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Recency preference in the human sentence processing mechanism

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Abstract

Cuetos and Mitchell (1988) observed that in constructions in which a relative clause can attach to one of two possible sites, English speakers prefer the more recent attachment site, but Spanish speakers prefer the least recent attachment site, in violation of the proposed universal principle Late Closure (Recency Preference), which favors attachments to the most recent sites. Based on this evidence, Cuetos and Mitchell concluded that Late Closure is not a universal principle of the human sentence processing mechanism. In this paper, we provide new evidence from Spanish and English self-paced reading experiments on relative clause attachment ambiguities that involve three possible attachment sites. The results of our experiments suggest that a principle like Late Closure is in fact universally operative in the human parser, but that it is modulated by at least one other factor in the processing of relative clause attachment ambiguities. We propose that the second factor involved in the processing of these and related constructions is the principle of Predicate Proximity, according to which attachments are preferred to be as structurally close to the head of a predicate phrase as possible, and we further consider the origins and predictions of the theory combining these two factors.

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1. Introduction

One proposed universal principle of the human sentence processing mechanism is Late Closure (Frazier, 1978, 1987; Frazier & Rayner, 1982; cf. Right Association (Kimball, 1973)):

(1) Late Closure:
When possible, attach incoming lexical items into the clause or phrase currently being processed (i.e., the lowest possible nonterminal node dominating the last item analyzed).

This principle explains the existence of the strongly preferred reading in (2) and the garden-path effect in (3) (see Carreiras & Clifton, 1993, for a survey of other Late Closure effects):

(2) John said Bill died (# will die) yesterday.
(3) # Since Jay always jogs a mile seems light work. (Frazier & Rayner, 1982)

The preferred reading of (2) links the adverbial *yesterday* to the second (lower) clause: the clause currently being processed. This preference is so strong that even the incompatibility of the future tense (*will die*) and the past tense modifier (*yesterday*) has little apparent effect on it, resulting in processing difficulty.[1] The preference in (3) to attach the noun phrase *a mile* as direct object of the verb *jogs*, rather than as the subject of the matrix clause to come (Frazier & Rayner, 1982; Mitchell, 1987), is also explained by Late Closure, because the direct object attachment is to the clause currently being processed, whereas the matrix subject attachment is not.

Until recently, effects like those in (2) and (3) had provided the bulk of the evidence for Late Closure as a universal parsing principle, and the effects, although strong, had been demonstrated only in English. Cuetos and Mitchell (1988) and Mitchell and Cuetos (1991a) (henceforth, C & M) attempted to address this concern by examining the attachment preferences of a relative clause (RC) to potential noun phrase (NP) attachment sites, in both Spanish and English:

(4) (a) El periodista entrevisto a la hija del coronel que tuvo el accidente.
(b) The journalist interviewed the daughter of the colonel who had had the accident.

[1] We will prefix sentences causing noticeable processing difficulty with the symbol "#".

The sentences in (4) are ambiguous because the RC *que tuvo el accidente* (*who had had the accident*) can modify either the NP headed by *coronel* (*colonel*) or the NP headed by *hija* (*daughter*). Late Closure predicts a preference for attachment to the most recent NP *coronel* (*colonel*). In an English questionnaire study using items like (4b), C & M found that attachment to the second (more recent) NP was preferred over attachment to the first NP, indicating that subjects tended to follow Late Closure. Using similar items in an on-line study, Clifton (1988) provided further evidence for a Late Closure preference in English (but see also Carreiras & Clifton, 1993, and Gilboy, Sopena, Clifton, & Frazier, 1995, discussed briefly below).

In contrast, in a Spanish version of their questionnaire, C & M found that the preferred RC attachment site in items like (4a) was the first NP (*hija*), indicating that Spanish speakers tended to follow the opposite strategy to Late Closure, usually termed Early Closure (cf. Kimball, 1973; Church, 1980). C & M also found evidence for an Early Closure preference in Spanish in self-paced reading studies, using items similar to (4a), but with an additional phrase which could disambiguate the attachment of the RC: Reading times were slower on the disambiguating phrase when it forced attachment to the more recent NP than when it forced attachment to the less recent NP.

Other researchers have found similar differences between Spanish and English RC attachment preferences: Carreiras and Clifton (1993) performed on-line studies in Spanish and English and observed an Early Closure preference in Spanish, but no preference one way or the other in American English. (C & M's studies involved British English.) In a questionnaire study investigating constructions similar to the ones used by C & M, Gilboy et al. (1995) found that changing the kinds of prepositions and nouns involved in the ambiguity caused similar preference changes in the two languages, but that overall, high attachment seemed to be more preferred in Spanish than in English.

Based on the high attachment preference in Spanish RC attachments, C & M concluded that Late Closure does not apply in these constructions in Spanish. However, as noted by C & M (p. 92), there is evidence for Late Closure from other Spanish constructions. For example, the Spanish translation of (2) results in the same strong low attachment preference as in English:

(5) Juan dijo que Bill se murió (# morirá) ayer.
"John said Bill died (# will die) yesterday."

That Late Closure seems to apply in other Spanish constructions (and in many constructions in other languages) suggests an alternative to C & M's conclusion: that Late Closure is also applying in Spanish RC attachments, but that a second interacting factor masks its effects. If this hypothesis is correct, then in Spanish RC attachments, the second factor creates a

preference for high attachment which is stronger than the Late Closure preference to attach low.

In order to investigate the possibility that a second factor is interacting with Late Closure in Spanish RC constructions, we can examine a slightly more complex structure with three possible attachment sites instead of the two used in C & M's studies. For example, in (6) below, the RC *que fue dañada en la inundación* ("that was damaged in the flood") can grammatically attach to any of the three preceding NPs:

(6) la lámpara cerca de la pintura de la casa que fue dañada en la inundación
"the lamp near the painting of the house that was damaged in the flood"

The C & M proposal, that high attachments are preferred in Spanish RC constructions and that Late Closure does not apply, predicts that the RC in (6) will preferentially attach to the highest NP *la lámpara* ("the lamp"). After the high site, the middle site *la pintura* ("the painting") will be preferred over the low site *la casa* ("the house") if the preference ranking extends across all sites. If, instead, the high preference applies only to the highest site, then the low and middle sites should not differ. In either case, a monotonic ordering of the attachment sites is predicted, because C & M proposed a single preference factor for these constructions. Note also that a monotonic preference ordering is predicted if the relevant single factor allows a range of values from strong high attachment preference to strong low attachment preference, such that English tends to prefer low attachment and Spanish tends to prefer high attachment in RC ambiguities.

Alternatively, if there are two factors involved in the preference ranking, then non-monotonicity among the attachment site preferences is possible. In particular, if a low preference factor similar to Late Closure applies in conjunction with a high preference factor, then we might expect both the highest and lowest sites to be preferred over the intermediate site in (6). We will refer to the low preference factor as *Recency Preference* (Gibson, 1991; cf. Stevenson, 1994), a variant of Late Closure which applies to all potential attachment sites and can interact with other preference factors to determine attachment preferences.[2]

(7) Recency Preference:
Preferentially attach structures for incoming lexical items to structures built more recently.

[2] The principle of Late Closure is a preference strategy which chooses one attachment site over other alternatives, but does not explicitly rank the other alternatives. The others are not considered (if at all) until a later stage of processing (reanalysis), when Late Closure no longer necessarily applies (Inoue & Fodor, 1996; Frazier, 1994).

The experiments below use constructions like (6) in both Spanish and English to attempt to determine whether there is evidence for two different factors operating together to determine preferences in RC attachment ambiguities. We examine Spanish in Experiment 1 and the corresponding English constructions in Experiment 2.

EXPERIMENT 1

Experiment 1 addresses the question of whether a single factor is responsible for the attachment preferences in Spanish RC attachment ambiguities, by examining comprehension difficulty in constructions involving three potential NP attachment sites, as in the template in (8) and the example in (9):

(8) NP_1 Prep NP_2 Prep NP_3 RC

(9) (a) las lámparas cerca de las pinturas de la casa que fue dañada en la inundación
(b) las lámparas cerca de la pintura de las casas que fue dañada en la inundación
(c) la lámpara cerca de las pinturas de las casas que fue dañada en la inundación
"the lamp(s) near the painting(s) of the house(s) that was damaged in the flood"

Although the RC can initially attach to any of the three NPs in these examples, all but one site is ruled out when the singular verb *fue* ("was") is processed, because only one of the NP sites is singular. Thus the difficulty ordering of the examples in (9) should correspond to an attachment site preference ranking.

If a single factor is responsible for the attachment preferences here (and in C & M's two-site ambiguities), then a monotonic difficulty ordering among the attachment sites is expected, either (NP_1, NP_2, NP_3) or (NP_3, NP_2, NP_1). Because the evidence from Spanish two-site RC attachment ambiguities suggests that high attachment (NP_1) is preferred, the single-factor theory most naturally predicts a preference ordering of (NP_1, NP_2, NP_3) in Spanish.

In contrast, if two factors are responsible for the preferences in Spanish RC attachment ambiguities, then other preference orderings of the three sites are possible. In particular, if one of these factors (e.g., Recency Preference) favours low attachment (to NP_3) and another factor favours high attachment (to NP_1), then preference orderings of (NP_1, NP_3, NP_2) or (NP_3, NP_1, NP_2) are likely.

2. Method

2.1. Subjects

Twenty-six native Spanish speakers from the Boston, Massachusetts academic community (primarily undergraduates and graduate students) participated, either as volunteers or for $4.00. Two subjects were excluded because of poor performance in the paraphrase task (described below). The 24 subjects included were from Mexico (8 subjects), Puerto Rico (6), Spain (3), Argentina, Chile, El Salvador, Guatemala, Peru, and Venezuela; the remaining subject was a native of the United States, with a Mexican father, and learned Spanish in the home.

