Regressive eye movements and sentence parsing: On the use of regression-contingent analyses

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Altmann, Garnham, and Dennis (1992) recently advocated the use of a regression-contingent analysis in eye movement studies dealing with parsing of sentences containing temporary structural ambiguities. Using experimental sentences preceded by referentially supportive contexts, they demonstrated a different pattern of results when regressive eye movements were eliminated from the data set than when regressions were included. The regression-contingent analysis that they used involves an implicit assumption that regressive eye movements are a necessary consequence of subjects' being garden pathed. We report some data which demonstrate that garden path effects are sometimes even stronger in the absence of regressions and, thus, argue that readers can be garden pathed without making regressions.

The issue of how contextual information influences sentence parsing has become very important in the debate concerning the extent to which the human sentence-processing mechanism is modular (Fodor, 1983; Forster, 1979). A considerable amount of data now favors what has been referred to as the *garden path model* (Frazier, 1979; Frazier & Rayner, 1982). These data suggest that initial parsing decisions are not influenced by within-sentence pragmatic information (Perfetti, Beverly, Bell, Rodgers, & Faux, 1987; Rayner, Carlson, & Frazier, 1983), by prior contextual information (Ferreira & Clifton, 1986; Mitchell, Corley, & Garnham, 1992; Rayner, Garrod, & Perfetti, 1992), or by syntactic subcategorization properties of the main verb in a sentence (Ferreira & Henderson, 1990; Mitchell, 1989). According to the garden path model, initial parsing decisions are based on syntactic knowledge. Both semantic and pragmatic information are used to interpret the resulting structure, and, in cases of garden paths, they help guide reanalysis processes.

In opposition to the garden path model, *interactive models* (which have taken more than one form) are based on the premise that a number of sources of information are capable of influencing parsing decisions. Taraban and McClelland (1988, 1990) argued in favor of an unrestricted interactive mechanism in which all possible sources of information are capable of influencing initial parsing decisions. Others (Altmann, 1988; Altmann & Steedman, 1988; Crain & Steedman, 1985; Perfetti, 1990) have proposed weakly interactive models in which syntactic biases

are important, but in which semantic and pragmatic information can (and frequently do) provide the basis for choosing among syntactically proposed alternatives. There are now also considerable data (Altmann, 1988; Altmann & Steedman, 1988; Trueswell, Tanenhaus, & Kello, 1993) that are consistent with interactive models.

Altmann, Garnham, and Dennis (1992) recently reported two experiments dealing with the influence of referential contexts on sentence parsing. Their paper is important for two reasons. First, unlike the findings of most studies in which it has been demonstrated that pragmatic or contextual information can influence initial parsing decisions, Altmann et al.'s (1992) results are based on eye movement data. The studies most frequently cited as supporting the view that contextual factors are vital in determining initial parsing decisions have involved the use of the self-paced reading paradigm (see Altmann, 1988; Altmann & Steedman, 1988; Taraban & McClelland, 1988). Self-paced reading provides only one measure per segment of text, whereas the eye movement technique allows the experimenter to differentiate, for example, between first-pass and total reading time (which includes rereading time resulting from regressive eye movements). In contrast to the results of most reported eye movement studies, Altmann et al. (1992) found evidence that favors the contextual override of initial parsing decisions.¹

The second reason why Altmann et al.'s (1992) article is important is that they introduced a *regression-contingent analysis* of first-pass reading time. In this analysis, first-pass reading times for target sentences were divided into trials in which regressions were made and those in which no regressions were made. Altmann et al. claimed that analyzing the two types of trials separately led to very different conclusions for sentences read in supportive contexts. In particular, they argued that, because regression-contingent analyses were not previously performed, prior studies in which eye movement data have been used to investigate the first pass effects of nonsyntactic factors (e.g.,

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Ferreira & Clifton, 1986; Rayner et al., 1983) may have failed to yield override effects "simply because *noncontingent* first-pass reading times can hide the disambiguating effects of these factors" (Altmann et al., 1992, p. 704).

In this note, we focus mainly on the issue of using regression-contingent analyses to investigate parsing strategies. Later, we will return to the issue of contextual override of initial parsing decisions. Our interest in regression-contingent analyses is primarily methodological, but we argue that there are also theoretical implications in adopting such a procedure. We also present some data which demonstrate that Altmann et al.'s (1992) conclusions about when regressions occur in sentence parsing are not generalizable.

