BRIEF REPORTS

Inhibitory neighbor priming effects in eye movements during reading

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We report an eye movement experiment investigating whether prior processing of a word's orthographic neighbor in a sentence influences subsequent word processing during reading. There was greater difficulty in early word processing when a target word's neighbor rather than a control word appeared earlier in a sentence; this effect was uninfluenced by the relative lexical frequency of the word and its neighbor. We discuss this inhibitory neighbor priming effect in terms of competitive network models of word recognition and the process of lexical identification in the E-Z Reader model of oculomotor control (e.g., Reichle, Pollatsek, Fisher, & Rayner, 1998).

A wealth of research has indicated that the speed with which a word can be identified is influenced by its orthographic neighborhood (see Andrews, 1997, for a review). According to Coltheart, Davelaar, Jonasson, and Besner (1977), *orthographic neighbors* are defined as words formed from a target word by substituting one letter for another, while preserving letter positions and length (for an expanded definition, see, e.g., Davis & Taft, 2005).

Research has shown that words that have higher frequency neighbors in the lexicon are identified more slowly than matched control words without higher frequency neighbors. This inhibitory neighborhood frequency effect has been observed widely in studies using the lexical decision task and related methodologies (e.g., Bowers, Davis, & Hanley, 2005a, 2005b; Carreiras, Perea, & Grainger, 1997; Davis & Taft, 2005; Grainger, 1990; Grainger, O'Regan, Jacobs, & Segui, 1989; Huntsman & Lima, 1996; but for failures to replicate this effect, see, e.g., Forster & Shen, 1996). The effect has also been investigated by measuring eye movements during reading, where inhibitory effects have been observed both for words that have higher frequency neighbors and for words that have larger numbers of higher frequency neighbors (Perea & Pollatsek, 1998; Pollatsek, Perea, & Binder, 1999). These effects emerged relatively late in the eye-movement record (i.e., in total reading times for the target word and in regressions and spillover effects for following words)

and have been attributed to readers initially misidentifying a word that has a higher frequency neighbor and subsequently making a regressive eye movement to refixate and reprocess that word.

Particularly clear evidence of neighborhood interference comes from studies in which identification of a word (e.g., *blue*) is shown to be inhibited by prior processing of a word that is its orthographic neighbor (e.g., *blur*) as opposed a control word that is not its neighbor (e.g., *gasp*). This inhibitory neighbor priming effect has been widely reported in research employing masked priming, where a forward mask is presented, followed by a briefly presented prime that, in turn, is followed by a target word (or nonword) to which participants make a lexical decision response (Bijeljac-Babic, Biarreau, & Grainger, 1997; Brysbaert, Lange, & van Wijnendaele, 2000; Davis & Lupker, 2006; De Moor & Brysbaert, 2000; Drews & Zwitserlood, 1995; Grainger, Colé, & Segui, 1991; Grainger & Ferrand, 1994; Segui & Grainger, 1990). Neighboring primes have also been shown to slow the recognition of target words in unmasked priming studies, where prime words are presented for longer durations and without a mask (Colombo, 1986; Lupker & Colombo, 1994; Segui & Grainger, 1990).

Inhibitory neighborhood effects have been interpreted within competitive network models of word recognition, such as the interactive activation (IA) and self-organizing

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lexical acquisition and recognition (SOLAR) models (e.g., Davis, 2003; Grainger & Jacobs, 1996; McClelland & Rumelhart, 1981), where they are attributed to competition between lexical candidates. Specifically, during lexical identification, letters that constitute a word activate the lexical entry for that word, as well as for words sharing these letters; and activation of these lexical competitors can interfere with target word identification. The inhibitory neighbor priming effect observed in priming research is attributed to the prior presentation of a word's neighbor as a prime, effectively giving a lexical competitor a head start in processing.

Masked priming research has also obtained larger inhibitory priming effects when the frequency of the prime word is higher than that of the target word (Davis & Lupker, 2006; Segui & Grainger, 1990). Competitive network models attribute this prime frequency effect to a higher frequency prime word supplying a strong competitor for a lower frequency target word during lexical identification, but not vice versa. However, the effect is reversed in unmasked priming, where inhibitory effects have been obtained only for primes that are lower in frequency than the target word (Colombo, 1986; Lupker & Colombo, 1994; Segui & Grainger, 1990). It is argued that in these studies, conscious identification of the prime word results in inhibition of higher frequency lexical competitors and that this interferes with subsequent identification of a higher frequency target word.

