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Neighborhood Size and Neighborhood Frequency Effects in Word Recognition

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What are the effects of a word's orthographic neighborhood on the word recognition process? Andrews (1989) reported that large neighborhoods facilitate lexical access (the neighborhood size effect). Grainger, O'Regan, Jacobs, & Segui (1989) reported that higher frequency neighbors inhibit lexical access (the "neighborhood frequency effect"). Because neighborhood size and neighborhood frequency typically covary (words with large neighborhoods will usually possess higher frequency neighbors), these findings would seem to contradict one another. In the present study, 6 experiments on the effects of neighborhood size and neighborhood frequency indicated that, at least for low-frequency words, large neighborhoods do facilitate processing. However, the existence of higher frequency neighbors seems to facilitate rather than inhibit processing. The implications of these findings for serial and parallel models of lexical access are discussed.

Much of the research on visual word recognition has focused on the issue of lexical access. Consequently, a number of models of the lexical access process have been proposed, each providing a slightly different account of the various factors that affect this process. Consider, for example, the factor that is probably the most studied in this literature—printed-word frequency. The standard finding is that high-frequency words are processed faster than low-frequency words. In Forster's (1976) serial search model, this effect is explained in terms of a serial-search process. According to the model, the entries in the lexicon are organized according to word frequency. The search for a match between the sensory input and the correct lexical entry proceeds in a serial manner, starting with the closest matching higher frequency entries. Thus, high-frequency words are identified more quickly than low-frequency words by virtue of their order in the search set. Alternatively, in "activation-based" models, such as McClelland and Rumelhart's (1981) interactive–activation model, frequency effects are attributed to the higher resting activation levels for high-frequency words. High-frequency words are recognized more quickly than low-frequency words because they require less sensory activation to reach a recognition threshold.

The present research focuses on a factor that has received somewhat less attention than word frequency, although it has been the subject of numerous investigations in the past few years. That is, recently there have been a number of studies investigating the effects of a word's orthographic neighborhood on recognition latencies and analyzing the implications of these effects for models of lexical access (Andrews, 1989, 1992; Grainger, 1990; Grainger, O'Regan, Jacobs, & Segui, 1989; Grainger & Segui, 1990). Further, this research is not without controversy, as two sets of findings have emerged that appear to be contradictory. The goal of the present investigation is to provide a detailed evaluation of the effects of orthographic neighborhoods on word recognition in an attempt to shed more light on the issues that these findings have raised.

In both the earlier work and the present studies, a word's *orthographic neighborhood* is defined as the set of words that can be created by changing one letter of the word while preserving letter positions (Coltheart, Davelaar, Jonasson, & Besner, 1977). For example, the words *pike, pine, pole,* and *tile* are all orthographic neighbors of the word *pile.*

Most models of word recognition suggest that the lexical entries of the orthographic neighbors of a word will be activated and play some role in the lexical access process. This is clearly the case with models of lexical access that incorporate a serial-search mechanism (e.g., Forster, 1976; Paap, Newsome, McDonald, & Schvaneveldt, 1982). For example, as noted, in Forster's (1976) serial-search model, the lexicon is organized in terms of word frequencies, and a serial-comparison processor searches over the entries of this frequency-ordered lexicon. More specifically, when a word is presented, its sensory representation is compared with the closest matching lexical entry of the highest frequency, and

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if there is a match between the two, the comparison process is terminated and lexical access is achieved. If this initial comparison does not yield a match, the next highest frequency lexical entry is checked—a process that continues, one comparison at a time, until the correct match is found. Because the lexical entries of a word's orthographic neighbors would most closely match the word itself, the size of a word's orthographic neighborhood would be an important determinant of the speed of lexical access. Specifically, increases in the size of a word's orthographic neighborhood should produce increases in the time required for lexical access.

The activation–verification model (Paap et al., 1982) assumes an initial spreading of activation through a network of sublexical and lexical units. The activation stage serves to isolate a set of lexical candidates that are consistent with the gross sensory features of the input stimulus, and then a more detailed serial process (the "verification process") checks each candidate item to determine whether it matches the sensory representation. Like Forster's (1976) model, the order in which the candidates are submitted to the serial search or verification process is based on word frequency: High-frequency words in the candidate set are checked or verified before low-frequency words. Because a word's orthographic neighbors are highly similar to the word itself, they would tend to be the members of the candidate set, with increases in neighborhood size producing increases in the size of the candidate set. Consequently, as in the Forster (1976) model, the size of the word's neighborhood should be an important determinant of the speed of lexical access. Increases in a word's neighborhood size should produce increases in the size of the candidate set, which should in turn produce increases in the time required for lexical access.

Coltheart et al. (1977), using a lexical decision task, were the first to specifically examine the effects of neighborhood size. They reported that neighborhood size had no effect for words and an inhibitory effect for nonwords: Nonwords with many neighbors were responded to more slowly than those with few neighbors. More recently, however, Andrews (1989) has reported that neighborhood size does have an effect for words, but it is an effect that interacts with word frequency. In particular, Andrews (1989) found that lexical decision and naming latencies to low-frequency words with large neighborhoods were shorter than the latencies to low-frequency words with small neighborhoods, whereas neighborhood size had little effect on the response latencies to high-frequency words. This interaction was not present in a delayed-naming task. Even more recently, Andrews (1992) has reported a significant neighborhood size effect for high-frequency words in a standard naming task, although this effect was still numerically smaller than the neighborhood size effect for low-frequency words. All of these results are clearly at odds with serial-based models of lexical access. Large neighborhoods should produce larger candidate sets, which should increase the amount of time required for the verification or comparison stage. Further, this processing delay should be most pronounced with low-frequency words. Thus, Andrews' (1989) results are exactly the opposite of what these models would predict.

Andrews (1989) concluded that her results could be best explained in terms of the reciprocal activation mechanism embodied in the interactive–activation model (McClelland & Rumelhart, 1981). Specifically, low-frequency words with many neighbors would have shorter identification latencies than would low-frequency words with few neighbors because words with many neighbors would receive more reciprocal activation from their sublexical constituents. One can imagine why this might be so by considering the sequence of events leading to the lexical access of low-frequency words with large and small neighborhoods.

On presentation of a low-frequency word with many neighbors, the lexical units of that stimulus and its neighbors are activated. Because the resting activation levels for low-frequency words are fairly low, the initial first-pass activation of the lexical node corresponding to the presented stimulus is not sufficient to achieve lexical access. Excitatory feedback from both the lexical unit of the stimulus and the partially activated neighbors increases the activation of their corresponding sublexical units, which in turn increases the activation level of the target's lexical unit and its neighbors once again, eventually culminating in lexical access once the lexical unit corresponding to the target has reached an activation threshold.

A low-frequency word with few neighbors, however, will not benefit as much from this reciprocal activation mechanism. Because fewer neighbors will be initially activated, the excitatory feedback to the sublexical units of the original stimulus and its neighbors will not be as great, and consequently the number of cycles or the amount of time required for lexical access will increase. In contrast, high-frequency words are assumed to have higher resting activation levels than do low-frequency words in the interactive–activation model, and Andrews (1989) suggested that this would make them less sensitive to these lexical–sublexical reverberations, because they could reach an activation threshold sufficiently quickly through direct activation alone.

Andrews's (1989) findings and explanation for her neighborhood size effect appear to conflict with data reported by Grainger and colleagues (Grainger, 1990; Grainger et al., 1989; Grainger & Segui, 1990). These authors have argued that the important neighborhood variable in word recognition is not the size of a word's neighborhood but the frequency of a word's neighbors relative to its own frequency (referred to as *neighborhood frequency*). Grainger and colleagues have suggested that both serial search models and the interactive–activation model predict that words with higher frequency neighbors would be processed more slowly than words with no higher frequency neighbors. In serial search models with frequency-ordered search (Forster, 1976; Paap et al., 1982), the presence of higher frequency neighbors in a word's orthographic neighborhood would delay lexical access because these words must be evaluated first. Thus, as the number of higher frequency neighbors increases so should the amount of delay (referred to as *cumulative inhibition*). The reason the interactive–activation model predicts the same effect (according to

Grainger and colleagues) is because of the lateral inhibition between lexical nodes. When a neighborhood is activated by a target word, each lexical node begins to inhibit its neighbors. Higher frequency neighbors, which have high resting levels of activation, are much more powerful inhibitors than lower frequency neighbors. The result is an observable delay in lexical access for words that possess higher frequency neighbors. Yet the interactive–activation model does not appear to predict any cumulative inhibition like serial search models do, because many higher frequency neighbors would inhibit each other as well as the target word.

To test this prediction, Grainger et al. (1989) conducted a study in which neighborhood frequency was manipulated 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. Target-word frequency was equated across the four conditions. Lexical decision latencies did not differ between the first two conditions, which suggested there was no absolute neighborhood size effect (i.e., the presence of orthographic neighbors did not influence lexical access). Grainger et al. (1989) did find, however, that responses to words with one higher frequency neighbor were slower than responses to words with no higher frequency neighbors, suggesting that higher frequency neighbors inhibited lexical access. Finally, there was no cumulative neighborhood frequency effect: Responses to words with many higher frequency neighbors were not significantly slower than responses to words with a single higher frequency neighbor. Similar results were obtained using gaze duration as the dependent variable.

Interestingly, the neighborhood frequency effect does not arise in a naming task, as reported by Grainger (1990). In this study lexical decision and naming latencies to medium- and low-frequency words with no higher frequency neighbors, one higher frequency neighbor, or many higher frequency neighbors were examined. Neighborhood size was equated across these four conditions. In the lexical decision task, responses to words with no higher frequency neighbors were faster than responses to words with higher frequency neighbors, and, as before, there was no cumulative neighborhood frequency effect. In the naming task, however, there was no reliable neighborhood frequency effect (in fact, there was a small facilitatory neighborhood frequency effect).

Grainger and Segui (1990) also reported an inhibitory neighborhood frequency effect in a lexical decision task, and the lack of a cumulative inhibitory neighborhood frequency effect in all of these studies led Grainger and Segui (1990) to conclude that the neighborhood frequency effect is best explained by the interactive–activation model. Further, Jacobs and Grainger (1992) have recently demonstrated that, with the appropriate parameter settings, the interactive–activation model can simulate their neighborhood frequency effect (although their implementation cannot simulate Andrews's [1989] facilitatory neighborhood size effect).

The pattern of results reported thus far leads to the following generalizations: (a) having a large number of neighbors speeds lexical access (especially for low-frequency words) and (b) having a higher frequency neighbor delays lexical access. Given that these two word attributes would seem to be highly correlated (words with large neighborhoods will usually possess higher frequency neighbors, especially in the case of low-frequency words), this would appear to create somewhat of an empirical contradiction. In an attempt to account for this apparent contradiction, Grainger (1990) has suggested that because neighborhood size tends to be correlated with bigram frequency, any facilitatory effects of neighborhood size in lexical decision may actually be due to bigram frequency. Similarly, any facilitatory effects of neighborhood size in naming "may simply be due to the fact that words with more neighbors have more frequent spelling-to-sound correspondences" (Grainger et al., 1989, p. 189). In response to these suggestions, Andrews (1992) has conducted several experiments in which target frequency, neighborhood size, and bigram frequency were manipulated. Her results still showed a facilitatory effect of neighborhood size when bigram frequency was controlled in both lexical-decision and naming tasks. As noted earlier, for the first time Andrews (1992) also found a facilitatory neighborhood size effect for high-frequency words in the naming task. No effects of bigram frequency were observed in either task, however, which supports Andrews's claim that these facilitatory effects really are neighborhood size effects.

Andrews (1992) has pointed out that the inhibitory neighborhood frequency effect is predominately a lexical-decision phenomenon and has never been observed in a naming task. Thus, there is a possibility that any inhibitory effects of neighborhood frequency could be "postlexical" and not due to lexical-access processes. In theory, these postlexical effects could, to some degree, counteract the effects of neighborhood size in lexical-decision tasks, producing inhibition in that task but not in the naming task. Unfortunately, one implication of this argument is that facilitatory neighborhood size effects should be somewhat larger in naming tasks than in lexical-decision tasks, a result inconsistent with Andrews's (1989, 1992) data.

