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Parafoveal preview effects depend on both preview plausibility and target predictability

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Abstract

Recent studies using the boundary paradigm have shown that readers benefit from a parafoveal preview of a plausible continuation of the sentence. This plausibility preview effect occurs irrespective of the semantic or orthographic relatedness of the preview and target word, suggesting that it depends on the degree to which a preview word fits the preceding context. The present study tested this hypothesis by examining the impact of contextual constraint on processing a plausible word in the parafovea. Participants' eye movements were recorded as they read sentences in which a target word was either highly predictable or unpredictable. The boundary paradigm was used to compare predictable, unpredictable and implausible previews. The results showed that target predictability significantly modulated the effects of identical and plausible previews. Identical previews yielded significantly more benefit than plausible previews for highly predictable targets, but for unpredictable targets a plausible preview was as beneficial as an identical preview. The results shed light on the role of contextual predictability in early lexical processing. Furthermore, these data support the view that readers activate a set of appropriate words from the preceding sentence context, prior to the presentation of the target word.

Keywords

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

Until recently it was widely assumed that readers of English rarely extracted semantic information from words in the parafovea (see e.g., Rayner, Schotter, & Drieghe, 2014). The absence of semantic parafoveal processing was initially viewed as being consistent with the serial lexical processing assumption underlying the E-Z Reader model of eye movement control (Reichle, Pollatsek, Fisher, & Rayner, 1998). However, there is now clear evidence from studies using the boundary paradigm (Rayner, 1975) that upcoming words are sometimes processed to the lexical/semantic level before they are subsequently fixated in first-pass reading (e.g., Hohenstein & Kliegl, 2014; Schotter, 2013; Schotter, Lee, Reiderman, & Rayner, 2015; Veldre & Andrews, 2016c). Attempts to account for such evidence in E-Z Reader with model simulations suggest that semantic preview effects are, in principle, compatible with the timing constraints imposed by the model's serial processing assumption (Schotter, Reichle, & Rayner, 2014). However, the precise source of semantic preview effects remains unclear.

Recent studies using the boundary paradigm have established that the benefit from a semantically related preview cannot be attributed to the integration of overlapping semantic features shared by the preview and target word. Veldre and Andrews (2016a) compared semantically related and unrelated previews that were either plausible or implausible continuations of the pre-target sentence. The results showed that there was no benefit from preview/target semantic relatedness when preview plausibility was controlled. However, first-pass fixation durations on the target were significantly shorter when the preview was a plausible continuation of the sentence than when it was implausible, regardless of the preview's relatedness to the target (see also Schotter & Jia, 2016; Yang, Wang, Tong, & Rayner, 2012; Yang, Wang, Slattery, & Rayner, 2014). These data imply that, to some degree, preview effects depend on the contextual acceptability of the preview word in the *sentence*.

Veldre and Andrews (2016b) extended these findings to show that the mechanism underlying the plausibility preview effect operates in parallel with sublexical integration of the preview and target. They compared previews that were either orthographically related or unrelated to the target word and either plausible or implausible continuations of the sentence. In contrast to the absence of any semantic relatedness effect, there was an independent preview/target *orthographic* relatedness benefit over and above the effect of preview plausibility. Taken together, these data suggest that there are two separate mechanisms underlying preview effects. Plausible words benefit reading due to the fit between the parafoveal word and the sentence in tandem with the ‘classic’ preview effect due to integration of the *sublexical* features shared by the preview and target across fixations.

There is also evidence that parafoveal processing effects in the boundary paradigm reflect both benefits accrued from preprocessing valid previews and costs associated with preprocessing invalid previews (e.g., Kliegl, Hohenstein, Yan, & McDonald, 2013). Vasilev and Angele (2016) therefore argued that the term ‘preview benefit’ that is widely used in the literature is potentially misleading and should be replaced by more neutral terminology, such as ‘N+1 preview effects’. We follow this recommendation in the following review of relevant literature and summary of our results to acknowledge the range of mechanisms that contribute to parafoveal influences during sentence reading. The question of precisely what mechanisms underlie these preview effects is considered in the Discussion.

While the studies described above provide evidence of a robust effect of preview plausibility, they used neutral sentences in which the target and preview words were all low in *cloze predictability*, assessed by instructing an independent sample of participants to generate the word most likely to appear next in the sentence. This was important in order to isolate the effect of parafoveal processing from contextual prediction. However, it raises the question of whether the plausibility preview effect can be observed when the sentence is

constrained towards a particular word. The effect of contextual predictability on eye movement measures is well established (see Staub, 2015 for a review). Words that are predictable from the sentence context are more likely to be skipped and receive shorter fixations than unpredictable words. Critically, if preview effects depend on contextual fit, there should be a larger benefit from previews of highly predictable words than from unpredictable, but otherwise contextually acceptable, words.

