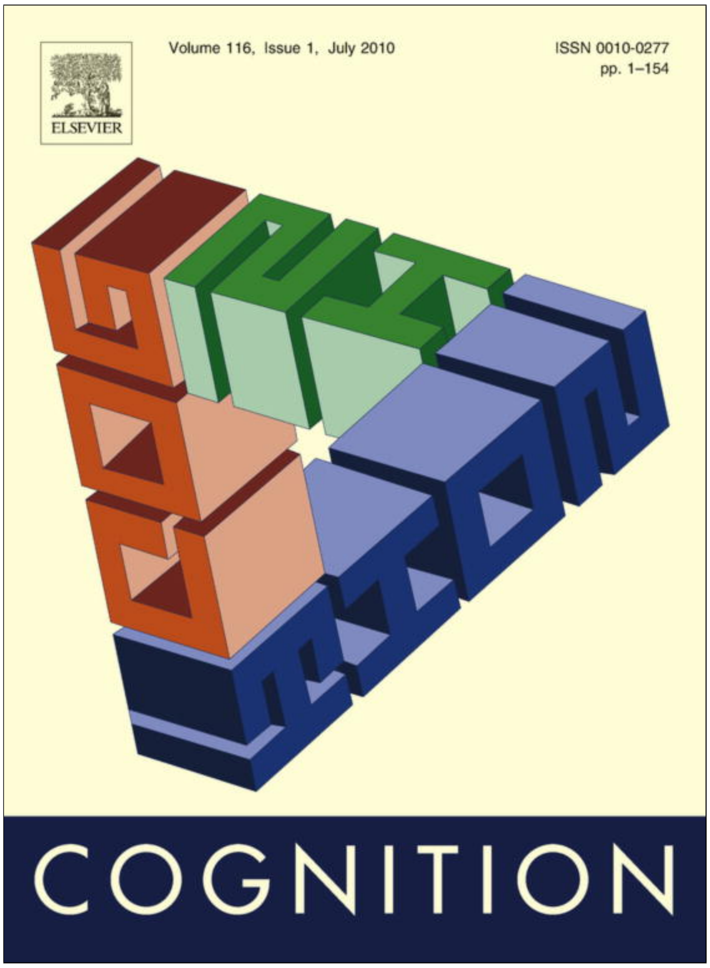
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Eye movements and processing difficulty in object relative clauses

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ABSTRACT

It is well known that sentences containing object-extracted relative clauses (e.g., *The reporter that the senator attacked admitted the error*) are more difficult to comprehend than sentences containing subject-extracted relative clauses (e.g., *The reporter that attacked the senator admitted the error*). Two major accounts of this phenomenon make different predictions about where, in the course of incremental processing of an object relative, difficulty should first appear. An account emphasizing memory processes (Gibson, 1998; Grodner & Gibson, 2005) predicts difficulty at the relative clause verb, while an account emphasizing experience-based expectations (Hale, 2001; Levy, 2008) predicts earlier difficulty, at the relative clause subject. Two eye movement experiments tested these predictions. Regressive saccades were much more likely from the subject noun phrase of an object relative than from the same noun phrase occurring within a subject relative (Experiment 1) or within a verbal complement clause (Experiment 2). This effect was further amplified when the relative pronoun *that* was omitted. However, reading time was also inflated on the object relative clause verb in both experiments. These results suggest that the violation of expectations and the difficulty of memory retrieval both contribute to the difficulty of object relative clauses, but that these two sources of difficulty have qualitatively distinct behavioral consequences in normal reading.

1. Introduction

One of the most reliable and widely-discussed findings in the sentence processing literature is the difference in comprehension difficulty between two types of English relative clause. In subject-extracted relative clauses (SRCs), as in (1a), the noun that is modified by the relative clause (*reporter*) is also the agent of the relative clause verb (*attacked*), and on a standard syntactic analysis is linked to a phonologically empty element in the verb's subject position (e.g., Haegeman, 1994; Heim & Kratzer, 1998). In object-extracted relative clauses (ORCs), as in (1b), the modified noun is the theme or patient of the relative clause verb, and is linked to an empty element in object position.

(1) a. The reporter that attacked the senator admitted the error.
b. The reporter that the senator attacked admitted the error.

A standard finding, from a wide range of paradigms, is that ORCs are harder to process than SRCs (e.g., Gordon, Hendrick, & Johnson, 2001; King & Just, 1991; Traxler, Morris, & Seely, 2002; see also, e.g., Mak, Vonk, & Schriefers, 2002, 2006, for Dutch, and Friederici, Steinhauer, Mecklinger, & Meyer, 1998, for German). This difficulty difference is modulated by a range of factors, such as the animacy and semantic similarity of the noun phrases (Gennari & MacDonald, 2008; Gordon, Hendrick, & Johnson, 2004; Gordon et al., 2001; Traxler, Williams, Blozis, & Morris, 2005). The effect is clearly not attributable to lexical factors, as the same words are present in (1a) and (1b). The difficulty of

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ORCs would also appear to be distinct from the difficulty that occurs in garden path sentences, in which there is a temporary ambiguity between two syntactic analyses, with the parser initially choosing the incorrect analysis (e.g., Frazier & Rayner, 1982). Thus, this finding suggests a role for a syntactic processing strategy or resource that is operative in relatively simple, unambiguous sentences, the deployment of which has measurable consequences.

An influential proposal due to Gibson and colleagues (e.g., Gibson, 1998; Grodner & Gibson, 2005; Warren & Gibson, 2002) attributes the difficulty of ORCs to the operations of working memory. The argument proceeds as follows. In both (1a) and (1b) there is a syntactic and thematic dependency between the matrix subject (*the reporter*) and the relative clause verb (*attacked*). *The reporter* must therefore be held in memory until *attacked* is encountered, at which point it must be retrieved. Critically, the retrieval of *the reporter* is likely to be more difficult when this element is farther back in the sentence, with other material intervening; Lewis and colleagues (Lewis & Vasishth, 2005; Lewis, Vasishth, & Van Dyke, 2006) have explicitly emphasized the role of retrieval interference. In (1b), the reader or listener must, upon encountering *attacked*, retrieve *the reporter* over the intervening element *the senator*; in (1a), there is no such intervening material. Gibson and colleagues have claimed that it is essentially this difference in retrieval difficulty (or, in the terminology of Gibson, 1998, "integration cost") that explains the overall difference in comprehension difficulty. More generally, Gibson and colleagues have claimed that the proximity (or *locality*) of the elements that participate in grammatical dependencies predicts on-line comprehension difficulty in a range of sentence types, with long-distance dependencies leading to difficulty at the point of integration.

A rather different theory of the difficulty of ORCs is based on the claim that comprehenders anticipate likely sentence continuations, and that syntactic processing difficulty is inversely related to the degree to which the input accords with these expectations (Hale, 2001; Levy, 2008; cf. Frazier & Fodor, 1978; Kimball, 1975). According to this view, ORCs are difficult primarily because they are uncommon compared to SRCs (Roland, Dick, & Elman, 2007). After encountering the relativizer *that* in (1), an SRC is a much more likely continuation than is an ORC, and therefore an SRC is preferentially expected by the reader or listener. An ORC is therefore surprising, and difficulty-inducing.

In what follows, these two general ways of accounting for ORC difficulty will be referred to as the *memory-based* and *expectation-based* accounts. There is an appealing symmetry between them, as they emphasize, respectively, the role of backward-looking and forward-looking processes in language comprehension. There is, indeed, substantial evidence that both memory retrieval (e.g., Martin & McElree, 2008; McElree, Foraker, & Dyer, 2003) and structural prediction (e.g., Lau, Stroud, Plesch, & Phillips, 2006; Staub & Clifton, 2006) are involved in syntactic processing.

Grodner and Gibson (2005) conducted two experiments that were designed, in part, to test competing predictions of these two accounts of ORC processing difficulty. These predictions relate to the point at which difficulty should first arise in the course of incremental processing of an ORC. Grodner and Gibson pointed out that, in contrast to the memory-based account's prediction of difficulty at the ORC verb (*attacked* in 1b), expectation-based accounts predict difficulty at the point at which a rare construction is first encountered, i.e., at the subject of the ORC (*the senator* in 1b). Levy (2008) notes that on his Surprisal model, according to which difficulty on an input word is a function of the probability mass that the parser has assigned to the syntactic structures that are pruned away by this word, "The cost of low expectation for object RCs should be paid at the embedded subject, which is where the bulk of the expectation devoted to seeing a subject-extracted RC is pruned away" (Levy, 2008, p. 1164; see Hale, 2001, for an explicit simulation of processing difficulty on the first word of an ORC).