An alternative possibility, however, is that both of the effects are real, and there is no empirical contradiction. That is, a careful consideration of Andrews's and Grainger and colleagues' stimuli suggests that when one of these factors has been varied, the other has been fairly well controlled. For example, in Andrews's (1989) studies, 90% of her low-frequency words with large and small neighborhoods had higher frequency neighbors. In most of the studies reported by Grainger and colleagues, neighborhood size was equated across conditions. Neighborhood size was allowed to vary (by necessity) by Grainger et al. (1989) in order to create the contrast between words with no neighbors and words with no higher frequency neighbors. The average neighborhood size for the latter condition was, however, quite small (2.2). Thus, it is quite possible that both effects exist.

The only data that seem to create an empirical contradiction is the contrast between the words with one higher frequency neighbor (average neighborhood size of 2.6) and words with many higher frequency neighbors (average neighborhood size of 7.9) in Grainger et al. (1989). These two conditions did not differ in the lexical-decision task in spite of the neighborhood size difference. The latter condition did, however, produce a (nonsignificant) 36-ms advantage in gaze duration. Thus, even these data provide some support for the reality of Andrews's neighborhood size effect.

What may be more problematic, however, is the reality of the neighborhood frequency effect. Although these effects were quite clear in earlier reports (Grainger, 1990; Grainger & Segui, 1990; Grainger et al., 1989), Grainger, O'Regan, Jacobs, and Segui (1992) reported that the effect did not arise for words whose higher frequency neighbor differed at the second letter position. More recently, Grainger (1992) reported data showing the effect being restricted to five-letter words. With four-letter words, the neighborhood frequency effect was equally large; however, it was facilitatory rather than inhibitory.

What would seem to be called for here is the systematic manipulation of both the neighborhood size and neighborhood frequency factors (along with word frequency), to further establish the reality of each of these effects as well as to evaluate the nature of their interactions. The existence of neighborhood size effects and neighborhood frequency effects has important implications for all models of lexical access, so it would seem to be imperative that the effects of these variables be sorted out. This is the approach taken in Experiments 1 and 2.

Experiment 1

In this experiment we factorially manipulated word frequency, neighborhood size, and neighborhood frequency. The dependent variable was lexical-decision latency.

Method

Participants. Thirty undergraduate students from the University of Western Ontario participated in this experiment for course credit. All were native English speakers and had normal or corrected-to-normal vision.

Stimuli. All stimuli were four-letter strings. High-frequency words had a mean Kuçera and Francis (1967) normative frequency of 159; low-frequency words had a mean normative frequency of 15.5. Large-neighborhood words had more than eight neighbors, and small-neighborhood words had less than six neighbors. To be considered a neighbor of a word, a word had to either appear in the Kuçera and Francis (1967) norms or a 100,000-word computer-based dictionary. The average neighborhood sizes, as well as the mean Kuçera and Francis normative frequencies for the words in each condition of this experiment are listed in Table 1.

The third factor manipulated was neighborhood frequency, defined by Grainger et al. (1989) as the presence or absence of higher frequency neighbors in a word's orthographic neighborhood. Half the words had at least one neighbor of higher frequency than themselves, whereas the other half of the words did not possess any neighbors that appeared to be higher in frequency.

For high-frequency words with higher frequency neighbors, the mean Kuçera and Francis (1967) frequency of the highest frequency neighbor of each word was more than two times that of the mean target frequency. For low-frequency words with higher frequency neighbors, the mean Kuçera and Francis (1967) frequency of the highest frequency neighbor of each word was greater than 200 per million. For the high-frequency words with no higher frequency neighbors, the mean frequency of the highest frequency neighbor of each word was substantially lower than the mean target frequency (see Table 1).

Selecting low-frequency words with no higher frequency neighbors (especially ones with large neighborhoods) proved to be a bit more difficult. The main problem is that in many of the neighborhoods the higher frequency words in the neighborhood are virtually identical in Kuçera–Francis frequency to the potential target words (i.e., the word that seemed to be the most frequent in its neighborhood). Given that the Kuçera and Francis (1967) norms

Table 1
Mean Word Frequency, Subjective Frequency Rating (Rating), and Neighborhood Size (N) for the Stimuli Used in Experiments 1 and 2

	Low-frequency words				High-frequency words			
Neighborhood frequency	Small N		Large N		Small N		Large N	
	Target	NBF	Target	NBF	Target	NBF	Target	NBF
Higher-frequency neighbors								
Frequency	15.5	221.3	12.9	411.8	139.9	371.8	151.9	571.8
Rating	3.4	5.7	3.5	5.7	5.6	5.6	5.5	6.2
N	3.6		10.8		3.9		10.8	
No higher-frequency neighbors								
Frequency	16.7	9.5	16.8	23.6	166.7	66.1	178.6	101.4
Rating	3.4	2.9	3.6	3.9	5.3	4.4	5.6	5.3
N	3.4		9.8		3.5		10.6	
		Zero N			Small N			Large N
Nonwords								
N		0.0			3.9			13.4

Note. NBF refers to the average frequency of the highest frequency neighbor.

tend to be somewhat unreliable for low-frequency words (Gernsbacher, 1984; Gordon, 1985), we felt it was necessary to try to get converging evidence on the question of which words did indeed possess higher frequency neighbors. To accomplish this, we obtained subjective frequency ratings of potential target words and their neighbors. Twenty-five participants (who did not participate in any of our other experiments) were asked to estimate the frequency with which all of our potential target words and their neighbors (476 words in total) appeared in printed English. Words were presented one at a time on a computer monitor, and the participants were asked to estimate the word's frequency on a scale from 0 (*very infrequent*) to 9 (*very frequent*). The response scale was always present on the computer screen, and the subjects typed their responses using the computer keyboard.

Any word that received the highest subjective frequency ratings (compared with its neighbors) and that had the highest Kuçera and Francis frequency ratings was deemed to be the highest frequency word in the neighborhood (and thus possessed no higher frequency neighbors). In a number of instances, however, one of the potential target word's neighbors had a slightly higher rating than the target word on one, but not both, of these measures. In these situations, the decision was that these neighbors were not unambiguously higher in frequency than the potential target, and thus, it was legitimate to include the target word in its no-higher-frequency-neighbors condition. What this creates, of course, are situations in which the target's highest frequency neighbor may have either a slightly higher Kuçera and Francis frequency or a slightly higher subjective frequency rating. In fact, as Table 1 indicates, for the low-frequency, large-neighborhood words with no higher frequency neighbors, the mean Kuçera and Francis frequency and the mean subjective frequency rating for the target words' highest frequency neighbor were actually slightly larger than the mean values on those measures for the targets themselves (note, however, that this was not the case for the words in the low-frequency, small-neighborhood, no-higher-frequency-neighbors condition). Possible implications of this less-than-pure manipulation of neighborhood frequency will be discussed subsequently. (The complete set of words used in Experiments 1 and 2 is presented in Appendix A.)

Apparatus and procedure. Stimuli were presented on a color VGA monitor driven by a 80386-based microcomputer (AMI 386 Mark II). Participants indicated the lexicality of stimuli (word or nonword) by pressing one of two buttons on a three-button response box. The presentation of stimuli was synchronized with the vertical retrace rate of the monitor (14 ms), and response latencies were measured to the nearest millisecond.

Each trial was initiated by a 1-s 2,000 Hz warning tone, after which a fixation point appeared at the center of the videomonitor. One second after the onset of the fixation point, the stimulus was presented directly above the fixation point. Stimuli were presented in uppercase letters in all of the experiments. Responses were made by pressing one of two buttons on the response box. The participant's response terminated the stimulus display, and the next trial was initiated after a timed interval of 2 s.

Each participant completed 14 practice trials before the collection of data. (These practice stimuli were not used in the experiment proper.) During the practice trials participants were provided with feedback as to the latency and accuracy of each response. The order in which the 210 stimuli were presented in the experiment was randomized for each participant. Participants were provided with a 2-min rest period after every 50 trials.

Design. A 2 (Word Frequency) × 2 (Neighborhood Size) × 2 (Neighborhood Frequency) factorial design was used. There were 15 words in each of the eight conditions, for a total of 120 words. Three groups of four-letter, orthographically legal nonwords were also used, each group varying in neighborhood size, with mean neighborhood sizes of 0, 3.9, and 13.4. Thus, the experiment consisted of 120 word and 90 nonword trials.[1]

Results

Response latencies of less than 250 ms or more than 1,500 ms were considered outliers and were removed from the data set. A total of 11 observations (0.17%) were removed by this procedure. The mean response latencies of correct responses and the mean error rates are shown in Table 2. The word data were submitted to a 2 (Word Frequency) × 2 (Neighborhood Size) × 2 (Neighborhood Frequency) repeated-measures analysis of variance (ANOVA). For the nonwords, the zero, small, and large neighborhood size conditions were submitted to a one-factor repeated-measures ANOVA. Response latencies were submitted to both a subject (F_s) and an item (F_i) analysis.

Response latencies. Word frequency had a significant effect on response latencies in both the subject and item analyses: $F_s(1, 29) = 151.2$, $p < .001$, $MSE = 1{,}591.1$; $F_i(1, 112) = 55.2$, $p < .001$, $MSE = 2{,}425.2$. The main effect of neighborhood size was significant only in the subject analysis: $F_s(1, 29) = 15.6$, $p < .001$, $MSE = 864.27$; $F_i(1, 112) = 2.99$, $p < .10$, $MSE = 2{,}425.2$. Averaged response latencies to words with large neighborhoods were 15 ms faster than those to words with small neighborhoods, replicating Andrews's (1989) neighborhood size effect. However, the main effect of neighborhood frequency (the presence or absence of a higher frequency neighbor) was not significant in either the subject or item analysis: $F_s(1, 29) = 3.09$, $p < .10$, $MSE = 874.95$; $F_i < 1$). Thus, overall there was no significant inhibitory neighborhood frequency effect like that reported by Grainger et al. (1989); in fact, the small difference that was observed (6 ms) was in the opposite direction.

The interaction between word frequency and neighborhood size was not reliable in the subject, $F_s(1, 29) = 1.42$, $p > .20$, $MSE = 856.93$, or item analysis ($F_i < 1$). Thus, unlike Andrews (1989), we did not find that the neighborhood size effect was limited to low-frequency words. In fact, the neighborhood size effect for high-frequency words (19 ms) was slightly larger than that for low-fre-

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[1] The median rating of the 120 stimuli was 4.36. The correlation between the subjective ratings and the Kuçera and Francis (1967) norms was .77 ($p < .001$) for the 120 stimuli used in Experiments 1 and 2. Interestingly, we consistently found that the correlations between the subjective ratings and item mean RTs were higher than the correlations between the Kuçera and Francis norms and the item mean RTs. In Experiment 1, the correlation between the subjective ratings and the item mean RTs was −.62 ($p < .001$), whereas the correlation between the Kuçera and Francis norms and the item mean RTs was −.45 ($p < .001$). In Experiment 2 (standard naming), the correlation between the subjective ratings and the item mean RTs was −.37 ($p < .001$), whereas the correlation between the Kuçera and Francis norms and the item mean RTs was −.25 ($p < .01$).

Table 2
Mean Lexical Decision Latencies (in Milliseconds) and Error Rates (ER) in Experiment 1

	Low-frequency words				High-frequency words			
	Small N		Large N		Small N		Large N	
Neighborhood frequency	*M*	ER (%)	*M*	ER (%)	*M*	ER (%)	*M*	ER (%)
Higher frequency neighbors	587	8.0	564	6.9	532	3.8	506	1.1
No higher frequency neighbors	588	7.6	590	13.3	525	3.1	512	2.0

	Zero N		Small N		Large N	
	M	ER (%)	*M*	ER (%)	*M*	ER (%)
Nonwords	591	2.6	663	7.3	698	18.2

Note. N = neighborhood size.

quency words (10 ms). There was no reliable interaction between word frequency and neighborhood frequency in either analysis, $F_s(1, 29) = 1.71$, $p > .20$, $MSE = 1{,}575.4$; $F_i < 1$.

