Parafoveal-on-Foveal Effects in High-Skill Spellers: Disambiguating Previews Influence Ambiguous Word Recognition

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Abstract

Parafoveal-on-foveal (POF) effects occur when reading time on a fixated word in the fovea is influenced by the upcoming word in the parafovea. Evidence for POF effects have been inconsistent and met with methodological scrutiny (Drieghe, 2011), but recent research suggests that skill differences in spelling may impact POF effects (Veldre & Andrews, 2014). To extend this literature, the current study examines the influence of spelling ability on POF effects by leveraging semantic ambiguity. Participants read sentences containing an ambiguous target immediately followed by a disambiguating word as their eye movements were recorded. Disambiguating words were manipulated to be either consistent or inconsistent with the likely interpretation of the ambiguous word. Results indicate that high-skilled spellers have longer reading times on the target word when the disambiguating word is inconsistent. These findings suggest that POF effects may be possible, particularly within a highly-skilled subset of skilled readers.

Keywords: parafoveal-on-foveal effects; word skipping; parafoveal preview; semantic ambiguity; eye movement control; spelling; individual differences

Introduction

Skilled reading requires that printed word forms automatically activate a word's meaning. Typically, word meaning recognition is achieved while a reader's eyes remain fixated on the word (Rayner, 1998). Other information – such as word length and spelling – can be extracted from the area just to the right of a fixation, known as the parafovea (see Schotter, Angele & Rayner, 2012 for a review). Evidence that semantic information can also be extracted from the parafovea has, until recently, been limited to non-alphabetic languages, in particular, Chinese (Yan, Zhou, Shu, & Kliegl, 2012). Recent research suggests semantic parafoveal processing *can* occur in alphabetic languages, such as English, but that this effect may be limited to a highly-skilled subset of the skilled reader population (Veldre & Andrews, 2016). Together, this research suggests that characteristics of the language itself and the proficiency of individual readers within the language influence the degree to which a reader can benefit from semantic parafoveal processing.

Benefits received from parafoveal preview are typically observed as either a benefit or a cost once the preview word is ultimately fixated (Schotter et al., 2012). These studies demonstrate that lexical information in the parafovea is extracted on the prior fixation. However, serial models of eye movement control account for these effects by assuming that parafoveal preprocessing occurs for many words after processing of the fixated word is complete (Schotter, Reichle, Rayner, 2014). In contrast, POF effects occur when processing of a word in the parafovea influences processing time on the currently fixated word. Thus, POF effects are observed on the fixated word as a result of a manipulation in the parafovea. Several studies have demonstrated POF effects when orthographic previews are illegal or visually distinctive (Inhoff, Starr, Schindler, 2000; Kennedy, 2000; Rayner, 1975; Vitu, Brysbaert, & Lancelin, 2004). However, evidence for lexical-semantic POF effects has been inconsistent and elusive in natural reading (see Brothers, Hoversten, and Traxler, 2017 for a review).

Research has provided evidence that lexical-semantic information in the parafovea can influence foveal processing, however, tasks used in these studies are not representative of natural reading (Kennedy, Pynte, and Ducrot, 2002; López-Peréz, Dampuré, Hernández-Cabrera, Barber, 2016). Using a boundary-change paradigm, researchers found that parafoveal preview manipulations of length and frequency interacted with foveal gaze duration, evidence of a POF effect (Kennedy, Pynte, & Ducrot, 2002). Others have failed to replicate POF effects in natural reading tasks (Angele, Slattery, Yang, Kliegl, & Rayner; 2008; Rayner, Juhasz, & Brown, 2007). These studies have explained increased fixations on a target as the result of mislocated saccades, saccades intended to land on the parafoveal word but falling short, rather than parafoveal manipulations (Drieghe, Rayner, & Pollatsek, 2008). Recent evidence derived from fixation-related potentials (a methodology that couples traditional ERP approaches with eye movement data) suggests that a word in the parafovea can be processed and immediately integrated with ongoing foveal processing (López-Peréz, et al., 2016). This evidence implies that parafoveal processing occurs rapidly, is able to influence foveal word processing, and is readily available for integration during ongoing foveal processing. Preview benefits, even semantic preview benefits, can be accounted for by predominant models of eye movement control (e.g. EZ Reader and SWIFT), nonetheless, they make different predictions regarding parafoveal-on-foveal (POF) effects (Engbert, Nuthmann, Richter, & Kliegl 2005; Reichle, Rayner, & Pollatsek, 2003).

