Does number interference occur during sentence processing?

Katja Suckow (k.suckow@dundee.ac.uk)
School of Psychology, The University of Dundee
Dundee, DD1 4HN, UK

Roger P.G. van Gompel (r.p.g.vangompel@dundee.ac.uk)
School of Psychology, The University of Dundee
Dundee, DD1 4HN, UK

Abstract

Models of interference in sentence processing claim that object relative clauses are harder to process than subject relatives due to interference between the subject and object noun phrase. The interference effect for object relatives at the verb should be more pronounced when the two noun phrases retrieved from memory are similar. To test this, two eye tracking experiments manipulated whether the number feature of the noun phrases (singular or plural) was either the same or different. Both experiments showed the well-known relative clause effect. However, in Experiment 1 the effect of number congruency was in the opposite direction from that predicted by interference. Experiment 2 showed the interaction predicted by similarity based interference at sentence wrap-up, but because this interaction was observed later than the relative clause effect and only occurred in Experiment 2, it suggests that retrieval interference due to cue overlap is a weak effect that might be the result of a checking procedure in syntactically complex sentences.

Keywords: sentence processing; similarity based interference; working memory.

Introduction

There is much evidence that object relative clauses such as (1) are more difficult to understand than subject relative clauses such as (2) (e.g., King & Just, 1991). It is generally believed that this difficulty stems from limitations in working memory (Gibson, 1998; Gordon, Hendrick, & Johnson, 2001; Lewis, 1996; King & Just, 1991).

1. The banker that the accountant helps counted the money.
2. The banker that helps the accountant counted the money.

For example, King and Just (1991) found that readers with low working memory experienced more difficulty with object than subject relatives. More recently, Lewis (1996) and Van Dyke and Lewis (2003) have proposed an account that assumes that working memory demands increase when two similar linguistic items (e.g., two noun phrases) need to be retrieved simultaneously, slowing down sentence processing. Lewis and Vasishth (2005) proposed an ACT-R account that explains how the processing of subject and object relatives is affected by the similarity of the noun phrases.

Consistent with this, Gordon, Hendrick, and Johnson (2001) found that object relatives are easier to process when the embedded noun phrase is a name (*Joe*) and the head noun a definite noun phrase (*the barber*) compared to when both are definite noun phrases.

However, Van Dyke and Lewis's (2003) and Lewis and Vasishth's (2005) similarity based interference account claims that interference is not just due to similarity in the type of noun phrase but also due to similarity of other features. Van Dyke and Lewis (2003) described how the degree of overlap between a retrieval cue and two similar linguistic items affects the retrieval of these items. Two items (the subject and object noun phrase) have to be retained in memory in object relatives until they can be integrated with the verb. At the point of integration at the verb, retrieval cues are used to identify the target item from memory. When items in memory share retrieval cues it is difficult to identify this target. Thus, a similarity based interference effect arises for items with retrieval cue similarity. The account of Lewis and Vasishth (2005) predicts that a similarity based interference effect arises at the embedded verb in object relatives because two items have to be retrieved from memory instead of only one for subject relatives. This interference effect at the verb should be larger when these two items share retrieval cues.

For example, in object relatives like (1) the two subject and object noun phrases (*the accountant* and *the banker*) need to be simultaneously retrieved at the embedded verb (*helps*). On the other hand, only one noun phrase (*the banker*) needs to be accessed at the verb (*helps*) in subject relatives like (2). The similarity based interference effect that occurs with object relatives should be particularly strong when the two noun phrases that need to be retrieved are similar. Thus, because both the difficulty of object relatives and the difficulty of retrieving items that share retrieval cues are effects of interference at the embedded verb, they should occur at the same time.

Van Dyke and Lewis (2003) claim that number information is one of the retrieval cues for identifying a target. In relative clauses, congruency in the number feature of the subject and object noun phrase may have a strong effect on interference, because the subject has to agree in number with the verb: The retrieval cues of the target item (the subject noun phrase) have to match the number cue of the search probe (the verb). If the object has the same number as the subject and therefore also matches the number feature of the verb, this should result in interference when the subject and object are integrated with the verb. Thus, according to the retrieval cue based interference account, retrieval difficulty at the verb (e.g., *helps*) in object relatives should be more pronounced when the two noun phrases in memory share the same number than when they do not.

