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Masked Priming with Orthographic Neighbors: a Test of the Lexical Competition Assumption

by

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Abstract

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 is predicted to delay the word's identification. Using the masked priming paradigm (Forster & Davis, 1984), Segui and 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 explanations for these findings are discussed along with their theoretical implications.

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Masked Priming with Orthographic Neighbors: a Test of the Lexical Competition Assumption

Language researchers have long been interested in examining the processes involved in the visual identification of words. As a result of their investigations, a number of models have been proposed embodying certain assumptions about the nature of lexical processing. In models that incorporate competition among activated lexical units (e.g., Davis, 2003; Grainger & Jacobs, 1996; McClelland & Rumelhart, 1981; McClelland, 1987), the competition between a presented word and its orthographic neighbors is assumed to play a central 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*. According to activation-based models, the orthographic neighbors of a word become partially activated when that word is read due to their similar orthography, and the lexical units of the word and its neighbors compete against one another via mutually inhibitory connections until the target's lexical unit exceeds a threshold level of activation.

The relative frequency of a word and its orthographic neighbors is especially important in these models, because it strongly affects how quickly the lexical competition can be settled, 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 without 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). Similar results were obtained when eye movements were monitored and gaze duration was the dependent variable.

Grainger et al.'s (1989) initial 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 involved the lexical decision task (e.g., Carreiras, Perea, & Grainger, 1997; Forster & Shen, 1996; Grainger, 1990; Grainger & Jacobs, 1996; Grainger et al., 1989; Grainger & Segui, 1990; Huntsman & Lima, 1996, 2002; Perea & Pollatsek, 1998; Sears, Hino, & Lupker, 1995; Sears, Campbell, & Lupker, 2006; 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, Campbell, & Lupker, 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, the most apparent being the possibility that the inhibitory process is simply less powerful in English than in other languages. In the present research, we explore the possibility that inhibitory processing in English may be more readily detectable in another experimental paradigm: masked priming using word neighbor primes.

The single-word paradigm

Most of the initial studies of the neighborhood frequency effect used the single-word paradigm. In these experiments, typically two sets of words are created, each set equated in terms of word frequency, bigram frequency, word length, and number of orthographic neighbors. For one set all of the words have at least one higher frequency neighbor and for the other set none of the words have any higher frequency neighbors. Responses to the two different sets of words (such as lexical decision latencies and error rates) are then compared, and any difference is attributed to the existence of higher frequency neighbors.

Although the single-word paradigm is the most straightforward method to test many psycholinguistic hypotheses, one of its major drawbacks is the difficulty creating two sets of words that differ only by the single variable of interest. Because there are so many potential lexical properties to consider (including normative frequency, word length, age of acquisition, imagability, concreteness, regularity, familiarity, etc.), creating two sets of words equated on all relevant lexical properties can often be very difficult. This issue is usually of no concern when an effect can be replicated with different stimuli, but when an effect does not replicate across different stimulus sets concerns over generalizability arise. As an example, Perea and Pollatsek (1998) reported an effect of neighborhood frequency in a single-word lexical decision task, with lexical decision latencies to words with higher frequency neighbors being slower than the latencies to words without any higher frequency neighbors. However, when Sears, Campbell, and Lupker (in press) attempted to replicate their results they were only partially successful. They were able to replicate the neighborhood frequency effect in the lexical decision task only when they used Perea and Pollatsek's items and the same lexical decision instructions (in Perea & Pollatsek's lexical decision experiment, participants were asked to emphasize accuracy over speed). When Sears et al., gave participants more typical lexical decision instructions ("respond as quickly and as accurately as possible) and the same items there was no neighborhood frequency effect, nor was there a neighborhood frequency effect when Perea and Pollatsek's lexical decision instructions were used with a different set of items that also manipulated neighborhood frequency. Ultimately, Sears et al. concluded that the inhibitory effect of neighborhood frequency in Perea and Pollatsek's experiment was due to the particular combination of the lexical decision instructions and the word and nonword stimuli used in that experiment. This type of outcome is always a risk when the single-word paradigm is used.

The priming paradigm

In the present research the priming paradigm was used to avoid many of the issues inherent with the single-word paradigm. Unlike the single-word paradigm in which responses to different sets of words are compared, in the masked priming paradigm, responses to the same words are compared. In the priming paradigm, two words are presented in rapid succession, and the effect of the first word (the prime) on the responses to the second word (the target) is measured. Instead of manipulating the target's characteristics the characteristics of the primes are manipulated while keeping the target word constant. For example, responses to the same target (e.g., *tide*) are measured after having been primed by an orthographically related word (e.g., *side*) and by an orthographically unrelated word (e.g., *need*). Because differences in the response latencies to the same target are the basis of effect, there are no concerns about uncontrolled stimulus differences among the experimental conditions artifactually producing an effect, as can arise in other paradigms (for a discussion, see Forster, 2000). In studies of the neighborhood frequency effect, another advantage is that by presenting a target's neighbor as a prime, one can observe the direct effect of the neighbor activation on the identification of target, rather than merely inferring the neighbor activation via responses to different sets of words.

Neighborhood Frequency Effects in the Masked Priming Paradigm

In the present research the masked priming paradigm (Forster & Davis, 1984; for a review, see Kinoshita & Lupker, 2003) was used to examine the lexical competition assumption incorporated in activation-based models of visual word identification. In the masked priming paradigm, 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 masked, few participants notice the prime. Thus, its impact on target processing can be assessed in the absence of any conscious prime influence.

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*). Grainger and Segui argued that this result is consistent with the lexical competition assumption of the interaction-activation 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 the higher frequency neighbor of the target word, inhibitory priming is expected. On the other hand, the model 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, Grainger and Segui 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 primes, there was a 10 ms facilitation effect from lower frequency 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 the 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) lexical decision latencies were delayed relative to when the same words were primed by unrelated control primes. Similarly, when low-frequency targets (with a mean normative frequency of 9) were primed by medium-frequency neighbors lexical decision latencies were also delayed relative to when primed by control primes. Lower frequency neighbor primes (either of low-frequency or of medium-frequency) did not produce inhibitory priming.

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 primed by unrelated control primes. This result must be interpreted with some caution, however, as the participants in the study were French-English bilinguals (native speakers of French), and so it is not clear whether the effect was due to the stimuli being English or the participants being French speakers. Another limitation of their experiment is that it 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, similarly, 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 the neighborhood frequency effect in 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 this aspect of Segui and Grainger's (1990) results. In their Experiment 1, however, they 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 produced neither a significant interaction between prime type (neighbor prime or control prime) and target frequency (low-frequency target or 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 interactive-activation model (Davis, 2003), Davis and Lupker showed that, depending on how parameters are selected, the model could be made to predict a non-zero (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, due the fact that 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 build 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 (1990) 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 a facilitation or a null effect; e.g., Davis & Lupker, 2006; Forster, 1987; Forster & Davis, 1991; Forster et al., 1987; Forster & Taft, 1994; Forster & Veres, 1998). The risk of using unfamiliar words as primes (which are likely to be very low-frequency words) is that these words will be unknown to some participants, effectively making them nonword primes, and as a consequence any inhibitory neighbor priming will 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 96.5%, and for the low-frequency words it was 95.6%. Forty pairs of four-letter orthographic neighbors were selected as the critical stimuli (the descriptive characteristics of all the stimuli are listed in Table 1). For each pair, each neighbor served as either a prime or a target depending on the condition the pair was assigned to. Both members of the pairs had large neighborhoods ($M = 10.0$), and one member of the neighbor pair was much higher in normative frequency than the other: the high-frequency neighbors had a mean Kucera and Francis (1967) normative frequency per million words of 528.2 and the low-frequency neighbors had a mean normative frequency of 14.7. Of the 40 pairs of neighbors, in 16 of the pairs the two neighbors differed from one another at the first letter position (e.g., side–TIDE), in 19 of the pairs the neighbors differed from one another at one of the middle letter positions (e.g., lift–LEFT, and wife–WIPE), and in 5 of the pairs the neighbors differed at the last letter position (e.g., half–HALT). For each neighbor pair, two four-letter control primes with similar normative frequencies and neighborhood sizes were selected. These quartets of words (the neighbor pair and the two control primes) were used to create the four prime-target conditions: 1) higher frequency neighbor prime–lower frequency neighbor target (e.g., help–HEAP), 2) higher frequency control prime–lower frequency neighbor target (e.g., area–HEAP), 3) lower frequency neighbor prime–higher frequency neighbor target (e.g., heap–HELP), and 4) lower frequency control prime–higher frequency 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 the word lengths, normative word frequency, neighborhood size, and lexical decision accuracy rates.

Forty nonword targets of four letters in length and with many neighbors ($M = 10.0$) 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 (these were the neighbor primes) and the other member of the pair did not share any letters with the target (these were the control primes). During the experiment half of the nonword targets were preceded by neighbor primes (e.g., fake–VAKE), and half were preceded by control primes (e.g., bolt–VAKE). There were two counterbalancing conditions 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 17-inch 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. 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 target remained in the display 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 interactive-activation (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 50 cycles in our simulations is equivalent to 5 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 numbers of cycles 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 14 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 (0.6% of the word trials and 2.4% 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) x (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, all 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, control 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 responses latencies of correct responses and the mean error rates are listed in Table 2.

Word targets. In the analysis of response latencies, the main effect of prime type was significant, $F_s(1, 54) = 25.30, p < .001, MSE = 1109.2$; $F_i(1, 78) = 19.89, p < .001, MSE =$ 1,085.3, with slower responding to targets primed by orthographic neighbors (577 ms) than to targets primed by control words (555 ms). There was no effect of prime type on error rates, both Fs < 1. There was a significant effect of target frequency in the response latency analysis, $F_s(1, 54) = 128.5, p < .001, MSE = 2{,}725.7$; $F_i(1, 78) = 70.12, p < .001, MSE = 4{,}083.5$, and in the error analysis as well, $F_s(1, 54) = 69.8, p < .001, MSE = 56.3$; $F_i(1, 78) = 17.87, p < .001, MSE = 174.7$. 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. 10.0%). As can be seen in Table 2, there was no hint of an interaction between target frequency and prime type, for either response latencies or for error rates (all Fs < 1), with virtually identical priming effects from high- and low-frequency neighbor primes (24 ms and 21 ms, respectively). Planned comparisons confirmed that the 24 ms inhibition effect was statistically significant, $t_s(54) = 3.13, p < .01, SEM = 7.7$; $t_i(39) = 2.95, p < .01, SEM = 8.7$, as was the 21 ms inhibition effect, $t_s(54) = 4.09, p < .001, SEM = 5.1$; $t_i(39) = 3.62, p < .01, SEM = 5.8$.