Orthographic Skill and Parafoveal Processing

Average skilled readers benefit from parafoveal preview of upcoming words. This benefit may be tied to efficient lexical processing of the word in the fovea. In serial models of eye movement control, lexical access occurs in two stages; the orthographic representation is accessed first (L1) and indicates to the reader that the second stage, meaning access (L2) is imminent (Reichle, et al., 2003). Completion of L1 signals that it is safe to begin building a saccadic program to the upcoming word because L2 completion is likely. Sometimes L2 can occur so rapidly that access is complete before actual movement of the eyes. In this case, readers may be able to covertly shift attention, but not the eyes, to the word in the parafovea (Schotter, et al., 2014). However, research has shown that parafoveal preview benefits are associated with individual differences even within the skilled reader population (Ashby, Yang, Evans, & Rayner, 2012; Rayner, Reichle, Stroud, Williams, & Pollatsek, 2006; Veldre & Andrews, 2014; 2016).

Recent evidence suggests that the ability to extract semantic information from the parafovea is associated with skilled readers who also demonstrate strong spelling ability (Veldre & Andrews, 2016). Spelling tasks require access to accurate, orthographic representations which are central to skilled reading. High-skill spellers are thought to have fast access to accurate orthographic knowledge. This encourages bottom-up word recognition processes. During reading, rapid access to a fixated word's meaning may provide a window of opportunity for high-skill spellers to extract information from the parafovea (Veldre & Andrews, 2016).

Specifically, in Veldre and Andrews (2016), they found that highly-skilled readers, particularly those with good spelling skills, were able to extract semantic information from the preview when it was plausible. The authors suggest that orthographic knowledge, indexed by spelling ability, supports fast access to meaning for both the fixated word and the potential to achieve lexical access of the parafoveal word. Efficient bottom-up processing of both the fixated word and the word in the parafovea may support POF effects among high-skill spellers.

Semantic Ambiguity

Semantically ambiguous words have two or more distinct meanings but share a common sound and a common spelling. Choosing the correct meaning depends on the context in which it appears. Research shows that when context is not available, the most frequent meaning of the word will be selected and integrated with the sentential representation (e.g. Dopkins, Morris, & Rayner, 1992; Duffy, Morris, & Rayner, 1988; Rayner, Pacht, & Duffy, 1994; Sereno, Pacht, & Rayner, 1992). However, when context comes before an ambiguous word that has one dominant meaning, and the context supports the less-frequent meaning, readers spend longer fixating on the ambiguous word (Dopkins et al., 1992; Duffy, et al., 1988; Rayner et al., 1994; Sereno et al., 1992). The prior context supports the activation of the less-frequent meaning allowing it to compete for selection with the most-frequent meaning. This competition and selection process results in longer reading times (see Dopkins et al., 1992 for a review).

Current Study

All target words in the current study are ambiguous in that they have one frequent and one less-frequent meaning (biased ambiguous words). Targets followed semantically neutral context that did not suggest a particular meaning. According to ambiguity effects, because disambiguating context always followed the ambiguous word, all readers were expected to quickly activate the most-frequent meaning, regardless of the word in the parafovea (Dopkins et al., 1992; Duffy, et al., 1988; Rayner et al., 1994; Sereno et al., 1992). The parafoveal word provided disambiguating information consistent with the likely interpretation or inconsistent with the likely interpretation, however, according to serial models of eye movement control, this should not influence reading on the ambiguous target. Given recent evidence that parafoveal information can influence meaning access and integration, the parafoveally presented words in the current study may provide enough disambiguating evidence, particularly for high-skill spellers, to select the less-frequent meaning of the ambiguous word (López-Peréz et al., 2016). Thus, longer reading times on the ambiguous word when the parafoveal word is inconsistent is analogous with ambiguity studies that find longer reading times with prior supportive context for the less-frequent meaning and would indicate a POF effect.

Method

Participants

Participants included 153 Kent State University student volunteers in exchange for course credit. All participants had normal or corrected vision, were native speakers of English, and had no reported reading disabilities.

Skills Assessment

All participants completed a spelling skill assessment consisting of recall and recognition measures. The spelling to dictation task (M = 9.45; SD = 4.69) was comprised of 20 words adapted from Burt and Tate (2000). Scores ranged from 0% to 100% correct. The spelling recognition measure consisted of 50 common words. Twenty-five words were spelled correctly, and 25 words were spelled incorrectly. Spelling recognition was measured by calculating d', a response bias analysis that accounts for the rate of hits and false alarms. Scores from the recall test were standardized. Spelling scores were combined to form a composite score of spelling skill.

