedded clause subject, there is an additional embedded subject-verb dependency which needs to be completed, and therefore the ambiguous verb will be parsed as an embedded clause verb.

Notice also that the account based on satisfaction of grammatical dependencies not only matches our account in empirical coverage—it is also based on a theoretical claim very similar to the RALR account. Whereas RALR forces the parser to maintain existing structural *commitments*, the dependency-completion account forces the parser to honor existing structural *predictions*. Under both accounts, prior parsing decisions impose strong constraints on the search for analyses for new material. With regard to structures like (3), the two accounts are very similar in spirit and make almost identical predictions. The two accounts differ in regard to the parsing of simpler structures like (1). Under the RALR account, lessons from the parsing of sentences like (3) can be applied to the parsing of simple sentences like (1), and they suggest that the parser attempts to find an alternative attachment site for the incoming verb before ultimately identifying the parse involving reanalysis. Under the dependency-completion account, on the other hand, results about the parsing of (3) do not tell us much about how the parser goes about identifying the correct parse of sentences like (1).

CONCLUSION

Incremental parsing involves repeated cycles of grammatical search leading to structural commitments. The two experiments reported here investigated the extent to which the structural commitments made at one cycle of parsing guide the grammatical search process at subsequent cycles. Most existing models of parsing take some stand on this issue, but there have been very few empirical tests of this. The results of our experiments indicate that the parser is strongly guided by its existing commitments in searching for analyses of new material. One straightforward way of implementing this is in the form of the *Reanalysis As a Last Resort* constraint, but as we have emphasized, similar effects can be captured in other ways, in the form of a lateral inhibition mechanism, or in the form of a commitment to satisfy existing structural predictions.

The effects of verb-class and reading-span group observed in our experiments confirm previous findings in the literature about the effects of lexical item-specific information in parsing and the variability of these effects across speakers. However, these effects interact with our main findings in a very simple manner. They affect the decisions that are made at one cycle of parsing, and thus they automatically affect the commitments that the parser honors at subsequent steps of parsing.

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APPENDIX A: RAW READING TIMES

TABLE 4

Raw, Untrimmed Reading Times (ms/word), Experiment 1

	High attachment		Low attachment	
	Ambig.	Unambig.	Ambig.	Unambig.
1	422	422	428	424
2	—	—	—	428
3	448	434	444	419
4	495	583	528	439
5	420	491	431	400
6	419	431	441	403
7	432	471	444	434
8	448	449	539	447
9	463	435	567	421
10	389	382	458	386
11	419	390	467	403
12	443	425	470	428
13	—	—	447	416
14	409	423	434	413

TABLE 5

Raw, Untrimmed Reading Times (ms/word), Experiment 2, NP-only Verbs

	High attachment	
	Ambig.	Unambig.
1	486	460
3	470	409
4	499	509
5	404	430
6	462	411
7	451	436
8	457	497
9	421	424
10	361	375
11	388	403
12	393	424
13	—	—
14	387	370

TABLE 6

Raw, Untrimmed Reading Times (ms/word), Experiment 2, Strongly NP-Biased Verbs

	High attachment		Low attachment	
	Ambig.	Unambig.	Ambig.	Unambig.
1	465	468	457	451
3	427	438	427	472
4	515	544	473	482
5	441	520	433	465
6	450	428	459	426
7	426	474	471	437
8	470	497	511	468
9	441	427	582	447
10	375	382	383	395
11	382	394	414	396
12	399	419	433	421
13	—	—	436	439
14	386	406	423	401

TABLE 7

Raw, Untrimmed Reading Times (ms/word), Experiment 2, Weakly NP-Biased Verbs

	High attachment		Low attachment	
	Ambig.	Unambig.	Ambig.	Unambig.
1	470	451	480	460
3	434	437	421	425
4	479	524	492	496
5	425	425	445	403
6	447	458	449	428

TABLE 7—(*Continued*)