To test this account the current study investigated whether object relatives are harder to process when the two noun phrases in memory share the same number retrieval cue than when the number retrieval cues are different.

In sum, similarity-based interference models make the following three predictions for the experiments: (1) object relatives should be harder to process than subject relatives; (2) object relatives should be particularly hard to process when the subject and object noun phrase have the same number; (3) because both the relative clause and number effect predicted in (1) and (2) are due to interference when the noun phrases are retrieved at the verb (*helps*), the effects should occur simultaneously.

Experiment 1

We conducted an eye movement reading experiment that contrasted sentences containing an embedded object relative clause with an embedded subject relative. The two initial noun phrases were either the same or different in number.

Participants

Experiment 1 had 40 participants. All participants were non-dyslexic English native speakers and members of Dundee University. They received course credits in exchange for their participation. Participant treatment was in accordance with the ethical standards. The study was approved by the ethics committee at the University of Dundee.

Materials and Design

Table 1 shows a sample item in all conditions and the areas of interest for the eye movement analyses. Thirty-two critical sentences were created in eight different conditions. The experiment had a 2x2x2 design with the factors (1) relative clause type (subject vs. object relative), (2) number congruency (subject and object noun phrases same vs. different in number) and (3) counterbalancing of number information (NP2 singular vs. plural). Because the number counterbalancing variable was not of theoretical interest, we collapsed across it in the analyses.

Eight lists were created. Each list contained 32 critical items, with four items in each of the eight conditions. One condition of each item appeared in each list. Five participants were randomly assigned to each list. In addition to the 32 experimental items, 85 filler sentences were presented and yes/no comprehension questions were presented after each sentence.

Apparatus and Procedure

The experiment was carried out using the Experiment Builder Program from SR Research on a PC. An Eyelink 1000 Desktop Mount recorded participants eye movements at a 1000Hz sampling rate. The experiment was controlled by the Experiment Builder software on a separate PC. DataViewer (SR research) as well as R (R 2.13.1 foundation for statistical computing) were used for data analysis.

Results

Three different eye-tracking measures were analysed for each region. *First pass duration* is the duration from entering an area of interest for the first time until leaving it into any direction. This measure does not include fixations that occurred after readers had fixated a subsequent region (i.e. the region of interest was skipped). *Regression path duration* is the sum of fixations from entering the area from the left for the first time until the first fixation outside to the right of the region occurs. That means that there should be no fixation on a right-bound region before entering the region in regression path duration. *Total reading time* is the sum of all fixations in an interest area.

Figure 1 shows regression path duration and total reading time in the different interest areas for Experiment 1. Since there were no differences between the conditions in first pass duration, we omit the plot for this measure here.

We conducted both analyses of variance with subjects (F1) and items (F2) as a random variable. Relative clause type and number congruency were treated as within subject and within item fixed variables. In addition, subject group was a fixed between subject variable in the by-subject analyses and item group a between item variable in the by-item analyses.

In the following results section we only report analyses of the variables that showed significant effects by subjects or by items.

Critical Region (*helps the accountant*). The analyses of variance showed a main effect of relative clause for regression path duration: $F1(1,32) = 33.03$, $p < .005$; $F2(1,24) = 35.09$, $p < .01$. Reading times for object relatives were longer than for subject relatives. Total reading time at the critical region also showed an effect of relative clause: $F(1,32) = 30.95$, $p < .01$; $F2(1,24) = 31.86$, $p < .01$, indicating that object relatives took longer to read than subject relatives.

Spillover 1 Region (*counted*). Analyses of variance showed a main effect of relative clause type for the regression path duration measure, $F1(1,32) = 32.68$, $p < .01$; $F2(1,24) = 57.42$, $p < .01$. Mean reading times for object relatives were longer than for subject relatives. The analyses also showed a main effect of number congruency for regression path duration: $F1(1,32) = 9.75$, $p < .01$; $F2(1,24) = 14.22$, $p < .01$. Reading times were longer when the noun phrases were different than the same in number. The analyses of regression path duration also showed an interaction effect between relative clause type and number congruency, $F1(1,32) = 5.80$, $p < .05$; $F1(1,24) = 5.40$, $p < .05$. Simple effect analyses for the object relatives showed that they took longer to read when the noun phrases were different than the same in number: $F1(1,32) = 8.94$, $p < .01$; $F2(1,24) = 12.22$, $p < .01$. In contrast, simple effect analyses for subject relatives showed that there was no difference between the same and different conditions ($Fs < 1$). For the total reading time measure, there was a main effect of relative clause type, $F1(1,32) = 25.11$, $p < .01$; $F2(1,24) = 15.87$, $p < .01$. Reading times for object relatives were longer than for the subject relatives. In addi-