The above-mentioned priming research has used word recognition tasks (usually lexical decision) to investigate the recognition of isolated words. However, a natural extension of this research is to investigate whether inhibitory neighbor priming effects also occur between words during normal sentence comprehension. This approach was taken in the present experiment, which used measures of eye movements to investigate whether prior exposure to a word's orthographic neighbor earlier in a sentence would affect the processing of that word. A related study that used a different technique to investigate neighbor priming effects during reading was reported by Williams, Perea, Pollatsek, and Rayner (2006), who used the bound-

ary technique (Rayner, 1975) to investigate the effects of parafoveal preview of a word's neighbor on subsequent word recognition. This preview can be considered to be a form of priming in which a preview word (or nonword) in the parafovea acts in a similar way to a prime, by changing into the target word as the reader's point of fixation crosses an invisible boundary. Previews in this experiment were identical to the target word (e.g., *sleet*) or a neighboring word (e.g., *sweet*) of higher or lower frequency than the target word (or a neighboring nonword, e.g., *speet*). The results revealed a facilitatory preview effect for higher frequency neighbors on target word processing, in contrast to the inhibitory priming effects observed in studies of single-word recognition.

Williams et al. (2006) explained their results in terms of the account of lexical identification that is integral to the E-Z Reader model of oculomotor control (e.g., Pollatsek, Reichle, & Rayner, 2006; Reichle, Pollatsek, Fisher, & Rayner, 1998; Reichle, Rayner, & Pollatsek, 2003). In this model, lexical identification is the primary determinant of when a reader moves his/her eye. It occurs in two stages: an initial familiarity check where likely lexical candidates become activated, followed by a verification stage when full lexical identification occurs. Williams et al. suggested that parafoveal preview of a word's neighbor principally affects the familiarity check by activating letter representations that are mostly shared with the target word and perhaps by also weakly activating the neighbor word's lexical entry. The benefit occurs for high-frequency neighbors only, because their increased familiarity produces more effective letter activation. Williams et al. argued that inhibitory neighborhood effects in other eye movement experiments (e.g., Perea & Pollatsek, 1998; Pollatsek et al., 1999), which emerge relatively late in the eye movement record, are the result of competition between lexical entries during the verification stage of lexical identification.

In contrast to the technique employed by Williams et al. (2006), in the present experiment sentences were presented entirely normally without the use of the boundary paradigm. In this experiment, the neighbor prime appeared earlier in the sentence than did the target word, and

Low-frequency prime word (e.g., blur/gasp)–high-frequency target word (e.g., blue)

1. There was a| blur_{prime}| as the| blue_{target}| lights_{spillover}| of the police car whizzed down the street.
2. There was a| gasp_{prime}| as the| blue_{target}| lights_{spillover}| of the police car whizzed down the street.

High-frequency prime word (e.g., blue/town)–low-frequency target word (e.g., blur)

3. In the photograph, the| blue_{prime}| lights were a| blur_{target}| against_{spillover}| the cold night sky.
4. In the photograph, the| town_{prime}| lights were a| blur_{target}| against_{spillover}| the cold night sky.

Figure 1. Example of sentence stimuli. Vertical lines delineate regions of analysis.

we were interested to determine whether the presence of the prime influenced subsequent processing of the target. We used sentences like those in Figure 1. Prime and target words were orthographic neighbors, one higher in frequency than the other (e.g., *blue* vs. *blur*), or constituted a control word matched for length and frequency that had no orthographic overlap with the target word, which appeared in place of the neighbor prime (e.g., *town* and *gasp*).

Inhibitory effects at the target word would be consistent with results from priming studies (e.g., Davis & Lupker, 2006; Segui & Grainger, 1990), demonstrating that competition between lexical candidates impedes target word identification during normal reading as well as in the lexical decision task. Inhibitory effects would also be consistent with findings of Williams et al. (2006), because, despite their having observed facilitatory effects of a parafoveal preview of a neighbor word in their study, their account predicts that a neighboring word that is fully identified prior to a reader fixating the target word will inhibit target word identification, because it provides a lexical competitor for the target during the verification stage of lexical identification. On some occasions, this may result in misidentification of the target word.