Nonword targets. There was an effect of prime type in the error analysis, $F_s(1, 54) = 6.90, p < .05, MSE = 26.3$; $F_i(1, 39) = 4.90, p < .05, MSE = 20.2$, but not in the response latency analysis, $F_s(1, 54) = 1.10, p > .10, MSE = 912.4$; $F_i < 1$. Nonwords were correctly rejected significantly more often when primed by neighbor primes (7.0%) than when primed by control primes (9.6%).

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 relative to an unrelated control 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 model did indeed make similar predictions here (i.e., a strong inhibition effect for the high frequency prime-low frequency target pairs and a much weaker effect for the low frequency prime-high 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 control 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 (34 ms vs. 13 ms) Nonetheless, 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 our results, however, we felt it was necessary to conduct a new experiment with a different set of stimuli and additional stimulus controls, the details of which are described below.

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 issues we chose to focus on: the neighborhood size of the primes (and the targets), and the normative frequency of the primes preceding nonwords. Neither of these variables was explicitly controlled in Segui and Grainger's study and hence, neither was explicitly controlled in the present Experiment 1. One could, however, argue that each could have had some impact on the size of the priming effects.

With regard to the neighborhood size issue, previous research has shown that (facilitory) priming effects for nonword neighbors and word targets are influenced by the number of neighbors the stimuli possess (i.e., "the density-constraint effect"; Forster, 1987; Forster et al., 1987; Forster & Taft, 1994). In particular, small neighborhood targets seem to be more prone to show facilitation, and hence, potentially less likely to show inhibition. In Experiment 1, the average neighborhood sizes were reasonably large, however, about 11% of the critical stimuli had few neighbors (i.e., less than four neighbors). In Experiment 2, only words and nonwords with many neighbors (more than five) were used.

Second, 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, 2002; Masson & Bodner, 2003). In Experiment 1, nonword targets were 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 aware of these relationships, 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 (related and unrelated). 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 would have been even larger than observed.) Although to our knowledge there have been no reports of this type of effect, we decided to safeguard against this possibility by manipulating the normative frequency of the nonword primes. 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), and so the prime frequency was not predictive of the target's lexicality.

Method

Participants. Fifty-eight 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 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 97.3% 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). Sixty-five percent of these pairs (26 of the

40 pairs) were used in Experiment 1. All of the words had at least 6 neighbors, with an average of 10.2 neighbors. One member of the neighbor pair was much higher in frequency than the other, with the high-frequency neighbors having a mean normative frequency of 506.9 and the low-frequency neighbors having a mean normative frequency of 12.5. Of the 40 pairs of neighbors, in 14 of the pairs the two neighbors differed from one another at the first letter position, in 23 of the pairs the neighbors differed at one of the middle letter positions, and in 3 pairs the neighbors differed at the last letter position. For each neighbor pair, two control primes of the same length and with similar normative frequencies neighborhood sizes were selected. The descriptive characteristics of the stimuli are listed in Table 3.

Forty nonwords of four and five letters in length, all with large neighborhoods, were also selected. For these nonwords, 40 words of matching length and neighborhood size were selected to serve as primes. The primes were either an orthographic neighbor of the nonword (the neighbor primes) or a word that did not share any letters with the nonword (the unrelated primes). As noted, half of the primes were high-frequency words and the other half were low-frequency words. The pairing of the stimuli and the creation of the counterbalancing lists was identical to Experiment 1, except that four counterbalancing lists were required for the nonwords, rather than two, as a result of the frequency manipulation for the nonword primes.

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

Simulations. The simulations were conducted in the same manner as described in Experiment 1. The predictions of the interactive-activation 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, 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, control prime) x 2 (Target Frequency: low, high) factorial ANOVA, with both subject (F_s) and item (F_i) analyses carried out. In the subject analysis all factors were within-subject factors, and in the item analysis Prime Type was a within-item factor and Target Frequency was a between-item factor. For the nonword data, response latencies and error rates were analyzed with a 2 (Prime Type: neighbor prime, control prime) x 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, $F_s(1, 55) = 57.36, p < .001, MSE = 1{,}027.7$; $F_i(1, 78) = 28.17, p < .001, MSE = 1{,}554.2$, and on errors, $F_s(1, 55) = 9.71, p < .01, MSE = 69.9$; $F_i(1, 78) = 5.46, p < .05, MSE = 88.9$. 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 control primes (548 ms and 5.2% errors). As expected, there was a main effect of target frequency for both response latencies, $F_s(1, 55) = 125.76, p < .001, MSE = 1{,}460.1$; $F_i(1, 78) = 64.98, p < .001, MSE = 2{,}366.1$, and for errors, $F_s(1, 55) = 15.56, p < .001, MSE = 86.8$; $F_i(1, 78) = 9.55, p < .01, MSE = 101.0$. Responses to high-frequency targets were faster (536 ms) and more accurate (4.5% errors) than responses to low-frequency targets (593 ms and 9.4% errors). Most important was the absence of an interaction between prime type and target frequency in the response latency analysis, $F_s(1, 55) = 3.01, p = .09$, $MSE = 1,040.6$; $F_i\ (1, 78) = 1.39, p > .10$, $MSE = 1,554.1$, and in the error analysis (both $Fs < 1$). Planned comparisons showed that both the 40 ms inhibition effect from higher frequency neighbor primes and the 25 ms inhibition effect from lower frequency primes were statistically significant, $t_s(55) = 6.30, p < 001$, $t_i(39) = 4.27, p < 001$, and $t_s\ (55) = 4.30, p < 001$, $t_i(39) = 3.18, p < .01$, respectively. Thus, like the situation in Experiment 1, there was really 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, $F_s(1, 55) = 1.59, p > .10$, MSE =1,624.6; $F_i < 1$, and no interaction, $F_s(1, 55) = 1.08, p > .10$, $MSE = 983.2$; $F_i < 1$. In the error analysis there was no effect of prime type (both Fs < 1), but there was an effect of prime frequency in the subject analysis, $F_s(1, 55) = 7.50, p < .01$, $MSE = 53.60$; $F_i\ (1, 38) = 1.33, p > .10$, $MSE = 107.7$. Nonwords were responded to more accurately when primed by low-frequency words (5.7%) than when primed by high-frequency words (8.4%). The interaction was not significant (both Fs < 1).

Discussion

The main goal of Experiment 2 was to replicate the results of Experiment 1 with a different group of participants, with a more controlled set of stimuli, all of which had large neighborhoods, and where the prime frequency was not predictive of the target's lexicality. As in Experiment 1, our key results were: 1) a significant inhibitory priming effect, and 2) the size of 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 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 inhibit target identification to essentially the same degree, results which conflict with the lexical competition assumptions that are currently implemented in the IA model. Thus the question remains as to why we observed inhibitory priming from lower frequency neighbors while Segui and Grainger (1990) did not. One possibility is that Segui and Grainger's stimuli differed from our own 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 lower frequency target, it is possible that Segui and Grainger selected stimuli from neighborhoods consisting of a single very higher 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, 2003), four-letter

French words (which Segui & Grainger used) have an average of 6.4 neighbors while 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 this could go some distance toward explaining Segui and Grainger's inability to find inhibition when higher frequency targets are primed by lower frequency neighbors. Thus, the possibility that the discrepancy between our results and those of Segui and Grainger stems from differences in the neighborhood size of the stimuli seemed worthy of exploration. The idea that neighborhood size is important 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 ($M = 3.5$). Accordingly, in Experiment 3, we manipulated the neighborhood size of our stimuli (many vs. few) to gauge the effect of the neighborhood size factor on inhibitory neighbor priming. 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 lack of a target frequency by prime type interaction), with a different set of stimuli and a different group of participants.

Method

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

Stimuli. As in the previous experiments, only words with a high lexical decision accuracy rate 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 97.5% 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 (>5, $M = 9.4$ neighbors), and 40 pairs with few neighbors (<4, $M = 2.7$ neighbors). Seventy-eight of the 80 pairs (97.5%) were not used in the previous experiments. The descriptive statistics for these stimuli are listed in Table 6.

For the 40 neighbor pairs with many neighbors, one member of each pair was much higher in normative frequency than the other ($M = 347.6$ vs. 19.6 occurrences per million). In 17 of the pairs the two neighbors differed at the first letter position, in 22 of the pairs the neighbors differed at one of the middle letter positions, and in one pair the neighbors differed at the last position.

For the 40 neighbor pairs with few neighbors, again, one member of the pair was much higher in normative frequency than the other ($M = 356.6$ vs. 21.3). In 14 of the pairs the two neighbors differed from one another at the first letter position, in 21 of the pairs the neighbors differed at one of the middle letter positions, and in 5 pairs the neighbors differed at the last letter position. Unrelated primes of similar normative frequency and neighborhood size were selected for each of the neighbor pairs.

Eighty-nonwords of four and five letters in length were selected, 40 with many neighbors and 40 with few neighbors. Eighty word pairs, of matching word length and neighborhood size, were selected to serve as primes. The primes were either an orthographic neighbor of the nonword (the neighbor primes) or a word that did not share any letters with the nonword (the unrelated primes). 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. Eight counterbalancing lists were created such that each word served as a target the same number of times, but a particular pairing for the target was rotated across lists so that each participant saw each target only once (the nonword pairs were also rotated across these lists).

Apparatus and procedure. The apparatus and procedure were identical to 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. Note that for the words with small neighborhoods, the model also predicts that there will be no priming effect from lower frequency neighbor primes.