Stimuli & Design

Forty-one unique student participants took part in a norming study indicating that semantically neutral contexts still biased one meaning of the ambiguous words syntactically. Participants were presented with the beginning of the experimental sentences up to and including the ambiguous word but were not provided with any disambiguating information (ex. We watched her duck). They were then asked to provide the likely interpretation of the ambiguous word.

All ambiguous words were rated as having one likely interpretation (70% or above) and one less likely interpretation. The disambiguating word is either consistent or inconsistent with this likely interpretation. For the example, 'We watched her duck out of the way', a verb interpretation of 'duck' was reported by 70% of norming participants so, out_{n+1}, is considered consistent with this interpretation. In the sentence, 'We watched her duck eat all the bread', eat_{n+1}, is inconsistent with the more likely interpretation (see Table 1 for examples of consistent and inconsistent sentences). Targets consisted of both noun-noun (ex. fans) and noun-verb (ex. duck) ambiguities. Norming participants indicated that, in the case of the noun-verb ambiguous targets, the verb interpretation was more consistent for all items.

Targets ranged in length from 4-8 letters (M = 6). The length of disambiguating words ranged from 3-7 letters. in the inconsistent condition (M = 5.4) and from 3-6 letters in the consistent condition (M = 4.4). Targets and disambiguating words fit within a combined 13-character window (Consistent, M = 10.16; Inconsistent M = 11.26). Disambiguating words were all high in bigram frequency which did not differ across conditions, (consistent, M = 1650; inconsistent, M = 1682, suggesting that disambiguating words consisted of frequently encountered orthographic patterns. Target words were embedded in 20 sentences with non-constraining prior context. They appeared prior to a disambiguating word either consistent or inconsistent with its likely meaning (see Table 1 for example).

Table 1 : Sentence Example for the consistent and inconsistent disambiguating context.

Condition	Sentence Example
Consistent	We watched her duck *out* of the way.
Inconsistent	We watched her duck *eat* all the bread.

Note: Target words are underlined; N+1 is italicized

Apparatus

Data were collected using an SR Research Eyelink 1000 Plus eye tracker with a sampling rate of 1000Hz. Stimuli were presented on a 21.5-inch iMac Retinal Display screen. Participants were seated approximately 60cm from this screen. Reading was binocular, however, eye movements were recorded from the right eye only. One degree of visual angle was equal to 2.4 letters.

Procedure

Before beginning the reading sessions, the participant's right eye was calibrated, validated, and drift corrected. During calibration, participants followed a white circle through a nine-point fixation pattern. Successful calibration is indicated by less than .50 degrees of visual error to all nine points. The degree of visual angle was assessed before every trial and recalibration was performed when necessary.

Participants were instructed to read 20 experimental sentences and 24 filler sentences silently for comprehension as their eye movements were recorded. Participants ended a trial by pressing a button. Comprehension questions were presented following 12 filler trials. Participants indicated a yes or no answer by pressing a button. The reading session took approximately 15 minutes to complete.

Participants also completed a skills assessment. The spelling to dictation task was administered via an audio recording; participants were instructed to write the correct spellings as they listened to the word alone and the word in a sentence. The spelling to recognition test was untimed and required participants to identify misspelled words from a list containing both correctly and incorrectly spelled words.

Measures

First Pass Time refers to the sum of all fixations on the target word before the eyes leave it. It includes fixations and refixations but excludes regressions from other regions. Only fixations launched from earlier areas of the sentence are included in this measure.

Skipping Rate is calculated as probability of fixation. This measure only includes skips during first pass. Skips of the disambiguating word were only included if they were launched from the target word, rather than an earlier part of the sentence.

Spelling Total A composite spelling score was created for each participant. Scores on the spelling to dictation test were standardized. Standardized recognition scores were computed to account for response bias. A composite measure of spelling ability was created from these standardized scores. Spelling ability was analyzed as a continuous variable.

Disambiguating Condition refers to the word that follows the ambiguous target and provides context to indicate the intended meaning of the word in the continuation of the sentence. Consistent disambiguating words indicate the more likely meaning is appropriate in the sentence (coded as 0.5);

inconsistent disambiguating words indicate the less-likely meaning is appropriate (coded as -0.5) and were centered prior to entry into the model as a fixed effect.

Results

In what follows, a linear (Model 1 - lmer) and a logit (Model 2 - glmer) mixed random effects model using the lme4 function (Bates, Mächler, Bolker, & Walker, 2015) in R are reported. Each model implemented the maximal random effects structure permitting model convergence, and included participant and item set as random intercepts. All continuous variables were centered prior to entry into each model. Fixation durations less than 100ms and greater than 1,000ms. This resulted in a loss of less than 1 % of data. Thirteen participants were excluded from analyses for failing to answer comprehension questions with 80% accuracy.

