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Word Misperception, the Neighbor Frequency Effect, and the Role of Sentence Context: Evidence From Eye Movements

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An eye movement experiment was conducted to investigate whether the processing of a word can be affected by its higher frequency neighbor (HFN). Target words with an HFN (birch) or without one (spruce) were embedded into 2 types of sentence frames: 1 in which the HFN (birth) could fit given the prior sentence context, and 1 in which it could not. The results suggest that words can be misperceived as their HFN, and that top-down information from sentence context strongly modulates this effect. Implications for models of word recognition and eye movements during reading are discussed.

Keywords: eye movements, reading, lexical processing, word neighbors

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Word identification is clearly an important first step in understanding the meaning of what is on the printed page and an important contributor to what moves the eyes forward across a line of text. This is demonstrated by the fact that variables such as the frequency of a word, its predictability from the prior context, and whether it is lexically ambiguous have clear and reliable effects on how long that word is fixated (see Rayner, 1998, for a review). The fact that high-frequency words are fixated for less time than low-frequency words indicates that the speed of identifying a word during reading is influenced by its frequency. A common way this is conceptualized is that the visual input excites a lexical entry, with the word being identified when some threshold of activation is reached, and for higher frequency words, the excitation reaches the threshold more rapidly than for lower frequency words. This raises the question of whether the excitation of the lexical entry of the word actually presented is the only relevant factor in determining the speed of its activation. For example, when a word like *gloss* is read, is the lexical entry for *gloss* the only one that is excited, or are orthographically similar words (like *glass*) also activated and if so how does this affect lexical processing?

Whether (and to what extent) activation for a particular orthographic string can spread to similar orthographic strings is an important question in the field of reading research. In fact, there are numerous computational models of word recognition that assume some type of spread of activation (Coltheart, Rastle, Perry, Langdon, & Ziegler, 2001; Davis, 1999, 2003; Grainger & Jacobs, 1994, 1996; McClelland & Rumelhart, 1981; Paap, Newsome, McDonald, & Schvaneveldt, 1982; Rumelhart & McClelland, 1982). That is, many models assume that multiple words can be activated, to varying extents, by a single orthographic input. However, computational models of eye movements during reading tend to overlook spreading activation. For instance, the E-Z Reader (Pollatsek, Reichle, & Rayner, 2006; Rayner, Ashby, Pollatsek, & Reichle, 2004; Reichle, Pollatsek, Fisher, & Rayner, 1998; Reichle, Pollatsek, & Rayner, 2007; Reichle, Rayner, & Pollatsek, 1999, 2003), SWIFT (Engbert, Nuthmann, Richter, & Reinhold, 2005; Laubrock, Kliegl, & Engbert, 2006; Richter, Engbert, & Kliegl, 2006) and Glenmore (Reilly & Radach, 2003, 2006) models do not attempt and can not currently account for effects because of spreading activation. That is these models assume (largely for computational convenience) that only the target word is contributing to its lexical processing.[1]

The central issue here is whether activation that spreads amongst orthographically similar word representations in the lexicon influences word processing, and therefore eye movements, during reading. The metric of orthographic similarity used here is the classic neighbor definition of Coltheart, Davelaar, Jonasson, and Besner (1977): Two words are neighbors if they have the same number of letters and differ in exactly one letter position (e.g., *glass* and *gloss* are neighbors). It is possible that when a reader encounters the printed word *gloss* it will activate orthographically similar words (*glass*) and this activation may influence the processing of *gloss*. Moreover, if one or more of the neighbors have substantially higher frequencies in the language than the word actually presented, it is possible that activation of this higher frequency neighbor (HFN) could compete with the activation of the "correct" lexical entry and produce inhibitory effects. More formally, an inhibitory *neighbor frequency effect* refers to a pro-

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[1] Note that this is separate from the topic of serial versus parallel lexical processing. Models like SWIFT and Glenmore assume that multiple words in a sentence can be processed in parallel. However, for each of these words the process of going from print to meaning is occurring without influence from orthographic neighbors.

cessing cost for words with one or more HFNs, compared with control words that are matched on other variables but do not have HFNs. Whether or not this type of inhibition occurs and whether sentence context can modulate any such inhibition are the main issues in the present research.

