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Lexical and Post-Lexical Complexity Effects on Eye Movements in Reading

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The current study investigated how a post-lexical complexity manipulation followed by a lexical complexity manipulation affects eye movements during reading. Both manipulations caused disruption in all measures on the manipulated words, but the patterns of spill-over differed. Critically, the effects of the two kinds of manipulations did not interact, and there was no evidence that post-lexical processing difficulty delayed lexical processing on the next word (c.f. Henderson & Ferreira, 1990). This suggests that post-lexical processing of one word and lexical processing of the next can proceed independently and likely in parallel. This finding is consistent with the assumptions of the E-Z Reader model of eye movement control in reading (Reichle, Warren, & McConnell, 2009).

Keywords: Reading, sentence complexity, eye movements, E-Z Reader, word frequency

Introduction

Researchers who are interested in reading and lexical processing have gathered extensive evidence about the influence of lexical variables on eye movements in reading. Researchers who are interested in sentence processing have made frequent use of experiments testing eye movements in reading to evaluate theories of post-lexical processing. These literatures are for the most part entirely distinct. Only a few recent reviews (Rayner, 1998; Clifton, Staub & Rayner, 2007) have attempted to look closely at the similarities and differences between eye movements to lexical manipulations versus syntactic or discourse manipulations, and there are very few experiments that have concurrent manipulations at both levels.

From the body of work investigating lexical processing, it has become evident that lexical manipulations, like word frequency, meaning ambiguity, and word familiarity have predictable effects on eye movements. Lexical effects are typically observed in early eye-movement measures, like first-fixation duration and gaze duration, and are consistent across experiments (Rayner, 1998). Post-lexical manipulations, by which we mean syntactic and/or certain kinds of context/discourse manipulations, seem to be more variable. In some cases they affect measures as early as first-fixation duration, but more often they appear in measures such as regressions and rereading. Sometimes similar manipulations lead to slightly different patterns of eye movements (Clifton et al., 2007). Perhaps because there seems to be a clearer link between lexical processing and eye movements, models of eye-movement control in reading have tended to focus on accounting for the ways in which lexical processing, attention, and oculomotor factors combine to drive eye movements and have disregarded the influences of post-lexical processing on eye movements (Engbert, Nuthmann, Richter, & Kliegl, 2005; McDonald, Carpenter, & Shillcock, 2005; Reichle, Pollatsek, Fisher, & Rayner, 1998; Reilly & Radach, 2006; for a review, see Reichle, Rayner, & Pollatsek, 2003). Only recently has one model, E-Z Reader (Reichle, Warren, & McConnell, 2009), begun to try to explain how post-lexical processing might be coordinated with lexical processing, attention, and oculomotor factors to account for patterns of eye movements in reading. This endeavor is important not just for improving our understanding of eye movement control during reading, but also because it forces us as researchers to consider how lexical and post-lexical processing are coordinated.

There is surprisingly little research that simultaneously investigates lexical and post-lexical processing. This kind of research is important, in that we know rela-

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tively little about how lexical and post-lexical processing are coordinated across the entirety of a sentence. Within the sentence processing literature, researchers generally assume that readers identify upcoming words one at a time, and when each word is identified it is incrementally integrated into whatever syntactic representation has been built for the input thus far (e.g. Frazier, 1987; Grodner & Gibson, 2005; Lewis & Vasishth, 2005). In addition to a syntactic representation, readers also must build semantic or discourse representations of the propositions and referents referred to in the sentence. For example, after a reader identifies the word *kicked* in a cleft structure like *It was Bill who John kicked*, she must engage in extensive post-lexical processing and build dependencies in both a syntactic and a referential/semantic representation between *kicked* and *who* or *Bill*, with the result that Bill is interpreted as the entity being kicked. According to memory-based theories of sentence processing (e.g. Gordon, Hendrick, & Johnson, 2001; Grodner & Gibson, 2005; Lewis & Vasishth, 2005), building the syntactic and semantic structure at *kicked* above is difficult because it requires re-accessing prior syntax and referents that are difficult to remember because of memory interference or decay.

It is widely assumed that the identification of a word must precede its integration into syntactic and propositional representations, even though there is little work directly testing this assumption (but cf. Staub, 2009 for evidence that is difficult to reconcile with it). The current experiment continues to operate under this assumption, but investigates the closely related and similarly understudied question of how lexical and post-lexical processing on two consecutive words are cascaded. Must a reader wait until post-lexical processing on word N is complete before beginning lexical processing on word N+1? If so, it would suggest that lexical and post-lexical processing are done in stages and may be co-dependent on similar representations and resources. If not, it would suggest that lexical and post-lexical processing can be done in parallel to at least some degree and likely rely on separate representations and resources. The current experiment begins to investigate this question by looking at the eye movement ramifications of following a manipulation of post-lexical complexity with an immediate manipulation of lexical processing difficulty. It also aims to determine whether there are differences or similarities in the long-term time course of eye-movement disruption to lexical vs. structural manipulations.