Grodner and Gibson (2005) employed a non-cumulative, word-by-word self-paced reading paradigm (Just, Carpenter, & Wooley, 1982), in which participants press a button to reveal the sentence one word at a time, with each word disappearing as the next is displayed. In their first experiment they compared SRCs and ORCs as in (1a and b), and found no slowdown in reading time on the noun phrase within an ORC (*the senator*), compared to the same noun phrase within an SRC; indeed, per word response times (RTs) on this phrase were an average of 7 ms shorter in an ORC than in an SRC. (Though the presentation of the experimental sentences was word-by-word, Grodner and Gibson reported results only for the entire noun phrase region.) However, they found a significant 67 ms slowdown on the verb within an ORC (*attacked*), compared to the same verb within an SRC. This pattern is clearly consistent with the predictions of the memory-based account of ORC difficulty. The results of a second experiment argued against the possibility that slower reading of the verb in the initial experiment was actually due to difficulty processing the relative clause subject that appeared only downstream, rather than appearing on the subject itself. In this second experiment, inserting material between the relative clause subject and the verb (e.g., *The administrator who the nurse from the clinic supervised*...) actually increased, rather than decreased, reading times on the verb, and there was no reliable reading time increase on the intervening material (*from the clinic*) compared to a control condition in which this material appeared in a matrix clause. The increase in reading time on the verb with more intervening material is predicted by a memory-based account, but cannot be explained by spillover. Levy (2008) notes that his own Surprisal model predicts the reverse pattern, with shorter reading times on the ORC verb as more material intervenes between subject and verb.

In contrast to Grodner and Gibson (2005), Gennari and MacDonald (2008) conducted a self-paced reading study that found a slowdown on the ORC subject, in certain conditions. Thus, there is some inconsistency within studies using the self-paced reading paradigm. But in addition, radically different results have recently been reported by Forster, Guerrera, and Elliot (2009) in two experiments using the "maze" task (e.g., Nicol, Forster, & Veres, 1997). In this task, readers move through a sentence in a self-paced, word-by-word manner, as in the standard non-cumulative self-paced reading task. Unlike in that task, however, each word is presented together with a word in a different syntactic category. For each pair of words, the participant must press either a left or right button to select the member of the pair that could continue the sentence in a sensible manner. For example, after reading the initial word *The*, the two words *banker* and *amazes* would be presented. The participant would choose *banker*, at which point the two words *that* and *truck* would be presented. The participant would then choose *that*, and so on.

As in other studies, Forster et al. (2009) found that ORCs took longer to read than SRCs. However, a comparison of RTs for each word revealed that the effect was restricted to the determiner, which elicited 137 ms longer RTs in the ORC condition than in the SRC condition. Relative clause type did not affect RTs for the noun or the verb. Essentially the same pattern was obtained in a follow-up experiment that paired each word with a nonword, rather than with a word in a different syntactic category, requiring, in effect, a forced-choice lexical decision response for each frame. In this experiment there was a significant 64 ms effect for the determiner, and again there were no reliable effects for the noun or verb. In sum, in the maze task, the difficulty in processing ORCs appeared entirely at the very beginning of the clause: In a sentence such as (1b), participants took a relatively long time to select *the* as a sensible continuation after, e.g., *The reporter that*, when this word was paired either with a word from a different syntactic category or with a nonword, with no additional slowdown appearing on the subsequent noun (*senator*) or the following verb (*attacked*). Forster et al. (2009) interpreted the localized effect on the ORC determiner as reflecting the need to overcome an experience-based "bias" toward SRCs; they suggested that once the participant has overcome this bias, as she must do in order to recognize *the* as a possible continuation following *that*, there is no additional difficulty in processing an ORC.

Thus, the standard self-paced reading task and the maze variant have delivered opposed verdicts about whether readers experience difficulty at the beginning of an ORC, or at the ORC verb. The maze task explicitly requires the participant to accept each word as a possible sentence continuation (or more precisely, as a better continuation than the other member of the pair), and under these circumstances the determiner that begins an ORC elicits long RTs. But when an explicit word-by-word judgment of acceptability is not required, as in the standard self-paced reading task, it appears that difficulty does not reliably appear until the ORC verb (though cf. Gennari & MacDonald, 2008).

The present paper addresses two questions related to this conflicted state of affairs. First, it asks whether, in normal reading, difficulty in processing ORCs appears at the ORC subject, the ORC verb, or both. This question is addressed by focusing on the details of the eye movement record for each word of the relative clause, in two experiments in which readers' eye movements are monitored during normal reading. Second, it asks how any difficulty that does appear at each of these points is manifested. Unlike self-paced reading and the maze task, the eyetracking paradigm delivers multi-dimensional data. Disruption to normal left-to-right processing may take the form of an increase in fixation durations, an increase in the probability of a regressive (i.e., leftward) saccade, or both. It will be argued that these data patterns have plausibly distinct theoretical interpretations, and that the actual pattern of results informs our understanding of the nature of the difficulty associated with ORCs.

It is important to note that three previous experimental studies, each consisting of multiple experiments, have compared readers' eye movements when processing English SRCs and ORCs (Gordon, Hendrick, Johnson, & Lee, 2006; Traxler et al., 2002, 2005), with all of these studies finding evidence for increased difficulty in ORCs, generally in the form of an increase in the incidence of regressive eye movements out of an ORC, and a corresponding increase in reading time measures that include fixation durations during regressive re-reading. (With the exception of a single experiment, Traxler et al., 2002, Experiment 3, there has been no significant increase in first pass reading time on an ORC compared to an SRC.) But somewhat surprisingly, none of these studies has separately examined eye movement behavior on the individual words within the relative clause; in all cases, the entire relative clause was treated as a single region for the purpose of analysis of the eye movement data. Thus, we have no information from these studies about whether the difficulty that appears in the eye movement record arises when the reader encounters the subject of the ORC, the verb of the ORC, or both.

A corpus-based study by Demberg and Keller (2007) comes closest to addressing the question of interest. Demberg and Keller applied a mixed-effects regression model to eye movement data from the Dundee Corpus (Kennedy & Pynte, 2005), including in the model factors such as word length, word frequency, and the landing position of the eyes within each word. They found that for verbs occurring within relative clauses, relative clause type was indeed a significant predictor of readers' first fixation duration (the duration of the first fixation on the word, when the word was fixated on first pass reading), gaze duration (the summed duration of all first pass fixations), and total time (the sum of all fixations on the word). For each of these measures, readers spent longer on the verb when it appeared within an ORC. They also compared reading times on the word following the relative pronoun (*attacked* in 1a, *the* in 1b), and found that (again including length and frequency in the model) first fixation durations were actually longer for SRCs than for ORCs. The first of these results was interpreted as supporting a memory-based model (specifically, Gibson, 1998), while the latter result was interpreted as especially problematic for accounts emphasizing experience-based expectations (specifically, Hale, 2001), which predict long reading times on the first word of an ORC.

However, these results should be viewed with some caution. First, Roland (2009) has shown that Demberg and Keller's finding of longer reading times on a verb within an ORC than on one within an SRC is due to a single extremely difficult ORC sentence in the Dundee corpus. When this one sentence is excluded, the highly significant effect of relative clause type ($p < .01$ for total time) is now far from significance ($p = .56$). Second, the finding of longer reading times on the word following the relative pronoun in an SRC than in an ORC depends on a comparison between words with radically different lexical characteristics, usually verbs vs. determiners. Unsurprisingly, Demberg and Keller found that the rate of word skipping was very different in the two conditions, as word length and frequency both influence skipping probability (e.g., Drieghe, Rayner, & Pollatsek, 2005).

Experiment 1 of the present paper simply tested the classic contrast exemplified in (1), separately examining eye movement patterns on each word within the relative clause. To anticipate the results, disruption first appeared on the ORC subject, but also appeared later, at the ORC verb. Notably, these effects were different in kind, with the first appearing exclusively in regression-based measures, and the latter appearing in measures of first pass reading time. Experiment 2 then tested ORCs against a different control condition, one in which the same lexical material, in the same order, appeared within a verbal complement clause. Experiment 2 also tested the effect of omitting the relative pronoun on the processing of ORCs, in order to further explore the predictions of an expectation-based account, and to investigate the potential role of syntactic misanalysis (Clifton & Frazier, 1989; Frazier & Clifton, 1989; Traxler et al., 2002).