Results

To be consistent with the previous experiments, data from participants with 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 (0.4% 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, control prime) x 2 (Target Frequency: low, high) x 2 (Neighborhood Size: many, few) factorial ANOVA. In 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, control prime) x 2 (Prime Frequency: low, high) x 2 (Neighborhood Size: many, few) 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 neighborhood size and prime frequency were between-item factors. The mean response latencies and the mean error rates for the word targets are listed in Table 7; the data for the nonword targets is 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%) when targets were primed by neighbor primes than when they were primed by unrelated primes (546 ms and 5.3%). 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%). There was also a main effect of neighborhood size in the subject analyses, both for response latencies, $F_s(1, 55) = 4.07$, $p < .05$, $MSE = 1{,}335.2$; $F_i(1, 156) = 1.36$, $p > .10$, $MSE = 5{,}186.6$, and for errors, $F_s(1, 55) = 5.07$, $p < .05$, $MSE = 85.3$; $F_i(1, 156) = 1.61$, $p > .10$, $MSE = 191.3$. 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 (6.8% errors) than target words with few neighbors (559 ms and 8.8%).

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 target frequency and prime type, $F_s\ (1, 55) = 8.61, p < .01, MSE = 64.9$; $F_i\ (1, 156) = 5.80, p < .05, MSE = 68.7$. 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 x 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 31 ms inhibition effect for high-frequency neighbor targets, both of which were statistically significant, $t_s\ (55) = 3.76, p < .001, t_i$ $(39) = 4.18, p < .001$, and $t_s\ (55) = 4.54, p < .001, t_i\ (39) = 4.67, p < .001$, 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.[4]

For the words with few neighbors, on the other hand, a different pattern emerged. There was evidence of a Prime Type x 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, the response latencies to targets primed by lower frequency primes and by unrelated primes being identical (529 ms). The 18 ms inhibition effect produced by a higher frequency neighbor 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 due to the fact that both lower frequency and higher frequency neighbor primes produced inhibition when the words had many neighbors (as was the case in Experiments 1 and 2), whereas only higher frequency neighbor primes produced inhibition when the words had few neighbors. This latter result is consistent with Grainger and Segui's (1990) results, and confirms our initial suspicion 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, $F_s(1, 55) = 9.62$, $p < .01$, $MSE = 1{,}790.3$; $F_i(1, 76) = 2.09$, $p > .10$, $MSE = 2{,}301.6$. 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, $F_s(1, 55) = 39.83$, $p < .001$, $MSE = 1{,}674.9$; $F_i(1, 76) = 12.27$, $p < .01$, $MSE = 2{,}301.6$, 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 (644 ms) and more error prone (13.3%) than responses to nonwords with few neighbors (620 ms and 5.2% errors). The only interaction was in the analysis of errors rates, where the Prime

Frequency x Neighborhood Size interaction was significant in the subject analysis, $F_s(1, 55) = 12.78$, $p < .01$, $MSE = 80.8$; $F_i(1, 76) = 2.91$, $p = .09$, $MSE = 92.2$. For the nonwords with few 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%) than when primed by low-frequency words (7.1 %).

Discussion

In Experiment 3, we manipulated the neighborhood size of the stimuli to test the possibility that the discrepancy between our results in Experiments 1 and 2 and Segui and Grainger's (1990) results may have been due to differences in the neighborhood size of the stimuli used. The results of this experiment would appear to confirm this suspicion: 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, which produces essentially the same pattern of inhibition effects regardless of neighborhood size of the stimuli. As can be seen in Table 7, for both large and small neighborhood targets, inhibition was predicted only for the high frequency prime-low frequency target pairs. This is because in the simulations, the lexical competition is dominated by the prime and the target nodes and as a consequence the neighborhood size of prime and targets plays a relatively minor role (see Davis, 2003).

The finding that neighborhood size matters here raises the inevitable question of what component of the neighborhood matters. In neighbor priming experiments, one can define three types of neighbors. Considering, for example, the prime-target pair, help-HEAP, some words are neighbors only to the prime (e.g., HELD), others are neighbors of only the target (e.g., HEAL) while 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). While the prime only neighbor (e.g., HELD) or target only neighbor (e.g., HEAL) are activated upon either 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 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 3.4 shared neighbors), whereas for the pairs with few neighbors, less 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 0.48 shared neighbors). This proposal is quite consistent with the results of Experiment 2 in Davis and Lupker (2006). In their experiment, 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.

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., bore-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 (e.g., bore-

BORN), or, in a few instances, shared a single neighbor of very low normative frequency (e.g., for a neighbor pair lend-LEAD, *lewd* was a shared neighbor, and for a neighbor pair lash-LAST *lass* was a shared neighbor), and in the control condition the primes were not orthographically related to the targets (e.g., gang-BORN). Because Experiment 3 demonstrated that the neighborhood size of the primes and targets is important, these were also manipulated in Experiment 4: In Experiment 4A the primes and targets had many neighbors and in Experiment 4B the primes and targets had few neighbors.

Experiment 4

Method

Participants. Eighty-five University of Calgary undergraduate students volunteered to participate in the experiment in exchange for partial 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) with many neighbors ($M = 11.0$) 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 was primed by one of the three prime types, 1) primes that were orthographic neighbors of the target and shared at least one neighbor with the target, with a mean of 3.3 shared neighbors (the mean normative frequency of the highest frequency shared neighbor was 169.2; the mean lexical decision accuracy rate to the highest frequency shared neighbor was 97.3%, Balota et al., 2002), 2) primes that were orthographic neighbors of the target but shared no neighbors with the target 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%, Balota et al., 2002), and 3) unrelated primes that were not orthographically related to the targets. The three prime types were matched as closely as possible on normative word frequency (*M* = 17.7) and the number of neighbors (*M* = 10.4). To make the proportion of neighbor pairs and unrelated pairs equal, an additional 14 unrelated prime-target fillers of similar lexical characteristics were shown to participants.

As noted, all of the critical targets were of very high normative frequency (*M* = 413.6), and would therefore by 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 words were shown in the lexical decision task, an additional 56 word targets with low normative frequencies (*M* = 11.9) were shown to participants. All of these filler targets had many orthographic neighbors (*M* = 10.0) 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* = 12.6) with many neighbors (*M* = 10.1), half of them primed by orthographic neighbors and the other half primed by orthographically unrelated control words.

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 (unlike the situation when the words have many neighbors, where there may be 10 or more neighbors to choose from). As a result, for Experiment 4B, unlike

Experiment 4A, we could not use the same control prime for the shared neighbor condition and the non-shared neighbor condition; different unrelated primes had to be used for the shared neighbor condition and the non-shared neighbor condition.

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) and the other of low normative frequency (M = 14.7). All of the words had few neighbors, with a mean of 3.6 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 = 1.2; the mean normative frequency of the highest frequency shared neighbor was 91.8; the mean lexical decision accuracy rate to these words was 96.2%,) and for the second set the primes and target had no shared neighbors or a single shared neighbor of very low normative frequency (M = 0.5 occurrences per million; the mean number of shared neighbors was 0.1; the mean lexical decision accuracy rate to these shared neighbors was 48.5%, Balota et al., 2002).

For each neighbor prime, a control prime of the same length and with a similar normative frequency and neighborhood size was selected. The descriptive characteristics of the stimuli are listed in Table 3. An additional 60 word targets of low normative frequencies (M = 14.5) were added to the stimulus set so that participants saw a mixture of high- and low-frequency words, like 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 neighborhood effect on word targets was stronger when the nonwords had many neighbors than when they had few neighbors. To capitalize on this effect, 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 Experiment 4A, where all the nonwords had large neighborhoods. Two sets of 30 nonwords with similar characteristics were selected. One set of the nonwords had many neighbors ($M = 9.9$) and the other set of nonwords had few neighbors ($M = 3.1$). All nonwords were primed by words that were matched in length and neighborhood size, and were either orthographic neighbors of the nonwords or control words. The primes preceding nonword targets were all low in normative frequency ($M = 14.6$). To maintain an equal number of word and nonword items, an additional 60 nonwords were added to the stimulus set. All of these filler nonwords were primed by low-frequency words ($M = 14.2$), with half primed by their orthographic neighbors and the other half primed by control words. As with the preceding experiments, counterbalancing lists were created in such a way that 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 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 analysis (0.91% 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, control 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 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, $F_s(2, 82) = 5.31, p < .01, MSE = 1132.3$; $F_i(2, 82) = 3.43, p < .05, MSE = 2015.5$. Responses to targets were 22 ms slower when primed by neighbor primes with shared neighbors than when primed by unrelated primes, $t_s(41) = 2.71, p < .05, SEM = 7.8$; $t_i(41) = 2.48, p < .05, SEM = 8.7$. The same was true when the targets were primed by neighbor primes without shared neighbors—responses to targets without shared neighbors were 21 ms slower than responses to targets primed by unrelated primes $t_s(41) = 2.71, p < .05, SEM = 7.8$; $t_i(41) = 2.13, p < .05, SEM = 10.7$. 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. But there was no evidence 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 Fs < 1).

Nonword targets. There was no effect of prime type in the response latency analysis or in the error analysis (all Fs < 1)

Experiment 4B: Words with Few Neighbors

As was done in the previous experiments, the data from participants with error rates greater than 20% were excluded ($n = 3$), and response latencies less than 300 ms or greater than 1,200 ms were considered outliers and removed from all analyses (0.96% 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 control primes, and by comparing responses to targets primed by neighbor primes without shared neighbors to their corresponding orthographically unrelated control primes. The nonword data were analyzed by a 2 (Prime Type: neighbor prime, control prime) x 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.

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, $F_s(1, 39) = 6.33$, $p < .05$, $MSE = 28.43$; $F_i(1, 29) = 3.36$, $p = .08$, $MSE = 40.17$. Participants made more errors to targets when they were primed by neighbors (6.3%) than when they were primed by control 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, $F_s(1, 39) = 7.05$, $p < .05$, $MSE = 15.44$; $F_s(1, 29) = 5.05$, $p < .05$, $MSE = 16.14$. 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 control 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 control primes (a difference of 3.3%). The more important result, however, 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 control primes, but this was true regardless of whether the primes and target shared neighbors.