Henderson and Ferreira (1990)'s foveal-load hypothesis is one of the few sources of predictions about the way that post-lexical processing on word N will be coordinated with lexical processing on word N + 1. This hypothesis predicts that manipulating the difficulty of post-lexical processing on a word will influence the time course of lexical processing of the subsequent word. Henderson and Ferriera used a parafoveal preview manipulation to demonstrate that readers accomplish less parafoveal processing on an upcoming word if the currently fixated word is more difficult to process. Critically, in their second experiment, the manipulation of the difficulty of the currently fixated word was accomplished by making it a point in the sentence at which syntactic revision was necessary or not. They found that in conditions in which syntactic revision was required, fixations were longer on the syntactically disambiguating word and readers did less parafoveal processing on the following word. Their evidence for this was an interaction between complexity and preview such that there was more benefit to having a correct preview of an upcoming word if the currently fixated word was syntactically easier to process. Additionally, although they reported no influence of syntactic complexity on first fixation or gaze durations on the following word, a closer look at Henderson and Ferreira's data suggests that syntactic complexity inflated first fixation durations by about 30 milliseconds in conditions in which the preview of this word had been either correct or nearly correct. Both of these pieces of evidence suggest that readers were slower to begin lexical processing on the next word (given that lexical processing is often started parafoveally) after a point of increased post-lexical processing. The reason that inflated first-fixation durations on the word following the syntactic manipulation can be interpreted as evidence of slowed lexical processing is that many researchers make the assumption that what drives the eyes to saccade after initially fixating a word is the completion of an initial stage of lexical processing (e.g. Reichle et al., 1998). This means that a delay in starting lexical processing on a word should result in longer first-fixation durations on that word. The fact that increased post-lexical difficulty delayed upcoming lexical processing suggests that either some of the same resources or processes are devoted to both lexical and post-lexical processing, or that there is some degree of seriality in the coordination of lexical and post-lexical processing. Specifically, this evidence is consistent with the hypothesis that lexical processing on an upcoming word is delayed until post-lexical processing on the current word has either progressed to some predetermined stage or has been completed.

Another prediction that Kliegl, Nuthmann, and Engbert (2006) have argued follows from Henderson and Ferreira's (1990) foveal-load hypothesis is that frequency effects on word N + 1 should be larger if there is a higher processing load on word N. It is not clear to us why this hypothesis should predict a larger frequency effect on N + 1 rather than simply delayed lexical processing, but

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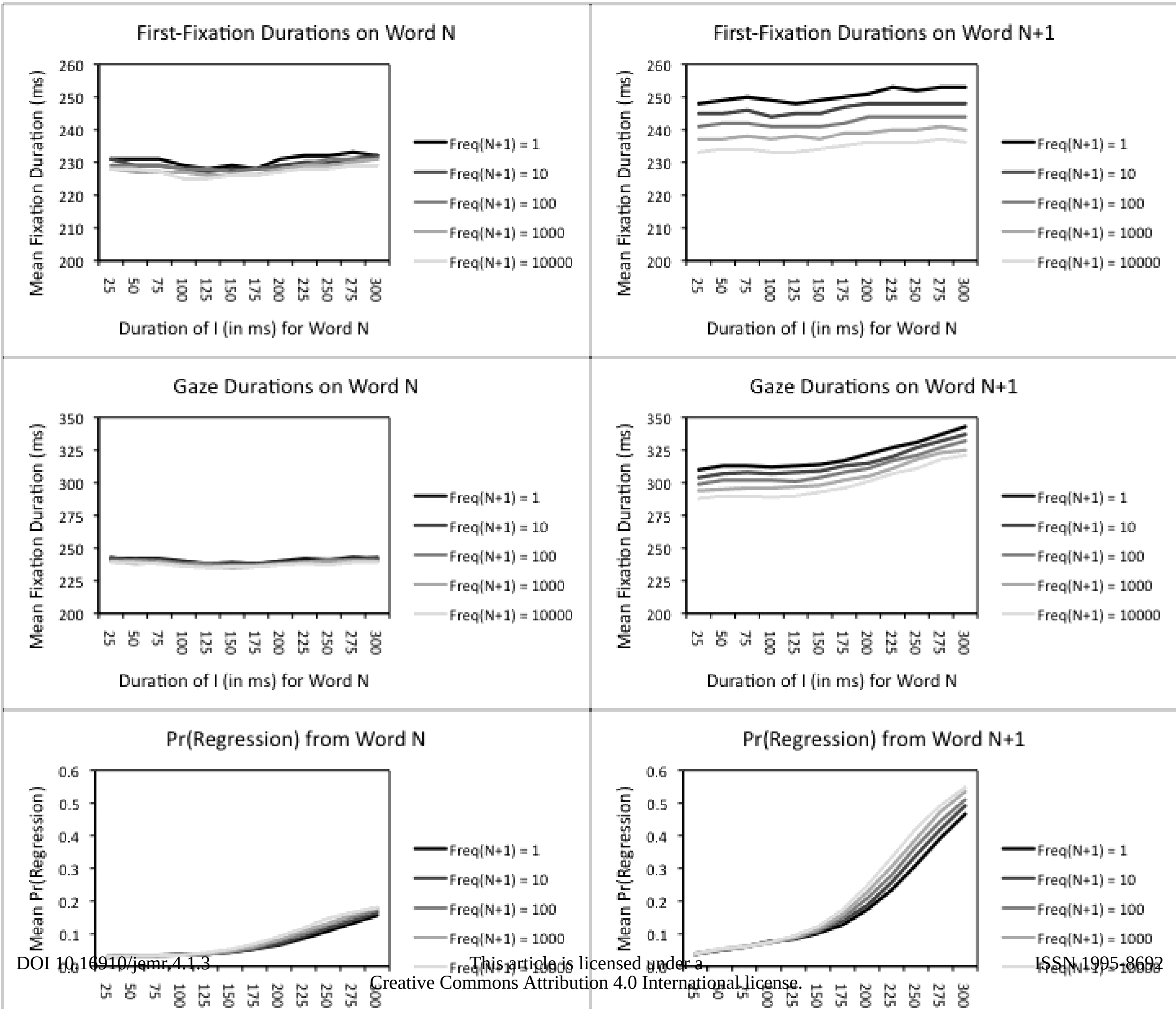
Kliegl et al. report such an interaction in their data, with larger frequency effects on word N + 1 in cases in which word N was low rather than high frequency. If, consistent with Henderson and Ferreira, syntactic and lexical manipulations of foveal load have similar effects on parafoveal preview, then Kleigl et al.'s finding of an interaction might predict a similar interaction in the current experiment, with larger lexical frequency effects after a point of high syntactic complexity.