Several studies have found evidence of an interaction between sentence context and parafoveal preview validity, suggesting that context information affects the early stages of lexical processing (Balota, Pollatsek, & Rayner, 1985; Juhasz, White, Liversedge, & Rayner, 2008; Schotter et al., 2015; White, Rayner, & Liversedge, 2005). Seminal evidence was provided by Balota et al.'s (1985) comparison of preview effects for predictable and unpredictable targets in sentences like: *Since the wedding was today, the baker rushed the wedding cake/pies to the reception*. Highly predictable targets, like *cake*, yielded larger benefits from both identical and orthographically related previews (e.g., *cahe*) than unpredictable, but plausible, targets, like *pies*. Balota et al. argued that readers make greater use of parafoveal information about contextually predictable words. Interestingly, when the preview was a plausible but non-identical preview (i.e., *pies* as a preview for *cake* or vice-versa) there was little benefit over an anomalous preview (but see Drieghe, Rayner, & Pollatsek, 2005). While this suggests that the plausibility preview effect is not modulated by sentence constraint, it is not clear whether the predictable and unpredictable words used in the Balota et al. study were equivalently plausible continuations of the sentence.¹

The present study compared highly predictable and unpredictable target words that were carefully matched on plausibility within the sentence. Predictability and plausibility are clearly correlated to some extent. An implausible word will always be an unpredictable sentence continuation, and a word that is high in cloze predictability is necessarily plausible

in the sentence, but the converse does not hold. Plausible sentence continuations span a range of cloze probabilities and, as illustrated by the target *pies* in the above example from Balota et al. (1985), a word that is rarely generated in a cloze task can still be a perfectly acceptable continuation of the sentence. If the plausibility preview effect depends on the degree of contextual fit between the preview and the sentence, the plausibility of the preview word should modulate fixation duration during first-pass reading regardless of the predictability of the target word.

The study was also designed to provide more refined insight into the contextual relationships underlying the plausibility effect. Previous evidence for a plausibility preview effect derives from comparisons between a plausible preview and a syntactically and/or semantically anomalous preview. Rather than reflecting the contextual fit of the preview in the developing sentence, the effect may be due to the semantic relatedness of the preview to the preceding sentence context. A word that is contextually implausible may be easy to identify and thereby yield a preview benefit, if it contains semantic features that are consistent with the beginning of the sentence.

Evidence that the benefit of sentence constraint results from graded activation of a set of words that are semantically related to the preceding context is provided by Schotter et al.'s (2015) finding that semantically related, but often implausible, previews produced a benefit in sentences that were moderately constrained towards the meaning of the preview/target words. Critically, this effect was not present in neutral sentences. This suggests that sentence context information might preactivate a set of semantically related words, whether or not they are plausible in the sentence. However, because Schotter et al.'s study was not designed to investigate the role of preview plausibility, their effect may be due to small differences in acceptability between the semantically related previews and the unrelated condition, which was almost invariably an implausible sentence continuation.

Thus the present study investigated preview effects for predictable and unpredictable targets that were carefully matched on plausibility within highly constraining sentence contexts. To determine the source of effects of predictability and plausibility on parafoveal processing, we compared three preview types to an implausible unrelated word baseline: an identical preview, a plausible preview, and a contextually implausible preview that was semantically related to the beginning of the sentence.

METHOD

Participants

Ninety-five students from The University of Sydney (62 female; mean age 19.0 years) participated as part of a wider study investigating individual differences in language proficiency. 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 critical stimuli were 80 highly constraining sentences, 9-19 words in length ($M=13.9$), in which one member of a pair of target words (range: 4-8 letters) was embedded. For each pair of targets, one word was the most probable continuation of the preceding context (Predictable target) and the other word was an equally plausible but low probability continuation (Unpredictable target). Both words appeared as targets across counterbalanced lists but participants only saw each sentence frame once. Thus, in half the sentences read by each participant the target was a predictable word and in the other half it was unpredictable.

The boundary paradigm was used to compare four parafoveal preview conditions: (1) *Identical*: identical to the target, i.e. either a predictable or unpredictable continuation of the sentence; (2) *Plausible*: a plausible but non-identical continuation of the sentence, i.e., an unpredictable word when the target was a predictable word and vice versa; (3) *Implausible*

Related: an implausible continuation of the sentence that was semantically related to the pre-target sentence context; or (4) *Implausible Unrelated*: a matched implausible word that was unrelated to the sentence context. All sentences appeared in all preview conditions across eight counterbalanced lists.

1a)The lawyer feared his client was probably; guilty when he was preparing the case.
 1b)The lawyer feared his client was probably; insane when he was preparing the case.
 1c)The lawyer feared his client was probably; courts when he was preparing the case.
 1d)The lawyer feared his client was probably; mirror when he was preparing the case.

2a)To reduce glare, they dimmed the bright; screen at the far end of the office.
 2b)To reduce glare, they dimmed the bright; lights at the far end of the office.
 2c)To reduce glare, they dimmed the bright; squint at the far end of the office.
 2d)To reduce glare, they dimmed the bright; honour at the far end of the office.

