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Beyond cloze probability:

Parafoveal processing of semantic and syntactic information during reading

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ABSTRACT

Theories of eye movement control in reading assume that early oculomotor decisions are determined by a word's frequency and cloze probability. This assumption is challenged by evidence that readers are sensitive to the contextual plausibility of an upcoming word: First-pass fixation probability and duration are reduced when the parafoveal preview is a plausible, but unpredictable, word relative to an implausible word. The present study sought to establish whether the source of this effect is sensitivity to violations of syntactic acceptability. In two experiments, the gaze-contingent boundary paradigm was used to compare contextually plausible previews to semantically acceptable and anomalous previews that either matched or violated syntactic rules. Results showed that readers benefited from the convergence of semantic and syntactic acceptability early enough in the timecourse of reading to affect skipping. In addition, both semantic and syntactic plausibility yielded preview effects on target fixation duration measures, providing direct evidence of parafoveal syntactic processing in reading. These results highlight the limitations of relying solely on cloze probability to index contextual influences on early lexical processing. The implications of the data for models of eye movement control and language comprehension are discussed.

Keywords

Reading, eye movements, parafoveal preview benefit, plausibility, syntax

Word count: 9952 (excluding Abstract, References, Footnotes, Tables, and Figures)

The question of when and how context influences lexical processing has been long debated. Evidence from a range of methodologies has clearly confirmed that contextually predictable words are identified more quickly than unpredictable words. But the mechanisms responsible for predictability benefits remain a source of ongoing theoretical and empirical debate (e.g., Kutas, DeLong, & Smith, 2011; Staub, 2015) which has been re-energized by recent developments in probabilistic models of sentence and discourse processing (e.g., Hale, 2001; Levy, 2008). Recent investigations of the impact of semantic plausibility and syntactic acceptability on parafoveal preview effects on eye movements during sentence reading provides a new source of insight into this issue.

The major current theories of eye movement control share the assumption that early decisions about whether, and for how long, to fixate a word in first-pass reading are determined by processes involved in lexical retrieval for the currently attended word(s) (Engbert, Nuthmann, Richter, & Kliegl, 2005; Reichle, Pollatsek, Fisher, & Rayner, 1998). This is most explicit in the influential E-Z Reader model which assumes a serial word identification process in which "lexical access is the engine driving the eyes forward" (Reichle et al., 1998, p. 135). Contextual predictability influences early word identification in E-Z Reader because the parameters governing the two stages of lexical access implemented in the model are word frequency and *cloze probability*, which is estimated by the proportion of participants who generate a word given the prior context in an offline production task (Taylor, 1953).¹ In E-Z Reader higher-level contextual information that is not captured by cloze probability only affects a subsequent postlexical integration stage that can interrupt forward saccade planning when integration fails due to severe semantic or syntactic violation, resulting in pauses or regressions to resolve the comprehension difficulty (Reichle, Warren, & McConnell, 2009).

¹ Lexical processing is also indirectly affected by word length in E-Z Reader via the impact of acuity limitations.

Recent evidence from studies examining *parafoveal processing* using the gaze-contingent *boundary paradigm* (Rayner, 1975) appears to challenge a purely postlexical account. The boundary paradigm assesses whether parafoveal processing of a word contributes to its subsequent identification by replacing a target word within a sentence with a different stimulus until the reader's eyes cross the space immediately to the left of the word. This paradigm has provided clear evidence of a *parafoveal preview benefit* from stimuli that are orthographically or phonologically similar to the target relative to an unrelated string, indicating that readers extract sublexical information from upcoming words. These preview effects have typically been attributed to *trans-saccadic integration* of the features of the preview and target (Rayner, 1975; Schotter, Angele, & Rayner, 2012).

Semantic influences on parafoveal processing

Although early research using the boundary paradigm found no benefit from semantically related previews (e.g., Rayner, Balota & Pollatsek, 1986; Hyönä & Häikiö, 2005; see also Rayner, Schotter, & Drieghe, 2014), robust semantic preview effects have now been observed in a number of different languages including German (e.g., Hohenstein & Kliegl, 2014), Finnish (White, Bertram, & Hyönä, 2008), and Chinese (Tsai, Kliegl, & Yan, 2012; Yan, Richter, Shu, & Kliegl, 2009), as well as English (Rayner & Schotter, 2014; Schotter, 2013; Schotter, Lee, Reidermann, & Rayner, 2015; Veldre & Andrews, 2016a). This evidence implies that readers can process at least some parafoveal words sufficiently deeply to extract semantic information. In principle, these effects are compatible with the trans-saccadic integration account of parafoveal preview effects if it is assumed that this form of integration can operate on semantic features (Schotter, 2013). However, recent evidence suggests that semantic preview effects cannot be explained by trans-saccadic integration because they depend on the contextual plausibility of the preview in the sentence, rather than the semantic relationship between the preview and target.

Veldre and Andrews (2016b) used the boundary paradigm to assess the independent contributions of semantic relatedness and contextual plausibility to semantic preview effects: For example, the target word *boots* in the sentence, *He needed some suitable **boots** because he was a keen hiker*, was replaced with a preview that was both semantically related to the target word and contextually plausible (e.g., *shoes*) or with a locally plausible continuation of the sentence that was semantically unrelated to the target (e.g., *games*). The results revealed a significant preview benefit on first-pass measures of reading from contextually plausible parafoveal previews that were semantically unrelated to the target relative to contextually implausible preview words (e.g., *check*). This plausibility preview effect was equivalent to the benefit from previews that were both plausible and semantically related to the target, suggesting that plausibility, rather than relatedness was the critical factor. Importantly, both the target word and the plausible preview word were very low in cloze probability, ruling out an explanation of the effect based on predictability.

These findings replicate evidence of plausibility preview effects in Chinese reading (Yang, Wang, Tong, & Rayner, 2012; Yang, Li, Wang, Slattery, & Rayner, 2014) and have been confirmed in independent studies in English (Schotter & Jia, 2016). Veldre and Andrews (2017a) also showed that plausibility preview effects are independent from, and co-occur with, “standard” preview effects due to sublexical overlap. A factorial manipulation of preview plausibility and the orthographic similarity between the preview and target revealed independent, additive effects of the two manipulations on first-pass reading measures, suggesting that orthographic and plausibility preview effects may reflect different mechanisms (Veldre & Andrews, 2017a). The plausibility preview effect has also been observed for unpredictable but plausible previews in sentences that were constrained towards a specific target word (Veldre & Andrews, 2017b). Plausibility preview effects influence the early processes reflected in first-pass measures of fixation duration, and have been observed

as early in the time course as skipping (Veldre & Andrews, 2017a, 2017b). However, the early benefits are often counteracted in late fixation measures such as total duration because of high regression rates to targets that replace plausible previews (Schotter & Jia, 2016; Veldre & Andrews, 2016b, 2017a, 2017b).

The very early effects of plausibility appear to conflict with previous evidence that plausibility does not influence skipping rates (e.g., Abbott & Staub, 2015; Abbott, Angele, Ahn, & Rayner, 2015; Angele, Laishley, Rayner, & Liversedge, 2014; Angele & Rayner, 2012) and are difficult to reconcile with E-Z Reader's post-lexical account of the impact of contextual integration. The current research was designed to clarify whether, and under what circumstances, the plausibility of the upcoming word affects skipping. Plausibility preview effects also have more general implications for understanding the role of parafoveal information in reading. Evidence that parafoveal preview is influenced by the contextual fit of the preview in the preceding sentence context suggests that preview effects are, in part, due to mechanisms that are sensitive to higher order semantic and syntactic information. The present study aims to further specify the source of this contextual influence.

Parafoveal effects of syntactic information

Rather than arising from contextual plausibility *per se*, the benefits of plausible parafoveal previews may reflect early sensitivity to syntactic acceptability. Such a view is consistent with accounts assuming that initial sentence parsing is based on structural cues such as syntactic attachment rather than semantic plausibility (e.g., Clifton, Traxler, Mohamed, Williams, Morris, & Rayner, 2003). A purely syntactic basis for the effect cannot be ruled out because the implausible word baseline used in previous demonstrations of the plausibility preview effect often differs from the target/plausible word in grammatical class. For example, while all the implausible words used by Veldre and Andrews (2016b) were semantically unacceptable, approximately 55% also violated local phrase structure rules, e.g.,

the preview was a verb when only a noun would be syntactically acceptable. If syntactic information plays a critical role in readers' initial parsing of the sentence (e.g., Clifton et al., 2003), previews that violate syntactic rules may yield a greater, or more rapid, processing disruption than previews that are semantically anomalous but syntactically legal.

Consistent with this possibility, studies in which participants are exposed to sentences containing various types of semantic and grammatical errors have provided behavioral and neurophysiological evidence suggesting a quantitative or qualitative dissociation between detection of syntactic and semantic anomalies. McElree and Griffith (1995) found that participants were faster to categorize sentences as anomalous that contained a word class violation (e.g., *Some people hastily books*) compared to a thematic role violation (*Some people amuse books*). Event-related potential (ERP) evidence also suggests a distinction between sensitivity to semantic and syntactic anomalies. Semantically inappropriate words elicit a negative component, peaking at about 400 ms after stimulus onset, known as the N400 (e.g., Kutas & Hillyard, 1980). In contrast, syntactic anomalies elicit a variety of responses depending on the type of violation, including the P600 (e.g., Osterhout & Holcomb, 1992), and an early (200 ms) left anterior negativity (ELAN) associated with violations of phrase structure rules (e.g., Friederici, Pfeifer, & Hahne, 1993; Neville, Nicol, Barss, Forster, & Garrett, 1991). This evidence supports an early role for syntactic processing that is independent of semantic constraints.

Evidence for early sensitivity to syntactic information has also been observed in studies of eye movements during reading. Braze, Shankweiler, Ni, and Palumbo (2002) compared congruent sentences to semantically anomalous and syntactically anomalous sentences that differed by a single target verb, e.g., *The cats won't usually **eat/bake/eating** the food we put on the porch*. Both types of anomalies produced inflated fixation durations but the disruption from the syntactic violation was evident on the target verb while the semantic

anomaly effect was only observed on the following word. In a study of Chinese reading, Yang, Wang, Chen, and Rayner (2009) compared congruent sentences to sentences containing a word that was either semantically anomalous or both semantically and syntactically anomalous. First-pass reading times were longer for the target region in both violation conditions than in the congruent condition, but the syntactic violation was significantly more disruptive than the semantic violation on first-pass measures of reading for the target region. Although these studies suggest a dissociation between semantic and syntactic processing on the eye movement record, the effects might have been magnified by strategies induced by the presence of a high proportion of anomalous sentences.