Another source of predictions about the ways that adjacent lexical and post-lexical manipulations may or may not interact to drive eye movements is the E-Z Reader model of eye-movement control in reading (Reichle et al., 2009). Within all versions of the E-Z Reader model, lexical processing is assumed to be the primary determinant of when the eyes move forward in a text (see Reichle, 2011). Within the most recent version of the model, post-lexical processing is assumed to primarily drive regressions. The model hypothesizes that post-lexical and lexical processing generally progress independently, with the completion of lexical processing on a word driving the simultaneous start of post-lexical processing on that word and lexical processing on the next. However, there are two ways in which post-lexical processing can interrupt lexical processing and force lexical reprocessing. First, if post-lexical processing on word N is still not complete when lexical processing on word N+1 has finished, a regression is programmed so that word N can be reprocessed (a situation termed *slow integration failure*). Second, if post-lexical processing of word N quickly fails, as for example might happen if it had a syntactic category that could not be integrated into the structure built for the sentence thus far, then a regression is programmed so the word N can be reprocessed (termed *rapid integration failure*). Figure 1 presents a series of simulations investigating E-Z Reader's predictions about the ramifications that manipulating the duration of post-lexical processing on word N and the frequency of word N+1 would have on first-fixation durations, gaze durations, and first-pass regressions out. Intui-

Figure 1.
Results of E-Z Reader simulations varying the duration of post-lexical processing, t(I), on word N and the frequency of word N+1.



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tively, it seems that the model should predict that if the duration of post-lexical processing on word N is parametrically increased and the duration of lexical processing on word N+1 is parametrically decreased, the proportion of regressions out of words N and N+1 should increase. This is because E-Z Reader assumes that a regression will be programmed if lexical processing on word N+1 finishes before post-lexical processing on word N is complete. However, the simulations in Figure 1 indicate that this effect only holds for cases in which the duration of post-lexical processing is extremely long. The simulations also demonstrate that E-Z Reader predicts that a frequency manipulation on word N+1 will affect eye-movement measures on word N+1 but not on word N. Note that this is different from the prediction of eye-movement models assuming distributed lexical processing. Such models should predict an effect of the frequency of word N+1 on eye-movement measures on word N (e.g., Engbert et al., 2005; Kliegl et al., 2006; Reilly & Radach, 2006).

The current experiment manipulated syntactic complexity on a word and lexical frequency on the following word in order to explore any potential interactions between the two types of complexity and to determine the differences and similarities between the long-term time courses of eye movement effects to these kinds of manipulations. According to Henderson and Ferreira's (1990) foveal-load hypothesis, a high syntactic processing load on word N should reduce the amount of parafoveal processing that occurs on word N + 1, delaying lexical processing. Kliegl et al. (2006)'s data, in combination with this foveal-load hypothesis may also predict that there will be larger frequency effects following a point of high syntactic complexity. According to E-Z Reader, there should be more regressions from a high-frequency word than a low-frequency word following a point of extremely slow post-lexical processing. However, because previous E-Z Reader simulations of datasets with strong post-lexical manipulations have not found post-lexical processing times even close to the range necessary to drive this effect (cf. Reichle et al, 2009; Warren, White, & Reichle, 2009), this prediction is likely not testable.