Figure 1. Examples of the preview conditions used in the experiment: (a) identical, (b) plausible, (c) implausible and contextually related, (d) implausible and unrelated. Sentence 1 has a predictable target word and unpredictable plausible preview. Sentence 2 has an unpredictable target word and predictable plausible preview. The invisible boundary is represented by the dashed line. In all conditions, the identical target word was displayed when the reader's eye crossed the boundary.

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 write down the word that was most likely to come next. The results of the cloze task showed that the predictable targets had high cloze completion rates ($M=70\%$, range: 40-100%) while the unpredictable targets were low in cloze predictability ($M=1\%$, range: 0-15%). The implausible preview words were never generated as responses in the cloze task.

To confirm the plausibility manipulation, a separate group of 25 participants provided plausibility ratings on a 7-point scale for the sentence frames up to and including the

target/preview words. The sentence fragments ending with the implausible related and implausible unrelated previews were rated as significantly lower in acceptability than each of the plausible previews [all $t_s > 23.87$, $p_s < .001$]. However, there were no significant differences in acceptability between the two plausible previews, or between the two implausible previews [$t_s < 1.99$, $p_s > .05$].

A further group of 22 participants provided ratings of semantic similarity between each of the implausible previews and the pre-target sentence frame on a 7-point scale. The implausible related preview was judged to be significantly more related to the meaning of the pre-target sentence than the implausible unrelated preview [$t(79) = 22.35$, $p < .001$].

The stimulus characteristics and norming data are presented in Table 1.

Table 1

Mean (and Standard Deviation) Stimulus Characteristics and Norming Data

Variable	Preview word			
	Predictable	Unpredictable	Implausible related	Implausible unrelated
Word length	5.03 (1.10)	5.03 (1.10)	5.03 (1.10)	5.03 (1.10)
Log frequency (HAL)	9.85 (1.52)	9.20 (1.70)	9.30 (1.86)	10.37 (1.18)
Letter overlap with predictable target (%)	100.00 (0.00)	9.54 (14.33)	10.07 (14.10)	8.30 (13.93)
Letter overlap with unpredictable target (%)	9.54 (14.33)	100.00 (0.00)	8.54 (12.59)	8.40 (14.36)
Cloze predictability (%)	69.80 (19.39)	1.17 (3.13)	0.00 (0.00)	0.00 (0.00)
Sentence fragment plausibility (1-7 scale)	6.36 (0.70)	6.11 (0.73)	2.66 (1.12)	2.31 (0.93)
Semantic relatedness to sentence fragment (1-7 scale)	-	-	5.39 (1.06)	1.90 (0.67)

Note. Letter overlap calculated as the percentage of letters shared with the target in the same position.

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 80 experimental trials, which were presented in an individually randomised order. 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 25% of experimental trials, the sentence was followed by a multiple-choice comprehension question that required a moderate understanding of the meaning of the sentence.²

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 (4.7% of total fixations). Trials were eliminated if the participant blinked immediately before or after fixating the target word (2.2% 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 (8.8% of trials). Target gaze durations above 1200 ms, go-past durations above 2000 ms, and total durations above 3000 ms were also excluded (<1% of trials). These exclusions left 6727 trials (88.5% of the data) available for analysis. All participants answered at least 75% of the comprehension questions correctly ($M=96.5\%$).

The following reading measures were analyzed: *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., this measure includes fixations on the target and any subsequent fixations on words earlier in the sentence), and *total duration* (the sum of all fixations on the target word including first-pass reading and any later rereading). The probability of the reader making a *first-pass fixation* on the target; the probability of *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.

Table 2

Mean (and Standard Deviation) Reading Measures on the Target across Conditions

Measure	Predictable target word				Unpredictable target word			
	Identical Predictable preview	Plausible Unpredictable preview	Implausible Related preview	Implausible Unrelated preview	Identical Unpredictable preview	Plausible Predictable preview	Implausible Related preview	Implausible Unrelated preview
<i>Fixation Duration Measures (ms)</i>								
First fixation	217 (36)	249 (43)	264 (38)	272 (48)	232 (48)	232 (40)	257 (40)	266 (37)
Single fixation	217 (40)	253 (51)	270 (43)	281 (52)	234 (51)	234 (47)	264 (50)	277 (44)
Gaze duration	232 (43)	282 (38)	293 (49)	305 (54)	256 (57)	262 (56)	298 (52)	305 (50)
Go-past duration	273 (96)	346 (92)	379 (90)	386 (98)	316 (98)	315 (110)	386 (96)	393 (102)
Total duration	277 (88)	381 (79)	386 (71)	382 (83)	330 (92)	410 (107)	415 (91)	406 (79)
<i>Fixation Probability Measures</i>								
First-pass fixation	.72 (.14)	.78 (.15)	.80 (.14)	.82 (.12)	.76 (.14)	.73 (.15)	.81 (.14)	.82 (.13)
Regressions out	.09 (.13)	.16 (.16)	.21 (.15)	.21 (.17)	.13 (.14)	.10 (.13)	.21 (.14)	.19 (.16)
Regressions in	.15 (.14)	.27 (.16)	.24 (.17)	.21 (.15)	.20 (.15)	.39 (.19)	.27 (.17)	.25 (.15)