In Altmann et al.'s (1992) study, subjects read short passages of text as their eye movements were recorded. The passages contained target sentences such as the following examples:

1. He told the woman that he'd risked his life for many people in similar fires.
2. He told the woman that he'd risked his life for to install a smoke detector.

In these sentences, the clause beginning *that he'd risked* is temporarily ambiguous. It can be attached high to the verb as a complement in Sentence 1 (minimal attachment) or low to the noun as a relative clause in Sentence 2 (non-minimal attachment). Only when the disambiguating region (*many people* in Sentence 1 and *to install* in Sentence 2) is reached can the reader confidently make the appropriate attachment for the ambiguous phrase. Altmann et al. found that sentences like Sentence 2 took longer to read in isolation (null context condition) than did sentences like Sentence 1 or control sentences (of which only the relative reading is possible) like Sentence 3:

3. He asked the woman that he'd risked his life for to install a smoke detector.

Furthermore, the difficulty was localized primarily in the disambiguating region. This is consistent with the interpretation that is based on the principle of minimal attachment (Frazier, 1979; Frazier & Rayner, 1982) and with much other research as well (Britt, Perfetti, Garrod, & Rayner, 1992; Ferreira & Clifton, 1986; Frazier & Rayner, 1982; Rayner et al., 1983; Rayner & Frazier, 1987; Rayner et al., 1992).

In addition to obtaining reading times for target sentences in a null context, Altmann et al. (1992) obtained reading times when the target sentences were preceded by contexts (consisting of several sentences) designed to bias readers toward one of the interpretations of the structurally ambiguous clause; that is, they constructed a complement-supporting context or a relative-supporting context. In contrast to the null context condition, Altmann et al. found that reading times in the complement and relative versions did not differ from each other. However, with referential supporting contexts, the probability of

making a regression out of the disambiguating region was greater in the relative condition (.34) than in either the complement (.19) or the control (.21) condition. This pattern of regression probabilities was similar to the pattern in the null context: .44, .21, and .25 for the relative, complement, and control conditions, respectively.

When Altmann et al. (1992) separated the trials in which a regression was made from those in which no regression occurred, the latter type yielded a very clear pattern of results: there were no differences in reading times between the three conditions. Because subjects did not make regressions out of the disambiguating region in the relative condition on 66% of the trials, Altmann et al. concluded that their data support the proposition that referential contexts lead to override effects, and, thus, that first-pass parsing decisions can be influenced by nonsyntactic factors. They also strongly defended the methodology of separating trials on the basis of whether or not a regression was made. In arguing for this distinction, they seem to be assuming that syntactic garden paths must result in regressive eye movements.² However, such an assumption is at odds with other eye movement data that have been collected.

In the first systematic eye-tracking study of the garden path theory of parsing, Frazier and Rayner (1982) observed three distinct patterns of eye movements when readers reached the disambiguating region: (1) regressions back to the ambiguous region; (2) forward saccades and long fixations until readers apparently understood the sentence; or (3) short forward saccades and long fixations until the end of the sentence, when readers regressed to the beginning of the sentence to reread it. Frazier and Rayner pointed out that the same subject often displayed all three patterns and that the frequency of occurrence of each pattern was roughly equal. Thus, equating regressions with garden pathing is inconsistent with the results reported previously by Frazier and Rayner. Indeed, our observation of much eye movement data has been quite consistent with the points initially made by Frazier and Rayner.

To examine the generalizability of Altmann et al.'s (1992) regression-contingent analysis, we reexamined data from a study reported by Rayner et al. (1992) that was conceptually similar to that of Altmann et al. (1992). Subjects in Rayner et al.'s (1992) study also read passages of text that contained a sentence with a temporary structural ambiguity that was disambiguated toward either a minimal attachment or a nonminimal attachment reading. The passages in which the target sentences were embedded were biased toward either minimal or nonminimal attachment.³

Unlike Altmann et al. (1992), Rayner et al. (1992) reported no contextual override on first-pass reading; context had an effect, but it was delayed and seemed primarily to influence reanalysis as indicated by differences in second-pass reading times.⁴ Thus, Rayner et al.'s data are ideal for the purpose of assessing the regression-contingent analysis, because garden path effects in context were obtained. If regressions are a necessary consequence of garden pathing, then, when a regression-contingent anal-