Table 1: Example material and areas of interest for Experiment 1

	critical region	**spillover 1**	**spillover 2**	**wrap-up**
Subject relative/same number				
The banker that	helps the accountant	counted	the money	several times.
The bankers that	help the accountants	counted	the money	several times.
Object relative/same number				
The banker that	the accountant helps	counted	the money	several times.
The bankers that	the accountants helps	counted	the money	several times.
Subject relative/different number				
The bankers that	help the accountant	counted	the money	several times.
The banker that	helps the accountants	counted	the money	several times.
Object relative/different number				
The bankers that	the accountant helps	counted	the money	several times.
The banker that	the accountants help	counted	the money	several times.

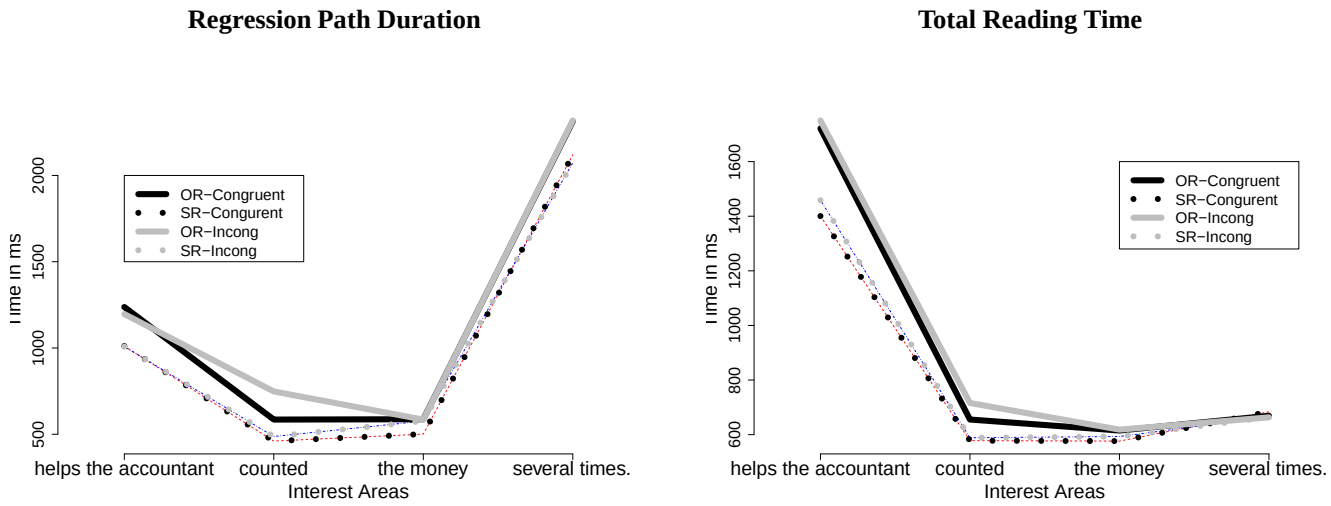

Figure 1: Regression Path and Total Reading Times in Experiment 1

tion, the analyses of the total reading time measure indicated a marginal effect of number congruency, F1(1,32) = 3.41, p = .07, F2(1,24) = 2.96, p = .09, with the different condition being read slower than the same condition.

Spillover 2 Region (*the money*). There were no effects in the spillover 2 region.

Wrap-up Region (*several times*). An analysis of variance of the regression path duration measure showed a main effect of relative clause type in the wrap-up region that was significant by subjects, F1(1,32) = 7.01, $p < .05$; but not by items, F2(1,24) = 4.18, p = .05, with object relatives being slower than subject relatives.