The data were analyzed by (generalized) linear mixed-effects models (LMM) using the *lme4* package (Version 1.1-10; Bates, Maechler, Bolker, & Walker, 2015) in *R* (Version 3.2.2; R Core Team, 2015). Planned sum contrasts tested the difference between the unrelated preview and each of the identical, plausible, and related previews. Fixed effects testing the interactions between target predictability (predictable vs. unpredictable; coded as a sum contrast) and each of the preview effects were also included. The models included subject and item random intercepts and random slopes for target predictability and the preview contrasts.³ 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 Tables 3 and 4.

Target Fixation Rate

The fixation rate analysis included only the preview contrasts because the decision to skip a word occurs before the target word is visible, i.e. before the reader crosses the boundary, and therefore cannot be affected by properties of the target word. Relative to an implausible unrelated word in the parafovea, readers were significantly more likely to skip predictable [$z=-6.7$] and unpredictable words [$z=-3.8$]. However, there was no difference in fixation probability between the implausible related and unrelated previews [$z=-1.5$]. Thus, first-pass fixation rate was primarily affected by the extent to which the upcoming word was an acceptable continuation of the sentence.⁴

Table 3

Results of the Linear Mixed-Effects Models for Fixation Duration Measures. Significant

Effects are Indicated in Bold.

Measure	Fixed effect	<i>b</i>	<i>SE</i>	<i>t</i>
First fixation duration	Intercept	248.08	4.58	54.19
	Target predictability	-2.18	1.52	-1.44
	Identical PE	-46.55	5.57	-8.36
	Plausibility PE	-30.32	5.48	-5.53
	Relatedness PE	-8.85	4.02	-2.20
	Target predictability × Identical PE	7.96	3.54	2.25
	Target predictability × Plausibility PE	-6.66	3.56	-1.87
	Target predictability × Relatedness PE	-1.66	3.52	-0.47
Single fixation duration	Intercept	252.46	4.83	52.31
	Target predictability	-2.31	1.70	-1.35
	Identical PE	-54.62	6.06	-9.02
	Plausibility PE	-37.51	6.11	-6.14
	Relatedness PE	-12.19	4.58	-2.66
	Target predictability × Identical PE	9.79	3.82	2.56
	Target predictability × Plausibility PE	-6.60	3.88	-1.70
	Target predictability × Relatedness PE	-1.69	3.87	-0.44
Gaze duration	Intercept	277.93	5.75	48.30
	Target predictability	0.41	2.23	0.18
	Identical PE	-62.03	6.81	-9.10
	Plausibility PE	-34.01	7.26	-4.69
	Relatedness PE	-9.62	5.01	-1.92
	Target predictability × Identical PE	9.98	4.57	2.18
	Target predictability × Plausibility PE	-11.17	4.60	-2.43
	Target predictability × Relatedness PE	1.18	4.53	0.26
Go-past duration	Intercept	348.37	10.72	32.48
	Target predictability	1.78	3.72	0.48
	Identical PE	-97.32	13.37	-7.28
	Plausibility PE	-59.94	11.83	-5.07
	Relatedness PE	-7.25	9.62	-0.75
	Target predictability × Identical PE	14.19	8.39	1.69
	Target predictability × Plausibility PE	-21.42	8.41	-2.55
	Target predictability × Relatedness PE	-0.88	8.32	-0.11
Total duration	Intercept	372.26	11.65	31.96
	Target predictability	15.48	4.16	3.72
	Identical PE	-92.43	10.50	-8.81
	Plausibility PE	0.80	10.10	0.08

Relatedness PE	4.12	8.18	0.50
Target predictability $\times$ Identical PE	11.75	7.55	1.56
Target predictability $\times$ Plausibility PE	-1.37	7.57	-0.18
Target predictability $\times$ Relatedness PE	0.69	7.48	0.09

Note. PE = preview effect contrast relative to the implausible unrelated condition.

Target Fixation Measures

Target predictability. For trials on which the target was fixated, there were no significant main effects of target predictability on first-pass reading measures [all $|t|s < 1.8$] or on the likelihood of regressing from the target word [$z = -1.0$]. However, as detailed below, this was qualified by interactions between predictability and parafoveal preview on first-pass reading. On total duration, unpredictable targets were associated with significantly longer fixations than predictable targets [$t = 5.9$] due to a higher rate of regressions to unpredictable targets [$z = 5.3$].

Identical preview effect. There was a significant benefit from an identical preview relative to an implausible unrelated preview across all fixation duration measures [all $|t|s > 7.2$]. Readers were also significantly less likely to regress out of and into the target after an identical preview [both $|z|s > 3.3$].

