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Masked Priming With Orthographic Neighbors: A Test of the Lexical Competition Assumption

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In models of visual word identification that incorporate inhibitory competition among activated lexical units, a word's higher frequency neighbors will be the word's strongest competitors. Preactivation of these neighbors by a prime is predicted to delay the word's identification. Using the masked priming paradigm (K. I. Forster & C. Davis, 1984, J. Segui and J. Grainger (1990) reported that, consistent with this prediction, a higher frequency neighbor prime delayed the responses to a lower frequency target, whereas a lower frequency neighbor prime did not delay the responses to a higher frequency target. In the present experiments, using English stimuli, it was found that this pattern held only when the primes and targets had few neighbors; when the primes and targets had many neighbors, lower frequency primes delayed responses to higher frequency targets essentially as much as higher frequency primes delayed responses to lower frequency targets. Several possible explanations for these findings are discussed along with their theoretical implications. Considered together, the results are most consistent with activation-based accounts of the masked priming effect.

Keywords: masked priming, orthographic neighbors, neighborhood frequency, inhibitory priming

Language researchers have long been interested in understanding how people read, with the processes involved in the visual identification of words being the focus of many of their investigations. As a result of these investigations, a number of models of visual word identification have been developed, each embodying certain assumptions about the nature of lexical processing. The major models are the serial-search models (e.g., Forster, 1989), the parallel distributed processing models (e.g., Seidenberg & McClelland, 1989; Plaut, McClelland, Seidenberg, & Patterson, 1996), and the activation-based models (e.g., Davis, 2003; Grainger & Jacobs, 1996; McClelland & Rumelhart, 1981).

In all of these models, the speed with which a word is identified is influenced by the reader's knowledge of other, orthographically similar words (i.e., the word's orthographic neighbors). Consider, for example, activation-based models in which the role of orthographic neighbors is especially important. According to activation-based models, when a word is presented, the lexical representation of the word and the lexical representations of its neighbors are activated. Selection of the target word then occurs through a process of competitive inhibition, with the lexical units of the word and those of its neighbors competing against one another by means of mutually inhibitory connections until the target's lexical unit exceeds a threshold level of activation. That is, these models assume not only that there is competition among activated lexical units but also that the nature of the competition between a presented word and its orthographic neighbors plays a major role in the word identification process.

A word's orthographic neighbors are traditionally defined as those words that can be created by changing any one letter of the word while maintaining letter positions (Coltheart, Davelaar, Jonasson, & Besner, 1977); for example, *base*, *case*, *east*, *easy*, *else*, and *vase* are all orthographic neighbors of *ease*. The frequency relationship between a word and its orthographic neighbors is especially important in activation-based models, because it strongly affects how quickly the lexical competition can be resolved, which in turn determines how quickly the word can be identified. According to the models, higher frequency neighbors, due to their higher resting activation levels, can exert more inhibition on the lexical unit of a word than can lower frequency neighbors. As a result, the lexical unit of a word with higher frequency neighbors will accumulate activation more slowly than the lexical unit of a word without higher frequency neighbors due to the greater degree of interlexical inhibition. Words with higher frequency neighbors are thus predicted to be responded to more slowly and less accurately than words with-

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out higher frequency neighbors (an inhibitory neighborhood frequency effect).[1]

Grainger, O'Regan, Jacobs, and Segui (1989) were the first to test this prediction. They manipulated neighborhood frequency by using words with no neighbors, words with some neighbors but none of higher frequency, words with exactly one higher frequency neighbor, and words with many higher frequency neighbors, with target word frequency equated across these four conditions. Using the lexical decision task, they found that responses to words with higher frequency neighbors were slower than responses to words without higher frequency neighbors, although there was no cumulative neighborhood frequency effect (responses to words with many higher frequency neighbors were no slower than responses to words with a single higher frequency neighbor).

Grainger et al.'s (1989) report spawned a great deal of empirical attention, as the neighborhood frequency effect appeared to provide the necessary evidence for the lexical competition mechanism embodied in activation-based models. Most of the subsequent research on this topic has also involved the lexical decision task (e.g., Carreiras, Perea, & Grainger, 1997; Forster & Shen, 1996; Grainger, 1990; Grainger & Jacobs, 1996; Grainger & Segui, 1990; Huntsman & Lima, 1996, 2002; Perea & Pollatsek, 1998; Sears, Campbell, & Lupker, 2006; Sears, Hino, & Lupker, 1995; Siakaluk, Sears, & Lupker, 2002), although there have also been a number of studies using perceptual identification tasks (e.g., Carreiras et al., 1997; Grainger & Jacobs, 1996; Grainger & Segui, 1990; Sears, Lupker, & Hino, 1999), the semantic categorization task (Carreiras et al., 1997; Forster & Shen, 1996; Sears et al., 1999), the naming task (Carreiras et al., 1997; Sears et al., 1995), and tasks in which eye movements are monitored (Perea & Pollatsek, 1998; Sears et al., 2006). Many of the results reported in these studies have supported Grainger et al.'s initial result—words with higher frequency neighbors were processed more slowly (and less accurately) than words without higher frequency neighbors.

An important point to note, however, is that most of the research showing an inhibitory neighborhood frequency effect has been done in languages other than English (namely, French, Spanish, and Dutch; see Mathey & Zagar, 2000, for different results using French stimuli). In contrast, the studies that have used English stimuli have typically reported null or facilitory neighborhood frequency effects (e.g., Forster & Shen, 1996; Huntsman & Lima, 2002; Sears et al., 1995; Sears et al. 1999; Sears et al., 2006; Siakaluk et al., 2002; see Perea & Pollatsek, 1998, for an exception). This pattern has led some investigators (Andrews, 1997; Sears et al., 2006) to argue that there are important language differences concerning the role that inhibition plays in orthographic processing, in particular, an obvious possibility would be that the inhibitory process is simply less powerful in English than in other languages. Alternatively, the English orthographic lexicon may be structured differently, such that a different definition of what constitutes an orthographic neighbor may be required. In the present research, we explored the possibility that inhibitory processing in English may be more readily detectable in another experimental paradigm: masked priming using word neighbor primes.

Neighbor Inhibition Effects in the Masked Priming Paradigm

In the masked priming paradigm (Forster & Davis, 1984; for a review, see Kinoshita & Lupker, 2003), a trial consists of the presentation of a forward mask ("XXXX"), a prime word (typically presented for less than 60 ms), and a target word. Because the prime word is presented so briefly and then replaced, few participants are aware of its existence, much less its identity. Thus, the assumption is that its impact on target processing can be assessed in the absence of any conscious prime influence. Another major advantage of the masked-priming paradigm is that the same stimuli are responded to in different experimental conditions; for example, responses to the target (e.g., *side*) are measured after having been primed by an orthographic neighbor (e.g., *tide*) and by an orthographically unrelated word (e.g., *doll*). Because differences in the response latencies to the same target are the basis of the effect, there are no concerns about uncontrolled stimulus differences among the experimental conditions that can affect results in paradigms where responses to single words are collected (for a discussion of this issue, see Forster, 2000).

Using the masked priming paradigm, Segui and Grainger (1990) observed that lexical decision latencies were significantly slower when a word target was primed by a higher frequency neighbor (e.g., *avec-AVEU*) than when it was primed by an unrelated word of equivalent frequency (e.g., *puis-AVEU*). Segui and Grainger argued that this result is consistent with the lexical competition assumption inherent in models like the interactive activation (IA) model (McClelland & Rumelhart, 1981; McClelland, 1987). Because a word's higher frequency neighbors will be the word's strongest competitors, their preactivation by the prime makes them even stronger competitors, hence, delaying the word's identification. Thus, when the prime is a higher frequency neighbor of the target word, inhibitory priming is expected. On the other hand, the model also predicts that, when the prime is a lower frequency neighbor of the target, there should be little or no inhibitory priming, because preactivation of a word's lower frequency neighbors will not significantly increase their ability to compete with the target word. Consistent with this prediction, Segui and Grainger also reported that lexical decision latencies to a word target primed by a lower frequency neighbor (e.g., *aveu-AVEC*) were no different than the latencies to the same word primed by an unrelated word (e.g., *fond-AVEC*). (In fact, in contrast to the 48-ms inhibitory effect from higher frequency neighbor primes, there was a 10-ms facilitation effect from lower frequency neighbor primes, although it was not statistically significant). This pattern of results was obtained when using French stimuli (Experiment 2) and Dutch stimuli (Experiment 3). Two other studies, one in French (Bijeljac-Babic, Biardeau, & Grainger, 1997) and the other in Dutch (De Moor & Brysbaert, 2000), reported the same inhibitory effect from higher frequency neighbor primes.

Segui and Grainger (1990; Experiment 3) also demonstrated that it is the relative prime–target frequency and not the absolute frequency of the primes and targets that is critical for producing an inhibition effect. When medium frequency words (with a mean normative frequency of 192 occurrences per million) were primed by higher frequency neighbors (with a mean normative frequency of 874 occurrences per million), lexical decision latencies were

[1] For an examination and discussion of orthographic neighborhood effects in parallel distributed processing models (Seidenberg & McClelland, 1989; Plaut, McClelland, Seidenberg, & Patterson, 1996), see Sears et al. (1999).

delayed relative to when the same words were primed by unrelated primes. When the medium-frequency targets were primed by lower frequency neighbors (with a mean normative frequency of 9 occurrences per million) on the other hand, lexical decision latencies were not delayed relative to when they were primed by unrelated primes.

In light of its theoretical significance, there have been surprisingly few attempts to replicate Segui and Grainger's (1990) results using English words. In one, Bijeljac-Babic et al. (1997) reported that their participants responded to targets significantly more slowly when they were primed by higher frequency neighbor primes relative to when they were primed by unrelated primes. This result must be interpreted with some caution, however, as the participants in the study were native French speakers (i.e., French-English bilinguals). Hence, their English lexicons may have evolved to reflect more the nature of French than the nature of English. In addition, their experiment was limited to examining the effect of higher frequency neighbor primes on lower frequency targets (i.e., all of the neighbor primes were higher in frequency than the targets). Such was also the case in an earlier study by Grainger and Ferrand (1994), who also reported that higher frequency neighbor primes delayed responding to lower frequency English targets. That is, neither set of investigators tested the effect of lower frequency neighbor primes on the processing of higher frequency targets. Inhibitory priming from higher frequency neighbor primes is only one of the two key predictions of the activation-based models; equally important is the essential absence of inhibitory priming from lower frequency neighbor primes.

The most thorough examination of these issues using the masked-priming task with English stimuli was conducted by Davis and Lupker (2006). Across three experiments, these authors consistently found significant inhibition effects using higher frequency neighbor primes and lower frequency targets, replicating that aspect of Segui and Grainger's (1990) results. In their Experiment 1, however, Davis and Lupker also used lower frequency neighbor primes and higher frequency targets and these stimuli also produced a small inhibition effect. That is, unlike Segui and Grainger (1990), Davis and Lupker found neither a significant interaction between prime type (neighbor prime vs. unrelated prime) and target frequency (low-frequency target vs. high-frequency target primed by an opposite frequency prime) nor evidence that low-frequency primes fail to inhibit high-frequency targets. Interestingly, in their simulations using a version of the IA model (Davis, 2003), Davis and Lupker showed that, depending on how the parameters are selected, the model could be made to predict a nonzero (e.g., 9 ms) inhibition effect for lower frequency primes and higher frequency targets. What was also true, however, was that simulations showed the inhibition effect from higher frequency neighbor primes is always predicted to be much larger than the inhibition effect from lower frequency neighbor primes, because the higher frequency neighbors of a word are more effective competitors.

The Present Research

Inhibitory priming from higher frequency neighbor primes is a key prediction of the activation-based models, but it has received surprisingly little attention in studies that have used English stimuli. Apart from Davis and Lupker's (2006) Experiment 1, even less attention has been paid to the other, equally important prediction of the models, the prediction that lower frequency neighbor primes will produce little, if any, inhibitory priming. The present research was designed to test both of these predictions and to expand on the work of both Segui and Grainger (1990) and Davis and Lupker.

The purpose of Experiment 1 was to determine whether we would replicate the interaction between prime type and target frequency reported by Segui and Grainger and, like Segui and Grainger, whether we would also find no evidence of inhibition when lower frequency neighbors primed higher frequency targets. Apart from the different language used (i.e., English, rather than French), Experiment 1 was a direct replication of Segui and Grainger's experiment.

Experiment 1

Method

Participants. Sixty undergraduate students from the University of Calgary volunteered to participate in the experiment for bonus course credit. All participants were native speakers of English and reported having normal or corrected-to-normal vision.

Stimuli. When selecting the prime words, care was taken to ensure that the words were well known to participants, because it is known that the lexicality of the prime changes the nature of the priming effect (i.e., unlike word primes, nonword primes inevitably produce either facilitation or a null effect; e.g., Davis & Lupker, 2006; Forster, 1987; Forster, Davis, Schoknecht, & Carter, 1987; Forster & Davis, 1991; Forster & Taft, 1994; Forster & Veres, 1998). One potential problem with using low-frequency words as primes is that some of these words could be unknown to some participants, effectively making them nonword primes. As a consequence, any inhibitory neighbor priming produced by low-frequency word primes would be underestimated. To avoid this problem, we consulted the lexical decision data from the English Lexicon Project database (Balota et al., 2002) and only selected words with high lexical decision accuracy rates (thereby reducing the likelihood that these words would be unknown to participants). For the high-frequency words used in the experiment, the mean lexical decision accuracy was 96.9%, and for the low-frequency words it was 95.6%.