More recent research has used the boundary paradigm to assess whether word class information in the parafovea affects eye movements when participants are not consciously aware of violations. Kim, Radach, and Vorstius (2012) showed that readers of Korean were sensitive to previews which provided invalid orthographic information about syntactic class, but these effects may be specific to the morphosyntactic structure of this writing system. In English, Brothers and Traxler (2016) recently reported that readers were less likely to skip a word when the preview was a syntactically anomalous word from a different grammatical class (e.g., *The admiral would not **confess/surgeon** to any of the charges*). In their first two experiments, the reduced skipping rate for syntactically anomalous previews was assessed against a valid preview condition, involving no display change, raising questions about whether the disruption is specifically due to syntactic violation rather than to the differences in display change and orthographic, phonological and semantic similarity that were confounded with preview validity. Brothers and Traxler's third experiment included an additional critical control condition of a syntactically and locally semantically plausible preview that was orthographically different from the target (e.g., *The man tried to **grab/join/beer** the phone from my hand*.) This study demonstrated that the skipping rate for

syntactically anomalous previews was approximately 3% lower than the plausible control condition, but found no differences between plausible and anomalous previews on either early or late fixation measures. Brothers and Traxler interpreted their data as evidence that “word-class information plays a critical role in online reading comprehension and can influence even the earliest stages of word recognition” (p. 1901). However, their results cannot discriminate whether the skipping effects were specifically due to syntactic violation rather than contextual misfit because the syntactically anomalous previews were also semantically unacceptable continuations of the pre-target sentence. Their findings are, in fact, the same as Veldre and Andrews' (2016b, 2017a) results in showing that contextually plausible previews yield a benefit on skipping rates relative to previews that are semantically and syntactically inappropriate in the sentence context. This comparison does not distinguish whether the source of these differences lies in specific sensitivity to word class or in the contextual plausibility of the preview (Veldre & Andrews, 2016b, 2017a).

Similar ambiguities arise from Snell, Meeter, and Grainger's (2017) recent investigation of syntactically valid and invalid previews in the boundary paradigm which found a preview benefit from a non-target word from the same word class as the target relative to a preview from a different word class. Snell et al. interpreted these findings as supporting Brothers and Traxler's (2016) claim that word class information is extracted early in online reading, and suggested that the fact that their syntactic preview effects manifested in fixation duration as well as skipping may reflect their use of Dutch rather than English stimuli and participants. However, Snell et al. did not assess the contextual plausibility of their previews and the examples they provide indicate that both plausible and implausible syntactically valid previews were included. Thus, their results also fail to clearly distinguish the relative contribution of syntactic and contextual plausibility to preview effects on skipping rate and early fixation measures.

EXPERIMENT 1

Previous research using the boundary paradigm has demonstrated parafoveal influences of contextual fit of preview words. However, the relative contribution of semantic and syntactic sources of information remains unclear. Are there independent effects of the semantic and syntactic fit of a preview word with the preceding sentence context, or graded effects of contextual plausibility as predicted by probabilistic accounts (e.g., Levy, 2008)? And do the independent or joint effects of semantic and syntactic plausibility manifest in skipping effects or in early fixation measures or both? Disentangling these issues is important to evaluating the validity of models of eye movement control such as E-Z Reader. Effects of word class or contextual plausibility on first-pass fixation measures are potentially compatible with early post-lexical integration processes, like those assumed by E-Z Reader (Abbott & Staub, 2015; Reichle et al., 2009) while skipping effects appear more compatible with predictive anticipatory processes (e.g., Kutas et al., 2011) that are influenced by higher-order contextual information that is not captured by cloze probability.

Experiment 1 addressed these issues by investigating the independent contributions of syntactic and semantic plausibility to parafoveal preview effects. To achieve this, we compared the effects of semantically and syntactically plausible previews, like those used in our previous experiments, with semantically anomalous previews that either matched or violated the expected word class of the upcoming word (see Figure 1). This design allows assessment of the independent effects of both semantic and syntactic mismatch with the preceding sentence context on both skipping rates and early fixation measures.

---INSERT FIGURE 1 HERE---

Method

Participants

The final sample comprised 59 undergraduate students (mean age: 22.0 years) from The University of Sydney.² All had normal or corrected-to-normal vision and reported that English was the first language they learned to read and write. Participants received partial course credit as compensation.

Materials and Design

The stimuli were 100 sentences, 8-18 words in length ($M=11.98$), in which a critical target word (range: 4-7 letters) was embedded. To minimize repetition of the sentence structures, the target words were from different grammatical classes: 63 nouns, 19 verbs, and 18 adjectives/adverbs. The boundary paradigm was used to compare four parafoveal preview conditions (see Figure 1): (1) *Identical*: identical to the target, (2) *Plausible*: a plausible continuation of the sentence that shared the same grammatical class as the target word but was semantically unrelated to it, (3) *Implausible/No violation*: a contextually implausible continuation of the sentence that shared the same grammatical class as the target word, (4) *Implausible/Violation*: a contextually implausible continuation that was from a different word class to the target word. To avoid word-class ambiguities, all target and preview words were selected so that the appropriate syntactic class was the dominant usage of each word (85% or higher) according to part of speech norms in the SUBTLEX corpus (Brysbaert, New, & Keuleers, 2012). All sentences appeared in all preview conditions across four counterbalanced lists.

Stimulus validation. A separate group of 20 participants from the same population of undergraduate students provided cloze norming data. They were given each sentence frame up to and including the pre-target word and asked to provide the word that was most likely to come next. The results of the cloze task showed that the identical and plausible words were generated less than 3% of the time, on average, confirming that neither was predictable from

² One participant was replaced due to eye tracker calibration failure. One additional participant was excluded from the analyses because heavy blinking throughout the experiment resulted in a high level of data loss.

the sentence context. The anomalous preview words were never generated as responses in the cloze task (see Table 1). Although the specific lexical item was rarely generated as a response in the cloze task, there was high agreement between the word class of responses and the target ($M=94.18\%$, $SD=15.00\%$), confirming that the target was syntactically predictable.

To confirm the plausibility manipulation, a separate group of 19 participants provided plausibility ratings on a 5-point scale for the sentence frames up to and including the target/preview words. The sentence fragments ending with the Word class match and Word class violation previews were rated as significantly lower in acceptability than the Identical and Plausible previews [all $t_s > 77.35$, $p_s < .001$]. However, there were no significant differences in acceptability between the Identical and Plausible previews, or between the two anomalous previews [$t_s < 1.32$, $p_s > .203$]. The stimulus characteristics and norming data are presented in Table 1.

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Apparatus

An SR Research EyeLink 1000 system was used to record participants' eye movements as they read sentences on a 21-inch CRT monitor, which had a refresh rate of 150 Hz. The sentences occupied a single line and were presented in black monospaced font on a gray background. Viewing was binocular but fixation position was monitored from the right eye. Participants were seated 60 cm from the monitor and a chin and forehead rest was used to minimize head movements. At this distance 2.5 characters subtended 1 degree of visual angle.

Procedure

Participants were instructed to read the sentences for meaning and to respond to occasional comprehension questions. The experiment began with a three-point calibration procedure followed by three practice trials and the 100 experimental trials, which were

presented in an individually randomized order and intermixed with 24 filler sentences. At the beginning of each trial a fixation point appeared at the location of the first letter of the sentence. Once the participant made a stable fixation on this point, the sentence was displayed or a new calibration procedure was performed if necessary. Mean calibration error was less than 0.3 degrees of visual angle. The participant pressed a key when s/he finished reading the sentence. On all practice trials and approximately 30% of experimental and filler trials, the sentence was followed by a multiple-choice comprehension question that required a moderate understanding of the meaning of the sentence.

Results

Fixations below 80 ms that were within one letter space of an adjacent fixation were merged with that fixation and remaining fixations below 80 ms or above 1000 ms were eliminated (1.86% of total fixations). Trials were eliminated if the participant blinked immediately before or after fixating the target word (3.02% of trials) or if the display change completed more than 10 ms into a fixation or was triggered by a saccade that ultimately landed to the left of the boundary (10.12% of trials). Target gaze durations above 1200 ms, and go-past and total durations above 2000 ms were also excluded (<0.5% of trials). These exclusions left 5141 trials (87.14% of the data) available for analysis. Mean comprehension accuracy was 94.6%, indicating participants read the sentences for meaning. Following the experiment participants were asked if they noticed anything unusual about the display and, if so, to estimate the number of display changes they noticed. The majority of participants ($n=37$) were unaware of the presence of display changes. Removing the 12 participants who reported awareness of more than 5 display changes did not change the pattern of results reported below.

The following reading measures were analyzed: the probability of *skipping* the target during first-pass reading; *first fixation duration* (the duration of the first fixation on the target

word regardless of the number of first-pass fixations it receives), *single fixation duration* (the fixation duration in cases when only one first-pass fixation is made on the target word), *gaze duration* (the sum of all first-pass fixations on the target word). We also analyzed two late measures of reading: *go-past duration* (the sum of all fixations from the first fixation on the target word until a word to the right is fixated, i.e., including first-pass fixations on the target, any subsequent fixations on words earlier in the sentence, and any rereading of the target), and *total duration* (the sum of all fixations on the target word including first-pass reading and any later rereading of the target after later words in the sentence are fixated). The probability of the reader making a *first-pass refixation* prior to leaving the target; *regressions out* of the target to words earlier in the sentence; and *regressions in* to the target from words later in the sentence were also analyzed. Means for each target/preview condition on each of these measures are presented in Table 2.

---INSERT TABLE 2 HERE---

The data were analyzed by (generalized) linear mixed-effects models (LMM) using the *lme4* package (Version 1.1-11; Bates, Maechler, Bolker, & Walker, 2015) in *R* (Version 3.3.1; R Core Team, 2016). Planned successive difference contrasts tested (1) *Identical preview effect*, the difference between the Identical preview and the Plausible preview; (2) *Plausibility preview effect*, the difference between the Plausible preview and the Implausible/No violation preview; and (3) *Syntactic validity effect*, the difference between the Implausible/No violation and the Implausible/Violation previews. The models included subject and item random intercepts and random slopes for the preview effects. Estimates 1.96 times larger than their standard errors were interpreted as significant at the .05 alpha level because, given the number of observations, the *t* statistic in LMMs effectively corresponds to the *z* statistic. The (G)LMM estimates for coefficients, standard errors, and *t/z* values for the fixed effects are reported in Table 3. Parallel analyses conducted on log-transformed duration

measures yielded an identical pattern of significant results to the analyses of raw measures reported below, unless noted otherwise.