This was qualified by a significant Target Predictability $\times$ Identical Preview interaction on first fixation, single fixation, gaze duration [all $ts > 2.1$], and regressions out [$z = 2.4$] but not on go-past, total duration [$ts < 1.7$], or regressions in [$z < 1$]. As illustrated in Figure 2, readers benefited more from the availability of valid parafoveal information about a predictable word than an unpredictable word, replicating Balota et al. (1985). However, follow-up LMMs revealed that the identical preview effect was statistically significant for both predictable targets [$|t|s > 8.1$ and $z = -5.5$] and unpredictable targets [$|t|s > 6.2$ and $z = -2.2$].

Table 4

Results of the Generalised Linear Mixed-Effects Models for Fixation Probability Measures.

Significant Effects are Indicated in Bold.

Measure	Fixed effect	<i>b</i>	<i>SE</i>	<i>z</i>
First-pass fixation	Intercept	1.45	0.10	13.92
	Predictable word PE	-0.66	0.10	-6.68
	Unpredictable word PE	-0.37	0.10	-3.77
	Relatedness PE	-0.14	0.10	-1.47
Regressions out	Intercept	-1.91	0.11	-16.85
	Target predictability	-0.05	0.04	-1.25
	Identical PE	-0.72	0.16	-4.59
	Plausibility PE	-0.65	0.13	-5.01
	Relatedness PE	0.07	0.11	0.61
	Target predictability × Identical PE	0.29	0.12	2.43
	Target predictability × Plausibility PE	-0.22	0.12	-1.84
	Target predictability × Relatedness PE	0.11	0.10	1.02
Regressions in	Intercept	-1.36	0.12	-11.11
	Target predictability	0.22	0.05	4.48
	Identical PE	-0.35	0.11	-3.14
	Plausibility PE	0.58	0.11	5.48
	Relatedness PE	0.20	0.11	1.88
	Target predictability × Identical PE	0.04	0.11	0.36
	Target predictability × Plausibility PE	0.15	0.10	1.50
	Target predictability × Relatedness PE	-0.02	0.10	-0.17

Note. PE = preview effect contrast relative to the implausible unrelated condition.

Plausibility preview effect. There was a significant *plausibility preview effect* across first-pass reading measures and regressions out [all $|t|s > 4.7$ and $z = -5.0$]. Readers fixated on the target for a shorter duration, and were less likely to regress from the target, when the preview was a plausible unrelated word than when it was an implausible unrelated word. This result confirms that an unrelated preview word can benefit reading when it is a plausible continuation of even a highly constrained sentence context. While this is inconsistent with the finding of Balota et al. (1985), a close replication by Drieghe et al. (2005) found that an

unpredictable word preview yielded a significant benefit over an anomalous word when the target was highly predictable.

There was no significant difference between the plausible and implausible conditions on total duration [$t < 1$] because readers were significantly *more* likely to regress back to the target after a plausible but non-identical preview [$z = 5.5$].

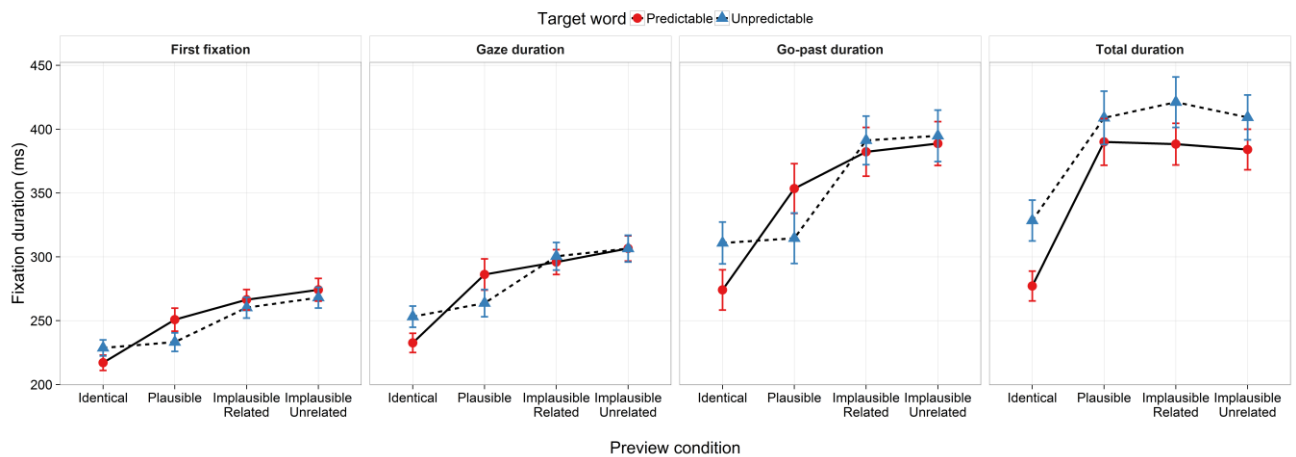


Figure 2. Mean first fixation duration, gaze duration, go-past duration, and total duration on the target in each preview condition. Red circles represent predictable target words and blue triangles represent unpredictable target words. Error bars are 95% confidence intervals.