Like Segui and Grainger's (1990) stimuli, all of our stimuli were four letters in length. Forty pairs of four-letter orthographic neighbors were selected as the critical stimuli (the descriptive statistics for these stimuli are shown in Table 1; the stimuli are listed in the Appendix). Most of these words had large neighborhoods (M = 9.8 neighbors). For each pair, each neighbor served as either a prime or a target depending on the condition the pair was assigned to. One member of the neighbor pair was much higher in normative frequency (Kucera & Francis, 1967) than the other (see Table 1). Of the 40 pairs of neighbors, the two neighbors differed from one another at the first letter position (e.g., *side–TIDE*) in 16 of the pairs, the neighbors differed from one another at one of the middle letter positions (e.g., *lift–LEFT*, and *wife–WIPE*) in 19 of the pairs, and the neighbors differed at the last letter position (e.g., *half–HALT*) in 5 of the pairs. For each neighbor pair, two four-letter unrelated primes with similar normative frequencies and neighborhood sizes were selected. These quartets of words (the neighbor pair and the two unrelated primes) were used to create the four

Table 1
Mean Kucera & Francis (1967) Normative Frequency and Neighborhood Size of the Stimuli Used in Experiment 1

Stimulus characteristic	Target	Neighbor prime	Unrelated prime
Higher frequency prime-lower frequency target	*HEAP*	*help*	*area*
Frequency	14.6 (11.4)	529.2 (417.8)	535.1 (404.3)
Number of neighbors	9.8 (4.0)	9.8 (4.7)	7.8 (4.2)
Lower frequency prime-higher frequency target	*HELP*	*heap*	*grin*
Frequency	529.2 (417.8)	14.6 (11.4)	14.5 (11.4)
Number of neighbors	9.8 (4.7)	9.8 (4.0)	9.9 (3.8)
Word prime-nonword target	*VAKE*	*fake*	*bolt*
Frequency	—	22.1 (30.2)	21.9 (29.3)
Number of neighbors	9.8 (3.9)	10.0 (4.8)	10.0 (4.6)

Note. Standard deviations in parentheses.

prime–target conditions: (a) higher frequency neighbor prime–lower frequency neighbor target (e.g., *help–HEAP*), (b) higher frequency unrelated prime–lower frequency target (e.g., *area–HEAP*), (c) lower frequency neighbor prime–higher frequency neighbor target (e.g., *heap–HELP*), and (d) lower frequency unrelated prime–higher neighbor target (e.g., *grin–HELP*). Four counterbalanced lists were created such that half of the participants saw each member of the pair presented as a target (i.e., a participant saw either *HEAP* or *HELP*, not both words) and each target was presented to a participant only once (in either the related or the unrelated condition). The related and unrelated primes were matched on word length, normative word frequency, neighborhood size, and lexical decision accuracy (Balota et al., 2002).

Forty nonword targets four letters in length and with many neighbors ($M = 9.8$) were also selected. For these nonwords, 40 pairs of words with similar neighborhood sizes were chosen to serve as primes. One member of the prime word pair was an orthographic neighbor of the target and the other member of the pair was orthographically unrelated to the target. During the experiment, half of the nonword targets were preceded by neighbor primes (e.g., *fake–VAKE*), and half were preceded by unrelated primes (e.g., *bolt–VAKE*). There were two counterbalancing lists for nonword targets.

Apparatus and procedure. Each participant was tested individually in a dimly lit room. The experiment was programmed using the DMDX software package (Forster & Forster, 2003). Stimuli were presented on a 17-in. video display driven by a Pentium-class microcomputer.

The sequence and timing of events during each trial were identical to those in Segui and Grainger's (1990) experiment. Primes were presented in lower case and targets in uppercase. Each trial began with the presentation of a fixation marker ("+") in the center of display, which was presented for 500 ms. A visual mask ("####") then appeared in the center of the display for 500 ms, followed by the prime. The prime was presented for 60 ms and was immediately replaced by the target. Participants were instructed to quickly and accurately indicate whether the target was a word or not by pressing one of two buttons (labeled *yes* and *no*) on a response box placed in front of them. The existence of the prime word was not mentioned. The target remained on the screen until a response was made. Each participant completed 36 practice trials prior to the experimental trials (these practice stimuli were not used in the experimental trials). The order in which the experimental trials were presented was randomized separately for each participant.

Simulation procedure and simulation data. Simulations with the IA model (McClelland & Rumelhart, 1981) were conducted using the procedures outlined in Davis (2003).[2] The parameters used in the simulations were identical to those used in the original IA simulations reported by McClelland and Rumelhart in all but two ways. First, the integration rate of the model was ten times smaller than in McClelland and Rumelhart's simulations (e.g., a prime duration of 60 cycles in our simulations is equivalent to 6 cycles in the original model). Second, the assumption was made that the onset of the target has the effect of resetting letter-level activities (as in the Davis & Lupker, 2006, simulations). The mean number of simulation cycles to criterion for the words used in Experiment 1 are presented in Table 2. As can be seen in Table 2, the simulations reveal that the model predicts a substantially larger inhibitory neighbor priming effect from higher frequency primes (a difference of 50 cycles for neighbor vs. unrelated primes) than from lower frequency primes (a difference of 12 cycles).

Results

Data from participants with overall error rates greater than 20% were excluded from all analyses ($n = 5$). We treated response latencies less than 300 ms or greater than 1,200 ms as outliers, and these were removed from all analyses (1.0% of the word trials and 2.1% of the nonword trials). For the word data, response latencies of correct responses and error rates were submitted to a 2 (prime type: neighbor prime, unrelated prime) × 2 (target frequency: high, low) factorial analysis of variance (ANOVA). Both subject (F_s) and item (F_i) analyses were carried out. In the subject analysis, both factors were within-subject factors; in the item analysis, prime type was a within-item factor and target frequency was a between-item factor. For the nonword data, prime type (neighbor prime, unrelated prime) was the single factor and was a within-subject factor in the subject analysis and a within-item factor in the item analysis. The mean response latencies of correct responses and the mean error rates are listed in Table 2.

[2] We thank Colin Davis for providing us with all of the simulation data reported in our experiments.

Table 2
Mean Lexical Decision Latencies (RT, in ms), Percentage Errors, and Simulation Cycles for the Word Targets in Experiment 1

	Prime-target frequency					
	High-low			Low-high		
Prime type	RT	Errors	Simulation	RT	Errors	Simulation
Neighbor	618	11.1	252	537	1.8	204
Unrelated	594	9.5	202	516	1.8	192
Difference	−24	−1.6	−50	−21	0.0	−12

Note. The mean response latency and the mean error rate for nonword targets primed by word neighbors was 670 ms and 7.0%; for nonword targets primed by unrelated words the mean response latency was 664 ms and the mean error rate was 9.5%.

Word targets. In the analysis of response latencies, the main effect of prime type was significant, $F_s(1, 54) = 23.63$, $p < .001$, MSE =1,141.2; $F_i(1, 78) = 19.89$, $p < .001$, MSE = 1,085.3, with slower responding to targets primed by orthographic neighbors (578 ms) than to targets primed by unrelated words (555 ms). There was no effect of prime type on error rates, $F_s < 1$; $F_i(1, 78) = 1.29$, $p > .25$, MSE = 37.42. There was a significant effect of target frequency in the response latency analysis, $F_s(1, 54) = 134.6$, $p < .001$, MSE = 2,573.8; $F_i(1, 78) = 70.12$, $p < .001$, MSE = 4,083.5, and in the error analysis as well, $F_s(1, 54) = 69.8$, $p < .001$, MSE = 56.4; $F_i (1, 78) = 17.43$, $p < .001$, MSE = 179.1 Responses to high-frequency targets were faster than responses to low-frequency targets (527 ms vs. 606 ms), and fewer errors were made to high-frequency targets (1.8% vs. 10.3%). The most important result was the absence of an interaction between prime type and target frequency, for either response latencies (both Fs < 1) or for error rates, $F_s < 1$, $F_i (1, 78) = 1.20$, $p > .25$, MSE = 37.42. As can been seen in Table 2, there were virtually identical priming effects from high- and low-frequency neighbor primes (24 ms and 21 ms, respectively). Power analyses of the test of the interaction indicated that power was 96% in the subject analysis of response latencies and 92% in the item analysis of response latencies (using the effect sizes from the Prime Type × Target Frequency interactions in Experiment 3; power was calculated using the G*Power 3.0 software package, Faul, Erdfelder, Lang, & Buchner, 2007.)

Nonword targets. There was an effect of prime type in the error analysis, $F_s(1, 54) = 6.90$, $p < .05$, MSE = 25.9; $F_i (1, 39) = 3.55$, $p = .07$, MSE = 35.5, but not in the response latency analysis (both Fs <1). Nonwords were responded to more accurately when primed by neighbor primes (7.0% errors) than when primed by unrelated primes (9.5% errors).

Discussion

Using French and Dutch stimuli, Segui and Grainger (1990) found that a higher frequency neighbor prime slowed lexical decision latencies to a lower frequency target in comparison to an unrelated prime. This was not the case when the prime was a lower frequency neighbor of the target, consistent with the lexical competition assumptions embodied in activation-based models of visual word identification (McClelland & Rumelhart, 1981; Davis, 2003), as well as simulations reported by Grainger (1992) using Segui and Grainger's stimuli. Our simulations with the stimuli used in Experiment 1 demonstrated that the version of the model we used made similar predictions (i.e., a strong inhibition effect for the higher frequency prime–lower frequency target pairs and a much weaker effect for the lower frequency prime–higher frequency target pairs). Experiment 1 was therefore a straightforward test of these predictions.

Like Segui and Grainger (1990), we found that higher frequency neighbor primes significantly slowed target identification relative to higher frequency unrelated primes. Unlike Segui and Grainger, however, we found no hint of an interaction between prime type (neighbor vs. unrelated) and target frequency. Our 21 ms inhibition effect for higher frequency neighbor targets was essentially equivalent to the 24 ms inhibition effect for lower frequency neighbor targets. Recall that Davis and Lupker (2006) also failed to find a significant interaction, although they did report a somewhat larger difference between these two conditions (13 ms for higher frequency neighbor targets vs. 34 ms for lower frequency neighbor targets). In any case, our results do help establish the fact that the inhibitory priming effect from neighbor primes reported in other languages also exists for English word targets. Thus, our test of the predictions of the IA model yielded at least a partial success. Before drawing any theoretical inferences from these results, however, we felt it would be useful to conduct a new experiment with a different set of stimuli and additional stimulus controls, the details of which are described below.

Before turning to Experiment 2 we should address what may be an obvious question: Could the lack of an interaction between prime type and target frequency be related to the fact that our stimuli, particularly our low-frequency stimuli, were selected so as to be quite familiar to participants? That is, although our low-frequency words were selected to have normative frequencies similar to Segui and Grainger's (1990) low-frequency words, our low-frequency words were also selected to have high levels of accuracy based on the lexical decision data from the English Lexicon Project database (so as to reduce the likelihood that they would be unknown to participants). The question one might then ask is whether the normative frequencies of these low-frequency primes were greatly underestimated and, if so, whether this could have been responsible for the inhibition effect when these words primed high-frequency targets (i.e., had the words been truly low in frequency there would have been no inhibition effect). Two observations are relevant to this question.

First, as can be seen in Table 1, when these low-frequency primes were targets, responses to these words were much slower and less accurate than the responses to the high-frequency words, which indicates that, subjectively, they were not high-frequency words. That is, even if their normative frequencies were underestimated, that underestimation was not so great that they were equivalent in normative frequency to the high-frequency words.

Second, and more important, even if these low-frequency primes were substantially higher in frequency than their normative frequencies would suggest, one would not expect that to have had much of an effect on their ability to inhibit high-frequency words. As Segui and Grainger (1990) showed in their experiments, it was the relative prime–target frequency and not the absolute frequency of the primes and targets that was critical for producing an inhibition effect: When low-frequency neighbors primed high-frequency targets, there was no inhibition effect, nor was there an effect when low-frequency neighbors primed medium-frequency targets where the absolute frequency difference of the two was much smaller. Thus, there is no reason to believe that had our low-frequency words been lower in frequency there would not have been an inhibition effect.

The caveat, of course, is that if our low-frequency words had been substantially lower in frequency, some of them may have effectively been nonwords to many of our participants. As noted, nonword primes typically facilitate responses to word targets. Thus, the priming effect in the low-frequency prime condition would have been a mixture of inhibition and facilitation, potentially leading to a null effect. It is possible that something of this sort may have occurred in other studies that have used low-frequency primes and high-frequency targets, including Davis and Lupker (2006) and Segui and Grainger (1990). However, it will not be an issue in any of our experiments because all of our low-frequency stimuli were selected to be familiar to participants.

Experiment 2

The purpose of Experiment 2 was to determine if we could replicate Segui and Grainger's (1990) results by using an alternative set of stimuli. In particular, there were two stimulus selection issues we chose to focus on: the normative frequency of the primes preceding nonword targets and the neighborhood size of the primes (and the targets). Neither of these variables was explicitly controlled in Segui and Grainger's study and, hence, neither was explicitly controlled in our Experiment 1. One could, however, argue that each could have had some impact on the size of the priming effects.

First, with respect to the issue of the normative frequency of the primes preceding nonword targets, recent masked priming studies have shown that, under some conditions, the nature of the prime–target relationship can affect the magnitude of the priming effect observed (Bodner & Masson, 2001; 2003). In Experiment 1, nonword targets were almost always primed by low-frequency words. Thus, whenever the prime was a high-frequency word, the target was inevitably a word. In contrast, following low-frequency primes, the target was a word only 33% of the time. If participants were somehow sensitive to this relationship (presumably, at a subconscious level), there could have been an impact on the observed priming effects.[3] Specifically, the participants could have been biased toward responding "yes" on high-frequency prime trials. If so, the overall inhibition effect from higher frequency neighbor primes may have been diminished (i.e., the inhibition effect for high-frequency primes and low-frequency targets should have been even larger than observed). Although to our knowledge there have been no reports of this type of effect in the literature, we decided to safeguard against this possibility by changing the nature of the primes for the nonword targets. In Experiment 2, half of the primes for nonword targets were high-frequency words and half were low-frequency words (which remained true for the word targets). Thus, the prime's frequency was not predictive of the target's lexicality.

Second, with regard to the neighborhood-size issue, previous research has shown that facilitation effects for nonword neighbor primes and word targets are affected by the number of neighbors the stimuli possess (i.e., the density-constraint; Forster, 1987; Forster & Davis, 1991; Forster et al., 1987; Forster & Taft, 1994). In particular, small-neighborhood targets seem to be more prone to show facilitation. Therefore, one could argue that small-neighborhood targets would potentially be less likely to show inhibition. In Experiment 1, although the average neighborhood sizes were reasonably large, not all of the words had large neighborhoods, and about 15% of the critical stimuli had few neighbors (i.e., fewer than four neighbors), which means that the sizes of the inhibition effects we observed might have been artificially constrained. To control for neighborhood size in Experiment 2, only words and nonwords with many neighbors (at least five) were used.

Method

Participants. Fifty-eight undergraduate students from the University of Calgary volunteered to participate in this experiment for bonus course credit. All participants were native speakers of English and reported normal or corrected-to-normal vision. None of these students participated in Experiment 1.