Many studies have found that a word's HFNs can cause inhibition in shallow orthographies such as French, Spanish, and Dutch (Carreiras, Perea, & Grainger, 1997; Grainger, 1990; Grainger & Jacobs, 1996; Grainger, O'Regan, Jacobs, & Segui, 1989; Grainger & Segui, 1990; van Heuven, Dijkstra, & Grainger, 1998). However, the work on this issue for English, which has a deep orthography, is inconsistent (see Andrews, 1997). Of the studies designed to investigate neighbor frequency using English stimuli, some show inhibition from HFNs (Huntsman & Lima, 1996; Paap, Johansen, Chun, & Vonnahme, 2000; Paterson, Liversedge, & Davis, 2009; Perea & Pollatsek, 1998; Sears, Campbell, & Lupker, 2006, Experiment 1A), some show null effects (Forster & Shen, 1996, Experiment 4; Huntsman & Lima, 2002; Sears et al., 2006, Experiments 1B–3B), and some show facilitation (Forster & Shen, 1996, Experiments 1–3, Sears, Hino, & Lupker, 1995).

Eye Movements and the Neighbor Frequency Effect

Not all tasks are well suited for investigating neighbor frequency effects.[2] However, eye tracking has proven useful in studying many aspects of reading and is especially valuable in studying the time course of processing. Consider the italicized words in the sentence: "Because of the sudden change in temperature, the *frost* (*front*) turned into water." The sentence makes perfect sense with the word *frost* in it; however, if a reader were to misperceive the word as its HFN *front*, the sentence would no longer make sense. Rayner, Warren, Juhasz, and Liversedge (2004) showed that when sentences become anomalous there are fairly immediate effects on eye fixations but when sentences become only implausible the effects are delayed. This suggests that if interference effects are because of misperceiving the word as its HFN, the effects may occur on or after the target word depending on the HFN's fit with context. In the case of the example sentence, there is nothing anomalous at the target word if *frost* is read as *front*, as the sentence could end as "the *front* porch became icy." Only upon reaching later disambiguating material would the reader discover the error and eye tracking is sensitive to these errors. For instance, readers fixate longer on disambiguating text or they look back (regress) to the target word (Frazier & Rayner, 1982, 1987).

There are now a handful of studies that have used eye tracking to investigate the effects of neighbor frequency. Perea and Pollatsek (1998) examined neighbor frequency effects using both the lexical decision task and eye-movement measures of reading. Their stimuli were words that were equated on neighborhood size, but which had either no HFNs or at least one HFN. In a reading task, they found no significant difference between items with HFNs and those without them in first-pass reading measures (first fixation and gaze duration, see Table 1 for definitions). However, in later measures, such as regressions back to the target word and total fixation time, they did find inhibitory effects of neighbor frequency. This pattern of data is consistent with the view that sometimes words are misperceived as an HFN (Pollatsek, Perea, & Binder, 1999). However, Sears et al. (2006) pointed out a number of problems with the items from Perea and Pollatsek and were unable to replicate their inhibitory effects. Based on their results, Sears et al. concluded that a word's HFNs have little to no effect on reading times or on postidentification processing. This conclusion is seriously challenged by eye movement data from Paterson et al. (2009) showing a significant inhibitory effect for words with neighbors when the neighbor appears earlier in the sentence. However, as this effect relies on having recently processed the neighbor word, it is possible that the effect in Peterson et al. is due to inhibition of the target word from residual activation of its neighbor word and not necessarily because of spreading activation from the target word to its neighbor.[3] In contrast, the current study does not employ orthographic priming and therefore more directly investigates the possibility that activation can spread from a target word to its neighbors.

In the present experiment, subjects read sentences that contained one of two types of target words: experimental target words (which had an HFN), and control words (which did not). Additionally, there were two types of sentences in which these words could be embedded: in neutral sentences, both the target word and its HFN were consistent with the prior text but the HFN was anomalous with post-target text; in biased sentences, the target word was consistent with the prior text, but the HFN was anomalous. In the neutral condition, it is possible for the HFN of the experimental target word to receive both bottom-up activation from the experimental target and top-down activation from prior sentence context. Therefore, if activation spreads from a word to its neighbor with sentence context influencing this activation then misperceptions of the experimental target words (assessed by the number of regressions back to the target relative to controls) should be greatest in the neutral sentence frame condition. These misperceptions may go unnoticed during initial processing, because the HFN would fit with prior text. If this is the case there should be little effect of the target word (experimental vs. control) on initial eye movement measures (first fixation and gaze duration). However, inhibition should be present in later measures (second pass time and regressions back to the target word) once the reader has discovered the error. In the biased sentences, the HFN receives the same bottom-up support from the experimental target words as in the neutral condition but any top-down modulation would be inhibitory which should lead to fewer target word misperceptions.