The Neighborhood Size × Neighborhood Frequency interaction was reliable in the subject analysis, $F_s(1, 29) = 5.41$, $p < .05$, $MSE = 921.89$, but not in the item analysis, $F_i(1, 112) = 1.41$, $p > .10$, $MSE = 2{,}425.2$. This interaction reflected the fact that, collapsed across word frequency, only words with higher frequency neighbors exhibited any appreciable neighborhood size effect. For words with higher frequency neighbors, a 24-ms neighborhood size effect was observed. The neighborhood size effect for words with no higher frequency neighbors was only 5 ms. However, it would seem to be more accurate to say that only low-frequency words with no high frequency neighbors failed to exhibit a neighborhood size effect, as an examination of Table 2 reveals. Nonetheless, there was no three-way interaction between word frequency, neighborhood size, and neighborhood frequency ($F_s < 1$ and $F_i < 1$).

Alternatively, one can consider this interaction in terms of neighborhood frequency. In this case, words with large neighborhoods exhibited a 16-ms neighborhood frequency effect, whereas words with small neighborhoods were relatively unaffected by the neighborhood frequency manipulation (−3 ms). However, as noted, contrary to Grainger et al.'s (1989) findings, the neighborhood frequency effect for words with large neighborhoods was facilitatory, not inhibitory.

Error rates. The main effect of word frequency was significant, $F_s(1, 29) = 53.0$, $p < .001$, $MSE = 47.02$, as was the main effect of neighborhood frequency, $F_s(1, 29) = 4.63$, $p < .05$, $MSE = 31.40$. Participants committed fewer errors to high-frequency words and to words with higher frequency neighbors. The main effect of neighborhood size was not significant ($F_s < 1$).

The interaction between word frequency and neighborhood size was reliable: $F_s(1, 29) = 5.87$, $p < .05$, $MSE = 45.57$. For low-frequency words, errors were more common when the word possessed a large neighborhood, whereas for high-frequency words just the opposite was observed. There was also a reliable interaction between word frequency and neighborhood frequency, $F_s(1, 29) = 5.66$, $p < .05$, $MSE = 22.12$. More errors were made to low-frequency words with no higher frequency neighbors than to low-frequency words with higher frequency neighbors, but neighborhood frequency had no effect on the error rates to high-frequency words.

As with the analysis of response latencies, the interaction between neighborhood size and neighborhood frequency was reliable, $F_s(1, 29) = 7.35$, $p < .05$, $MSE = 36.37$. For words with higher frequency neighbors, error rates were lower when the word possessed a large neighborhood, consistent with the pattern of response latencies. For words with no higher frequency neighbors, error rates were higher when the word possessed a large neighborhood. The three-way interaction between word frequency, neighborhood size, and neighborhood frequency was not statistically reliable, $F_s(1, 29) = 3.34$, $p < .10$, $MSE = 31.96$.

Nonwords. Response latencies to nonwords increased as a function of neighborhood size, an effect that was reliable in both the subject and item analyses: $F_s(2, 58) = 140.0$, $p < .001$, $MSE = 636.86$; $F_i(2, 87) = 40.8$, $p < .01$, $MSE = 2{,}279.2$. A similar pattern was observed with error rates; that is, error rates also increased as neighborhood size increased, $F_s(2, 58) = 58.3$, $p < .001$, $MSE = 33.17$.

Andrews (1992) has reported that nonwords do not exhibit a neighborhood size effect when bigram frequency is controlled. Because bigram frequency was not controlled across the three nonword conditions in this experiment, we evaluated this claim in the following way. A subset of 20 nonwords from each of the small and large neighborhood conditions were selected that had approximately equal summed bigram frequencies (Mayzner & Tresselt, 1965). The nonwords with small neighborhoods had a mean summed bigram frequency of 165, whereas the nonwords with large neighborhoods had a mean summed bigram frequency of 160. Nonetheless, we still obtained a neighborhood size effect: Response latencies were faster for nonwords with small neighborhoods, $F_s(1, 29) = 14.6$, $p < .01$, $MSE = 673.14$; $F_i(1, 38) = 3.45$, $p < .10$, $MSE = 2{,}486.08$, and errors were less frequent, $F_s(1, 29) = 37.0$, $p < .001$, $MSE = 36.51$.

Discussion

The important results of Experiment 1 are as follows. First, manipulations of neighborhood frequency had no real effect on the response latencies to high-frequency words and low-frequency words with small neighborhoods. For low-frequency words with large neighborhoods, the presence of higher frequency neighbors seemed to facilitate lexical access. Although Grainger and colleagues have repeatedly observed delayed responding to words with higher frequency neighbors in the lexical-decision task (Grainger, 1990; Grainger & Segui, 1990; Grainger et al., 1989, 1992), we have clearly not replicated those results here.

Second, there was a facilitatory effect of neighborhood size, and there was no interaction between neighborhood size and word frequency. Thus, whereas Andrews (1989) found that only low-frequency words exhibited a neighborhood size effect, we found approximately equal neighborhood size effects for high- and low-frequency words. One possible explanation for this discrepancy might be that, unlike in the present study, Andrews (1989) did not control for the existence of higher frequency neighbors. As noted, in the present experiment there was a significant Neighborhood Size × Neighborhood Frequency interaction because the neighborhood size effect was larger when the words possessed higher frequency neighbors (a result that was especially noticeable for the low-frequency words). An examination of Andrews's (1989) stimuli reveals that almost all of her low-frequency words (27/30) did possess a higher frequency neighbor, whereas only about half (16/30) of her high-frequency words did. Thus, one could argue that the neighborhood size effect for her low-frequency stimuli was somewhat inflated.

Although this argument might have some validity, the present data certainly suggest that it cannot be the whole story. If one eliminates the data from the low-frequency words with no higher frequency neighbors (as Andrews essentially did), one finds a 23-ms neighborhood size effect for low-frequency words in contrast to the 19-ms neighborhood size effect for the high-frequency words, a difference that is clearly nonsignificant ($F < 1$). Thus, our failure to replicate Andrews's (1989) Neighborhood Size × Word Frequency interaction must reflect more than the fact that low-frequency words with no higher frequency neighbors do not appear to show a neighborhood size effect. It also appears to reflect the fact that we have observed a reasonably large neighborhood size effect with our high-frequency words. As noted, Andrews (1992) has also reported the existence of a significant (12-ms) neighborhood size effect with high-frequency words in a more recent experiment. Thus, the existence of a 19-ms effect here is perhaps not too surprising. In any case, we will return to the question of neighborhood size effects with high-frequency words in Experiment 3.

Experiment 2

Several investigators have argued that lexical-decision latencies do not reflect the nature of the lexical access process very well because the task involves a decision or response component (e.g., Balota & Chumbley, 1984), something the standard naming task presumably lacks. Thus, to argue that the effects observed in Experiment 1 are due to lexical access processes, it is necessary to demonstrate that similar effects occur in a naming task. Accordingly, in Experiment 2 we conducted a naming task using the same word stimuli used in Experiment 1.

Method

Participants. Thirty undergraduate students from the University of Western Ontario participated in this experiment for course credit. All were native English speakers and had normal or corrected-to-normal vision. None of these participants had taken part in Experiment 1.

Stimuli. The stimuli were the 120 words used in Experiment 1.

Apparatus and procedure. Stimuli were presented on a monochrome VGA monitor driven by a 80486-based microcomputer (Trillium 433C). A voice key was used to collect naming latencies. The presentation of stimuli was synchronized with the vertical retrace rate of the system monitor (14 ms), and all naming latencies were measured to the nearest millisecond.

Each trial was initiated by a 1-s 2,000 Hz warning tone, after which a fixation point appeared in the center of the screen. One second after the onset of the fixation point, a word was presented directly above the fixation point. Participants were instructed to pronounce the presented words as quickly and as accurately as possible and were told to emphasize accuracy over speed. Stimuli remained on the screen until the participant made a response.

Participants completed 20 practice trials before the collection of data. The order in which the 120 words were presented in the experiment was randomized separately for each participant. Participants were provided with a 1-min rest period after every 30 trials.

Results

Naming latencies of less than 250 ms or greater than 1,000 ms were excluded from both the subject and item analyses (1.1% of the data). The mean naming latencies were analyzed in a 2 (Word Frequency) × 2 (Neighborhood Size) × 2 (Neighborhood Frequency) repeated-measures ANOVA. Naming latencies were submitted to both a subject (F_s) and item (F_i) analysis. Pronunciation errors were rare (less than 1.5% of the trials), so error rates were not analyzed.

The results are shown in Table 3. The main effect of word frequency was significant in both the subject, $F_s(1, 29) = 33.1$, $p < .001$, $MSE = 502.13$, and item analyses, $F_i(1, 112) = 20.5$, $p < .001$, $MSE = 8{,}978.7$. The main effect of neighborhood size was also significant in both the subject, $F_s(1, 29) = 14.4$, $p < .001$, $MSE = 363.98$, and item analyses, $F_i(1, 112) = 5.43$, $p < .05$, $MSE = 2{,}376.3$. Naming latencies to words with large neighborhoods were 9 ms faster than those to words with small neighborhoods, which again replicates Andrews's (1989) basic effect.

In addition, the main effect of neighborhood frequency (the presence or absence of a higher frequency neighbor) was significant in the subject analysis, $F_s(1, 29) = 4.83$,

Table 3
Mean Naming Latencies (in Milliseconds) and Error Rates (ER) in Experiment 2

Neighborhood frequency	Low-frequency words				High-frequency words			
	Small N		Large N		Small N		Large N	
	M	ER (%)	*M*	ER (%)	*M*	ER (%)	*M*	ER (%)
Higher frequency neighbors	466	2.0	443	1.7	449	0.9	435	0.4
No higher frequency neighbors	454	1.6	471	0.7	450	0.4	433	1.3

Note. N = neighborhood size.

$p < .05$, $MSE = 163.08$; $F_i < 1$. Overall, the presence of a higher frequency neighbor in a word's orthographic neighborhood was slightly facilitatory: Average naming latencies to words with higher frequency neighbors were 4 ms faster than the latencies to words with no higher frequency neighbors. Thus, we failed to obtain any global inhibitory neighborhood frequency effect with either the lexical decision or naming task.

These effects were, however, qualified by a three-way interaction between word frequency, neighborhood size, and neighborhood frequency, which was reliable in the subject and item analyses, $F_s(1, 29) = 26.1$, $p < .001$, $MSE = 250.37$; $F_i(1, 112) = 6.76$, $p < .05$, $MSE = 2{,}960.7$. For high-frequency words, the effect of neighborhood size was facilitatory for words with higher frequency neighbors and for words with no higher frequency neighbors. For low-frequency words, however, the nature of the neighborhood size effect was contingent on neighborhood frequency. Naming latencies to words with higher frequency neighbors were facilitated by large neighborhoods, whereas naming latencies to words with no higher neighbors were not. As noted, a similar pattern of neighborhood size effects was observed in the lexical decision data, although the three-way interaction was not significant in that analysis. That is, as can be seen in Table 4, where the neighborhood size effect is depicted in relation to word and neighborhood frequency, only low-frequency words with no higher frequency neighbors failed to exhibit a facilitatory neighborhood size effect in both experiments.

Table 4
Neighborhood Size Effects Observed in the Lexical Decision Task (Experiment 1) and in the Naming Task (Experiment 2)

Neighborhood frequency	Lexical decision task		Naming task	
	LF words	HF words	LF words	HF words
Higher-frequency neighbors	+23	+26	+23	+14
No higher-frequency neighbors	−2	+13	−17	+17

Note. Neighborhood effect size was calculated as the difference (in milliseconds) between words with small neighborhoods and words with large neighborhoods. + refers to facilitatory effect; − refers to inhibitory effect; LF = low frequency; HF = high frequency.