We also manipulated the relative lexical frequency of the prime and target words. As discussed earlier, masked priming research has shown a prime frequency effect, whereby higher frequency neighbor primes exert a greater inhibitory influence on lower frequency target words than vice versa (Davis & Lupker, 2006; Segui & Grainger, 1990). However, in these experiments participants were not consciously aware of the prime. In contrast, Segui and Grainger found the opposite effect in an unmasked priming study when primes were consciously identified prior to target word identification. We investigated whether a prime frequency effect would be found in normal reading. Because in normal reading prime words will clearly have been fully identified prior to fixation on a target word, it seems reasonable to anticipate a similar inversion of the prime frequency effect to that obtained by Segui and Grainger, with greater inhibition for neighbor primes that are lower rather than higher in frequency than the target word.

METHOD

Participants

Thirty-two native English speakers were recruited from the University of Leicester.

Design and Materials

Twenty-six sets of five-letter words and 22 sets of four-letter words were selected from the stimuli of Davis and Lupker (2006; see the Appendix). Each set comprised two neighbors (e.g., *blue* and *blur*) and two orthographically unrelated control words of the same length (e.g., *gasp* and *town*). Neighboring words differed by one letter, and the letter position that was changed varied across the materials. We used CELEX (Baayen, Piepenbrock, & Gulikers, 1995) to match each neighbor for frequency (counts per million words) with a control word. The only significant difference in frequency occurred between high- and low-frequency pairs (e.g., high-frequency neighbor = 313, low-frequency neighbor = 9, high-frequency control word = 318, low-frequency control word = 7) [$F(1,47) = 6.26, p = .02$; other F s < 1].

Prime and target pairs were inserted into pairs of identical sentence frames. In neighbor priming conditions, either the lower frequency neighbor preceded the higher frequency neighbor (e.g., *blur-blue*) or vice versa (e.g., *blue-blur*). We created nonneighbor priming conditions by substituting appropriate control words for neighbor primes (e.g., *gasp-blue*; *town-blur*). Thus, four sentences were constructed for each set, manipulating orthographic relatedness and prime-target frequency. Sentences were presented in counterbalanced lists, so that each participant saw only one of the four. The average separation of prime and target words was 1.8 words (7.4 characters). Textual distance between primes and targets was identical for sentences containing the same target and did not differ significantly for sentences containing different targets. Sentences were matched for plausibility: Ten participants supplied plausibility ratings for each version of the sentences, which did not differ significantly ($F < 1$).

Procedure

Eye movements were recorded using a Fourward Technologies Generation 6 DPI (dual Purkinje image) eyetracker at the University of Leicester, employing standard stimulus-presentation and data-acquisition procedures.

RESULTS

Regions

Five scoring regions were used (see Figure 1). Region 1 contained text preceding the prime. Region 2 was the prime word. Region 3 contained words between the prime and target words. Region 4 was the target word. Region 5 contained the next word (or two words if the next word was a short function word).

Analysis

An automatic procedure pooled or deleted short or long fixations. Analyses for each region excluded trials with zero first-pass reading times. We report first-fixation duration (duration of the first fixation on a word), gaze duration (sum of all fixations on a word before a saccade from it), and total reading time (sum of all fixations) for Regions 2 and 4, and single-fixation duration (duration of the fixation on a word receiving only one first-pass fixation) for Region 4 only. First-fixation duration and first-pass reading time (equivalent to gaze duration for regions containing several words) are reported for Regions 3 and 5, and the frequency of regressions and regression-path reading time (sum of first-pass fixations within a region along with fixations that reinspect earlier portions of text before a fixation is made to the right of this region; e.g., Livensedge, Paterson, & Pickering, 1998) are reported for Regions 2–5.

We conducted two 2 (lexical frequency: high or low) $\times$ 2 (orthographic similarity: neighbors or nonneighbors) repeated measures ANOVAs, computing error variance over participants (F_1) and sentences (F_2). Mean reading times are shown in Table 1.