Method

Subjects

Thirty-two students from the University of Massachusetts, Amherst participated. They were all native English speakers with normal or corrected-to-normal vision. They received either course credit or cash as compensation for their time.

[2] For example, lexical decision is insensitive to cases where the subject identifies the lexical representation of a word's HFN as this would still constitute a *yes* response. In fact, Paap et al. (2000; see also Grainger & Jacobs, 2005) found that words are sometimes misperceived as their HFNs using the Reicher/Wheeler task. When the incorrect letter alternative in the forced choice Reicher/Wheeler task forms a word that is higher in frequency (an HFN) than the word actually presented, subjects are less accurate at reporting the correct letter.

[3] Paterson et al. also suggested that this could be an episodic memory effect.

Table 1
Target Measures

	Neutral context		Biased context	
Measure	Experimental	Control	Experimental	Control
First fixation	231 (40)	229 (37)	226 (25)	226 (32)
Single fixation	237 (51)	229 (37)	232 (29)	228 (30)
Gaze duration	260 (58)	250 (44)	251 (38)	250 (39)
Total time	349 (115)	296 (87)	289 (70)	277 (61)
Second pass	90 (74)	51 (57)	39 (39)	31 (34)
Skip%	19.0 (15.4)	17.3 (14.4)	16.9 (13.4)	16.4 (13.9)
Refixation%	13.7 (12.0)	11.9 (9.0)	15.5 (10.9)	14.8 (11.4)
Regression%	21.0 (14.3)	11.3 (10.9)	8.8 (8.1)	6.5 (7.6)

Note. Times are in milliseconds rates in percentages, with *SD*s in parentheses. First fixation, single fixation, gaze and are all contingent on the target not being skipped. First fixation is the duration of the initial fixation, single fixation is the duration of the initial fixation contingent on there being only one first pass fixation, gaze duration is the sum of all first-pass fixations, total time is the sum of all fixations on the target. Second pass is the sum of all rereading fixations on the target regardless if it was initially skipped. Skip% is the percentage of trials the target was initially skipped. Refixation% is the percentage of trials in which the target was fixated more than once in first-pass reading. Regression% is the percentage of trials in which the target was fixated as a result of a regressive saccade.

Apparatus

Eye movements were recorded from the subject's right eye (viewing was binocular) with an Eyelink 1000 eye-tracker interfaced with a Pentium 4 computer. This eye tracker samples and records the position of the reader's eye every millisecond. Subjects were seated 50 cm away from a 19-inch ViewSonic monitor. Text was displayed in a 12-point font, and 3 characters equaled 1° of visual angle (spatial resolution was $<0.02°$).

Design and Stimuli

Forty-four words (four to six letters long) with at least one HFN were paired with 44 control words that do not have an HFN.[4] The neighborhood statistics were calculated using N-Watch (Davis, 2005) and the English Lexicon Project website (Balota, Cortese, Hutchison, Neely, Nelson, Simpson, et al., 2002). The target and its HFN always shared the same first letter. Additionally, the HFN could be used as the same part of speech (syntactic category) as the target word itself. The experimental and control words were also equated for a number of other variables that have been shown to influence fixation durations: word frequency, mean log bigram frequency (MLBF), number of syllables, and number of low-frequency neighbors. They were also equated on frequency according to the Francis and Kucera (1982) norms, CELEX (Baayen, Piepenbrock, & van Rijn, 1995), and HAL (Burgess, 1998; Burgess & Livesay, 1998) to avoid problems because of oddities in any one estimate. For all of the experimental words, the HFN was rated as higher in frequency in all three corpuses. The means for these word variables are presented in Table 2.