Why this particular result would occur is unclear. Although it may reflect a real difference between low-frequency words with and without higher frequency neighbors, we suspect that it might have something to do with the compromises made in selecting the low-frequency words with no higher frequency neighbors (see the *Method* section of Experiment 1). In Experiments 4, 5, and 6, we again consider the question of whether low-frequency words with no higher frequency neighbors produce neighborhood size and neighborhood frequency effects. In these experiments, however, only low-frequency words were used. Consequently, selecting more appropriate sets of words was somewhat easier because the low-frequency words selected did not have to match a set of high-frequency words on the neighborhood size factor. Contrary to the results of Experiments 1 and 2, in all the subsequent experiments there is clear evidence of a neighborhood size effect for low-frequency words with no higher frequency neighbors (as well as for low-frequency words with higher frequency neighbors).

Discussion

In terms of the initial motivation for this research, the results thus far paint at least one rather clear picture. We have produced absolutely no evidence that the presence of higher frequency neighbors globally inhibits response latencies, as was observed by Grainger et al. (1989) and Grainger and Segui (1990). In the lexical-decision task, the presence of higher frequency neighbors had no reliable influence on the response latencies to high-frequency words with large or small neighborhoods. This was also the case for low-frequency words with small neighborhoods, whereas responses to low-frequency words with large neighborhoods were, if anything, facilitated when they possessed higher frequency neighbors (see Table 2).

Similar results were obtained with the naming task: Neighborhood frequency did not affect the naming latencies to high-frequency words with large or small neighborhoods, and responses to low-frequency words with large neighborhoods were slightly facilitated (see Table 3). Clearly, the data as a whole do not support Grainger et al.'s (1989) and Grainger and Segui's (1990) contention that the effect of higher frequency neighbors on response latencies is of an inhibitory nature. Indeed, perhaps one of the more interesting findings at this point is the tendency toward a facilitation effect for low-frequency words with large neighborhoods and higher frequency neighbors. What should be kept in mind, however, is that this "effect" involves the one word set for which the most compromises had to be made (low-frequency words with large neighborhoods but no higher frequency neighbors). Thus, little should be made of this trend at present. The status of neighborhood frequency effects will be examined again in Experiments 4, 5, and 6.

On the other hand, although significant neighborhood size effects were observed, it is of some concern that we did not replicate the Word Frequency × Neighborhood Size interaction first reported by Andrews (1989). Andrews found that large neighborhood size had a facilitatory effect on lexical decision and naming latencies to low-frequency words and little, if any, effect for high-frequency words. In contrast, we have observed somewhat the opposite result in Experiments 1 and 2: Collapsed across neighborhood frequency, large neighborhood size had a somewhat larger facilitatory effect on both naming and lexical-decision latencies to high-frequency words. We noted earlier that the majority of Andrews's (1989) low-frequency words possessed higher frequency neighbors and that when only the parallel conditions in our design were considered, the neighborhood size effects for both low- and high-frequency words were still quite similar. This was true of the naming data of Experiment 2 as well. As also noted earlier, the main reason for this lack of an interaction seems to be the existence of a noticeable neighborhood size effect for the high-frequency words.

Given that we have replicated Andrews's (1989) neighborhood size effect but not her Word Frequency × Neighborhood Size interaction, we felt it was necessary to investigate the neighborhood size effect for high-frequency words more closely. In particular, one major difference between our experiments and hers was that our high-frequency words had lower Kuçera and Francis frequencies. Thus, one possibility is that these words were simply not high enough in frequency to eliminate the neighborhood size effect. To examine this hypothesis, Experiment 3 involved both lexical decision (Experiment 3a) and naming (Experiment 3b) tasks similar to those used by Andrews (1989), but with words much higher in frequency than those used in Experiments 1 and 2.

Experiment 3

Method

Participants. A total of 45 undergraduate students from the University of Western Ontario participated in the experiments for course credit. Twenty-one students participated in Experiment 3a (lexical decision), and the remaining 24 participated in Experiment 3b (naming). All were native English speakers and had normal or corrected-to-normal vision. None had participated in the previous experiments.

Stimuli. A total of 60 word stimuli were used in each of the two experiments, 15 stimuli in each of high-frequency/small-neighborhood, high-frequency/large-neighborhood, low-frequency/small-neighborhood, and low-frequency/large-neighborhood conditions. The majority of the words (65%) were taken from Andrews (1989). Twenty filler words were added, so that word trials consisted of 80 word stimuli. An additional 40 pronounceable nonwords were used in the lexical decision task. These were the same set of nonwords Andrews (1989) had used, with 20 possessing large neighborhoods and the remainder possessing small neighborhoods. All of the stimuli were four letters in length.

High-frequency words had a mean Kuçera and Francis (1967) frequency of 271 per million, whereas low-frequency words had a mean frequency of 8 per million. Words with large neighborhoods had a mean neighborhood size of 14.2, words with small neighborhoods had a mean neighborhood size of 3.5. Half of the high-frequency stimuli possessed higher frequency neighbors (15/30), and the majority of low-frequency stimuli possessed higher frequency neighbors (26/30). Nonwords with large and small neighborhoods had means of 13.9 and 3.0 neighbors, respectively. Table 5 contains the descriptive statistics for the stimuli in each of these conditions. (The complete set of experimental words used in Experiments 3a and 3b is presented in Appendix B.)

Apparatus and procedure. Stimuli were presented on a color VGA monitor driven by the 80486-based microcomputer used in Experiment 2. For the lexical-decision task, participants used a two-button Microsoft serial mouse to indicate the lexicality of the presented stimulus (word or nonword). A voice key was used for the naming task. The presentation of stimuli was synchronized with the vertical retrace rate of the system monitor (14 ms), and all response latencies were measured to the nearest millisecond.

Participants completed 20 practice trials before the collection of data. Each trial was initiated by a 1-s 2,000 Hz tone that served as a warning signal. Stimuli remained on the screen until the participant made a response. There was a 2-s delay between each trial.

For the lexical decision task, participants were instructed to respond "Word" or "Nonword" as quickly and as accurately as possible by pressing one of the two mouse buttons. Participants in the naming task were instructed to pronounce the presented words as quickly and as accurately as possible. They were instructed to emphasize accuracy over speed.

Results

Lexical decision (Experiment 3a). Response latencies of less than 250 ms or greater than 1,500 ms were excluded from the analysis of correct responses in both the subject and item analyses (1.82% of the data). The mean response latencies and error rates for words were analyzed in a 2

Table 5
Mean Word Frequency and Neighborhood Size (N) for the Stimuli Used in Experiment 3

Stimuli	Small N		Large N	
	Target	NBF	Target	NBF
Low-frequency words				
Frequency	8.1	30.4	8.2	672.1
N	3.5		14.3	
High-frequency words				
Frequency	278.0	177.0	264.5	658.9
N	3.5		14.2	
Nonwords				
N	3.0		13.9	

Note. NBF = average frequency of the highest frequency neighbor.

(Word Frequency) × 2 (Neighborhood Size) repeated-measures ANOVA.

For the word data, there was a main effect of word frequency, $F_s(1, 20) = 116.1, p < .001, MSE = 2{,}765.0$; $F_i(1, 56) = 45.8, p < .001, MSE = 5{,}635.3$ and a main effect of neighborhood size that was significant in the subject, $F_s(1, 20) = 7.17, p < .05, MSE = 2{,}162.4$, but not the item analysis, $F_i(1, 56) = 2.11, p > .10, MSE = 5{,}635.3$. The Word Frequency × Neighborhood Size interaction was only reliable in the subject analysis, $F_s(1, 20) = 8.27, p < .01, MSE = 1{,}595.9$; $F_i(1, 56) = 1.93, p > .10, MSE = 5{,}635.3$. This interaction reflected the fact that large neighborhood size had a facilitatory effect on the response latencies to low-frequency words but little effect on the response latencies to high-frequency words. Response latencies to low-frequency words with large neighborhoods were 52 ms faster than those to low-frequency words with small neighborhoods, whereas response latencies to high-frequency words with large and small neighborhoods differed by only 2 ms (Table 6).

An analysis of error rates yielded a similar pattern of results. The main effect of word frequency was significant, $F_s(1, 20) = 47.0, p < .001, MSE = 45.94$, as was the main effect of neighborhood size, $F_s(1, 20) = 5.32, p < .05, MSE = 25.39$. The interaction between word frequency and neighborhood size was also significant, $F_s(1, 20) = 5.65, p < .05, MSE = 30.23$. Low-frequency words with large neighborhoods were responded to more accurately than low-frequency words with small neighborhoods, whereas neighborhood size had little effect on the accuracy of responses to high-frequency words (Table 6).

A separate analysis of nonword latencies and errors revealed that responses to nonwords with small neighborhoods were faster, $F_s(1, 20) = 11.3, p < .01, MSE = 1{,}865.6$; $F_i(1, 38) = 4.39, p < .05, MSE = 5{,}084.0$, and more accurate, $F_s(1, 20) = 28.5, p < .001, MSE = 46.13$) than were responses to nonwords with large neighborhoods (Table 6).

Naming (Experiment 3b). Naming latencies less that 250 ms or greater than 1,000 ms were excluded from both the subject and item analyses (1.9% of the data). The mean naming latencies were analyzed in a 2 (Word Frequency) × 2 (Neighborhood Size) repeated-measures ANOVA. Pronunciation errors were rare (less than 1.5% of the trials), so error rates were not analyzed.

As with the lexical decision data, there were significant main effects of word frequency, $F_s(1, 23) = 26.1, p < .001, MSE = 225.54$, and neighborhood size, $F_s(1, 23) = 6.24, p < .05, MSE = 178.56$, and a significant Word Frequency × Neighborhood Size interaction, $F_s(1, 23) = 26.2, p < .001, MSE = 306.50$. The main effect of word frequency was reliable in the item analysis, $F_i(1, 56) = 6.71, p < .05, MSE = 606.01$, but the main effect of neighborhood size was not ($F_i < 1$). The interaction between word frequency and neighborhood size was significant in the item analysis, $F_i(1, 56) = 8.02, p < .01, MSE = 606.01$. As before, large neighborhoods facilitated the responses to low-frequency words but had little effect on the responses to high-frequency words. These data are shown in Table 7.

Table 6
Mean Lexical Decision Latencies (in Milliseconds) and Error Rates (ER) in Experiment 3a

	Small N		Large N	
Stimuli	*M*	ER (%)	*M*	ER (%)
Low-frequency words	669	13.9	617	8.5
High-frequency words	520	0.9	518	1.2
Nonwords	705	6.2	749	17.3

Note. N = neighborhood size.

Discussion

The results of both the lexical decision and naming experiments clearly replicate Andrews's (1989) findings: Large neighborhood size has a facilitatory effect on response latencies to low-frequency words but little effect on the response latencies to high-frequency words. This being the case, the fact that we found no Word Frequency × Neighborhood Size interaction in Experiments 1 or 2 appears to be explainable. The results of Experiment 3 suggest that the neighborhood size effect for high-frequency words in Experiments 1 and 2 was a consequence of the relatively low Kuçera and Francis frequencies of the high-frequency words used in these experiments. As can be seen from Table 1, the high-frequency stimuli used in Experiments 1 and 2 had an average Kuçera and Francis frequency of 159 per million, whereas the high-frequency words of Experiment 3 had an average frequency of 271 per million (Table 5). Andrews's (1989) high-frequency words had an average frequency of 261 per million. If the neighborhood size effect decreases with increasing word frequency, it would be most pronounced with low-frequency words and nonexistent for very-high-frequency stimuli. If this is true, then the fact that we obtained a neighborhood size effect for high-frequency words in Experiments 1 and 2 but not in Experiment 3 could be explained in terms of these frequency differences.

This may not be the full story, however. As we previously noted, results from a recent experiment by Andrews (1992) suggested that the neighborhood size effect may not be exclusive to low- or medium-frequency words. Andrews (1992) also observed a significant (12 ms) facilitatory neighborhood size effect for high-frequency words in a standard naming task, and no Word Frequency × Neighborhood Size interaction. These neighborhood size effects were obtained even though the mean frequencies of her high-frequency words were even greater than those in our replication (381 per million). Clearly, the nature of the neighborhood size effect for high-frequency words is not completely understood at this point, and further investigation into other possible contributing variables is required.