Region 2 (Prime Word)

There was a 17-msec lexical frequency effect in gaze durations for prime words [$F_1(1,31) = 8.62, p < .01$; $F_2(1,47) = 4.81, p < .05$]. Total reading times were longer for primes that were neighbors of the target word than for

Table 1
Eye Movement Data for Regions 2–5

Measures of Reading	Orthographic Relatedness of Prime and Target Words							
	Neighbors				Nonneighbors			
	Neighbors		Nonneighbors		Neighbors		Nonneighbors	
	LF Prime (e.g., <i>blur</i>) HF Target (e.g., <i>blue</i>)	HF Prime (e.g., <i>blue</i>) LF Target (e.g., <i>blur</i>)	LF Prime (e.g., <i>gasp</i>) HF Target (e.g., <i>blue</i>)	HF Prime (e.g., <i>town</i>) LF Target (e.g., <i>blur</i>)	LF Prime (e.g., <i>gasp</i>) HF Target (e.g., <i>blue</i>)	HF Prime (e.g., <i>town</i>) LF Target (e.g., <i>blur</i>)	LF Prime (e.g., <i>gasp</i>) HF Target (e.g., <i>blue</i>)	HF Prime (e.g., <i>town</i>) LF Target (e.g., <i>blur</i>)
	<i>M</i>	<i>SE</i>	<i>M</i>	<i>SE</i>	<i>M</i>	<i>SE</i>	<i>M</i>	<i>SE</i>
Region 2 (Prime Word)								
First-fixation duration (msec)	226	6.4	220	6.1	224	4.8	216	5.3
Gaze duration (msec)	258	10.3	248	8.3	261	7.9	236	6.4
Regressions (%)	17.8	3.2	16.8	2.6	17.9	3.0	20.3	3.2
Regression-path reading time (msec)	347	19.3	321	16.8	338	18.5	344	22.5
Total reading time (msec)	385	25.7	346	20.9	334	14.4	328	14.7
Region 3 (Intervening Text)								
First-fixation duration (msec)	231	6.2	223	6.5	218	5.1	229	8.1
First-pass reading time (msec)	299	13.1	296	12.0	291	11.2	312	14.2
Regressions (%)	16.3	2.6	11.7	2.5	15.8	2.9	16.2	2.9
Regression-path reading time (msec)	271	21.9	236	16.9	269	21.7	297	27.7
Region 4 (Target Word)								
First-fixation duration (msec)	233	6.4	237	7.0	224	6.0	221	4.9
Single-fixation duration (msec)	236	5.9	239	7.3	227	6.7	230	6.3
Gaze duration (msec)	264	8.8	266	7.7	248	7.1	253	8.5
Regressions (%)	15.2	2.3	15.7	2.8	11.1	1.8	16.8	2.1
Regression-path reading time (msec)	292	22.8	292	21.5	261	17.1	248	13.7
Total reading time (msec)	383	19.9	383	19.0	324	14.3	353	18.4
Region 5 (Spillover)								
First-fixation duration (msec)	228	6.4	228	6.0	218	5.8	230	6.1
First-pass reading time (msec)	593	24.3	581	30.4	583	24.0	592	25.2
Regressions (%)	19.7	2.7	23.2	2.7	16.3	2.4	16.2	2.4
Regression-path reading time (msec)	1,022	64.3	1,041	62.4	899	59.8	937	58.4

Note—HF, high frequency; LF, low frequency.

controls [$F_1(1,31) = 5.88, p < .05$; $F_2(1,47) = 4.04, p = .05$]. No other effects were reliable ($F_s < 3.1$).

Region 3 (Intervening Text)

No effects were significant ($F_s < 3.0$).

Region 4 (Target Word)

Inhibitory priming effects were observed for first-fixation durations, gaze durations, and total reading times [12-msec first-fixation effect, $F_1(1,31) = 5.79, p < .05$, $F_2(1,47) = 6.29, p < .05$; 15-msec gaze duration effect, $F_1(1,31) = 4.31, p < .05$, $F_2(1,47) = 5.98, p < .05$; 45-msec total reading time effect, $F_1(1,31) = 9.48, p < .01$, $F_2(1,47) = 8.83, p < .01$]. The effect for single fixation durations was marginal [9-msec effect, $F_1(1,31) = 2.95, p = .10$, $F_2(1,47) = 4.95, p < .05$]. In addition, regression-path reading times were longer for target words that followed a neighbor prime rather than for a control word [38-msec effect, $F_1(1,31) = 10.31, p < .01$, $F_2(1,47) = 3.76, p = .06$]. Despite a trend for larger inhibitory priming effects in first-fixation durations when prime words were lower in frequency than target words (16 msec vs. 9 msec), this interaction was not significant ($F_s < 1$). No other effects were significant ($F_s < 2.5$). Thus, there was clear evidence of an inhibitory neighbor priming effect for target words, but no significant modulation of this effect by the relative lexical frequency of prime and target words.