Discussion

Experiment 1 showed that object relatives were harder to process than subject relative clauses in regression path and total reading times for the critical region (*help the accountant*) and the spillover 1 region (*counted*). There was an effect of number congruency in total reading times in the spillover 1 region, with the different number conditions being harder than the same number conditions. A similar effect was also found in regression path duration in the same region, though it only occurred with object relatives. The direction of these congruency effects is opposite to that predicted by similarity based interference models, which claim that the same number condition should be more difficult. The reversed effect may be due to priming of number information from the first to the second noun. Most important, this suggests that similarity-based interference due to number congruency does not appear to have a strong effect on the processing of subject or object-relative clauses.

Experiment 2

Experiment 1 showed an effect of relative clause type but no effect of number interference. It is possible that number interference does occur, but that in contrast to what is predicted by the similarity based interference account, it is a later effect. Number interference may occur after initial syntactic analysis of the relative clause, when readers check whether the verb also agrees with noun phrases other than the subject. This sort of mechanism is similar to the account put forward by Sturt (2003) for a delayed effect of *unaccessible antecedents* in anaphor resolution. Sturt (2003) argues that processes associated with this effect are not part of initial anaphor interpretation but later procedures like recovery and sentence wrap-up.

Because the region after the relative clause was relatively long in Experiment 1, the retrieval interference effect due to cue overlap may be spread out over the region and difficult to detect. Therefore, the final region after the relative clause was shortened in Experiment 2. The same materials as in Experiment 1 were tested without the final region (e.g., *several times*).

Participants

The number of participants and the selection criteria for these participants were the same as in Experiment 1.

Materials and Design

The materials in this experiment were the same as in Experiment (1) with one difference. Instead of two spillover regions and a wrap-up region after the critical region, there was only one spillover region followed by a sentence wrap-up region. Table 2 shows a sample item with the interest areas for this experiment.

Apparatus and Procedure

The procedure and the apparatus were the same as in Experiment 1.

Results

Figure 2 shows the plots for first pass duration and total reading time and Figure **??** the plot for regression path duration in the different interest areas. We analysed the results from first pass duration, regression path duration and total reading time in the same way as in Experiment 1.

Critical Region (*helps the accountant*). In regression path duration, we observed a main effect of relative clause type F1(1,32) = 17.81, $p < .01$; F2(1,24) = 16.91, $p < .01$. Object relatives had longer reading times than subject relatives. The total reading time measure also showed a main effect of relative clause type, F1(1,32) = 46.07, $p < .01$; F2(1,24) = 31.80, $p < .01$. Reading times for object relatives were longer than for subject relatives.

Spillover Region (*counted*). First pass duration showed a main effect of relative clause, F1(1,32) = 8.95, $p < .01$; F2(1,24) = 8.65, $p < .01$: Object relatives took longer than subject relatives. In regression path duration, there was an effect of relative clause type that was significant by subjects F1(1,32) = 6.23, $p < .05$ but marginal by items F2(1,24) = 3.81, p = .06. Analyses of total reading time for this region showed a significant main effect of relative clause F1(1,32) = 39.00, $p < .01$; F2(1,24) = 26.94, $p < .01$. Mean reading times for object relatives were longer than for subject relatives.

Sentence Wrap-Up region (*the money.*). In first pass duration, there was a marginal effect of relative clause by subjects: F1(1,32) = 3.41, $p < .10$ but no effect by items F2(1,24) = 1.97. There was also an effect of number congruency by subjects F1(1,32) = 4.42, $p < .05$ but not by items F2(1,24) = 2.51, $p < .15$, with a longer first pass duration when the noun phrases shared the same number cue than when they did not. Most importantly, there was an interaction between relative clause type and number congruency in first pass duration F1(1,32) = 4.10, p = .05; and F2(1,24) = 4.91, $p < .05$. Simple effect analyses for object relative clauses showed that they had longer reading times when the noun phrases were the same than different in number: F1(1,32) = 6.20, $p < .05$;

Table 2: Areas of interest for the materials used in Experiment 2.

	critical	spillover	wrap-up
Subject relative			
The banker(s) that	help(s) the accountant(s)	counted	the money.
Object relative			
The banker(s) that	the accountant(s) help(s)	counted	the money.