Before proceeding, it should be noted that the integration cost theory of Gibson (1998; Grodner & Gibson, 2005) and the Surprisal theory of Hale (2001) and Levy (2008) may be seen as representative of larger classes of memory-based (e.g., Gordon et al., 2001; Just & Carpenter, 1992; Lewis & Vasishth, 2005; Waters & Caplan, 1996) and experience-based (Gennari & MacDonald, 2008; MacDonald & Christiansen, 2002; Reali & Christianson, 2007) accounts of ORC difficulty. The present focus on the Gibson account on the one hand, and the Hale/Levy account on the other, is motivated by the fact that these two theories make relatively explicit, and opposed, predictions about where difficulty should appear in ORCs. For example, though the Lewis and Vasishth (2005) model predicts difficulty at the verb in an ORC, due to retrieval costs, this model also predicts difficulty at the start of the ORC, due to an expectation-based component in the form of a left-corner parsing algorithm.[1] (Indeed, even within the model proposed by Gibson (1998), in addition to the integration cost that is localized to the ORC verb, there is also a "storage cost" that slows processing while a long-distance dependency is unresolved, i.e., between the matrix subject and the verb in an ORC (see also Chen, Gibson, & Wolf, 2005); however, this element of the theory proposed by Gibson (1998) does not figure in the predictions made by Grodner and Gibson (2005).) Similarly, though MacDonald and Christiansen (2002) attribute the difference in processing difficulty between SRCs and ORCs to the relative frequency of each of these structures in the comprehender's experience, their implemented model actually predicts long reading times at the ORC verb. The question of which, if any, of the existing accounts successfully predicts the patterns observed in the present experiments will be taken up in the General Discussion.

2. Experiment 1

2.1. Method

2.1.1. Participants

Twenty-eight students at the University of Massachusetts Amherst participated in the experiment in exchange for course credit. All were native speakers of English, had normal or corrected-to-normal vision, and reported no reading or other language-related disorders.

2.1.2. Materials

The materials for this experiment consisted of 24 pairs of sentences similar to example (2), in which a sentence-initial subject was modified by either an SRC (2a) or an ORC (2b); the only difference between the sentences in each pair was the word order within the relative clause.

(2) a. The employees that noticed the fireman hurried across the open field.
b. The employees that the fireman noticed hurried across the open field.

In 16 of the 24 items, the relative pronoun *who* was used, while *that* was used in the remaining eight items. The full set of items is provided in Appendix A.[2]

The items were separated into two lists, so that each subject read one version of each sentence and 12 of each type overall. The 24 experimental sentences were intermixed with 116 unrelated fillers, and presented to each participant in an individually randomized order after eight practice trials. Two-choice comprehension questions were presented after approximately 60% of all trials in the experiment, including fillers; average accuracy was 79.1%. This overall level of accuracy was affected by the fact that some comprehension questions, associated with filler items that were part of unrelated experiments, were designed to be especially difficult; when questions associated with these subexperiments are excluded, average accuracy was 94.4%.

In order to investigate a question unrelated to the topic of the present article, the frequency of the matrix verb was also manipulated. For example, for sentence (2) half of the participants read a version in which *hurried* was replaced by the lower-frequency verb *hustled*. While there were clear effects of word frequency on reading times on this verb, there was no hint of an interaction between the frequency manipulation and the clause type manipulation, on any measure (all $ps > .2$). The analyses presented here collapse over the frequency manipulation.

[1] Thanks to Shravan Vasishth for pointing this out, and for providing predicted RTs, based on the Lewis and Vasishth (2005) model, for the determiner *the* within an SRC and ORC: 150 ms and 279 ms, respectively.

[2] It was intended for both noun phrases (e.g., *the employees* and *the fireman*) to denote animate entities, but due to an oversight, there was a single item in which both noun phrases were inanimate. To accommodate one of the conditions in Experiment 2, this one item had to be modified for that experiment (see below). In neither experiment did inclusion of this item affect the patterns of means or statistical significance.

2.1.3. Procedure

Subjects were tested individually, and eye movements were recorded using an EyeLink 1000 (SR Research, Toronto, Ontario, Canada) eyetracker, interfaced with a PC computer. The sampling rate was 1000 Hz. Stimuli were displayed on an Iiyama CRT monitor. Subjects were seated 55 cm from the computer screen. At this distance, 3.69 characters subtended 1° of visual arc. The angular resolution of the eyetracker is 10–30 min of arc. Viewing was binocular, but only the right eye was recorded. All critical sentences were displayed on a single line. Sentences were presented in 11 pt Monaco font. Before the experiment began, each participant was instructed to read for comprehension in a normal manner. A calibration procedure was then performed, and re-calibration was carried out between trials as needed. The participant triggered the onset of each sentence by fixating a box on the left edge of the computer screen. The experiment lasted approximately 45 min. The experiment was implemented using the EyeTrack software, and initial stages of data analysis were carried out using EyeDoctor and EyeDry (http://www.psych.umass.edu/eyelab/software/).

2.2. Results

Prior to analysis, trials on which there was a track loss or any other data collection error were deleted. A total of 37 trials were deleted on this basis. In addition, eye fixations less than 80 ms in duration, and within one character of the previous or subsequent fixation, were incorporated into this neighboring fixation. Remaining fixations shorter than 80 ms or longer than 1000 ms were deleted; 1.6% of fixations fell below the 80 ms cutoff, while a total of four fixations, none of which fell on a critical region, exceeded the 1000 ms cutoff.

For the purpose of analysis of the eye movement data, the critical sentences were divided into regions as illustrated in (3):

(3) a. The employees| that| noticed| the| fireman| hurried| across the open field.
b. The employees| that| the| fireman| noticed| hurried| across the open field.

Results for the regions 2–6 (i.e., the relative pronoun through the matrix verb) will be discussed below. For each word, three reading time measures were computed. *First fixation duration* is the duration of the reader's first eye fixation on the word, for those trials on which the region was fixated on the reader's first pass through the sentence. *Gaze duration* is the sum of all first pass fixations on the word before leaving it for the first time, either to the left or to the right. *Go-past time* is the sum of all fixations beginning with the first fixation on the critical word (again, including only those trials on which the reader made a first pass fixation) until the reader leaves the critical word to the right, including any time spent to the left of the critical word as a result of regressive eye movements and any time spent re-reading the critical word before moving on to the rest of the sentence. Two binary dependent measures were also computed: the proportion of trials on which the reader's first pass through the word ended with a regressive saccade to an earlier region of the sentence, rather than a forward saccade; and the proportion of trials on which the word was skipped on first pass reading. See Staub and Rayner (2007) for discussion of these and other eye movement measures.

The overall reading time means and the proportion of trials on which there were regressions and skips, for each region, are shown in Table 1. To assess the statistical

Table 1

Means (in ms) for reading time measures, and proportions for regressions and skipping measures, by condition, for each critical word of sentences in Experiment 1. Significant and marginal effects based on linear mixed effects models described in the text are identified ($p < .01^{**}$; $p < .05^{*}$; $p < .10^{\wedge}$).

	Relative pro (*that*)	Determiner (*the*)	Noun (*fireman*)	RC verb (*noticed*)	Matrix verb (*hurried*)
First fixation duration					
SRC	224	230	239	223	286
ORC	232	231	222	267	286
RC type effect	8	1	-17^{**}	44^{**}	0
Gaze duration					
SRC	237	239	316	270	357
ORC	250	249	266	318	346
RC type effect	$13^{\wedge}$	10	-50^{**}	48^{**}	−11
Go-past time					
SRC	283	272	375	333	429
ORC	303	382	459	420	432
RC type effect	20	110^{**}	84^{**}	87^{**}	3
p(regress)					
SRC	0.12	0.12	0.16	0.17	0.11
ORC	0.11	0.36	0.40	0.15	0.11
RC type effect	−0.01	0.24^{**}	0.24^{**}	−0.02	0.00
p(skip)					
SRC	0.32	0.55	0.12	0.10	0.02
ORC	0.32	0.48	0.12	0.03	0.02
RC type effect	0	$-0.07^{\wedge}$	0	-0.07^{**}	0

reliability of the reading time effects, a linear mixed effects model (Baayen, Davidson, & Bates, 2008) was fit to the data for each dependent measure on each word, with random intercepts for subjects and items, and with relative clause type as a fixed effect. Analysis of the regressions out and skipping measures used mixed effects logistic regression, with the same random and fixed factors (Jaeger, 2008). Analyses were carried out using R, an open source programming language and environment for statistical computing (R Development Core Team, 2007), and in particular the lme4 package for linear mixed effects models (Bates, 2005; Bates & Sarkar, 2007). Models with random subject and item slopes were also constructed, to assess variability in the size of the experimental effects across subjects and items. Based on log likelihood comparison, the larger model was found to have a significantly better fit, at the .05 level, for only four of 25 analyses (5 dependent measures × 5 regions), and for these four analyses the inclusion of random slopes did not substantially alter the model's estimate of the clause type effect, and did not alter patterns of significance. Thus, only the simpler model will be reported here. Table 2 provides the model's estimate, for each dependent measure on each word, of the effect of clause type; a positive value indicates an increase in reading time or an increase in the probability of a regression or skip in the ORC condition. *p*-values for the linear mixed effects models are based on mcmc sampling (Baayen, 2008; Bates, 2005); for logistic regression, they are based on the *z* distribution. The results for each word will be discussed in the order in which the words appear in an ORC.