Region 5 (Spillover Region)

There were more regressions and longer regression path reading times when target words followed a neighbor prime than when they followed a control word [5.1% regression frequency effect, $F_1(1,31) = 6.28, p < .05$, $F_2(1,47) = 4.92, p < .05$; 113-msec regression path reading time effect, $F_1(1,31) = 9.41, p < .01$, $F_2(1,47) = 6.85, p < .05$]. No other effects were significant ($F_s < 2.8$).

DISCUSSION

The results reveal that prior exposure to a word's neighbor earlier within a sentence slows subsequent processing of that word during normal reading. Because this effect emerged in early reading-time measures (i.e., first-fixation duration and gaze duration), we can conclude that the inhibitory influence of a previously identified neighbor is present by the time the target word is fixated. This effect is consistent with findings from priming research showing that presentation of a word's neighbor as a prime impedes that word's recognition. Our results therefore extend a phenomenon observed in studies of isolated word recognition into the domain of silent reading and form a bridge between these two literatures. The effect seemingly differs from that observed in other research on eye movements during reading (e.g., Perea & Pollatsek, 1998; Pollatsek et al., 1999) where the neighborhood characteristics of a word have had a relatively late influence on lexical

processing, an effect that has been attributed to readers often misidentifying words that have higher frequency neighbors. In contrast with this finding, the present results suggest that prior activation of a word's neighbor can influence early stages of lexical processing.

Competitive network models (e.g., Davis, 1999, 2003; Grainger & Jacobs, 1996; McClelland & Rumelhart, 1981) would explain the inhibitory priming effect in the present experiment in terms of prior exposure to a word's neighbor providing activation for a lexical competitor that interferes with subsequent target word identification. A fundamental assumption associated with these models is that activation of a lexical entry decays over time and is inhibited when other lexical entries become activated as other words are read. Therefore, the models can be used to explain the present findings in terms of competition among lexical entries, insofar as activation of the prime word's lexical entry has not decayed or has not been inhibited substantially in the interval between identification of the prime word and fixation on the target word. Because clear inhibitory priming effects were observed, it could be argued that there was sufficient ongoing activation of the prime word's lexical entry for this to interfere with target word identification when prime words were separated from target words by only one or two (often function) words.

However, this inhibitory priming effect might also be explained by an episodic account of lexical priming (e.g., Tenpenny, 1995). According to this approach, when prime and target words are read separately (as in the present experiment) and when these words are orthographically similar, the processing of the target word evokes an episodic memory trace encoded during the processing of the prime word. In repetition priming, the evoked memory of a prime word that was processed earlier could then facilitate subsequent target word identification. However, it seems likely that, when the prime is a neighbor of the target, this evoked memory would interfere with target word identification. It has been argued (e.g., Tenpenny, 1995) that episodic approaches have an advantage in explaining longer term priming effects (but see Bowers, 2000, and Davis, 1999, for discussions of how an abstractionist account offered by competitive network models can also explain such effects). However, which account provides the best explanation for intersentential intralexical priming effects during reading remains to be determined.

Consider now how the present findings relate to the account of neighbor priming effects proposed by Williams et al. (2006). Williams et al. accounted for the parafoveal effects in their experiment in terms of the two-stage account of lexical identification in the E-Z Reader model (e.g., Reichle et al., 1998), proposing that virtually all processing in the parafovea is associated with an initial familiarity check stage of identification, during which lexical and orthographic representations become activated. They argued that preview of a word's neighbor activates the neighboring word's lexical entry and associated letter representations. Because almost all of these letters are shared with the target word, this increased letter activation

facilitates target word identification. However, Williams et al. suggested that because prime word identification is only partially completed before the target word is fixated, its lexical entry does not become as active as it would if the prime word were actually fixated and therefore does not provide a strong lexical competitor for the target word. Consequently, lexical competition is not observed during the familiarity check, and parafoveal preview of a word's neighbor can, on balance, facilitate lexical identification. Williams et al. also argued that inhibitory neighborhood effects that emerge after parafoveal processing of a word (e.g., Perea & Pollatsek, 1998; Pollatsek et al., 1999) are attributable to competition between lexical entries during the second, verification stage of identification, which may result in misidentification of the word. The present findings are consistent with Williams et al.'s account of lexical identification in the E-Z Reader model, because they indicate that prior exposure to a word's neighbor can give rise to effects of lexical competition in early measures of eye movements (i.e., first-fixation duration, gaze duration) as soon as the word is fixated.