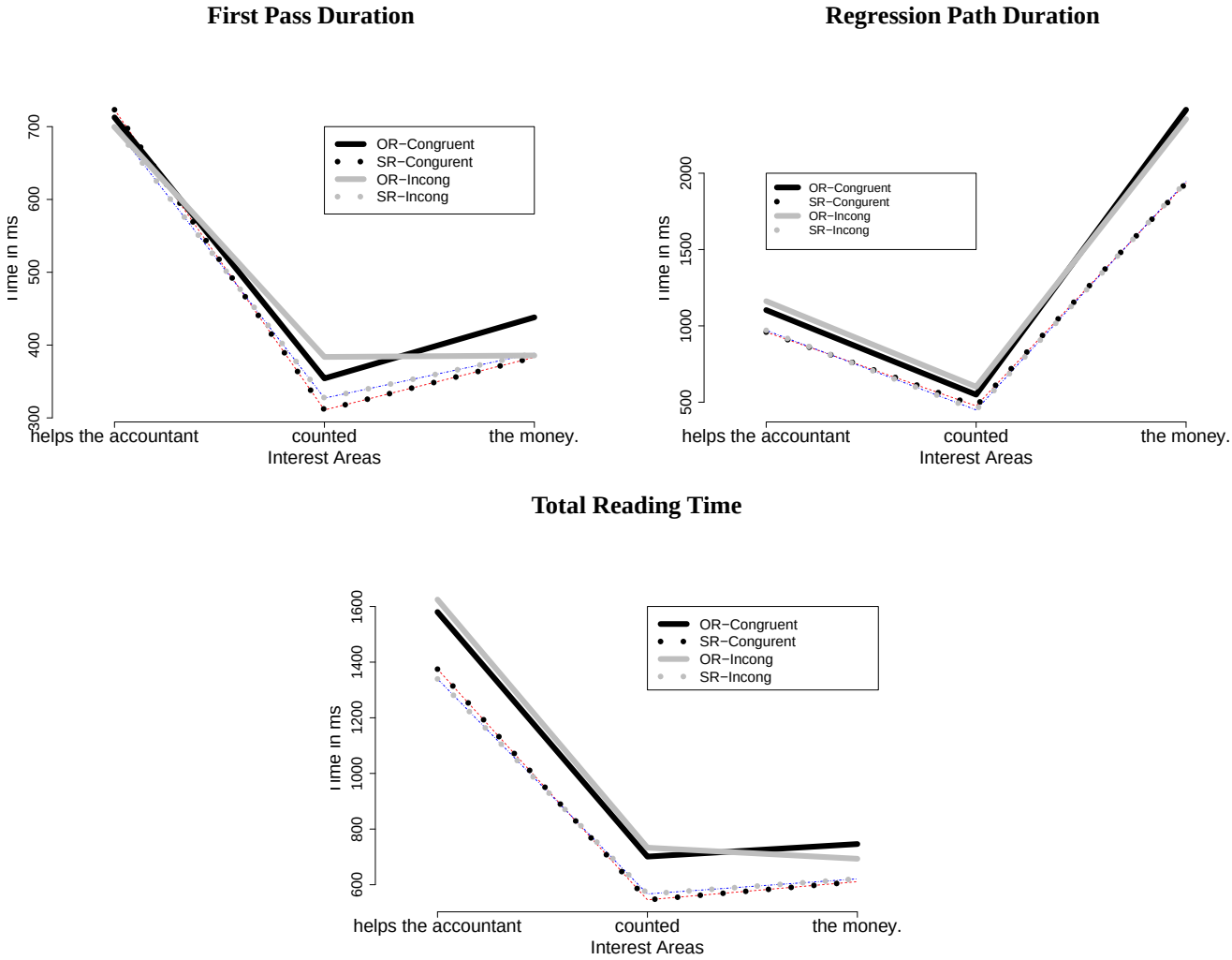

Figure 2: First Pass, Regression Path and Total Reading Times in Experiment 2

F2(1,24) = 5.97, $p < .05$. Simple effect analyses for subject relatives showed that there was no difference between the same and different noun phrases (Fs < 1). The analyses of regression path duration showed a main effect of relative clause type F1(1,32) = 22.76, $p < .01$; F2(1,24) = 10.70, $p < .01$. Object relatives had longer reading times than subject relatives. In the total reading time measure, we observed an effect of relative clause F1(1,32) = 18.63, $p < .01$; F2(1,24) = 16.88, $p < .01$. Object relatives took longer to read than subject relatives.