Each pair of target words was embedded into two sentence frames—a neutral frame and a biased frame for a total of 88 unique sentence frames. The target words never occupied the first or last two word positions of the sentences. In the neutral sentence frame, both the target word and its HFN were plausible continuations of the pretarget text; however, the post-target text in these sentence frames was incompatible with the HFN. In the biased sentence frames, the target words (experimental and control) fit better with pretarget text than the experimental target's HFN did. The sentence context manipulations were very similar to those employed in the study of lexical ambiguity resolution (Duffy, Morris, & Rayner, 1988). The following are examples of a neutral and biased sentence frame (the target words are in parenthesis with the experimental target appearing first; the HFN appears in brackets at the end of the sentence).

Neutral. Due to the freezing rain, the (brunch/buffet) was postponed a week. [branch]

Biased. Everyone said the food at the (brunch/buffet) was simply magnificent. [branch]

Latin square counterbalancing of the sentences was employed such that each target word was seen exactly once by every subject (half in the neutral context and half in the biased context). In this way every subject read 22 items in each of the four experimental conditions created by the 2 (sentence frame: neutral vs. biased) × 2 (target word: experimental vs. control) repeated measures within-subject design.

Procedure

At the start of the experiment, subjects completed a calibration procedure by looking at a random sequence of fixation points presented horizontally across the middle of the computer screen. This procedure was repeated during a validation process, and the average error between calibration and validation was calculated. If this error was greater than .4° of visual angle the entire procedure was repeated. At the start of each trial, a black square (50 pixels wide and 50 pixels tall) appeared on the left side of the computer screen, which coincided with the left side of the first letter in the sentence. Once a stable fixation was detected within this area,

[4] For these studies, an HFN had to have a frequency of at least 20 occurrences per million words and be higher in frequency than the target word. This resulted in a few control words that had a marginally HFN according to the traditional definition. The full set of stimuli are available upon request to the author.

Table 2
Target Word Properties

Variable	Experimental	Control	HFN
Kucera & Francis	12	13	139
CELEX	15	16	127
LOG HAL	7.9	8.0	10.6
MLBF	2.7	2.6	3.0
Number of letters	5.1	5.0	5.1
Number of syllables	1.2	1.3	1.3
Number of LF neighbors	2	2	4

Note. HFN = higher frequency neighbor; MLBF = mean log bigram frequency; LF = low frequency.

the sentence replaced it on the screen. Twelve practice sentences were presented prior to the experimental sentences. All sentences were presented vertically centered on the computer monitor, and sentence order was randomized for each subject. Subjects were instructed to read silently for comprehension and to press a button on a keypad when they finished reading the sentence. Comprehension questions appeared on the screen after a third of all the items. These *yes/no* questions required the subjects to respond via button press.

Normative Data

Off-line ratings of how well each of the targets fit into the two sentence frames were collected from 36 subjects, who did not participate in the eye-tracking portion of the experiment. These ratings confirmed that both the experimental and control target words fit equally well into the sentences, all $|ts| < 1$.

It was also important that the HFN of the experimental target fit with the prior text in the neutral but not the biased items. Another 24 subjects rated (on a 5-point scale centered at zero) whether the experimental word or its HFN fit better with the initial sentence fragments. The mean rating for neutral items was −0.58 indicating a small but significant preference for the HFN $t(43) = -4.68$, $p < .001$, but the rating for biased items was 1.58 indicating a strong preference for the experimental targets, $t(43) = 16.58$, $p < .001$. The *t*-test of the interaction contrast between context and the fit of the HFN was also significant, $t(43) = 14.53$, $p < .001$.

Results

Prior to analysis, fixation durations less than 80 ms were removed from the data record (less than 1% of the total fixations). Additionally, fixation durations over 1,000 ms that were on or adjacent to the target word resulted in the trial's deletion (less than 1% of trials). Data exclusion was evenly distributed across conditions. Subjects were correct on 96% of comprehension questions. Two analyses of variance (ANOVAs) were conducted on each of the dependent measures (one with subjects as a random effect and one with items as a random effect). Eye-movement measures are presented in Table 1. The remainder of this section will be broken into two parts. The first will consist of the early eye-movement measures (first fixation duration, single fixation duration, gaze duration, skipping percentage, and refixation rate). These measures are considered early because they are influenced by the decision to move the eyes past or off the target word (Rayner, 1998). The second part will consist of late eye-movement measures (total time, second pass time, and percent regressions to the target). These measures are affected by later processing or reprocessing of the target words.