Table 2
Linear mixed-effect model estimate of effect of relative clause type on each dependent measure in Experiment 1, by region, with SE of estimate, *t* or *z* value, and *p*-value. For reading time measures, a positive estimate reflects an increase in reading time, in ms, in ORC condition compared to SRC condition. For regressions and skipping, a positive estimate reflects an increase in log(odds) of a regression or a skip in ORC condition compared to SRC condition.

Relative pronoun (that)				
	Estimate (ms)	SE	*t* value	*p*-value
First fixation	9.60	7.91	1.21	.23
Gaze	15.86	9.29	1.71	.09
Go-past	22.01	16.95	1.30	.19
	Estimate (log odds)	SE	*z* value	*p*-value
Regressions out	−.06	.31	−.21	.83
Skipping	−.02	.19	−.11	.91
Determiner (the)				
	Estimate (ms)	SE	*t* value	*p*-value
First fixation	1.41	9.28	.15	.88
Gaze	9.59	11.57	.83	.41
Go-past	111.49	23.13	4.82	<.001
	Estimate (log odds)	SE	*z* value	*p*-value
Regressions out	1.58	.33	4.76	<.001
Skipping	−.28	.16	−1.76	.08
Noun (fireman)				
	Estimate (ms)	SE	*t* value	*p*-value
First fixation	−17.04	5.99	−2.85	<.01
Gaze	−46.78	13.93	−3.36	<.001
Go-past	90.38	21.75	4.16	<.001
	Estimate (log odds)	SE	*z* value	*p*-value
Regressions out	1.33	.21	6.26	<.001
Skipping	.02	.27	.06	.95
RC verb (noticed)				
	Estimate (ms)	SE	*t* value	*p*-value
First fixation	44.36	6.61	6.71	<.001
Gaze	50.76	10.99	4.62	<.001
Go-past	89.39	21.50	4.16	<.001
	Estimate (log odds)	SE	*z* value	*p*-value
Regressions out	−.14	.23	−.59	.55
Skipping	−1.36	.41	−3.35	<.001
Matrix verb (hurried)				
	Estimate (ms)	SE	*t* value	*p*-value
First fixation	.44	8.34	.05	.96
Gaze	−.10	11.62	−.86	.39
Go-past	3.50	22.47	.16	.88
	Estimate (log odds)	SE	*z* value	*p*-value
Regressions out	−.02	.26	−.08	.93
Skipping	.30	.70	.43	.67

2.2.1. Relative pronoun

On the relative pronoun (*that*), reading times were numerically longer in the ORC condition, though this difference was not reliable for any measure. There was no effect of clause type on regressions or skips. Thus, it appears that there were no reliable parafoveal-on-foveal effects (e.g., Kennedy & Pynte, 2005): The identity of the next word as a verb, as in the SRC condition, or a determiner, as in the ORC condition, did not reliably influence eye movements on the relative pronoun.

2.2.2. Determiner

The effect of clause type on first fixation and gaze duration on the determiner (*the*) did not approach significance. However, go-past time was 110 ms longer on the determiner when it occurred in an ORC, due to the fact that first pass regressions out of the determiner were much more likely in the ORC condition (36% vs. 12%). Both of these effects were highly significant. The determiner was skipped very frequently in both conditions, as would be expected due to its length and frequency (Drieghe, Pollatsek, Staub, & Rayner, 2008; Drieghe et al., 2005). Skipping was more frequent in SRCs, though this difference was only marginally significant ($p = .08$). In sum, while clause type did not influence the time readers spent on the determiner before leaving it, and had only a marginal effect on the probability of skipping this word, clause type had a very large effect on the direction of the saccade that terminated inspection of the word, and therefore had a large effect on go-past time.

2.2.3. Noun

Mean first fixation duration and gaze duration were actually shorter on the noun (*fireman*) in ORCs than in SRCs (17 ms and 50 ms effects, respectively); both of these effects were highly significant. On the other hand, mean go-past time was much longer in ORCs than in SRCs (an 84 ms effect), due to many more regressions in the ORC condition (40% vs. 16%). Again, both of these effects were highly significant. A possible explanation for this divergence between measures is discussed below. Finally, there was no hint of a skipping effect.

2.2.4. Relative clause verb

On the relative clause verb (*noticed*), all three reading time measures were significantly longer in ORCs, with much of the effect (44 ms) appearing in the first fixation duration measure. There was no effect of clause type on the probability of a regression. Though the rate of verb skipping was low in both conditions, it was significantly lower in ORCs (3%) than in SRCs (10%). However, this result may have an explanation in terms of surface word order, as the word prior to the ORC verb was a noun, while the word prior to the SRC verb was the short, high-frequency relative pronoun; Drieghe et al. (2005; see also Henderson & Ferreira, 1990) have shown that skipping rates are influenced by the processing difficulty of the preceding word.

2.2.5. Matrix verb

On the matrix verb (*hurried*) the clause type manipulation had no significant effects on any measure.

2.2.6. Supplementary analyses

Several supplementary analyses were also conducted. First, given that the determiner was frequently skipped on first pass reading, it was of interest to determine whether eye movement behavior on the noun was notably different when the determiner was skipped and when it was fixated. Unsurprisingly, the noun was much less likely to be skipped when the determiner was skipped than when it was not (2% vs. 22%; $p < .001$; as above, p-values for supplementary analyses are based on mixed models with random subject and item intercepts). The effect on noun skipping of whether the determiner was skipped was slightly larger for SRCs (1% vs. 26%) than for ORCs (3% vs. 20%), but the interaction of the two factors was only marginal ($p = .08$). First pass regressions from the noun were more common when the determiner was skipped (35% vs. 18%; $p < .001$), but there was no interaction between this factor and clause type ($p > .10$). Due to the regressions effect there was also an effect of determiner skipping on go-past time on the noun ($p < .001$), but there was no interaction with clause type, and there were no effects of determiner skipping on first fixation duration or gaze duration on the noun ($ps > .20$).

An analysis was also conducted to examine contingencies between regressing from the determiner and regressing from the noun. Overall, regressions from the noun were slightly more likely when there was no regression from the preceding determiner (29% vs. 23%; note that a skip of the determiner was counted as a no regression trial, for this analysis). Though this effect appeared to be more pronounced for ORCs (43% vs. 25%) than for SRCs (16% vs. 17%), the interaction of the two factors was not significant ($p > .10$). It is important to note that this analysis had relatively little power, due to the fact that there were few regressions from each word in the SRC condition.

Finally, an additional set of supplementary analyses assessed the extent to which eye movement behavior on the ORC verb depended on whether or not the reader had made an interword regression from either of the two words of the preceding noun phrase. Overall, the probability that a reader made at least one interword regression on this region was .50 in the ORC condition, compared to .19 in the SRC condition. Thus, on half of the trials, by the time the verb in the ORC had been reached, there was some overt indication of prior processing difficulty. Table 3 provides the means and proportions for each measure on the ORC verb, for each of the two subsets of trials. There is no indication that a prior regression modulated any aspect of the reader's eye movement behavior on the verb (all $ps > .20$).

2.3. Discussion

The results may be summarized as follows. First, there was evidence of processing difficulty on the noun phrase in an ORC, compared to an SRC, in the form of an increased probability of making a regressive saccade from each of the two words of this phrase, and a corresponding increase in go-past time on each word. However, there were no effects of clause type on first fixation duration or gaze duration on the determiner, and in fact the pattern for these measures on the noun went in the opposite direction from the go-past and regressions effects, with shorter times in the ORC condition.

The pattern across dependent measures on the noun may be related to the observation (e.g., Altmann, Garnham, & Dennis, 1992; Mitchell & Shen, 2009; Rayner & Sereno, 1994) that word inspections prior to a regression are often shorter than word inspections prior to a progressive saccade. In the present case, regressions were much more common in the ORC condition. Mitchell and Shen (2009) have noted that short fixations prior to a regression are especially likely when the processing difficulty that ultimately induces a regression actually begins on the previous word, and have shown that this prediction emerges from the most recent iteration of the E-Z Reader model of eye-movement control in reading (E-Z Reader 10; Reichle, Warren, & McConnell, 2009). Indeed, in the present experiment first fixations on the noun were much shorter before regressions than before progressions (207 ms vs. 240 ms), as were gaze durations (218 ms vs. 320 ms), with these patterns holding across both clause types. One difficulty for this explanation of the present results, however, is that even inspections of the noun that terminated in a forward saccade were shorter in ORCs than SRCs (294 ms vs. 338 ms). A second difficulty is that, as discussed below, Experiment 2 replicated the finding of an inflated regression rate out of an ORC noun, but did not replicate the finding of short first fixation and gaze durations. For present purposes, the critical results are simply that (1) there is indeed processing disruption at the very beginning of an ORC and that (2) this disruption takes the form of an increase in regressive saccades from each word of the ORC subject, rather than an increase in reading time while the eyes continue to move forward.