Table 1
Example Prepositional Phrase Attachment and Reduced Relative Clause Target Sentences
and Scoring Regions from Rayner, Garrod, and Perfetti (1992)

		Region			
Prepositional Phrase Attachment		1	2	3	4
Minimal		He put/the cattle/in the barn/to protect them/from the weather./			
Nonminimal		He put/the cattle/in the barn/out to pasture/for spring grazing./			
Reduced Relative Clause		1	2	3	4
Minimal		The wine/matured in the casks/and was then/bottled for several months./			
Nonminimal		The wine/matured in the casks/was the best/he had ever tasted./			

Note—Region 1, initial noun phrase; Region 2, ambiguous phrase or clause; Region 3, disambiguating region; Region 4, postdisambiguating region.

ysis (in which trials with regressions are eliminated from the data set) is performed on Rayner et al.'s (1992) data, the garden path effect should be eliminated or considerably weakened according to Altmann et al.'s (1992) argument that noncontingent analyses can hide the disambiguating effects of contextual information.

Eighteen subjects were tested in Rayner et al.'s (1992) study. Two of these subjects made a regression from the disambiguating or postdisambiguating region on almost every trial, so their data were eliminated from further consideration. The remaining 16 subjects made regressions from the disambiguating or postdisambiguating region⁵ on 4%–67% of the trials, with the overall probability of regressing being .31.⁶ In addition, it should be noted that Rayner et al. used two different structures: prepositional phrase (PP) attachments and reduced relative (RR) clauses.⁷ The sentences were divided into four regions. For the PP-attachment sentences, these regions corresponded to (1) an initial noun phrase, (2) the ambiguous prepositional phrase, (3) the disambiguating region, and (4) the post-disambiguating region. For the RR sentences, the regions were the same, except that the second region was the ambiguous RR clause. Table 1 shows examples of sentences from Rayner et al.'s study.

The data from trials in which subjects did *not* make regressions from the disambiguating or postdisambiguating regions were computed to provide mean scores for each region for first-pass reading time (see Table 2). These data were then subjected to a 2 (sentence type: PP versus RR) $\times$ 2 (attachment: minimal vs. nonminimal) $\times$ 4 (region) analysis of variance (ANOVA). This analysis yielded a marginally significant effect of sentence type [$F(1,15) = 3.98, p < .07$], indicating that RR sentences were more difficult than PP attachment sentences, which is not at all surprising, since the former are structurally more complex than the latter. There was a significant main effect of attachment [$F(1,15) = 9.11, p < .01$], with nonminimal attachment sentences being more difficult (as indexed by longer first-pass reading times) than minimal attachment sentences. Finally, there was a highly significant interaction of attachment $\times$ region [$F(3,45) = 11.47, p < .001$]. As is evident in Table 2, the nature of this interaction revealed that there was little difference between minimal and nonminimal attachment sentences in Regions

1 and 2, but that there were large differences in Region 3 and, to some extent, in Region 4.

Subsequent ANOVAs performed separately on the PP and RR sentences yielded identical results. For the PP set, there was a main effect of attachment [$F(1,15) = 4.72, p < .05$] and an interaction of attachment $\times$ region [$F(3,45) = 5.81, p < .01$]. For the RR set, the corresponding F s were 8.76, $p < .01$, and 3.66, $p < .05$. Pairwise comparisons indicated that the minimal and nonminimal attachment versions did not differ in Regions 1 and 2 (all F s < 1), but there were significant differences between the two sentence types in the other two regions [in Region 3, $F(1,15) = 15.78$ and 22.43, p s $< .001$; in Region 4, $F(1,15) = 8.31$ and 4.69, p s $< .05$, for the PP and RR sets, respectively].