Nonword targets. There was no effect of prime type in the analysis of response latencies, $F_s(1, 39) = 1.97$, $p > .15$, $MSE = 860.2$; $F_i(1, 58) = 1.53$, $p > .22$, $MSE = 1164.1$, 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, $F_s(1, 39) = 27.1$, $p < .001$, $MSE = 1352.5$; $F_i(1, 58) = 6.41$, $p < .05$, $MSE = 2711.8$, as well as for errors, $F_s(1, 39) = 12.15$, $p < .01$, $MSE = 46.3$; $F_i(1, 58) = 2.31$, $p = .13$, $MSE = 182.7$. 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 (684 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, $F_s(1, 39) = 2.95$, $p = .09$, $MSE = 1837.4$; $F_i(1, 58) = 2.67$, $p = .11$, $MSE = 1164.1$, 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, 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 any shared neighbor with the target, or unrelated words. Although both experiments replicated the basic effects observed in the previous experiments, such that there was a significant inhibition effect from lower frequency neighbor primes for the words with many neighbors but not for the words with few neighbors, there was no indication that this inhibition effect was moderated by shared neighbors. Our results therefore suggest that 1) being a shared neighbor does not give additional competitiveness to a lower frequency neighbor, and 2) the inhibition effects from lower frequency neighbors in the preceding experiments were not due to differences in the number of shared neighbors but rather due to the differences in overall neighborhood sizes.

General Discussion

The purpose of the present research was to determine whether the inhibitory neighborhood frequency effect is reliably observed in English using the masked priming paradigm. Considered together, the results were quite clear—in all of our experiments we found that orthographic neighbor primes delayed target identification. In Experiment 1 and 2, only words with many neighbors were tested and in Experiment 3, both words with many neighbors and words with few neighbors are tested. In Experiment 1, target identification was significantly delayed by neighbor primes, and the effect was observed irrespective of prime-target relative 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 important 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 (about 65% of the word stimuli were from Experiment 1). Although the size of the inhibition effect from higher frequency neighbors (40 ms) was numerically larger than the effect from lower frequency neighbors (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 which the frequency characteristics of the primes preceding nonwords were controlled similarly to Experiment 2. In Experiment 3 we again replicated the first two experiments with a new set of stimuli. For words with many neighbors, there were equivalent inhibition effects from higher frequency neighbor primes (27 ms) and from lower frequency neighbor primes (31 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 an orthographic neighbor competes with a target's representation, delaying the word identification process (Davis, 2003, Grainger, 1999). The results of the present study therefore suggest that similar to other alphabetical languages such as French, German, and Dutch, lexical competition plays a significant 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 a prime's having a frequency advantage over the target. According to the models, inhibition from neighbors should be observed only when the primes are higher in frequency than the targets. This neighborhood frequency effect should be observed irrespective of the neighborhood sizes of the stimuli; the model essentially predicts the same pattern of inhibition effects for words with many neighbors and for words with few neighbors (Davis, 2003).

In our experiments, it was clear that for the words with many neighbors, lower frequency neighbor primes inhibit target identification of higher frequency targets as much as higher frequency neighbor primes inhibit lower frequency targets. This was always the case despite the fact that the difference in normative frequency between primes and targets was very large (e.g., 300–500 occurrences per million). The simulations run using the present stimuli showed some inhibition from lower frequency neighbor primes; however, the sizes of inhibitions were considerably smaller compared with the effect from higher frequency neighbor primes (only a third to a fourth of the size of the effect from higher frequency neighbor primes). On the other hand, for the words with few neighbors, only the higher frequency neighbor primes reliably inhibited target identification and there was absolutely no effect when these primes and targets were reversed. The simulations predicted the behavioral results quite accurately, an inhibitory priming effect from higher frequency primes, and no effect from lower frequency primes.

In Experiment 3, we manipulated the neighborhood size of the stimuli to test the possibility that the discrepancy between our results in Experiments 1 and 2 and Segui and Grainger's (1990) results may have been due to differences in the neighborhood size of the stimuli used. In Experiments 1 and 2, we observed inhibitory priming from lower frequency neighbors while Segui and Grainger did not. We speculated that Segui and Grainger's stimuli differed from the stimuli used in Experiments 1 and 2 with respect to neighborhood size: that Segui and Grainger's stimuli had fewer neighbors than the words used in Experiments 1 and 2, all of which had large neighborhoods. To test this hypothesis, in Experiment 3 we manipulated the neighborhood size of our stimuli (many vs. few) to gauge the effect of the neighborhood size factor on inhibitory neighbor priming. Our results indicated that the neighborhood size of the stimuli is important—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 (replicating Segui & Grainger's results). This outcome is not readily predicted by the activation models; in fact, the models' predictions are essentially the same for words with many neighbors and for words with few neighbors (Davis, 2003)[5].

Shared Neighbor as an Explanation for the Different Inhibition Effects by Neighborhood Size

The interaction between the relative prime-target frequency and the neighborhood size that we observed in the present study clearly is inconsistent with the prediction of the interactive-activation model. The obvious question is then, what could be the source of this discrepancy? One possible factor that was tested in Experiment 4 was shared neighbor effects. Because words with many neighbors are more likely to have shared neighbors than words 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.

This hypothesis had some support based on data reported by Davis and Lupker (2006, Experiment 2). In that experiment, for higher frequency primes and lower frequency target pairs, there was a much stronger inhibition effect when primes and targets had a shared neighbor than when they did not have a shared neighbor (but 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 2003) is due to the lexical inhibition from shared neighbors. The logic is that the lexical inhibition produced by these shared neighbors offset a facilitation effect occurring at the sub-lexical level, resulting in an overall null effect. Similarly, a study by Van Heuven, Dijkstra, and Grainger (2001) lend 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. Their stimuli had a medium number of neighbors (*M* = 4.5). They found that nonword neighbor primes did not facilitate target identification when the prime and target had a shared neighbor, whereas primes did facilitate target identification when the prime and target did not have a shared neighbor. These results all suggest that the shared neighbors play a role in producing a strong inhibition effect, and give support to the possibility that the inhibition from lower frequency neighbor primes in the present experiments is due to the presence of shared neighbors, rather than neighborhood size per se.

Experiment 4 was conducted to directly test this shared neighbor hypothesis. We manipulated the shared neighbor status of lower frequency neighbor primes and higher frequency targets, such that in one condition, the pairs had at least one shared neighbor and in the other condition, they did not have any shared neighbors. The test of this hypothesis produced clear-cut results: 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 neighbor 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). We observed a small inhibition effect in errors; however, again there was no effect of shared neighbors on this inhibition effect. 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 lower than that of targets, which was always the case in Experiments 1, 2, and 3 as well. Therefore, whether there is an inhibitory effect of shared neighbor when those neighbors are higher in frequency than target was not tested. For present purposes (i.e., providing a closer examination of the results of Experiment 3), such a manipulation was not relevant.

Based on the results of Experiment 4, we therefore ruled out the possibility that the results of Experiment 3 was a shared neighbor effect. The question then still remains: What is causing the interaction between neighborhood size, priming, and relative prime-target frequency? That is, what causes large neighborhood targets to show one pattern and small neighborhood target to show a different one?

Speed of Lexical Activation as an Explanation

First, we focus on the relation between the prime duration and the speed of lexical activation. In priming studies, researchers often manipulate the prime duration to investigate the time course of lexical activation processes (e.g., Ferrand, & Grainger, 1992; Ferrand & Grainger,1994; Perfetti & Tan, 1998). Previous priming studies investigating neighborhood effects have shown that depending on the prime duration, even the same stimuli produce qualitatively different effects. It has been found that when the prime duration is very short (typically shorter than 40 ms) orthographically similar primes facilitate target identification, whereas at longer prime durations (e.g., 50-67 ms) the facilitory effect disappears for nonword primes (Ferrand, & Grainger, 1992; Ferrand & Grainger, 1994) or turns into inhibition for word primes (Perfetti & Tan, 1998). These qualitatively different results can be explained within the framework of lexical activation models; the facilitory priming effect being attributed to a sublexical facilitation effect via between-layer excitatory connections and the inhibitory priming effect being attributed to lexical inhibition via within-layer inhibition connections (e.g., see Ferrand & Grainger, 1992; Perea & Rosa, 2000; Perfetti & Tan, 1998). Thus, previous studies indicate that it seems that the lexical inhibition starts to emerge when the prime duration is around or longer than 50 ms.

In the present experiments, we employed a prime duration of 60 ms (as did Segui & Grainger, 1990, and Davis & Lupker, 2006). It is possible that 60 ms is sufficiently long for words with many neighbors to initiate lateral inhibition process, but too short for words with few neighbors. We do known that for low-frequency words, lexical decision latencies are faster for words with many neighbors than for words with few neighbors (Andrews, 1992). This type of result suggests that lexical selection is completed more quickly for low-frequency words with many neighbors. We also know that words with large neighborhoods are identified more accurately than words with small neighborhoods in a standard perceptual identification task using forward and backward masks of 42 ms and a 28 ms target presentation (Sears, Lupker, & Hino, 1999). These results also suggest that lexical selection is completed more quickly for low-frequency words with many neighbors. If so, then it is possible that with a 60 ms prime duration low-frequency words with many neighbors were activated sufficiently to produce inhibition, while low-frequency words with few neighbors were not. Prime duration would, presumably, only affect low-frequency primes; because high-frequency words have higher resting activation levels in the activation models, their lexical units would be sufficiently activated with 60 ms prime duration, regardless of their neighborhood size. Thus, high-frequency primes should show inhibition independent of their neighborhood status (as was observed in the present experiments).

However, a piece of evidence against the speed of activation hypothesis comes from Perea and Rosa (2000)'s study in Spanish. In their masked priming study employing a 60 ms prime duration, there was a significant repetition effect for low-frequency words that had no neighbors (i.e., hermit words). Assuming the effect reflects a lexical process, this suggests that a 60 ms prime duration is sufficiently long for a hermit word's lexical information to be sufficiently activated, implying that a 60 ms prime duration is also sufficiently long for words with few neighbors.

Another problem for this hypothesis is that it is based on the idea that lexical decisions are made on the bases of lexical activation only (i.e., faster decision latency indicates faster lexical retrieval). However, it has been suggested that faster decision latencies for large neighborhood low-frequency words may not reflect faster completion of lexical retrieval. Rather, they may be due to a strategy that participants employ. As outlined in Grainger and Jacob's multiple read out (MRO) model (1996). According to the model, a lexical decision can be made either on the basis of activation of a single lexical unit or on the basis of the global level of activation (the summed lexical activation produced by the word and all of its neighbors). Lexical decision response can be triggered by whichever activation reaches threshold faster. According to the model, words with many neighbors are responded to faster than words with few neighbors when lexical decisions are made based on global activation, and hence, the neighborhood size effect not reflect lexical processing (but see Andrews, 1998; Siakaluk et al., 2002, for the potential problems of this model). Obviously, if faster identification time for words with many neighbors does not mean faster lexical retrieval, then the speed of lexical activation hypothesis cannot account for the difference as a function of neighborhood size.