	High attachment		Low attachment	
	Ambig.	Unambig.	Ambig.	Unambig.
7	435	461	481	460
8	480	468	562	461
9	425	453	562	479
10	375	380	436	401
11	365	391	413	395
12	434	417	452	439
13	—	—	469	445
14	395	401	421	423

TABLE 8

Raw, Untrimmed Reading Times (ms/word), Experiment 2, S-Biased Verbs

	High attachment		Low attachment	
	Ambig.	Unambig.	Ambig.	Unambig.
1	475	461	481	482
3	437	470	459	460
4	485	514	479	487
5	399	554	437	435
6	455	487	477	456
7	460	476	484	487
8	601	506	490	486
9	558	458	490	454
10	400	399	390	383
11	403	402	407	398
12	400	423	407	420
13	—	—	452	455
14	387	384	393	412

APPENDIX B: EXPERIMENTAL MATERIALS FOR EXPERIMENT 1

Each of the items in this list represents a full set of stimuli from Experiment 1. The complementizer *that* was used as a disambiguator in the low unambiguous condition, and a case-marked pronoun (*him/her*) was used as a disambiguator in the high unambiguous condition. The first reflexive (*himself/herself*) listed in each example agrees with the main clause subject and is the one used in the high-attachment conditions; the second reflexive listed was used in the low-attachment conditions. The first completion listed was used in the high-attachment conditions; the second completion listed was used in the low-attachment conditions.

A full set of conditions from item number (1) can be seen below, with regions that varied across conditions in italics.

high ambiguous

The smart fellow who mentioned *the senator's wife* got a job for *himself* with the powerful lobbyist *soon thereafter*.

high unambiguous

The smart fellow who mentioned *her* got a job for *himself* with the powerful lobbyist *soon thereafter*.

low ambiguous

The smart fellow who mentioned *the senator's wife* got a job for *herself* with the powerful lobbyist *got some hush money*.

low unambiguous

The smart fellow who mentioned *that the senator's wife* got a job for *herself* with the powerful lobbyist *got some hush money*.

The embedding verbs in the strongly NP-biased class were *discover*, *acknowledge*, *hear*, *appreciate*, *warn*, and *understand*, and the weakly-biased verbs were *know*, *doubt*, *mention*, *fear*, and *notice*.

Weakly NP-Biased Conditions

1. The smart fellow who mentioned (that) {the senator's wife/her} got a job for {himself/herself} with the powerful lobbyist {soon thereafter/got some hush money}.
2. The quiet woman who mentioned (that) {the violent man/him} caused big trouble for {herself/himself} with the local police {by discussing the incident at all/was thought to be an informant}.
3. The busy woman who mentioned (that) {her sick son/him} picked up the prescription {herself/himself} from the neighborhood pharmacy {after work/was accused of neglect}.
4. The nervous man who mentioned (that) {the accused woman/her} cursed very loudly at {himself/herself} before the important hearing {about the robbery/was asked about the robbery}.
5. The attentive waitress who mentioned (that) {the sick man/him} opened the bathroom door {herself/himself} in a big hurry {so he could get in/sent someone to see if he needed help}.
6. The experienced monk who doubts (that) {the new nun/her} wrote in the ledger {himself/herself} about the membership increase {of the last five years/told the bishop about the potential problem}.
7. The angry woman who doubts (that) {the lazy man/him} called the state police {herself/himself} at about three o'clock {to report her suspicions/thinks his wife made the call}.
8. The pig-headed girl who doubts (that) {the stupid boy/him} reported the transgressions {herself/himself} to the principal {after school/thinks the class snitch was the culprit}.
9. The distrustful woman who doubts (that) {the strange man/him} locked the front door {herself/himself} after the big party {for the neighbors/asked who really locked the door}.
10. The famous knight who doubts (that) {the lazy girl/her} fed the hungry horses {himself/herself} before the

evening meal {of potatoes and roast beef/looked for footprints in the dirt}.