In addition to showing Rayner et al.'s (1992) data in terms of a regression-contingent analysis, Table 2 also shows the means for the full data set. The striking aspect of this comparison is that the difference between the minimal and nonminimal attachment versions is actually *non-*

Table 2
First-Pass Reading Time (in Milliseconds/Character)
for the Prepositional Phrase Attachment and
Reduced Relative Clause Sentences in the Different Regions

		Region			
Attachment	Trials	1	2	3	4
Prepositional Phrase Attachment					
Minimal	all	31	27	29	31
	no regressions	30	27	26	29
	with regressions	31	27	31	32
Nonminimal	all	29	27	34	32
	no regressions	30	26	33	34
	with regressions	29	27	34	31
Reduced Relative Clause					
Minimal	all	33	31	28	32
	no regressions	32	30	27	29
	with regressions	33	31	29	34
Nonminimal	all	34	31	35	31
	no regressions	34	30	36	33
	with regressions	34	31	34	30

Note—Region 1, initial noun phrase; Region 2, ambiguous phrase or clause; Region 3, disambiguating region; Region 4, postdisambiguating region.

merically *larger* in Regions 3 and 4 when no regression occurred: in Region 3 for the PP set, the difference is 7 msec per character as opposed to 5 msec per character for the entire data set, whereas for the RR set, the difference is 9 msec per character as opposed to 7 msec per character; in Region 4 for the PP set, the difference is 5 msec per character as opposed to 1 msec, whereas for the RR set, the difference is 4 msec per character as opposed to -1 msec. Thus, our reanalysis of Rayner et al.'s (1992) data indicates that the garden path effect was at least as strong when trials with regressions were eliminated.⁸ This finding suggests that regressions are not a hallmark of readers' being garden pathed. As Frazier and Rayner (1982) originally suggested, readers can be garden pathed but perform a reanalysis without necessarily moving their eyes back to the point of ambiguity.

Why does the garden path effect become stronger in Rayner et al.'s (1992) data when regressions are eliminated, but much weaker (or nonexistent) in Altmann et al.'s (1992) data when the regression-contingent analysis is used? Unfortunately, we do not have a ready explanation for the discrepancy between the two data sets. One possibility is that readers in Rayner et al.'s (1992) study may have followed a strategy of either making long fixations without regressing or quickly regressing upon encountering a difficult region of text. In comparison, readers in Altmann et al.'s (1992) study may have often fixated for a long time and then regressed, resulting in long reading times prior to a regression from a difficult region. However, a careful examination of Altmann et al.'s data suggests that this was not the case. In all regions, fixations prior to a regression were considerably shorter than fixations in the absence of a regression (by about 15 msec per character), *except* in the case of the disambiguating region of sentences in a referentially supporting context (where the difference was approximately 1 msec per character).

Other possible reasons for the difference could be related to the composition of the sample of subjects or the experimental materials. For example, Just and Carpenter (1992) have reported differences in parsing strategies as a function of memory span, with high-span readers treating syntactically ambiguous clauses differently than low-span readers. There may have been memory span differences between subjects in Altmann et al.'s (1992) and Rayner et al.'s (1992) studies. Alternatively, Altmann et al.'s use of a single verb (*told*) in all but one of their experimental sentences may have increased their subjects' sensitivity to subtle contextual factors. Finally, we note that in a recent study by Altmann, Garnham, and Henstra (1994), a regression-contingent analysis was not used because readers regressed so infrequently. We can only assume that the dearth of regressions in that study was due to differences in memory span in their sample as opposed to the Altmann et al. (1992) sample and/or structural differences between the target sentences in the two studies.

At the moment, the difference between the two data sets remains something of a mystery. Although we do not have

an explanation for the difference, the important point that we wish to emphasize is that regressions are not an infallible indicator of garden pathing as the Frazier and Rayner (1982) results and the reanalysis of the data from Rayner et al. make clear.

In an earlier paper, Altmann and Steedman (1988) suggested that the advantages of eye movement data over other types of data used in studies of parsing were quite minimal. In a subsequent paper, we (Rayner, Sereno, Morris, Schmauder, & Clifton, 1989) argued that eye movement data are much more useful in adjudicating between alternative views of parsing, because first- and second-pass reading can be discriminated (an impossibility with other standard techniques such as self-paced reading). Although we are encouraged that Altmann and his colleagues now find eye movement data useful in sentence-parsing research, we also think it important that researchers not be misled into believing that regressions, and regressions only, provide invariable evidence of garden pathing.