Methods

Participants. 48 undergraduates at the University of Pittsburgh participated for course credit. The data from two additional participants was not included in analyses because they were missing data (due to skips and blinks) on 50% or more of either of the critical words during first-pass reading. All participants were native English speakers with normal or corrected-to-normal (via contact lenses) vision.

Apparatus. An Eyelink 1000 eye-tracker (SR Research) monitored the gaze location of participants' right eyes during reading. The eye tracker has a spatial resolution better than 30′ arc and a 1000 Hz sample rate. Participants viewed the stimuli binocularly on a monitor 63 cm from their eyes; approximately 3 characters equaled 1° of visual angle.

Materials. The materials consisted of 24 items in a 2 × 2 design crossing syntactic complexity (simple vs. complex) with word frequency (high, low). An example is provided in (1), with the two critical words underlined:

Simple, Low Frequency
(1a) Joe and Lisa <u>married</u> <u>hastily</u> on a vacation to Las Vegas.

Simple, High Frequency
(1b) Joe and Lisa <u>married</u> <u>quickly</u> on a vacation to Las Vegas.

Complex, Low Frequency
(1c) It was Joe who Lisa <u>married</u> <u>hastily</u> on a vacation to Las Vegas.

Complex, High Frequency
(1d) It was Joe who Lisa <u>married</u> <u>quickly</u> on a vacation to Las Vegas.

The first critical word (*married* above) was always a verb. This verb was the locus of the syntactic complexity manipulation. In the simple conditions, the verb followed a conjoined NP and completed a syntactically simple unit. In the complex conditions, the verb completed an object cleft structure. In this kind of structure, the verb is a point of high post-lexical processing complexity because the cleft object (*Joe* above) must be retrieved from memory at the verb in order to build the syntactic and semantic representations necessary to determine who did what to whom (Gordon et al., 2001; Warren & Gibson, 2005). One of the strengths of this manipulation is that the three words preceding the verb are similar in content and identical in length across conditions (e.g., *Joe and Lisa* or *Joe who Lisa*), providing a relatively well-controlled pre-target region. The second critical word was the adverb immediately following the verb. In almost all cases this adverb modified the preceding verb, however in a few cases (mostly in the high frequency conditions) the adverb modified a later phrase. Adverbs were matched for length within items. Low-frequency adverbs had a mean frequency of 7.5 per million (Francis & Kuc-

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era, 1982), whereas high-frequency adverbs had a mean frequency of 127 per million. Both critical words were a minimum of five characters long to increase the likelihood that they would be fixated. All content words except for the critical adverb whose frequency was manipulated were the same for each item across conditions. Because the items in another experiment run with this one had two sentences, the experimental sentences were followed by a sentence on the next line. This sentence was the same for every condition within an item; for the example in (1), the sentence that followed was: "An Elvis was one of the witnesses." Eye movements on this second sentence were not analyzed.

The 24 experimental items were combined with 66 filler items and 28 items from an unrelated experiment. Conditions were counterbalanced across four presentation lists using a Latin square design. After approximately 60% of the sentences in the experimental session, participants answered a yes/no comprehension question using a button response. Half required a "yes" response.

Procedure. The experiment lasted 40-55 minutes. A chinrest and forehead rest minimized head movements. Participants were asked to read normally, for comprehension, and were told that after some passages they would need to answer a comprehension question. After the participant was seated at the eye tracker and had been instructed as to the format of the experiment, the tracker was aligned and calibrated. Calibration was checked between trials and the tracker was recalibrated as necessary.

Results

Eye movements across four regions of the sentence were analyzed. Region 1 was the critical verb. Region 2 was the critical adverb. Region 3 was the word following the adverb, or if that word was less than five characters, it was the following two words. Region 4 was the remainder of the sentence. All fixations with durations less than 80 ms or over 1000 ms were eliminated from analyses, as were trials in which there was a blink on either the critical verb or adverb. After taking skips and eliminated fixations and blinks into account, the critical verb and adverb were each fixated on an average of 91% of trials. The amount of missing data was similar across conditions (ranging from 6% to 12% for the critical verb and 8% to 10% for the critical adverb).

Participants answered 94% of the comprehension questions correctly (*SD* = 2.4%), indicating that they were engaged in the task and reading the sentences. Four eye movement measures were analyzed on each region (Inhoff & Radach, 1998): (1) *first-fixation duration* is the duration of the initial fixation on a word, provided that fixation was made during first-pass reading; (2) *gaze duration* is the sum of the durations of all fixations on a word during first-pass reading; (3) *Go-past time* (or *regression-path duration*) is the sum of all fixations (including regressive fixations) from the first fixation on a word during first-pass reading until the eyes move past the word; and (4) *first-pass regressions out* is the proportion of trials on which a regression was launched from a word during first-pass reading. 2x2 repeated measures ANOVAs with both participants (F_1) and items (F_2) as random factors were used to analyze the data.