It is possible to explain the facilitory neighborhood size within the framework of lexical competition models, as suggested by Andrews (1992). Words with many neighbors can be identified faster if co-activated neighbor units a send strong letter level activation back to target's letter units, which in return raise activation of the target word unit. It is thus possible to assume that the lexical decision can be made solely at the lexical level rather than by a strategy. However, if this explanation was true, then the neighborhood size effect in the priming effect would be also facilitory, as the neighbor primes as well as the co-activated neighbors of the primes (especially shared neighbors) should send stronger letter level activation to the target[6]. As is apparent, we have observed otherwise in the present experiments. Taken together, these considerations suggest that it is unlikely that the speed of activation hypothesis can adequately explain why low-frequency primes with large neighborhoods produce inhibition whereas low-frequency primes with small neighborhoods do not.

Stimulus Selection as Explanation

A second possible explanation for why the present experiments found equivalent inhibition effects from lower frequency and higher frequency primes may be due to the fact that our stimuli, even low frequency stimuli, were chosen to be very familiar. That is, even though the mean normative frequencies of our stimuli were similar to those in previous studies (i.e., 10-35 occurrences per million), we had selected only stimuli that had high levels of accuracy in previous lexical decision experiments based on information from the English Lexicon Project Database(Balota, et al., 2002). Because activation levels in the simulations are determined solely on the basis of object frequency, they may have underestimated the inhibitory power from our lower frequency neighbor primes.

Unfortunately, although this explanation may be able to account for why there was inhibition from lower frequency primes when it did exist, what it cannot explain is why the effect disappeared with in other circumstances. The same processes that led to the selection of targets in Experiments 1 and 2 were at work in selecting the low frequency small neighborhood words in Experiment 3. Thus, if this explanation was correct, we should have observed an inhibition effect both for the words with many neighbors and for the words with few neighbors. That is, there is no reason to expect that an inhibition effect due to the higher familiarity of our lower frequency neighbor primes should occur for the words with many neighbors, but not for the words with few neighbors.

Neighborhood Size Effect as an Explanation

Previous studies have suggested that masked priming effects reflect relatively pure lexical process with minimal contamination of strategic factors (Kinoshita & Lupker, 2003). For one, as primes are presented below conscious threshold, it prevents participants from making decisions based on the conscious appreciation of the prime- target relationship. In addition, the fact that a priming effect is observed only for word targets (being nonexistent or considerably smaller for nonword targets) also supports the interpretation that the effect is reflecting lexical processing. Further evidence supporting the lexical origin of the masked priming effect comes from cross-language priming (e.g., Gollan, Foster, & Frost 1997; Jiang & Foster, 2001; Kim & Davis, 2002). In these studies, significantly priming effects have been observed for prime and target that are presented in different scripts (e.g., Hebrew-English, Chinese-English, and Korean-English). This effect would not be observed if the priming effects are produced at the sublexical level due the perceptual similarity of primes and target. Thus, it does seem clear that the present data require a lexically-based explanation[7].

Further, it appears that the inhibition effect for high-frequency targets following low frequency primes is a real "neighborhood size effect". To demonstrate this fact, we conducted a post-hoc analysis by regressing priming effects by the number of the prime's neighbors, collapsing across all our experiments (we excluded the items with more than 17 neighbors, as the priming effects for these words were based on only two to three items and their mean priming effects were not deemed reliable). Figure 1 shows the relationship between the number of the prime's neighbors and the size of the inhibition effect for the 295 cases were a lower frequency prime primed a higher frequency neighbor (the neighborhood size range from 1 to 16). The correlation was significant, $r = .22, p < .001$, indicating that as the number of lower frequency prime's neighbors increased, there was a stronger inhibition effect.

To examine the inhibition effect more closely, the mean priming effect was plotted per the number of prime's neighbors in Figure 2. As can be seen, the priming effect shows a facilitation trend when the higher frequency target is the only neighbor of the prime ($M = 1$), with the effect turning into inhibition as the number of the prime's neighbors increases. Figure 2 also suggests the effect seems to level off when neighborhood size is larger than 9, although the correlation did not become substantially stronger when we confined the correlation to the words with neighborhood sizes of 1 to 9 ($r =. 27, p < .001$).

As noted, empirically, these patterns of inhibitory effects associated with the neighborhood size could certainly explain why in previous studies lower-frequency primes sometimes showed slight facilitation or weak inhibition depending on the stimuli used (Segui & Grainger, 1990; Davis & Lupker, 2006). For instance, Davis and Lupker found a 13 ms inhibition effect from lower frequency primes with their stimuli, which had a mean neighborhood size of 3.5. The correlational analysis of the data from our experiment showed the size of the priming effect to be 9 ms when the mean neighborhood size was calculated to be 3.5. It can also explain why we did not find any inhibition effect in Experiment 3, but found a small effect in errors in Experiment 4B, as the neighborhood size of the former was smaller than the latter ($M =$ 2.6 and 3.6 respectively).

Interestingly, the same correlational analysis for higher frequency prime and lower frequency target pairs shows no relation between the number of prime's neighbors and the size of the priming effect, $r = .037$, ns. This result suggests that the principles may be different when high-frequency versus low-frequency primes are used. One other correlational analysis lends additional support to this conclusion. We correlated the size of the inhibition effect from higher frequency neighbors and from lower frequency neighbors for each participant in Experiment 1, 2 and 3. Only words with many neighbors were included in the analysis, as these were the words that produced equivalent inhibition effects from higher and lower frequency neighbor primes. If the same mechanism was underlying priming effects from higher and lower frequency neighbors, one would assume that there would be a moderate to strong correlation between the size of inhibition brought about by these two different primes. Stated differently, a participant who experienced a large priming effect from a higher frequency neighbor primes would also be expected to experience a large priming effect from a lower frequency neighbor prime (and vice versa) were the underlying mechanism the same. On the other hand, if the different mechanisms were responsible for the two priming effects the priming effects would be unlikely to be correlated. Our results showed that there was no correlation between the two priming effects, $r = .12$, $p > .10$, suggesting that different mechanisms are involved.

Another piece of evidence suggesting that different inhibition mechanisms may be operating for lower frequency and higher frequency neighbor primes come from the findings that shared neighbors influenced target identification differently for low- and high-frequency neighbor primes. In Experiment 4, we did not find that shared neighbors play a significant role in target identification for lower frequency neighbor primes. This finding is clearly inconsistent with the result of Davis and Lupker's (2006) Experiment 2; these authors did find that a shared neighbor was powerful inhibitor for higher frequency neighbor primes. The obvious implication of such an inconsistency is that a shared neighbor produces inhibition only when the neighbor primes are higher in frequency than the target. It may be that for primes that are higher frequency neighbors, the lexical competition is dominated by the prime's word units and co-activated shared neighbors, and consequently, neighborhood size plays little role in priming. However, for lower frequency primes, the activation of the neighborhood size itself is the key element.

All of these observations lead us to ask how the neighborhood size of the words affects the lexical competition process when low frequency words prime higher frequency neighbors. One obvious possibility is that the neighbors of the primes that are *not* the neighbor of the target (i.e., prime-only neighbors) are actually capable of inhibiting target identification if there are enough of them. Further, it appears that words may actually have more neighbors than originally proposed (Colheart et al., 1997). For example, target identification can be slowed down by a word prime that is shorter or longer than the target's word length (De Moor & Bysbaert, 2000; Drews & Zwiserlood, 1995) and also by a prime that shares only the first syllable of the target (Carreiras & Perea, 2002). These results suggest that the target's word unit receives inhibitory signals from a far larger range of words than the original model assumed, as do the findings of Janack et al., (2004)'s study. These authors found that a lower frequency prime that has a 50% overlap (e.g., lash–CAST) with the target significantly delayed target identification in a lexical decision task (their prime duration was 48 ms). The size of inhibition from such partial primes was as large as from conventional orthographic neighbor primes, where primes and target had 75% letter level overlap (e.g., mast– CAST or cash-CAST). These findings suggest that a word that has a partial overlap with the target competes with a target unit as strongly as orthographic neighbors.

Our stimuli consisted of four-and five-letter words, and consequently, a prime's neighbors also had at least 50% letter level overlap with the target. For instance, for a four-letter neighbor pair heap–HELP, a prime only neighbor *heat* has 50% letter level overlap with the target HELP, and a shared neighbor *hemp* has 75% letter level overlap. Likewise, for a five-letter neighbor pair shirt–SHORT, the prime only neighbor *shift* has a 60% overlap with SHORT, and a shared neighbor *shout* has 80% overlap with SHORT. It is likely then, that the linear relation between the size of the inhibition effect and the number of the prime's neighbors observed in the present study was due to the prime-only neighbors collectively competing with the target unit.

An alternative possibility that should be considered is that the inhibition effect may have been caused by a single partial neighbor that is higher in frequency than the target. As the number of the prime's neighbors increases, the probability of the prime having a higher frequency partial neighbor increases. Because as just suggested a partial prime can be a strong inhibitor in the competition process, it is important to test whether the effect was strictly associated with the number of the prime's neighbors or if it was associated with a single partial neighbor that was higher in frequency than the target. Accordingly, we conducted an additional correlational analysis (based on 209 cases) only with the prime-target pairs where the target was the highest frequency neighbor of the prime's neighbor gang. In such cases, the target was the strongest competitor in a group of neighbors and consequently there was no prime only target that was higher in frequency than the target. The results were consistent with our first correlational analysis: the size of the inhibition effect increased as the number of prime's neighbors increased, $r = .31, p < .001$. Based on this finding, our observations that lower-frequency neighbors inhibited higher frequency targets for words with many neighbors is most likely due to the prime's neighbors collectively competing with the target unit, which consequently delayed target identification.

It is important to note that our post-hoc analyses were conducted based on the number of the prime's neighbors; our results do not exclude the possibility that the neighborhood size effect is due to the number of target's neighbors or another variable that is highly correlated with neighborhood size. As for the former, we conducted a correlational analyses based on the number of target's neighbors. The association was smaller but still statistically significant, $r = .17, p < .01$. As the neighborhood size of the primes and targets was highly correlated, ($r = .82$), it is not possible to determine which factor contributed to the neighborhood size effect more critically (or could be both). This is a very important factor that calls for further research, as this has a direct bearing on our understanding of the mechanism of the inhibition, and consequently, it will affect how the model's parameters should be modified to better predict empirical results.