Finally, although we did not manipulate neighborhood frequency in this experiment, we can make the following observations. The number of low-frequency words possessing higher frequency neighbors in the large- and small-

Table 7
Mean Naming Latencies (in Milliseconds) and Error Rates (ER) in Experiment 3b

	Small N		Large N	
Stimuli	*M*	ER (%)	*M*	ER (%)
Low-frequency words	526	0.9	500	1.6
High-frequency words	492	1.0	503	2.1

Note. N = neighborhood size.

neighborhood conditions was similar (15 and 11, respectively). Nonetheless, we still obtained a neighborhood size effect. In fact, as Table 5 shows, low-frequency words with large neighborhoods had much higher frequency neighbors than did low-frequency words with small neighborhoods, yet responses to these low-frequency words with large neighborhoods were faster, not slower, than responses to low-frequency words with small neighborhoods. For high-frequency words with large neighborhoods, 11 words possessed higher frequency neighbors, whereas only four words with small neighborhoods did. An examination of Table 5 reveals that the average frequency of the highest frequency neighbors of high-frequency words with large neighborhoods was higher than that of the words themselves, whereas the average frequency of the highest frequency neighbors of high-frequency words with small neighborhoods was lower than that of the words themselves. Nonetheless, we failed to obtain any difference between these two conditions in either the lexical decision or naming task.

Experiment 4

Although it is possible to reconcile the results of Experiments 1 and 2 with Andrews's (1989, 1992) neighborhood-size studies, we clearly have not obtained any evidence of inhibitory neighborhood frequency effects of the nature that Grainger et al. (1989) have reported. Although Grainger et al. (1989) and Grainger and Segui (1990) found that higher frequency neighbors inhibit lexical access, our results suggest that, if anything, higher frequency neighbors may facilitate the lexical access of low-frequency words while having little or no effect on the lexical access of high-frequency words.

We conducted a fourth experiment to more precisely examine the role of a word's higher frequency neighbors in the lexical access process. Like Grainger et al. (1989), we used four neighborhood conditions. Target words possessed (a) no neighbors, (b) no neighbors of higher frequency, (c) one neighbor of higher frequency, or (d) many neighbors of higher frequency. Unlike the Grainger et al. (1989) experiments, we also manipulated the neighborhood size of words that possessed neighbors: The words had either large or small neighborhoods. Because we did not obtain reliable neighborhood frequency effects for high-frequency words in the previous experiments, only low-frequency words were used in this experiment.

Unlike Experiments 1 and 2, in which neighborhood frequency was manipulated as a dichotomous variable, this design allows a more precise evaluation of the role of a word's higher frequency neighbors. In addition, the three word conditions with no higher frequency neighbors (zero, small, and large neighborhoods) allowed us to attempt to replicate Grainger et al.'s (1989) results, showing no neighborhood size effect when words possess no higher frequency neighbors.

Method

Participants. A total of 63 students from the University of Western Ontario participated in the two experiments, 28 in Experiment 4a (lexical decision) and 35 in Experiment 4b (naming). The participants in Experiment 4a participated for course credit; those in Experiment 4b were paid for their participation. All were native English speakers and had normal or corrected-to-normal vision. None had participated in the previous experiments.

Stimuli. All of the stimuli were four-letter low-frequency words, with a mean Kuçera and Francis (1967) frequency of 16.2. Words with small neighborhoods had no more than 6 neighbors; words with large neighborhoods had at least 8 neighbors. The mean neighborhood size of words with large neighborhoods was 10.7, for words with small neighborhoods it was 3.4.

The neighborhood frequency factor was divided into four levels. Words could possess no neighbors, no higher frequency neighbors, one higher frequency neighbor, or many higher frequency neighbors. Words with many higher frequency neighbors possessed at least two neighbors of higher frequency. The last three of these conditions were crossed with the neighborhood size (large versus small) factor.

For the word conditions, the mean summed bigram frequencies (Mayzner & Tresselt, 1965) were matched as closely as possible. As with Experiments 1 and 2, we obtained subjective frequency estimates for the target words and their highest frequency neighbors. Forty-three students participated in this procedure. The mean subjective frequency ratings for the target words and their highest frequency neighbor are listed in Table 8, along with other descriptive statistics for these stimuli.[2,3] (The complete set of experimental words used in Experiments 4a and 4b are presented in Appendix C.)

Three groups of four-letter nonwords were also used, with mean neighborhood sizes of 0, 3.9, and 13.4. There were 30 items in each of the three groups. These were the same set of nonwords used in Experiment 1.

Apparatus and procedure. The apparatus and procedure for Experiment 4a (lexical decision) were identical to those of Exper-

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[2] The correlation between the subjective ratings and the Kuçera and Francis (1967) norms for these low-frequency stimuli was .34 ($p < .001$). For Experiment 4a (lexical decision), the correlation between the subjective ratings and the item mean RTs was −.55 ($p < .001$), and the correlation between the Kuçera and Francis norms and the item mean RTs was −.38 ($p < .001$). In Experiment 4b (naming), the correlation between the subjective ratings and the item mean RTs was −.44 ($p < .001$), whereas the correlation between the Kuçera and Francis norms and the item mean RTs was −.13 ($p < .10$).

[3] It may be noted that, once again, some compromises had to be made in selecting low-frequency words with no higher frequency neighbors (as described in Experiment 1). In the present circumstances, however, these compromises were fewer in number and were essentially limited to the large-neighborhood condition.

Table 8

Mean Word Frequency, Subjective Frequency Rating (Rating), Neighborhood Size (N), and Bigram Frequency (BF) for the Stimuli Used in Experiment 4

Neighborhood size	Neighborhood frequency								
	No higher frequency neighbors			1 higher frequency neighbor			More than 1 higher frequency neighbor		
	Target	NB1	NB2	Target	NB1	NB2	Target	NB1	NB2
				Words					
Zero									
Frequency	13.7	0.0	0.0						
Rating	3.5								
N	0.0								
BF	99.0								
Small									
Frequency	15.2	6.7	3.0	14.9	116.0	8.3	15.4	208.0	82.5
Rating	3.3	3.1		3.4	4.9		3.6	5.2	
N	3.5			3.3			3.4		
BF	113.4			105.8			113.6		
Large									
Frequency	21.2	21.6	14.2	18.4	116.5	20.0	14.7	466.3	106.7
Rating	4.0	4.2		4.0	4.9		3.8	5.5	
N	10.0			10.2			12.0		
BF	110.5			116.0			111.5		
				Nonwords					
	N		BF						
Zero	0.0		39.8						
Small	3.9		123.5						
Large	13.4		208.0						

Note. Neighborhood frequency does not apply to nonword data. NB1 refers to the average frequency of the highest frequency neighbor. NB2 refers to the average frequency of the second highest frequency neighbor.

iment 1. The apparatus and procedure for Experiment 4b (naming) were identical to those of Experiment 2.

Design. The six basic conditions produced a 2 (Neighborhood Size: large or small) × 3 (Neighborhood Frequency: none, one, or many higher frequency neighbors) factorial design. There were 14 words in each of the six conditions, an additional 14 words in the zero neighborhood condition, seven filler words, and a total of 90 nonwords divided equally among the three nonword conditions for use in Experiment 4a.

Results

Lexical decision (Experiment 4a). Response latencies of less than 250 ms or greater than 1,500 ms were excluded from the analysis. A total of 28 observations (0.53% of the data) were removed by this procedure. The mean response latencies for correct responses and the mean error rates are shown in Table 9. The six basic word conditions were submitted to a 2 (Neighborhood Size) × 3 (Neighborhood Frequency) repeated-measures ANOVA. In addition, words possessing no higher frequency neighbors (words with no neighbors, and words with large and small neighborhoods but no higher frequency neighbors) were submitted to a separate one-factor repeated-measures ANOVA. For the nonwords, the zero, small, and large neighborhood size conditions were submitted to a one-factor repeated-measures ANOVA.

In the first analysis, the main effect of neighborhood size was significant, $F_s(1, 27) = 10.8$, $p < .01$, $MSE = 2{,}496.6$; $F_i(1, 78) = 5.28$, $p < .05$, $MSE = 4{,}502.3$. Responses to words with large neighborhoods were an average of 25 ms faster than responses to words with small neighborhoods. The main effect of neighborhood frequency was significant

Table 9

Mean Lexical Decision Latencies (in Milliseconds) and Error Rates (ER) in Experiment 4a

Neighborhood size	Neighborhood frequency					
	No higher frequency neighbors		1 higher frequency neighbor		More than 1 higher frequency neighbor	
	M	ER (%)	*M*	ER (%)	*M*	ER (%)
			Words			
Zero	624	15.5				
Small	625	16.8	585	9.2	591	10.0
Large	585	6.5	570	6.6	570	3.8
			Nonwords			
	M	ER (%)				
Zero	607	2.5				
Small	668	6.6				
Large	703	12.1				

Note. Neighborhood frequency does not apply to nonword data.

in the subject analysis, $F_s(2, 54) = 7.39$, $p < .01$, $MSE = 1{,}734.9$, but not in the item analysis, $F_i(2, 78) = 1.45$, $p > .20$, $MSE = 4{,}502.3$. Neighborhood frequency and neighborhood size did not interact, $F_s(2, 54) = 1.56$, $p > .20$, $MSE = 1{,}443.0$; $F_i < 1$.

Averaged response latencies to words with no higher frequency neighbors, one higher frequency neighbor, and more than one higher frequency neighbor were 605, 577, and 580 ms, respectively. Newman-Keuls comparisons revealed that responses to words with no higher frequency neighbors were significantly slower than responses to words with one higher frequency neighbor, $Q(54) = 3.55$, $p < .05$, and to words with more than one higher frequency neighbor, $Q(54) = 3.17$, $p < .05$. The latter two conditions did not differ, $Q(54) = 0.38$, $p > .25$. Thus, the neighborhood frequency effect was due to the fact that response latencies were faster when a word possessed higher frequency neighbors than when it did not.

Error rates were submitted to a 2 (Neighborhood Size) × 3 (Neighborhood Frequency) repeated-measures ANOVA. The main effect of neighborhood size was significant, $F_s(1, 27) = 29.0$, $p < .001$, $MSE = 58.48$, as was the main effect of neighborhood frequency, $F_s(2, 54) = 9.69$, $p < .01$, $MSE = 35.23$. Errors were more frequent to words with small neighborhoods than to words with large neighborhoods, and error rates generally decreased as the number of higher frequency neighbors in a word's orthographic neighborhood increased. Thus, the facilitatory effects of a large neighborhood size and the presence of higher frequency neighbors was also evident in the pattern of error rates. There was also an interaction between neighborhood size and neighborhood frequency, $F_s(2, 54) = 3.91$, $p < .05$, $MSE = 53.31$, which reflected the fact that the neighborhood size effect on error rates was slightly larger when words did not possess higher frequency neighbors.

Recall that Grainger et al. (1989) found that lexical-decision latencies to words with no neighbors and words with some neighbors but none of higher frequency did not differ, which led them to suggest that there was no absolute neighborhood size effect. To address this issue, we submitted the response latencies to words with no higher frequency neighbors in our design (words with no neighbors and words with large and small neighborhoods and no higher frequency neighbors) to a one-factor repeated-measures ANOVA. In contrast to Grainger et al.'s (1989) findings, we obtained a significant main effect of neighborhood size for the words that did not possess higher frequency neighbors, $F_s(2, 54) = 9.57$, $p < .001$, $MSE = 1{,}492.52$; $F_i(2, 39) = 2.54$, $p < .10$, $MSE = 4{,}462.43$. Newman-Keuls tests indicated that responses to words with large neighborhoods and no higher frequency neighbors were faster than responses to words with small neighborhoods and no higher frequency neighbors, $Q(54) = 5.47$, $p < .01$, and faster than responses to words with no neighbors, $Q(54) = 5.34$, $p < .01$. There was no difference between the zero and small neighborhood size conditions, $Q(54) = 0.13$, $p > .25$. An analysis of the error rates for these conditions yielded a complementary pattern of effects.