2.2. Materials

Eighteen complex NP items of the form shown above in (8) and (9) were constructed. Each item contained an initial NP followed by two PPs and a relative clause which was a plausible modifier for any of the three preceding NPs. However, the number of the verb in the relative clause always matched the number of only one of the preceding NPs. Thus each item had a low attachment version, a middle attachment version, and a high attachment version, depending on which NP matched the number of the relative clause verb, as in (9). The head nouns of all three potential attachment sites in all items were non-human and had regular plural forms. The complementizer in the relative clause was always *que* and the disambiguating verb was usually *fue* ("was") or *fueron* ("were"), so that a minimum of semantic information about the relative clause was available at the point of disambiguation. The items are listed in Appendix A.

The stimuli were constructed such that the second (low) PP always preferentially attached to NP_2 rather than NP_1, so that attachment of the relative clause to NP_2 would be allowed by the grammar (i.e., no crossed branches). The preference for the second PP (PP_2) to attach to NP_2 was created syntactically, semantically, and/or pragmatically. To ensure that PP_2 attached as intended, 20 subjects, none of whom were involved in the main experiment, completed a written survey, using the 18 experimental items and 22 fillers. The subjects participated as volunteers from the Spanish-speaking community of Pittsburgh, Pennsylvania. Each item in the survey consisted of an NP followed by two PPs. Immediately following each item, the subject was asked to circle the noun which was modified by the second PP. The two choices (the noun from the first NP and the noun from the first PP) were listed to the right of the question, with the noun from the NP listed first for half the items and the noun from the first PP listed first for the other half. The 40 experimental and filler items were presented on four pages with the order of pages randomized for each subject. Some subjects completing the survey noted that the phrasing of the question about

attachment was unnatural for one item, which displayed only a 20% preference for attachment of PP_2 to NP_2. Excluding this item, the overall preference for attachment of PP_2 to NP_2 was 86%. Given the possibility that some of the stimuli may occasionally have been treated as ungrammatical, we conducted additional analyses excluding the four items for which the attachment of PP_2 to NP_2 was preferred below 80% (the items marked with an asterisk in Appendix A). These analyses are discussed in the Results section below. The percentage of subjects preferring attachment of PP_2 to NP_2 over NP_1 is shown with each item in Appendix A.

The 18 experimental items were combined with 60 fillers to form three lists. Half of the fillers were grammatical and acceptable complex NP fragments of Spanish, and half were ungrammatical or unacceptable (e.g., incorrect agreement, crossed branches, missing words, multiple center embeddings, or subjacency violations). The fillers were of approximately the same length and complexity (number of words and constituents) as the experimental items. The experimental items were counterbalanced across the lists so that each list contained exactly one version (high, low, or middle attachment) of every item. Ten practice items were also constructed to be similar to the fillers.

2.3. Procedure

The stimuli were presented on an IBM PS/2 computer. A subject saw two screens of instructions, followed by the 10 practice items and then the 78 experimental and filler items. The experimental and filler items were presented in a different random order for each subject. On every practice item, and on one-third of the other items, the subject was asked to paraphrase the item for the experimenter, to ensure that subjects were attending to the stimuli. On the practice items, the experimenter corrected the subject's errors.

At the beginning of a trial, the item was displayed on the screen with all non-space characters replaced by dashes. When the subject pressed the space bar, the first word of the item was displayed, replacing the corresponding dashes. When the subject pressed the space bar a second time, the first word reverted to dashes, and the second word was displayed in place of the appropriate dashes. Each subsequent press of the space bar revealed the next word and removed the previous word. Pressing the space bar on the last word of the item caused the item to be replaced by a request to paraphrase the item just read or a request to press the space bar again to continue with the experiment. The computer recorded the time between each button-press.

In addition, the subject was instructed to press a key marked "NO" just above the space bar if, at any point during the display of an item, the item became unacceptable (ungrammatical) in Spanish. Both the instructions and the practice items included some clearly ungrammatical fragments as

examples. Display of an item was terminated whenever the subject indicated that it had become ungrammatical. Subjects could still be asked to paraphrase an item if they had decided it was ungrammatical. All instructions, materials, and feedback were presented in Spanish, and most subjects completed the experiment in less than 30 minutes.

2.4. Analysis

We analyzed both the cumulative percentage of ungrammaticality judgements and the reading times. In both of these measures, effects should appear where the attachment of the relative clause is disambiguated (*fue dañada* in (9)). For the purposes of analysis and presentation of the data only, items were separated into seven regions as shown in Fig. 1, and we present analyses only of the disambiguating region and the following two regions.

In addition, because there is dialectal variation in Spanish across the countries of origin of the subjects, Appendix B reports the country of origin and condition means at the disambiguating region for each subject included in the experiment. Although we are not aware of any evidence of relevant syntactic differences across dialects (including the current experiment), C & M's two-NP-site evidence comes from students at the University of Oviedo in Spain, whereas the data presented below come from a wider range of dialects. The dialectal variation which is known to exist is lexical, and two subjects reported that they did not know the word *papalote* in item 13; thus Appendix A includes condition means at the disambiguating region for each item.

NP_1	PP_1		PP_2	complementizer
la(s) lámpara(s)	*cerca de la(s) pintura(s)*		*de la(s) casa(s)*	*que*
"the lamp(s)"	"near the painting(s)"		"of the house(s)"	"that"
disambiguation	remainder	final word		
fue dañada	*en la*	*inundación*		
"was damaged"	"in the"	"flood"		

Fig. 1. Regions used for analysis.

3. Results

Trials on which the subject indicated that the item was ungrammatical prior to the disambiguating verb in the relative clause were excluded from all of the following analyses. This affected less than 3.0% of the trials.

3.1. Cumulative grammaticality judgements

The cumulative percentage of ungrammaticality judgements by region is shown in Fig. 2. An item was scored as ungrammatical in a given region if

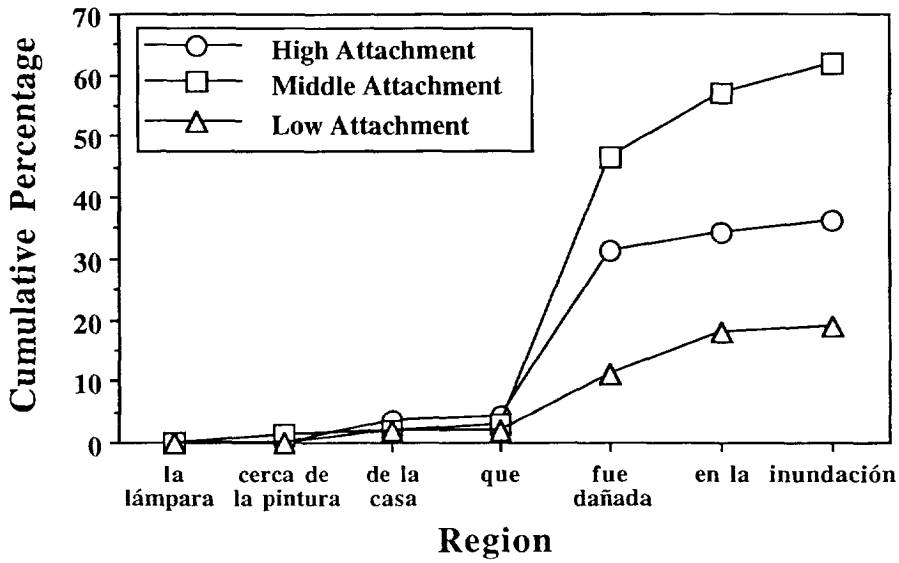

Fig. 2. Experiment 1 cumulative ungrammaticality judgements by region. Although excluded from analyses, trials judged ungrammatical prior to the disambiguation are shown for completeness.

the subject indicated that the item was ungrammatical on any word of the region or in any preceding region.

In the disambiguating region, a main effect of attachment was present ($F1(2, 46) = 18.635$, $p < .001$; $F2(2, 34) = 23.132$, $p < .001$), and the low attachment condition was judged significantly better than either of the other two conditions (vs. middle: $F1(1, 23) = 47.222$, $p < .001$; $F2(1, 17) = 44.286$, $p < .001$; vs. high: $F1(1, 23) = 10.653$, $p < .005$; $F2(1, 17) = 16.834$, $p < .005$). In addition, the high attachment condition was judged better than the middle attachment condition ($F1(1, 23) = 6.483$, $p < .05$; $F2(1, 17) = 8.256$, $p < .05$). As is apparent from Fig. 2, this same pattern persisted into the remaining two regions: A main effect of attachment was present, the low attachment condition was judged ungrammatical less often than the high and middle attachment conditions, and the high attachment condition was judged ungrammatical less often than the middle attachment condition (all $ps < .05$).

Finally, to ensure that the relative difficulty of the middle attachment condition was not simply a result of its being ruled out by the grammar, the same analyses were performed excluding the four items (marked with an asterisk in Appendix A) most likely to be ruled out by the grammar on the basis of the written survey described in the Materials section. Removing the four items had no effect on the pattern of results: All three attachment conditions still differed in the disambiguating region, all $ps < .05$.

3.2. Reading times

A regression equation predicting reading time from word length was constructed for each subject, using all items (filler and experimental) except for those experimental items judged ungrammatical prior to the disambiguation. For any item judged ungrammatical, the word on which the judgement was made was also excluded. 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 extraneous variance by subtracting out a baseline for each subject, and by controlling for noise due to length effects. See Ferreira and Clifton (1986) and Trueswell and Tanenhaus (1991) for some discussion. The raw reading times by condition in each region are reported in Appendix D; although significance levels are consistently weaker in the raw times, the pattern of data is the same as that in the residual reading times.