Implications for the Neighborhood Frequency Effect in the Lexical Decision Task

We noted earlier that most of the support for the inhibitory neighborhood frequency effect has come from studies in languages other than English (French, Spanish, and Dutch); studies using English stimuli typically had observed no inhibitory effect of higher frequency neighbors (e.g., Forster & Shen, 1996; Sears et al., 2006). These results suggest that lexical competition plays little role in the reading of English words. In the present research, we used the masked priming paradigm and found evidence of lexical competition. We also found that when words have some neighbors, lower frequency neighbors can strongly inhibit higher frequency targets, and with enough neighbors, lower frequency neighbors can inhibit higher frequency target as much as higher frequency neighbors inhibit lower frequency targets. Such results indicate that for English words, the number of competitors may be just as important as the frequency of those competitors. If this process also operates when single words are responded to then it could explain why the neighborhood frequency effect has been difficult to observe in English. That is, if the number of neighbors is important for producing inhibition effect, then, when words are equated on neighborhood size, words with a higher frequency neighbor should be identified no more slowly than words without higher frequency neighbors.

The difficulty with this explanation is that if the neighborhood size effect was indeed inhibitory, as suggested by the results of the current study, then in a lexical decision task one would expect that words with many neighbors would be identified more slower than words with few neighbors, assuming all other relevant variables are equated. Of course, we know this is not the case--low frequency words with many neighbors are responded to faster than low-frequency words with few neighbors (e.g., Andrews, 1989; 1992; Sears et al., 1995).

In the end, it possible that the two paradigms – the single word paradigm and the masked priming paradigm-- are capturing different processes in visual word identification, and thus they may not necessarily produce comparable behavioral results. For one, the faster response latencies to words with many neighbors in the single word paradigm is know to be associated with a strategy used by participants (e.g., using word likeness as a cue; e.g., Grainger & Jacobs, 1996). On the other hand,, the lexical competition in the masked prime paradigm may be artificially inflated due to the prime presentation, and may therefore not reflect normal word identification processing. Ultimately, although beyond the scope of the present investigation, reconciling these two sets of result will be important for understanding the role of the lexical competition process in the visual identification of English words.

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 (i.e., a neighborhood frequency effect). On the other hand, when words have many neighbors, the model underestimates the strength of inhibition from lower frequency neighbors. Our post-hoc analyses revealed that this inhibition is strongly related to the number of neighbors of the lower frequency primes (and their targets). As such a relationship was not observed for higher frequency neighbors, it appears that the inhibition effects are produced by different mechanisms, although the sizes of inhibition from lower frequency and higher frequency primes were statistically equivalent.

The significant inhibition effect from lower frequency neighbor primes for words with many neighbors is clearly at odds with a prediction of most versions of lexical competition models; namely, that only higher frequency neighbor primes are competitive enough to prolong word identification processing. Additional research will be necessary to expand upon the findings we have reported here and to clarify their implications for models of lexical processing.

Footnotes

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

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

[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 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 provide 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 primes and asked to identify them, performance was fairly poor. In the present experiments participants were not told about the presence of the primes. In addition, they were told that visual stimulus presented prior to target (e.g., "+" and "####") were irrelevant to the task and could be ignored.

[4] In a combined analysis of the data from Experiments 1, 2 and 3 (words with many neighbors only), there was no two-way interaction between prime type and target frequency (all Fs < 1), reinforcing the conclusion that the priming effects from higher frequency and lower frequency primes were equivalent. The absence of a three-way interaction between experiment, target frequency, and prime type, F_s $(2, 164) = 1.27$, $p > .20$; $F_i < 1$, in the same analysis indicates that

the inhibition effects from higher and lower frequency primes did not significantly differ among the three experiments.

[5] We cannot rule out the possibility that the inhibition effect from lower frequency primes is a phenomenon unique to English, and that it reflects a genuine cross-language difference in how orthographic neighbors influence visual word identification. As previously noted, although there have been many reports of inhibitory neighborhood frequency effects in languages other than English, an inhibitory frequency effect has seldom been observed in studies that have used English stimuli. Thus, if lexical competition models are accurate reflections of how lexical processing works, there would appear to be clear differences between readers of English versus other languages.

[6] It is important to note that it may not be appropriate to compare the effects observed in single-word paradigm and in priming paradigm with the same mechanism (especially in the lexical decision task), as they may reflect the different processes (e.g., Forster & Veres, 1998; Perea & Rosa, 2002).

[7] The inhibitory neighbor priming effect observed in the present experiments is consistent with the activation based account of the masked priming effect, which assumes that the priming is caused by a prime pre-activating the lexical node of the target and orthographically similar words (e.g., Grainger & Jacobs, 1996; McClelland & Rumelhart, 1981). On the other hand, inhibitory priming effects lend no support to the retrospective (episodic) account of the masked priming effect (e.g., Bodner & Masson, 1997; Masson & Bodner, 2003). According to this view, the masked priming effect is explained in terms of the prime presentation creating a new processing resource in memory, which is subsequently recruited to help 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 the target on neighbor-prime trials than on unrelated-prime trials. Thus, our results have rather important implications for the retrospective account of masked priming effects.

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Appendix A – Items used in Experiment 1

Neighbor prime, unrelated prime and higher and lower frequency target and for nonword targets (targets in uppercase).

Higher frequency targets			Lower frequency targets		
tide	doll	SIDE	side	need	TIDE
tire	mess	TIME	time	said	TIRE
toll	link	TOLD	told	less	TOLL
cord	maze	COLD	cold	rest	CORD
roam	goat	ROOM	room	mind	ROAM
weep	grim	WEEK	week	miss	WEEP
oven	dusk	OPEN	open	four	OVEN
tape	push	TYPE	type	dark	TAPE
gong	cube	LONG	long	same	GONG
lift	mode	LEFT	left	once	LIFT
sigh	cult	HIGH	high	year	SIGH
wipe	scar	WIFE	wife	cost	WIPE
pity	deaf	CITY	city	knew	PITY
foam	plot	FORM	form	hand	FOAM
nest	bold	BEST	best	face	NEST
cage	moss	CASE	case	kind	CAGE
bull	rope	FULL	full	girl	BULL
dune	rash	DONE	done	past	DUNE

tree	goal	FREE	free	word	TREE
lone	tear	LOVE	love	turn	LONE
halt	coin	HALF	half	west	HALT
fork	lawn	WORK	work	life	FORK
mate	tent	RATE	rate	view	MATE
bark	pine	BACK	back	over	BARK
pact	dime	FACT	fact	away	PACT
lime	bark	LIKE	like	even	LIME
shoe	burn	SHOW	show	five	SHOE
dawn	flew	DOWN	down	last	DAWN
heap	grin	HELP	help	area	HEAP
hood	lure	GOOD	good	made	HOOD
meal	sand	REAL	real	body	MEAL
herd	slip	HEAD	head	part	HERD
hose	math	HOME	home	used	HOSE
pill	cake	WILL	will	some	PILL
mace	pout	MAKE	make	well	MACE
bind	swan	FIND	find	look	BIND
tame	mink	TAKE	take	know	TAME
bell	rail	WELL	well	each	BELL
gown	fuel	TOWN	town	road	GOWN
doom	brew	DOOR	door	name	DOOM

<u>Nonword Targets</u>

rank	hits	RUNK
paws	lick	GAWS
mist	ripe	MEST
task	soft	TASH
pawn	leak	CAWN
lock	dive	LOCT
joke	beam	JOPE
vast	cell	GAST
cast	pink	CALT
bash	pore	BUCH
duct	harp	MUCT
pale	bear	PALT
hang	bomb	HALG
trip	vote	TWIP
sour	mall	SOUT
clam	mute	CHAM
fork	cave	FOCK
sled	weed	SLOD
drip	surf	DRIM
tale	rent	ZALE
bake	boot	VAKE
mice	pork	BICE

lied	oath	FIED
ties	bees	HIES
yard	roll	FARD
gaze	pops	GARE
fake	bolt	VAKE
mile	rear	MIDE
wipe	hunt	WIGE
flea	chop	FLEY
fine	hall	FINC
loop	drag	TOOP
tool	dean	ZOOL
kite	tint	KIRE
pigs	robe	TIGS
coma	skit	COGA
vase	foul	VUSE
void	echo	VOLD
hire	dash	ZERE
bind	reek	GIND

Appendix B – Items used in Experiment 2

Neighbor prime, unrelated prime for higher and lower frequency targets and for nonword targets (targets in uppercase).

Higher frequency targets			Lower frequency targets		
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
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
heap	grin	HELP	help	form	HEAP

Nonword Targets

hand	does	HOND	rank	hits	RUNK
been	more	BEEG	mist	ripe	MEST
last	here	LASP	lock	dive	LOCT
came	last	CIME	joke	beam	JOPE
feet	hard	FENT	sour	mall	SOUT
held	gave	HEND	clam	mute	CHAM
rise	clay	RIBE	tale	rent	ZALE
ball	race	BALP	peak	monk	PEAM
still	might	SMILL	lusty	slash	NUSTY
river	miles	HIVER	snack	tiles	SCACK
dead	bill	GEAD	ties	bush	MIES
land	tell	LANS	gaze	pops	GARE
line	seen	LIDE	wipe	hunt	WIGE
your	then	YOOR	loop	drag	TOOP
give	days	TIVE	vase	foul	VUSE
note	walk	NOKE	bake	boot	VAKE
poor	wait	POOD	mice	pork	BICE
deal	hope	BEAL	lied	oath	GIED
short	words	SHORY	grade	mines	GRAKE
reach	eight	KEACH	crime	baker	TRIME

Appendix C – Items used in Experiment 3

Neighbor prime, unrelated prime for higher and lower frequency target (in uppercase) and for nonword targets (in uppercase).