---INSERT TABLE 3 HERE---

Pretarget Word Reading Measures

There were no significant effects of preview condition on fixation durations on the pre-target word [all $|t|s < 1$], providing no evidence of parafoveal-on-foveal effects.

Target Word Skipping

Readers were equally likely to skip the target in the Identical and Plausible preview conditions [$z < 1$]. The skipping rate was significantly higher in the Plausible preview condition than in the Implausible/No violation condition [$z = 2.15$] but there was no difference in skipping rates between the Implausible/No violation and Implausible/Violation conditions [$z < 1$]. A supplementary analysis, collapsing across the two plausible preview conditions (i.e., Identical and Plausible), confirmed that skipping was significantly lower for both Implausible/No violation [$b = 0.26$, $SE = 0.11$, $z = 2.35$] and Implausible/Violation previews [$b = 0.30$, $SE = 0.11$, $z = 2.79$]. These findings imply that skipping of the target word was determined by whether or not the parafoveal word was a plausible continuation of the sentence but not by the grammatical class of the preview, independently of contextual plausibility.

Target Word Reading Measures

Across all fixation duration measures, there was a significant *identical preview effect* because readers spent less time reading the target word in the Identical preview condition compared to the Plausible preview condition [all $|t|s > 3.02$]. Readers were also less likely to regress back to the target [$z = -4.46$] after an Identical preview compared to a Plausible preview.

There was a significant *plausibility preview effect* across all first-pass measures because readers spent less time fixating the target word when the preview was Plausible compared to an Implausible/No violation preview [all $|t|s > 2.78$]. This extends previous evidence by demonstrating that observing a plausibility preview effect does not depend on syntactic violations in the implausible baseline: There is a significant benefit to first-pass reading from a semantically plausible preview relative to an implausible, but syntactically legal, word. The plausibility preview effect was not significant on total duration [$t = -1.05$]. The analysis of regressions in revealed that readers were marginally *more* likely to regress to the target after a Plausible preview compared to an Implausible/No violation preview [$z = 1.86$], suggesting that late rereading counteracted the early benefit of a Plausible preview. The selective impact of plausibility on first-pass reading is consistent with previous reports of plausibility preview effects (Schotter & Jia, 2016; Veldre & Andrews, 2016b, 2017a, 2017b).

Finally, there was a significant *syntactic validity preview effect* that was restricted to gaze and go-past duration, which were lower in the Implausible/No violation condition than in the Implausible/Violation condition [both $|t|s = 2.23$]. The syntactic validity effect was not significant on either first or single fixation duration [both $|t|s < 1.61$] and did not extend to total duration [$|t| < 1$] because readers were equally likely to regress to the target in the two anomalous conditions [$z = 1.40$]. The discrepancy in the significance of the effect between early and later measures of first-pass reading suggests that the two implausible previews may have differentially affected regressions-out or refixations of the target. The analysis of regressions out revealed no significant differences between any of successive difference contrasts tested on the preview conditions [all $|z|s < 1.78$]. However, a supplementary analysis that collapsed across the two anomalous conditions revealed a significant difference in regressions out between plausible and implausible preview conditions [$b = -0.33$, $SE = 0.13$, $z = -2.51$]. Finally, readers were significantly more likely to refixate the target during first-pass

reading after an Implausible/Violation preview compared to Implausible/No violation preview [$z=-2.39$]. Refixation probability did not differ between any of the other conditions [both $|z|<1.15$]. This pattern of findings suggests that parafoveal syntactic violations influence re-processing of both the target word itself, and the earlier words in the sentence.

The pattern of results on first-pass measures suggests that the effect of syntax emerges relatively late: the two implausible conditions did not differ significantly on first or single fixation duration, only on gaze duration. However, it is possible that the syntactic validity effect on earlier measures was obscured by including trials with immediate regressions from the target word that terminate a first fixation prematurely (Altmann, Garnham, & Dennis, 1992; Veldre and Andrews, 2016b). We therefore ran supplementary analyses on 'regression-contingent' measures of first, single, and gaze duration (Mitchell, Shen, Green, & Hodgson, 2008) in which trials with regressions out of the target (15.5% of trials) were excluded. The pattern of significant effects for the Identical preview effect and Plausibility preview effect did not change in this restricted analysis. However, when regressions out were excluded the syntactic validity preview effect was significant on all first-pass measures: first fixation duration [$b=-10.21$, $SE=4.11$, $t=-2.49$], single fixation duration [$b=-12.55$, $SE=4.50$, $t=-2.79$], and gaze duration [$b=-16.43$, $SE=5.81$, $t=-2.83$]. Thus, the benefit from a preview of a syntactically legal word was evident from the first fixation on the target word for trials on which the reader did not immediately make a regression, but obscured by variance due to trials on which a syntactic mismatch triggered a rapid regression to earlier in the sentence.

Discussion

The results of Experiment 1 provide several important insights into parafoveal preview effects. Consistent with earlier studies (Veldre & Andrews, 2017a, 2017b), the benefits of plausible parafoveal previews were evident in the earliest eye movement index of processing, skipping rate. The present data add to the earlier evidence by showing that

skipping effects appear to be due to the contextual plausibility of the preview word rather than syntactic violations in the implausible condition. Readers were more likely to skip the target in the identical and plausible conditions than in either of the anomalous conditions. However, there was no evidence that word class information alone affected the decision to fixate the target because skipping rates did not differ for anomalous previews according to their match with the expected grammatical class. The results of Experiment 1 therefore suggest that Brothers and Traxler's (2016) finding of a higher skipping rate for a locally plausible preview relative to a syntactically anomalous preview reflects the contextual misfit, rather than the syntactic misfit, of their anomalous baseline condition and that Snell et al.'s (2017) word class effects on skipping may also have arisen from a failure to control semantic plausibility.

Nevertheless, the fixation duration data provide evidence that readers *were* sensitive to syntactic information in the parafovea. There were significant parafoveal syntactic validity effects on gaze and go-past duration in the unrestricted analysis, and across first-pass measures in the regression-contingent analysis, which imply that word class information was extracted from the preview before the reader's eyes crossed the boundary. However, the fact that the syntactic validity effect was limited to first-pass fixation duration measures suggests that parafoveal syntactic information is not processed early enough to affect skipping.

An alternative explanation of the lack of very early sensitivity to syntactic violations in Experiment 1 is that both the Implausible/No violation and Implausible/Violation previews provided invalid semantic information. It is therefore possible that an early effect of syntax on eye movements was counteracted by interference from mismatching contextual information. Experiment 2 was designed to test whether readers showed sensitivity to syntactic violations on word skipping when the previews were contextually plausible words. Experiment 2 also used a more subtle manipulation of syntactic validity to provide a stronger

test of parafoveal syntactic processing. Specifically, the syntactic violations used in Experiment 2 were subject-verb agreement and verb tense errors. Such grammatical violations have previously been shown to affect first-pass reading times on, or immediately after, the critical verb region in eye movement experiments (Dillon, Mishler, Sloggett, & Phillips, 2013; Pearlmuter, Garnsey, & Bock, 1999). However, it is currently unknown whether such violations can be detected in the parafovea.

EXPERIMENT 2

Method

Participants

Sixty undergraduate students (mean age: 19.0 years) from The University of Sydney participated in Experiment 2 and received partial course credit as compensation.³ None of the participants completed Experiment 1 or any of the validation studies. All had normal or corrected-to-normal vision and were either native English speakers or had begun to learn English by age 5.

Materials and Design

The stimuli were 100 sentences, 9-18 words in length ($M=12.32$), in which a critical target word (range: 4-7 letters) was embedded. The boundary paradigm was used to compare four parafoveal preview conditions (see Figure 2): (1) *Identical*: identical to the target, (2) *Plausible*: a semantically and syntactically plausible continuation of the sentence, (3) *Plausible/Violation*: a semantically plausible but syntactically invalid continuation of the sentence due to a subject/verb agreement error or a verb tense error, (4) *Implausible/No Violation*: a semantically implausible continuation of the sentence that matched the word class of the target word. All sentences appeared in all preview conditions across four counterbalanced lists.

³ Two participants were replaced due to eye tracker calibration failure.

---INSERT FIGURE 2 HERE---

Stimulus validation. A separate group of 20 participants provided cloze norming data. The results of the cloze task showed that the Identical, Plausible, and syntactically valid forms of the Plausible/Violation previews were all generated less than 5% of the time, on average, and were therefore not predictable from the sentence context. The anomalous preview words were never generated as responses in the cloze task (see Table 5).

A separate group of 20 participants provided plausibility ratings for the sentence frames up to and including each of the target/preview words and the syntactically valid form of the Plausible/Violation preview. The sentence fragments ending with the Plausible/Violation and Implausible/No Violation previews were rated as significantly lower in acceptability than the Identical and Plausible previews [all $t_s > 12.67$, $p_s < .001$]. However, there were no significant differences in acceptability between the Identical and Plausible previews, or between the two anomalous previews [$t_s < 1$]. Plausibility ratings were also collected for the contextually valid form of the Plausible/Violation condition which confirmed that they did not differ in plausibility to the Identical and Plausible previews [$t_s < 1.19$, $p_s > .242$]. The stimulus characteristics and norming data are presented in Table 4.

---INSERT TABLE 4 HERE---

Apparatus

The apparatus and display parameters were identical to Experiment 1.

Procedure

The procedure was identical to Experiment 1.

Results

The same data trimming procedure was applied as in Experiment 1. Blinks and track loss resulted in the elimination of 3.82% of trials, early and late display changes occurred in 7.63% of trials, and long fixation durations accounted for less than 0.5% of trials. These

exclusions left 5294 trials (88.23% of the data) available for analysis. Mean comprehension accuracy was 93.6%. As in Experiment 1, the majority of participants were unaware of the presence of display changes ($n=32$). Removing the 12 participants who reported awareness of more than 5 display changes did not affect the pattern of results reported below.

---INSERT TABLE 5 HERE---

The same reading measures were analyzed as in Experiment 1 and means for each condition on these measures are presented in Table 5. Planned successive difference contrasts tested (1) *Identical preview effect*, the difference between the Identical preview and the Plausible preview; (2) *Syntactic agreement preview effect*, the difference between the Plausible preview and the Plausible/Violation preview; and (3) the difference between the Plausible/Violation and the Implausible/No Violation previews. The (G)LMM estimates for coefficients, standard errors, and t/z values for the fixed effects are reported in Table 6.