A second question addressed in the present experiment was whether relative prime–target frequencies influenced target word recognition. Normal reading more closely resembles unmasked priming as opposed to masked priming, because in both normal reading and unmasked priming the prime word will have been consciously identified prior to the target word being processed. Recall that unmasked priming shows that lower frequency neighbor primes produce greater inhibitory effects than do higher frequency neighbor primes (Segui & Grainger, 1990). Therefore, we might have expected to see a similar modulation of neighborhood priming effects by prime frequency in the present experiment. Although the inhibitory neighbor priming effect was numerically greater for targets that followed lower rather than higher frequency prime words, this modulatory effect of frequency fell far short of statistical significance. Note also that we did not obtain any basic effect of lexical frequency for the target word itself (and that this was true even when the target words followed control words). The lack of such an effect at the target word is especially notable, given the robustness of the frequency effect observed at the prime word. Clearly, there has to be some reason for the lack of such an effect.

One possible explanation that has been raised previously (e.g., Rayner & Duffy, 1986; see also Reichle et al., 2003) is that the absence of frequency effects at the target word may be due to a spillover frequency effect from the prime word. Note that lower frequency target words always followed higher frequency prime or control words in the present experiment, and vice versa, which raises the possibility that participants were continuing to process a more costly lower frequency prime or control word as they fixated the following higher frequency target word. If this were the case, recognition of a higher frequency target word would be impeded by this spillover effect, thereby substantially reducing the likelihood of observing frequency effects at the target word.

Turning to the prime word data, as expected, here we obtained a standard lexical frequency effect (for neighbor and nonneighbor primes) in gaze durations, confirming the effectiveness of the manipulation of prime word frequency. A separate effect was observed in total reading times, which were longer for primes that were neighbors of the target word than for control words. Because this effect occurred exclusively in total reading times for the prime word (with concomitant increases in regressions and regression path reading times occurring only at the target word and posttarget region), it is readily explained in terms of readers making a regressive saccade from the target word or posttarget region in order to reinspect and reprocess the prime word.

Such regressive eye movements were most likely the result of readers having increased difficulty in processing the target word, and possibly even misidentifying this word, when it followed a neighbor word prime. However, it could be argued that these effects are instead due to a delayed influence of neighborhood characteristics of the prime words spilling over onto target word processing. That is to say, rather than reflecting neighbor priming, the effect may have been caused by an inhibitory neighborhood effect during prime word processing, because of neighbor primes having more higher frequency neighbors than did the control words, and because of this effect's emerging relatively late in processing (e.g., Perea & Pollatsek, 1998; Pollatsek et al., 1999). Fortunately, this alternative explanation of the effect can be ruled out by demonstrating that the prime and control words did not differ significantly in terms of the number of higher frequency neighbors. We used the N-Watch program (Davis, 2005) for this computation, and, indeed, there were no such differences (neighbor primes = 0.84, control words = 1.03, $F < 1.4$). Therefore, the total reading time effect at the prime word cannot be due to a delayed inhibitory neighborhood frequency effect.

In conclusion, the present results demonstrate that exposure to a word's orthographic neighbor earlier in a sentence interferes with word identification during normal sentence comprehension. The fact that this phenomenon occurred between words of a sentence that was read normally indicates that eye movements during reading are sensitive to naturally occurring intrasentential, interlexical influences. Furthermore, such relationships have implications for the process of lexical identification that occurs as we read sentences. The results are consistent with research employing priming methodologies using isolated words and can be accommodated within a two-stage account of lexical identification as per the E-Z Reader model. Thus, the present experimental findings extend a phenomenon observed in studies of single-word recognition and therefore form a bridge between the domains of isolated word recognition and silent reading. Future research is needed in order to establish how orthographic information from earlier in a sentence carries across intervening words to affect the lexical processing of words read later in the sentence.