Early Eye Movement Measures

For first fixation duration, and single fixation duration all Fs were less than 1. For gaze duration, there was a 10-ms neighbor frequency effect in the neutral condition but only a 1-ms neighbor frequency effect in the biased condition; however, neither the main effect nor the interaction reached significance, *p*s > .15. Target words were skipped during first-pass reading 17.4% of the time, and refixated during first-pass reading on 14.0% of the trials. However, there were no significant effects of target type nor was there a significant interaction with context all *F*s < 1.

Late Eye Movement Measures

Second pass and total time were significantly longer for experimental targets than controls, $F_1(1, 31) = 12.50$, $p < .001$, $\eta_p^2 = 0.47$, $F_2(1, 43) = 6.07$, $p < .05$, $\eta_p^2 = 0.12$; $F_1(1, 31) = 16.68$, $p < .001$, $\eta_p^2 = 0.35$, $F_2(1, 43) = 6.11$, $p < .05$, $\eta_p^2 = 0.12$, respectively. Of greater importance was the significant context by target type interaction for second pass (31 ms), $F_1(1, 31) = 7.04$, $p < .05$, $\eta_p^2 = 0.19$, $F_2(1, 43) = 5.12$, $p < .05$, $\eta_p^2 = 0.11$, and total time (41 ms), $F_1(1, 31) = 11.49$, $p < .01$, $\eta_p^2 = 0.27$, $F_1(1, 43) = 7.13$, $p < .05$, $\eta_p^2 = 0.14$, because the neighbor frequency effect was significantly larger in the neutral contexts. These second pass and total time effects are likely attributable in large part to regressions back to the target words. However, the measures are not simply redundant. Second pass and total time include progressive rereading of the target following a regression to pretarget text. In addition, differences in regression rates can be used as a lower bound estimate of the rate of misperceiving the experimental targets. There were significantly more regressions to experimental words than to controls, $F_1(1, 31) = 22.28$, $p < .001$, $\eta_p^2 = 0.42$, $F_2(1, 43) = 13.85$, $p < .001$, $\eta_p^2 = 0.24$, as well as a significant context by target type interaction mirroring the second pass and total time data, $F_1(1, 31) = 8.63$, $p < .01$, $\eta_p^2 = 0.22$, $F_2(1, 43) = 6.28$, $p < .05$, $\eta_p^2 = 0.13$.

Post Hoc Analyses

The data from the current experiment indicate that the presence of an HFN can have a significant inhibitory impact on reading. However, inhibition only occurred in the neutral contexts (where the high-frequency neighbor could fit with prior sentence context). In the offline rating study, there was a slight preference for the high-frequency neighbor over the actual experimental target word in the neutral contexts. To investigate whether the inhibition obtained in the current study was limited to those items for which the neighbor fit better than the target, the neutral items were split into two groups. Group A items had been rated as being very neutral ($t < 1$), indicating both the target and its HFN fit equally well with the pretarget text. Group B items favored the neighbor $t(21) = -15.82$, $p < .001$. The data were reanalyzed with the addition of the new median split variable (see Table 3).

Table 3
Target Post Hoc Measures

Measure	Truly neutral		HFN preferred	
	Experimental	Control	Experimental	Control
First fixation	230 (41)	224 (40)	233 (50)	231 (42)
Single fixation	237 (58)	224 (37)	238 (58)	233 (42)
Gaze duration	286 (64)	241 (54)	253 (64)	254 (45)
Total time	336 (109)	284 (107)	356 (143)	302 (94)
Second pass	72 (70)	47 (55)	102 (98)	52 (67)
Skip%	19.4 (15.4)	21.5 (14.4)	18.9 (13.4)	14.3 (13.9)
Refixation%	14.9 (14.7)	8.2 (9.1)	12.2 (12.4)	15.3 (13.0)
Regression%	18.8 (16.1)	11.8 (12.2)	21.9 (18.8)	10.6 (12.9)

Note. HFN = higher frequency neighbor. Times are in milliseconds rates in percentages, with *SD*s in parentheses. Skip% is the percentage of trials the target was initially skipped. Refixation% is the percentage of trials in which the target was fixated more than once in first-pass reading. Regression% is the percentage of trials in which the target was fixated as a result of a regressive saccade.