On the relative clause verb, there were effects on all three reading time measures, with longer reading times when the verb appeared in an ORC. A substantial amount of the increase in reading time can be localized to first fixation duration. However, readers were no more likely to make a regressive saccade from the verb in the ORC configuration than in the SRC configuration. Interestingly, reading patterns on this verb did not vary depending on whether the reader had shown signs of difficulty on the preceding noun phrase in the form of an interword regression. Thus, it is not the case that reading time on the verb is

Table 3
Means/proportions for each dependent measure on ORC verb in Experiments 1 and 2, by whether the reader did or did not make an interword regression while reading the preceding noun phrase. Note that the data for Experiment 2 are collapsed across the two ORC conditions.

	First fixation	Gaze	Go-past	p(regress)	p(skip)
Experiment 1					
Regression	272	317	425	0.16	0.04
No regression	261	319	415	0.14	0.03
Experiment 2					
Regression	262	322	391	0.10	0.02
No regression	261	315	404	0.14	0.05

inflated specifically on those trials on which the ORC subject already caused disruption; nor is it the case that there is a trade-off between the difficulty at the two locations, with inflated reading time on the verb appearing in those cases where the reader did not fully respond to the ORC subject. Reading time on the ORC verb appears to be inflated regardless of whether the reader made a regression while reading the ORC subject.

Finally, there was no effect of the clause type manipulation on the matrix verb; while some previous eye movement experiments have reported an effect of clause type on this verb (Gordon et al., 2006, Experiment 1; Traxler et al., 2002, Experiments 1 and 3; Traxler et al., 2005, Experiments 1 and 3), others have not (Traxler et al., 2002, Experiment 2; Traxler et al., 2005, Experiment 2).

In sum, these results appear to confirm that, as in the maze task (Forster et al., 2009), processing difficulty in ORCs begins as soon as a reader encounters a determiner after a relative pronoun. Unlike in the Forster et al. experiments, however, there was continued difficulty on the subsequent noun, and there was also difficulty on the relative clause verb. What is notable in the present experiment is that the difficulty on the noun phrase and the subsequent verb appear to be different in kind: The former is manifested entirely in the form of an increased rate of regressive saccades from each of the two words of the noun phrase, with no increase in first pass reading time, while the latter is manifested in the form of an increase in reading time on the verb, with no effect on the regression rate.

The interpretation of these results will be taken up in the General Discussion. First, however, it is critical to assess the extent to which the findings from Experiment 1 are due to confounding factors involved in the comparison of ORCs and SRCs. For example, it is possible, in principle, that regressions are generally quite likely out of a subject noun phrase, or are generally quite likely out of a phrase occurring after a functional element such as a relative pronoun, even when the material in question is not a relative clause subject. It is also possible, in principle, that the reading time effect on the verb is attributable to differences in the verb's linear position in the sentence in the ORC and SRC structures.

3. Experiment 2

Experiment 2 tested the reliability of the findings from Experiment 1 by comparing eye movements patterns on an ORC to identical lexical material, appearing in the same linear order, in a syntactic environment that should cause no processing difficulty, namely a verbal complement clause. An example is in (4a), with the comparable ORC in (4b):

(4) a. The employees hoped that the fireman noticed the people who were still in the building.
b. The employees that the fireman noticed hurried across the open field.

If the high rate of regressions out of the subject of an ORC is due to superficial configurational properties, then readers should also be likely to regress out of *the fireman* in (4a). If, on the other hand, this inflated regression rate is specific to encountering the subject of an ORC, no such pattern should emerge. Similarly, if the inflated reading time on the ORC verb is due to the fact that the verb appears later in the sentence in an ORC than in an SRC, this effect should disappear in the comparison of (4a and b).

Experiment 2 was also intended to investigate an additional prediction of an expectation-based account, by manipulating the presence of an overt relative pronoun. An ORC, unlike an SRC, can occur without an overt relative pronoun, as in (4c):

(4) c. The employees the fireman noticed hurried across the open field.

If the difficulty on *the fireman* in an ORC is due to a violation of experience-based expectations, this difficulty ought to become even more pronounced when *that* is absent. The probability that the words *The employees that* will continue with an ORC is low, compared to the probability that they will continue with an SRC; the probability that the words *The employees* will continue with an ORC is even lower. The relative pronoun restricts the possible continuations to relative clauses, and given this restriction, the probability of an ORC increases dramatically (Roland et al., 2007). In the terms of the Surprisal model (Hale, 2001; Levy, 2008), in the absence of the relative pronoun there are many more potential structures, associated with more probability mass, that are ruled out by the arrival of the determiner. Encountering *the* after *The employees that* eliminates the probability that the parser has assigned to the SRC structure, while encountering *the* directly after *The employees* eliminates the probability assigned to a simple active structure, a passive structure, etc. (It is worth noting that the prediction of increased ORC difficulty in the absence of a relative pronoun has not, to this author's knowledge, been explicitly derived in any expectation-based model, as has the more general prediction of ORC difficulty.)

The comparison of ORCs with and without a relative pronoun also serves to test a prediction of a rather different explanation of ORC difficulty, the Active Filler account of Frazier and Clifton (Clifton et al., 1989; Frazier et al., 1989), which also predicts difficulty on the subject noun phrase of an ORC. According to this account, ORCs are difficult to process because they actually do contain a short-lived syntactic ambiguity, and comprehenders tend to initially adopt the incorrect analysis. The Active Filler account (which has been used to explain a range of processing phenomena involving long-distance dependencies; see Staub, 2007; Staub, Clifton, & Frazier, 2006, for discussion) proposes that when a comprehender encounters an element (a "filler") that is associated with an empty syntactic constituent later in the sentence (a "gap"), the parser posits the gap at the first licensed location, reanalyzing if necessary. The relativizer *that* is such a filler, and the first licensed gap site would be a subject gap immediately following this word, leading to the analysis in (5a). But encountering *the fireman* would alert the reader that this analysis cannot be correct, leading to processing difficulty; this is known as a "filled gap effect" (e.g., Frazier et al., 1989; Stowe, 1986). The correct analysis is in (5b).

(5) a. The employees that$_i$ t_i
b. The employees that$_i$ the fireman noticed t_i

Interestingly, this account predicts that ORCs should become easier to process, not harder, in the absence of the overt relativizer. If there is no overt relativizer, there is no syntactic ambiguity that can trigger the erroneous postulation of a subject gap in the relative clause, so no processing difficulty is predicted. When the parser encounters *the fireman* in (4c), the only possible relative clause analysis is one on which this phrase is the subject of a relative clause that will ultimately contain an object gap.[3] Thus, assuming that the contrast between (4a) and (4b) reinforces the conclusion that readers do experience difficulty on the subject of an ORC, the contrast between (4b) and (4c) may elucidate the cause of this difficulty: If (4c) is even more difficult than (4b), this is broadly consistent with the predictions of an expectation-based account, while if it is less difficult, this favors the Active Filler account.

3.1. Method

3.1.1. Participants

Thirty students at the University of Massachusetts Amherst participated in the experiment in exchange for course credit. All were native speakers of English, had normal or corrected-to-normal vision, and reported no reading or other language-related disorders.

[3] Note that an analysis on which the two initial noun phrases are part of a conjunction, with a missing comma, may also be possible in principle, e.g., *The employees the fireman and the police chief all watched the cloud of smoke.*

3.1.2. Materials

Twenty-four triplets like the sentences in (4a–c) were constructed for this experiment, based on the materials used in Experiment 1. The (b) version of each item was based on an ORC item from Experiment 1, with the modification that all items used the relative pronoun *that*. The other two versions were created by inserting the critical material in a complement clause with the complementizer *that*, as in (4a), and by eliminating the overt relative pronoun from the first version, as in (4c). See Appendix A for the full list of items. Each participant read one version of each of the items, and eight of each type overall. The 24 experimental items were intermixed with 108 unrelated fillers, and presented in a random order to each participant following eight practice trials. Questions appeared after approximately 1/3 of all trials, including fillers; participants averaged 85.4% correct.

3.1.3. Procedure

The procedure was identical to Experiment 1.

3.2. Results

A total of 47 trials were deleted due to track loss. Fixations shorter than 80 ms were again deleted (2.3% of fixations), while no fixations exceeded the 1000 ms cutoff. For the purpose of data analysis, sentences were divided into regions as shown in (6):

(6) a. The employees hoped| that| the| fireman| noticed| the people who were still in the building.
b. The employees| that| the| fireman| noticed| hurried| across the open field.
c. The employees| the| fireman| noticed| hurried| across the open field.