AUTHOR NOTE

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REFERENCES

- ANDREWS, S. (1997). The effect of orthographic similarity on lexical retrieval: Resolving neighborhood conflicts. *Psychonomic Bulletin & Review*, 4, 439-461.
- BAAZEN, R. H., PIEPENBROCK, R., & GULIKERS, L. (1995). The CELEX Lexical Database (Release 2) [CD-ROM]. Philadelphia: Linguistic Data Consortium, University of Pennsylvania.
- BIJELJAC-BABIC, R., BIARDEAU, A., & GRAINGER, J. (1997). Masked orthographic priming in bilingual word recognition. *Memory & Cognition*, 25, 447-457.
- BOWERS, J. S. (2000). In defense of abstractionist theories of repetition priming and word identification. *Psychonomic Bulletin & Review*, 7, 83-99.
- BOWERS, J. S., DAVIS, C. J., & HANLEY, D. A. (2005a). Automatic semantic activation of embedded words: Is there a "hat" in "that"? *Journal of Memory & Language*, 52, 131-143.
- BOWERS, J. S., DAVIS, C. J., & HANLEY, D. A. (2005b). Interfering neighbours: The impact of novel word learning on the identification of visually similar words. *Cognition*, 97, B45-B54.
- BRYBAERT, M., LANGE, M., & VAN WIJNENDAELE, I. (2000). The effects of age-of-acquisition and frequency-of-occurrence in visual word recognition: Further evidence from the Dutch language. *European Journal of Cognitive Psychology*, 12, 65-85.
- CARREIRAS, M., PEREA, M., & GRAINGER, J. (1997). Effects of the orthographic neighborhood in visual word recognition: Cross-task comparisons. *Journal of Experimental Psychology: Learning, Memory, & Cognition*, 23, 857-871.
- COLOMBO, L. (1986). Activation and inhibition with orthographically similar words. *Journal of Experimental Psychology: Human Perception & Performance*, 12, 226-234.
- COLTHEART, M., DAVELAAR, E., JONASSON, J. F., & BESNER, D. (1977). Access to the internal lexicon. In S. Dornic (Ed.), *Attention and performance VI* (pp. 535-555). Hillsdale, NJ: Erlbaum.
- DAVIS, C. J. (1999). *The self-organising lexical acquisition and recognition (SOLAR) model of visual word recognition*. Unpublished doctoral dissertation, University of New South Wales.
- DAVIS, C. J. (2003). Factors underlying masked priming effects in competitive network models of visual word recognition. In S. Kinoshita & S. J. Lupker (Eds.), *Masked priming: The state of the art* (pp. 121-172). Philadelphia: Psychology Press.
- DAVIS, C. J. (2005). N-Watch: A program for deriving neighborhood size and other psycholinguistic statistics. *Behavior Research Methods*, 37, 65-70.
- DAVIS, C. J., & LUPKER, S. J. (2006). Masked inhibitory priming in English: Evidence for lexical inhibition. *Journal of Experimental Psychology: Human Perception & Performance*, 32, 668-687.
- DAVIS, C. J., & TAFT, M. (2005). More words in the neighborhood: Interference in lexical decision due to deletion neighbors. *Psychonomic Bulletin & Review*, 12, 904-910.
- DE MOOR, W., & BRYBAERT, M. (2000). Neighborhood-frequency effects when primes and targets are of different lengths. *Psychological Research*, 63, 159-162.
- DREWS, E., & ZWITZERLOOD, P. (1995). Morphological and orthographic similarity in visual word recognition. *Journal of Experimental Psychology: Human Perception & Performance*, 21, 1098-1116.
- FORSTER, K. I., & SHEN, D. (1996). No enemies in the neighborhood: Absence of inhibitory neighborhood frequency effects in lexical decision and semantic categorization. *Journal of Experimental Psychology: Learning, Memory, & Cognition*, 22, 696-713.
- GRAINGER, J. (1990). Word frequency and neighborhood frequency ef-