11. The handsome man who noticed (that) {the famous actress/her} called the fashion magazine {himself/herself} after the gala fundraiser {for the charity/was surprised the woman's assistant didn't call}.

12. The nice man who noticed (that) {the sick woman/him} opened the bathroom door {himself/herself} despite the strong protestations {of the staff/ of the staff tried to reassure her}.

13. The observant woman who noticed (that) {the mistreated man/him} informed the personnel department {herself/himself} about the frightening incident {a few days after it happened/was pleased with the response}.

14. The young mother who noticed (that) {the disabled man/him} warned the hospital staff {herself/himself} about the broken wheelchair {as soon as she could/felt sorry for him}.

15. The middle-aged man who knows (that) {the famous woman/her} invited the political press {himself/herself} to the news conference {about the big scandal/was not pleased by her action}.

16. The smart girl who knows (that) {the foolish boy/him} told the long story {herself/himself} during the story hour {at the library/gained a new respect for him}.

17. The creative woman who knows (that) {the funny man/him} wrote some comedy sketches {herself/himself} about the amusing escapades {she had seen/thinks he should publish them}.

18. The bilingual man who knows (that) {the well-traveled woman/her} translated the travel books {himself/herself} without any extra help {from a dictionary/was quite impressed with the result}.

19. The nosy guy who knows (that) {the depressed woman/her} told some hilarious jokes {himself/herself} at the doctor's office {in order to cheer her up/thinks she might be faking her depression}.

20. The paranoid man who fears (that) {the deceptive woman/her} locks the barroom doors {himself/herself} after the last call {every night/thinks he will be locked in}.

21. The grumpy woman who fears (that) {the scruffy man/him} called the building management {herself/himself} after the late-night disturbance {in the stairwell/tried to appease him}.

22. The anxious man who fears (that) {the deranged woman/her} wrote the accusatory statement {himself/herself} at the police station {to get her arrested/expects the police to visit}.

23. The sleepless woman who fears (that) {the night watchman/him} checks the window blinds {herself/himself} during the late movie {every night/is planning to buy a dog}.

24. The inexperienced nanny who fears (that) {the cranky handyman/him} fixed the squeaky door {herself/himself} with some cooking oil {so the man wouldn't have to come in the house/knows the door will need to be fixed again soon}.

Strongly NP-Biased Conditions

25. The quiet man who heard (that) {the terrified woman/her} called the county police {himself/herself} at around four o'clock {in the morning/in the morning was shocked at the lack of any response}.

26. The quiet girl who heard (that) {the mischievous boy/him} opened the front door {herself/himself} despite many strong warnings {that the boy shouldn't be allowed in/hoped he wouldn't get in trouble}.

27. The intelligent man who heard (that) {the clumsy woman/her} turned on the light {himself/herself} on the front porch {so she wouldn't fall/decided to install an automatic light}.

28. The caring woman who heard (that) {the depressed man/her} called the mental hospital {herself/himself} about the serious side-effects {he was experiencing/ was relieved at the news}.

29. The kind man who discovered (that) {the injured woman/her} called the emergency room {himself/herself} from a nearby payphone {after the late-night accident/offered to drive her to the hospital}.

30. The surprised woman who discovered (that) {the drunk man/him} locked the front door {herself/himself} with the spare key {to keep him away/was amazed he could even walk}.

31. The hungry man who discovered (that) {the starving woman/her} stole the big roast {himself/herself} from the deserted kitchen {of the restaurant/asked her to share some with him}.

32. The angry woman who discovered (that) {the badly-beaten man/him} protested to the authorities {herself/himself} about the rampant violence {for over an hour/ was proud of his courage}.

33. The fickle actress who understood (that) {the strange man/him} wrote the bizarre stories {herself/himself} in just three days {despite being sick/wondered at the man's brilliance}.