Model 1 - Target Word: First Pass Time

In the first model, we evaluated first pass time on the ambiguous, target word by total spelling skill and disambiguating condition. The highest correlation between the random slopes was moderate (.45). The random effects structure was reduced until the correlations in the variance-covariance structure was < .4 (final highest correlation =- .38; Veldre & Andrews, 2014). The final model set spelling skill as the random slope with participant as the random intercept. The results from this model indicated a main effect of spelling skill and an interaction between spelling skill and disambiguating condition[1] (marginal R^2 = .02; conditional R^2 = .20; see Table 2 for model output). For every unit increase in the total spelling skill, the time on the target word increased when the disambiguating word was inconsistent, relative to when the word was consistent[2] (see Figure 1).

Table 2: Model 1 - Standardized estimates (unstandardized), standard errors, *t* and *p*-values

	B	*SE*	*t*	*p*
Spelling	-0.12(-1.61)	0.05	-2.48	$.01^{**}$
Condition	0.00(2.65)	0.02	0.17	0.87
Spelling x Condition	-0.06(-1.61)	0.02	-2.68	$.01^{**}$

Model 2 - Skipping the Parafoveal Word

In the second model (logit), the random effects structure permitting model convergence was used -- spelling skill set as the random slope (largest random effects correlation = -0.123). Results indicated a main effect of disambiguating condition (B = 0.32, SE = .06, z = 5.01, p < .001; marginal R^2 = .03; conditional R^2 = .23; see Table 3 for model output). This suggests that n+1 was skipped significantly more often in the consistent condition than the inconsistent condition. See Table 4 for skill group means.

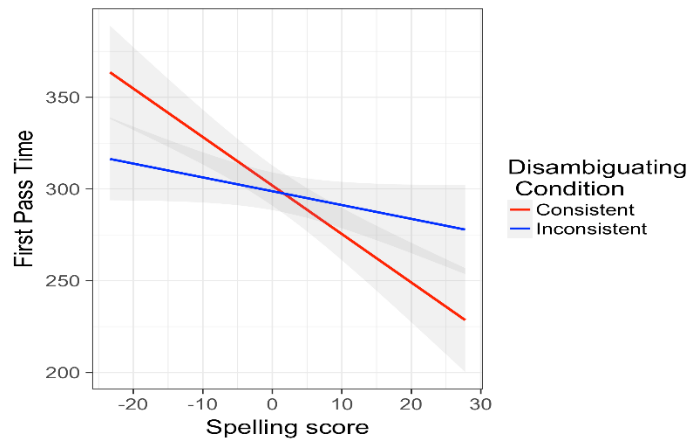

Figure 1: Relationship between first pass time (centered) on the target word and spelling score (centered) as a function of disambiguating condition (Consistent v. Inconsistent).

Table 3: Model 2 - Standardized estimates, standard errors, *z* and *p*-values, and OR: odds ratio

	B	*SE*	*z*	*p*	*OR*
Spelling	0.00	0.11	0.02	0.98	1.00
Condition	0.34	0.07	5.17	$< .001^{***}$	1.40
Spelling x Condition	0.04	0.07	0.60	0.55	1.04

Table 4: Skipping rate on the parafoveal word

	Disambiguating Condition	
Spelling Skill	Inconsistent	Consistent
Low	15%	23%
Average	16%	26%
High	17%	27%

Note: Low-skill = <33% on spelling measures; High-skill = >65% on spelling measures

Discussion

The results of the current study indicate that first pass time on an ambiguous target is influenced by both spelling skill and parafoveally-presented disambiguating words. The results show that as spelling skill increases, time to read the ambiguous word in the inconsistent condition increases relative to the consistent condition. Skipping the disambiguating word, however, was not significantly influenced by spelling ability; all readers were more likely to skip the disambiguating word in the consistent condition. Taken together, the results suggest that skilled readers may be able to use semantic information from an upcoming word

[1] The spelling by condition interaction was also present in first fixation data, (B = -0.05, SE = .02, t = -2.23, p < .05)

[2] First pass time was also analyzed by last location position (near or far) within the ambiguous word, however, location did not influence the pattern of results therefore both near and far location trials are included in analyses for power.

to disambiguate the currently fixated word.