Table 1 reports means on the critical verb (region 1). All measures showed a reliable main effect of structure, with longer fixation durations or more regressions in the complex condition than in the simple condition, first-fixation: $F_1(1,47) = 9.12$, $p = .004$; $F_2(1,23) = 8.45$, $p = .008$; gaze duration: $F_1(1,47) = 5.86$, $p = .019$; $F_2(1,23) = 9.10$, $p = .006$; go-past: $F_1(1,47) = 518.26$, $p < .001$; $F_2(1,23) = 21.99$, $p < .001$; first-pass regressions out: $F_1(1,47) = 11.95$, p = .001; $F_2(1,23) = 6.88$, $p = .015$. There were no reliable effects of the frequency of the upcoming adverb, and no interactions.

Table 1
Average eye movement measures on Region 1, the critical verb, in milliseconds (standard errors in parentheses).

	First Fix	Gaze	Go-Past	%Reg out
Simple-HF	218 (5.7)	282 (10.7)	319 (14.8)	8 (.02)
Simple-LF	226 (7.0)	272 (9.5)	334 (18.3)	11 (.02)
Complex-HF	243 (8.7)	299 (10.9)	409 (18.5)	18 (.02)
Complex-LF	235 (7.5)	292 (9.5)	389 (21.4)	16 (.03)

Table 2 reports means on the critical adverb (region 2). First-fixations and gaze durations were inflated when the adverb was low-frequency rather than high-frequency, first-fixation: $F_1(1,47) = 11.61$, $p = .001$; $F_2(1,23) = 10.48$, $p = .004$; gaze duration: $F_1(1,47) = 14.99$, $p < .001$; $F_2(1,23) = 12.63$, $p = .002$. These measures showed no fully reliable effects of structure [by items there was a marginally reliable effect of structure in first-fixation, $F_2(1,23) = 3.19$, $p = .087$] nor any interactions [in the participants analysis there was a marginally reliable interaction in gaze duration with a pattern such that the frequency effect appeared larger in the simple as compared to complex conditions, $F_1(1,47) = 3.65$, $p = .062$; $F_2(1,23) = 2.46$, $p = .131$]. Go-past on the adverb

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showed fully reliable effects of both structure, with longer times in complex than simple conditions, $F_1(1,47) = 5.15$, $p = .028$; $F_2(1,23) = 4.40$, $p = .047$, and frequency, with longer times for low- compared to high-frequency adverbs, $F_1(1,47) = 11.71$, $p = .001$; $F_2(1,23) = 10.14$, $p = .004$, but no interaction. First-pass regressions out on the adverb showed an effect of structure that was fully reliable by participants and marginally reliable by items, $F_1(1,47) = 4.85$, $p = .033$; $F_2(1,23) = 3.53$, $p = .073$, with more regressions from the complex conditions. There was a marginal effect of frequency in the analysis by participants, $F_1(1,47) = 3.71$, $p = .060$; $F_2(1,23) = 1.61$, $p = .217$, with more regressions from low-frequency adverbs. These factors did not interact.

Table 2
Average eye movement measures on Region 2, the critical adverb, in milliseconds (standard errors in parentheses).

	First Fix	Gaze	Go-Past	%Reg out
Simple-HF	218 (6.1)	251 (9.0)	294 (13.8)	8 (.02)
Simple-LF	240 (7.0)	306 (14.3)	377 (25.2)	12 (.02)
Complex-HF	228 (7.1)	273 (11.0)	351 (21.0)	16 (.02)
Complex-LF	243 (8.1)	294 (13.4)	404 (24.0)	13 (.02)

In region 3, a spillover region after the adverb, effects patterned similarly to region 2. Means are provided in Table 3. First-fixation and gaze duration again were reliably affected only by frequency, first-fixation: $F_1(1,47) = 3.40$, $p = .072$; $F_2(1,23) = 7.767$, $p = .011$; gaze duration: $F_1(1,47) = 4.73$, $p = .035$; $F_2(1,23) = 16.06$, $p = .001$, with longer reading times in low frequency conditions. These measures showed no effect of structure and no interaction. Like in region 2, go-past was affected by both structure, $F_1(1,47) = 5.10$, $p = .029$; $F_2(1,23) = 5.16$, $p = .033$, and frequency, $F_1(1,47) = 6.65$, p = .013; $F_2(1,23) = 14.23$, $p = .001$, but there was no interaction between the two. In region 3, first pass regressions out were not reliably affected by either experimental manipulation.

Table 3
Average eye movement measures on Region 3, the spillover region after the critical adverb, in milliseconds (standard errors in parentheses).