Items judged ungrammatical at any point were excluded from further analyses, and three subjects were excluded: Two had judged all the items in the high attachment condition ungrammatical, and one had judged all the items in the middle attachment condition ungrammatical. The remaining data were trimmed by excluding residual reading times beyond 4 standard deviations from the appropriate attachment condition × position cell mean. This trimming affected 1.2% of the data.

Fig. 3 plots the residual reading time data by condition and region. At the

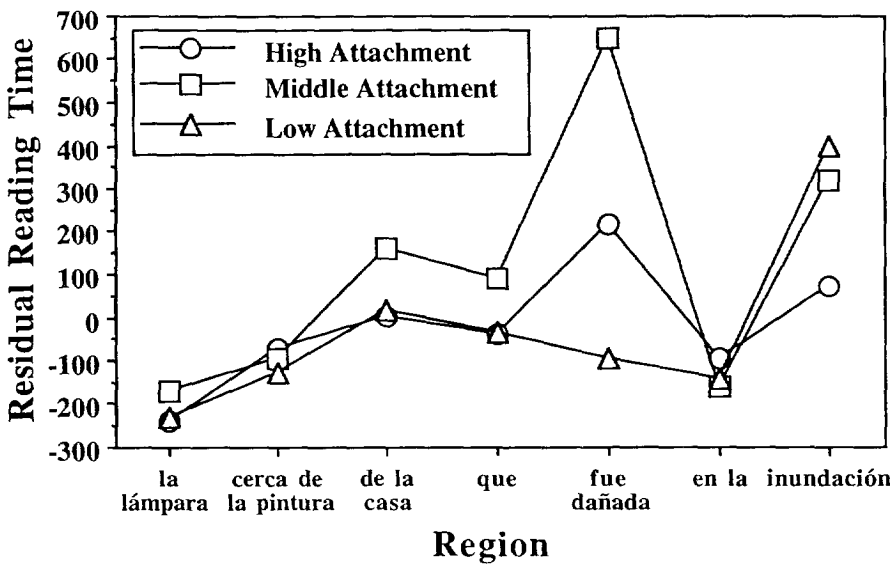

Fig. 3. Experiment 1 residual reading time per word (ms) by region.

disambiguation, a main effect of attachment was present ($F1(2, 40) = 15.264$, $p < .001$; $F2(2, 34) = 13.074$, $p < .001$). Furthermore, all three conditions differed significantly: Low attachments were faster than both high attachments ($F1(1, 20) = 15.066$, $p < .005$; $F2(1, 17) = 13.995$, $p < .005$) and middle attachments ($F1(1, 20) = 21.958$, $p < .001$; $F2(1, 17) = 24.486$, $p < .001$), and high attachments were faster than middle attachments ($F1(1, 20) = 8.788$, $p < .01$; $F2(1, 17) = 5.311$, $p < .05$). Thus low attachments are fastest, middle attachments are slowest, and high attachments are intermediate. Data from the following regions were not analyzed, because we had no particular predictions about reading times in these regions.

As was done for the cumulative grammaticality judgement analyses, we re-analyzed the disambiguating region reading time data excluding the four items most likely to be judged ungrammatical in the middle attachment condition. The analysis by subjects duplicated the effects described above: Low attachments were fastest, middle attachments were slowest, and high attachments were intermediate (all $ps < .05$). The items analysis also duplicated the analysis including all 18 items, with the exception that the high attachment versus middle attachment comparison did not reach significance ($p < .12$). However, this lack of significance was not the result of a change in the middle attachment condition, as would be expected if the difficulty of the middle attachment condition was caused by the ungrammaticality of some of the items. The difference between the two means changed from 453 ms to 414 ms, and the majority of this shift was due to a change in the high attachment condition mean, which increased by 28 ms. The middle attachment condition mean decreased by only 10 ms. Furthermore, the effect size computed when considering all 18 items was $d = .56$, and it was quite similar when computed using only the 14 items ($d = .47$). Thus the change in significance was the result of an increase in the standard deviation (rather than the mean) of both conditions, along with a corresponding decrease in degrees of freedom (and power). The middle attachment condition was therefore more difficult than either of the low or high attachment conditions, and this difference was not the result of the middle attachment being ruled out by the grammar.

4. Discussion

The results of Experiment 1 indicate that Spanish-speaking subjects have less difficulty with low attachments (to NP_3) than with either middle (NP_2) or high (NP_1) attachments, and high attachments are in turn easier than middle attachments. All of these effects are present in both grammaticality judgements and reading times. These results are not compatible with the single-factor explanation of RC attachment preferences, because the preference ordering does not proceed monotonically from the least recent site to the most recent site, or vice versa. Rather, these results necessitate the

existence of at least two factors in determining Spanish RC attachment preferences. The fact that this non-monotonicity appears as the middle site being the worst and the extremity sites being preferred suggests that each of the two factors is providing strongest support to one of the two extremity sites, with Recency Preference a plausible candidate for the low attachment preference factor. We discuss some possibilities for the high attachment factor below in the General Discussion.

Beyond the evidence of non-monotonicity, however, these results are surprising, in that the low site is most preferred, whereas in Spanish two-site RC ambiguities, the high site is generally preferred. This change in preferences for two- versus three-site ambiguities suggests that the bias created by the low preference factor (Recency Preference) in favor of attachment to a site continues to decrease as sites become less recent, so that increasingly distant sites are increasingly harder to attach to, on the basis of this factor.[3] Therefore, as the number of sites increases, the effect of Recency Preference eventually dominates the effect of the high preference factor. We discuss how the factors interact in more detail in the General Discussion.

Thus the results of Experiment 1 suggest that Recency Preference applies in Spanish RC attachment ambiguities, and that it interacts with a second factor which creates a preference for high attachments. C & M propose (p. 93) that the high attachment preference seen in Spanish may be a special purpose strategy, particular to Spanish. Another possibility is that the high attachment preference factor is also present in English, but that it is weaker than Recency Preference in English (unlike in Spanish), so that Recency Preference dominates even in two-site RC attachment ambiguities.

Experiment 2 examines these two possibilities by considering attachment preferences in three-site RC attachment ambiguities like those in Experiment 1, but in English. If the high attachment preference factor is a special purpose attachment strategy for Spanish, then we should observe only effects of Recency Preference in English, resulting in a monotonic preference order of (NP_3, NP_2, NP_1). On the other hand, if the high attachment preference factor also applies in English, then non-monotonic preference orderings of the attachment sites are possible. In particular, the high site (NP_1) should be preferred over the middle site (NP_2). Furthermore, the low site (NP_3) is likely to be most preferred because it is preferred in English two-site cases, and because it overwhelms the high attachment preference factor in Spanish three-site cases.

[3] We have been discussing these preference factors as biases *in favor of* attachment to particular sites, but they can equivalently be discussed in terms of biases *against* attachment to non-preferred sites. See the General Discussion.

EXPERIMENT 2

Experiment 2 examines whether there is any evidence for the high attachment preference factor in English, where both VP attachment ambiguities like (2) and two-site RC attachment ambiguities like (4b) show effects only of Recency Preference. In order to test this possibility, English three-site RC attachment ambiguities similar to those in Spanish from Experiment 1 were constructed. An example is given in (10):

(10) (a) the lamps near the paintings of the house that was damaged in the flood
(b) the lamps near the painting of the houses that was damaged in the flood
(c) the lamp near the paintings of the houses that was damaged in the flood

The structure of these items is as in (8) and is the same as in the corresponding Spanish versions: The verb in the relative clause agrees in number with exactly one of the potential NP attachment sites.

If the high attachment preference factor does not apply in English and operates instead as a special purpose strategy in Spanish, then Recency Preference should determine the preference ranking, predicting an ordering of (NP_3, NP_2, NP_1). Alternatively, if the high attachment preference factor also applies in English, then a non-monotonic preference ordering of (NP_3, NP_1, NP_2) is possible.

5. Method

5.1. Subjects

Thirty Massachusetts Institute of Technology undergraduates were paid $4.00 each for their participation in the study. All were native speakers of English.

5.2. Materials

English versions of the experimental, filler and practice items from Experiment 1 were constructed. In some cases, the relative clause was changed, so that the disambiguating verb was always *was* or *were*. The stimuli were also modified so that the number of words was the same in all items. The experimental items are listed in Appendix C.

As in Experiment 1, a written survey was conducted to ensure that in the experimental items, PP_2 preferentially attached to NP_2. The surveys were

constructed exactly as in Experiment 1. Fifteen subjects, none of whom were involved in the main experiment, participated as volunteers. Across the 15 subjects and all 18 experimental items, the preference for PP_2 to attach to NP_2 was 98%, indicating that, as intended, the possibility of attachment to the middle site in the three attachment site constructions was not ruled out by the grammar. The percentage of subjects preferring attachment of PP_2 to NP_2 over NP_1 is shown with each item in Appendix C.

5.3. Procedure

The procedure was exactly as in Experiment 1. All instructions, materials, and feedback were presented in English. Most subjects completed the experiment in approximately 20 minutes.

6. Results

The items were analyzed in seven regions as in Experiment 1 (see Fig. 1). Trials on which an item was judged ungrammatical prior to the disambiguation were excluded from all analyses, affecting less than 1.0% of the data.