34. The generous nobleman who understood (that) {the persuasive woman/her} bought the powerful telescope {himself/herself} for the small college {in order to promote science/promised to fund a new observatory}.

35. The pious man who understood (that) {the religious woman/her} financed the church restoration {himself/herself} with the large inheritance {from a distant cousin/was impressed with her devotion}.

36. The unhappy man who understood (that) {the shy woman/her} reported the continuing problems {himself/herself} in an angry phone message {to the apartment manager/visited the woman to settled the dispute}.

37. The kind man who acknowledged (that) {the considerate woman/her} typed the generous contribution {himself/herself} into the charity database {after receiving the check/showed appreciation for the help}.

38. The magnanimous prince who acknowledged (that) {the quiet woman/she} accepted all the blame {himself/herself} for the many errors {of his subjects/pardoned her after the investigation}.

39. The grateful woman who acknowledged (that) {the maintenance man/him} answered all the questions {her-

self/himself} about the serious incident {at the refinery/thanked him profusely}.

40. The beloved duchess who acknowledged (that) {the rich man/him} saved the well-known charity {herself/himself} despite the financial problems {following the scandal/praised him at the banquet}.

41. The big policeman who warned (that) {the angry saleswoman/her} ran down the street {himself/herself} after the getaway car {following the robbery/hoped the other cops wouldn't shoot her}.

42. The neighbor woman who warned (that) {the macho boy/him} shot the rabid dog {herself/himself} with a large shotgun {before going to work/thought she should call his parents}.

43. The concerned priest who warned (that) {the meddling woman/her} opened all the mail {himself/herself} in the church office {so she wouldn't read the letters/told the worried parishioner to contact him by phone}.

44. The young widow who warned (that) {the little boy/him} opened the locked cabinet {herself/himself} with a small screwdriver {while he was outside/told the babysitter to watch him closely}.

45. The health-conscious man who appreciates (that) {the beautiful woman/her} takes good care of {himself/herself} throughout the entire year {by eating regularly and walking everywhere/wants to ask her on a date}.

46. The ambitious boy who appreciates (that) {his smart sister/her} does lots of homework {himself/herself} after swim team practice {because he wants to get into a good college/understands that she doesn't have time to help him}.

47. The good-natured landlady who appreciates (that) {the nice man/him} cleans the big house {herself/himself} before the day's end {so the house will be clean for him/is thinking about lowering his rent}.

48. The thoughtful woman who appreciates (that) {the young man/him} pays all the utilities {herself/himself} before the due date {to keep the man happy/wants to keep the man as a roommate}.

APPENDIX C: EXPERIMENTAL MATERIALS FOR EXPERIMENT 2

The stimuli in Experiment 2 followed the same pattern as the stimuli in Experiment 1 except for the following changes: Four verb classes were used (NP-only, Strongly NP-biased, Weakly NP-biased, S-biased); both high and low unambiguous conditions used a case-marked pronoun as a disambiguator; all stimulus sentences were embedded within a clause whose subject provided an antecedent for the disambiguating pronoun. The antecedent for the disambiguating pronoun in the unambiguous conditions corresponded to the ambiguous NP in the ambiguous conditions (e.g., *the senator's wife* in example (1) below). Many of the stimuli with strongly or weakly NP-biased verbs were based on stimuli used in Experiment 1. In items with NP-only verbs there were no low conditions, since these would be ungrammatical. Items 1–40 were used in one block of trials, items 41–80 in a second block. The order of presentation of the two blocks was counterbalanced across subjects.

A full set of stimuli from item (1) is shown below, with regions that varied across conditions in italics.

high ambiguous

The congressional staffers were not surprised that the smart fellow who mentioned *the senator's wife* leaked the important news *himself* to the powerful lobbyist *soon thereafter*.

high unambiguous

The senator's wife was not surprised that the smart fellow who mentioned *her* leaked the important news *himself* to the powerful lobbyist *soon thereafter*.

low ambiguous

The congressional staffers were not surprised that the smart fellow who mentioned *the senator's wife* leaked the important news *herself* to the powerful lobbyist *got some hush money*.

low unambiguous

The senator's wife was not surprised that the smart fellow who mentioned *she* leaked the important news *herself* to the powerful lobbyist *got some hush money*.