- fects in lexical decision and naming. *Journal of Memory & Language*, **29**, 228-244.
- GRAINGER, J., COLÉ, P., & SEGUI, J. (1991). Masked morphological priming in visual word recognition. *Journal of Memory & Language*, **30**, 370-384.
- GRAINGER, J., & FERRAND, L. (1994). Phonology and orthography in visual word recognition: Effects of masked homophone primes. *Journal of Memory & Language*, **33**, 218-233.
- GRAINGER, J., & JACOBS, A. M. (1996). Orthographic processing in visual word recognition: A multiple read-out model. *Psychological Review*, **103**, 518-565.
- GRAINGER, J., O'REGAN, J. K., JACOBS, A. M., & SEGUI, J. (1989). On the role of competing word units in visual word identification: The neighborhood frequency effect. *Perception & Psychophysics*, **45**, 189-195.
- HUNTSMAN, L. A., & LIMA, S. D. (1996). Orthographic neighborhood structure and lexical access. *Journal of Psycholinguistic Research*, **25**, 417-429.
- LIVERSEGE, S. P., PATERSON, K. B., & PICKERING, M. J. (1998). Eye movements and measures of reading time. In G. Underwood (Ed.), *Eye guidance in reading and scene perception* (pp. 55-75). New York: Elsevier.
- LUPKER, S. J., & COLOMBO, L. (1994). Inhibitory effects in form priming: Evaluating a phonological competition explanation. *Journal of Experimental Psychology: Human Perception & Performance*, **20**, 437-451.
- MCCLELLAND, J. L., & RUMELHART, D. E. (1981). An interactive activation model of context effects in letter perception: I. An account of basic findings. *Psychological Review*, **88**, 375-407.
- PEREA, M., & POLLATSEK, A. (1998). The effects of neighborhood frequency in reading and lexical decision. *Journal of Experimental Psychology: Human Perception & Performance*, **24**, 767-779.
- POLLATSEK, A., PEREA, M., & BINDER, K. S. (1999). The effects of "neighborhood size" in reading and lexical decision. *Journal of Experimental Psychology: Human Perception & Performance*, **25**, 1142-1158.
- POLLATSEK, A., REICHLE, E. D., & RAYNER, K. (2006). Tests of the E-Z Reader model: Exploring the interface between cognition and eye-movement control. *Cognitive Psychology*, **52**, 1-56.
- RAYNER, K. (1975). The perceptual span and peripheral cues in reading. *Cognitive Psychology*, **7**, 65-81.
- RAYNER, K., & DUFFY, S. A. (1986). Lexical complexity and fixation times in reading: Effects of word frequency, verb complexity, and lexical ambiguity. *Memory & Cognition*, **14**, 191-201.
- REICHLE, E. D., POLLATSEK, A., FISHER, D. L., & RAYNER, K. (1998). Toward a model of eye movement control in reading. *Psychological Review*, **105**, 125-157.
- REICHLE, E. D., RAYNER, K., & POLLATSEK, A. (2003). The E-Z Reader model of eye-movement control in reading: Comparisons to other models. *Behavioral & Brain Sciences*, **26**, 445-526.
- SEGUI, J., & GRAINGER, J. (1990). Priming word recognition with orthographic neighbors: Effects of relative prime-target frequency. *Journal of Experimental Psychology: Human Perception & Performance*, **16**, 65-76.
- TENPENNY, P. L. (1995). Abstractionist versus episodic theories of repetition priming and word identification. *Psychonomic Bulletin & Review*, **2**, 339-363.
- WILLIAMS, C. C., PEREA, M., POLLATSEK, A., & RAYNER, K. (2006). Previewing the neighborhood: The role of orthographic neighbors as parafoveal previews in reading. *Journal of Experimental Psychology: Human Perception & Performance*, **32**, 1072-1082.

APPENDIX
Prime and Target Word Stimuli

Neighbors		Nonneighbors	
High Frequency	Low Frequency	High Frequency	Low Frequency
royal	loyal	fresh	timid
blue	blur	town	gasp
able	axle	high	thug
iron	icon	edge	chef
club	clue	desk	mask
jury	fury	taxi	whip
thus	thud	else	howl
from	frog	with	grub
queen	queer	coast	moist
turn	turf	oval	clip
unit	knit	body	chef
both	moth	away	clip
inch	itch	food	knee
piece	niece	music	shrug
motor	rotor	chain	scalp
knock	knack	alarm	flute
fault	vault	siren	crime
media	medic	crowd	fluff
cruel	gruel	nasty	poppy
step	stew	task	loaf
magic	manic	teeth	fiery
lady	lazy	desk	numb
thumb	thump	rival	spark
chief	thief	woman	badge
anger	angel	shock	relic
tree	trek	film	lava
leave	weave	front	dodge
sign	sigh	army	atom
house	mouse	thing	drill
dance	lance	shirt	beret
outer	otter	brass	flock
deny	defy	chat	gulp
under	udder	among	mango
angle	ankle	rugby	thigh
onion	union	table	chalk
force	farce	sight	stunt
even	oven	just	folk
only	oily	most	vile
legal	regal	ended	suave
reply	repay	argue	kneel
hurt	hurl	bent	skim
drug	drum	sofa	jazz
open	omen	rest	saga
burn	burp	rage	pant
about	abort	pilot	halve
aside	abide	loose	dodge
solar	polar	furry	magic
state	skate	power	canoe

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