We now return to the issue of contextual override of initial parsing decisions. In Experiment 1 of Altmann et al. (1992), readers regressed from the disambiguating region on roughly one-third of the trials. Altmann et al. focus on the fact that the probability of regressing in the relative condition sentences was less when they were preceded by referential as opposed to null contexts (34% vs. 44%). Yet it should be noted that even with preceding referential contexts, subjects regressed more in the relative than in the control condition sentences (34% vs. 21%). This seems to us to be a glass half-full versus a glass half-empty situation. Altmann et al., who are sympathetic to the notion that felicitous contexts result in contextual override, are impressed that the percentage of regressions decreases when supporting contextual information biases the relative clause interpretation. However, those who are sympathetic to the notion that contextual influences have their impact on reanalysis processes and not on initial parsing decisions might well be impressed with the fact that subjects still regressed on one third of the trials even when there was a favorable context. At this point in the debate about the effect of semantic and pragmatic information on initial parsing decisions, rather than argue over *whether* or not context has an influence, it seems to us that the most prudent strategy would be to determine *when* contextual information does and does not influence such decisions (see Britt et al., 1992; Rayner et al., 1992).

Finally, we note that Altmann et al. (1992) make a good point in arguing that researchers using eye movement data need to be aware of differing patterns of results that depend on whether or not readers make a regression. We have informally noted some differences in data patterns between subjects who do and do not make frequent regressions. However, it will not invariably be the case that conclusions will differ if readers do or do not regress. Indeed, our observation, borne out by the data reported here, is that garden path effects can be demonstrated *both* by an increase in regressions and by longer reading times in the absence of a regression.

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NOTES

1. Britt, Perfetti, Garrod, and Rayner (1992) also reported a contextual override effect in an eye movement study. However, they found that the extent to which context could influence initial parsing decisions depended on the type of sentence structure employed in the study: with temporary structural ambiguities involving the attachment of a prepositional phrase, they obtained override effects; with reduced relative clause constructions, they did not. Trueswell et al. (1993) have also reported an eye movement study in which they found that subcategorization properties of verbs can influence initial parsing decisions.

2. Altmann et al. (1992) do acknowledge that regressions cannot represent the hallmark of garden pathing. They note that, when garden path sentences are presented in isolation, first-pass reading times in the absence of a regression reflect the processing complexities that accompany a garden path. Despite the fact that Altmann et al. (1992) are apparently aware that regressions are not a necessary consequence of garden pathing, we believe that their article leaves the reader with the impression that this is the case for garden path sentences presented in context. Our aim in the present article is to examine the generalizability of the idea that regressions are the primary indicator of garden pathing in context.

3. Rayner et al. (1992) compared reading times for target sentences that appeared in either biasing or null contexts. For the purpose of the present analyses, only the biasing context data are relevant.

4. As with all studies in which context manipulations occur, one can raise questions about the effectiveness of the context. As we have noted, context did have an influence in terms of reanalysis processes, but one can always argue that a stronger context may have influenced first-pass reading time as well. Furthermore, the contexts in Rayner et al. (1992) were not of the same type as those used by Altmann et al. (1992). But these factors are largely irrelevant for the purpose of examining the generalizability of the regression-contingent analysis.

5. The results reported here are based on data in which readers made a regression from either the disambiguating region or the postdisambiguating region. If regressions are the only hallmark of being garden pathed, it makes sense to use the regression-contingent analysis on trials in which subjects regressed only after having reached the disambiguating region. Altmann et al. included data from a given region-contingent upon the occurrence of a regression from that region, rather than making their analysis contingent on a regression from the disambiguating (or disambiguating and postdisambiguating) region. We also carried out a regression-contingent analysis with the same procedure used by Altmann et al. When we did so, the pattern of data was not different from that presented in Table 2.

6. Slightly over half (57%) of the regressions were initiated from the disambiguating region, with the remainder initiated from the postdisambiguating region. Of all regressions, 58% were regressions to the ambiguous region; the remainder were equally divided between regressions to the initial noun phrase and to the disambiguating region.

7. Rayner et al. (1992) also varied the extent to which the target PP or RR clause was in the discourse focus when it was encountered. In the present analysis, we collapsed across this variable since it had no effect on first-pass reading time.

8. Statistical analyses were not performed to compare the *no regressions* condition with the *with regressions* condition. Too much data was missing in the latter condition, because some subjects regressed as infrequently as 4% of the time.