The verb classes contained the following: 6 strongly NP-biased verbs, *hear*, *acknowledge*, *appreciate*, *discover*, *warn*, *understand*; 4 weakly NP-biased verbs, *know*, *mention*, *doubt*, *notice*; 3 S-complement biased verbs, *claim*, *believe*, *suspect*, and 19 verbs which only allow NP-complements, *abuse*, *admire*, *adore*, *annoy*, *defy*, *despise*, *disappoint*, *feed*, *fire*, *harass*, *humiliate*, *love*, *overcharge*, *pity*, *prosecute*, *rescue*, *supervise*, *support*, *treat*. Some speakers judge that *despise*, *adore*, and *love* allow sentential complements under certain circumstances. However, we have found no informants that allow these verbs to appear with *that*-less sentential complements, and therefore these verbs are unambiguous in our experimental materials.

Weakly NP-Biased Conditions (Block A)

1. The congressional staffers were not surprised that the smart fellow who mentioned {the senator's wife/her/she} leaked the important news {himself/herself} to the powerful lobbyist {soon thereafter/got some hush money}.

2. The neighborhood gossips reported that the busy woman who mentioned {the sick boy/him/he} picked up the prescription {herself/himself} from the local pharmacy {after work/was accused of neglect}.

3. The restaurant managers were glad that the attentive waitress who mentioned {the sick man/him/he} opened the bathroom door {herself/himself} in a big hurry {so he could get in/sent someone to see if he needed help}.

4. The family friends stated that the angry woman who doubts {the apathetic man/him/he} called the state police {herself/himself} at about three o'clock {to report her suspicions/thinks the man's son made the call}.

5. The curious children observed that the anxious woman who doubted {the strange man/him/he} locked the front door {herself/himself} after the big party {for the neighbors/asked who really locked the door}.

6. The editors proved that the handsome man who noticed {the famous actress/her/she} called the fashion magazine {himself/herself} after the gala fundraiser {for the charity/tried to interrupt the call}.

7. The witnesses discovered that the conscientious woman who noticed {the mistreated man/him/he} informed the personnel department {herself/himself} about the frightening incident {a few days after it happened/had fired several employees}.

8. The rowdy boys remarked that the thoughtful man who noticed {the young girl/her/she} closed the fireplace doors {himself/herself} before the birthday party {at the mansion/congratulated her on her forethought}.

9. The proud parents boasted that the smart girl who knows {the childish boy/him/he} told the long story {herself/himself} during the story hour {at the library/gained a new respect for him}.

10. The book publisher heard that the bilingual man who knows {the well-traveled woman/her/she} translated the travel books {himself/herself} without any extra help {from a dictionary/was quite impressed with the result}.

Strongly NP-Biased Conditions (Block A)

11. The neighbors were surprised that the quiet man who heard {the terrified woman/her/she} called the county police {himself/herself} at around four o'clock {in the morning/in the morning didn't say anything to anybody}.

12. The family members believe that the intelligent man who heard {the handicapped woman/her/she} turned on the light {himself/herself} on the front porch {so the woman wouldn't fall/decided to install an automatic light}.

13. The hospital staff was surprised that the kind man who discovered {the injured woman/her/she} called the emergency room {himself/herself} from a nearby payphone {after the late-night accident/offered to drive her to the hospital}.

14. The vagrants stated that the hungry man who discovered {the starving woman/her/she} stole the big roast {himself/herself} from the deserted kitchen {of the restaurant/asked her to share some with him}.

15. The movie studio was surprised that the fickle actress who understood {the strange man/him/he} wrote the bizarre stories {herself/himself} in just three days {despite being sick/wanted to put on the stories}.