<u>Higher frequency targets</u> / <u>Lower frequency targets</u>

Many neighbors

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

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
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
unite	choke	UNTIL	until	world	UNITE
threw	crazy	THREE	three	small	THREW

<u>Nonwords</u>

Many neighbors

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

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

Stimuli Used in Experiment 4A

A prime with a sheared neighbor, prime without shared neighbor, unrelated prime and word target and neighbor prime and unrelated prime for nonword targets (targets in uppercase).

wail	mall	vine	WALL
wand	watt	bead	WANT
moan	meal	wake	MEAN
fled	fees	hide	FEED
mild	mint	dusk	MIND
gold	mood	tall	GOOD
ward	worn	tail	WORD
lend	leap	shoe	LEAD
stall	spill	loser	STILL
nine	nose	slow	NONE
cheek	chick	liner	CHECK
stork	stack	wired	STOCK
wade	wipe	null	WIDE
bean	beep	haze	BEEN
lake	lime	pump	LIKE
lock	loop	peas	LOOK
fail	fill	meat	FALL
mist	mess	beam	MISS
mane	mice	hull	MINE

bail	bull	sink	BALL
tame	tile	maps	TIME
weak	weep	dice	WEEK
rent	nest	tray	REST
rats	rake	hint	RATE
lift	lice	pads	LIFE
shirt	shoot	crash	SHORT
stare	stove	lever	STORE
casts	caves	plank	CASES
fuel	fill	wire	FULL
bunk	bang	yarn	BANK
bust	belt	noon	BEST
camp	cape	whip	CAME
deed	deaf	wart	DEAD
herd	harm	wool	HARD
sail	skid	doll	SAID
lent	loft	rail	LEFT
lash	lust	wink	LAST
bore	barn	gang	BORN
stags	stale	marry	STAGE
witch	latch	bells	WATCH
loved	liked	crown	LIVED
roam	root	lean	ROOM

-	-	link	SOME
-	-	torn	PAST
-	-	pies	LAND
-	-	seam	BACK
-	-	pipe	REAL
-	-	tale	SHOT
-	-	poll	RACE
-	-	rank	LOST
-	-	deck	HOUR
-	-	mode	DARK
-	-	slid	NAME
-	-	patch	LIGHT
-	-	track	LEVEL
-	-	jolly	STATE
<u>Nonword targets</u>			
	tear	hunt	TEAD
	vase	sand	VUSE
	joke	sung	JOPE
	rode	push	VODE
	peak	monk	PEAM
	ties	tact	MIES
	fate	stem	FITE
	tops	bush	TOAS

cash	male	COSH
bell	fame	BEEL
span	pork	SPAG
purse	clock	PORSE
blink	tunes	BLINT
smack	tiger	SPACK
sour	pail	SOUT
gaze	pops	GARE
sway	punk	SMAY
limp	tire	LOMP
bone	gear	BOTE
hate	mold	HAIE
crap	lamp	CRAN
nick	wars	NINK
hash	peep	HASS
card	sing	CARO
sole	drag	SOLK
crack	mania	CRECK
sheep	brave	SPEEP
silly	baker	SOLLY
wins	boot	WUNS
bass	sons	BASU
warn	tide	WARL

lint	toss	LINN
bent	gate	BONT
tomb	slug	TOMP
bowl	rang	MOWL
boil	sane	BOOL
dawn	cure	BAWN
cope	flag	COSE
fake	jaws	FIKE
shade	liver	SHACE
dates	grave	DASES
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

Stimuli Used in Experiment 4B

A neighbor prime, unrelated prime, and target for a shared neighbor and for no shared neighbor condition, and neighbor prime, unrelated prime, and nonword target with small neighbors and many neighbors (target in uppercase).

Shared neighbor			No Shared Neighbor		
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			Small 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

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
		Lower-frequency prime - higher frequency target	
	HEAP	help	area
Frequency	14.7 (11.3)	528.2 (418.2)	535.1 (404.2)
N	9.9 (4.0)	10.0 (4.6)	7.8 (4.1)
		Higher-frequency prime – lower frequency target	
	HELP	*heap*	*grin*
Frequency	528.2 (418.2)	14.7 (11.3)	14.5 (11.4)
N	10.0 (4.6)	9.9 (4.0)	9.9 (3.8)
		Word prime – nonword target	
	VAKE	*fake*	*bolt*
Frequency	–	22.1 (30.2)	22.0 (29.4)
N	9.9 (3.8)	10.0 (4.8)	10.1 (4.6)

Note. N = number of neighbors. Standard deviations in parentheses.

Table 2

Mean Lexical Decision Latencies (in Milliseconds), Percentage Errors, and Simulation Cycles for Word Targets in Experiment 1

Prime type	Prime-target frequency					
	High-low			Low-high		
	RT	Errors	Simulation	RT	Errors	Simulation
Neighbor	618	11.1	252	537	1.8	206
Control	594	8.9	202	516	1.8	192
Difference	-24	2.2	-50	-21	0.0	-14

Note. The mean response latency and the mean error rate for nonword targets primed by word neighbors was 670 ms and 7.2%; for nonword targets primed by control words the mean response latency was 664 ms and the mean error rate was 9.6%.

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	12.5 (7.7)	506.9 (420.5)	495.6 (435.6)
N	10.3 (3.8)	10.1 (3.9)	8.9 (2.9)
	lower frequency prime - higher frequency target		
	HELP	*heap*	*grin*
Frequency	506.9 (420.5)	12.5 (7.7)	13.2 (7.7)
N	10.1 (3.9)	10.3 (3.8)	9.2 (3.5)
	High-frequency prime – nonword target		
	NOKE	*note*	*walk*
Frequency	–	415.5 (480.2)	433.3 (523.6)
N	9.9 (4.3)	10.5 (4.1)	10.5 (3.3)
	Low-frequency prime – nonword target		
	CHAM	*clam*	*mute*
Frequency	–	14.7 (9.8)	14.1 (9.2)
N	10.3 (4.3)	9.8 (3.7)	10.1 (3.6)

Note. N = number of neighbors. Standard deviations in parentheses.

Table 4

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

Prime type	Prime-target frequency					
	High-low			Low-high		
	RT	Errors	Simulation	RT	Errors	Simulation
Neighbor	613	11.3	263	548	6.1	210
Control	573	7.5	205	523	2.9	196
Difference	-40	3.8	-58	-25	3.2	-14

Table 5

Mean Lexical Decision Latencies (in Milliseconds) and Percentage Errors for Nonword Targets in Experiments 2 and 3

Prime type	Prime frequency			
	High		Low	
	RT	Errors	RT	Errors
		Experiment 2		
Large N				
Neighbor	634	8.2	623	5.5
Control	634	8.6	632	5.9
Difference	0	0.4	9	0.4
		Experiment 3		
Large N				
Neighbor	631	15.0	648	10.9
Control	640	13.8	659	13.2
Difference	9	-1.2	9	2.3
Small N				
Neighbor	614	3.8	625	6.3
Control	619	3.0	622	7.9
Difference	5	0.8	-3	1.6

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
Large N			
	Higher frequency prime – lower frequency target		
	HEAP	*help*	*area*
Frequency	19.6 (13.1)	347.6 (317.4)	353.3 (348.0)
N	9.6 (4.1)	9.2 (3.9)	9.3 (3.9)
	Lower frequency prime – higher frequency target		
	HELP	*heap*	*grin*
Frequency	347.6 (317.4)	19.6 (13.1)	20.3 (13.9)
N	9.2 (3.9)	9.6 (4.1)	9.2 (3.9)
	High-frequency prime – nonword target		
	JAME	*name*	*form*
	–	237.7 (172.3)	244.2 (212.0)
	9.2 (3.1)	9.6 (2.6)	8.9 (2.9)
	Low-frequency prime – nonword target		
	BOTE	*bone*	*weak*
	–	19.7 (9.0)	20.4 (9.6)
	9.7 (3.1)	10.0 (2.7)	9.9 (3.3)

Small N

	Higher frequency prime – lower frequency target		
	OMEN	*open*	*girl*
Frequency	21.3 (22.0)	356.6 (373.9)	348.3 (365.0)
N	2.9 (1.1)	2.4 (1.2)	2.6 (1.0)
	Lower frequency prime – higher frequency target		
	OPEN	*omen*	*wrap*
Frequency	356.6 (373.9)	21.3 (22.0)	20.6 (19.1)
N	2.4 (1.2)	2.9 (1.1)	2.6 (1.0)
	High frequency prime – nonword targets		
	HARO	*feel*	*hard*
Frequency	–	284.5 (258.1)	280.9 (209.5)
N	2.2 (1.1)	2.2 (1.4)	2.7 (1.3)
	Low frequency prime – nonword targets		
	FRAL	*oral*	*pond*
Frequency	–	21.8 (12.7)	22.1 (12.5)
N	2.8 (1.2)	2.2 (1.1)	2.8 (1.2)

Note. N = number of neighbors. Standard deviations in parentheses.

Table 7

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

Prime type	Prime-target frequency					
	High-low			Low-high		
	RT	Errors	Simulation	RT	Errors	Simulation
	Words with many neighbors					
Neighbor	585	11.6	224	548	7.0	197
Control	558	6.2	195	517	2.5	188
Difference	-27	5.4	-29	-31	4.5	-9
	Words with few neighbors					
Neighbor	598	16.3	216	529	6.4	186
Control	580	7.1	196	529	5.4	186
Difference	-18	9.2	-20	0	1.0	0

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)	17.1 (14.3)	18.9 (19.6)	17.2 (12.9)
N	11.0 (4.0)	10.2 (3.5)	10.4 (3.9)	10.4 (3.2)
	Low frequency primes – nonword targets			
	BLINT	*blink*		*tunes*
Frequency	–	17.8 (12.3)		18.8 (11.8)
N	9.4 (3.8)	10.2 (4.0)		10.1 (4.2)

Note. N = number of neighbors. Standard deviations in parentheses. The shared neighbor status (primes-target pairs with or without a shared neighbor) was not a factor for nonword trials.

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*	*diary*
Frequency	214.7 (187.1)	15.8 (18.8)	14.2 (17.4)
N	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)	14.9 (11.9)
N	3.4 (1.0)	3.4 (1.5)	3.5 (1.2)
	Low-frequency prime – nonword target (Small N)		
	RANEL	*panel*	*split*
Frequency	–	15.0 (12.5)	15.1 (12.5)
N	3.1 (1.4)	3.2 (1.5)	2.9 (1.7)
	Low-frequency prime – nonword target (Large N)		
	SHASE	*shake*	*candy*
Frequency	–	14.2 (9.4)	15.2 (10.2)
N	9.9 (2.8)	9.9 (2.3)	9.9 (3.1)

Note. N = number of neighbors. Standard deviations in parentheses.