Stimuli. As in Experiment 1, we consulted the English Lexicon Project database (Balota et al., 2002) to select words with high lexical decision accuracy rates in order to reduce the likelihood that a word would be unknown to participants. For the high-frequency words selected, the mean accuracy rate was 97.4%; and, for the low-frequency words, it was 96.4%. The critical stimuli consisted of 40 pairs of four- and five-letter orthographic neighbors (30 pairs of four-letters in length and 10 pairs of five-letters in length). Twenty-five of the 40 pairs were used in Experiment 1 (all the stimuli are listed in the Appendix). All of the words had at

[3] It is very unlikely that such prime–target relationships were consciously appreciated by participants. In our preliminary research, we examined the visibility of the primes at varying prime durations. We informed participants about the presence of the primes and asked them to make a decision only to the primes. Participants were asked to press the *yes* button on a button box when a prime contained the letter "e," and to press the *no* button when the prime did not contain the letter "e" (the e-detection program was provided by K. I. Forster). With a 60-ms prime duration, the accuracy rate was 69% (in a replication with a different group of participants, the accuracy rate was 63%). Thus, even when told of the presence of the primes and asked to identify them, performance was fairly poor. In the present experiments, participants were not informed of the presence of the primes and were told that the mask (####) presented prior to the target was irrelevant to the task.

least 5 neighbors, with an average of 10.2 neighbors. Of the 40 pairs of neighbors, the two neighbors differed from one another at the first letter position in 14 of the pairs, the neighbors differed at one of the middle letter positions in 15 of the pairs, and the neighbors differed at the last letter position in 11 pairs. For each neighbor pair, two unrelated primes of the same length and with similar normative frequencies and neighborhood sizes were selected. The descriptive statistics for the stimuli are listed in Table 3.

Forty nonwords of four or five letters in length, all with large neighborhoods, were also selected. For these nonwords, 40 word-pairs of matching length and neighborhood size were selected to serve as primes. Half of these pairs involved high-frequency words, half involved low-frequency words. One word in each pair was an orthographic neighbor of the nonword and the other was orthographically unrelated to the target. There were four counterbalancing lists for word trials and two counterbalancing lists for nonword trials. The pairing of the stimuli and the creation of the counterbalancing lists was the same as described in Experiment 1.

Apparatus and procedure. The apparatus and procedure were identical to those in Experiment 1.

Simulations. The simulations were conducted in the same manner as described in Experiment 1. The predictions of the IA model (Davis, 2003) for the stimuli used in this experiment are shown in Table 4. As was the case for the stimuli used in Experiment 1, the model predicts a much larger inhibitory priming effect from higher frequency neighbor primes (58 cycles) than from lower frequency neighbor primes (14 cycles).

Results

To be consistent with Experiment 1, data from participants with overall error rates greater than 20% were excluded from all analyses ($n = 2$), and response latencies less than 300 ms or greater than 1,200 ms were treated as outliers and removed from all analyses (0.3% of the word trials, 1.0% of the nonword trials). For the word data, the subject and item analyses of response latencies and error rates were carried out in the same manner as described in Experiment 1. For the nonword data, response latencies and error rates were analyzed with a 2 (prime type: neighbor prime, unrelated prime) × 2 (prime frequency: low, high) factorial ANOVA. Prime type and prime frequency were within-subject factors in the subject analyses; and, in the item analyses, prime type was a within-item factor and prime frequency was a between-item factor. Table 4 lists the mean response latencies and the mean error rates to word targets; the data for the nonword targets is listed in Table 5.

Word targets. There was a significant effect of prime type on response latencies, $F_s(1, 55) = 57.38$, $p < .001$, $MSE = 1{,}027.7$; $F_i(1, 78) = 28.17$, $p < .001$, $MSE = 1{,}554.1$, and on errors, $F_s(1, 55) = 9.71$, $p < .01$, $MSE = 69.9$; $F_i(1, 78) = 5.38$, $p < .05$, $MSE = 90.3$. Responses to targets were slower (581 ms) and less accurate (8.7% errors) when the targets were primed by neighbor primes than when they were primed by unrelated primes (548 ms and 5.2% errors). As expected, there was a main effect of target frequency for both response latencies, $F_s(1, 55) = 125.72$, $p < .001$, $MSE = 1{,}460.3$; $F_i(1, 78) = 64.98$, $p < .001$, $MSE = 2{,}366.1$, and for errors, $F_s(1, 55) = 17.07$, $p < .001$, $MSE = 85.0$; $F_i\ (1, 78) = 10.49$, $p < .01$, $MSE = 98.8$. Responses to high- frequency targets were faster (536 ms) and more accurate (4.4% errors) than responses to low-frequency targets (593 ms and 9.5% errors). Most important was the absence of an interaction between prime type and target frequency in the response latency analysis, $F_s(1, 55) = 3.01$, $p = .09$, $MSE = 1{,}040.8$; $F_i\ (1, 78) = 1.39$, $p > .20$, $MSE = 1{,}554.1$, and in the error analysis (both Fs < 1). (Power analyses of the test of the interaction, conducted in the same manner as in Experiment 1, indicated that power was 97% in the subject analysis of response latencies and 92% in the item analysis of response latencies.) Thus, like the situation in Experiment 1, there was virtually no evidence that inhibition from a neighbor prime was affected by the relative frequency of the prime and target, as higher frequency primes and lower frequency primes produced reasonably good-sized and statistically equivalent inhibitory priming effects.

Nonword targets. For response latencies, there was no effect of prime type (both Fs < 1), no effect of prime frequency, $F_s(1, 55) = 1.59$, $p > .20$, $MSE = 1{,}624.6$; $F_i < 1$, and no interaction, $F_s(1, 55) = 1.08$, $p > .20$, $MSE = 983.2$; $F_i < 1$. In the error analysis, there was no effect of prime type (both Fs < 1), but there

Table 3
Mean Kucera & Francis (1967) Normative Frequency and Neighborhood Size of the Stimuli Used in Experiment 2

Stimulus characteristic	Target	Neighbor prime	Unrelated prime
Higher frequency prime-lower frequency target	*HEAP*	*help*	*area*
Frequency	12.6 (7.7)	507.9 (420.2)	495.3 (435.7)
Number of neighbors	10.3 (3.8)	10.1 (3.9)	9.0 (2.9)
Lower frequency prime-higher frequency target	*HELP*	*heap*	*grin*
Frequency	507.9 (420.2)	12.6 (7.7)	13.3 (7.8)
Number of neighbors	10.1 (3.9)	10.3 (3.8)	9.8 (3.5)
High-frequency prime-nonword target	*NOKE*	*note*	*walk*
Frequency	—	430.5 (539.1)	433.2 (523.8)
Number of neighbors	10.2 (4.2)	10.5 (4.1)	10.4 (3.5)
Low-frequency prime-nonword target	*CHAM*	*clam*	*mute*
Frequency	—	14.7 (9.8)	14.0 (9.1)
Number of neighbors	10.1 (4.4)	9.8 (3.7)	10.0 (3.6)

Note. Standard deviations in parentheses.

Table 4
Mean Lexical Decision Latencies (in milliseconds), Percentage Errors, and Simulation Cycles, for the Word Targets in Experiment 2

	Prime-target frequency					
	High-low			Low-high		
Prime type	RT	Errors	Simulation	RT	Errors	Simulation
Neighbor	613	11.3	263	548	6.1	210
Unrelated	573	7.7	205	523	2.7	196
Difference	−40	−3.6	−58	−25	−3.4	−14

was an effect of prime frequency in the subject analysis, $F_s(1, 55) = 7.50$, $p < .01$, $MSE = 53.60$; F_i (1, 38) = 1.33, $p > .20$, $MSE = 107.7$. Nonwords were responded to more accurately when primed by low-frequency words (5.7% errors) than when primed by high-frequency words (8.4% errors). The interaction was not significant (both Fs < 1).

Discussion

The purpose of Experiment 2 was to determine if we could replicate Segui and Grainger's (1990) results with a different set of stimuli, all of which had large neighborhoods, and in a situation in which the prime's frequency was not predictive of the target's lexicality. As in Experiment 1, the key results were: (a) a significant inhibitory priming effect, and (b) the size of the inhibition effect did not differ as a function of relative prime and target frequency. The former result is a direct replication of Segui and Grainger (1990) in French and, more recently, Davis and Lupker (2006) in English. The latter result replicated our Experiment 1 and was not consistent with Segui and Grainger's results. In Segui and Grainger's original study, there was no inhibition when a high-frequency target was primed by a lower frequency neighbor (in fact, there was a small facilitation effect). These results, like the results of Experiment 1, also conflict with the IA model's prediction of a much larger inhibitory priming effect from higher frequency neighbor primes than from lower frequency neighbor primes (Table 4).

Experiment 3

The results from the first two experiments indicate that higher frequency and lower frequency neighbor primes delay responding to targets to essentially the same degree, results that conflict with the lexical competition assumptions that are currently implemented in the IA model. As noted, these results differed from those of Segui and Grainger (1990), who did not find inhibitory priming from lower frequency neighbors. An obvious question, therefore, is what could explain the discrepancy between the two sets of results.

One possibility is that Segui and Grainger's (1990) stimuli may have differed from our stimuli with respect to neighborhood size. Although Segui and Grainger did not control for, or report, the neighborhood size of their stimuli, it is possible that the words they used mostly had small neighborhoods, whereas, for reasons noted earlier, the words used in both Experiments 1 and 2 had large neighborhoods. In order to optimize the contrast between a higher frequency neighbor prime and a lower frequency target, it is possible that Segui and Grainger selected stimuli from neighborhoods consisting of a single very high frequency neighbor and a small number of lower frequency neighbors. It is also worth noting that French words tend to have fewer neighbors than English words of the same length; for example, according to a French word database (New, Pallier, Brysbaert, & Ferrand, 2004), four-letter French words (which Segui & Grainger used) have an average of 6.4 neighbors, whereas four-letter English words have an average of 9.2 neighbors (according to the complete lexicon created by Balota et al., 2002). If, as hypothesized earlier, small-neighborhood words are easier to facilitate (using nonword primes) and more difficult to inhibit, it is possible that a difference in neighborhood size could go some distance toward explaining why Segui and Grainger did not find any inhibition when higher frequency targets were primed by lower frequency neighbors.

The suggestion that inhibition effects tend to be smaller with small-neighborhood targets could also explain why the inhibition effect for low-frequency primes and high-frequency targets in Davis and Lupker (2006) was smaller than the same effect here, as Davis and Lupker's stimuli had relatively small neighborhoods (M = 2.4 neighbors). Thus, the question of whether inhibitory priming effects do vary as a function of neighborhood size seemed worthy of exploration. Accordingly, in Experiment 3, we manipulated the neighborhood size of our stimuli (many neighbors vs. few neighbors). An additional advantage of this design was that, for the stimuli with many neighbors, we had yet another opportunity to replicate the inhibitory neighbor priming effect with low-frequency primes and high-frequency targets (and, indeed, the absence of a Prime Type × Target Frequency interaction), with a different set of stimuli and a different group of participants.

Method

Participants. Fifty-seven undergraduate students from the University of Calgary volunteered to participate in the experiment

Table 5
Mean Lexical Decision Latencies (RT, in ms) and Percentage Errors for the Nonword Targets in Experiments 2 and 3

	Prime frequency			
	High		Low	
Experiment and prime type	RT	Errors	RT	Errors
Experiment 2				
Neighbor	634	8.2	623	5.5
Unrelated	634	8.6	632	5.9
Difference	0	0.4	9	0.4
Experiment 3				
Nonwords with many neighbors				
Neighbor	631	15.2	648	10.9
Unrelated	640	13.8	659	13.2
Difference	9	−1.4	11	2.3
Nonwords with few neighbors				
Neighbor	614	3.8	625	6.3
Unrelated	619	3.0	622	7.9
Difference	5	−0.8	−3	1.6

for bonus course credit. All participants were native speakers of English and reported normal or corrected-to-normal vision. None of these students participated in the previous experiments.

Stimuli. As in the previous experiments, only words with high lexical decision accuracy rates in the English Lexicon Database (Balota et al., 2002) were selected for use as stimuli (for the high-frequency words the mean accuracy rate was 97.6%; and, for the low-frequency words, it was 96.6%). Eighty pairs of four- and five-letter orthographic neighbors were selected, 40 pairs with many neighbors ($\geq$5, $M = 9.4$) and 40 pairs with few neighbors ($\leq$4, $M = 2.7$). The descriptive statistics for these stimuli are shown in Table 6 (the stimuli are listed in the Appendix).

For the 40 neighbor pairs with many neighbors, the two neighbors differed at the first letter position in 17 of the pairs, the neighbors differed at one of the middle letter positions in 16 of the pairs, and the neighbors differed at the last position in 7 pairs. For the 40 neighbor pairs with few neighbors, the two neighbors differed from one another at the first letter position in 14 of the pairs, the neighbors differed at one of the middle letter positions in 17 of the pairs, and the neighbors differed at the last letter position in 9 of the pairs. Unrelated primes of similar normative frequency and neighborhood size were selected for all of the neighbor pairs.

Eighty nonwords of four or five letters in length were selected, 40 with many neighbors and 40 with few neighbors. Eighty word pairs of matching length and neighborhood size were selected to serve as primes. The primes were either orthographic neighbors of the nonword or orthographically unrelated to the targets. Within each neighborhood-size condition (few neighbors or many neighbors), half of the primes were high-frequency words and the other half were low-frequency words. There were eight counterbalancing lists for word targets and two counterbalancing lists for nonwords. As in the other experiments, all items were presented across participants, but the same item was presented only once to each participant.

Apparatus and procedure. The apparatus and procedure were identical to those in Experiment 1.

Simulations. The simulations were carried out in the same manner as described in Experiment 1. The mean number of cycles (Davis, 2003) and priming effect sizes for the stimuli used in Experiment 3 are listed in Table 7. As can be seen in Table 7, for the words with both large and small neighborhoods, the model again predicts a much larger inhibitory priming effect from higher frequency neighbor primes than from lower frequency neighbor primes. In fact, note that at least for the words with small neighborhoods, the model predicts that there will be no priming effect at all from lower frequency neighbor primes.