---INSERT TABLE 6 HERE---

Pretarget Word Reading Measures

As in Experiment 1, there were no significant effects of preview condition on fixation durations on the pre-target word, i.e. no parafoveal-on-foveal effects [all $|t|s < 1$].

Target Word Skipping

Readers were equally likely to skip the target in the Identical and Plausible preview conditions [$|z| < 1$]. The skipping rate was significantly higher in the Plausible preview condition than in the Plausible/Violation condition [$z=2.36$] but there was no difference in skipping rates between the Plausible/Violation and Implausible/No Violation conditions [$z < 1$]. A supplementary analysis, collapsing across the Identical and Plausible preview conditions, confirmed that the skipping rate was significantly lower for both Plausible/Violation [$b=0.23$, $SE=0.11$, $z=1.99$] and Implausible/No violation previews [$b=0.37$, $SE=0.12$, $z=3.07$]. These findings converge with the results of Experiment 1 in

showing that skipping of the target word was determined by whether or not the parafoveal word was both a syntactically and semantically plausible continuation of the sentence.

Target Word Reading Measures

Across all fixation duration measures, there was a significant *identical preview effect* because readers spent less time reading the target word in the Identical preview condition compared to the Plausible preview condition [all $|t|s > 3.01$]. Readers were also less likely to regress out of the target [$z = -2.94$] and regress back to the target [$z = -5.85$] after an Identical preview compared to a Plausible preview.

There was a significant *syntactic agreement preview effect* because readers spent less time fixating the target word when the preview was Plausible compared to a Plausible/Violation preview on first fixation duration, gaze duration, and go-past duration [all $|t|s > 2.20$]. Readers were also significantly more likely to regress out of the target after a Plausible/Violation preview relative to a Plausible preview [$z = -3.15$]. The syntactic agreement effect was marginally significant on single fixation duration [$t = -1.93$] but did not approach significance on total duration [$|t| < 1$] because readers were equally likely to regress to the target in the two conditions [$z = 1.02$]. This extends previous evidence by demonstrating that readers' first pass processing benefits from a preview of a plausible word relative to the very stringent control of a semantically plausible but syntactically invalid word.

Finally, gaze duration was significantly lower in the Plausible/Violation condition than the Implausible/No Violation condition [$t = -2.19$]. This difference was not significant on first or single fixation duration [both $|t|s < 1.67$]⁴, suggesting that it was principally due to refixations during first-pass reading. The analysis of first-pass refixations confirmed that readers were significantly less likely to refixate the target after a Plausible/Violation than

⁴ The difference between the Plausible/Violation and Implausible/No Violation previews was significant in the analysis of log single fixation duration [$b = -0.05$, $SE = 0.02$, $t = -2.11$] suggesting it may have been obscured in the analysis of raw fixation durations by variance due to occasional long fixations. No other effects changed significance in the analyses of log transformed data.

after an Implausible/No Violation preview [$z=-2.18$]; refixations did not differ significantly among the other conditions [both $|z|s<1.91$]. There was no difference between the two conditions on go-past duration [$t<1$] but readers were significantly *more* likely to regress out of the target after a Plausible/Violation than after an Implausible/No Violation preview [$z=2.44$]. This pattern of findings suggests that parafoveal syntactic violations in a semantically plausible preview are more likely to produce immediate regressions from the target word whereas semantic violations that are syntactically acceptable are more likely to prolong reading of the target word. The two anomalous conditions did not differ on total duration [$t<1$] or on regressions in [$z=1.10$].

As for Experiment 1, we also ran analyses on first, single, and gaze duration excluding the subset of trials in which regressions were made out of the target (16.2% of trials). The pattern of significant effects was identical in this restricted analysis, suggesting that regressions out did not obscure differences between Plausible/Violation and Implausible/No violation previews on early first-pass measures.

Discussion

The results of Experiment 2 shed further light on the role of syntactic information in early oculomotor planning. The benefit from a Plausible preview relative to a Plausible/Violation preview was observed on both skipping rate and first-pass reading measures on the target word itself, even though the syntactic violation was semantically plausible in the sentence. This finding extends the plausibility preview effect by showing that readers benefit from the convergence of semantic and syntactic acceptability in the parafovea, and that this information is available early enough in the timecourse of reading to affect the decision to skip the upcoming word.

While the effect of a Plausible/Violation preview was equivalent to the effect of an Implausible/No Violation preview on skipping, there was a significant benefit from

previewing a semantically plausible, but syntactically invalid preview over an implausible, syntactically acceptable preview on gaze duration on the target word. This relatively late benefit may suggest that the cost from previewing a semantically anomalous word outweighs the cost from previewing a relatively minor syntactic anomaly.

However, there were also qualitative differences in readers' responses to syntactic compared to semantic violations. Semantically plausible previews that mismatched in syntactic agreement yielded an increase in regressions from the target word to earlier in the sentence relative to semantically implausible previews that were syntactically acceptable. This suggests that readers may plan regressive saccades to repair an apparent syntactic violation on the basis of parafoveal information. Implausible previews from the expected syntactic word class were associated with a different form of re-analysis reflected in a higher rate of first-pass refixations of the target word than observed for agreement error previews. Refixations commonly occur in response to a range of processing difficulties such as low frequency words, unpredictable words in constraining contexts, and long words (Rayner, 2009). The increased refixations after Implausible/No Violation previews suggest that processing costs can also arise from attempts to integrate a syntactically acceptable, but semantically anomalous parafoveal word into the developing sentence representation. These costs may reflect processes involved in assessing alternative meanings of the word, or figurative interpretations, that may resolve the apparent anomaly which are not enlisted when the word is syntactically inappropriate in the context.

GENERAL DISCUSSION

The primary goal of this study was to investigate the contribution of syntactic and semantic information to parafoveal processing. Until recently, there was a broad consensus that readers of English rarely process parafoveal words to the lexical/semantic level (see Schotter et al., 2012). The results of the present research add to a growing body of evidence

that has challenged this view by demonstrating higher-level processing of parafoveal previews (Schotter, 2013; Schotter et al., 2015; Schotter & Jia, 2016; Veldre & Andrews, 2016a, 2016b, 2017a, 2017b). Taken together, the results of Experiments 1 and 2 reveal graded contributions of semantic and syntactic plausibility to parafoveal preview effects on target fixation durations. Relative to an implausible word that was syntactically unacceptable in the sentence context, readers showed the most benefit from a preview that was both semantically and syntactically plausible in the preceding sentence context; significantly less benefit from a syntactically invalid word that was semantically plausible; and less benefit still from an implausible word that only matched the word class expected from the sentence context. This pattern of results suggests that readers extract both semantic and syntactic information from the parafovea and that this information can accrue very early in the timecourse of reading.

However, in contrast to the fixation duration results, the effects on skipping appear to be more discrete in nature. Skipping rates for previews that were both semantically and syntactically plausible were significantly higher than for previews that were anomalous on either dimension, but there was no evidence of the graded effects of anomaly observed on fixation duration measures. This implies that, at least some of the time, preprocessing a word in the parafovea can affect early oculomotor planning, but only if it matches both semantic and syntactic expectancies. The findings of the present study have a number of implications for understanding the nature of the information extracted from the parafovea during reading.

Firstly, the present data extend evidence of the plausibility preview effect by confirming that it reflects the overall contextual fit of the preview, rather than its syntactic validity alone. In Experiment 1, plausible previews were associated with a significant benefit on both skipping rates and first-pass reading measures of the target word relative to semantically anomalous previews from the same word class.

In addition to replicating and extending effects of preview plausibility, the present data also provide novel evidence of parafoveal preview effects of syntactic validity and syntactic agreement. In Experiment 1, readers showed a significant benefit to first-pass reading from previewing a word from the expected word class, relative to a preview violating that expectation. Furthermore, in Experiment 2, we observed a significant benefit from a plausible preview over a semantically acceptable but syntactically inappropriate continuation. The latter finding is particularly compelling evidence of early sensitivity to syntactic violations given that the Plausible/Violation previews were often highly orthographically similar to a fully plausible word. The significant syntactic validity effect on first-pass measures implies that previous estimates of the plausibility preview effect (e.g., Schotter & Jia, 2016; Veldre & Andrews, 2016b, 2017a, 2017b) may have been inflated by the costs associated with including word class violations and other syntactic anomalies in the implausible baseline condition. However, as summarized above, there was still a significant benefit from a plausible preview relative to baselines matched on syntactic validity (Experiment 1) and semantic acceptability (Experiment 2). These very early graded effects of contextual plausibility appear to provide strong evidence of high level processing of parafoveal information.

A possible alternative account is that parafoveal sensitivity to word class reflects orthographic differences between words of different grammatical classes, rather than sensitivity to syntactic violations *per se* (e.g., Arciuli, McMahon, & de Zubicaray, 2012; Kemp, Nilsson, & Arciuli, 2009). In a recent eye movement study, Farmer, Yan, Bicknell, and Tanenhaus (2015) found that orthographically typical nouns (e.g., *marble*) received shorter first-pass fixation durations than ‘verb-like’ nouns (e.g., *insect*) in sentences that were strongly constraining towards a noun continuation. The effect was found to be contextually graded because there was no effect of typicality in sentences that were only weakly

constraining towards a noun continuation. Although it is possible that such orthographic differences between words from different grammatical classes could contribute to the syntactic validity effects observed in the present studies, it is unclear whether a purely orthographic account can explain the relatively late emergence of the effect: word class did not affect skipping and only had an effect after the target was directly fixated. Furthermore, Experiment 2 provided a stronger test of parafoveal syntactic processing by comparing plausible previews that produced subtle violations of syntactic rules, such as errors of subject-verb agreement or verb tense. These previews often had high orthographic overlap with a fully plausible continuation (e.g., a plural form). Nevertheless, there was a robust difference between the Plausible/Violation condition and the Plausible condition on skipping and fixation duration, implying that readers were highly sensitive to the syntactic acceptability of upcoming words, rather than merely showing sensitivity to sublexical differences between words of different grammatical classes.