The Predictability $\times$ Plausibility Preview interaction was significant on gaze and go-past duration [both $|t| > 2.4$]. As can be seen in Figure 2, this interaction was in the opposite direction to the identical preview interaction. For unpredictable targets, a plausible preview (i.e., a high predictability word) was almost as beneficial as an identical preview. In contrast, for predictable targets, a plausible preview (i.e., a low predictability word) provided little benefit over an implausible word.⁵ In order to determine whether the reduced benefit from an unpredictable but plausible word was statistically significant, follow-up LMMs were conducted separately for the predictable and unpredictable targets. These analyses revealed that the plausibility preview effect was indeed significant for predictable targets (i.e.,

unpredictable previews) on first fixation duration [$b=-23.71$, $SE=6.64$, $t=-3.57$], single fixation duration [$b=-30.97$, $SE=7.83$, $t=-3.96$], gaze duration [$b=-22.79$, $SE=8.50$, $t=-2.68$], and go-past duration [$b=-40.15$, $SE=14.91$, $t=-2.69$], but not total duration [$t<1$]. The plausibility preview effect was also significant for unpredictable targets (i.e., predictable previews) on first fixation duration [$b=-35.88$, $SE=6.39$, $t=-5.61$], single fixation duration [$b=-43.70$, $SE=7.86$, $t=-5.56$], gaze duration [$b=-43.78$, $SE=8.14$, $t=-5.38$], and go-past duration [$b=-79.66$, $SE=17.75$, $t=-4.49$], but not total duration [$t<1$].

To provide further insight into the source of the plausibility effect and directly confirm the opposite interactions of preview identity and plausibility with target predictability, a supplementary analysis compared just the identical and plausible preview conditions. Predictability significantly modulated the difference between the identical and plausible previews on first fixation duration [$b=8.25$, $SE=2.07$, $t=3.98$], single fixation duration [$b=8.80$, $SE=2.15$, $t=4.10$], gaze duration [$b=14.12$, $SE=2.93$, $t=4.82$], and go-past duration [$b=18.93$, $SE=5.39$, $t=3.52$]. Across measures, for predictable targets, the difference between the identical and plausible previews was highly significant [all $|t|s>4.35$] but, for unpredictable targets, there was no significant difference between these conditions [all $|t|s<1.17$].

Implausible related preview effect. There was a small but significant benefit from a contextually related implausible preview on the early measures of first fixation duration and single fixation duration [both $|t|s>2.3$] but not on gaze, go-past, or total duration [all $|t|s<1.9$].⁶ The implausible related condition did not differ significantly from the implausible unrelated condition on regressions out [$z<1$] or regressions in to the target [$z=1.9$].

The Predictability $\times$ Implausible Related Preview interaction was not significant on any measure [all $|t|s$ and all $|z|s<1$].

DISCUSSION

This research investigated the influence of sentence context on parafoveal processing. Specifically, we assessed whether the plausibility preview effect is modulated by the contextual predictability of the preview/target word. The study yielded several important findings.

First, the benefit from an identical preview was modulated by target predictability: highly predictable words produced a larger preview effect than unpredictable words, replicating previous findings (Balota et al., 1985; Juhasz et al., 2008; Schotter et al., 2015; White et al., 2005). This suggests that contextually predictable words are more efficiently processed in the parafovea than unpredictable words and converges with evidence of predictability effects on skipping (e.g., Drieghe et al., 2005) to support the proposition that sentence context information affects the earliest stages of word processing (Staub, 2015).

Second, the results showed a strong plausibility preview effect which replicated recent findings in both English and Chinese (Schotter & Jia, 2016; Veldre & Andrews, 2016a, 2016b; Yang et al., 2012; Yang et al., 2014), and extended the plausibility preview effect beyond neutral sentence frames to constrained sentence contexts. Critically, the extent of benefit from a plausible but non-identical preview depended on whether the target was predictable from the sentence context. A highly predictable word preview provided as much benefit as an identical preview on first pass measures when the target was a plausible but unpredictable word. In contrast, when the target was a highly predictable word, the benefit from a plausible relative to an implausible preview, though statistically significant, was smaller and substantially less than the benefit of an identical preview. As elaborated below, these findings suggest that readers generate expectancies in highly constrained contexts which facilitate parafoveal processing of words that match these predictions.