16. The church leaders thought that the pious man who understood {the religious woman/her/she} financed the church restoration {himself/herself} with the large inheritance {from a distant cousin/was impressed with her devotion}.

17. The institute employees believe that the kind man who acknowledged {the considerate woman/her/she} typed the generous contribution {himself/herself} into the charity database {after receiving the check/mentioned her to the board members}.

18. The corporate office was pleased that the grateful woman who acknowledged {the maintenance man/him/he} answered all the questions {herself/himself} about the serious incident {at the refinery/thanked him profusely}.

19. The store managers thought that the big policeman who warned {the angry saleswoman/her/she} ran down the street {himself/herself} after the getaway car {immediately after the robbery/told the other cops not to shoot}.

20. The nuns thought that the concerned priest who warned {the meddling woman/her/she} opened all the mail {himself/herself} in the church office {so she wouldn't read the letters/told the worried parishioner to contact him by phone}.

S-Biased Conditions (Block A)

21. The truancy office knows that the concerned woman who suspected {the short boy/him/he} called the youth center {herself/himself} after the recent fight {to report what she knew/intends to talk to the boy's parents}.

22. The executive committee thinks that the perceptive woman who suspects {the friendly man/him/he} started the malicious rumor {herself/himself} during the civic meeting {because she wanted to keep the man from getting elected/didn't tell anyone of her suspicions}.

23. Some classmates reported that the scheming girl who suspects {the grumpy boy/him/he} ate the incriminating evidence {herself/himself} before the school meeting {so the boy couldn't get her in trouble/told the teacher about her suspicions}.

24. The loan company learned that the depressed man who suspects {the devious woman/her/she} sold the engagement ring {himself/herself} at the pawn shop {for five-hundred dollars/went to the pawn shop to look for the ring}.

25. The coaches are amused that the young boy who believes {the neighbor girl/her/she} buys some peppermint gum {himself/herself} before every baseball game {because the gum is supposed to bring the team good luck/hopes she will give him some gum}.

26. The dealership knows that the dark-haired woman who believes {the knowledgeable salesman/him/he} wants the blue car {herself/himself} despite the peeling paint {on the car/the car is a good deal}.

27. The police stated that the charming woman who believes {the dishonest man/him/he} bought the valuable artifacts {herself/himself} from the disreputable store {at the man's insistence/thinks the man deserves to be cheated}.

28. The agency staff was surprised that the excited woman who claimed {the small boy/him/he} opened the front door {herself/himself} without any help {despite holding the boy with both hands/made such a big deal about it}.

29. The sales clerks couldn't believe that the kind woman who claimed {the errant boy/him/he} purchased the expensive clothing {herself/himself} with a credit card {so that the store would not prosecute him for theft/doesn't think the boy's father will believe her}.

30. The dispatch office stated that the dismayed mother who claimed {the runaway boy/him/he} called the state police {herself/himself} from a pay phone {because the phone at home was broken/thinks the police should have gone to the pay phone to pick the boy up}.

NP-Only Conditions (Block A)

31. The homeless people think that the brilliant woman who supported {the impoverished man/him} called the large charity herself after the fund drive to see if he had applied for aid.

32. The office supervisors know that the nice man who fired {the incompetent woman/her} wrote the critical evaluation himself during the long flight back to the home office.

33. The smuggling ring fears that the stern woman who prosecuted {the violent man/him} called the immigration office herself after the deportation hearing to make sure that he couldn't get back in.

34. The alert siblings remarked that the vengeful boy who defied {the young woman/her} opened the large package himself on the kitchen table.

35. The concerned relatives were glad that the valiant woman who rescued {the injured man/him} battled the car fire herself for over fifteen minutes until the firefighters arrived.

36. The office staff said that the compassionate man who treated {the depressed woman/her} filed the insurance forms himself with the insurance company the woman had.