The mechanisms underlying parafoveal preview effects

As well as providing insight into the nature of the information extracted from parafoveal words, the present results have a number of implications for accounts of the mechanisms underlying parafoveal preview effects. These findings add to recent evidence that preview effects are not solely due to trans-saccadic integration of preview and target information (e.g., Risse & Kliegl, 2012, 2014; Schotter & Jia, 2016; Schotter & Leinenger, 2016; Schotter, Leinenger, & von der Malsburg, 2017; Veldre & Andrews, 2016b, 2017a, 2017b; Yang et al., 2012; Yang et al., 2014). Based on simulations of semantic preview benefit in E-Z Reader (Schotter, Reichle, & Rayner, 2014), Schotter and Leinenger (2016) proposed an alternative *forced fixation* account of preview effects which centers on a key assumption about the relationship between lexical processing and saccadic programming in E-Z Reader.

The model assumes that programming of a saccade to the next word (word $n+1$) is triggered by the completion of an early stage of word identification (L_1) for the currently attended word (word n), and that the further lexical processing required for full identification (L_2) continues during the 150 ms delay before the programmed saccade is executed. If L_2 completes before the planned saccade has been executed, the model assumes that covert attention shifts to word $n+1$, allowing its processing to begin before it is directly fixated. This *decoupling* of attention from the fixation location accounts for preview benefits and the skipping that occurs when L_1 completes for word $n+1$ quickly enough to allow the saccade planned to that word to be cancelled and re-programmed. It also, according to Schotter and Leininger (2016), leads to occasional ‘forced fixations’ which occur when L_1 completes for word $n+1$ too late in the planning process for the previously programmed saccade to that word to be cancelled. This triggers the programming of a new saccade from the location of word $n+1$ and results in a short ‘forced’ fixation on word $n+1$ that is terminated by execution of the new saccade planned on the basis of its prior parafoveal processing.

In the boundary paradigm, such forced fixations will be based on processing of the *preview* word rather than the target. Critically, if there is a systematic difference in processing difficulty between two preview conditions, forced fixations due to more quickly processed previews will manifest as a preview benefit: easier parafoveal words are more likely to be processed sufficiently quickly to either allow execution of a skip, or yield a forced fixation. More difficult words will not be processed as quickly and will therefore be more likely to result in a ‘long’ fixation on the target. The impact of these long fixations may be magnified by costs associated with the discrepancy between the preview word that triggered the oculomotor planning process and the target word that replaced it during the reader's saccade. However, for easy previews the discrepancy between the preview and target word may never be noticed, unless the target is subsequently refixated during later rereading, perhaps due to

failures in later integration processes or lingering uncertainty about the identity of the target (Schotter et al., 2017). It is these later processes that account for the absence of plausibility effects on total fixation duration because early preview benefits are counteracted by regressions (Schotter & Jia, 2016; Veldre & Andrews, 2016b, 2017a, 2017b).

Forced fixations provide a possible explanation of how preview effects can arise from differences in preview processing alone, independently of the relationship between the preview and the target. However, the replicability of plausibility effects across different samples and stimulus sets, even against the very rigorous control conditions used in the present studies is difficult to reconcile with the relatively low incidence of forced fixations predicted by Schotter et al.'s (2014) E-Z Reader simulations. More importantly, extending this account to plausibility and syntactic preview effects requires explanation of why plausible and implausible previews that are matched on both word frequency and cloze probability - the parameters that affect lexical processing in E-Z Reader - should differ in processing difficulty.

One possibility is that the effects of preview plausibility are due to processing *costs* for implausible previews that arise from failures in postlexical integration processes. E-Z Reader assumes that this triggers cancellation of all planned saccades and planning of regressions back to the source of processing difficulty (Reichle et al., 2009). Veldre and Andrews (2016b) suggested that this mechanism may account for the plausibility preview effects observed on first-pass reading measures and early regressions out of the target. Specifically, following the sequence of events leading to a forced fixation on word $n+1$ and the initiation of saccadic planning away from the target location, lexical access (L_2) of the preview word completes and a postlexical integration stage begins. For plausible previews, postlexical integration should complete without difficulty, resulting in a short fixation on the target word. However, for implausible previews, postlexical integration may fail rapidly,

cancelling the planned forward saccade and producing a lengthened fixation on the target and/or a regression from the target. Rapid postlexical integration failure may be more likely to occur for implausible previews that violate both syntactic and semantic expectancies, potentially contributing to graded effects of parafoveal violation.

It is more problematic to extend this purely postlexical account to explain the plausibility preview effects on skipping rates observed in both of the present studies. In E-Z Reader, a reduced skipping rate for implausible words implies that L_1 processing of the parafoveal word completed during the labile saccade program, cancelling the planned saccade to word $n+1$, and that the subsequent L_2 processing and postlexical integration failure occurred rapidly enough to cancel the skipping saccade, resulting in a saccade to word $n+1$. Abbott and Staub (2015) reported that E-Z Reader simulations demonstrated occasional rapid integration failures for implausible words that resulted in cancellation of a planned skip, but these effects were restricted to short words and only yielded very small effects on skipping even when the probability of integration failure was high.

It is important to acknowledge that the present evidence of semantic and syntactic plausibility effects on skipping appears to conflict with previous findings that readers' skipping decisions are insensitive to the plausibility of upcoming words. For example, Abbott and Staub (2015) recently applied Bayesian analysis methods to confirm the absence of plausibility effects on skipping. Their target words were slightly longer than those used in the present study (an average of 6.5 letters vs. 5.1 letters), resulting in a lower overall skipping rate compared to the present studies and potentially reducing the impact of parafoveal processing. More importantly, in contrast to the present use of the boundary paradigm, in which participants are not consciously aware of the presence of plausibility violations in otherwise plausible sentences, Abbott and Staub measured eye movements in normally presented sentences of which a substantial proportion were implausible because of an

animacy violation. Awareness of the plausibility violations may have induced a more cautious reading strategy among participants, obscuring the small effect of plausibility on skipping rates. However, this criticism does not apply to research using the boundary paradigm to show that readers are more likely to skip high frequency words regardless of semantic or syntactic acceptability. For instance, readers are more likely to skip parafoveal previews of the article *the* than contextually valid but lower frequency content word previews (Abbott et al., 2015; Angele et al., 2014; Angele & Rayner, 2012). The discrepancy between these data and the present results may reflect the previous studies' use of three-letter target words, which have a much higher base rate of skipping than the 4-7 letter words used in the present study.

To assess whether the present skipping effects were carried by short words, we conducted a supplementary GLMM analysis of the plausibility effects on skipping, combining the data from Experiments 1 and 2, which included the factor of word length. There were significant main effects of word length [$b=-0.65$, $SE=0.04$, $z=-14.76$] and plausibility [$b=0.28$, $SE=0.06$, $z=4.73$], but these two factors did not significantly interact, and the trend was actually in the direction of a larger effect of plausibility for long words [$b=0.12$, $SE=0.07$, $z=1.72$]. This analysis therefore provided no evidence that the plausibility effects on skipping depended on word length.

Thus, it seems unlikely that the small, but robust plausibility effects observed on skipping in both the present experiments and earlier studies (Veldre & Andrews, 2017a, 2017b) can be reconciled with E-Z Reader's current post-lexical integration mechanisms. It remains possible that word length, word frequency, and plausibility interact on skipping rates. For example, frequency may outweigh plausibility for very short words but not for longer words. Further research will be necessary to disentangle the contributions of these factors to

skipping rates and determine their implications for models of eye movement control during reading.

Beyond cloze probability

Whatever the outcome of more refined investigations, the present results confirm previous evidence that sentence context affects lexical processing in a way that is not fully captured by the measures of cloze probability typically used to index predictability (Staub, Grant, Astheimer, & Cohen, 2015). The targets and previews used in this study were all very low on this index, yet robust plausibility preview effects were observed on skipping and all fixation duration measures except total duration. More generally, the relative rarity of highly predictable words in text (Luke & Christianson, 2016) raises questions about the utility (Jackendoff, 2002) and generality of the anticipatory lexical prediction mechanisms assumed to underpin effects of cloze probability in many recent models of language comprehension (e.g., Christiansen & Chater, 2016; Kutas et al., 2011) to low constraint sentence contexts like those used in the present studies. Recent evidence that a plausible but unpredictable word is read just as quickly in a neutral context as in a high constraint context in which another word is highly predictable is also difficult to reconcile with anticipatory prediction mechanisms (Frisson, Harvey, & Staub, 2017).

A sentence context that does not constrain toward a single lexical item may still activate a concept, or a range of words, that share semantic features (e.g., DeLong, Urbach, & Kutas, 2005; Schotter et al., 2015; Van Petten & Luka, 2012). Encountering a word that shares this activated semantic information may yield a benefit to early lexical processing that is evident on the eye movement record, even if it is not highly predictable. Consistent with this view, eye movement studies have reported robust predictability effects for words low in cloze probability (e.g., Frisson, Pickering, & Rayner, 2005; Luke & Christianson, 2016). Converging evidence from recent ERP studies suggests that there are distinct neural

responses to manipulations of cloze probability and plausibility. DeLong, Quante, and Kutas (2014) observed that low cloze sentence continuations elicited post-N400 positivities that were modulated by plausibility: anomalous words elicited the typical posterior P600 observed for incongruent events (e.g., Kuperberg, 2007) while plausible words that did not match the most expected completion, elicited a late frontal positivity that was suggested to reflect suppression of the higher probability completion (see also Lau, Namyst, Fogel, & Delgado, 2016). These findings converge with results of the present study in suggesting that broader dimensions of contextual fit, which are not captured by standard indices of cloze probability, affect early eye movements associated with lexical processing.

Whatever the mechanisms responsible for the impact of previous context, the present evidence of parafoveal influences of the semantic and syntactic fit of the upcoming word confirms that the integration processes contributing to comprehension operate highly incrementally, on an essentially word-by-word basis (e.g., Altmann & Mirkovic, 2009; Rayner, Cook, Juhasz, & Frazier, 2006). Such a view is compatible with recent probabilistic accounts of language comprehension which assume that comprehenders continuously generate and update expectancies about upcoming words based on previous context and prior knowledge (e.g., Hale, 2001; Smith & Levy, 2013). Rather than assuming the linear relationship between cloze probability and reading time instantiated in current models of eye movement control (e.g., Engbert et al., 2005; Reichle et al., 1998), these models assume that the speed of processing an upcoming word is an inverse *logarithmic* function of its contextual predictability yielding graded effects, even among low cloze probability completions.