6.1. Cumulative grammaticality judgements

The cumulative percentage of ungrammaticality judgements by region (including those trials judged ungrammatical prior to the disambiguation) is shown in Fig. 4. In the disambiguating region, the results are very similar to those from Experiment 1: A significant main effect of attachment was present ($F1(2, 58) = 7.856$, $p < .001$; $F2(2, 34) = 4.990$, $p < .05$), and individual mean comparisons indicated that the low attachment condition was judged ungrammatical less often than either the high attachment ($F1(1, 29) = 6.250$, $p < .05$; $F2(1, 17) = 4.509$, $p < .05$) or the middle attachment condition ($F1(1, 29) = 14.107$, $p < .001$; $F2(1, 17) = 8.649$, $p < .01$). However, although the high attachment condition was judged ungrammatical less often numerically than the middle attachment condition, this difference was not significant ($F1(1, 29) = 2.546$, $p > .12$; $F2(1, 17) = 1.585$, $p > .20$). Also as in Experiment 1, the pattern in the following two regions matched that in the disambiguation.

6.2. Reading times

Residual reading times were calculated for each subject's data exactly as in Experiment 1. Items judged ungrammatical at any point were excluded from further analyses, and one subject, who had judged all items in the high attachment condition ungrammatical, was also excluded. Trimming was performed as in Experiment 1, affecting 1.1% of the data. Raw reading

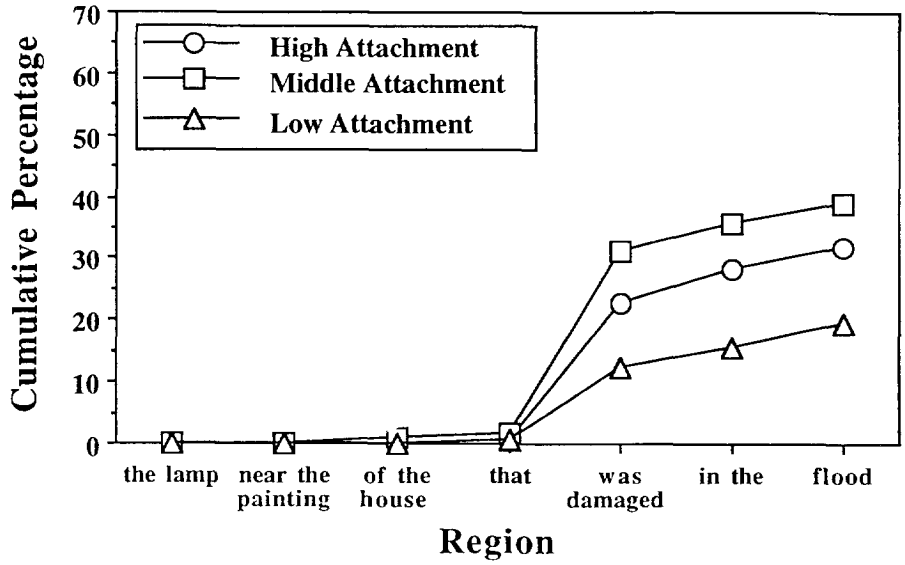

Fig. 4. Experiment 2 cumulative ungrammaticality judgements by region.

times are reported in Appendix D, and the data patterns discussed below for the residual reading times are also present in the raw reading times.

The data are plotted in Fig. 5. In the disambiguating region, the main effect of attachment was significant ($F1(2, 56) = 10.197$, $p < .001$;

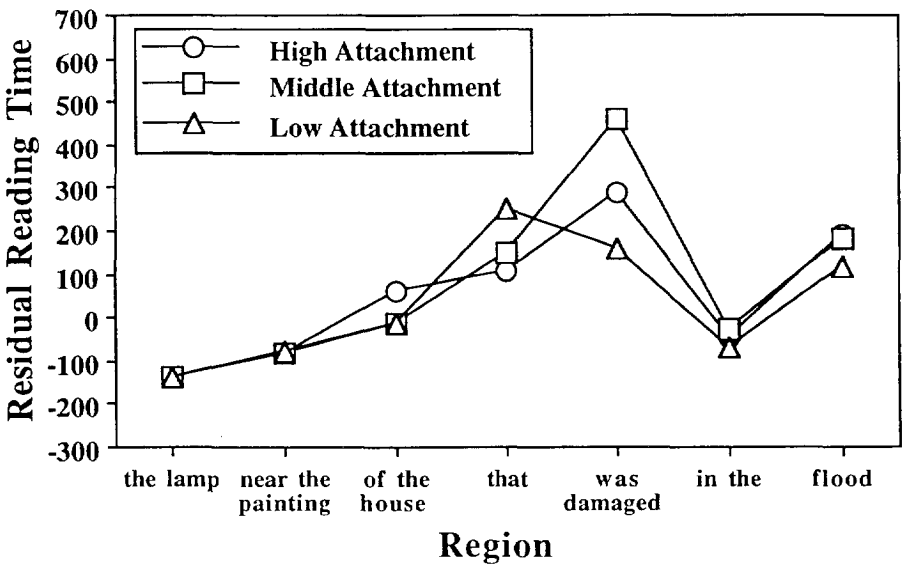

Fig. 5. Experiment 2 residual reading time per word (ms) by region.

$F2(2, 34) = 7.766$, $p < .005$), and all three conditions differed from each other, with low attachment fastest, high attachment intermediate, and middle attachment slowest. Low attachment was faster than both high attachment ($F1(1, 28) = 6.217$, $p < .05$; $F2(1, 17) = 7.646$, $p < .05$) and middle attachment ($F1(1, 28) = 12.872$, $p < .005$; $F2(1, 17) = 12.470$, $p < .005$), and high attachment was faster than middle attachment, though this difference was marginal by items: $F1(1, 28) = 7.950$, $p < .01$; $F2(1, 17) = 3.655$, $p < .08$. Thus as in the judgement data, subjects display an immediate preference for low attachments, but the reading time data also differentiate between the high and middle attachment conditions: Although neither attachment is initially preferred, subjects have less difficulty attaching to the highest site than to the middle site.

7. Discussion

Both the grammaticality judgement data and the reading time data in this experiment show that English-speaking subjects have an initial preference for low attachments (to NP_3). This manifested itself as difficulty with both high (NP_1) and middle (NP_2) attachments as soon as they were forced by syntactic agreement constraints. Experiment 2 also showed that middle attachments are more difficult than high attachments, and this non-monotonicity provides strong evidence that a high preference factor operates in addition to Recency Preference in English, as in Spanish.

GENERAL DISCUSSION

Experiments 1 and 2 provide strong evidence for non-monotonicity in RC attachment ambiguities, which argues against a single-factor explanation. We propose a two-factor explanation in which one factor (Recency Preference) favors attachment to most recent sites, and the other factor favors attachment to the highest (least recent) sites. The evidence for the choice of Recency Preference as one of the factors in English and Spanish comes from: (1) VP attachment preferences; (2) two-site RC attachments in English; and (3) three-site RC attachments in both Spanish and English. The only evidence against Recency Preference in these two languages comes from Spanish two-site RC attachments, and Experiment 1 suggests that Recency Preference is operating in such constructions but is dominated by the second preference factor.[4]

[4] The only other reported case of a non-recent attachment preference that we know of comes from Dutch two-NP-site ambiguities, in which a high attachment preference obtains as in Spanish (Brysbaert, 1993; Brysbaert & Mitchell, 1993). If the two-factor hypothesis discussed here is correct, then evidence for Recency should be observed in a Dutch three-site experiment, as it is in Spanish.

So the evidence for Recency is clear, but a number of questions remain with respect to these preference factors. In particular, the factor responsible for the high attachment preference remains to be specified. Furthermore, the relationship between the two factors needs to be worked out in some detail: The preference ordering must change between two- and three-site RC attachment ambiguities in Spanish while preserving the recency preferences in English and in VP attachments across both languages. Finally, the possible sources of these preference factors need to be discussed. These issues are addressed in the next three sections, followed by some additional predictions of the theory developed below.

8. The high attachment preference factor

Whereas there appears to be substantial support for Recency Preference as the low preference factor, we have not specified the nature of the high preference factor. A number of facts are relevant to identifying this factor. First, neither Spanish nor English seems to exhibit any effects of the high preference factor in two-site VP attachment ambiguities. Second, a low attachment preference is present in English two-NP-site RC ambiguities, but it appears to be much weaker than the VP attachment preference. For example, C & M found only a 58% versus 37% preference advantage for low attachment in a questionnaire study. Third, there is a weak high attachment preference in Spanish two-NP-site RC ambiguities – C & M found a 62% versus 36% advantage for high attachment in their Spanish questionnaire. Fourth, evidence from three-NP-site attachment ambiguities in both English and Spanish suggests that the high preference factor is active in attachments to NPs in both languages. The combination of these four facts suggests that the high attachment preference factor must differentiate between NP and VP attachment sites, applying to NP sites but not to VP sites. Finally, the high preference factor applies to direct and indirect object positions (as evidenced by C & M's Spanish two-site data) as well as bare NP positions (as in the Experiment 1 and 2 data). These constraints rule out many possible conceptions of the high attachment preference factor. Several potential candidates are considered below.

One possibility that is not compatible with all of the data is *primacy preference*, a preference to attach to the least recent available site, which might be justified from general properties of short-term memory (in particular, the serial position effect in recall; see, for example, Murdock, 1962; Tulving, 1968; and the references in each). This proposal suffers at least two pitfalls. First, assuming that either recency or primacy is parameterized (recency must dominate primacy in English, but primacy must dominate recency in Spanish, in order to account for the English versus Spanish two-NP-site preference difference), this proposal fails to differentiate between NP and VP attachment sites, incorrectly predicting either a high attachment preference in Spanish VP attachment ambiguities or a low

preference in Spanish NP attachment ambiguities. Second, the evidence for primacy from the short-term memory literature comes from studies involving stimuli with a clearly defined beginning. The analogy of memory stimuli to the linguistic attachment items suffers because the latter do not have a clearly defined beginning: The highest site depends on the phrase being attached. In the short-term memory literature, the primacy effect results from placing items into memory as they are encountered, but the list of possible attachment sites in the linguistic stimuli is not available until the attaching phrase is encountered. Relatedly, depending on how it interacts with linguistic constraints, primacy also might predict that attachments to both the subject NP and the verb in C & M's stimuli would be preferred over attachments to the direct or indirect object, counter to the observed data.