The same reading time measures were computed as in Experiment 1. The reading time means and the probability of a regression or skip, for each region, are shown in Table 4.

As for Experiment 1, mixed effects models with random subject and item intercepts were used to assess the reliability of the experimental effects. Two comparisons were of primary interest: the comparison between conditions (a) and (b), which will be referred to as the *relative clause effect*; and the comparison between conditions (b) and (c), which will be referred to as the *absent pronoun effect*. (Obviously, for the relative pronoun/complementizer region, only the former of these effects could be analyzed; for the matrix verb region, only the latter could be analyzed.) To capture these effects, the model employed treatment coding in which the (b) condition served as the intercept, allowing for direct comparison of each of the two other conditions with this baseline. The parameter estimates for the relative clause effect, and associated *p*-values, are shown in Table 5, and for the absent pronoun effect this information is in Table 6. Note that because condition (b) was treated as the model intercept, longer reading times, or more regressions or skips, in condition (b) compared to condition (a) are associated with negative estimates in Table 5. As for Experiment

Table 4
Means (in ms) for reading time measures, and proportions for regressions and skipping measures, by condition, for each critical word of sentences in Experiment 2. The *relative clause effect* is (ORC with *that* – comp clause); the *absent pronoun effect* is (ORC without *that* – ORC with *that*). Significant and marginal effects are identified ($p < .01^{**}$; $p < .05^{*}$; $p < .10^{\wedge}$).

	Pronoun/comp (*that*)	Determiner (*the*)	Noun (*fireman*)	Embedded verb (*noticed*)	Matrix verb (*hurried*)
First fixation duration					
Comp clause	233	208	225	258	–
ORC with *that*	251	215	227	261	270
ORC without *that*	–	263	237	261	272
Relative clause effect	18*	7	2	3	–
Absent pronoun effect	–	48**	10	0	2
Gaze duration					
Comp clause	251	212	270	298	–
ORC with *that*	267	218	270	320	319
ORC without *that*	–	305	284	317	319
Relative clause effect	16^	6	0	22*	–
Absent pronoun effect	–	87**	14	−3	0
Go-past time					
Comp clause	283	268	333	359	–
ORC with *that*	321	332	400	378	374
ORC without *that*	–	422	591	417	389
Relative clause effect	38*	64*	67^	19	–
Absent pronoun effect	–	90**	191**	39	15
p(regress)					
Comp clause	.06	.19	.14	.11	–
ORC with *that*	.12	.35	.23	.09	.10
ORC without *that*	–	.31	.50	.16	.12
Relative clause effect	.06^	.16**	.09*	−.02	–
Absent pronoun effect	–	−.04	.27**	.07*	.02
p(skip)					
Comp clause	.39	.44	.12	.06	–
ORC with *that*	.30	.48	.14	.04	.03
ORC without *that*	–	.54	.05	.04	.02
Relative clause effect	−.09*	.04	.02	−.02	–
Absent pronoun effect	–	.06	−.09**	0	−.01

1, each model was compared to a larger model with random subject and item slopes as well as intercepts. Unlike in Experiment 1, there were two analyses in which this larger model was found to result in a significant improvement in model fit and also eliminated what was a significant effect in the smaller model. These cases are discussed below.

3.2.1. Relative pronoun/complementizer

There were effects on all reading time measures on the word *that*, with significantly longer first fixation and go-past times on the relative pronoun than on the complementizer, and marginally longer gaze durations. In addition, there were marginally more regressions out of the relative pronoun, and significantly fewer skips of the relative pronoun. However, it was on this region that the model with random subject and item slopes delivered a better fit, and a different verdict, than the simpler model: Neither the first fixation effect nor the go-past effect was fully significant in the larger model, with t values of 1.55 and 1.42 respectively. Thus, the relative clause effect on reading time on the word *that* should be viewed with some caution.

3.2.2. Determiner

There was no relative clause effect on first fixation or gaze duration on the determiner. However, there was a significant effect on go-past time, due to the fact that there was a significant relative clause effect on regression probability, with more regressions from the determiner in the ORC with *that* condition than in the complement clause condition. The relative clause effect on skipping was not significant. There was a significant absent pronoun effect on all three reading time measures, with longer reading times when the pronoun was absent. The absent pronoun had no effect on either the regression rate or the skipping rate.

3.2.3. Noun

There was no relative clause effect on first fixation duration or gaze duration on the noun, but there was a marginal relative clause effect on go-past time. The relative clause effect on the regression rate was significant, with more regressions in the ORC with *that* condition than in the complement clause condition. The relative clause effect on skipping was not significant. There was no absent pronoun effect on first fixation or gaze duration, but there were large and significant effects on both go-past time and the regression rate, with more regressions and longer go-past times in the absent pronoun condition. The absent pronoun did significantly affect skipping, with fewer skips of the noun when the pronoun was absent.

3.2.4. Embedded verb

The only significant relative clause effect on the embedded verb was on the gaze duration measure, with longer gaze duration in the ORC with *that* condition than in the complement clause condition. The only significant absent pronoun effect was on the probability of a regression.

Table 5
Linear mixed-effect model estimate of relative clause effect on each dependent measure in Experiment 2, by region, with SE of estimate, *t* or *z* value, and *p*-value. Note that the ORC with *that* condition served as the intercept for treatment coding; thus, a negative estimate reflects shorter reading times, or fewer regressions or skips, in complement clause condition compared to ORC with *that* condition.

Relative pronoun/complementizer (that)				
	Estimate (ms)	SE	*t* value	*p*-value
First fixation	−21.96	9.07	−2.42	<.05
Gaze	−20.88	10.45	−2.00	.06
Go-past	−47.02	19.45	−2.42	<.05
	Estimate (log odds)	SE	*z* value	*p*-value
Regressions out	−.85	.47	−1.81	.07
Skipping	.25	.11	2.32	<.05
Determiner (the)				
	Estimate (ms)	SE	*t* value	*p*-value
First fixation	−5.34	10.17	−.52	.60
Gaze	−4.93	12.53	−.39	.69
Go-past	−64.50	28.31	−2.28	<.05
	Estimate (log odds)	SE	*z* value	*p*-value
Regressions out	−.87	.30	−2.88	<.01
Skipping	−.21	.19	−1.08	.28
Noun (fireman)				
	Estimate (ms)	SE	*t* value	*p*-value
First fixation	−1.89	7.93	−.24	.81
Gaze	.68	13.18	.05	.96
Go-past	−60.90	31.53	−1.93	.055
	Estimate (log odds)	SE	*z* value	*p*-value
Regressions out	−.63	.28	−2.23	<.05
Skipping	−.17	.30	−.56	.57
Embedded verb (noticed)				
	Estimate (ms)	SE	*t* value	*p*-value
First fixation	−3.54	8.18	−.43	.65
Gaze	−24.01	11.07	−2.17	<.05
Go-past	−17.32	23.49	−.74	.45
	Estimate (log odds)	SE	*z* value	*p*-value
Regressions out	.27	.33	.80	.42
Skipping	.28	.49	.56	.57

Table 6
Linear mixed-effect model estimate of absent pronoun effect on each dependent measure in Experiment 2, by region, with SE of estimate, *t* or *z* value, and *p*-value. Note that the ORC with *that* condition served as the intercept for treatment coding in linear mixed model; thus, a positive estimate reflects longer reading times, or more regressions or skips, when *that* was absent.

Determiner (the)				
	Estimate (ms)	SE	*t* value	*p*-value
First fixation	48.89	10.92	22.58	<.001
Gaze	86.78	13.41	6.47	<.001
Go-past	89.00	30.02	2.97	<.01
	Estimate (log odds)	SE	*z* value	*p*-value
Regressions out	−.23	.29	−.79	.43
Skipping	.21	.19	1.12	.26
Noun (fireman)				
	Estimate (ms)	SE	*t* value	*p*-value
First fixation	10.87	7.80	1.39	.17
Gaze	15.66	12.99	1.21	.24
Go-past	195.75	31.07	6.30	<.001
	Estimate (log odds)	SE	*z* value	*p*-value
Regressions out	1.46	.24	6.15	<.001
Skipping	−1.33	.40	−3.32	<.001
Embedded verb (noticed)				
	Estimate (ms)	SE	*t* value	*p*-value
First fixation	−.04	8.16	−.00	.99
Gaze	−6.28	11.06	−.57	.58
Go-past	37.84	23.45	1.61	.11
	Estimate (log odds)	SE	*z* value	*p*-value
Regressions out	.69	.31	2.21	<.05
Skipping	−.25	.55	−.45	.65
Matrix verb (hurried)				
	Estimate (ms)	SE	*t* value	*p*-value
First fixation	2.00	7.96	.25	.81
Gaze	−.39	11.21	−.03	.97
Go-past	14.81	22.26	.67	.50
	Estimate (log odds)	SE	*z* value	*p*-value
Regressions out	.22	.32	.67	.50
Skipping	−.31	.71	−.44	.66

3.2.5. Matrix verb

There were no significant or marginal absent pronoun effects on the matrix verb.