	First Fix	Gaze	Go-Past	%Reg out
Simple-HF	210 (6.0)	265 (11.6)	324 (13.7)	12 (.02)
Simple-LF	217 (4.8)	283 (9.7)	372 (22.8)	14 (.02)
Complex-HF	209 (5.3)	275 (11.2)	354 (18.3)	14 (.02)
Complex-LF	220 (9.5)	302 (13.8)	427 (31.6)	15 (.03)

Region 4 was the remainder of the sentence; means are reported in Table 4. There were no reliable effects of the experimental manipulations on first-fixation or gaze durations in this region. However, there was a reliable effect of structure on go-past times, with longer times associated with the complex conditions, $F_1(1,47) = 5.66$, $p = .022$; $F_2(1,23) = 6.86$, $p = .015$. Go-past was not reliably affected by frequency, and there was no interaction between structure and frequency in this measure. First-pass regressions out showed the same pattern, with slightly smaller effects. There were more regressions from the final region of complex sentences than simple sentences, $F_1(1,47) = 3.70$, $p = .060$; $F_2(1,23) = 4.35$, $p = .048$, but no reliable effects of frequency and no interactions.

Table 4
Average eye movement measures on Region 4, the sentence-final region, in milliseconds (standard errors in parentheses).

	First Fix	Gaze	Go-Past	%Reg out
Simple-HF	217 (6.9)	524 (25.7)	817 (45.1)	39 (.03)
Simple-LF	212 (5.5)	516 (27.8)	811 (47.5)	38 (.03)
Complex-HF	214 (5.5)	515 (29.4)	932 (50.0)	45 (.04)
Complex-LF	206 (5.3)	515 (30.6)	849 (50.5)	42 (.04)

Simulations were run to determine whether E-Z Reader (Reichle et al., 2009) could capture the patterns of data on the critical verb and adverb in the current study. These simulations were completed using the Schilling,

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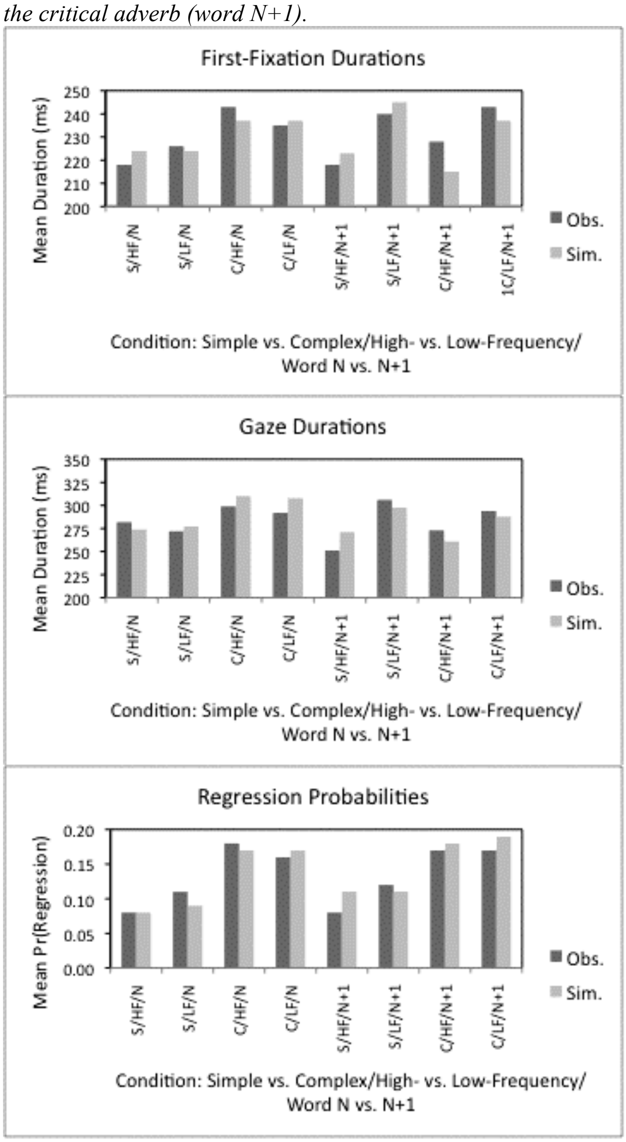
Chumbley, and Rayner (1998) sentences frames; the critical verb (word N), the preceding word (word N-1), and the critical adverb (word N+1) were embedded within these frames by setting the lengths and frequencies of these words equal to their observed values and their cloze-predictabilities equal to zero. Multiple grid-searches of the model's parameter space were then completed to find those values that minimized the absolute deviation between the mean observed and simulated first-fixation durations, gaze durations, and regressions out for words N and N+1 across the four conditions. These parameters and their values were: (1) α_1 = 101 ms; (2) α_2 = 7 ms; (3) α_3 = 8 ms; (4) $t(I)$ = 50 ms; and (5) p_F = 0.15. The first three of these parameters control the rate of lexical processing and are within a few milliseconds of the parameters reported and used in Reichle et al. (2009). The parameter $t(I)$ is the mean minimal post-lexical integration time and is 25 ms greater than the default used in Reichle et al. (2009) and Warren et al. (2009). The fact that there are small differences between these best-fitting parameter values and the best-fitting values in previous simulations may be due to differences among participants (e.g., individual differences in reading ability) and/or differences in the text materials (e.g., text difficulty). The last parameter, p_F, is the probability of rapid integration failure; although this parameter has no default value, the value that provided the best fit to our data is similar to those used in previous simulations. Finally, because the $t(I)$ and p_F parameters reflect the post-lexical processing difficulty associated with specific words, their values were allowed to vary on the critical verb (word N) to simulate the simple and complex conditions. In the simple conditions, the duration of post-lexical processing, $t(I)$, was 70 ms and the probability of rapid post-lexical integration failure, p_F, was 0.15. In the complex conditions, $t(I)$ was also 70 ms but p_F was 0.47. Again, these parameter values are well within the ranges of those reported for simulations in Reichle et al. (2009) and Warren et al. (2009). (All other parameters were set equal to their default values; for a full description of all of the parameters, see Reichle et al., 2009.) The results of the final simulation using these parameters and 1,000 statistical subjects per conditions are shown in Figure 2. As can be seen, E-Z Reader does a relatively good job of simulating the experimental results. Note that in this simulation, the duration of post-lexical processing is both considerably shorter than necessary to drive predictions about an interaction in regressions out and does not vary across the complexity conditions.