Such models may also explain why contextually unacceptable previews disrupt online processing. For example, Levy's (2008) 'surprisal theory' assumes that a word that is inconsistent with probabilistic expectancies about upcoming words is more difficult to process, and requires the allocation of resources to update expectancies for possible

interpretations.⁵. The surprisal response to unexpected words therefore “serves as a causal bottleneck between the linguistic representations constructed during sentence comprehension and the processing difficulty incurred at a given word within a sentence” that is reflected in behavior (p. 1128). This mechanism is compatible with the present evidence of early disruption from processing of implausible previews. Levy’s assumption that predictions are probabilistic and computed from all available sources of information also accounts for the effects of both syntactic and semantic plausibility observed in the present data. Plausible previews that were low in cloze predictability, but fit the sentence context both semantically and syntactically produced a benefit on skipping that was evident before the target was fixated, consistent with the view that a set of possible continuations is activated (e.g., Staub, 2015; Veldre & Andrews, 2017b) and that such pre-activation facilitates parafoveal processing of those words.

Importantly, the dissociation between the effects of violation type on skipping and target fixation duration suggests that the reading system has more information than just “something is wrong”. The reduced skipping for all violation previews suggests that semantics and syntax both contribute to contextual expectancies. However, the graded nature of the preview effects on first-pass reading reflects the impact of specific responses triggered by different types of anomaly. Previews that were semantically anomalous showed a processing cost that was primarily reflected in refixations of the target word. In contrast, syntactic violation previews elicited re-processing of words earlier in the sentences. These distinct processes suggest that the reading system has access to precise information about the source of the processing difficulty very early in the timecourse of saccade planning and attempts to repair an apparent comprehension error arising from parafoveally processed

⁵ Although the implementation of surprisal theory does not directly compute the discrepancy between the input and the expected word, Levy (2008) showed that the updating required to generate the most likely next word in a fully parallel, incremental, probabilistic system is formally equivalent to the difficulty in replacing the current distribution of expectancies with a revised set on the basis of new input (Hale, 2001).

information. These findings are broadly compatible with re-analysis processes triggered by a mismatch between the preview word and the probabilistic expectancies generated from previous context (Levy, 2008) but require a more sophisticated mechanism than the post-lexical response to integration failure in E-Z Reader, as well as re-consideration of its assumption that cloze probability is the only source of contextual effects on lexical retrieval.

In conclusion, this research provides direct evidence of parafoveal processing of syntactic information in reading and establishes that the plausibility preview effect derives from both semantic and syntactic plausibility. Preview effects in the boundary paradigm therefore appear to reflect a combination of processes. Sub-lexical effects of orthographic and phonological overlap between the preview and target may be due to the trans-saccadic integration processes assumed in traditional accounts (e.g., Rayner, 1975; Schotter et al., 2012). However, preview effects are also modulated by the difficulty of processing the preview word, independently of its relationship to the target. Critically, the difficulty of preview processing is affected by its compatibility with higher-order semantic and syntactic information extracted from the preceding sentence context that goes beyond the cloze probability effects on lexical processing predicted by current models (Engbert et al., 2005; Reichle et al., 1998) and influences the earliest eye movement measures. Word skipping was affected by whether or not the upcoming word was both a semantically and syntactically valid continuation of the sentence. In contrast, parafoveal plausibility and syntactic acceptability yielded graded effects on first-pass reading measures that reflected the impact of distinct re-analysis processes. These data demonstrate that cloze probability alone is insufficient to capture the impact of contextual information on early oculomotor decisions in reading and highlight the role of incremental, probabilistic expectancies about upcoming words on parafoveal processing during sentence reading.

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APPENDIX A

Sentence materials used in Experiment 1. The target word is indicated in bold.

Sentence frame	Identical	Plausible	Implausible/ No violation	Implausible/ Violation
Her plane will probably depart later than expected this afternoon.	depart	refuel	stroke	hostel
Greta's dog would often choose the bowl with the treats in it.	choose	ignore	wring	career
A riot was sure to quickly occur if the people were not helped.	occur	erupt	drown	piano
The magnificent bald eagle feeds from the edge of the cliff.	feeds	soars	swore	theft
The front porch was rapidly tidied in anticipation of the visitors.	tidied	mended	bribed	oyster
The hot beans were lazily placed on the table for the guests.	placed	cooked	taught	island
Patty needed to buy some rice from the store on her way home from work.	rice	pens	seas	pray
The steaming asphalt was carefully spread on the road.	spread	poured	warned	nights
David began to prepare his supper instead of watching television.	supper	speech	injury	gained
They auctioned an antique chair for which there were several bidders.	chair	clock	skill	drank
She stared at the bright green turf feeling proud of her gardening skills.	turf	bean	bias	defy
He hoped that the heavy armour would protect him in battle.	armour	donkey	angles	wander
She hoped she would be a good parent even though she was very young.	parent	farmer	method	forget
The fresh water should be immediately carried to the thirsty patrons.	carried	offered	elected	clothes
The liquid flowed into a metal tank before draining into the ocean.	tank	tube	goat	woke
The old buddies often played poker after work on Tuesdays.	poker	chess	salad	react
The council recorded the number of registered cars during the annual audit.	cars	dogs	sins	seek
He intended to bring back a large sword as a souvenir from his trip.	sword	cigar	agony	fetch
They noticed the young lion as they glanced around the clearing.	lion	folk	lump	sits
My sister has a large room even though she's much younger than me.	room	head	king	does
They needed to fill at least four mugs before the preacher began the sermon.	mugs	rows	wars	earn
She lifted up the small potato from the kitchen counter.	potato	kettle	months	occupy
We visited an ancient forest during our holiday in Spain.	forest	castle	memory	create
They visited the quaint church before booking their wedding.	church	houses	policy	worked
Tina had always wanted a huge yard in her dream house.	yard	pool	mile	cope
Marie lay down on her lawn because she was exhausted from exercising.	lawn	sofa	myth	flew
They stepped out into the dark avenue after hearing a strange noise.	avenue	garage	metres	gather
He backed away from the dangerous cliff before continuing on his trek.	cliff	snake	lungs	swear

She eventually found a spare stool behind the crowded bar.	stool	glass	uncle	begin
The wooden crate was filled with jars that moved when she tried to close it.	jars	mice	pubs	bury
He could see the small budgie under the table in the living room.	budgie	peanut	cliche	unlock
She was very fond of his new beard but she did not tell him.	beard	boots	hills	fired
He looked worried when he thought he had broken his ankle but it turned out to be okay.	ankle	blade	genes	bless
I just saw the most expensive handbag that I think I have ever seen.	handbag	diamond	thunder	chooses
Martha carried her expensive violin inside a special protective case.	violin	pearls	border	vanish
They could not see into the dark mist when they walked through the forest.	mist	pond	hips	hire
The young boy hid his precious coin under his clothes at the back of the closet.	coin	doll	poet	fled
They escorted the other army away from the fight.	army	kids	news	fell
We stared at the little house from inside the tour bus.	house	women	voice	today
They were all impressed by the talented artist when they toured the studio.	artist	worker	jacket	brings
Tracy likes going to the nearby mall to have fun on the weekends.	mall	city	arms	gets
The diamond ring had beautiful jewels around the gold band.	jewels	shapes	poetry	extend
Jason was nervous walking past police who were standing outside the embassy.	police	ladies	theory	talked
Rosa thought she had broken her elbow when she fell off the wall.	elbow	phone	grass	shown
We waited at the nearby bench for the others to arrive.	bench	lobby	logic	dealt
The church received a beautiful organ from an anonymous donor.	organ	bible	wrist	argue
The wooden box gradually became dirtier the longer we carried it.	dirtier	heavier	happier	sweater
The dogs are always noisy when people come to visit.	noisy	eager	steep	ocean
The swords in the museum were shiny and covered with jewels.	shiny	blunt	blond	thigh
The beautiful backyard was truly vast at their new family home.	vast	lush	deaf	eggs
Last night, my dreams were very weird so I wrote about them in my journal.	weird	lucid	beady	syrup
The tall man looked very thin in his brand new tuxedo.	thin	rich	inky	laws
The new student answered the question easily when no one else raised their hand.	easily	slowly	highly	energy
Karen jumped over the stream boldly before everyone else.	boldly	safely	namely	whisky
The clerk shouted for us to quickly move towards the counter.	move	turn	grow	food
After reading the newspaper, Matthew felt shame about Australia's treatment of refugees.	shame	anger	trunk	greet
She gave the dog a quick bath after returning from the beach.	bath	meal	nose	paid
She enjoyed the warm shower after a long day at work.	shower	breeze	degree	divide
We bought some chips before we watched the big game.	chips	jeans	halls	steal
The kids brought a small torch with them to the campsite.	torch	spoon	phase	renew

Bill was an excellent partner because he was always prepared to listen.	partner	student	chapter	mention
He needed to buy some suitable boots for when his kids came to visit.	boots	games	knees	apply
The council tore down the building near the busy dock because it was too dangerous.	dock	mall	hand	mend
Rose enjoyed the dark green spinach while she ate her salad at lunchtime.	spinach	scenery	hostage	confuse
When Jim eats Indian food he often chokes because of the intense spices.	chokes	coughs	reigns	thrift
The violent thug's enemy started a massive brawl.	enemy	mates	resin	shone
She located her mother's skirt near the back of the wardrobe.	skirt	linen	unity	tempt
He accepted the shiny robe after winning the championship bout.	robe	coin	brow	hang
Melanie thought that the man was quite mental after learning of his violent crimes.	mental	horrid	sugary	juggle
Betting for the next race will cease in the next couple of minutes.	cease	begin	thank	river
The tiny butterfly was easily caught by the curious youngster.	caught	helped	caused	coffee
The beautiful painting had been bought when the gallery was closed.	bought	framed	tasted	chapel
They found the rusty metal pans during the archaeological dig.	pans	keys	beef	adds
The thin spaghetti needed heating because everybody was hungry.	heating	serving	feeding	ceiling
Suzy recently began attending bingo as a way to make new friends.	bingo	choir	fraud	spill
They thought that Joel was a real hero but he did not have many friends.	hero	hoot	volt	lurk
He bought an orange vest that he planned to take to the party.	vest	soda	doom	lend
There was a terrible noise when the waiter dropped the tray of drinks.	noise	brawl	brass	drove
Jim thought the restaurant's menu was too spicy but he booked anyway.	spicy	meaty	angry	bunch
The professor's coat looked very loose but we tried not to laugh.	loose	dirty	vague	faith
The way the kids fixed the sink was very stupid but it was the best they could do.	stupid	clumsy	sleepy	ghosts
Somehow, the food stayed cool after the long trip.	cool	soft	tall	seat
The music at the party was particularly dull so we left early.	dull	poor	lost	luck
We could tell that the cakes and pastries were lousy from the strange colour.	lousy	stale	weary	virus
They climbed into the cramped wagon before deciding where to go next.	wagon	booth	mouse	leant
The massive truck carrying dirt arrived at the construction site.	dirt	wood	ears	sing
They were making renovations to the outdated foyer which greatly inconvenienced patrons.	foyer	cafes	curry	froze
The tourists took photos of the magnificent moon before getting back on the bus.	moon	lake	tone	blew
Dale's favourite horse at the stable was huge and very lively.	huge	grey	wavy	desk
The chef decided he would baste the chicken for tonight's special.	baste	carve	annul	grape
She remembered that Kathy naps every afternoon after lunch.	naps	jogs	juts	gent