3.2.6. Supplementary analyses

As for Experiment 1, a supplementary analysis showed that the noun was much less likely to be skipped when the determiner was skipped (2% vs. 18%, $p < .001$), and again, the interactions between this effect and the experimental manipulations were not significant ($p > .20$). Again, regressions from the noun were more common when the determiner was skipped (36% vs. 23%, $p < .01$), and again there were no interactions with the experimental manipulations ($p > .20$). Exactly the same pattern held for go-past time, and there were no effects of determiner skipping on first fixation duration or first pass time. As in Experiment 1, regressions from the noun were less frequent when there had been a regression from the determiner (31% vs. 21%, $p < .01$), and there was no interaction with sentence type ($p > .20$).

Readers made an interword regression from one of the two words of the critical noun phrase on 22% of trials in complement clause condition, 36% of trials in the ORC with *that* condition, and 58% of trials in the ORC without *that* condition. As in Experiment 1, the presence of such a regression did not affect reading time on the embedded verb. Table 3 provides the means for each dependent measure on this verb, combined across the two ORC conditions, depending on whether a prior regression was made.

3.3. Discussion

The two central results from Experiment 1 were that regressions are especially likely out of the subject of an ORC, and that reading time is inflated on the verb of an ORC. Experiment 2 confirmed that these findings are not due to superficial word order differences between ORCs and SRCs, as essentially the same pattern of results was obtained when a verbal complement clause was used as a control condition. There was some indication that the word *that* was more difficult to process as a relative pronoun than as a complementizer, though this effect was not reliable in an analysis that included random subject and item slopes. However, the results from the subsequent determiner replicated Experiment 1, as this word elicited more regressions and longer go-past time in an ORC than in a complement clause. There were once again more regressions from the subsequent noun, though this effect was smaller than in Experiment 1, and the corresponding go-past effect was only marginally significant. The 'reverse' first fixation and gaze effects seen on the noun in Experiment 1 did not appear in this experiment. Gaze duration on the embedded verb was longer when this verb appeared in an ORC than in a complement clause; unlike in Experiment 1, the first fixation and go-past effects were not significant. In sum, the present experiment, like Experiment 1, found difficulty on the ORC subject in regression-based measures, and difficulty on the ORC verb in the form of longer reading time, but not in the form of more regressions. As in Experiment 1, reading time on the ORC verb was not modulated by whether or not the reader had previously made a regression from either word of the clause's subject.

This experiment also revealed that the absence of a relative pronoun makes an ORC more difficult to process, with this effect appearing almost entirely on the ORC subject. When the relative pronoun was absent there were longer reading times on the determiner on all measures, and many more regressions and much longer go-past times on the subsequent noun. There were more regressions out of the ORC verb when the relative pronoun was absent, but this effect did not translate into significantly longer reading times. These results are broadly consistent with the predictions of an expectation-based model of ORC processing difficulty, and clearly inconsistent with the predictions of an account based on the Active Filler strategy, as the latter account predicts that the absence of *that* should eliminate the reader's tendency to erroneously postulate a subject gap.

4. General discussion

The experiments presented here provide clear answers to the two questions raised in the Introduction. The first question was simply whether, in normal reading, processing difficulty appears on the ORC verb, as in self-paced reading (Grodner & Gibson, 2005), or on the ORC subject, as in the maze task (Forster et al., 2009). The second question was whether the multi-dimensional data provided by the eye movement record would illuminate the nature of the processing difficulty that arises at each of these locations.

The answer to the first question is that there is difficulty in both places. Moreover, the difficulty in the two locations appears to be independent, insofar as it is possible to address this issue. It is not the case that difficulty on the verb depends in any straightforward way on the presence of earlier difficulty on the subject, as reading times on the verb, in both experiments, were similar whether or not the reader showed overt signs of difficulty on the subject in the form of a regressive eye movement. Thus, it appears that the self-paced reading task and the maze task each miss some aspect of the data pattern that emerges in normal reading, with the former failing to reveal the difficulty on the ORC subject, and the latter failing to reveal the difficulty on the ORC verb. An explanation of these facts, in terms of the demands of the two tasks, will not be taken up here, though clearly this is an important issue for researchers using these tasks.

An attractive theoretical conclusion based on these findings is that *both* experience-based expectations *and* processes of memory retrieval make a contribution to the difficulty of comprehending ORCs. Indeed, Levy (2008) has suggested that it may be the case both that "surprisal has a major effect on word-by-word processing difficulty" and that "the retrieval and integration of a long-distance dependent incurs a substantial processing cost comparable to the cost of a highly surprising word" (p. 1166). As noted in the Introduction, simulations by Lewis and Vasishth (2005) explicitly predict difficulty at both of the relevant points, with a 129 ms processing cost on the ORC determiner (see footnote 1) and a 105 ms cost on the ORC verb (Lewis & Vasishth, 2005, Table 3). In the model, these two costs arise from, respectively, the need to revise an expectation for an SRC when the ORC determiner is encountered, and the difficulty of memory retrieval at the ORC verb. The model also correctly predicts little if any processing cost on the matrix verb following an ORC, consistent with the results of Experiment 1. Thus, the Lewis and Vasishth (2005) model would appear to receive substantial empirical support from the present data.

However, the second critical point to be gleaned from the present data is that the difficulty that emerges on the ORC subject and verb are apparently different in kind. In both experiments, each of the two words of the ORC subject triggered a large number of regressive eye movements, but no increase in first pass reading time (with the exception of the condition in which the relative pronoun was omitted, in Experiment 2), and in both experiments, there were inflated reading times on the ORC verb, but no increase in regressive eye movements. These results suggest that the simple notion of "processing difficulty" or "processing cost," as applied to ORCs, is in need of refinement. An adequate theory should predict not only the fact that difficulty does arise at each of the two critical points in an ORC, but that the difficulty at these two points has distinct behavioral consequences.[4]

Understanding these specific behavioral consequences requires a theory of the relation between linguistic processing and events in the eye movement record. Until recently, models of eye-movement control in reading (e.g., Engbert, Nuthmann, Richter, & Kliegl, 2005; Pollatsek, Reichle, & Rayner, 2006; Reichle, Rayner, & Pollatsek, 2003) have focused exclusively on the role of lexical and orthographic factors in determining when and where the eyes move. For example, these models have accounted for the role of factors such as lexical frequency and predictability in modulating the duration of fixations. However, they have not engaged with the large body of research demonstrating effects of sentence- and discourse-level factors on eye movements. Reichle et al. (2003) justified this strategy by noting, "We posit that higher-order processes intervene in eye-movement control only when 'something

[4] As noted in the Introduction, the storage cost proposal of Gibson (1998) may also predict processing difficulty at the ORC subject. As discussed here and below, however, the fact that the difficulty at the ORC subject takes the form of a large increase in the regression rate suggests some form of processing disruption or failure at this point, which is not predicted by the storage cost account.

is wrong' and either send a signal to stop moving forward or a signal to execute a regression. Hence, we view E-Z Reader as an explanation of what happens during reading when higher-level linguistic processing is running smoothly and doesn't intervene" (pp. 450–451). Recently, however, E-Z Reader 10 (Reichle et al., 2009) has explicitly attempted to capture saccadic behavior when "something is wrong." E-Z Reader 10 proposes that upon the completion of lexical access for each word, a syntactic and semantic "integration" stage begins. If this process of integration of the word with its sentence context either fails outright (*rapid integration failure*) or effectively "times out," lagging too far behind ongoing lexical processing of incoming words (*slow integration failure*), a forward-going saccade plan will be cancelled and replaced by a regressive saccade plan. (This plan will either be carried out, or will be again replaced by a forward-going saccade plan, in which case the repeated replacement results in a long fixation duration.)

For present purposes, what is most relevant about this enterprise is the assumption that, while fixation durations may be lengthened in cases in which processing is difficult but eventually succeeds, an interword regression is due to processing *failure*. This assumption captures an intuitive distinction between the apparent error signal in cases of, e.g., garden path disambiguation or implausibility, and the measurable but not insuperable difficulty that may accompany, e.g., processing of a low frequency, unexpected, or ambiguous word. Turning to the present data, this approach suggests that the long-distance integration of an ORC verb with the matrix subject induces some difficulty, but the integration succeeds without the need for the eye-movement control system to disrupt the forward movement of the eyes. (Note that E-Z Reader 10 may not actually be capable of modeling higher-level processing difficulty when this difficulty is manifested *only* in increased fixation durations; in the present version of the model, some proportion of integration failures will result in actual regressions.) Integrating the matrix subject as the theme of the ORC verb does not seem to require the reader to look back at the subject, in the printed text. Encountering the ORC subject, however, sometimes does result in a failure to compute a coherent sentence representation; presumably this is a failure to construct a legal syntactic parse of the input.