Results

To be consistent with the previous experiments, data from participants with overall error rates greater than 20% were excluded from all analyses ($n = 1$), and response latencies less than 300 ms or greater than 1,200 ms were treated as outliers and were removed from all analyses (0.5% of the word trials, 0.9% of the nonword trials). For the word data, response latencies of correct responses and error rates were submitted to a 2 (prime type: neighbor prime, unrelated prime) $\times$ 2 (target frequency: low, high) $\times$ 2 (neighborhood size: large, small) factorial ANOVA. In

Table 6
Mean Kucera & Francis (1967) Normative Frequency and Neighborhood Size of the Stimuli Used in Experiment 3

Stimulus characteristic	Target	Neighbor prime	Unrelated prime
Targets with many neighbors			
Higher frequency prime-lower frequency target	*HEAP*	*help*	*area*
Frequency	19.6 (13.2)	347.6 (317.1)	353.3 (348.0)
Number of neighbors	9.6 (4.1)	9.2 (3.9)	9.3 (3.9)
Lower frequency prime-higher frequency target	*HELP*	*heap*	*grin*
Frequency	347.6 (317.1)	19.6 (13.2)	20.3 (13.8)
Number of neighbors	9.2 (3.9)	9.6 (4.1)	9.2 (3.9)
High-frequency prime-nonword target	*JAME*	*name*	*form*
Frequency	—	237.7 (172.3)	244.2 (212.0)
Number of neighbors	8.5 (2.9)	9.6 (2.6)	8.8 (2.9)
Low-frequency prime-nonword target	*BOTE*	*bone*	*weak*
Frequency	—	19.7 (9.0)	19.3 (9.2)
Number of neighbors	9.7 (3.1)	10.0 (2.7)	10.2 (3.8)
Target with few neighbors			
Higher frequency prime-lower frequency target	*OMEN*	*open*	*girl*
Frequency	21.1 (22.1)	356.8 (373.8)	348.3 (365.0)
Number of neighbors	2.9 (1.1)	2.4 (1.2)	2.6 (1.1)
Lower frequency prime-higher frequency target	*OPEN*	*omen*	*wrap*
Frequency	356.8 (373.8)	21.1 (22.1)	20.6 (19.2)
Number of neighbors	2.4 (1.2)	2.9 (1.1)	2.6 (1.0)
High frequency prime-nonword target	*BLUG*	*blue*	*rich*
Frequency	—	280.9 (209.5)	284.5 (258.1)
Number of neighbors	2.6 (1.4)	2.7 (1.3)	2.2 (1.4)
Low frequency prime-nonword target	*MOOST*	*moist*	*vapor*
Frequency	—	21.8 (12.7)	22.2 (12.5)
Number of neighbors	2.8 (1.2)	2.4 (1.1)	2.1 (1.2)

Note. Standard deviations in parentheses.

Table 7
Mean Lexical Decision Latencies (RT, in ms), Percentage Errors, and Simulation Cycles for Word Targets as a Function of Neighborhood Size in Experiment 3

	Prime-target frequency					
	High-low			Low-high		
Prime type	RT	Errors	Simulation	RT	Errors	Simulation
Words with many neighbors						
Neighbor	585	11.6	224	549	7.0	197
Unrelated	558	6.3	195	517	2.5	188
Difference	−27	−5.3	−29	−32	−4.5	−9
Words with few neighbors						
Neighbor	598	16.3	216	529	6.4	186
Unrelated	580	7.1	196	529	5.4	186
Difference	−18	−9.2	−20	0	−1.0	0

the subject analysis, all factors were within-subject factors; and, in the item analysis, target frequency and neighborhood size were between-item factors and prime type was a within-item factor. For the nonword data, response latencies and error rates were analyzed with a 2 (prime type: neighbor prime, unrelated prime) × 2 (prime frequency: low, high) × 2 (neighborhood size: large, small) factorial ANOVA. In the subject analysis, all factors were within-subject factors; and, in the item analyses, prime type was a within-item factor and prime frequency and neighborhood size were between-item factors. The mean response latencies of correct responses and the mean error rates for the word targets are listed in Table 7; the data for the nonword targets are listed in Table 5.

Word targets. The main effect of prime type was significant both for response latencies, $F_s(1, 55) = 16.48$, $p < .001$, $MSE = 2{,}440.6$; $F_i(1, 156) = 31.29$, $p < .001$, $MSE = 1{,}472.3$, and for errors, $F_s(1, 55) = 27.62$, $p < .001$, $MSE = 101.4$; $F_i(1, 156) = 29.13$, $p < .001$, $MSE = 68.7$. Overall, responses to targets were slower (565 ms) and more error prone (10.3% errors) when targets were primed by neighbor primes than when they were primed by unrelated primes (546 ms and 5.3% errors). The main effect of target frequency was significant for response latencies, $F_s(1, 55) = 143.21$, $p < .001$, $MSE = 1{,}903.4$; $F_i(1, 156) = 42.81$, $p < .001$, $MSE = 5{,}186.6$, and for errors, $F_s(1, 55) = 33.66$, $p < .001$, $MSE = 83.2$; $F_i(1, 156) = 10.46$, $p < .01$, $MSE = 191.3$. As expected, responses to high-frequency targets were faster (531 ms) and more accurate (5.3% errors) than responses to low-frequency targets (580 ms and 10.3% errors). There was also a main effect of neighborhood size in the subject analyses, both for response latencies, $F_s(1, 55) = 4.07$, $p < .05$, $MSE = 1{,}335.2$; $F_i(1, 156) = 1.36$, $p > .20$, $MSE = 5{,}186.6$, and for errors, $F_s(1, 55) = 5.07$, $p < .05$, $MSE = 85.3$; $F_i(1, 156) = 1.61$, $p > .20$, $MSE = 191.3$. Consistent with previous research (e.g., Andrews, 1997), there was a neighborhood-size effect: Target words with many neighbors were responded to more quickly (552 ms) and more accurately (6.9% errors) than target words with few neighbors (559 ms and 8.8% errors).

Also consistent with previous research was the interaction between target frequency and neighborhood size in the subject analysis of response latencies, $F_s(1, 55) = 7.91$, $p < .01$, $MSE = 1{,}651.3$; $F_i(1, 156) = 1.70$, $p > .10$, $MSE = 5{,}186.6$, with a neighborhood-size effect for the low-frequency target words only. There were two other two-way interactions, one in the response latency analysis between prime type and neighborhood size, $F_s(1, 55) = 9.06$, $p < .01$, $MSE = 1{,}297.9$; $F_i(1, 156) = 4.11$, $p < .05$, $MSE = 1{,}472.3$, and the other in the error analysis between prime type and target frequency, $F_s(1, 55) = 8.61$, $p < .01$, $MSE = 64.9$; $F_i(1, 156) = 5.80$, $p < .05$, $MSE = 68.7$. Most important was the significant three-way interaction between prime type, target frequency, and neighborhood size, both for response latencies $F_s(1, 55) = 5.86$, $p < .05$, $MSE = 603.5$, and for errors, $F_s(1, 55) = 4.50$, $p < .05$, $MSE = 79.4$, although these were not statistically significant in the item analyses, $F_i(1, 156) = 2.56$ $p = .11$, $MSE = 1{,}472.3$, and $F_i(1, 156) = 3.71$, $p = .06$, $MSE = 68.7$, respectively.

The three-way interactions were followed up by analyzing the data for the words with many neighbors and the words with few neighbors separately (Prime Type × Target Frequency interaction contrasts). For the words with many neighbors, there was no interaction between prime type and target frequency for response latencies or for errors (all Fs < 1). There was a 27-ms inhibition effect for low-frequency neighbor targets and a 32-ms inhibition effect for high-frequency neighbor targets, both of which were statistically significant, $t_s(55) = 3.76$, $p < .001$, $SEM = 7.2$, $t_i(39) = 4.11$, $p < .001$, $SEM = 7.4$ and $t_s(55) = 4.54$, $p < .001$, $SEM = 6.9$, $t_i(39) = 4.67$, $p < .001$, $SEM = 7.5$, respectively. The differences in error rates were consistent with the response latencies and were also statistically significant (all ps $< .01$). These results mirror those of Experiments 1 and 2, where the words also had many neighbors, in that there was no hint of an interaction between prime type and target frequency (i.e., there were virtually identical priming effects from high- and low-frequency neighbor primes).

For the words with few neighbors, on the other hand, a different pattern emerged. There was evidence of a Prime Type × Target Frequency interaction, both for response latencies, $F_s(1, 55) = 3.70$, $p = .06$, $MSE = 1{,}224.7$; $F_i(1, 78) = 2.85$, $p = .10$, $MSE = 1{,}835.5$, and for errors, $F_s(1, 55) = 9.62$, $p < .01$, $MSE = 94.0$; $F_i(1, 78) = 7.80$, $p < .01$, $MSE = 82.8$. As can be seen in Table 7, only the higher frequency neighbor primes produced inhibition (598 ms vs. 580 ms), the response latencies to targets primed by lower frequency neighbor primes and by unrelated primes being identical (529 ms). The 18-ms inhibition effect produced by a higher frequency neighbor prime was significant $t_s(55) = 2.13$,

$p < .05$, $SEM = 8.3$; $t_i(39) = 2.47$, $p < .05$, $SEM = 10.8$, as was the 9.1% difference in errors, $t_s(55) = 3.72$, $p < .001$, $SEM = 2.4$; $t_i(39) = 3.69$, $p < .001$, $SEM = 2.5$ (the 1.0% difference in errors for the lower frequency primes was not significant; both $ps > .10$). Thus, the three-way interaction between prime type, target frequency, and neighborhood size in the overall analysis was because both lower frequency and higher frequency neighbor primes produced inhibition when the target words had many neighbors (as was the case in Experiments 1 and 2), whereas only higher frequency neighbor primes produced inhibition when the target words had few neighbors. This latter result is consistent with Grainger and Segui's (1990) results (as well as the simulations reported in Table 7), and supports our conjecture that the neighborhood size of the stimuli may be an important determinant of the inhibitory neighbor-priming effect.

Nonword targets. In the analysis of response latencies, there was a main effect of prime frequency in the subject analysis, $F_s(1, 55) = 9.62$, $p < .01$, $MSE = 1{,}790.3$; $F_i(1, 76) = 2.40$, $p > .10$, $MSE = 2{,}266.4$. Responses to the nonword targets were slightly faster when they were primed by high-frequency words than when they were primed by low-frequency words (626 ms vs. 639 ms). There was also an effect of neighborhood size, both for response latencies, $F_s(1, 55) = 39.83$, $p < .001$, $MSE = 1{,}674.9$; $F_i(1, 76) = 9.86$, $p < .01$, $MSE = 2{,}266.4$, and for errors, $F_s(1, 55) = 62.71$, $p < .001$, $MSE = 115.3$; $F_i(1, 76) = 16.64$, $p < .001$, $MSE = 155.3$. Consistent with previous research (Andrews, 1997), responses to nonwords with many neighbors were slower (645 ms) and more error prone (13.3% errors) than responses to nonwords with few neighbors (620 ms and 5.3% errors). The only interaction was in the analysis of errors rates, where the Prime Frequency × Neighborhood Size interaction was significant in the subject analysis, $F_s(1, 55) = 12.78$, $p < .01$, $MSE = 80.8$; $F_i(1, 76) = 2.37$, $p = .13$, $MSE = 155.3$. For the nonwords with few neighbors (but not for the nonwords with many neighbors) there was an effect of prime frequency, $F_s(1, 55) = 14.61$, $p < .001$, $MSE = 51.4$; $F_i(1, 76) = 9.57$, $p < .01$, $MSE = 28.0$, with nonword targets responded to more accurately when primed by high-frequency words (3.4% errors) than when primed by low-frequency words (7.1% errors).

Discussion

In Experiment 3, we manipulated the neighborhood size of the stimuli to test the hypothesis that the pattern of priming effects for low-frequency primes and high-frequency targets depends on the neighborhood size of the primes. The results of this experiment are consistent with this possibility: When the words had many neighbors, both higher frequency and lower frequency neighbor primes produced essentially equivalent inhibition (replicating again the results of Experiments 1 and 2); but, when the words had few neighbors, only higher frequency neighbor primes produced inhibition. This outcome is not readily predicted by the IA model. As shown in Table 7, for both large- and small-neighborhood targets, more inhibition was expected for the high-frequency-prime–low-frequency-target pairs than for the low-frequency-prime–high-frequency-target pairs. The finding that neighborhood size matters for low-frequency-prime–high-frequency-target pairs raises the inevitable question of what component of the neighborhood is responsible for the observed difference. This is the question we consider in Experiment 4.

Experiment 4

In neighbor priming situations, one can define three types of neighbors. Considering, for example, the prime–target pair, *help-HEAP;* some words are neighbors only of the prime (e.g., *held*), others are neighbors only of the target (e.g., *heal*), and some are neighbors of both (e.g., *hemp*). This last type of neighbor is referred to as a shared neighbor (Davis, 2003; Grainger & Jacobs, 1999). Whereas the prime-only neighbor (*held*) or target only neighbor (*heal*) are activated upon prime presentation or target presentation, respectively, a shared neighbor receives activation twice, at the time of prime presentation and at the time of target presentation. Therefore, shared neighbors may be especially competitive in the priming paradigm (see Davis, 2003, for a detailed discussion). Because stimuli with many neighbors are also more likely to have shared neighbors than stimuli with few neighbors, the inhibition effect from lower frequency neighbor primes with many neighbors could be essentially a shared-neighbor effect. Consistent with this interpretation, an examination of the words used in Experiment 3 revealed that for the pairs with many neighbors, almost all of the neighbor pairs had at least one shared neighbor (37 out of 40 pairs had at least one shared neighbor, with a mean of 3.6 shared neighbors), whereas for the pairs with few neighbors, fewer than a third of the words had a shared neighbor (14 out of 40 pairs had at least one shared neighbor, with a mean of 1.4 shared neighbors).

A number of results in the literature are also consistent with this interpretation. For example, Davis and Lupker (2006, Experiment 2) found that higher frequency primes and lower frequency targets with no shared neighbors showed much less evidence of inhibition than higher frequency primes and lower frequency targets with one shared neighbor (although see Mathey, Robert, & Zagar, 2004, for a different result). The argument has also been made that the reason there is no facilitation effect from nonword neighbor primes when targets have many neighbors (Davis, 2003; Forster, Mohan, & Hector, 2003) is the lexical inhibition from shared neighbors. The logic is that the lexical inhibition produced by these shared neighbors offsets whatever facilitation effect is produced by nonword neighbor primes, resulting in an overall null effect. Similarly, an experiment by van Heuven, Dijkstra, Grainger, and Schriefers (2001) lends support to the idea of a strong inhibitory role of shared neighbors. Van Heuven et al. manipulated the shared-neighbor status of nonword prime and word target pairs (the word targets had a mean of 4.1 neighbors). They found that, when a prime and target had a shared neighbor, the facilitatory effect on target identification was significantly smaller (12 ms) than when the prime and target did not have a shared neighbor (28 ms). These results all suggest that shared neighbors play a role in the lexical activation process and support the possibility that the inhibition from lower frequency neighbor primes in the present experiments was due to the existence of shared neighbors rather than neighborhood size per se.