A second possibility is to combine primacy with an assumption of *clause boundedness* (Milsark, 1983), whereby attachments are blocked outside of the current clause. This assumption correctly differentiates between VP and NP attachments in Spanish, because VPs above the current (most recent) site will not be available for attachment, but NPs in the same clause will. In addition to the extra stipulation required, however, this proposal suffers the same drawback as primacy without clause boundedness: It is not clear how to define the relevant beginning of the list of attachment sites in order to support the analogy to short-term memory.

A third possibility for the high preference factor is Frazier's (1990) Relativized Relevance Principle:[5]

(11) Relativized Relevance:
Other things being equal (e.g., all interpretations are grammatical, informative, and appropriate to discourse), preferentially construe a phrase as being relevant to the main assertion of the current sentence. (Frazier, 1990, p. 321)

Frazier does not specify what constitutes the "main assertion" of a sentence, but one possibility is that a sentence's main assertion is identified with the root sentence node, so that (11) results in a preference to attach as close as possible to the root S (IP) node in a sentence. Assuming that a root sentence node is always initially postulated, even before a verbal head has been encountered (e.g., Frazier & Fodor, 1978; Kimball, 1973; and numerous others since), Relativized Relevance prefers attachment to the non-recent NP in two-NP-site attachment ambiguities. This is because the

[5] As originally proposed, Relativized Relevance is not an on-line principle: It applies *after* Late Closure. However, Mitchell and Cuetos (1991a, 1991b) argue that this principle cannot account for Spanish high attachment preferences if it applies after Late Closure. Thus we will consider only an on-line version here which competes directly with Recency Preference (Late Closure).

non-recent NP is either the subject or the direct or indirect object of the root sentence node and is therefore structurally closer to it than the second NP, which is the object of a preposition. Unfortunately, this high attachment preference factor suffers the same downfall as primacy: It does not explain differences between VP- and NP-site attachment preference patterns. In particular, Relativized Relevance favors the higher of multiple VP sites, thus counteracting Recency in VP attachment ambiguities.

However, a simple extension of Relativized Relevance can account for the data. If, instead of preferring close attachments to the root S node, this factor prefers close attachments to *any* S node, then the difference between the NP and VP patterns is produced. In the NP case, only one S node is present, so the extension works just as Relativized Relevance does. In the VP case, each VP attachment site is in a separate clause and thus has its own associated S node, so the extended version of the factor does not prefer either site over the other, and Recency Preference is the only relevant factor. We will refer to the extension of Relativized Relevance as Predicate Proximity (cf. Milsark, 1983; Abney, 1989; Gibson's (1991, p. 137) Verbal Argument Attachment Preference property):[6]

(12) Predicate Proximity:
Attach as close as possible to the head of a predicate phrase.

Predicate Proximity is motivated by the fact that all grammatical utterances have a predicate at their core. Following Bowers (1993), we assume that a sentence is headed by a predicate phrase, although assuming an S (IP) or a projection of V will not affect the empirical predictions discussed here. Because all sentences include a predicate at their core, we hypothesize that the core predicate structure (i.e., the predicate and its arguments) is ranked more highly for attachment by the parser. Hence, if resources are short so that only a limited number of attachment sites can be left open, sites associated with a predicate phrase will be more available than others, because the comprehender has to retain these sites in order to understand the utterance. Thus incoming material is preferentially seen in terms of (potential) predicate phrases.

[6] Thanks to an anonymous reviewer for pointing out the relationship between Relativized Relevance and an earlier version of Predicate Proximity, verbal θ-grid preference, which (as noted by the reviewer) failed to capture the similarity in attachment preferences between constructions involving VPs and those involving non-verbal predicators, as in (i) and (ii), respectively:

(i) I read the letter on the table that I had written.
(ii) I was proud of the letter on the table that I had written.

Whereas *read* in (i) heads a VP, *proud* in (ii) does not. Predicate Proximity correctly predicts that the RC can be relatively easily attached to the less recent NP in both examples.

Combining Predicate Proximity and Recency yields a theory which handles the data discussed so far. In particular, Predicate Proximity does not differentiate between multiple VP (predicate) attachment sites, so that Recency dominates in such ambiguities, resulting in the observed low VP preference. In ambiguous RC attachments, Predicate Proximity favors the high site because this site is structurally closest to a predicate phrase, and Recency favours the low site. Just as in the case of Relativized Relevance, in order for Predicate Proximity to apply to the stimuli in Experiments 1 and 2, the parser must predict a root predicate phrase (sentence node) before its lexical head appears. This is because no overt matrix predicate phrase is present in these examples when the attachment decision is made. (See Gibson, 1991, and Gibson, Hickok, & Schütze, 1994, for discussion of one way of implementing this predictive parser.) Once the predicate phrase is postulated, the initial NP becomes the attachment site closest to it and is therefore favored by Predicate Proximity. In two-NP-site cases, this results in a conflict which is resolved in favor of whichever factor is stronger in the language being considered. In three-NP-site cases, this conflict results in a non-monotonic preference ordering in both English and Spanish. Thus although Predicate Proximity is not the only conceivable candidate for the high preference factor, it appears to handle the current data better than other possibilities we have considered. In the next section, we examine it and its interaction with Recency in more detail.

9. The relationship between Recency Preference and Predicate Proximity

The Predicate Proximity proposal accounts for the distinction between VP and NP attachment sites. The two facts that remain to be explained under this proposal are (1) how English and Spanish preferences can differ with respect to two sites but not with respect to three sites, and (2) how Spanish NP attachment preferences differ depending on how many sites are involved. In this section we present one possible implementation of the two interacting factors that yields the observed effects.

As mentioned in footnote 3, we can equivalently discuss Recency and Predicate Proximity in terms of support or positive activation for particular sites, or in terms of cost applied against other sites. Following Gibson (1991), we will use the cost metaphor. In order to account for the Spanish switch in preferences between two and three-site ambiguities, the cost associated with violating Recency must increase with distance from the most recent site, so that attachment to the least recent of three sites is more costly than attachment to the least recent of two sites. (Also, the cost associated with Predicate Proximity must increase more slowly than that associated with Recency – we will return to this point below.) At least two implementations of Recency give the required effect: in terms of a cost indexed by the number of intervening words (or, more generally, time steps) (e.g., Steven-

son, 1994), or in terms of a cost indexed by the number of intervening allowable attachment sites (e.g., Gibson, 1991). The evidence currently available does not distinguish between these two possibilities. For concreteness we will follow Gibson (1991), assuming definitions quantified by the number of intervening attachment sites.[7] Definitions of Recency and Predicate Proximity can thus be stated as follows, within the parsing framework of Gibson (1991), which assumes the existence of an abstract cost unit, the Processing Load Unit (PLU):

(13) Recency Preference (RP):
The cost associated with the structure resulting from attachment of structure X = a non-decreasing function f of (the number of more recent words that would also allow an attachment of structure X) $\times x_{RP}$ PLUs (adapted from Gibson, 1991).

(14) Predicate Proximity (PP):
The cost associated with the structure resulting from an attachment of structure X = a non-decreasing function g of (the number of words associated with sites structurally closer to the head of a predicate phrase that would also allow an attachment of structure X) $\times x_{PP}$ PLUs.

As defined in (13) and (14), the costs associated with Recency and Predicate Proximity increase according to the (as yet unspecified) functions f and g respectively, as applied to the number of better currently available attachment sites. As discussed above, f (associated with Recency) must be strictly increasing over the first three sites in order to account for Spanish RC references. There are many possible candidates for such a function. Gibson (1991) assumes a linearly increasing cost function but provides no empirical evidence distinguishing a linear function from other increasing functions. It turns out that the English three-NP-site attachment preferences provide evidence against a linearly increasing cost function. To see this, suppose that this function is linear. Then, by definition, the cost differential between the best and second-best sites according to Recency is the same as the cost differential between the second- and third-best sites. Suppose that the cost associated with the best (most recent) site is L_1 and that the linear cost increment between sites is x, resulting in Recency costs of L_1, $L_1 + x$, and $L_1 + 2x$ for the most recent, second most recent and third most recent

[7] In order to decide between these two Recency decay functions, Spanish three-site RC attachment ambiguities might be compared to corresponding Spanish two-site RC ambiguities, where the same number of words separates the least and most recent sites in each ambiguity. The site-based theory predicts a difference in preferences between the two- and three-site cases, while the word- or time-based theory predicts no difference.

Table 1
Attachment site costs for two NP sites assuming a linear decay function for Recency

Preference factor	Attachment site	
	NP_1 (high)	NP_2 (low)
Recency	$L_1 + x$	L_1
Predicate Proximity	H_1	H_2
Total	$L_1 + x + H_1$	$L_1 + H_2$

sites respectively.[8] Suppose also that the costs associated with the high preference factor (i.e., Predicate Proximity) for the top three NP sites are H_1, H_2 and H_3 respectively. Then the costs associated with the high and low sites in a two-NP-site ambiguity are $L_1 + x + H_1$ and $L_1 + H_2$ respectively (see Table 1). In order to obtain the observed low preference in English, it must be the case that the cost associated with the high site is more than that associated with the low site; that is, $L_1 + x + H_1 > L_1 + H_2$, which reduces to $x + H_1 > H_2$. However, in order to obtain the observed three-NP-site preferences in which the high site is favored over the middle site, it also must be the case that $L_1 + 2x + H_1 < L_1 + x + H_2$ (see Table 2), which reduces to $x + H_1 < H_2$. But this immediately contradicts the previous inequality, and thus the recency cost decay factor cannot be a linearly increasing function.