Within a framework that attributes the difficulty on the ORC subject to a violation of experience-based expectations, one way to account for this processing failure would be to propose that there is some degree of violation of expectations that cannot be accommodated by the same mechanism that is responsible for the usual, word-by-word update of the syntactic parse. In Hale's (2001) simulation of surprisal values for each word in an SRC and ORC, the first word of an ORC has a value that is approximately three times as great as any other word in either of the two structures. Indeed, in Hale's simulations the surprisal value of this word is only slightly lower than the surprisal value of the disambiguating verb *fell* in the classic main verb/reduced relative ambiguity *The horse raced past the barn fell*. From this perspective, it is notable that eye movement behavior at the beginning of an ORC shows some qualitative similarity to eye movement behavior at a point of garden path disambiguation (see Clifton, Staub, and Rayner (2007), for a review).

The apparent parsing failure at the ORC subject may also be explained on a serial parsing model (e.g., Frazier, 1987; Frazier & Rayner, 1982; van Gompel, Pickering, & Traxler, 2000), as long as such a model allows predictive structure-building (e.g., Frazier & Fodor, 1978; Staub et al., 2006). A serial parsing model asserts that a single syntactic parse is maintained, and that garden path effects arise when the input is simply inconsistent with the current parse, rather than consistent with a parse that has been assigned a low probability, as claimed by, e.g., Surprisal. The current parse must therefore be revised in order to integrate the new input, with the difficulty of this revision process potentially sensitive to a range of structural (e.g., Sturt, Pickering, & Crocker, 1999) or thematic (e.g., Rayner, Carlson, & Frazier, 1983) factors. A serial predictive parser would allow prediction of a specific syntactic structure into which yet-to-be encountered input may be slotted; the Lewis and Vasishth (2005) model implements precisely this idea, as its parser predicts a specific structure for which the input category is the leftmost node (i.e., the left corner; e.g., Johnson-Laird, 1983). Parsing failure may result when input disconfirms this specific prediction. As in the case of reanalysis after garden-pathing, structural revision mechanisms will then come into play. In the case under present consideration, it may be assumed that the arrival of the relative pronoun causes the reader to predictively build a structure corresponding to a subject relative, which must then be revised in the face of inconsistent input. When the relative pronoun is absent, presumably the predictively-built structure would not involve post-nominal modification of the matrix subject at all, and the onset of an ORC would trigger a revision in which an appropriate right-branch is inserted.[5]

5. Conclusion

Two experiments explored patterns of eye movements in the reading of English ORCs. Both experiments demonstrated processing difficulty on the subject noun phrase of these clauses, in the form of a large number of regressive saccades from both the determiner and the noun. This processing difficulty was made even more pronounced when the relative pronoun *that* was absent. In both experiments, difficulty also emerged on the relative clause verb, but in the form of inflated first pass reading time, not in the form of an increase in the regression rate. These findings suggest that the difficulty of object relatives may be due both to the violation of structural expectations and to processes of memory retrieval. However, to the extent that qualitatively distinct eye movement effects can be identified with qualitatively distinct processing phenomena (admittedly, an open question), the data suggest that different kinds of processing difficulty may underlie these effects, with outright parsing failures sometimes occurring when the reader

[5] From this perspective, the Active Filler strategy may be seen as a special case of a more general predictive mechanism.

encounters an unexpected ORC subject, but not at the ORC verb, where a long-distance memory retrieval is required.

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Appendix A

Sentences used in Experiment 1; material that varied between conditions shown in parentheses.

The bus driver who (followed the kids/the kids followed) wondered about the location of a hotel.
The chef who (distracted the cameraman/the cameraman distracted) poured the flour onto the counter.
The children who (woke the father/the father woke) bothered him about the trip to the beach.
The class that (disliked the teacher/the teacher disliked) skimmed the reading for the week.
The dancer that (loved the audience/the audience loved) ignored some basic principles.
The employees that (noticed the fireman/the fireman noticed) hurried across the open field.
The farmer that (approached the customers/the customers approached) lifted the chickens from their coop.
The farmer who (hired the rancher/the rancher hired) piled the seeds in long rows.
The firemen that (called the residents/the residents called) attacked the house with high-powered hoses.
The girl who (watched the parents/the parents watched) changed a critical part of the story.
The investigator who (phoned the agency/the agency phoned) considered Ms. Reynolds from accounting.
The judge who (addressed the witnesses/the witnesses addressed) noticed the defense attorneys.
The manager who (visited the boss/the boss visited) remembered some inconvenient facts.
The mathematician who (visited the chairman/the chairman visited) created a solution to the well-known problem.
The monkeys that (watched the zookeepers/the zookeepers watched) charged the bars of their cage.
The movie star who (visited the organizers/the organizers visited) proposed an annual prize.
The neighbor who (observed the couple/the couple observed) purchased the old Victorian house.
The pilot who (delayed the ground crew/the ground crew delayed) remained on the runway for a long time.

Appendix A (*continued*)

The soldiers that (helped the natives/the natives helped) climbed the big rock that blocked the path.
The speaker who (entertained the economists/the economists entertained) predicted a good year for the industry.
The table top that (rested on the box/the box rested on) screwed directly to the legs.
The trainer who (called the jockey/the jockey called) rubbed the horse's skin.
The veteran who (admired the coach/the coach admired) defeated his greatest rival.
The visitor who (introduced the student/the student introduced) walked across the quad.

Sentences used in Experiment 2; ORC conditions (with optional that) listed first, followed by sentence complement condition

The bus driver (that) the kids followed wondered about the location of a hotel.
The bus driver said that the kids followed him all the way to the hotel.
The chef (that) the cameraman distracted poured the flour onto the counter.
The chef knew that the cameraman distracted the guest on the show.
The children (that) the father woke bothered him about the trip to the beach.
The children heard that the father woke their grandmother for the party.
The class (that) the teacher disliked skimmed the reading for the week.
The class knew that the teacher disliked certain twentieth century writers.
The dancer (that) the audience loved ignored some basic principles.
The dancer saw that the audience loved the last movement of the performance.
The employees (that) the fireman noticed hurried across the open field.
The employees hoped that the fireman noticed the people who were still in the building.
The farmer (that) the customers approached lifted the chickens from their coop.
The farmer saw that the customers approached the horse in the pasture.
The farmer (that) the rancher hired piled the seeds in long rows.
The farmer believed that the rancher hired too many seasonal workers.
The firemen (that) the residents called attacked the house with high-powered hoses.
The firemen claimed that the residents called the station in a panic.
The girl (that) the parents watched changed a critical part of the story.
The girl worried that the parents watched to see if she was skipping school.

(*continued on next page*)

Appendix A (*continued*)

The investigator (that) the agency phoned considered Ms. Reynolds from accounting.
The investigator knew that the agency phoned the client because of the unpaid bills.
The judge (that) the witnesses addressed noticed the defense attorneys.
The judge heard that the witnesses addressed the defense attorneys by name.
The manager (that) the boss visited remembered some inconvenient facts.
The manager thought that the boss visited every second Tuesday of the month.
The mathematician (that) the chairman visited created a solution to the well-known problem.
The mathematician recalled that the chairman visited their German colleagues in May.
The monkeys (that) the zookeepers watched charged the bars of their cage.
The monkeys knew that the zookeepers watched when they charged the bars of their cage.
The movie star (that) the organizers visited proposed an annual prize.
The movie star hoped that the organizers visited his favorite charity.
The neighbor (that) the couple observed purchased the old Victorian house.
The neighbor thought that the couple observed the kids rather intently.
The pilot (that) the ground crew delayed remained on the runway for a long time.
The pilot believed that the ground crew delayed the flight intentionally.
The soldiers (that) the natives helped climbed the big rock that blocked the path.
The soldiers thought that the natives helped the enemy hide in the jungle.
The speaker (that) the economists entertained predicted a good year for the industry.
The speaker said that the economists entertained some ridiculous hypotheses.
The shipping company (that) the box came from was located in Akron.
The shipping company claimed that the box came with the dent already in it.
The trainer (that) the jockey called rubbed the horse's skin.
The trainer thought that the jockey called for assistance too often.
The veteran (that) the coach admired defeated his greatest rival.
The veteran knew that the coach admired the way he tutored the younger players.
The visitor (that) the student introduced walked across the quad.
The visitor said that the student introduced her at the cocktail party.

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