Nonwords. As in Experiment 1, response latencies to nonwords increased across the zero, small, and large neighborhood size conditions, $F_s(2, 54) = 114.3$, $p < .001$, $MSE = 579.60$; $F_i(2, 87) = 30.0$, $p < .001$, $MSE = 2{,}587.8$. Newman-Keuls tests revealed significant differences in response latencies among all three conditions (all $ps < .01$). Error rates also increased in conjunction with neighborhood size, $F_s(2, 54) = 18.1$, $p < .001$, $MSE = 35.52$.

Finally, we again examined whether there is a neighborhood size effect in nonword RTs when bigram frequency is controlled. Although Andrews (1992) failed to obtain such an effect, we again found a significant neighborhood size effect for the same subset of nonwords compared in Experiment 1, $F_s(1, 27) = 10.5$, $p < .01$, $MSE = 529.91$; $F_i(1, 38) = 1.14$, $p > .25$, $MSE = 3{,}085.8$.

Naming (Experiment 4b). Naming latencies of less than 250 ms or greater than 1,000 ms were excluded from the analysis (3.3% of the data). The naming latencies and error rates are shown in Table 10. Error rates in this experiment were somewhat greater than in previous experiments. Naming latencies and error rates were submitted to a 2 (Neighborhood Size) × 3 (Neighborhood Frequency) repeated-measures ANOVA.

As with the lexical decision data, the main effect of neighborhood size was significant in both the subject and item analyses, $F_s(1, 34) = 18.73$, $p < .001$, $MSE = 551.52$; $F_i(1, 78) = 5.08$, $p < .05$, $MSE = 703.83$. Words with large neighborhoods were responded to an average of 14 ms faster than words with small neighborhoods. There was also a main effect of neighborhood frequency, $F_s(2, 68) = 10.85$, $p < .001$, $MSE = 573.60$; $F_i(2, 78) = 4.51$, $p < .05$, $MSE = 703.83$. The interaction between neighborhood size and neighborhood frequency was not reliable, $F_s(2, 68) = 3.01$, $p < .10$, $MSE = 417.89$; $F_i < 1$.

Averaged response latencies to words with no higher frequency neighbors, one higher frequency neighbor, and more than one higher frequency neighbor were 476, 474, and 459 ms, respectively. Newman-Keuls tests revealed significant differences between the response latencies to words with no higher frequency neighbors and to words with more than one higher frequency neighbor, $Q(68) = 4.19$, $p < .05$, and between the response latencies to words with one higher frequency neighbor and to words with more than one higher frequency neighbor, $Q(68) = 3.70$, $p < .05$. Responses to words with one higher frequency neighbor

Table 10
Mean Naming Latencies (in Milliseconds) and Error Rates (ER) in Experiment 4b

	Neighborhood frequency					
	No higher frequency neighbors		1 higher frequency neighbor		More than 1 higher frequency neighbor	
Neighborhood size	*M*	ER (%)	*M*	ER (%)	*M*	ER (%)
Zero	486	3.6				
Small	487	2.2	477	3.2	468	1.6
Large	466	1.6	472	2.0	451	3.2

were not significantly faster than the responses to words with no higher frequency neighbors, $Q(68) = 0.49, p > .25$. In both the lexical-decision and naming tasks then, responses to words with more than one higher frequency neighbor were significantly faster than responses to words with no higher frequency neighbors. A repeated-measures ANOVA of error rates yielded no significant effects (all Fs < 1).

Finally, we again compared response latencies among the words with no higher frequency neighbors to determine whether there was a neighborhood size effect. Response latencies to words with no neighbors and words with large and small neighborhoods and no higher frequency neighbors were submitted to a one-factor repeated-measures ANOVA. There was a significant effect of neighborhood size, $F_s(2, 68) = 7.92, p < .01, MSE = 611.36$; $F_i(2, 39) = 1.63, p > .20, MSE = 967.70$, and Newman-Keuls tests revealed the same pattern of results as found with the lexical-decision task. Responses to words with large neighborhoods and no higher frequency neighbors were faster than responses to words with small neighborhoods and no higher frequency neighbors, $Q(68) = 5.02, p < .01$, and faster than responses to words with no neighbors, $Q(68) = 4.78, p < .01$. There was again no difference between the zero- and small-neighborhood conditions, $Q(68) = 0.23, p > .25$.

Overall then, the results from both the lexical-decision and naming tasks were reasonably consistent with one another: A facilitatory neighborhood size effect was evident for low-frequency words with and without higher frequency neighbors, and higher frequency neighbors facilitated responses to words with both large and small neighborhoods.

Discussion

In support of the trends observed in Experiments 1 and 2, we found that the presence of higher frequency neighbors in a low-frequency word's orthographic neighborhood facilitated responses. Lexical-decision and naming latencies were faster for words with higher frequency neighbors than for words with no higher frequency neighbors. Although these results appear to directly contradict the lexical-decision results of Grainger et al. (1989) and Grainger and Segui (1990), we should note that Grainger (1990) observed a similar facilitatory trend in a naming task (Experiment 1). At the very least, these data reinforce the suggestion that the inhibitory neighborhood frequency effect has limited generalizability. On the other hand, the neighborhood size effect observed in this experiment clearly supports the generalizability of Andrews's (1989, 1992) claim that large neighborhoods facilitate the processing of low-frequency words.

Finally, recall that in Experiments 1 and 2 there was no neighborhood size effect for low-frequency words with no higher frequency neighbors, whereas in these experiments there was. We suggested that a possible reason for the pattern in Experiment 1 was that we had to make a number of compromises in selecting the words in Experiment 1. Although some similar compromises were also made in Experiment 4, they were substantially fewer in number. Thus, it should be possible to have somewhat more confidence in the present results and to conclude that low-frequency words with no higher frequency neighbors also produce a neighborhood size effect. This conclusion will be reinforced by the results of Experiments 5 and 6.

Experiment 5

At this point it is unclear why we have consistently failed to replicate the Grainger et al. (1989) inhibitory neighborhood frequency effect. Although neighborhood frequency has been examined in Experiments 1, 2, 4a, and 4b, any evidence for a neighborhood frequency effect suggests that the effect is facilitatory rather than inhibitory. As was pointed out earlier, Grainger (1990) found a slightly facilitatory effect of neighborhood frequency in a naming task, and the majority of experiments demonstrating an inhibitory neighborhood frequency effect have used the lexical-decision task. Thus, the real discrepancy between our results and those of Grainger et al. (1989) is only found in the lexical-decision task.

As Seidenberg and colleagues have argued (Seidenberg, Waters, Barnes, & Tannenhaus, 1984; Waters & Seidenberg, 1985), there are many ways to successfully respond in a lexical-decision task. Thus, it is possible that our participants were making lexical decisions somewhat differently than were Grainger et al.'s (1989) participants. For example, although Grainger et al.'s participants may have been basing their responses entirely on successfully locating a word's unique lexical code, our participants' response process might have been biased by the initial level of lexical activation. Words with large neighborhoods would, of course, produce large levels of activation, thus creating a bias to respond "word." More relevant to the present discussion, however, is that the same may happen when a word has at least one quite-high-frequency neighbor. The result of this bias might be to either speed-up or short-circuit further processing. Thus, between the two groups of participants, there might have been a difference in the "depth" to which the stimuli were being processed, a difference that could be important in determining whether inhibitory or facilitatory neighborhood frequency effects are observed (Snodgrass & Mintzer, 1993).

More concretely, consider, for example, the Forster (1976) model. In this model a serial-comparison processor searches a defined set of lexical entries for a match between one of them and the word's sensory representation. The search is frequency-ordered, so that the highest frequency entries are checked first. Lexical access is ultimately achieved when a match is found. Thus, as Grainger et al. (1989) argued, higher frequency neighbors will delay lexical access because these words must be evaluated and rejected before finding a match.

In theory, however, this delay could be countered, or even reversed, if a strong enough bias had been provided before entering the comparison stage. That is, the bias could mean that participants would either accept partial matches or, in more extreme cases, if the bias were strong enough, not bother to engage the comparison process at all. Also note that the potentially conflicting roles of neighborhood size and neighborhood frequency described by Andrews (1989) and Grainger et al. (1989) would be easily explained within this framework. The neighborhood size effect would be attributed to the bias provided by a large degree of lexical activity and it would have a different locus than the neighborhood frequency effect, which would arise later during more detailed processing.

This hypothesis, which we refer to as the "depth-of-processing" hypothesis, suggests then that inhibitory neighborhood frequency effects should only occur when participants are forced to engage in an extensive lexical search before responding. To evaluate this hypothesis, we reasoned that one way to require participants to engage in an extensive lexical search would be to increase the difficulty of the word–nonword discriminations. In Experiment 5 this was accomplished by changing the nonword context: All of the nonwords used had a large number of neighbors. By using these large neighborhood nonwords, participants should be disinclined to use the level of lexical activation as a cue to responding, because the nonwords would also produce high levels of lexical activation. Rather, participants would be forced to examine each lexical candidate carefully and to not respond until the unique lexical entry of a stimulus had been found. If the depth-of-processing hypothesis is correct, we should now see evidence of an inhibitory effect of neighborhood frequency under these conditions.

Method

Participants. Thirty undergraduate students from the University of Western Ontario participated in this experiment for course credit. All the participants were native English speakers and had normal or corrected-to-normal vision. None had participated in the previous experiments.

Stimuli. All of the stimuli were four-letter low-frequency words, with a mean Kuçera and Francis (1967) frequency of 17.9. Words with small neighborhoods had no more than five neighbors; words with large neighborhoods had at least seven neighbors. The mean neighborhood size for words with large neighborhoods was 10.2, for words with small neighborhoods, it was 3.6.

The neighborhood frequency factor had two levels. Words possessed no higher frequency neighbors or one or more higher frequency neighbors. For the word conditions the mean summed bigram frequencies (Mayzner & Tresselt, 1965) were matched as closely as possible. The orthographically legal nonword stimuli all possessed large neighborhoods, with an average neighborhood size of 12.9. Descriptive statistics for these stimuli are shown in Table 11. (The complete set of words used in Experiment 5 is presented in Appendix D.)

Apparatus and procedure. The apparatus and procedure were the same as those used in Experiment 1.

Design. The four word conditions produced a 2 (Neighborhood Size) × 2 (Neighborhood Frequency) factorial design. There were 14 words in each of the four conditions and 56 large-neighborhood nonwords.

Table 11

Mean Word Frequency, Subjective Frequency Rating (Rating), Neighborhood Size (N), and Bigram Frequency (BF) for the Stimuli Used in Experiment 5

	Neighborhood frequency			
	No higher frequency neighbors		Higher frequency neighbors	
Neighborhood size	Target	NBF	Target	NBF
	Words			
Small				
Frequency	19.9	13.4	14.6	219.5
Rating	3.6	3.3	3.6	6.5
N	3.6		3.6	
BF	108.6		113.6	
Large				
Frequency	20.3	21.6	16.9	404.3
Rating	4.1	4.1	4.0	5.4
N	9.9		10.6	
BF	114.3		119.5	
	Nonwords			
	Target			
N	12.9			
BF	187.0			

Note. Neighborhood frequency does not apply to nonword data. NBF = average frequency of the highest frequency neighbor.

Results

Response latencies of less than 250 ms or greater than 1,500 ms were excluded from both the subject and item analyses. A total of 33 observations (0.9% of the data) were removed by this procedure. The mean response latencies for correct responses and the mean error rates are shown in Table 12. Note that we can infer that the use of large neighborhood nonwords increased the difficulty of the word–nonword discrimination by the fact that response latencies to words in this experiment were an average of 30 ms slower than those of Experiment 4a (where similar low-frequency words were used).

Table 12

Mean Lexical Decision Latencies (in Milliseconds) and Error Rates (ER) in Experiment 5

	Neighborhood frequency			
	No higher frequency neighbors		Higher frequency neighbors	
Neighborhood size	*M*	ER (%)	*M*	ER (%)
	Words			
Small	632	8.3	627	8.5
Large	619	6.1	611	3.8
	Nonwords			
	M	ER (%)		
Large	757	9.0		

Note. Neighborhood frequency does not apply to nonword data.