Because Recency Preference is intended to follow from universal properties of human short-term memory, a more natural choice of function is one motivated by results from the short-term and working memory literature: an increasing exponential decay function. In this literature, activation of an element in memory decays according to an exponential function of time, approaching an asymptote in the limit (see, for example, Anderson, 1980, 1983; McClelland & Rumelhart, 1981; and the references in each). In cost terms, the cost of attaching to a particular site increases with distance from the current word, but by smaller increments according to an exponential decay function. For example, attachment of a modifier to the third most

Table 2
Attachment site costs for three NP sites assuming a linear decay function for Recency

Preference factor	Attachment site		
	NP_1 (high)	NP_2 (middle)	NP_3 (low)
Recency	$L_1 + 2x$	$L_1 + x$	L_1
Predicate Proximity	H_1	H_2	H_3
Total	$L_1 + 2x + H_1$	$L_1 + x + H_2$	$L_1 + H_3$

[8] It is assumed that the cost for a site with respect to a preference factor does not depend on site that are ranked lower with respect to the same factor. Thus the costs assigned by a factor to its n best sites are assumed to be the same no matter how many more sites than n there are.

recently available site will be more costly than attachments to either the most recent or the second most recent sites, but the difference in cost between attachment to the second- and third-ranked sites will be smaller than the difference between the first- and second-ranked sites. For concreteness, we assume a decay function whose cost increment divides in half as the number of sites increases: If the initial cost increment is x_{RP} PLUs, then the cost associated with the nth most recent attachment is $(2-(1/2)^{n-2})*x_{RP}$ PLUs. Thus the cost of an attachment increases from 0 PLUs (the most recent site) to x_{RP} PLUs (the next most recent), to $1.5x_{RP}$ PLUs, to $1.75x_{RP}$ PLUs, etc., as attachments get further away.

The high preference factor Predicate Proximity may also be associated with a decay function g according to which increasingly lower sites are associated with increasingly more cost. However, in order to explain the changes in Spanish preferences across two- and three-site ambiguities, this decay function must have certain properties: If g changes at the same rate as the Recency decay function f, then the highest- versus lowest-site preferences will not vary with the number of sites, resulting in a uniform preference for the highest site in RC attachment ambiguities involving more than two NP sites. If the Predicate Proximity function g increases more rapidly than the Recency function f, then the highest site will become more and more strongly preferred as the number of sites increases, because the high preference factor will add more cost to the lower sites than the low preference factor will add to the higher sites. The only alternative is that the decay function associated with Predicate Proximity must change more slowly than the Recency decay function, so that Recency dominates in three site cases, even though Predicate Proximity dominates in two site cases. One very simple possibility is that the high preference function g is a single-step function, such that it associates the same cost with all sites other than the highest one (i.e., the change in cost after the first increment is zero). Under this proposal, attachments to the site closest to the head of the predicate phrase are associated with zero cost, while all other attachments are associated with x_{PP} PLUs.

In order to demonstrate that the two proposed factors can handle the current RC attachment facts, we consider first the relevant Spanish and English RC attachment ambiguities. In two-site ambiguities, the cost associated with attaching the RC to the high site is x_{RP} PLUs, whereas the cost associated with attaching to the low site is x_{PP} PLUs. In order to explain the difference between English and Spanish preferences, one of Recency or Predicate Proximity must have the potential to vary cross-linguistically, so that it is associated with a different cost in each of the two languages (cf. Cuetos & Mitchell, 1988; Mitchell & Cuetos, 1991a; Mitchell, 1994). Because Recency is assumed to follow from general properties of working memory, it is an unlikely candidate for parameterization. Predicate Proximity is not as independently well motivated, so we will assume that it (or its source) is the parameterized factor. (See the following section for

some speculation on the general source of this parameterization.) Thus Predicate Proximity must be associated with more cost than Recency in Spanish in order to explain the high site attachment preference, and it must be associated with less cost than Recency in English in order to explain the low site preference. This proposal is illustrated in Fig. 6: Fig. 6(A) shows the costs associated with the high and low attachment sites in English two-NP-site ambituities, and Fig. 6(C) shows the corresponding case for Spanish. In English, $x_{RP} > x_{PP}$, so the high site is associated with a greater total cost than the low site. In Spanish, $x_{RP} < x_{PP}$, so the relative ordering of the two sites reverses.

In three-site RC attachment ambiguities, the costs associated with the three prospective sites under the assumptions given here are NP_1: $1.5x_{RP}$; NP_2: $x_{RP} + x_{PP}$; and NP_3: x_{PP}. For English, we already have the constraint that $x_{RP} > x_{PP}$. If it is also the case that $x_{PP} > .5x_{RP}$, then the English three-site preferences result. As an example, suppose $x_{PP_{Eng}} = .8x_{RP}$. Then the costs associated with the three sites are: NP_1: $1.5x_{RP}$; NP_2: $1.8x_{RP}$; and

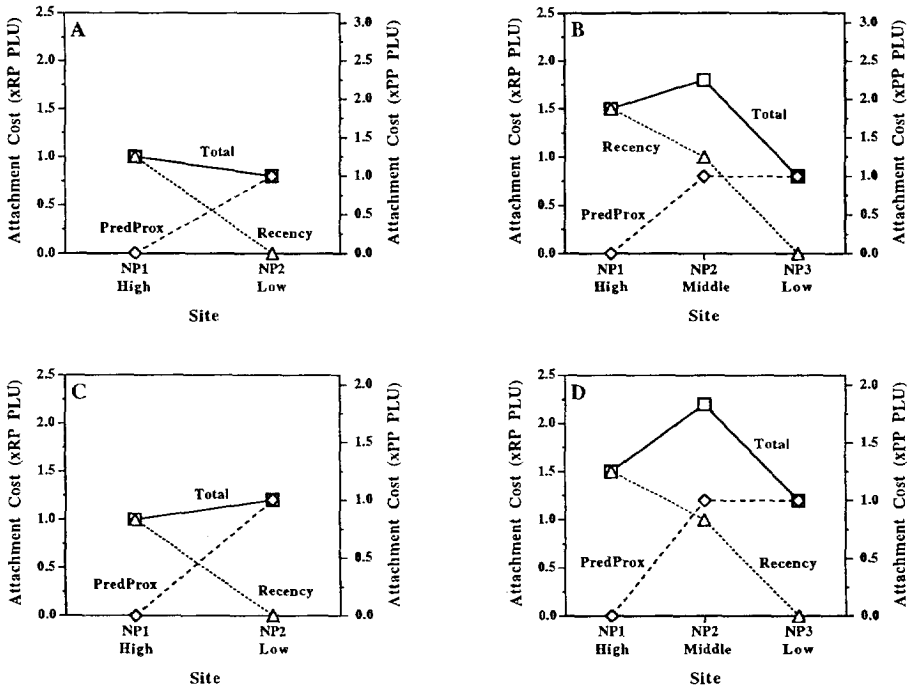

Fig. 6. Cost functions for Recency (triangles), Predicate Proximity (diamonds), and their summed totals (squares), in English two-NP-site (A), English three-NP-site (B), Spanish two-NP-site (C), and Spanish three-NP-site (D) attachments. The left axes are in x_{RP} units and are fixed across languages; the right axes are in x_{PP} units and reflect the proposed variation in the ratio of x_{PP} to x_{RP} across languages: for English, $x_{PP} = .8x_{RP}$; for Spanish, $x_{PP} = 1.2x_{RP}$. Greater attachment cost corresponds to greater difficulty in attachment to a site.

NP_3: $.8x_{RP}$; resulting in the desired (NP_3, NP_1, NP_2) preference ordering. This is the case shown in Fig. 6(B). For Spanish, we have the constraint that $x_{PP} > x_{RP}$. If it is also the case that $x_{PP} < 1.5x_{RP}$, then the Spanish three-site preferences result. For example, suppose that $x_{PP_{Span}} = 1.2x_{RP}$. Then the costs associated with the three sites are: NP_1: $1.5x_{RP}$; NP_2: $2.2x_{RP}$; and NP_3: $1.2x_{RP}$; resulting in the desired (NP_3, NP_1, NP_2) preference ordering. Fig. 6(D) shows this case. Thus the proposed decay functions are consistent with the preference orderings that are observed in each language, as long as the values associated with x_{RP} and x_{PP} are constrained to be relatively close together (i.e., $x_{PP} = x_{RP} \pm .5x_{RP}$).

The theory we have proposed in this section combining Recency and Predicate Proximity is admittedly somewhat speculative, because it is based on some assumptions for which we do not yet have much independent evidence. Although particular values for the decay functions associated with Recency Preference and Predicate Proximity have been selected somewhat arbitrarily, the range of choices is constrained by the data available so far in the literature and in the current experiments. This has also allowed us to make the theory explicit, and in addition to accounting for the data currently available, it makes a variety of additional testable predictions, some of which are discussed below.

10. Sources of cross-linguistic preference differences

Although the present experiments provide evidence favoring a human parsing mechanism based on universal principles, the question remains about why cross-linguistic differences exist. That is, even the two-factor theory proposed here includes one parameter which varies across languages, namely the cost associated with Predicate Proximity, and it is useful to consider the source of this difference across languages. Three potential sources or explanations for cross-linguistic sentence-processing variation seem to be available (see also Frazier & Rayner, 1988, and Mazuka & Lust, 1990, for similar discussions).