In Experiment 4 we tested this shared-neighbor hypothesis directly. In Experiment 4, all the primes were lower in frequency than the targets. There were three basic conditions. In the shared-neighbor condition, the primes shared at least one neighbor with the higher frequency target (e.g., *barn-BORN*, with the highest frequency shared neighbor being *burn*). In the no-shared-neighbor condition the primes did not share any neighbors with the target

Table 8
Mean Kucera & Francis (1967) Normative Frequency and Neighborhood Size of the Stimuli Used in Experiment 4A

Stimulus characteristic	Target	Neighbor prime		Unrelated prime
		With shared neighbor	Without shared neighbor	
Lower frequency primes-higher frequency targets	*SHORT*	*shoot*	*shirt*	*crash*
Frequency	413.6 (523.3)	17.9 (15.5)	18.9 (19.6)	17.3 (12.9)
Number of neighbors	11.1 (4.0)	10.1 (3.5)	10.5 (4.0)	10.3 (3.3)
Low frequency primes-nonword targets	*BLINT*		*blink*	*tunes*
Frequency	—		17.3 (12.2)	18.7 (11.7)
Number of neighbors	9.4 (3.8)		10.2 (4.0)	10.1 (4.2)

Note. Standard deviations in parentheses. Shared-neighbor status (prime-target pairs with or without a shared neighbor) was not a factor for nonword trials.

(e.g., *bore- BORN*), or, in a few instances, shared a single neighbor of very low normative frequency (e.g., for the neighbor pair *lend-LEAD*, *lewd* was a shared neighbor). In the unrelated condition, the primes were not orthographically related to the targets (e.g., *gang-BORN*). If the shared-neighbor hypothesis is correct, then lower frequency neighbor primes should produce inhibition only when these primes share neighbors with the higher frequency targets. Because Experiment 3 demonstrated that the neighborhood size of the primes and targets is important, neighborhood size was controlled in Experiment 4: In Experiment 4A the primes and targets had many neighbors and in Experiment 4B the primes and targets had few neighbors.

Method

Participants. Eighty-five University of Calgary undergraduate students volunteered to participate in the experiment for bonus course credit. Forty-two participated in Experiment 4A and 43 participated in Experiment 4B. All participants were native speakers of English and reported having normal or corrected-to-normal vision. None participated in more than one of these experiments.

Stimuli. For Experiment 4A, the critical stimuli were 42 high-frequency words (M = 413.6 occurrences per million) with many neighbors (M = 11.1) that served as targets. These were selected after consulting the English Lexicon Project database (Balota et al., 2002) to be sure that the words had high lexical decision accuracy rates (the mean accuracy rate was 97.2%). For each participant, each target (e.g., *MIND*) was primed by one of the three prime types, (a) primes that were orthographic neighbors of the target and shared at least one neighbor with the target (e.g., *mint*, *mine* being the shared neighbor), with a mean of 3.2 shared neighbors (the mean normative frequency of the highest frequency shared neighbor was 169.3 occurrences per million; the mean lexical decision accuracy rate to the highest frequency shared neighbor was 96.9%), (b) primes that were orthographic neighbors of the target but shared no neighbors with the target (e.g., *mild*) or shared a single neighbor of very low normative frequency (M = 2.4 occurrences per million; the mean number of shared neighbors was 0.26; the mean lexical decision accuracy rate to these shared neighbors was 49.1%), and (c) unrelated primes that were not orthographically similar to the targets (e.g., *dusk*).[4] The mean lexical decision accuracy rates (Balota et al., 2002) for these primes were 96.5%, 95.7%, and 96.6%, respectively. The three prime types were matched as closely as possible on normative word frequency (M = 18.0 occurrences per million) and the number of neighbors (M = 10.3). The descriptive statistics for these stimuli are shown in Table 8 (the stimuli are listed in the Appendix). To make the proportion of neighbor pairs and unrelated pairs equal, an additional 14 unrelated prime–target fillers of similar lexical characteristics were also presented. Fifty-six nonwords of four and five letters in length, all with many neighbors (M = 9.4) were also selected. Fifty-six word pairs of matching length and neighborhood size were selected to serve as primes for these nonwords. The primes were either an orthographic neighbor of the nonword or an orthographically unrelated word. All of the primes were low-frequency words (M = 18.0 occurrences per million). Unlike the word targets, shared-neighbor status was not manipulated for the nonword targets.

As noted, all of the critical word targets were of very high normative frequency (M = 413.6 occurrences per million) and would therefore be easy to distinguish from nonwords in a lexical decision task. To create a situation equivalent to the previous experiments, where both high- and low-frequency targets were shown in the lexical decision task, an additional 56 word targets with low normative frequencies (M = 11.9 occurrences per million) were shown to participants. All of these filler targets had many orthographic neighbors (M = 9.9) and were primed by orthographically related or orthographically unrelated words with similar normative frequencies. To maintain a 50/50 ratio of word to nonword targets, an additional 56 nonwords were also added to the stimulus set. All of the nonword fillers were primed by low-frequency words (M = 12.5 occurrences per million) with many neighbors (M = 10.1), half of them primed by orthographic neighbors and the other half primed by orthographically unrelated words. There were six counterbalancing lists for word targets and two counterbalancing lists for nonwords. All items were presented across participants, but the same item was presented only once to each participant. The same filler items were presented to all participants (the filler stimuli are available from the authors).

[4] It is important to note that because we wanted to maximize the relative prime–target frequency, the mean word frequency of the shared neighbors was always lower than that of targets, which was always the case in Experiment 3 as well. Therefore, whether there is an inhibitory effect of shared neighbors when one of those neighbors is higher in frequency than the target (or of equivalent frequency) was not tested. This may be an important issue for future research; however, for present purposes (i.e., providing a closer examination of the results of Experiment 3) such a manipulation was not relevant.

For Experiment 4B, it was not possible to use a within-item design, because when using words with few neighbors it is very difficult to find words that have two neighbors of equivalent normative frequency, one with a shared neighbor and the other without a shared neighbor. As a result, for Experiment 4B, unlike Experiment 4A, we could not use the same targets for the shared-neighbor condition and the nonshared-neighbor condition; separate sets of prime and target pairs were created; in one set, the pairs had a shared neighbor (e.g., *trail-TRAIN*, *trait* being the shared neighbor), and, in the other set, the pairs had no shared neighbor (e.g., *vague-VALUE*).

For Experiment 4B, the critical stimuli were two sets of 30 orthographic neighbor pairs, one member of the pair being of high normative frequency (M = 219.1 occurrences per million) and the other of low normative frequency (M = 14.9 occurrences per million). All of the words had few neighbors, with a mean of 3.5 neighbors. All of the words had high lexical decision accuracy rates (97.9% for the high-frequency words and 96.6% for the low-frequency words; Balota et al., 2002). For one set of these neighbor pairs, the primes and targets had at least one shared neighbor (M = 1.4; the mean normative frequency of the highest frequency shared neighbor was 75.4 occurrences per million; the mean lexical decision accuracy rate for these words was 97.3%,); and, for the second set, the primes and targets had no shared neighbors or a single shared neighbor of very low normative frequency (M = 1 occurrence per million; the mean number of shared neighbors was 0.1; the mean lexical decision accuracy rate for these shared neighbors was 42.0%). For each neighbor prime, an unrelated prime of the same length and with a similar normative frequency and neighborhood size was selected (e.g., *foggy-TRAIN; charm-VALUE*). The descriptive statistics for the stimuli are shown in Table 9 (the stimuli are listed in the Appendix).

An additional 60 word targets of low normative frequencies (M = 14.5 occurrences per million) were added to the stimulus set so that participants saw a mixture of high- and low-frequency words, as they did in our other experiments. Half of these low-frequency filler words were primed by their neighbors and the other half were primed by orthographically unrelated words.

Davis and Lupker (2006) reported that the inhibitory neighbor priming effect on word targets was stronger when the nonwords had many neighbors than when they had few neighbors. To capitalize on any potential effect here, we also included nonwords with many neighbors along with nonwords with few neighbors. Using nonwords with many neighbors also made the difficulty of the lexical decision more comparable to that in Experiment 4A, where all the nonwords had large neighborhoods. Two sets of 30 nonwords with similar characteristics were selected. One set of nonwords had many neighbors (M =10.0) and the other set had few neighbors (M = 3.1). All the nonwords were primed by words that were matched in length and neighborhood size and were either orthographic neighbors of the nonwords or unrelated words. The primes preceding nonword targets were all low in normative frequency (M = 15.1 occurrences per million). To maintain an equal number of word and nonword items, an additional 60 nonwords were added to the stimulus set, half of them with many neighbors (M = 9.3) and the other half with few neighbors (M = 3.1). All of these filler nonwords were primed by low-frequency words (M = 14.2 occurrences per million), with half primed by their orthographic neighbors and the other half primed by unrelated words. There were two counterbalancing lists for word targets and two counterbalancing lists for nonwords. All items were presented across participants, but the same item was presented only once to each participant. The same filler items were presented to all participants (the filler stimuli are available from the authors).

Apparatus and procedure. The apparatus and procedure were identical to those used in the preceding experiments.

Results

Experiment 4A: Words with Many Neighbors

To be consistent with the previous experiments, response latencies less than 300 ms or greater than 1,200 ms were treated as outliers and were removed from all analyses (0.9% of the word trials, 2.1% of the nonword trials). For the word data, prime type was the single factor and had three conditions: neighbor primes with shared neighbors, neighbor primes with no shared neighbors, and orthographically unrelated primes. Prime type was a within-subject factor in the subject analysis and a within-item factor in the item analysis. For the nonword data, prime type (neighbor prime, unrelated prime) was the single factor and was a within-subject factor in the subject analysis and a within-item factor in the item

Table 9
Mean Kucera & Francis (1967) Normative Frequency and Neighborhood Size of the Stimuli Used in Experiment 4B

Stimulus characteristic	Target	Neighbor prime	Unrelated prime
Lower frequency prime-higher frequency target with shared neighbor	*SMALL*	*stall*	*dairy*
Frequency	214.7 (187.1)	15.8 (18.8)	14.2 (17.4)
Number of neighbors	3.5 (1.1)	4.4 (1.2)	3.9 (1.3)
Lower frequency prime-higher frequency target without shared neighbor	*LEAVE*	*lease*	*fancy*
Frequency	223.5 (197.5)	14.0 (11.4)	15.0 (11.8)
Number of neighbors	2.8 (1.0)	3.4 (1.5)	3.5 (1.2)
Low-frequency prime-nonword target (many neighbors)	*SHASE*	*shake*	*candy*
Frequency	—	14.8 (9.1)	15.2 (10.2)
Number of neighbors	10.0 (2.9)	9.7 (2.2)	9.9 (3.1)
Low-frequency prime-nonword target (few neighbors)	*RANEL*	*panel*	*split*
Frequency	—	15.0 (12.5)	15.2 (12.5)
Number of neighbors	3.1 (1.4)	3.3 (1.6)	2.9 (1.7)

Note. Standard deviations in parentheses. Shared-neighbor status (prime-target pairs with or without a shared neighbor) was not a factor for nonword trials.

analysis. The mean responses latencies of correct responses and the mean error rates are listed in Table 10.

Word targets. The effect of prime type was significant in the analysis of response latencies, $F_s(2, 82) = 5.31$, $p < .01$, $MSE = 1{,}132.3$; $F_i(2, 82) = 3.44$, $p < .05$, $MSE = 2{,}015.5$. Responses to targets were 21 ms slower when primed by neighbor primes with shared neighbors than when primed by unrelated primes, $t_s(41) = 2.71$, $p < .05$, $SEM = 7.8$; $t_i(41) = 2.48$, $p < .05$, $SEM = 8.8$. The same was true when the targets were primed by neighbor primes without shared neighbors—responses to these targets were 21 ms slower than responses to targets primed by unrelated primes, $t_s(41) = 3.08$, $p < .05$, $SEM = 6.6$; $t_i(41) = 2.13$, $p < .05$, $SEM = 10.7$. Thus, like the situation in Experiments 1, 2, and 3 (where the primes and targets also had many neighbors), lower frequency neighbor primes produced inhibitory priming effects. There was no evidence, however, that the inhibition effect from lower frequency neighbor primes was contingent upon the primes and targets sharing neighbors, as the priming effects were nearly identical when the primes and targets shared a neighbor and when they did not. Error rates were consistent with the response latencies, although there was no effect of prime type on errors (both *F*s < 1). (Power was 99% in the subject analysis of response latencies and 98% in the item analysis of response latencies.)

Nonword targets. The nonword data are listed in Table 11. There was no effect of prime type in the response latency analysis or in the error analysis (all *F*s < 1).

Experiment 4B: Words with Few Neighbors

As was done in the previous experiments, the data from participants with overall error rates greater than 20% were excluded ($n = 3$) and response latencies less than 300 ms or greater than 1,200 ms were removed from all analyses (0.9% of the word trials; 2.0% of the nonword trials). For the word data, response latencies of correct responses and error rates were analyzed by comparing responses to targets primed by neighbor primes with shared neighbors to their corresponding orthographically unrelated primes and by comparing responses to targets primed by neighbor primes without shared neighbors to their corresponding orthographically unrelated primes. The nonword data were analyzed by a 2 (prime type: neighbor prime, unrelated prime) × 2 (neighborhood size: large, small) ANOVA. Both factors were within-subject factors in the subject analysis; in the item analysis, prime type was a within-item factor and neighborhood size was a between-item factor. The mean responses latencies of correct responses and the mean error rates are listed in Table 10.