The four basic word conditions were submitted to a 2 (Neighborhood Size) × 2 (Neighborhood Frequency) repeated-measures ANOVA. The main effect of neighborhood size was significant in the subject analysis, $F_s(1, 29) = 7.59, p < .01, MSE = 817.18$ but not the item analysis, $F_i(1, 52) = 1.32, p > .20, MSE = 2{,}893.9$. Words with large neighborhoods were responded to an average of 14 ms faster than words with small neighborhoods, which indicates that the neighborhood size effect was still present when the word–nonword discrimination was very difficult. The neighborhood frequency main effect was not significant in either the subject or item analyses (both *F*s < 1), although there was a trend toward facilitation (6 ms). The Neighborhood Size × Neighborhood Frequency interaction was not reliable ($F_s < 1$; $F_i < 1$).

Error rates were also submitted to a 2 (Neighborhood Size) × 2 (Neighborhood Frequency) repeated-measures ANOVA. The main effect of neighborhood size was significant, $F_s(1, 29) = 8.07, p < .01, MSE = 44.11$; there were more errors to words with small neighborhoods than to words with large neighborhoods. There was no main effect of neighborhood frequency ($F_s < 1$) and no Neighborhood Size × Neighborhood Frequency interaction, $F_s(1, 29) = 1.45, p > .20, MSE = 35.29$.

Discussion

The results of this experiment are clear: Responses to words with large neighborhoods were still facilitated when the difficulty of the word–nonword discrimination was increased and, more important, higher frequency neighbors in a word's orthographic neighborhood did not delay responding. The first of these results complements Andrews's (1989) finding of a reliable neighborhood size effect when less word-like nonwords are used in the lexical decision task. In Andrews's (1989) Experiment 2 the difficulty of the word–nonword discrimination was somewhat less than in Experiment 5, which might have biased participants to avoid extensive lexical searches and respond before lexical access was complete. To a lesser extent, the same could be said about our Experiments 1 and 4a. As shown in the present experiment, however, nonwords with large neighborhoods (which are very word-like), did not eliminate the facilitatory neighborhood size effect. The implication would seem to be, then, that neighborhood size effects have considerable generality.

The lack of an inhibitory neighborhood frequency effect clearly indicates that we have provided no support for the depth-of-processing hypothesis. That is, in spite of using large neighborhood nonwords, the only evidence of a neighborhood frequency effect was a nonsignificant trend toward facilitation. Thus, whatever factor might explain our inability to produce an inhibitory neighborhood frequency effect, it does not appear that it was because our participants were not processing words to a deep-enough level.

Experiment 6

In Experiment 6, we tried one more time to produce an inhibitory neighborhood frequency effect. Despite the fact that the initial experiments demonstrating inhibitory neighborhood frequency effects used four-letter words (Grainger, 1990; Grainger et al., 1989), as noted, Grainger (1992) has reported data suggesting that the neighborhood frequency effect may be more reliable with five-letter words. In particular, Grainger (1992) reported an inhibitory neighborhood frequency effect for five-letter words but an equally large facilitatory effect for four-letter words. Because all of our previous experiments have used four-letter words, one could argue that our failure to obtain an inhibitory neighborhood frequency effect is due to the fact that only four-letter words were used. To evaluate this possibility, we conducted a final experiment using only five-letter stimuli (words and nonwords).[4]

Method

Participants. Thirty-six undergraduate students from the University of Western Ontario participated in this experiment for course credit. All the participants were native English speakers and had normal or corrected-to-normal vision. None had participated in the previous experiments.

Stimuli. All of the word stimuli were five-letter low-frequency words, with a mean Kuçera and Francis (1967) frequency of 19.5. Words with small neighborhoods had no more than two neighbors ($M = 1.6$); words with large neighborhoods had at least six neighbors ($M = 7.4$). Also included was a single group of words that possessed no neighbors.

As in Experiment 5, the neighborhood frequency factor had two levels. Words possessed no higher frequency neighbors or one or more higher frequency neighbors. For words with no higher frequency neighbors, the mean frequency of the words' highest frequency neighbor was 8.6. For words with higher frequency neighbors, the mean frequency of the words' highest frequency neighbor was 245. (The complete set of experimental words used in Experiment 6 is presented in Appendix E.)

Three groups of five-letter, orthographically legal nonwords were used; zero-neighborhood nonwords, small-neighborhood nonwords ($M = 1.9$), and large neighborhood nonwords ($M = 7.7$). Descriptive statistics for the word stimuli are shown in Table 13.

Apparatus and procedure. The apparatus and procedure were the same as those used in Experiment 1.

Design. The four principal word conditions produced a 2 (Neighborhood Size) × 2 (Neighborhood Frequency) factorial design. There were 15 words in each of these four conditions, 15

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[4] There was also a second reason for conducting Experiment 6. Even though few compromises were made in selecting large-neighborhood words with no higher frequency neighbors in Experiment 5, the stimulus set still contained a couple of words that were not unambiguously at the top of their neighborhoods. The use of five-letter words allowed us to select a set of large-neighborhood words with no higher frequency neighbors that were unambiguously at the top of their neighborhoods. Note, however, that using five-letter words created a new problem. Neighborhoods for five-letter words are smaller and thus the neighborhood-size manipulation was weaker than in previous experiments.

Table 13
Mean Word Frequency and Neighborhood Size (N) for the Stimuli Used in Experiment 6

Neighborhood size	Neighborhood frequency: No higher frequency neighbors: Target	No higher frequency neighbors: NBF	Higher frequency neighbors: Target	Higher frequency neighbors: NBF
	Words			
Zero				
Frequency	18.2	0.0		
N	0.0			
Small				
Frequency	20.0	4.6	17.6	234.0
N	1.6		1.7	
Large				
Frequency	24.0	12.6	17.8	256.0
N	7.6		7.3	
	Nonwords			
	N			
Zero	0.0			
Small	1.9			
Large	7.7			

Note. Neighborhood frequency does not apply to nonword data. NBF = average frequency of the highest frequency neighbor.

words with no neighbors, and an additional 25 filler words. There were 30 nonwords in each of the zero-, small-, and large-neighborhood nonword groups.

Results

Response latencies of less than 250 ms or greater than 1,500 ms were excluded from both the subject and item analyses. A total of 43 observations (0.7% of the data) were removed by this procedure. The mean response latencies for correct responses and the mean error rates are shown in Table 14.

The four principal word conditions were submitted to a 2 (Neighborhood Size) × 2 (Neighborhood Frequency) repeated-measures ANOVA. There was a significant main effect of neighborhood size in the subject analysis, $F_s(1, 35) = 5.57$, $p < .05$, $MSE = 1{,}233.5$, but not in the item analysis, $F_i(1, 56) = 2.70$, $p > .10$, $MSE = 1{,}038.4$. Words with large neighborhoods were responded to an average of 14 ms faster than words with small neighborhoods. The main effect of neighborhood frequency was also significant in the subject analysis, $F_s(1, 35) = 4.60$, $p < .05$, $MSE = 939.86$, but not in the item analysis, $F_i(1, 56) = 1.83$, $p > .15$, $MSE = 1{,}038.4$. Words with higher frequency neighbors were responded to an average of 11 ms faster than words with no higher frequency neighbors. The Neighborhood Size × Neighborhood Frequency interaction was not reliable, $F_s < 1$, $F_i < 1$.

Error rates were also submitted to a 2 (Neighborhood Size) × 2 (Neighborhood Frequency) repeated-measures ANOVA. Although the pattern of error rates mirrored that seen in the RT data, there was neither a significant main effect of neighborhood size, $F_s(1, 35) = 2.04$, $p > .15$, $MSE = 18.24$, a significant effect of neighborhood frequency, $F_s(1, 35) = 1.95$, $p > .15$, $MSE = 26.66$, nor an interaction ($F_s < 1$).

We also examined the effect of neighborhood size across the three word conditions that possessed no higher frequency neighbors (words with no neighbors and words with large and small neighborhoods and no higher frequency neighbors). The mean RTs and error rates for these conditions were submitted to a one-factor repeated-measures ANOVA. The main effect of neighborhood size was significant in the subject RT analysis, $F_s(2, 70) = 6.40$, $p < .01$, $MSE = 1{,}198.7$, but not in the item analysis, $F_i(2, 42) = 2.53$, $p < .10$, $MSE = 1{,}249.9$. As can be seen in Table 14, responses to word with large neighborhoods and no higher frequency neighbors were 16 ms faster than responses to words with small neighborhoods and no higher frequency neighbors and 30 ms faster than responses to words with no neighbors. Multiple comparisons using the Newman-Keuls test revealed that neither the 14-ms difference between the small-neighborhood and zero-neighborhood conditions nor the 16-ms difference between the large and small neighborhood conditions were statistically reliable, $Q(70) = 2.42$, $p > .05$, and $Q(70) = 2.77$, $p > .05$, respectively. However, the 30-ms difference between the large-neighborhood and zero-neighborhood conditions was significant, $Q(70) = 5.19$, $p < .01$. This result reinforces our previous finding that words that possess no higher frequency neighbors exhibit a neighborhood size effect (Experiment 4). There was no significant main effect of neighborhood size in the analysis of error rates, $F_s < 1$.

Finally, the RTs and error rates for the three groups of nonwords (zero-, small-, and large-neighborhood sizes) were submitted to a one-factor repeated-measures ANOVA. As expected, response latencies to nonwords increased across the zero-, small-, and large-neighborhood size conditions, $F_s(2, 70) = 155.23$, $p < .001$, $MSE = 537.71$; $F_i(2, 87) = 28.9$, $p < .000$, $MSE = 2{,}455.2$; and error rates also

Table 14
Mean Lexical Decision Latencies (in Milliseconds) and Error Rates (ER) in Experiment 6

Neighborhood size	Neighborhood frequency: No higher frequency neighbors: *M*	No higher frequency neighbors: ER (%)	Higher frequency neighbors: *M*	Higher frequency neighbors: ER (%)
	Words			
Zero	617	4.2		
Small	603	4.4	590	3.5
Large	587	3.6	578	2.2
	Nonwords			
	M	ER (%)		
Zero	644	1.7		
Small	701	5.1		
Large	740	10.6		

Note. Neighborhood frequency does not apply to nonword data.

increased in conjunction with neighborhood size, $F_s(2, 70) = 31.45$, $p < .001$, $MSE = 22.93$.

Discussion

The results of this experiment clearly indicate that with five-letter words, the effect of neighborhood size and the effect of having higher frequency neighbors (neighborhood frequency) are both facilitatory. Thus, our inability to produce inhibitory neighborhood frequency effects in Experiments 1 through 5 was not due to our use of only four-letter words. Taken together, these results not only cast doubt on the validity of serial models of lexical access (because, in general, they predict inhibitory effects of both neighborhood size and neighborhood frequency), they also provide a serious challenge to the generality of Grainger et al.'s (1989) inhibitory neighborhood frequency effect.

General Discussion

The purpose of this investigation was to explore the apparently conflicting effects that are ascribed to orthographic neighborhoods by Andrews (1989) and Grainger et al. (1989). Andrews (1989, 1992) has found that large-neighborhood size has a facilitatory effect on lexical-decision and naming latencies for low-frequency words (and possibly for high-frequency words as well), and has argued that large neighborhoods facilitate lexical access. In contrast, Grainger et al. (1989) have argued that it is not neighborhood size but neighborhood frequency that influences the speed with which lexical access is accomplished. Their experiments have suggested that regardless of neighborhood size, the presence of higher frequency neighbors in a word's neighborhood inhibits lexical access.

By simultaneously manipulating neighborhood size and neighborhood frequency, we have provided a means of evaluating these claims. Our data clearly support Andrews' (1989, 1992) findings. On the other hand, Experiments 1, 2, and 5 suggested that neighborhood frequency does not appear to be a particularly important determinant of the speed of lexical access, because the presence of higher frequency neighbors had only a minimal effect on response latencies in these experiments. If anything, for low-frequency words with large neighborhoods, the presence of higher frequency neighbors seemed to facilitate responding. In Experiments 4 and 6 we observed reliable facilitatory neighborhood frequency effects for low-frequency words, independent of neighborhood size. Except for the small difference obtained for low-frequency words with small neighborhoods in the naming task (Experiment 2), we can offer no evidence to support Grainger et al.'s (1989) conclusion that the presence of higher frequency neighbors delays lexical access. Instead, our results suggest that neighborhood frequency is only important for low-frequency words and that its effect is a facilitatory one.