The third major issue addressed by the study was whether the semantic relatedness of the preview to the previous sentence context contributes to plausibility effects. Despite being rated as unacceptable sentence continuations, implausible words that were semantically related to the sentence context yielded shorter first and single fixation durations than implausible unrelated words. This early influence of semantic relatedness between the preview and context is consistent with the view that a range of likely upcoming word candidates are pre-activated based on the semantic information extracted from the sentence context, perhaps via spreading activation (Schotter et al., 2015; Staub, 2015). Consistent with Schotter et al.'s (2015) results, these findings suggest that readers benefit when the word in the parafovea matches one of these activated lexical candidates, even when it is an unacceptable continuation of the sentence. This implies that a preview's semantic relatedness to the preceding *sentence context* yields a small, but significant beneficial effect on early fixations.

These findings provide clear evidence that preview effects are influenced by the contextual predictability of both the preview and the target. Perhaps the most striking finding is that, for the constraining sentence contexts used here, a highly predictable word preview produced as much benefit on early processing of an unpredictable word target as an identical preview, demonstrating that preview predictability compensated for the disruptive effects of both display change and orthographic discrepancies between the preview and target. In contrast, when the target was the word most strongly predicted by the previous sentence context, identical previews produced substantially larger benefits than plausible (i.e., unpredictable) previews. Critically, there was still a significant plausibility preview benefit for highly predictable targets. These findings support Staub's (2015) conclusions from a systematic review of the effects of predictability on eye movements that readers activate a set of potential upcoming words, graded according to their cloze probability in the context, rather

than a single specific prediction, and that “the benefits of this pre-activation... accrue primarily in the very earliest stages of lexical processing” (Staub, 2015, p. 323). When the preview matched the most highly activated member of this set, it was processed very rapidly, yielding shorter initial target fixations and reduced likelihood of refixating the target or regressing to earlier in the sentence. Critically, similar but smaller benefits accrued when the preview was a plausible, but low probability continuation of the sentence, implying that activation extends beyond the most probable continuation, even in highly constrained contexts.

Importantly, this plausibility effect cannot be explained by preview/target relatedness. There was minimal orthographic overlap between the preview and target words, which did not differ across conditions. Additionally, while many of the preview/target pairs shared semantic features, Veldre and Andrews (2016a) found no evidence of an effect of preview/target semantic relatedness when plausibility was controlled, or that it modulated the preview plausibility effect. Thus, rather than reflecting a benefit from preview/target relatedness, the present findings are more likely to be due to a benefit of preview/sentence relatedness. However, it is unlikely that the plausibility preview effect can be solely attributed to lexical/semantic relationships between the preview and sentence. Although significant in our large sample, the benefit from implausible related previews was small (7-14 ms), and showed no sensitivity to the target predictability effects that modulated the benefits of plausible previews. Further research using more refined measures of semantic relatedness to both the context and target is necessary to confirm whether the preview effect for implausible but related words is robust. However, the present findings confirm that words that are semantically and syntactically plausible in the sentence yield a robust benefit on early target processing, even in highly constrained contexts. While these effects were observed on first-pass reading, the benefits of predictable and plausible previews did not extend to total

duration because they were counteracted by an increased likelihood of regressing back to the target after a plausible, non-identical preview.

This trade-off between the effects of preview plausibility on early and late measures of processing is consistent with recent explanations of how semantic preview effects (Schotter et al., 2014) and preview plausibility effects (Schotter & Jia, 2016; Veldre & Andrews, 2016a) can arise in E-Z Reader. Within this framework, sentence context could affect the magnitude of preview benefit by increasing the likelihood that a contextually related preview word is identified in the parafovea. Simulations of E-Z Reader have shown that it predicts a small proportion of trials on which the initial stage of lexical processing (L_1) of the parafoveal preview completes too late to cancel the previously programmed saccade and result in a skip, but before information from the target word is available from the visual system. Schotter et al. (2015) suggested that, on such trials, a forward saccade from the target location may be programmed and executed on the basis of preview processing alone. However, information extracted from the target, or the discrepancy between preview and target disrupts later integration processes reflected in increased regressions to the target. Although the completion of L_1 processing of parafoveal words occurred on less than 10% of trials in Schotter et al.'s (2014) simulations, it may be more common for the highly constrained contexts used here. Plausibility effects may also be magnified by trials on which post-lexical processing of the preview word is initiated before the forward saccade from the target word is executed. Failures in the coarse incremental integration processes assumed in E-Z Reader 10 (Reichle, Warren, & McConnell, 2009) may contribute to the higher refixation rates observed in the present data for both implausible previews and plausible but unpredictable previews (Veldre & Andrews, 2016a, 2016b). Plausibility preview effects may, therefore, reflect the cost of implausible previews as well as the benefits of previews that fit

the context. Further simulations will be necessary to confirm whether E-Z Reader can accommodate these data.

Similar findings that properties of a parafoveal preview directly affect target fixations have been described as *delayed parafoveal-on-foveal effects* (Risse & Kliegl, 2012, 2014). According to this view, processing difficulty of the preview word that occurs while the reader is still fixating the pre-target word spills over onto fixations on the target word. Evidence for this account comes from a study by Risse and Kliegl (2012) in which the difficulty of processing the parafoveal preview of word $n+2$ had no effect on word n but produced a small (4 ms) but significant effect on (postboundary) word $n+1$.