Table 10
Mean Lexical Decision Latencies (RT, in ms) and Percentage Errors for the Word Targets in Experiments 4A and 4B

Experiment and prime type	Primes with shared neighbors		Primes without shared neighbors	
Experiment 4A	RT	Errors	RT	Errors
Neighbor	568	3.1	568	3.4
Unrelated	547	2.9	547	2.9
Difference	−21	−0.2	−21	−0.5
Experiment 4B	RT	Errors	RT	Errors
Neighbor	575	6.3	556	4.0
Unrelated	572	3.3	550	1.7
Difference	−3	−3.0	−6	−2.3

Note. Priming effects in Experiment 4A were calculated using the same unrelated trials as shared-neighbor status was a within-item manipulation. Priming effects in Experiment 4B were calculated using different unrelated trials as shared-neighbor status was a between-item manipulation.

Table 11
Mean Lexical Decision Latencies (RT, in ms) and Percentage Errors for the Nonword Targets in Experiments 4A and 4B

Experiment and prime type	RT	Errors
Experiment 4A		
Neighbor	664	6.6
Unrelated	668	6.2
Difference	4	−0.4
Experiment 4B		
Nonwords with many neighbors		
Neighbor	682	10.3
Unrelated	687	10.2
Difference	5	−0.1
Nonwords with few neighbors		
Neighbor	663	7.8
Unrelated	645	5.2
Difference	−18	−2.6

Word targets. For the prime and target pairs with shared neighbors, there was no effect of prime type in the analysis of response latencies (both *F*s < 1), but there was an effect for errors in the subject analysis, $F_s(1, 39) = 6.33$, $p < .05$, $MSE = 28.44$; $F_i(1, 29) = 3.36$, $p = .08$, $MSE = 40.17$. Participants made more errors to targets when they were primed by neighbors (6.3%) than when they were primed by unrelated words (3.3%). Similarly, for the prime and target pairs without shared neighbors, there was no effect of prime type in the analysis of response latencies, $F_s(1, 39) = 1.76$, $p > .10$, $MSE = 506.05$; $F_i < 1$, but there was an effect in the analysis of errors, $F_s(1, 39) = 7.05$, $p < .05$, $MSE = 15.44$; $F_i(1, 29) = 5.06$, $p < .05$, $MSE = 16.15$. Again, error rates were slightly higher when a target was primed by a neighbor (4.0%) than when a target was primed by an orthographically unrelated word (1.7%).

In terms of response latencies, these results replicate the basic finding of Experiment 3: When the primes and targets have small neighborhoods, lower frequency primes do not produce inhibitory priming. On the other hand, unlike the situation in Experiment 3, the error data do suggest that there was some inhibitory neighbor priming, as neighbor primes led to slightly higher error rates than unrelated primes (a difference of 2.3%). Of course, because error rates were so low (averaging less than 5%), the variance estimates in the denominator of the *F* ratios are severely restricted due to a floor effect. Thus, one should be very cautious when interpreting this difference. The more important result was the lack of any evidence that the inhibition effect on error rates from lower frequency neighbor primes was contingent upon the primes and targets sharing neighbors. Neighbor primes led to slightly higher error rates than unrelated primes, but this was true regardless of whether the primes and target shared neighbors.

Nonword targets. The nonword data are listed in Table 11. There was no effect of prime type in the analysis of response latencies, $F_s(1, 39) = 1.97$, $p > .15$, $MSE = 860.2$; $F_i(1, 58) = 1.67$, $p > .20$, $MSE = 1{,}154.7$, or in the analysis of errors, $F_s(1, 39) = 2.40$, $p > .10$, $MSE = 33.5$; $F_i(1, 58) = 1.19$, $p > .25$, $MSE = 50.5$. The effect of neighborhood size was significant for response latencies, $F_s(1, 39) = 27.1$, $p < .001$, $MSE = 1{,}352.5$; $F_i(1, 58) = 6.51$, $p < .05$, $MSE = 2{,}736.6$, as well as for errors, $F_s(1, 39) = 12.16$, $p < .01$, $MSE = 46.3$; $F_i(1, 58) = 2.31$, $p = .13$, $MSE = 182.7$. Consistent with the previous literature (e.g., Andrews, 1997) and also with the results of Experiment 3, nonwords with many neighbors were responded to more slowly (685 ms) and with more errors (10.3%) than nonwords with few neighbors (654 ms and 6.5%). There was no interaction between prime type and neighborhood size in the analysis of response latencies or in the analysis of errors, $F_s(1, 39) = 2.95$, $p = .09$, $MSE = 1{,}837.4$; $F_i(1, 58) = 2.85$, $p = .10$, $MSE = 1{,}154.7$, and $F_s < 1$; $F_i < 1$, respectively.

Discussion

In this experiment we tested whether the inhibition effect from lower frequency neighbor primes observed in the previous experiments is a shared-neighbor effect. In Experiments 4A and 4B the primes were always lower in frequency than the targets, with the primes and targets in Experiment 4A having many neighbors and the primes and targets in Experiment 4B having few neighbors. In both experiments, the targets were primed by orthographic neighbors that had at least one shared neighbor with the target, orthographic neighbors that did not have a shared neighbor with the target, or unrelated words. Although both experiments replicated the basic effects observed in the previous experiments—there was a significant inhibition effect from lower frequency neighbor primes for the words with many neighbors but little evidence of one for the words with few neighbors—there was no indication that this inhibition effect was modulated by shared neighbors. Our results therefore suggest that (a) having a (low-frequency) shared neighbor does not increase the competition produced by a lower frequency neighbor prime and (b) the inhibition effects from lower frequency neighbors in the preceding experiments were not due simply to the activation of shared neighbors, but rather to the impact of activating large sets of neighbors.

General Discussion

One goal of the present research was to establish whether inhibitory neighbor priming (Segui & Grainger, 1990) is reliably observed in English. Considered together, the results were quite clear—in all of our experiments, we found that orthographic neighbor primes delayed target identification. In Experiments 1 and 2, only words with many neighbors were tested; and, in Experiment 3, both words with many neighbors and words with few neighbors were tested. In Experiment 1, target identification was significantly delayed by neighbor primes, and the effect was observed irrespective of relative prime–target frequency (with a 24-ms inhibition effect from higher frequency neighbor primes and a 21-ms inhibition effect from lower frequency neighbor primes). These results suggested that, for words with many neighbors, the relative frequency of the prime and the target is not crucial in the lexical competition process.

Experiment 2 replicated the main results of Experiment 1 with a different group of participants and a different set of stimuli. Although the size of the inhibition effect from higher frequency neighbor primes (40 ms) was numerically larger than the effect from lower frequency neighbor primes (25 ms), even with a relatively large number of participants ($N = 56$) this difference never approached statistical significance. Thus, there was no reason to believe that the priming effect from higher frequency neighbor primes was meaningfully different than the priming effect from lower frequency neighbor primes. The validity of this conclusion was reinforced by the results of Experiment 3. In Experiment 3 we again replicated the pattern of inhibition observed in the first two experiments using words with many neighbors. That is, for these words, there were equivalent inhibition effects from higher frequency neighbor primes (27 ms) and from lower frequency neighbor primes (32 ms). On the other hand, for the words with few neighbors, only higher frequency neighbor primes delayed target identification (by 18 ms).

All in all, these findings provide partial support for one of the fundamental assumptions of the activation-based models that incorporate lexical competition: that orthographic neighbors compete during target processing, delaying target identification (e.g., Davis, 2003; Davis & Lupker, 2006; Grainger & Ferrand, 1994; Segui & Grainger, 1990). That is, the results of the present study indicate that, as in other alphabetical languages—such as French, German, and Dutch—lexical competition does play a role in the word identification process in English. Our results, however, do challenge one of the key assumptions of the activation-based models, namely, that how effectively and strongly a neighbor prime inhibits target identification depends on the frequency relationship between the prime and the target. According to the models, inhibition from neighbors should be much stronger when the primes are higher in frequency than the targets. In addition, as shown in Table 7, this effect should be observed irrespective of the neighborhood sizes of the stimuli. That is, the model predicts essentially the same pattern of inhibition effects for words with many neighbors as for words with few neighbors (see also Davis, 2003). In contrast, the data show that this pattern only emerges for small-neighborhood targets.

The interaction between prime relatedness, relative prime–target frequency, and neighborhood size that we observed in Experiment 3 clearly is inconsistent with the predictions of the IA model. The obvious question, then, is what factor or factors give rise to this interaction? One possibility that was tested in Experiment 4 was that it was due to the impact of shared neighbors. Because primes and targets with many neighbors are more likely to have shared neighbors than primes and targets with few neighbors, an inhibition effect from lower frequency neighbors for words with many neighbors may have been due to the stronger lexical competition caused by the shared neighbors.

Experiment 4 was designed to directly test this shared-neighbor hypothesis. In one condition the related prime–target pairs had at least one shared neighbor and in the other condition they had none. The test of this hypothesis produced an unequivocal result: There was no effect of shared neighbors on the size of the inhibition effect. For the words with many neighbors (Experiment 4A), there were significant and equivalent inhibition effects from lower frequency neighbors whether the prime and target had a shared neighbor or not (the basic inhibition effect replicating the results of

Experiments 1 and 2). Similarly, there was no effect of shared neighbors for words with few neighbors (Experiment 4B). For the words with few neighbors, lower frequency primes did not delay response latencies to targets for either shared-neighbor or no-shared-neighbor pairs (the lack of an overall inhibition effect on response latencies replicating the results of Experiment 3). There was a small inhibition effect in the error data suggesting that inhibitory processes were at work even for these pairs; however, these data also indicate there was no differential effect of shared neighbors on this inhibition effect. Based on the results of Experiment 4, we therefore ruled out the possibility that the key result of Experiment 3 was a shared-neighbor effect.

The Prime's Neighborhood Size Is the Key Factor Responsible for the Interaction Between Prime Relatedness, Relative Prime–Target Frequency, and Neighborhood Size

The results of Experiments 3 and 4 clearly point to neighborhood size, per se, as the crucial factor in determining the size of the inhibitory priming effect from low-frequency neighbor primes. To determine if we could provide additional support for this conclusion, we correlated inhibitory priming effects with the number of the prime's neighbors, using the item data from all our experiments. For the 304 cases where a lower frequency neighbor prime primed a higher frequency target, the Pearson correlation was –.19, $p < .01$, indicating that, as the number of prime neighbors increased, the size of the inhibition effect also increased. This relationship can be seen graphically in Figure 1, in which the mean priming effect is plotted against the number of prime neighbors (excluding the means from the seven primes with 17 or more neighbors, as those means would be based on only two or three items each). The priming effect shows a slight trend toward facilitation when the higher frequency target is the only neighbor of the prime (i.e., when the number of neighbors = 1), with the effect turning into inhibition as the number of prime neighbors increases. Figure 1 also suggests that the effect seems to level off when the number of neighbors is larger than 9, although the correlation did not become substantially stronger when we confined the analysis to the words with 1 to 9 neighbors ($r = –.27$, $p < .001$, $N = 196$). This analysis provides further support for the conclusion that neighborhood size truly does determine the size of the inhibition effect when low-frequency neighbor primes and high-frequency targets are used.

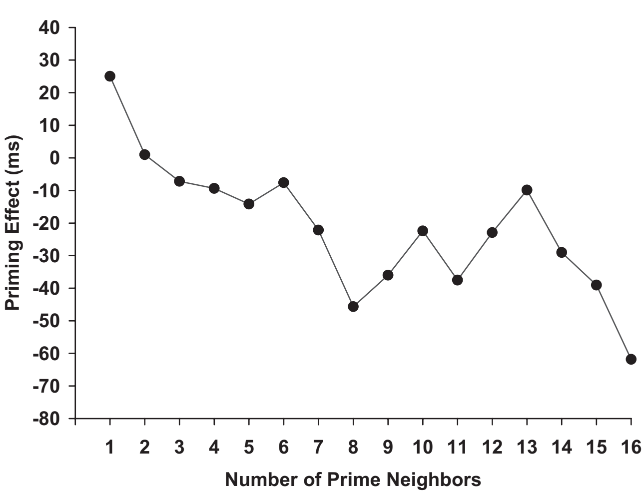

Figure 1. Mean priming effect as a function of the number of neighbors of the lower frequency prime for the pairs used in Experiments 1, 2, 3, and 4.

Additional evidence supporting this conclusion comes from the patterns of inhibitory effects associated with neighborhood size in Davis and Lupker (2006). That is, the small (13 ms) inhibition effect from low-frequency primes in their Experiment 1 could have been due to those primes having a mean neighborhood size of only 2.4. As can be seen in Figure 1, our data indicate that, for a neighborhood size of 2.4, the priming effect would be about 5 ms. It could also explain why we did not find any inhibition effect in Experiment 3, yet a small effect in errors in Experiment 4B, as the neighborhood size of the former was smaller than that of the latter ($M = 2.9$ and 3.9 neighbors, respectively). All of these results are consistent with the conclusion that as the prime's neighborhood size increases, there is an increasing likelihood of observing inhibitory priming. The small effect in the error rates of Experiment 4B may in fact be the beginning of an inhibition effect, one not yet strong enough to be observed in both the response latency and error data.

Although it seems clear that neighborhood size determines the size of the inhibition effect when low-frequency neighbor primes and high-frequency targets are used, there is no evidence that this same conclusion applies to high-frequency neighbor primes and low-frequency targets. Although in Experiment 3 the inhibition effect from high-frequency primes with large neighborhoods (27 ms) was slightly larger than the inhibition effect from high-frequency primes with small neighborhoods (18 ms), across all our experiments, there was no relation between the number of prime neighbors and the size of the priming effect for high–frequency-prime–low-frequency-target pairs, $r = .03$, *ns* ($N = 160$). This relationship can be seen graphically in Figure 2, in which the mean priming effect is plotted against the number of prime neighbors (excluding the three primes with 18 or more neighbors). This result suggests that the principles may be slightly different when high-frequency versus low-frequency primes are used.