37. The many bystanders thought that the concerned woman who adores {the teenage boy/him} called the rescue squad herself on a cell phone in her purse.

38. The delivery staff said that the well-known man who annoyed {the quick-tempered woman/her} sent the accusatory letter himself with a polite note taped to the top.

39. The police officers claimed that the cruel man who abused {the penniless woman/her} locked the thick door himself with the monstrous key so that she couldn't get out.

40. The children's teachers thought that the sweet girl who pitied {the poor boy/him} bought the new jacket herself as a birthday gift for the boy.

Weakly NP-Biased Conditions (Block B)

41. The private detectives think that the quiet woman who mentioned {the violent man/him/he} caused big trouble for {herself/himself} with the local police {by discussing the incident at all/is a big gossip}.

42. The court officials were amazed that the nervous man who mentioned {the accused woman/her/she} cursed very loudly at {himself/herself} before the important hearing {about the robbery/was asked about the robbery}.

43. The concerned parishioners heard that the experienced monk who doubts {the new nun/her/she} wrote in the ledger {himself/herself} about the attendance increase {of the last five years/told the bishop about the potential problem}.

44. The nosy classmates assumed that the pig-headed girl who doubts {the stupid boy/him/he} reported the transgressions {herself/himself} to the principal {after school/thinks the class snitch was the culprit}.

45. The talkative servants suspected that the famous knight who doubts {the lazy girl/him/he} fed the hungry horses {himself/herself} before the evening meal {of potatoes and roast beef/looked for footprints in the dirt}.

46. The anxious family appreciated that the nice man who noticed {the sick woman/her/she} opened the bathroom door {himself/herself} despite the strong protestations {of the staff/of the staff tried to reassure her}.

47. The visitors said that the young mother who noticed {the disabled man/him/he} warned the hospital staff {herself/himself} about the broken wheelchair {as soon as she could/put it in the corner}.

48. The persistent reporters remarked that the middle-aged man who knows {the famous woman/her/she} invited the political press {himself/herself} to the news conference {about the big scandal/was not pleased by her action}.

49. The talent agency thinks that the creative woman who knows {the funny man/him/he} wrote some comedy sketches {herself/himself} about the amusing escapades {she had seen/wants to publish them}.

50. The office staff learned that the nosy guy who knows {the depressed woman/her/she} told some hilarious jokes {himself/herself} at the doctor's office {in order to cheer her up/thinks she might be hiding her depression}.

Strongly NP-Biased Conditions (Block B)

51. The anxious friends were glad that the quiet girl who heard {the mischievous boy/him/he} opened the front door {herself/himself} despite many strong warnings {to leave the door locked/doesn't plan to tell anyone}.

52. The co-workers reported that the caring woman who heard {the depressed man/him/he} called the mental hospital {herself/himself} about the serious side-effects {he was experiencing/was relieved to hear the news}.

53. The freezing friends were upset that the surprised woman who discovered {the drunk man/him/he} locked the front door {herself/himself} with the spare key {to keep him away/took the key from him}.

54. The concerned relatives heard that the angry woman who discovered {the badly-beaten man/him/he} protested to the authorities {herself/himself} about the rampant violence {for over an hour/was proud of the man's courage}.

55. The faculty members were grateful that the generous benefactor who understood {the persuasive woman/her/she} bought the powerful telescope {himself/herself} for the small college {in order to promote science/promised to fund a new observatory}.

56. The irritated neighbors noted that the unhappy man who understood {the shy woman/her/she} reported the continuing problems {himself/herself} in an angry phone message {to the apartment manager/visited the woman to settle the dispute}.

57. The anxious family was delighted that the smart prince who acknowledged {the quiet woman/her/she} accepted all the blame {himself/herself} for the judgement errors {of his subjects/pardoned her after the investigation}.