The data for first and single fixation durations were similar to those from the main analysis with no significant effects, *F*s < 1. However, gaze durations on experimental targets in the group A items were 27 ms longer than controls while gaze durations on the experimental targets in the group B items were 1 ms shorter than controls, an interaction that was marginal by subjects and significant by items, $F_1(1, 31) = 3.65$, $p < .07$, $\eta_p^2 = 0.11$, $F_2(1, 42) = 5.54$, $p < .05$, $\eta_p^2 = 0.12$. A check of the gaze durations for the group A items indicated that this 27-ms difference was significant $t_1(31) = 2.57$, $p < .05$, $t_1(20) = 2.84$, $p < .01$. An effect in gaze duration but not in first fixation duration suggests that there may be a difference in the rate of first-pass refixations across conditions. The refixation rate for group A items was 14.9% on experimental targets and 8.2% on controls, but for group B items the rates were 12.2% and 15.3% respectively. The main effect of target type on refixation rate (experimental vs. control) was not significant, *F*s < 1; however, the interaction with context (group A vs. B) was, $F_1(1, 31) = 8.06$, $p < .01$, $\eta_p^2 = 0.21$, $F_2(1, 42) = 8.25$, $p < .01$, $\eta_p^2 = 0.16$.

In the late eye-movement measures, both group A and B displayed significant neighbor frequency inhibition: second pass time, $F_1(1, 31) = 13.23$, $p < .01$, $\eta_p^2 = 0.30$, $F_2(1, 42) = 6.75$, $p < .05$, $\eta_p^2 = 0.14$; total time, $F_1(1, 31) = 21.46$, $p < .001$, $\eta_p^2 = 0.41$, $F_2(1, 42) = 9.09$, $p < .01$, $\eta_p^2 = 0.18$; and regressions in, $F_1(1, 31) = 21.34$, $p < .001$, $\eta_p^2 = 0.41$, $F_2(1, 42) = 12.25$, $p < .005$, $\eta_p^2 = 0.23$. Interestingly, the size of the inhibitory effect was smaller for the group items A for which there was a significant inhibitory effect in early eye-movement measures (gaze duration and refixation rate). However, the interaction between item group and target word type never approached significance, *p*s > 0.2.

Given that the effect in gaze duration in the truly neutral contexts was attributable almost exclusively to refixations, and these items had smaller inhibitory effects in late eye-movement measures, an interesting follow-up question is whether subjects were just as likely to misperceive the target when it had been refixated (prior to moving to another word) as when it was fixated only once. To answer this question, regression rates for the neutral items (regrouping the A and B items together) were analyzed based on whether the item was refixated or fixated only once (excluding trials where the target was skipped). Because of the low rate of refixations (~13%), the analysis was performed using a linear mixed-effects (lme) model specifying subjects and items as crossed random effects.[5] The advantage of such an analyses is that it results in substantially less loss of statistical power in unbalanced designs than traditional ANOVAs over subjects (F_1) and items (F_2; see Baayen, 2008; Baayen, Davidson, & Bates, 2008).[6]

There was a significant main effect of the target word with experimental targets being regressed to 7.2% more often than controls, which replicated the earlier analysis of the regression data, $b = 12.59$, $SE = 2.12$, $p < .001$. There was also a main effect of whether the target word was refixated, with refixated targets being regressed to 4.7% less often than targets that were fixated only once, $b = 12.97$, $SE = 3.81$, $p < .001$. In addition, there was a significant interaction between these two factors, $b = 12.21$, $SE = 5.47$, $p < .05$. Experimental targets were regressed to 22% of the time when the target word was fixated exactly once in first pass reading but only 12.6% when it was refixated. Controls, on the other hand, were regressed to 9.4% when they were only fixated once and 10.8% when they were refixated. This suggests that refixating the experimental targets during first-pass reading

[5] An ANOVA on the item means yielded similar results; a significant main effect of the target word with experimental targets being regressed to more often than controls, $F(1, 31) = 7.24$, $p < .02$, $\eta_p^2 = 0.19$, a main effect of whether the target word was refixated with refixated targets being regressed to less often than those fixated only once, $F(1, 31) = 17.25$, $p < .001$, $\eta_p^2 = 0.36$, and significant interaction between these two factors $F(1, 31) = 8.98$, $p < .01$, $\eta_p^2 = 0.23$. However, given the empty cells in the data matrix the lme analysis is more appropriate here. Additionally, all of the effects in the current study that were significant with ANOVA were also significant with lme, and those that were not significant with ANOVA were not significant with lme.