The woman draped the black shawl loosely around her neck.	shawl	beads	skies	deter
Ron's pants are still too baggy even after tailoring.	baggy	short	dizzy	poles
The final exam seemed quite easy after the mid-semester quiz.	easy	fair	warm	wife
The perfume bottles in the store were extremely dusty because they were very unpopular.	dusty	cheap	rural	whale
The furry creatures lived in a smelly swamp that often floods when it rains.	swamp	sewer	motto	evade
Lydia was terrified that the tiger would appear before she got away.	appear	pounce	excuse	summer
Our dog would always sniff near the pretty roses outside our house.	sniff	shake	write	niece
This beautiful flower usually grows when the weather is warm.	grows	wilts	reads	socks
The shop around the corner sells fruit but the prices are very high.	fruit	bread	weeks	guess

APPENDIX B

Sentence materials used in Experiment 2. The target word is indicated in bold.

Sentence frame	Identical	Plausible	Plausible/ Violation	Implausible/ No violation
Her plane will probably refuel later than expected this afternoon.	refuel	depart	landed	stroke
She tried her best to be a good parent even though she was very young.	parent	farmer	actors	method
The council recorded the number of registered dogs during the annual audit.	dogs	cars	bike	sins
Tina had always wanted a huge yard in her dream house.	yard	pool	beds	mile
She eventually found an empty stool behind the crowded bar.	stool	glass	bowls	uncle
He looked worried when he thought he had broken both ankles but it turned out to be okay.	ankles	blades	hammer	genes
I spoke with a talented artist when I toured the studio.	artist	worker	ladies	jacket
Jason was nervous walking past police who were standing outside the embassy.	police	ladies	person	theory
The clerk shouted for us to quickly move towards the counter.	move	turn	goes	grow
Betting for the next race will cease in the next couple of minutes.	cease	begin	opens	thank
Suzy recently began attending bingo as a way to make new friends.	bingo	choir	party	fraud
He bought a blue vest from the new store at the shopping centre.	vest	soda	pens	doom
There was a terrible noise when the waiter dropped the tray of drinks.	noise	brawl	yells	brass
She remembered that Kathy naps every afternoon after lunch.	naps	jogs	sing	juts
Lydia was terrified that the tiger would appear before she got away.	appear	pounce	chases	excuse
All that I felt like was a piece of fresh fruit but the fridge was completely empty.	fruit	bread	foods	smoke
The school was surrounded by several homes and had space for two hundred students.	homes	shops	tower	pages
I bought a brand new phone with the money I got from my grandparents.	phone	dress	books	brain
On the surface of the water, a white yacht glided slowly towards the dock.	yacht	goose	geese	ranch
We had a delicious supper when we visited Gareth at his new house.	supper	cheese	olives	cotton
Gary's brand new suitcase burst open on the way to the airport.	burst	broke	break	built
The young grey elephant fell away from its mother.	fell	swam	swim	sang
I didn't realise that I had shut the lid of my jewellery box.	shut	lost	lose	died
We watched as a sleek lion killed the terrified zebra and began to eat it.	killed	caught	attack	bought
Theo listened to a few talks while he waited for his turn to speak.	talks	songs	album	woods
Greta's dog would often choose the bowl with the treats in it.	choose	ignore	sniffs	wring

The hot beans were quickly cooked on the stove for the guests.	cooked	placed	places	taught
The fresh water should be immediately carried to the thirsty patrons.	carried	offered	serving	elected
He intended to bring back a large sword as a souvenir from his trip.	sword	cigar	cakes	agony
They visited a quaint church before booking their wedding.	church	garden	houses	policy
Marie collapsed on her lawn because she was exhausted from exercising.	lawn	sofa	beds	myth
The wooden crate was filled with jars that moved when she tried to close it.	jars	mice	gift	pubs
I just saw a really expensive handbag that I think I want to buy.	handbag	diamond	cameras	thunder
Tracy likes going to a nearby mall to have fun on the weekends.	mall	city	pubs	arms
The church received a beautiful organ from an anonymous donor.	organ	bible	books	wrist
We bought some chips before we watched the big game.	chips	jeans	shirt	halls
He needed to buy some suitable boots for when his kids came to visit.	boots	games	table	knees
The office was located next to a busy dock and down the road from a school.	dock	café	bars	hand
The tiny butterfly was easily helped by the curious youngster.	helped	caught	chases	caused
The thin spaghetti needed heating because everybody was hungry.	heating	serving	drained	feeding
They climbed into a cramped wagon before deciding where to go next.	wagon	booth	buses	mouse
The woman draped a black shawl loosely around her neck.	shawl	cloak	beads	skies
The furry creatures lived in a smelly creek that often floods when it rains.	creek	sewer	pipes	motto
The large carrots were quickly peeled and added to the stir-fry.	peeled	washed	rinses	annoyed
Brendan cracked at least three teeth during the violent argument.	teeth	walls	plate	lines
The elderly patient would often moan because of the wound on her leg.	moan	ache	bled	buzz
I was sure that I would love the little kitten that followed us home.	love	keep	kept	bark
Becky's dogs would sometimes fight near the fence in her backyard.	fight	stand	stood	write
The limb of the great oak tree bent further towards the house with the passing years.	bent	grew	grow	paid
Patrick tried a number of techniques to deter foxes from his farm.	foxes	pests	mouse	bells
We were served a tasty snack before commencing our descent.	snack	juice	meals	waist
A riot was sure to quickly occur if the people were not helped.	occur	erupt	began	drown
Patty needed to buy some pens from the store on her way home from work.	pens	rice	bean	seas
The liquid flowed from a metal tube before draining into the ocean.	tube	tank	taps	goat
They noticed a young lion as they glanced around the clearing.	lion	poet	guys	lump
They needed to fill at least four mugs before the preacher began the sermon.	mugs	rows	seat	wars
She lifted up a small potato from the kitchen counter.	potato	kettle	plates	months
We visited an ancient castle during our holiday in Spain.	castle	forest	cities	memory
They stepped out into the dark garage after hearing a strange noise.	garage	avenue	alleys	metres

When she saw all the yellow cabs for the first time she became really excited.	cabs	corn	shoe	self
Martha carried an expensive violin inside a special protective case.	violin	wallet	pearls	border
The diamond ring had beautiful jewels around the gold band.	jewels	shapes	design	poetry
Stephanie enjoyed a long shower after a hard day at work.	shower	dinner	movies	degree
The kids brought a small torch with them to the campsite.	torch	spoon	tents	phase
When Jim eats Indian food he often chokes because of the intense spices.	chokes	coughs	wheeze	reigns
The beautiful painting had been bought when the gallery was closed.	bought	framed	steals	tasted
They thought that Joel was a real hero but he did not have many friends.	hero	hoot	nuts	volt
They were making renovations to a busy foyer which greatly inconvenienced patrons.	foyer	cabin	cafes	curry
I was surprised to see my brother fall over the finish line after tripping during the race.	fall	step	gets	fade
Our dog would always sniff near the pretty roses outside our house.	sniff	shake	howls	write
The teacher said that the children should watch when they get back to their desks.	watch	study	wrote	burst
We heard quite a few interesting women during the writers' festival.	women	ideas	story	faces
My partner and I would often argue during the day on weekends.	argue	sleep	slept	marry
The neighbour's cat would often visit with our dogs at the pond in our garden.	visit	drink	drank	speak
When Billy said he was going to grow a big beard everyone laughed at him.	beard	mango	pears	sauce
The magnificent bald eagle feeds from the edge of the cliff.	feeds	soars	swoop	swore
The front porch was rapidly mended in anticipation of the visitors.	mended	tidied	sweeps	bribed
They auctioned an antique chair for which there were several bidders.	chair	clock	vases	skill
The concert was held at a small arena and tickets sold out quickly.	arena	venue	clubs	diary
The old buddies would often play chess after work on Tuesdays.	chess	poker	balls	salad
My sister has a large room even though she's much younger than me.	room	head	eyes	king
He backed away from a dangerous cliff before continuing on his trek.	cliff	snake	lions	penny
He could see a tiny spider under the table in the living room.	spider	peanut	crumbs	stench
The young boy hid a precious coin under his clothes at the back of the closet.	coin	doll	toys	poet
We waited at a nearby bench for the others to arrive.	bench	lobby	gates	logic
She gave the dog a quick bath after returning from the beach.	bath	meal	pats	nose
Bill was an excellent partner because he was always prepared to listen.	partner	student	lawyers	chapter
He accepted a shiny medal after winning the championship bout.	medal	prize	gifts	thumb
They found some rusty metal pans during the archaeological dig.	pans	keys	fork	beef
The chef decided he would roast the chicken for tonight's special.	roast	carve	boils	annul
When their mother shouts, the kids usually obey in order to avoid being punished.	obey	hide	runs	melt

This beautiful flower usually grows when the weather is warm.	grows	wilts	bloom	reads
We inspected each of the lovely trees that surrounded the courtyard.	trees	rooms	hotel	weeks
I decided that I would meet some of my friends after class.	meet	draw	drew	fall
I will need to read three essays before class on Monday.	essays	papers	report	places
The family left the garage door broken when they went on holiday.	broken	closed	closes	afraid
The elderly woman would often faint on the porch in the hot afternoon sun.	faint	sweep	swept	burst
He lifted up a dirty knife and threw it at the wall in a fit of rage.	knife	cloth	rocks	price
My brand new puppy cried several times last night.	cried	awoke	awake	wrote
I eventually read through enough studies to be able to write my assignment.	studies	reports	article	fingers

Table 1

Mean (and Standard Error) Stimulus Characteristics and Norming Data for Experiment 1

Variable	Preview condition			
	Identical	Plausible	Implausible/ No violation	Implausible/ Violation
Length	5.08 (0.09)	5.08 (0.09)	5.08 (0.09)	5.08 (0.09)
Frequency (CELEX)	45.97 (8.03)	45.86 (7.98)	44.09 (6.51)	43.91 (6.39)
Orthographic neighborhood size	4.06 (0.42)	4.53 (0.43)	4.26 (0.43)	4.34 (0.44)
Dominant word class (%) ^a	97.59 (0.46)	96.62 (0.51)	97.94 (0.45)	0.92 (0.27)
Letter overlap with target ^b	1.00 (0.00)	0.11 (0.01)	0.10 (0.01)	0.10 (0.01)
Cloze probability	.02 (.01)	.02 (.01)	.00 (.00)	.00 (.00)
Rated plausibility (1-5 scale) ^c	4.57 (0.09)	4.54 (0.07)	1.49 (0.08)	1.33 (0.08)

^a Percentage of occurrence in SUBTLEX corpus of word matching part-of-speech of target word.