58. The board members were gratified that the beloved duchess who acknowledged {the rich man/him/he} saved the

popular charity {herself/himself} despite the financial problems {following the scandal/praised him at the banquet}.

59. The teenage friends feared that the neighbor woman who warned {the aggressive boy/him/he} shot the wild dog {herself/himself} with the powerful rifle {before going to work/would call the boy's parents}.

60. The visiting children thought that the young widow who warned {the little boy/him/he} opened the locked cabinet {herself/himself} with a small screwdriver {while the boy was outside/told the babysitter to watch him closely}.

S-Biased Conditions (Block B)

61. The newspaper said that the scared man who suspects {the irate woman/she/her} notified the police department {himself/herself} after the recent burglary {at the neighborhood store where the woman works/hopes that the woman will be arrested}.

62. The supervisors realized that the astute man who suspected {the brilliant woman/she/her} made the amazing discovery {himself/herself} in the government lab {before the woman announced her results/thinks that she should have taken the credit}.

63. The police think that the ailing woman who suspects {the ill-tempered boy/him/he} took the cash box {herself/himself} from the unlocked cabinet {so that the boy couldn't steal it/told the department manager what she thought had happened}.

64. The foundation employees heard that the destitute man who believes {the kind woman/her/she} visited the soup kitchen {himself/herself} after the severe storm {to get a good meal/asked about her health}.

65. The court jesters joked that the beautiful princess who believes {the dim-witted knight/him/he} contacts the war committee {herself/himself} before every committee meeting {to try to get the knight promoted/should worry more about someone else}.

66. The neighbors mentioned that the desperate man who believes {the cheerful woman/her/she} bought the new car {himself/herself} at the car dealership {that {the woman/she} recommended/thinks she made a foolish decision}.

67. The office staff wasn't surprised that the insecure man who believes {the reassuring woman/her/she} opened the mysterious package {himself/herself} before the long flight {because she told him to look inside/called to see if she liked the gift}.

68. The security company thought that the concerned father who claimed {the screaming girl/her/she} broke the small window {himself/herself} with a small rock {so he could open the door to rescue {his daughter/her}/said so to stay out of trouble}.

69. The family said that the aging uncle who claimed {the teenage girl/her/she} purchased the new car {himself/herself} at the car dealership {so {the girl/she} could have his old car/denied that he had anything to do with the purchase}.

70. The security officers stated that the scheming man who claimed {the little girl/her/she} removed the name tag {himself/herself} with a quick jerk {so no one would know that {the girl/she} was not his/tried to take {the girl/her} from the hospital}.

NP-Only Conditions (Block B)

71. The office workers remarked that the arrogant man who humiliated {the sad woman/her} paid the large fee himself with a personal check to show how rich he was.

72. The family members heard that the intelligent woman who loves {the good-looking man/him} called the fancy restaurant herself for dinner reservations that evening.

73. The school classmates guessed that the smiling father who loves {the precocious girl/her} bought the expensive doll himself as a birthday present for the girl.

74. The hotel staff noticed that the thoughtful man who admires {the ambitious woman/her} opened the front door himself at the sea-side resort just in time for the woman to enter.

75. The sympathetic lawyers were disappointed that the devious woman who deceived {the stupid man/him} claimed the large reward herself from the insurance company after the trial.

76. The staff supervisors remarked that the cruel man who despises {the stupid woman/her} presented the important report himself at the afternoon meeting so he could claim credit for it.

77. The family members noticed that the grumpy woman who harassed {the lazy man/him} stained the new couch herself with a greasy hamburger just after the couch was delivered.

78. The nursing staff said that the conscientious man who fed {the sick woman/her} answered the ringing phone himself in the hospital room since she was so sick.

79. The company president was glad that the sensible woman who supervises {the industrious man/him} wrote the glowing recommendation herself for the prestigious position that the man had applied for.

80. The accounting office noticed that the underhanded man who overcharged {the likable woman/her} wrote the critical invoice himself on the company letterhead late at night.

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