[6] These analyses were carried out using the lme4 program in R (Bates, Maechler, & Dai, 2008), an open-source programming language and environment for statistical computation (R Development Core Team, 2007). I report regression coefficients (bs, effects relative to the intercept), *SE*s, and *p* values estimated using posterior distributions for model parameters obtained by Markov Chain Monte Carlo sampling (Baayen, 2008; Baayen et al., 2008).

was enough to dramatically reduce the likelihood of misperceiving the word, or to enable repair of an initial misperception.

Discussion

The current research addressed two general questions related to lexical processing during reading. First, is processing of a word affected when that word is highly visually similar to a more frequent or familiar word; is processing of the word *frost* affected by the fact that *front* is visually similar to it and also more frequent? Second, does the contextual fit of a word's HFN mediate the neighbor frequency effect? The results indicate that top-down information from sentence context can mediate the neighbor frequency effect, as inhibition was present only when the HFN fit with the prior sentence context. However, given the correct contextual conditions having an HFN is inhibitory in early (gaze duration and refixations) and late (total time, second pass, regression rate) eye-movement measures. The pattern of results for the late eye-movement measures agrees with Perea and Pollatsek (1998), but not with Sears et al. (2006). Recently a similar finding was reported by Johnson (2007, 2009) using transposed letter neighbors. She also manipulated the fit of the neighbor with prior sentence context and found late inhibitory effects only with contexts in which the transposed letter neighbor could be a plausible continuation of the sentence.[7]

The inhibition in early eye-movement measures, while limited to contextual conditions where the target and its HFN fit equally well with prior text, are the first example of an inhibitory neighbor frequency effect in eye movements during reading of English without the use of explicit orthographic neighbor primes, and highlight the importance of top-down processing. Additionally, the early and late inhibitory neighbor frequency effects are not independent of each other. That is, when participants refixated a target with an HFN (causing longer gaze durations), the probability of their making a regression to the target (causing longer second-pass times) was dramatically reduced.

As noted in the introduction, many models of eye movements during reading do not allow for spreading activation and do not take into account aspects of a word's orthography and or phonology. To be fair, this is no doubt because of computational convenience. These models are not simply predicting RTs and error rates, but rather the complex spatial and temporal behavior of the eyes as they relate to language processing. However, these models will not be likely to account for effects such as those in the current study until they fully implement more detailed top-down and bottom-up word recognition processes.

The data are also consistent with those from Paap et al. (2000). They estimated that words were misperceived as their HFN approximately 12% of the time, which is comparable to the lower bound estimate of 9.8% in the current neutral context condition. Also, they found that priming the low-frequency target word all but eliminated these misperceptions. This is similar to the effect that sentence context had in the current study. They further demonstrated, with signal detection analyses, that this effect is not because of differences in perceptual sensitivity for low- and high-frequency words but rather to a difference in the decision criterion. As such, referring to the effect as one of misperception may seem inappropriate. However, in the context of normal reading a decision must be made about what word is being read and when this decision is in error the wrong meaning will be integrated into the sentence (at least temporarily). Thus, it seems appropriate to refer to this as a misperception (or perhaps misreading) whether it occurs because of initial encoding errors or to a later decision stage. Additionally, these data illustrate that errors in word processing can occur even under conditions where the reader can view the text for as long as they want. Therefore word misperception is not simply a phenomenon that occurs in a laboratory under conditions of brief exposure but is instead a rare part of the normal reading experience influenced by both the top-down and bottom-up aspects of the text.

[7] In the sentences used by Johnson, the post target contexts were not always incongruous with the transposed letter neighbor word. As a result, the inhibitory effects reported are likely to be underestimated. As such, direct comparisons between Johnson's study and the present study would not be appropriate.

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