First, processing preferences might be directly determined by parameters of Universal Grammar. On this account, a difference between the grammars of two languages causes the difference in their parsers, so that a particular set of linguistic parameter settings is expected to correlate perfectly across languages with whether the cost associated with Predicate Proximity is more or less than that associated with Recency. The second possible source of cross-linguistic parsing differences is an indirect relationship between preference factor costs and parameters of the grammar. In this case, although costs and parameter settings are correlated (though not necessarily as strongly as in a direct relationship), setting parameters of the grammar does not set parsing parameters. Instead, parameter settings in the grammar have

only the usual effect: Various constructions are allowed or disallowed. However, because different parameter settings license different sets of constructions, different languages will have different relative frequencies of various ambiguities and different relative frequencies of possible resolutions (attachments). Thus the source of cross-linguistic parsing differences is still cross-linguistic grammar differences, but the mechanism by which the parsing preferences are acquired is indirect and depends on the parser being sensitive to statistical patterns in the language's ambiguities. The third possible source of cross-linguistic parsing variation also requires a parser sensitive to the statistical ambiguity resolution patterns in a language, but it does not assume a close relationship between grammatical parameterization and parsing preference variation. Instead the parser is assumed to be parameterized independently of the grammar. The parser acquires whatever statistical biases are present in its input, and cross-linguistic variation in preferences may be simply a matter of historical accident. On this view, of course, no particular correlation is expected between grammatical and parsing parameters across languages.

C & M proposed two related sources for the variation in two-site RC attachment ambiguities in English and Spanish. The first is an explanation of the second type discussed above, in which a grammatical difference between the languages results in a statistical preference difference which the parser acquires: C & M (and Mitchell, Cuetos, & Zagar, 1990) suggested that the English–Spanish preference difference could be attributed to the grammatically specified difference in the permissibility of prenominal modifiers (adjectives in particular) in the two languages. They proposed that because the Spanish grammar forces adjectives to intervene between a noun and any of its prepositional or relative clause modifiers, NP attachment sites will tend to be farther away from the phrases which attach to them than in English, and thus relatively higher attachments will be more expected and less difficult in Spanish. However, Brysbaert (1993; see also Brysbaert & Mitchell, 1993) reports that high attachment is preferred in these same constructions in Dutch, which is like English in that adjectives precede the noun they modify, so this particular explanation for the relative advantage for high attachments in Spanish seems to fail.

In addition to the possibility of a grammatical parameterization account, C & M (and Mitchell, 1994) described a general version of the third explanation for parsing differences, that processing and grammatical cross-linguistic differences are not necessarily related in any particular way. They labelled their particular proposal the *linguistic tuning* hypothesis, according to which parsing preferences in ambiguous constructions are tuned by imitating the resolution patterns of similar ambiguities observed in the input. On this view, Recency (Late Closure) is a language-particular strategy, having nothing to do with built-in principles or computational mechanisms (e.g. memory limitations). Other attachment strategies, such as the Early Closure (high attachment) bias in Spanish RC attachments, are theoretically no less likely to occur.

The current data are compatible with this strong version of the linguistic tuning hypothesis. As stated, it predicts that statistical attachment preference biases in a language and the parsing preferences displayed by speakers of that language should match, and the data available are generally supportive of this prediction (see, for example, Gibson & Pearlmutter, 1994; Gibson & Loomis, 1994; Sedivy & Spivey-Knowlton, 1994; Juliano & Tanenhaus, 1994; Cuetos, Mitchell, & Corley, to appear; cf. Merlo, 1994). However, in order to derive predictions about when or whether statistical patterns and parsing preferences should differ, and in order to consider how preferences are acquired, more detail will be needed about which properties of the input the processor attends to for the purposes of tuning. For example, for the attachment ambiguities considered here, any of the following might be important: the category of the attaching phrase; the categories, number, and order of the potential attachment sites; and any other context intervening between the prospective sites. Whether a tuning algorithm considers these same properties important for other ambiguities also needs to be specified.

A weaker version of the linguistic tuning hypothesis is also available, however: As a basic claim about how the parser acquires preferences, linguistic tuning is a statement of the idea that preferences can be learned by counting how often an ambiguity is resolved with one interpretation versus another, and some form of this hypothesis would be required regardless of whether differences in the input arose by accident or as a result of grammatical parameterization, as long as grammatical parameters do not directly set preferences in the processor. The hypothesis in this form remains underspecified, but it leaves open the possibility of a relationship between the grammar and the parser as the source of variability across languages.

One potential explanation along these lines, which relies on this weaker version of linguistic tuning in the context of our Recency/Predicate Proximity theory, is that the average distance from the head of a predicate (verb) to its arguments (e.g., subject and object) in a language may determine the strength of Predicate Proximity in that language. The greater the average distance between a verb and its arguments, the more strongly the predicate needs to be initially activated in that language to permit the longer distance attachments. The more activated that the predicate is, the more the attachment to the predicate is preferred in an ambiguity, and the higher the cost associated with attaching to non-predicate sites. Thus the greater the average distance between a verb and its arguments in a language, the greater the cost of violating Predicate Proximity in that language.

Under this proposal, a language with rigid SVO word order like English will have a relatively weak Predicate Proximity strength, because the relatively low average distance from verbal heads to their arguments in English results in a low initial level of activation for English predicates. Thus Predicate Proximity is dominated by Recency in English. In Spanish, SVO is also a common word order, but this language allows other word orders like

VOS, in which the subject argument is relatively far from the predicate. Thus the strength of activation of the predicate in Spanish is more than that for English, resulting in a greater Predicate Proximity strength in Spanish.

At the moment, this explanation of the cross-linguistic attachment preference difference between English and Spanish is speculative because of the paucity of data from additional languages, but some of the predictions of this theory are clear. One prediction is that languages whose frequently occurring word orders include VOS, VSO, SOV or OSV will have relatively strong Predicate Proximity factors, resulting in a high preference in two-NP-site RC attachment ambiguities. Only languages with rigid word orders of SVO or OVS are predicted to have the low attachment preference in such ambiguities. Future work will be necessary to investigate these predictions.

11. Further predictions

Although the underlying source of the preference differences captured in the Recency/Predicate Proximity theory remains to be investigated, we have seen that the theory correctly accounts for the preference behavior observed in ambiguities involving two and three NP-attachment sites as well as two VP-attachment sites. An obvious additional test of this theory comes from attachment ambiguities involving more than three NP sites. Consider examples with four potential NP attachment sites:

(15) (a) NP_1 Prep NP_2 Prep NP_3 Prep NP_4 RC
(b) ?# the computer near the videotapes of the plays about the murders that was discussed on the TV
(c) # the computers near the videotape of the plays about the murders that was discussed on the TV
(d) # the computers near the videotapes of the play about the murders that was discussed on the TV
(e) the computers near the videotapes of the plays about the murder that was discussed on the TV

Intuitions suggest that attachment to either of the intermediate sites NP_2 or NP_3 is very difficult ((15c) and (15d)), as predicted by the theory. Furthermore, attachment to the most recent site NP_4 (15e) is correctly predicted to be acceptable. Finally, attachment to the least recent site NP_1 (15b) is correctly predicted to be degraded compared to the three-site case, because the least recent site is now more distant from the potential modifier. Moreover, Spanish versions of these examples result in the same general preferences.

The Recency/Predicate Proximity theory also seems to make appropriate predictions in examples of the form in (16):[9]

[9] Thanks to Don Mitchell for bringing these examples to our attention.

(16) (a) NP_1 Wh-rel Verb NP_2 RC
(b) Pedro miraba los libros que pertenecian a la chica que . . .
"Peter was looking at the books which belonged to the girl who/which . . ."
(c) # Peter looked at the books that were sitting on the table that have 300 pages.

These examples contain two prospective NP attachment sites, but unlike the examples discussed earlier, a predicate phrase intervenes, so that Predicate Proximity does not favor attachment to either site. Thus Recency Preference is predicted to dominate in both English and Spanish, resulting in a strong preference to attach the RC to NP_2 (*la chica* in (16b), *the table* in (16c)). Mitchell and Cuetos (1991b) report such a preference in Spanish for examples like (16b) (but cf. Cuetos et al., to appear). An NP_2 attachment preference appears to be present in English, as evidenced by the garden-path effect in (16c), in which number agreement forces attachment of the RC to NP_1.

Note that this Spanish result has an interesting consequence for the form of possible tuning theories. In particular, the fact that it is easier to attach to the more recent NP site in Spanish examples like (16b) implies that, for a tuning theory to be correct, people must maintain separate frequency counts for the different contexts in which an ambiguity occurs. This is because comprehenders prefer high attachment in some contexts (e.g., when only a preposition separates the two sites), but they prefer low attachment in others (e.g., when a clause intervenes).

A further prediction of the Recency/Predicate Proximity theory is that the preference ordering among attachments to prospective VP sites goes from most to least recent:[10] Predicate Proximity has no effect on competing VP sites, so Recency Preference dominates. Thus the attachment preference ordering for the adverbial *yesterday* in (17), from Frazier & Fodor (1978), is predicted to be VP_3, VP_2, VP_1:

(17) Joe [$_{VP_1}$ said that Martha [$_{VP_2}$ claimed that 1984 [$_{VP_3}$ will be blissful yesterday.