^b Proportion of letters shared with the target in the same position.

^c Plausibility rating for sentence up to and including the target/preview word.

Table 2

*Mean (and Standard Error) Reading Measures for the Target Word across Preview**Conditions in Experiment 1*

Measure	Preview condition			
	Identical	Plausible	Implausible/ No violation	Implausible/ Violation
Skipping (%)	20.21 (1.15)	19.82 (1.08)	16.14 (1.18)	16.93 (1.13)
First fixation duration (ms)	224 (3)	235 (3)	248 (3)	259 (3)
Single fixation duration (ms)	226 (3)	240 (3)	255 (3)	268 (3)
Gaze duration (ms)	245 (4)	259 (4)	278 (4)	296 (4)
Go-past duration (ms)	280 (7)	312 (7)	341 (7)	364 (7)
Total duration (ms)	317 (7)	370 (7)	381 (8)	386 (7)
First-pass refixation (%)	11.25 (1.33)	12.77 (1.34)	14.31 (1.27)	18.64 (1.40)
Regressions out (%)	10.53 (1.07)	13.96 (1.17)	16.87 (1.22)	19.85 (1.17)
Regressions in (%)	14.13 (1.27)	23.35 (1.71)	19.70 (1.08)	17.45 (1.10)

Table 3

Results of the (Generalized) Linear Mixed-Effects Models for Fixation Duration and Probability Measures in Experiment 1. Significant Effects are Indicated in Bold.

Measure	Fixed effect	<i>b</i>	<i>SE</i>	<i>t/z</i>
Skipping	Intercept	-1.70	0.12	-14.32
	Identical preview effect	0.01	0.11	0.09
	Plausibility preview effect	0.26	0.12	2.15
	Syntactic validity preview effect	0.03	0.14	0.23
First fixation duration	Intercept	239.12	4.83	49.56
	Identical preview benefit	-13.25	4.03	-3.29
	Plausibility preview effect	-13.59	4.27	-3.18
	Syntactic validity preview effect	-6.09	3.78	-1.61
Single fixation duration	Intercept	243.71	5.19	46.93
	Identical preview effect	-15.14	4.61	-3.29
	Plausibility preview effect	-15.96	4.67	-3.42
	Syntactic validity preview effect	-6.51	4.20	-1.55
Gaze duration	Intercept	264.80	6.10	43.43
	Identical preview effect	-15.94	5.27	-3.02
	Plausibility preview effect	-18.47	5.47	-3.38
	Syntactic validity preview effect	-11.13	5.00	-2.23
Go-past duration	Intercept	324.11	9.32	34.78
	Identical preview effect	-30.58	9.52	-3.21
	Plausibility preview effect	-29.17	10.48	-2.78
	Syntactic validity preview effect	-20.71	9.28	-2.23
Total duration	Intercept	362.69	13.32	27.22
	Identical preview effect	-54.50	11.18	-4.88
	Plausibility preview effect	-10.55	10.04	-1.05
	Syntactic validity preview effect	-5.32	9.43	-0.56
First-pass refixation	Intercept	-1.92	0.10	-20.26
	Identical preview effect	-0.20	0.17	-1.15
	Plausibility preview effect	-0.14	0.15	-0.91
	Syntactic validity preview effect	-0.33	0.14	-2.39
Regressions out	Intercept	-1.86	0.11	-17.54
	Identical preview effect	-0.27	0.15	-1.78
	Plausibility preview effect	-0.26	0.16	-1.63

	Syntactic validity preview effect	-0.17	0.13	-1.27
Regressions in	Intercept	-1.63	0.11	-15.25
	Identical preview effect	-0.75	0.17	-4.46
	Plausibility preview effect	0.27	0.14	1.86
	Syntactic validity preview effect	0.17	0.12	1.40

Table 4

Mean (and Standard Error) Stimulus Characteristics and Norming Data for Experiment 2

Variable	Preview condition			
	Identical	Plausible	Plausible/ Violation	Implausible/ No violation
Length	5.08 (0.09)	5.08 (0.09)	5.08 (0.09)	5.08 (0.09)
Frequency (CELEX)	51.25 (8.29)	51.48 (7.15)	52.63 (7.91)	51.39 (6.31)
Orthographic neighborhood size	4.34 (0.42)	4.48 (0.39)	5.14 (0.45)	4.46 (0.44)
Letter overlap with target ^a	1.00 (0.00)	0.10 (0.01)	0.10 (0.01)	0.10 (0.01)
Cloze probability	.02 (.01)	.04 (.02)	.00 (.00)	.00 (.00)
Rated plausibility (1-5 scale) ^c	4.39 (0.09)	4.36 (0.06)	1.38 (0.10)	1.43 (0.05)

^a Proportion of letters shared with the target in the same position.^c Plausibility rating for sentence up to and including the target/preview word.

Table 5

*Mean (and Standard Error) Reading Measures for the Target Word across Preview**Conditions in Experiment 2*

Measure	Preview condition			
	Identical	Plausible	Plausible/ Violation	Implausible/ No Violation
Skipping (%)	18.53 (1.04)	19.75 (0.98)	16.70 (1.17)	15.37 (1.12)
First fixation duration (ms)	230 (4)	244 (3)	256 (4)	262 (5)
Single fixation duration (ms)	231 (4)	249 (3)	259 (5)	273 (6)
Gaze duration (ms)	252 (5)	281 (3)	295 (4)	313 (6)
Go-past duration (ms)	288 (9)	342 (6)	383 (7)	377 (7)
Total duration (ms)	315 (10)	396 (7)	408 (6)	415 (8)
First-pass refixation (%)	11.44 (0.98)	14.31 (0.81)	15.80 (0.90)	20.80 (1.23)
Regressions out (%)	11.84 (1.12)	15.71 (1.07)	20.82 (1.25)	17.57 (1.19)
Regressions in (%)	13.21 (1.40)	23.69 (1.39)	21.67 (1.11)	20.43 (1.02)

Table 6

Results of the (Generalized) Linear Mixed-Effects Models for Fixation Duration and Probability Measures in Experiment 2. Significant Effects are Indicated in Bold.

Measure	Fixed effect	<i>b</i>	<i>SE</i>	<i>t/z</i>
Skipping	Intercept	-1.81	0.13	-13.60
	Identical preview effect	-0.10	0.11	-0.91
	Syntactic agreement preview effect	0.28	0.12	2.36
	Plausible/Violation vs. Implausible	0.14	0.16	0.88
First fixation duration	Intercept	244.25	5.34	45.71
	Identical preview effect	-15.87	4.31	-3.68
	Syntactic agreement preview effect	-11.00	4.22	-2.61
	Plausible/Violation vs. Implausible	-5.11	4.79	-1.07
Single fixation duration	Intercept	249.04	5.79	43.01
	Identical preview effect	-18.96	5.03	-3.77
	Syntactic agreement preview effect	-10.80	4.63	-2.33
	Plausible/Violation vs. Implausible	-10.69	6.69	-1.60
Gaze duration	Intercept	279.80	7.22	38.75
	Identical preview effect	-27.86	5.51	-5.06
	Syntactic agreement preview effect	-14.73	6.36	-2.32
	Plausible/Violation vs. Implausible	-14.29	6.63	-2.16
Go-past duration	Intercept	346.28	11.26	30.75
	Identical preview effect	-56.94	11.71	-4.86
	Syntactic agreement preview effect	-38.07	12.22	-3.12
	Plausible/Violation vs. Implausible	5.33	10.78	0.50
Total duration	Intercept	382.86	15.25	25.10
	Identical preview effect	-83.93	12.19	-6.89
	Syntactic agreement preview effect	-9.41	9.81	-0.96
	Plausible/Violation vs. Implausible	-8.87	9.79	-0.91
First-pass refixation	Intercept	-1.83	0.10	-17.86
	Identical preview effect	-0.27	0.14	-1.91
	Syntactic agreement preview effect	-0.12	0.14	-0.90
	Plausible/Violation vs. Implausible	-0.30	0.14	-2.18
Regressions out	Intercept	-1.80	0.11	-16.82
	Identical preview effect	-0.42	0.14	-2.94

	Syntactic agreement preview effect	-0.44	0.14	-3.15
	Plausible/Violation vs. Implausible	0.34	0.14	2.44
Regressions in	Intercept	-1.53	0.09	-16.78
	Identical preview effect	-0.93	0.16	-5.85
	Syntactic agreement preview effect	0.11	0.11	1.02
	Plausible/Violation vs. Implausible	0.13	0.11	1.10

- a) She eventually found a spare| stool behind the crowded bar.
- b) She eventually found a spare| glass behind the crowded bar.
- c) She eventually found a spare| uncle behind the crowded bar.
- d) She eventually found a spare| begin behind the crowded bar.

Figure 1. An example sentence in each of the four preview conditions from Experiment 1: (a) Identical, (b) Plausible, (c) Implausible/No violation, (d) Implausible/Violation. When the reader made a saccade across the invisible boundary, indicated by the dotted line, the preview was replaced by the target word.

- a) Her plane will probably| refuel later than expected this afternoon.
- b) Her plane will probably| depart later than expected this afternoon.
- c) Her plane will probably| landed later than expected this afternoon.
- d) Her plane will probably| stroke later than expected this afternoon.

Figure 2. An example sentence in each of the four preview conditions from Experiment 2: (a) Identical, (b) Plausible, (c) Plausible/Violation, (d) Implausible/No violation. When the reader made a saccade across the invisible boundary, indicated by the dotted line, the preview was replaced by the target word.