A further piece of evidence for this conclusion comes from the contrast between the present Experiment 4 and Davis and Lupker's (2006) Experiment 2. In our Experiment 4, using low-frequency primes and high-frequency targets, we did not find that shared neighbors affected the size of the inhibitory priming effect. In contrast, in Davis and Lupker's Experiment 2, using high-frequency primes and low-frequency targets, there was a strong shared-neighbor effect: Prime–target pairs without shared neighbors produced much smaller inhibition effects than prime–target pairs with shared neighbors. At this point, therefore, it appears that for primes that are higher frequency neighbors, the lexical competition is dominated by the prime's word units and any coactivated shared neighbors. The activation in other lexical units (i.e., the rest of the prime's neighborhood) does not appear to be strong enough to matter. However, for lower frequency primes, because the prime itself achieves a lower level of activation, the activation of the rest of the neighborhood can play a larger role in the inhibition process. In essence, even neighbors of the primes that are *not* neighbors of the target (i.e., prime-only neighbors) do

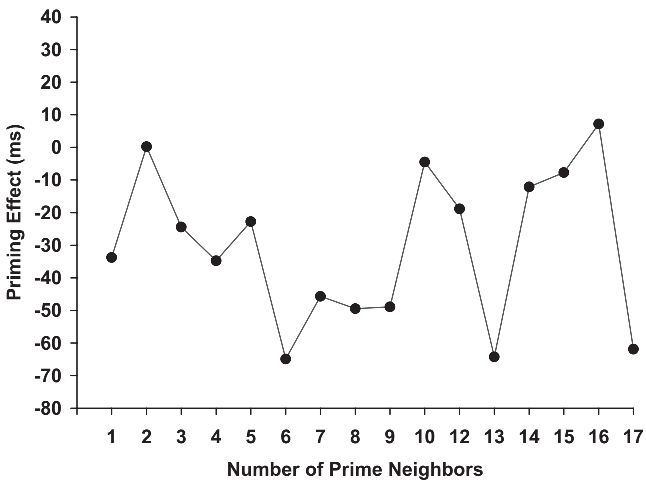

Figure 2. Mean priming effect as a function of the number of neighbors of the higher frequency prime for the pairs used in Experiments 1, 2, and 3.

inhibit target processing and, if there are enough of them, this inhibition will affect identification time.

Expanding the Neighborhood

There is a growing consensus among researchers that the common definition of neighborhoods (Coltheart et al., 1977) is very likely insufficient. For example, target identification can be slowed down by a word prime that is shorter or longer than the target (De Moor & Brysbaert, 2000; Drews & Zwitserlood, 1995) and also by a prime that shares only the first syllable with the target (Carreiras & Perea, 2002; see also Bowers, Davis, & Hanley, 2005). These findings suggest that the target's word unit receives inhibitory signals from word units that are not traditionally regarded as target neighbors. Further support for this suggestion comes from Janack, Pastizzo, and Feldman (2004). They found that a lower frequency prime that has a 50% letter overlap with the target (e.g., *lash-CAST*) significantly delayed target identification in a lexical decision task. Moreover, the size of inhibition from such partial primes was as large as from conventional orthographic neighbor primes where primes and targets had 75% overlap (e.g., *mast-CAST* or *cash-CAST*).

What these results suggest is that a word's effective neighborhood probably includes words that differ from it at more than one letter position. At the very least, it would include words that differ at two letter positions. Of course, if this conclusion is true, it entirely negates the qualitative distinction we have been making between prime-only, target-only, and shared neighbors. That is, in our analyses, "prime-only" neighbors are words that actually share $n - 2$ letter positions with the target. For example, for the four-letter neighbor pair *heap-HELP*, the prime-only neighbor *heat* shares two of four letters with the target *HELP*. Likewise, for the five-letter neighbor pair *shirt-SHORT*, the prime-only neighbor *shift* shares three of five letters with the target *SHORT*. If the definition of a neighbor is expanded in the manner suggested by the results cited above, these prime-only neighbors would become shared neighbors (as would any target-only neighbors). Ultimately, the best way of thinking about the prime–target neighborhood may be quantitatively rather than qualitatively. Two-letter different words like *HELP* and *HEAT* may be neighbors and may compete with one another; they may simply not compete to the same extent as conventional neighbors, like *HEAP* and *HELP*.

With this point in mind, an alternative possibility that should be considered is that the inhibition effect from low-frequency primes may have been caused by a single word that is an unconventional neighbor (i.e., one sharing less than $n - 1$ letters) that is higher in frequency than the target (e.g., for the pair *tide-SIDE*, *time* is an unconventional neighbor higher in frequency than the target). Certainly, as the prime's neighborhood size increases, the probability of the prime having a higher frequency neighbor of this sort would increase. Because such a neighbor could be a strong inhibitor in the competition process, it is important to investigate whether the inhibition effects from low-frequency primes might have been due to a single unconventional neighbor higher in frequency than the target. To test this possibility, we conducted a correlational analysis (based on 215 cases) with only the prime–target pairs where the target was the highest frequency neighbor of the prime, even if this unconventional definition of a neighbor were used. The results were consistent with our first correlational analysis: The size of the inhibition effect increased as the number of prime neighbors increased, $r = -.23$, $p < .001$. This analysis provides further evidence that the finding that lower frequency neighbors inhibited higher frequency targets for words with many neighbors is due to the prime's neighbors collectively competing with the target representation and, hence, slowing target identification, rather than the activation of an unconventional high-frequency neighbor.

It is important to note that although all of our post hoc analyses were conducted based on the number of prime neighbors, our results do not rule out the possibility that what is important is actually the number of target neighbors (as the density-constraint effect suggests for nonword neighbor primes; Forster, 1987; Forster & Davis, 1991; Forster et al., 1987; Forster & Taft, 1994) or another variable that is highly correlated with neighborhood size. With respect to the issue of target neighborhood size, we conducted a correlational analysis based on the number of target neighbors and found that the relation between target neighborhood size and the size of the inhibition effect was smaller but still statistically significant, $r = -.12$, $p < .05$, $N = 304$. Because the neighborhood size of the primes and targets was highly correlated ($r = .83$), there would be no way at present to determine unequivocally which neighborhood really mattered (assuming only one did). Nor would it really seem useful to try until the optimal way to define a word's neighborhood has been fully established. The critical point to make here is that in order for lower frequency neighbor primes to inhibit higher frequency targets, the primes need some help from their coactivated neighbors, whether they are, according to the conventional definition, prime neighbors or target neighbors (or both).

The strong inhibition effects for words with many neighbors found in the present experiments nicely parallels the density constraint found when using nonword neighbor primes (Forster, 1987; Forster & Davis, 1991; Forster et al., 1987). Thus, the two effects could have similar bases. That is, the absence of a facilitation effect for words with large neighborhoods could be caused by coactivated neighbors collectively producing enough inhibition to cancel out whatever facilitation effect comes from nonword neighbor primes (van Heuven et al., 2001).

Implications for Alternative Accounts of the Masked Priming Effect

The inhibitory neighbor priming effect observed in the present experiments is consistent with activation-based accounts of the masked priming effect, which assume that the priming is caused by a prime preactivating the lexical representation of the target and the lexical representations of orthographically similar words (e.g., Grainger & Jacobs, 1996; McClelland & Rumelhart, 1981). On the other hand, inhibitory priming effects are quite problematic for one of the alternative accounts of masked priming, Bodner and Masson's (1997; Masson & Bodner, 2003) retrospective (episodic) account. According to this view, masked priming effects are explained in terms of the prime presentation creating a new processing resource in memory, which is subsequently recruited to facilitate target identification. The similarity of the processing of the prime event and target event is the key for efficient processing; the more similar the two events, the faster the target should be identified. This account inevitably predicts that neighbor primes will facilitate target identification relative to unrelated primes, because the processing resources created for the prime will be more similar to those for the target on neighbor-prime trials than on unrelated-prime trials. Thus, the fact that our effects are inhibition effects would seem to rule out any interpretation of these results based on a retrospective account of masked priming effects.

Our results also have implications for models of lexical selection that do not incorporate discrete lexical representations, such as the parallel distributed processing models (e.g., Seidenberg & McClelland, 1989; Plaut et al., 1996). Unlike the activation-based models, in these models there are no abstract units corresponding to words; instead, the representation of a word is encoded across an interconnected network of units. Because there are no lexical representations for a prime to preactivate and no competition among activated lexical representations, it is not at all clear how these models could account for an inhibitory effect of neighbor primes on target identification. The presentation of a neighbor prime could activate a set of units corresponding to the prime, and some of those units could be shared with the target (due to their similar orthography), but any resulting priming effect would be expected to be facilitatory, not inhibitory. Inhibitory neighbor priming effects, whether from higher frequency or lower frequency neighbor primes, will therefore be a challenge for parallel distributed processing models to accommodate.

Conclusions

The present research, showing an inhibitory effect of neighbor primes on target identification in English, supports the basic assumption of lexical competition models of visual word identification. Further, our systematic manipulation of neighborhood size revealed that the inhibition effect interacts with neighborhood size and the prime–target frequency relationship. When words have few neighbors, the pattern of inhibition was accurately predicted by the simulations (inhibition from high-frequency neighbor primes but not from low-frequency neighbor primes). On the other hand, when words have many neighbors, the model underestimates the strength of inhibition from lower frequency neighbors. Our post hoc analyses support the idea that this inhibition is strongly related to the number of neighbors of the lower frequency primes (and their targets). Presumably, the prime's neighbors collectively compete with the target representation, thereby slowing target identification. Additional research will be necessary to determine how and if the principles embodied in these models can be altered to explain how these inhibition effects from groups of low-frequency neighbors can arise.

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Table A1

Items used in Experiment 1

Higher frequency targets			Lower frequency targets			Nonword targets		
Neighbor prime	Unrelated prime	Target	Neighbor prime	Unrelated prime	Target	Neighbor prime	Unrelated prime	Target
tide	doll	SIDE	side	need	TIDE	rank	hits	RUNK
tire	mess	TIME	time	said	TIRE	paws	lick	GAWS
toll	link	TOLD	told	less	TOLL	mist	ripe	MEST
cord	maze	COLD	cold	rest	CORD	task	soft	TASH
roam	goat	ROOM	room	mind	ROAM	pawn	leak	CAWN
weep	grim	WEEK	week	miss	WEEP	lock	dive	LOCT
oven	dusk	OPEN	open	four	OVEN	joke	beam	JOPE
tape	push	TYPE	type	dark	TAPE	vast	cell	GAST
gong	cube	LONG	long	same	GONG	cast	pink	CALT
lift	mode	LEFT	left	once	LIFT	bash	pore	BUCH
sigh	cult	HIGH	high	year	SIGH	duct	harp	MUCT
wipe	scar	WIFE	wife	cost	WIPE	pale	bear	PALT
pity	deaf	CITY	city	knew	PITY	hang	bomb	HALG
foam	plot	FORM	form	hand	FOAM	trip	vote	TWIP
nest	bold	BEST	best	face	NEST	sour	mall	SOUT
cage	moss	CASE	case	kind	CAGE	clam	mute	CHAM
bull	rope	FULL	full	girl	BULL	fork	cave	FOCK
dune	rash	DONE	done	past	DUNE	sled	weed	SLOD
tree	goal	FREE	free	word	TREE	drip	surf	DRIM
lone	tear	LOVE	love	turn	LONE	tale	rent	ZALE
halt	coin	HALF	half	west	HALT	bake	boot	NAKE
fork	lawn	WORK	work	life	FORK	mice	pork	BICE
mate	tent	RATE	rate	view	MATE	lied	oath	FIED
bark	pine	BACK	back	over	BARK	ties	bees	HIES
pact	dime	FACT	fact	away	PACT	yard	roll	FARD
lime	bark	LIKE	like	even	LIME	gaze	pops	GARE
shoe	burn	SHOW	show	five	SHOE	fake	bolt	VAKE
dawn	flew	DOWN	down	last	DAWN	mile	rear	MIDE
heap	grin	HELP	help	area	HEAP	wipe	hunt	WIGE
hood	lure	GOOD	good	made	HOOD	flea	chop	FLEY
meal	sand	REAL	real	body	MEAL	fine	hall	FINC
herd	slip	HEAD	head	part	HERD	loop	drag	TOOP
hose	math	HOME	home	used	HOSE	tool	dean	ZOOL
pill	cake	WILL	will	some	PILL	kite	tint	KIRE
mace	pout	MAKE	make	well	MACE	pigs	robe	TIGS
bind	swan	FIND	find	look	BIND	coma	skit	COGA
tame	mink	TAKE	take	know	TAME	vase	foul	VUSE
bell	rail	WELL	well	each	BELL	void	echo	VOLD
gown	fuel	TOWN	town	road	GOWN	hire	dash	ZERE
doom	brew	DOOR	door	name	DOOM	bind	reek	GIND

(*Appendixes continue*)

Table A2

Items used in Experiment 2

Word targets					
Higher frequency targets			Lower frequency targets		
Neighbor prime	Unrelated prime	Target	Neighbor prime	Unrelated prime	Target
tide	doll	SIDE	side	need	TIDE
tire	mess	TIME	time	said	TIRE
toll	link	TOLD	told	fact	TOLL
colt	kick	COLD	cold	rest	COLT
weep	grim	WEEK	week	miss	WEEP
lung	cube	LONG	long	same	LUNG
wipe	scar	WIFE	wife	cost	WIPE
tower	bitch	POWER	power	light	TOWER
plank	wires	PLANE	plane	taken	PLANK
sands	clock	HANDS	hands	moral	SANDS
bull	rope	FULL	full	west	BULL
lone	tear	LOVE	love	turn	LONE
halt	coin	HALF	half	seem	HALT
fork	lawn	WORK	work	life	FORK
mate	tent	RATE	rate	says	MATE
bark	pine	BACK	back	just	BARK
lift	mode	LEFT	left	mind	LIFT
pill	cake	WILL	will	some	PILL
laser	blank	LATER	later	means	LASER
clash	sting	CLASS	class	sound	CLASH
hood	lure	GOOD	good	made	HOOD
meal	sand	REAL	real	sure	MEAL
heal	slip	HEAD	head	part	HEAL
hose	math	HOME	home	went	HOSE
lime	bass	LIKE	like	them	LIME
maze	pout	MAKE	make	felt	MAZE
bind	swan	FIND	find	look	BIND
crown	silly	BROWN	brown	horse	CROWN
wound	slave	FOUND	found	night	WOUND
wager	spice	WATER	water	shall	WAGER
doom	babe	DOOR	door	name	DOOM
nest	jail	BEST	best	face	NEST
cage	slab	CASE	case	kind	CAGE
shoe	burn	SHOW	show	five	SHOE
heap	grin	HELP	help	form	HEAP
bell	pint	WELL	well	must	BELL
tame	mink	TAKE	take	less	TAME
root	sing	ROOM	room	seen	ROOT
lease	brick	LEAST	least	times	LEASE
pasty	snare	PARTY	party	right	PASTY
Nonword Targets					
Low-frequency primes			High-Frequency primes		
rank	hits	RUNK	hand	does	HOND
mist	ripe	MEST	been	more	BEEG
lock	dive	LOCT	last	here	LASP
joke	beam	JOPE	came	last	CIME
sour	mall	SOUT	feet	hard	FENT
clam	mute	CHAM	held	gave	HEND
tale	rent	ZALE	rise	clay	RIBE
peak	monk	PEAM	ball	race	BALP
lusty	slash	NUSTY	still	might	SMILL
snack	tiles	SCACK	river	miles	HIVER
ties	bush	MIES	dead	bill	GEAD
gaze	pops	GARE	land	tell	LANS
wipe	hunt	WIGE	line	seen	LIDE
loop	drag	TOOP	your	then	YOOR
vase	foul	VUSE	give	days	TIVE
bake	boot	VAKE	note	walk	NOKE
mice	pork	BICE	poor	wait	POOD
lied	oath	GIED	deal	hope	BEAL
grade	mines	GRAKE	short	words	SHORY
crime	baker	TRIME	reach	eight	KEACH