Figure 2.
Observed and simulated first fixation durations, gaze durations, and regression probabilities for the critical verb (word N) and the critical adverb (word N+1).



Discussion

The current experiment investigated eye movement reactions to a syntactic complexity manipulation and a subsequent lexical manipulation. Eye movement disruption associated with the complex structure appeared immediately at the verb and was apparent in every measure on the verb, including first-fixation duration. This disruption did not spill over onto first-fixation or gaze durations on the next word, but it was evident in the go-past measure in every subsequent region of the sentence. There

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were also more first-pass regressions out in the complex conditions both on the word after the verb and in the sentence-final region, suggesting a local increase in regressions on words around the syntactic manipulation and then a reappearance of this increase in regressions at the end of the sentence. This indicates that a relatively strong manipulation of syntactic complexity can have long lasting effects on eye movement patterns, and these long lasting effects are primarily manifested in regressions and re-reading.

The pattern of eye-movement disruption associated with object clefts in the current experiment is consistent with some aspects of other experiments investigating these structures. Using essentially the same manipulation, Warren et al. (2009) found disruption in go-past and regressions out but not first-fixation or gaze duration on the verb of an object cleft construction. Given the strong variability in post-lexical eye movement effects (e.g. Clifton et al., 2007), the fact that some experiments show effects in all measures but others only in some is not entirely surprising. Using self-paced reading and a slightly different manipulation, Warren and Gibson (2005) found that complexity effects apparent on the verb of an object cleft dissipated after the verb but subsequently reappeared on the sentence-final word, similar to the pattern in first-pass regressions out in the current study. This pattern, namely that readers regressed (and subsequently reread) more from around the area of the point of high structural difficulty, and again at the end of the sentence is consistent with accounts from the sentence processing literature suggesting that comprehenders are often unable to retrieve the necessary referents and/or syntax at the verb of an object cleft and are left confused about who did what to whom in the sentence (e.g., Gordon et al., 2001; Warren & Gibson, 2005). Perhaps readers reread in an attempt to provide memory support for this difficult retrieval, and if they reach the end of the sentence without a coherent representation of who did what to whom, they may be more likely to regress and reread.

The lexical manipulation on the critical adverb had a more local effect on eye movements. Low-frequency adverbs were associated with longer fixations in all fixation-based measures, and marginally more first-pass regressions out (in the analysis by participants). This frequency effect spilled over onto the region after the adverb, again inflating all fixation-based measures, but did not appear in the sentence-final region. This finding that disruption from a lexical frequency manipulation spilled over onto the subsequent word is consistent with many previous findings (e.g. Rayner & Duffy, 1986; Kliegl et al., 2006). The finding that this manipulation did not affect reading times on the word before the manipulation is consistent with the predictions of E-Z Reader, but not models assuming distributed lexical processing (e.g., Engbert et al., 2005; Kliegl et al., 2006; Reilly & Radach, 2006)