The effect for high-skill readers – longer reading times on the ambiguous word when the upcoming word supports the less likely meaning – is consistent with the effects predicted by the semantic ambiguity literature. When ambiguous words are preceded by context supporting their less-likely meaning, reading times on the ambiguous word increase; the supporting context results in a greater degree of activation for the less-likely meaning which allows it to compete for selection with the likely meaning (Dopkins et al., 1992; Duffy, et al., 1988; Rayner et al., 1994; Sereno et al., 1992). In the current study, disambiguating words immediately followed the ambiguous target rather than preceding it. Nevertheless, if the disambiguating word was accessed while fixating the ambiguous word, increased reading time may result from the same competition and selection processes that are engaged when context precedes an ambiguous word. In the current study, high-skill readers demonstrated effects consistent with the predictions derived from semantic ambiguity suggesting that semantic information from disambiguating previews influenced meaning access of the fixated, ambiguous word which indicates a POF effect.

Interestingly, less-skilled readers showed the opposite pattern – longer reading times on the ambiguous word when it was consistent with the likely interpretation. This seems to suggest a 'reverse POF effect,' however, inflated reading times in this condition may stem from increased rates of skipping the disambiguating word. Serial models of eye movement control, such as EZ Reader, suggest that reading time before a skip can be inflated as a result of saccadic reprogramming which occurs after lexical access of the fixated word (Rayner, Slattery, Drieghe & Liversedge, 2011). Therefore, inflated reading times before a skip are not POF effects but rather the result of post-access eye movement planning processes. In the current study, all readers were more likely to skip the disambiguating word in the consistent condition, however, only less-skilled readers demonstrated longer reading times in this condition. Thus, the 'reverse POF effect' observed for less-skilled readers may be explained by the additional time required before making a skip, however, this serial explanation does not account for the effect observed for high-skill readers.

The results of high-skill readers demonstrate a POF effect consistent with parallel accounts of word recognition. According to parallel models, such as SWIFT, all words are processed in parallel (Engbert, et al., 2005). Processing takes place within a gradient of attention that accommodates up to four words at a time. In this model, the target of the next saccade is the word that requires the most processing to reach a completion stage. In the current study, the parafoveal word provides evidence about the meaning of the fixated word. When the parafoveal word is inconsistent with the foveal word, this may indicate that the word within the gradient that requires the most additional processing is indeed the fixated, ambiguous word. Thus, high-skill readers may access the disambiguating word because it is within the attention gradient; access may signal that more processing is required to select the appropriate meaning of the fixated, ambiguous word.

Previous research has suggested POF effects are the result of mislocated saccades in which readers mistakenly land to the left of the word they intended to fixate (Drieghe, et al., 2008). In this case, processing is devoted to the intended word even though the eyes remain fixated on the previous word and therefore is not evidence of a POF effect. Although the current study cannot eliminate a mislocated saccade account, there are several considerations that make this explanation less likely. First, the first pass measure included only those trials where readers did not skip the ambiguous word. This eliminates the possibility that readers mistakenly fixated the disambiguating word before making a correction to fixate the ambiguous word. Second, the same effect that was observed in first pass was also observed in first fixation time. This, along with first pass measures, suggests that disambiguating previews exerted an early influence on word recognition and that this effect is not the result of refixations on the ambiguous word. Third, the location of the last fixation within the ambiguous word did not influence the pattern of results; the same effects were observed on the ambiguous word regardless of whether the last fixation was near the beginning of the word or near the end. Taken together, this suggests that mislocated saccades are unlikely to account for the full data pattern.

The results suggest that disambiguating parafoveal previews can impact ambiguous word recognition. However, it is important to note that the target ambiguous words used in the current study represent a unique class of words which may be uniquely sensitive to parafoveal preview manipulations. Additionally, semantic ambiguity effects are typically observed on an ambiguous word when context supporting the less-likely interpretation *precedes* it rather than follows directly after as in the current study. Finally, the current study investigates only initial processing differences resulting from disambiguating previews. Future research should consider latter impacts, such as integration and comprehension difficulties.

Conclusion

The current study provides further evidence that orthographic knowledge, measured by spelling ability, influences parafoveal processing, consistent with previous research demonstrating semantic preview benefits for strong spellers (Veldre & Andrews, 2016). The current results suggest that POF effects, like semantic preview benefits, may be limited to a subset of skilled readers who also have strong orthographic knowledge. This has important implications for models of skilled reading which assume that word recognition processes are uniform within the skilled reader population. Furthermore, this research suggests that orthographic knowledge continues to influence reading behavior well into adulthood. Ongoing research aims to better understand the role of orthographic knowledge during word recognition and its complex relationship with skilled, adult reading.

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