Table A3

Items used in Experiment 3

Higher frequency targets with many neighbors			Lower frequency targets with many neighbors		
Neighbor prime	Unrelated prime	Target	Neighbor prime	Unrelated prime	Target
pack	root	BACK	back	long	PACK
bare	fled	CARE	care	feed	BARE
coat	luck	COST	cost	week	COAT
deer	fond	DEEP	deep	wish	DEER
tale	rent	TAKE	take	year	TALE
bases	trace	BASIS	basis	short	BASES
frown	chick	BROWN	brown	party	FROWN
mouse	ditch	HOUSE	house	night	MOUSE
shame	pound	SHAPE	shape	break	SHAME
hound	slick	FOUND	found	later	HOUND
worn	fame	WORD	word	line	WORN
cast	sold	LAST	last	work	CAST
mail	shut	MAIN	main	look	MAIL
sell	trim	WELL	well	come	SELL
lift	mate	LIST	list	date	LIFT
pours	click	HOURS	hours	stage	POURS
tight	trail	EIGHT	eight	plane	TIGHT
wager	slash	WATER	water	still	WAGER
waken	dolly	TAKEN	taken	light	WAKEN
stuck	lover	STOCK	stock	horse	STUCK
weep	pine	KEEP	keep	lack	WEEP
tent	sole	WENT	went	same	TENT
hide	meat	SIDE	side	want	HIDE
star	wipe	STAY	stay	role	STAR
tide	ford	TIME	time	said	TIDE
boots	shirt	BOOKS	books	train	BOOTS
witch	stink	WATCH	watch	drove	WITCH
bound	match	SOUND	sound	lines	BOUND
spike	brink	SPOKE	spoke	fight	SPIKE
poker	hatch	POWER	power	least	POKER
fool	wave	FOOD	food	talk	FOOL
dull	beam	FULL	full	real	DULL
dive	roll	GIVE	give	told	DIVE
hang	tore	HAND	hand	took	HANG
hire	pump	HERE	here	good	HIRE
leach	towel	REACH	reach	daily	LEACH
rider	shell	RIVER	river	moral	RIDER
slate	marry	STATE	state	right	SLATE
shade	belly	SHARE	share	cover	SHADE
clash	sting	CLASS	class	miles	CLASH
Higher frequency targets with few neighbors			Lower frequency targets with few neighbors		
wept	bias	KEPT	kept	ones	WEPT
oily	reef	ONLY	only	what	OILY
fury	drug	JURY	jury	join	FURY
clue	loud	CLUB	club	whom	CLUE
stem	folk	STEP	step	else	STEM
thick	dress	THINK	think	young	THICK
colon	puffy	COLOR	color	bring	COLON
ratio	hurry	RADIO	radio	teeth	RATIO
studs	ruler	STUDY	study	north	STUDS
slant	curly	PLANT	plant	cause	SLANT
knob	trio	KNOW	know	each	KNOB
thug	ache	THUS	thus	knew	THUG
omen	wrap	OPEN	open	girl	OMEN
vary	poem	VERY	very	down	VARY
moth	verb	BOTH	both	used	MOTH
beard	pupil	BOARD	board	force	BEARD
chill	decay	CHILD	child	value	CHILL
pause	storm	CAUSE	cause	green	PAUSE
count	anger	COURT	court	stood	COUNT
depth	theme	DEATH	death	women	DEPTH

(*Appendixes continue*)

Table A3 (*continued*)

Items used in Experiment 3					
Higher frequency targets with many neighbors			Lower frequency targets with many neighbors		
Neighbor prime	Unrelated prime	Target	Neighbor prime	Unrelated prime	Target
text	acts	NEXT	next	free	TEXT
gown	riot	TOWN	town	type	GOWN
knit	skew	UNIT	unit	firm	KNIT
info	tidy	INTO	into	such	INFO
lazy	ruin	LADY	lady	sign	LAZY
spade	rally	SPACE	space	money	SPADE
older	metal	ORDER	order	white	OLDER
frost	notch	FRONT	front	union	FROST
flour	squat	FLOOR	floor	table	FLOUR
mayor	fifth	MAJOR	major	black	MAYOR
pity	twin	CITY	city	eyes	PITY
quit	oils	SUIT	suit	deny	QUIT
tree	duty	TRUE	true	data	TREE
sigh	acid	HIGH	high	away	SIGH
axle	tomb	ABLE	able	view	AXLE
yield	magic	FIELD	field	sense	YIELD
clone	bunny	ALONE	alone	speak	CLONE
dense	blunt	SENSE	sense	point	DENSE
untie	choke	UNTIL	until	world	UNTIE
threw	crazy	THREE	three	small	THREW
Nonword targets with many neighbors					
Low-frequency primes			High-frequency primes		
malt	punk	CALT	hard	feel	HARO
sail	toss	SALL	show	best	SHOF
bone	weak	BOTE	head	face	HEAB
meal	lane	MELL	name	form	JAME
dawn	cure	BAWN	felt	need	FILT
lever	fails	DEVER	might	years	VIGHT
stare	cared	STARP	sleep	taste	SLEED
silly	liver	SOLLY	round	spite	GOUND
hired	swing	PIRED	scale	takes	SCALK
shake	bunch	SHASE	shore	loved	SLORE
nick	wars	NINK	west	says	KEST
hash	peep	HASS	land	seem	MAND
card	coal	MARD	find	case	FING
barn	cone	BIRN	hope	road	HAPE
rail	tile	YAIL	home	less	HOBE
brick	stake	FRICK	sales	beach	SAPES
crack	spare	CRECK	shall	words	SHULL
pitch	candy	LITCH	carry	drawn	YARRY
dusty	chase	DUSHY	store	corps	STORT
dates	grave	DASES	parts	sweet	PARDS
Nonword targets with few neighbors					
duet	wolf	SUET	news	vote	NERS
self	inch	SELY	ever	upon	EFER
chef	zinc	CHEE	plan	goal	PLIN
curb	debt	GURB	evil	term	ESIL
plug	aunt	PHUG	area	once	APEA
sorry	plain	BORRY	place	today	PLICE
treat	honey	TRELT	close	thing	FLOSE
juice	haven	FUICE	style	worth	STYLA
merge	wrist	MERGS	asked	given	ACKED
panel	split	RANEL	group	large	BROUP
auto	gulf	ASTO	much	also	MUCT
soup	fuel	BOUP	blue	rich	BLUG
oral	pond	FRAL	size	fund	TIZE
cult	plea	CULD	army	edge	ARPY
bird	tube	BIRT	film	easy	GILM
exact	refer	EWACT	began	among	HEGAN
brush	royal	BRESH	whole	level	WHOLA
cheap	mason	THEAP	every	never	EVURY
moist	vapor	MOOST	heart	doing	HEERT
dodge	climb	MODGE	stand	wrote	STANF

Table A4

Stimuli Used in Experiment 4A

Words				Nonwords		
Prime with shared neighbor	Prime without shared neighbor	Unrelated prime	Target	Neighbor prime	Unrelated prime	Target
mall	wail	vine	WALL	tear	hunt	TEAD
watt	wand	bead	WANT	vase	sand	VUSE
meal	moan	wake	MEAN	joke	sung	JOPE
fees	fled	hide	FEED	rode	push	VODE
mint	mild	dusk	MIND	peak	monk	PEAM
mood	gold	tall	GOOD	ties	tact	MIES
worn	ward	tail	WORD	fate	stem	FITE
leap	lend	shoe	LEAD	tops	bush	TOAS
spill	stall	loser	STILL	cash	male	COSH
nose	nine	slow	NONE	bell	fame	BEEL
chick	cheek	liner	CHECK	span	pork	SPAG
stack	stork	wired	STOCK	purse	clock	PORSE
wipe	wade	null	WIDE	blink	tunes	BLINT
beep	bean	haze	BEEN	smack	tiger	SPACK
lime	lake	pump	LIKE	sour	pail	SOUT
loop	lock	peas	LOOK	gaze	pops	GARE
fill	fail	meat	FALL	sway	punk	SMAY
mess	mist	beam	MISS	limp	tire	LOMP
mice	mane	hull	MINE	bone	gear	BOTE
bull	bail	sink	BALL	hate	mold	HAIE
tile	tame	maps	TIME	crap	lamp	CRAN
weep	weak	dice	WEEK	nick	wars	NINK
nest	rent	tray	REST	hash	peep	HASS
rake	rats	hint	RATE	card	sing	CARO
lice	lift	pads	LIFE	sole	drag	SOLK
shoot	shirt	crash	SHORT	crack	mania	CRECK
stove	stare	lever	STORE	sheep	brave	SPEEP
caves	casts	plank	CASES	silly	baker	SOLLY
fill	fuel	wire	FULL	wins	boot	WUNS
bang	bunk	yarn	BANK	bass	sons	BASU
belt	bust	noon	BEST	warn	tide	WARL
cape	camp	whip	CAME	lint	toss	LINN
deaf	deed	wart	DEAD	bent	gate	BONT
harm	herd	wool	HARD	tomb	slug	TOMP
skid	sail	doll	SAID	bowl	rang	MOWL
loft	lent	rail	LEFT	boil	sane	BOOL
lust	lash	wink	LAST	dawn	cure	BAWN
barn	bore	gang	BORN	cope	flag	COSE
stale	stags	marry	STAGE	fake	jaws	FIKE
latch	witch	bells	WATCH	shade	liver	SHACE
liked	loved	crown	LIVED	dates	grave	DASES
root	roam	lean	ROOM	couch	swore	CORCH
				bare	flew	BARV
				ring	pack	RINT
				rude	moss	RADE
				jail	dive	JARL
				teen	rope	TEET
				wave	till	WAME
				bake	keen	BAGE
				vain	ripe	VAWN
				kite	ramp	WITE
				brag	oath	BLAG
				halt	limb	HELT
				grape	maker	GRAFE
				bench	grown	BETCH
				rally	lover	RELLY

(*Appendixes continue*)

Table A5

Stimuli Used in Experiment 4b

Shared neighbor			No Shared Neighbor		
Neighbor prime	Unrelated prime	Target	Neighbor prime	Unrelated prime	Target
waver	bland	WATER	joint	shear	POINT
storm	grain	STORY	blank	sunny	BLACK
trail	foggy	TRAIN	onion	slope	UNION
calf	grin	CALM	gloss	bunny	GLASS
basil	prank	BASIC	prick	leaky	PRICE
knot	herb	KNOW	vague	charm	VALUE
stoop	dryer	STOOD	honey	tends	MONEY
germ	cozy	TERM	verb	toad	VERY
stew	mesh	STEP	hangs	crane	HANDS
manor	spout	MAJOR	scent	buggy	SPENT
stall	dairy	SMALL	beard	penny	BOARD
fury	snap	JURY	choir	glove	CHAIR
glue	roam	BLUE	flame	tumor	BLAME
spade	blend	SPACE	dread	berry	DREAM
youth	drink	SOUTH	bloom	stray	BLOOD
flock	swear	BLOCK	pity	monk	CITY
roast	witty	COAST	clone	spicy	ALONE
plum	dial	PLUS	yearn	eject	LEARN
tense	decay	SENSE	lease	fancy	LEAVE
gown	clue	TOWN	quote	weary	QUITE
fried	spoon	TRIED	loyal	nurse	LOCAL
plate	rocks	PLACE	awake	delay	AWARE
stiff	lucky	STAFF	pause	print	CAUSE
brew	hurl	DREW	dawn	crew	DOWN
moth	tuba	MYTH	chick	perky	THICK
clove	meaty	CLOSE	weeds	apron	WEEKS
guilt	poets	BUILT	knee	bird	KNEW
fever	smell	NEVER	ratio	hurry	RADIO
forth	chain	NORTH	piper	frown	PAPER
steak	unite	SPEAK	scent	fatty	SCENE
Nonword targets					
Many neighbors			Few neighbors		
malt	punk	MALD	duet	wolf	SUET
sail	toss	SALL	vein	yeah	VOIN
bone	weak	BOTE	chef	zinc	CHEE
meal	lane	MELL	curb	epic	GURB
wears	folly	MEARS	plug	aunt	PHUG
lever	fails	DEVER	sorry	plain	BORRY
stare	cared	STARP	moist	vapor	MOOST
silly	clock	SOLLY	juice	haven	FUICE
hired	boots	PIRED	faint	coach	FAILT
shake	candy	SHASE	panel	split	RANEL
crack	spare	CRECK	rally	fists	RATLY
tapes	plank	TATES	scoop	fling	SCOOK
shack	mouse	CHACK	bonus	mixer	BONAS
paste	beans	MASTE	flake	loops	FRAKE
liver	seats	TIVER	spout	pecks	SPOUN
nick	wars	NINK	auto	ruin	ASTO
bees	lent	BEED	soup	fuel	BOUP
card	rode	CARM	oral	pond	FRAL
rail	tile	YAIL	cult	plea	CULD
jolly	spine	NOLLY	tube	gift	TUPE
brick	stake	FRICK	exact	refer	EWACT
tower	raced	FOWER	fence	worst	FELCE
pitch	wound	LITCH	cheap	mason	THEAP
dusty	sheer	DUSHY	treat	eager	TRELT
dates	grave	DASES	dodge	climb	MODGE
grape	poses	GRAME	tonic	chump	TONAC
prone	snare	PRONY	snoop	boxer	SQOOP
bully	shave	BOLLY	slung	cramp	SLENG
hoses	ditch	HOVES	combs	snout	COMBE
codes	shine	COLES	dummy	flips	LUMMY

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