Discussion

Object relatives were more difficult than subject relatives relatives in regression path duration and total reading time (in all three regions) and in first pass duration (in the spillover region). Most interesting, there was an interaction between relative clause type and number congruency in first pass time for the final wrap-up region (*the money*): object relatives were more difficult when the noun phrases had the same number than a different number, whereas there was no difference for subject relatives. Thus, the number congruency effect appeared later than the object relative difficulty. This is surprising given the predictions made by the interference models mentioned in the introduction. Both the relative clause effect and the number congruency effect are claimed to be due to memory interference that occurs when the subject and object noun phrase are retrieved at the embedded verb. Thus, the difficulty with object relatives and the number interference effect should have occurred in the same regions and measures.

General Discussion and Conclusion

Both Experiments 1 and 2 showed that object relatives are more difficult than subject relatives, which is in line with previous studies (Gibson, 1998; Gordon et al., 2001; Lewis, 1996; King & Just, 1991). This effect was found in the relative clause region (in regression path and total reading time in Experiment 1 and Experiment 2). However, neither Experiment 1 nor Experiment 2 found evidence for number interference in early measures. In Experiment 1, sentences were easier when the nouns had the same number than when their number was different. This is contrary to the predictions of similarity based interference accounts. In Experiment 2, there was evidence for number interference in object relatives, but this occurred during later processing, in the final region.

The observed delay of the number congruency effect in comparison to the relative clause effect in Experiment 2 is not consistent with memory interference models. They claim that difficulty with object relatives (compared to subject relatives) is due to interference that occurs when the subject and object noun phrase are retrieved at the embedded verb. Therefore, they predict that the number congruency effect should occur in the relative clause region, simultaneously with the slowdown with object relative clauses.

The results suggest that the interference effect is a later process that does not arise during structure building. One possibility is that it is due to a checking process that occurs when a sentence is structurally complex as is the case with object relatives. Because this checking process occurs after the relative clause has been constructed, it may have been spread out over the regions following the relative clause in Experiment 1. Because the part of the sentence following the relative clause was long in Experiment 1, it may have been impossible to detect the later interference effect. When the main clause predicate was shortened in Experiment 2, we did find evidence for later number interference.

Together, the experiments suggest that the effect of retrieval cue overlap is weak. In addition to being weak, it occurs later than the relative clause effect, indicating that the initial difficulty with object relatives is not due to interference. These findings are more in agreement with theories that assume that processing difficulty with object relatives is not due to interference, such as the locality account (Gibson, 1998), experienced-based accounts (e.g., Wells, Christiansen, Rae, Acheson, & MacDonald, 2009) and expectation models (Levy, 2007; Hale, 2006).

Acknowledgements

The research presented here was supported by the ESRC (Economic and Social Research Council).

References

Gibson, E. (1998). Linguistic complexity: Locality of syntactic dependencies. *Cognition, 68*, 1-76.

Gordon, P. C., Hendrick, R., & Johnson, M. (2001). Memory interference during language processing. *Journal of Experimental Psychology: Learning, Memory, and Cognition, 27*(6), 1411-1423.

Hale, J. (2006). Uncertainty about the rest of the sentence. *Cognitive Science, 30*(4), 609-642.

King, J., & Just, M. A. (1991). Individual differences in syntactic processing: The role of working memory. *Journal of Memory and Language, 30*, 580-602.

Levy, R. (2007). Expectation-based syntactic comprehension. *Cognition, 106*(3), 1126-1177.

Lewis, R. L. (1996). Interference in short-term memory: The magical number two (or three) in sentence processing. *Journal of Psycholinguistic Research, 25*(1), 93-115.

Lewis, R. L., & Vasishth, S. (2005). An activation-based model of sentence processing as skilled memory retrieval. *Cognitive Science, 29*, 375-419.

Sturt, P. (2003). The time-course of the application of binding constraints in reference resolution. *Journal of Memory and Language, 48*, 542-562.

Van Dyke, J., & Lewis, R. L. (2003). Distinguishing effects of structure and decay on attachment and repair: A cue-based parsing account of recovery from misanalyzed ambiguities. *Journal of Memory and Language, 49*, 285-316.

Wells, J. B., Christiansen, M. H., Rae, D. S., Acheson, D. J., & MacDonald, M. C. (2009). Experience and sentence processing: Statistical learning and relative clause comprehension. *Cognitive Psychology, 58*, 250-271.