In (17), *yesterday* clearly prefers to attach to the most recent VP, headed by *will*, but a tense clash blocks this possibility. As observed by Frazier and Fodor (1978, p. 301), the preference ranking of the other two sites is not clear. Intuitions indicate that both attachments are difficult to make, as predicted by the Recency/Predicate Proximity theory. Gordon (1982; see also Langendoen & Langsam, 1987) reports intuitions favoring a high attachment over a middle attachment in similar constructions, but Gibson and Loomis (1994) provide corpus data suggesting that the opposite pattern

[10] Thanks to Lyn Frazier for bringing this prediction to our attention.

may obtain: Middle site attachments were more frequent than high attachments. Future on-line studies will allow us to test this hypothesis more thoroughly.

12. Conclusions

Although C & M's data demonstrate a preference difference between English and Spanish, evaluation of the processing of similar constructions in each language does not favor abandoning Recency Preference as a universal principle of the human sentence processing mechanism. Rather, the evidence supports the existence of such a principle, and the non-monotonic preference ordering found in both English and Spanish argues in favor of the existence of a second factor as well. The nature of this second factor is not precisely known, but we propose Predicate Proximity, which favors attachments as close as possible to a predicate phrase. We argue that Predicate Proximity's strength varies across languages, but that Recency is fixed. This combination of Recency and Predicate Proximity predicts a variety of results in the literature and in the current experiments, and it makes strong testable predictions about additional patterns of data in other constructions. Finally, although the theory of parsing variation that we have proposed is in terms of parametric variation in the human sentence processor, nothing rules out the possibility that the variation can be explained in terms of parametric differences between the grammars of the two languages. Whether a connection between the grammars of the two languages and the parsing preferences in each can be discovered is a question for future research.

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Appendix A: Experimental items for Experiment 1

The items in Experiment 1 are listed below with their English translations. Because singular versus plural forms differed by more than just number-marking on the nouns, all three conditions (in the order high, middle, low attachment) are shown for the first two items (one plural relative clause, one singular). For the remainder, only the low attachment condition is shown with its English translation. Items marked wtih an asterisk were excluded from the supplemental analyses conducted in Experiment 1. (See the Materials and Results sections of Experiment 1.) The numbers in parentheses following each item are, respectively, (1) the percentage of subjects from the Experiment 1 written survey who indicated that the second PP attached to the second NP for that item; (2–4) the percentage of trials judged ungrammatical in the disambiguating region for the high, middle, and low attachment conditions; and (5–7) the mean residual reading time (ms/word) of items judged grammatical in the disambiguating region for the high, middle, and low attachment conditions.

1a. los árboles junto al gato con el gatito que fueron admirados por el niño
1b. el árbol junto a los gatos con el gatito que fueron admirados por el niño
1c. el árbol junto al gato con los gatitos que fueron admirados por el niño
1d. the tree next to the cat with the kittens that were admired by the child (95, 0, 38, 0, 192, −124, −109)

2a. el edificio cerca de los perros con los fósiles que fue claramente elogiado
2b. los edificios cerca del perro con los fósiles que fue claramente elogiado
2c. los edificios cerca de los perros con el fósil que fue claramente elogiado
2d. the buildings near the dogs with the fossil that was clearly praised (85, 57, 38, 13, −34, 2466, −216)

3a. el tabique cerca del pollo con los gallos que fueron pateados por el granjero
3b. the brick near the chicken with the roosters that were kicked by the farmer (100, 39, 13, 13, −195, 597, −3)

4a. los avisos arriba de los memos para el jefe que fue ignorado por los empleados
4b. the notices above the memos for the boss who was ignored by the employees (90, 40, 50, 25, 333, 299, 370)

5a. el anuncio del legado a los museos que impresionaron mucho al público
5b. the announcement of the legacy to the museums that much impressed the public (90, 0, 13, 0, 308, 325, −530)

6a. las revistas junto a las cartas para la acusada que fue consultada en el juicio
6b. the magazines near the letters to the defendant that was consulted in the trial (100, 43, 63, 0, 1419, 88, −12)

*7a. la nota del libro acerca de las teorías que resultaron dificiles de comprender
*7b. the note about the book about the theories that resulted in difficulty in understanding (65, 50, 25, 13, −208, 22, −620)

*8a. las revistas con las fotos de la película que fue criticada en T.V.
*8b. the magazines with the pictures of the movie that was criticized on TV (75, 63, 63, 0, 286, 1493, 69)

9a. el comentario del libro acerca de los asesinatos que causaron furor
9b the commentary of the book about the murders that caused a furor (85, 0, 63, 13, 401, 1545, 208)

10a. las lámparas cerca de las pinturas de la casa que fue dañada en la inundación
10b. the lamps near the paintings of the house that was damaged in the flood (80, 38, 71, 13, 215, 959, 28)

11a. el escudo cerca del esquema de los edificios que fueron terminados el lunes
11b. the coat of arms near the plan of the buildings that were finished on Monday (85, 25, 38, 13, 65, 613, −225)

*12a. los muebles debajo de los modelos del aparato que fue comprado en la subasta
*12b. the furniture under the models of the appliance that was bought at the auction (20, 50, 50, 25, 598, 686, 3)

13a. el listón en el papalote arriba de los árboles que ardieron por accidente

13b. the ribbon in the kite above the trees that were burned by accident (95, 13, 17, 13, 16, 710, −57)

*14a. los libros detrás de los tapetes debajo de la mesa que desapareció en el viaje
*14b. the books behind the rugs under the table that disappeared on the trip (75, 38, 71, 0, −84, 744, −213)

15a. la señal cerca del charco debajo de los carros que causaron problemas
15b. the signal near the puddle under the cars that caused problems (85, 25, 63, 13, 303, 1184, −327)

16a. los gabinetes detrás de los platones para el perro que fue comprado en México
16b. the cabinets behind the plates for the dog that was bought in Mexico (100, 38, 63, 0, 698, −119, 34)

17a. el paquete detrás del juguete para los gatitos que fueron olvidados el martes
17b. the package behind the toy for the kittens that were forgotten on Tuesday (85, 0, 50, 0, 19, 519, −266)

18a. los lagos cerca de los senderos para el caballo que fue filmado en el documental
18b. the lakes near the paths for the horse that was filmed in the documentary (80, 13, 25, 13, 155, 630, 244)

Appendix B: Subject means for Experiment 1

Table B.1
Experiment 1 ungrammaticality judgements and residual reading times by subject in the disambiguating region

Subject	Country of origin	Ungrammaticality Judgement percentage			Residual reading Time (ms/word)		
		High	Middle	Low	High	Middle	Low
1	Mexico	17	40	0	576	316	−230
2	Mexico	67	83	17	−45	959	207
3	Mexico	17	50	0	361	944	−39
4	El Salvador	33	33	0	3	284	−216
5	Guatemala	25	40	17	277	467	83
6	Mexico	33	100	0	1330	–	234
7	Spain	0	83	17	453	332	−245
8	Mexico	50	83	50	256	1279	19
9	Mexico	17	0	0	−12	1196	−720
10	Mexico	0	40	20	−149	−340	−51

Table B.1 (*Continued*)

11	Mexico	20	50	0	23	180	−252
12	Peru	33	33	33	953	−229	407
13	Spain	0	33	17	210	1180	328
14	Puerto Rico	33	33	17	142	663	−269
15	USA	100	67	17	–	308	60
16	Chile	40	50	0	49	544	−212
17	Venezuela	20	50	17	91	401	−150
18	Argentina	0	17	0	0	479	294
19	Puerto Rico	17	0	0	−321	471	−357
20	Puerto Rico	100	50	0	–	333	−36
21	Puerto Rico	50	33	0	432	977	−592
22	Puerto Rico	0	0	0	227	1402	171
23	Puerto Rico	0	33	0	645	683	6
24	Spain	17	67	0	153	3279	−89

Appendix C: Experimental items for Experiment 2

The items used in Experiment 2 are listed below. The three conditions were created by changing the number of two of the first three NPs to mismatch the number of the verb in the relative clause. The number in parentheses following the items is the percentage of subjects from the Experiment 2 written survey who indicated that the second PP attached to the second NP for that item.

1. the cushion beside the cat with the kitten that was in the nearby park (93)
2. the frisbees near the dogs with the carcasses that were found in the park (100)
3. the brick by the hen with the rooster that was kicked by the farmer (100)
4. the signs above the memos to the committees that were ignored by the workers (93)
5. the photo beside the letter to the company that was consulted in the lawsuit (100)
6. the plaques with the gifts to the museums that were very large and impressive (93)
7. the review of the book about the trial that was very long and complex (100)
8. the newspaper with the articles about the movies that were criticized on the TV (100)
9. the videotape of the play about the murder that was discussed for many weeks (100)
10. the lamps near the paintings of the houses that were damaged in the flood (100)
11. the chair below the drawing of the bed that was purchased at the auction (100)

12. the computers near the models of the buildings that were destroyed in the fire (100)
13. the design on the kite above the house that was small but very beautiful (100)
14. the sofas beside the rugs under the tables that were dropped by the movers (100)
15. the road-sign near the puddle below the car that was by the street corner (100)
16. the chairs by the bowls for the dogs that were next to the door (100)
17. the hat beside the toy for the puppy that was received as a gift (100)
18. the ponds near the barns for the horses that were visible in the photograph (86)

Appendix D: Raw reading times

Table D.1
Experiment 1 raw reading times (ms/word)

Attachment	Region						
	1	2	3	4	5	6	7
High	713	897	960	891	1403	635	1282
Middle	742	847	1216	872	1935	570	1916
Low	793	829	984	818	1098	609	1704

Table D.2
Experiment 2 raw reading times (ms/word)

Attachment	Region						
	1	2	3	4	5	6	7
High	399	454	610	618	870	451	783
Middle	498	446	534	695	1037	515	775
Low	406	466	543	844	785	453	757

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