Table 10

Mean Lexical Decision Latencies (in Milliseconds) and Percentage Errors for Word Targets in Experiment 4A and 4B

	Experiment 4A			
Prime type	Primes with shared neighbors		Primes without shared neighbors	
	RT	Errors	RT	Errors
Neighbor	569	3.1	568	3.4
Control	547	2.9	547	2.8
Difference	- 22	- 0.2	- 21	- 0.6
	Experiment 4B			
	RT	Errors	RT	Errors
Neighbor	575	6.3	556	4.0
Control	572	3.3	550	1.7
Difference	- 3	- 3.0	- 6	- 2.3

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

Table 11

Mean Lexical Decision Latencies (in Milliseconds) and Percentage Errors for Nonword Targets in Experiments 4A and 4B

Prime type	Experiment 4A	
	RT	Errors
Neighbor	664	6.6
Control	668	6.0
Difference	4	0.6
	Experiment 4B	
Small N		
Neighbor	663	7.8
Control	645	5.2
Difference	- 18	- 2.6
Large N		
Neighbor	682	10.3
Control	687	10.2
Difference	5	- 0.1

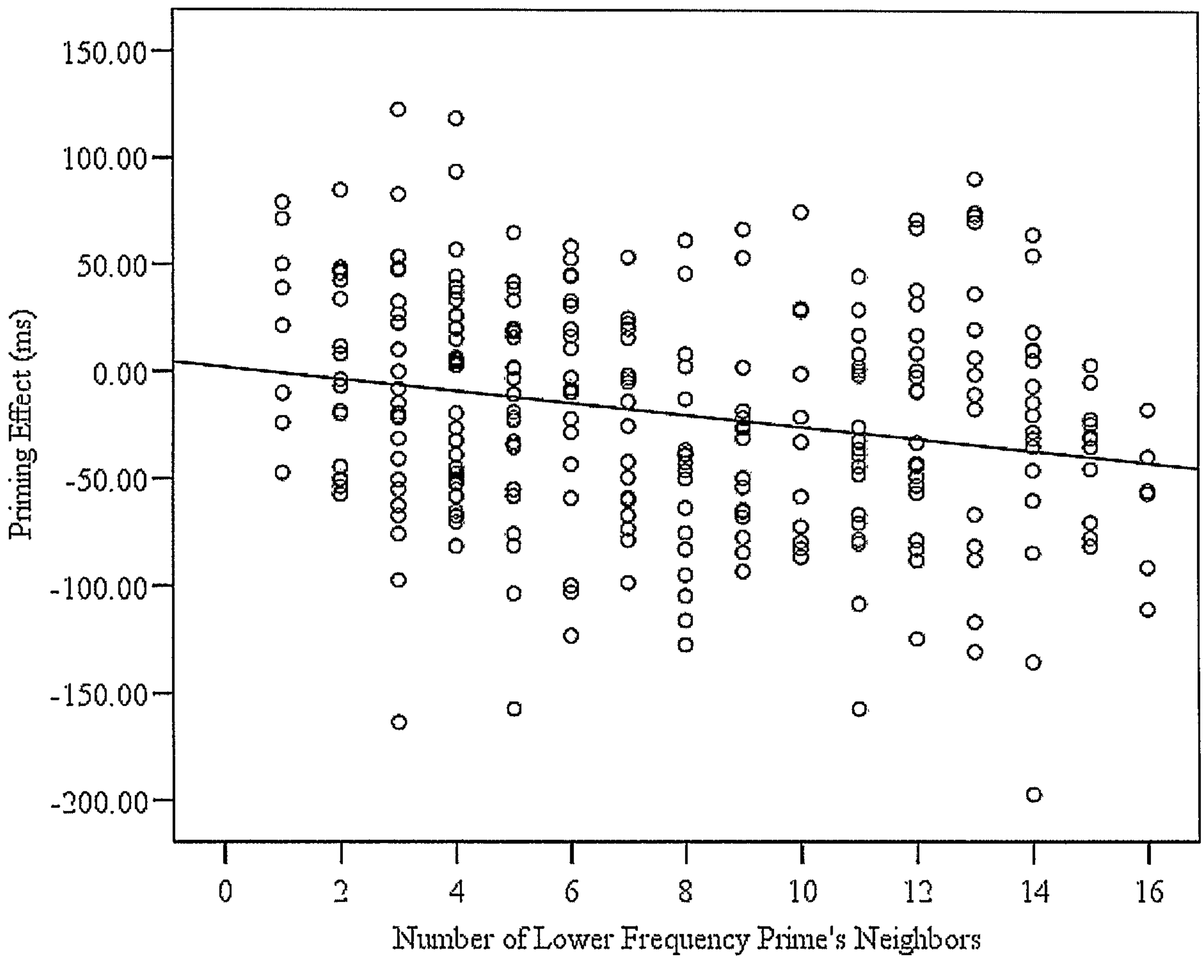

Figure 1. Number of prime's neighbors and priming effects (ms) based on lower-frequency neighbor prime and higher-frequency target pairs used in Experiment 1, 2, 3, and 4.

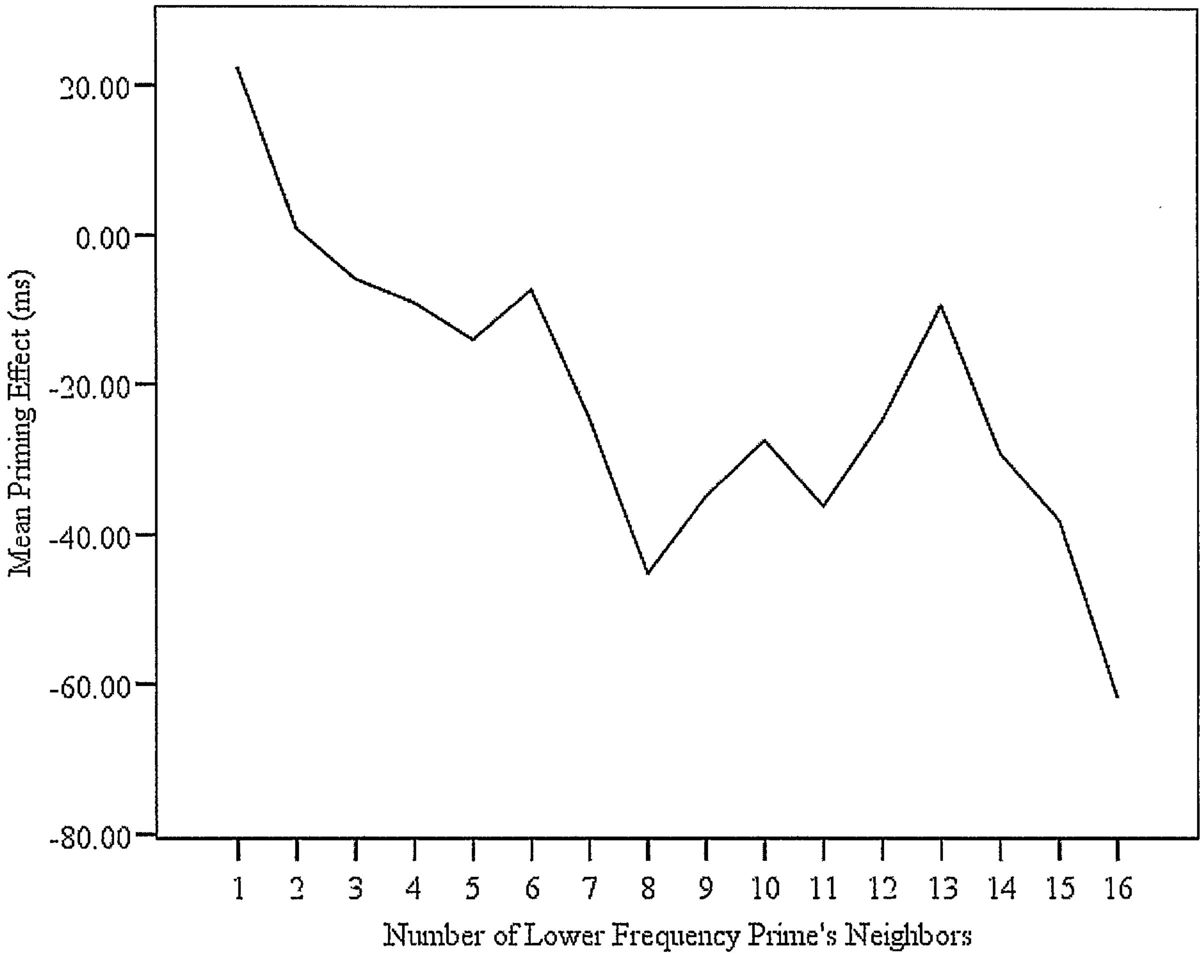

Figure 2. Number of prime's neighbors and mean priming effects (ms) based on lower frequency neighbor prime and higher-frequency target pairs used in Experiment 1, 2, 3, and 4.

Appendix B

UNIVERSITY OF CALGARY

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CERTIFICATION OF INSTITUTIONAL ETHICS REVIEW

This is to certify that the Conjoint Faculties Research Ethics Board at the University of Calgary has examined the following research proposal and found the proposed research involving human subjects to be in accordance with University of Calgary Guidelines and the Tri-Council Policy Statement on *"Ethical Conduct in Research Using Human Subjects"*. This form and accompanying letter constitute the Certification of Institutional Ethics Review.

File no:	**4260**
Applicant(s):	**Mariko Nakayama**
Department:	**Psychology**
Project Title:	**Neighborhood Frequency Effects in Masked Priming Paradigms**
Sponsor (if applicable):	

Restrictions:

This Certification is subject to the following conditions:

1. Approval is granted only for the project and purposes described in the application.
2. Any modifications to the authorized protocol must be submitted to the Chair, Conjoint Faculties Research Ethics Board for approval.
3. A progress report must be submitted 12 months from the date of this Certification, and should provide the expected completion date for the project.
4. Written notification must be sent to the Board when the project is complete or terminated.

Janice Dickin

Janice Dickin, Ph.D, LLB,
Chair
Conjoint Faculties Research Ethics Board

27 January 2005
Date:

Distribution: (1) Applicant, (2) Supervisor (if applicable), (3) Chair, Department/Faculty Research Ethics Committee, (4) Sponsor, (5) Conjoint Faculties Research Ethics Board (6) Research Services.