While the present data might also be described as delayed parafoveal-on-foveal effects, there are several reasons why we prefer an account based on direct effects of parafoveal processing on forward saccade programming. Firstly, we found no evidence that properties of the preview affected fixation time on the pre-target word, even for short target words (see Footnote 4). If the preview effects on target fixations were due to parafoveal-on-foveal effects that “arrived too late” to affect pre-target fixations, it would be expected that their impact would be observed on the pre-target word on at least some trials. The second reason that we prefer a saccade generation account is that, in addition to the effects of preview predictability/plausibility on target fixation duration, preview predictability also affected target first-pass fixation probability, reflecting higher skipping rates for previews of highly predictable words⁷, and plausible previews were also associated with a higher rate of regressions to the target. While this evidence is not necessarily inconsistent with a delayed parafoveal-on-foveal effect, it is directly predicted by the saccade generation account. Specifically, contextually predictable parafoveal words can be processed sufficiently quickly to trigger re-programming of a saccade to skip word $n+1$. On some trials this is executed but on other trials parafoveal processing is too sluggish to terminate the saccade to word $n+1$ and

is instead reflected in reduced fixation durations on the target word that replaces the plausible preview, and often followed by late regressions to the target word. While this account attributes both skipping and preview effects on target fixation duration to processing that occurred while the reader was fixated on the previous word, referring to them as delayed parafoveal-on-foveal processing seems to inappropriately broaden this term to potentially include *any* effect of preview processing that affects the post-boundary fixation.

Conclusion

These data add to a growing body of evidence of parafoveal semantic effects in English. We have demonstrated that the plausibility preview effect is not restricted to neutral sentences and can, in fact, be observed in sentences that are constrained toward a single word. Furthermore, the present results show that the magnitude of the plausibility preview effect depends on whether or not the preview is a predictable continuation of the sentence, shedding light on the role of context in early lexical processing.

FOOTNOTES

¹ Drieghe et al.'s (2005) Experiment 1 used 84 of Balota et al.'s (1985) 96 items. Their norming data suggested that the predictable and unpredictable words were not equally plausible sentence continuations (acceptability ratings of 4.47 and 2.32 out of 5, respectively).

² Participants also completed a battery of reading and spelling tests and an unrelated eye tracking experiment in the same session.

³ The LMM for total duration and the GLMM for regressions-in failed to converge with this random effects structure so the item random slopes for preview condition were removed from these models.

⁴ There was no effect of preview plausibility/predictability on pre-target fixation durations, i.e. no parafoveal-on-foveal effects [all $|t|s < 1.62$]. To probe whether the parafoveal-on-foveal effect was limited to short words, target length was included as a predictor in the models. There was a significant main effect of target length on pre-target gaze duration because readers spent less time fixating the pre-boundary word when the upcoming word was long [$b = -6.82$, $SE = 3.17$, $t = -2.15$]. However, target length did not interact with parafoveal preview [all $|t|s < 1.26$]. An additional analysis of just the shorter 4-letter targets (31 items) also showed no significant effects of preview predictability/plausibility on pre-target gaze duration [all $|t|s < 1.59$]. Thus, there was no evidence that properties of the preview affected fixations prior to the reader crossing the boundary.

⁵ The fact that the interaction between target predictability and plausibility preview was restricted to these “late” measures and was not observed on first or single fixation duration suggests that they arose from differences in the likelihood of refixating the target word. A GLMM on the likelihood of the reader immediately refixating the target word during first-pass reading confirmed the expected significant interaction between predictability and plausibility preview [$b = -0.34$, $SE = 0.16$, $z = -2.16$]. Follow-up GLMMs revealed that readers were equally likely to refixate *predictable* targets after a plausible (but unpredictable) preview as an implausible preview [$z < 1$]. However, readers were significantly less likely to refixate *unpredictable* targets after a plausible (i.e., highly predictable) preview than after an implausible preview [$b = -0.83$, $SE = 0.25$, $z = -3.37$]. Thus, the plausibility preview effect is due, in part, to a reduced likelihood of refixating the target during first pass reading following plausible, highly predictable previews.

⁶ The fact that this effect was restricted to the first fixation on the target was also reflected in refixation likelihood, which was equivalent for implausible related and unrelated previews [$b = 0.17$, $SE = 0.14$, $z = 1.20$].

⁷ We conducted a follow-up GLMM based on the subset of trials for which the preview was either a predictable or unpredictable word in order to confirm that the apparent difference in fixation likelihood was statistically significant. The results of this analysis revealed that readers were significantly less likely to fixate the target when the preview was a predictable word (72.4%) compared to an unpredictable word (77%) [$b = 0.14$, $SE = 0.05$, $z = 3.02$].

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