The current findings are not consistent with previous findings that a syntactic manipulation of foveal load affected the amount of parafoveal processing accomplished on the following word (Henderson & Ferreira, 1990). In the current experiment, unlike in Henderson and Ferreira's, there was no interaction between post-lexical processing on word N and lexical processing on word N + 1. However, Henderson and Ferreira's finding of an interaction may have been related to the interference caused by, and the reprocessing necessitated by, initially processing a nonsense string in the dissimilar preview condition. The foveal-load hypothesis might not predict an interaction under conditions like those in the current experiment, in which all words are presented correctly. If this is the case, then a better test of the foveal-load hypothesis is whether the main effects of complexity in first-fixation and gaze duration on word N spilled over onto word N + 1. This prediction follows from the assumption that what drives the eyes to saccade after initially fixating a word is the completion of an initial stage of lexical processing (e.g. Reichle et al., 1998). If this is the case, first-fixations, and possibly gaze durations, on a word should be longer the less parafoveal pre-processing that word received. In Henderson and Ferreira's (1990) data for conditions with correct previews, the syntactic complexity effect on word N did spill over onto first-fixation durations on word N + 1; although the reliability of this effect was not statistically tested, it was quite large and probably real. In the current experiment, there was no such spill over. One possible account for this discrepancy is the difference in the kind of post-lexical processing necessitated in the two experiments. Henderson and Ferreira's manipulation of syntactic complexity involved introducing a word with an unexpected syntactic category. This was a surprise to readers and forced them to revise their syntactic representations- a process that was likely not too difficult in this case, and that readers probably finished before reading further so that they could incorporate any further words into the newly-built correct structure. The current experiment's manipulation was different. Readers could anticipate that a point of high syntactic complexity was imminent based on the fact that the beginning of the sentence necessitated a cleft structure. More importantly, readers may have been unable to fully resolve the correct structure and meaning at the critical word, because of the difficult memory retrievals that were necessary. These considerations suggest that post-lexical processing difficulty may have been more distributed in the current experiment, and readers may have been more likely to read on with vague or incom-

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plete post-lexical representations than in Henderson and Ferreira's experiment. If this were the case, it would explain why post-lexical processing did not delay lexical processing in the current experiment.

Counter to Kliegl et al. (2006)'s interpretation of the foveal-load hypothesis, structural complexity and lexical frequency did not interact in the eye movement data. The pattern of means in gaze duration on the adverb was actually counter to this prediction, with a numerically larger difference in the structurally simple conditions. There are two relevant points here. First, as discussed above, it is not clear that the foveal-load hypothesis must predict a superadditive interaction on word N + 1. If increased post-lexical processing on word N simply delays the initiation of lexical processing on N + 1, there is no reason to expect that delay to interact with the duration of lexical processing. Second, the interaction Kliegl et al. (2006) observed was between lexical frequency on words N and N + 1, perhaps indicating that the same kind of processing must be cascaded in order to cause an interaction.

The findings of the current experiment suggest that lexical processing on word N + 1 may not have to wait for post-lexical processing on word N to either progress to some predetermined point or be completed. Evidence for this is the fact that first fixation and gaze durations on word N + 1 were unaffected by the manipulation of post-lexical processing on word N, and that there were no interactions between the post-lexical and lexical manipulations on words N and N + 1. These findings also suggest that lexical and post-lexical processing may rely on at least somewhat independent resources or processes. This characterization is consistent with the E-Z Reader model's (Reichle et al., 2009) assumptions about how post-lexical and lexical processing progress, namely that lexical processing on word N + 1 begins immediately upon completion of lexical processing on word N, without having to wait for post-lexical processing on N + 1, and that if post-lexical processing on word N affects eye movements on word N + 1 it does so via regressions and rereading.

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Appendix

Experimental items: conditions a and c used the low frequency adverb, which is first; conditions b and d used the high frequency adverb, which is second. To create conditions c and d from a and b, add an "it was" to the beginning of the sentence and replace "and" with "who," as in 1 below.

1a-b) Tim and Sam wrestled noisily/outside during practice yesterday.
1c-d) It was Tim who Sam wrestled noisily/outside during practice yesterday.
2a-b) Paul and Sue cuddled happily/closely while watching a movie.
3a-b) Cara and Molly debated heatedly/recently about who to vote for in the election.
4a-b) Mike and John were meeting locally/already to formulate a budget for the business.
5a-b) Joe and Lisa married hastily/quickly on a vacation to Las Vegas.
6a-b) Colette and Mark kissed eagerly/exactly once on the train.
7a-b) Kristen and Holly fought vocally/largely about U.S. foreign policy.
8a-b) Leah and Brian snuggled routinely/primarily when it was cold at night.
9a-b) Steve and Rob saluted solemnly/properly at the military funeral.
10a-b) Alan and Debbie divorced nicely/fairly after ten years of marriage.
11a-b) Jeff and Sarah dated socially/recently for several months.
12a-b) Rick and Ben battled madly/later for control of the TV remote.
13a-b) Beth and Nick embraced snugly/slowly for the first time in years.
14a-b) Colin and Alex debated adamantly/carefully about standardized testing in schools.
15a-b) Tom and Kate kissed tirelessly/frequently while in the movie theater.
16a-b) Rachel and Nicole hugged emotionally/immediately following the football team's big win.
17a-b) Josh and Drew wrestled superbly/recently at the national championship tournament.
18a-b) Ben and Dave debated stubbornly/frequently during family dinners.
19a-b) Allison and Susan were meeting irregularly/immediately following the conference.
20a-b) Phil and Karen fought aloud/twice about the death penalty.
21a-b) Irene and Victor snuggled shyly/often while watching the fireworks.

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22a-b) Eddie and Megan married humbly/abroad in a small ceremony.
23a-b) Bill and Christina hugged intimately/frequently before leaving the house.
24a-b) Marie and Robert embraced stiffly/quickly when no one was watching.

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