The total inability to replicate the inhibitory neighborhood frequency effect of Grainger et al. (1989) is quite puzzling. Although one could argue that our failure to obtain these effects in Experiments 1, 4, and 6 was due to participants' responding on the basis of the overall level of lexical activation (because only one-third of the nonwords in each experiment had large neighborhoods), such would not be the case in Experiment 5. Thus, it would appear that differences in the depth to which stimuli are processed in the lexical decision task cannot explain our failure to produce an inhibitory neighborhood frequency effect. In Experiment 6 we also investigated the possibility that the inhibitory neighborhood frequency effect is limited to five-letter words, as Grainger (1992) has reported, but we found no evidence to support this possibility either. Instead, our results indicate that the effects of both neighborhood size and neighborhood frequency are facilitatory for low frequency five-letter words.[5]

The present results then pose a severe challenge to the existence of a "true" inhibitory neighborhood frequency effect (i.e., that having a higher frequency neighbor per se slows word processing, as Grainger and colleagues have suggested). The reader should also be reminded that even Grainger and colleagues have not consistently obtained this effect. Grainger (1990) observed a trend toward a facilitatory neighborhood frequency effect in a naming task. Grainger et al. (1992) only observed an inhibitory effect for words when the higher frequency neighbor was created by changing the letter in the fourth position and not when the higher frequency neighbor was created by changing the letter in the second position. Finally, as noted, Grainger (1992) reported an inhibitory neighborhood frequency effect only for five-letter words. For four-letter words, an equally large facilitatory neighborhood frequency effect was observed, producing an overall null effect. These results would also appear to call into question the existence of a true inhibitory effect of neighborhood frequency.

Implications for Models of Lexical Access

As was pointed out by Andrews (1989, 1992), facilitatory neighborhood size effects are, in general, incompatible with serial-search models of lexical access (i.e., Becker, 1976; Forster, 1976; Paap et al., 1982). As a result, Andrews (1989) opted for an explanation in terms of McClelland and Rumelhart's (1981) interactive–activation model. That is, the neighborhood size effect for low-frequency words was assumed to be the consequence of reciprocal activation between sublexical and lexical units. Because low-frequency words with large neighborhoods would receive more feedback from the lexical to the sublexical level than low-frequency words with small neighborhoods, lexical access (achieved at a criterion activation level) would be facilitated. High-frequency words, because of their higher resting activation levels, would presumably be less affected by reciprocal activation, although as the results of both

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[5] We should note that one difference between the present experiments and those of Grainger and colleagues is language. That is, Grainger and colleagues' experiments were conducted in either French or Dutch. We fail to see, however, how this difference could have accounted for the contradictory results.

the present studies and those of Andrews (1992) indicate, neighborhood size can have at least a small effect even on higher frequency words. Interestingly, however, Jacobs and Grainger's (1992) attempts to simulate Andrews's (1992) neighborhood size effect with the interactive–activation model were unsuccessful. That is, it appears that the interactive-activation model, at least as implemented by Jacobs and Grainger (1992), does not actually predict a neighborhood size effect.

As noted, our results also suggest that the presence of higher frequency neighbors may facilitate the lexical access of at least low-frequency words. This result would also seem to be one that the interactive-activation model cannot predict, at least according to the simulations reported by Jacobs and Grainger (1992). The essential reason is because of the central role the lexical inhibition process plays in this model. (This would also seem to be the reason that the model cannot account for a facilitatory neighborhood size effect.) According to the model's assumptions, when lexical units are activated, they inhibit the lexical units of their neighbors. The degree to which a lexical unit inhibits its neighbors is a function of the resting activation level of the inhibiting unit. Thus, high-frequency words can inhibit their neighbors more than low-frequency words. Whenever a low-frequency word is presented, its neighbors are also partially activated. If those neighbors are higher in frequency, their lexical units will strongly inhibit the lexical unit of the presented word, retarding the growth of its activation, and hence prolonging lexical access. If those neighbors are low in frequency, the inhibition will be much less severe. The result is an inhibitory neighborhood frequency effect. Thus, on the basis of the simulations reported by Jacobs and Grainger (1992), it would seem that the interactive-activation model cannot account for either of our results (at least without considerable altering of parameter values).

On the other hand, if parameter values were changed appropriately, it seems quite possible that both a facilitatory neighborhood size effect and a facilitatory neighborhood frequency effect could be accommodated by the interactive-activation model. To begin with, it would first have to be assumed that the lexical inhibition process is somewhat less potent than in Jacobs and Grainger's (1992) simulation. If so, then words with many neighbors could reach an activation threshold more quickly through the reciprocal activation mechanism described by Andrews (1989). Furthermore, the presence of high-frequency neighbors could provide an additional contribution to this process if the degree of lexical to sublexical top-down activation was directly related to the resting activation levels of the lexical units themselves. Lexical units corresponding to the high-frequency neighbors of a target word would possess high resting activation levels, and if high resting activation levels produced stronger top-down activation, the effect would be accelerated. Thus, the same process that explains facilitatory neighborhood size effects in the interactive-activation model might also explain facilitatory neighborhood frequency effects. The question, of course, would be to what extent these parameter changes would harm the model's ability to account for other word recognition phenomena.

What appears to be a somewhat better model for explaining our findings is Seidenberg and McClelland's (1989) parallel distributed processing (PDP) model. In that model, there are no abstract units corresponding to words; the representation of a word is embodied in the pattern of activity across an interconnected network of units. Experience with words produces changes in the weights between the units. Word frequency effects arise because the network is exposed to high-frequency words much more often than low-frequency words during training and thus has more opportunities to encode their orthography. The result is that the model produces lower "phonological" and "orthographic" error scores for high-frequency words.

Seidenberg and McClelland (1989) have, in fact, shown that their model successfully simulates Andrews's (1989) naming data, producing a neighborhood size effect in the pattern of phonological error scores for low-frequency words. Andrews (1992) has also reached this conclusion. As Andrews pointed out, one might expect that words with large neighborhoods would produce lower phonological and orthographic error scores because the units and connections involved in encoding the representation of a word with many neighbors would be strengthened by the encoding of the neighbors. That is, words that are highly similar to one another would recruit similar units and connections, and these connections would be reinforced with every presentation of the word or its neighbors. Thus, compared with words with small neighborhoods, which would share connections with few other words, words with large neighborhoods should exhibit lower phonological and orthographic error scores.

As we have pointed out many times, the majority of Andrews's (1989) stimuli possessed higher frequency neighbors, and the fact that the Seidenberg and McClelland (1989) model can simulate her results leads us to suspect that the model would also predict that higher frequency neighbors would facilitate the recognition of low-frequency words. Just as a word with a large neighborhood will benefit from the encoding of its neighbors, a word with a large neighborhood and higher frequency neighbors should benefit even more. Recall that the word frequency effect in this model is a consequence of the differential opportunities the network has to encode the orthography of high- and low-frequency words: Higher frequency words are encoded more often and as such will strengthen their particular representation to a greater extent. Thus, the general argument is that low-frequency words with large or small neighborhoods and higher frequency neighbors will benefit from the presence of a higher frequency neighbor in their neighborhood because that neighbor will be a word whose representation has been encoded by the network many times. The strengthened connections between the units that encode the higher frequency neighbor will aid in its identification, and because many of the same units will be recruited by the target word, the identification of the target will be facilitated. Thus, higher frequency neighbors should affect the system in the same way as large neighborhoods would, by strengthening the connections among units that represent similar orthographies.

We found some support for this hypothesis by examining the mean phonological error scores for the words used in our naming experiments.[6,7] As can be seen in Figures 1 and 2, where the pattern of phonological error scores along with the RTs for the high- and low-frequency words of Experiment 2 are depicted, both a facilitatory neighborhood size and facilitatory neighborhood frequency effect seem to be predicted by the model. The facilitatory neighborhood frequency effect is most pronounced for words with large neighborhoods, which, at a general level, is the pattern that was observed in the naming data of Experiment 2.

Figure 3 shows the data and pattern of phonological error scores for the stimuli used in Experiment 3b. The pattern of phonological scores clearly reflects the interaction between neighborhood size and word frequency observed in that experiment. Finally, Figure 4 shows the data and the pattern of phonological error scores for the stimuli used in Experiment 4b. Once again the model predicts a neighborhood size effect (as was obtained in that experiment), and at least for words with large neighborhoods, the phonological error scores were lower when the words possessed higher frequency neighbors. Overall, this pattern of phonological error scores lends some support to our hypothesis that the identification of words with large neighborhoods or higher frequency neighbors should be facilitated according to the Seidenberg and McClelland (1989) model. This model then would appear to provide at least a qualitative account of the results of our naming experiments. The processing of low-frequency words with large neighborhoods or higher frequency neighbors would be facilitated because of the strengthened connections among the units encoding their neighbors.

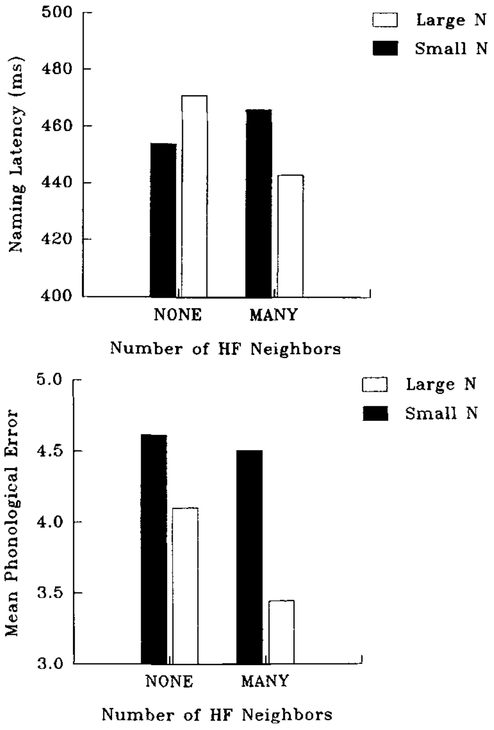

Figure 1. Mean response latencies and mean phonological error scores for the low-frequency words used in Experiment 2. N = neighborhood size; HF = higher frequency.

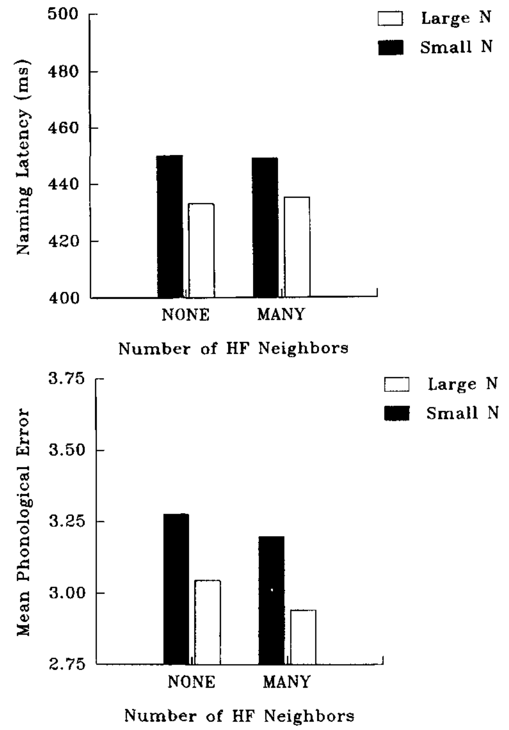

Figure 2. Mean response latencies and mean phonological error scores for the higher-frequency (HF) words used in Experiment 2. N = neighborhood size.

Despite these encouraging findings, in recent years the Seidenberg and McClelland (1989) model has come under increasing attack. Besner, Twilley, McCann, and Seergobin (1990) and Fera and Besner (1992) have shown that current implementations of the model have great difficulty in accurately pronouncing nonwords and that the overlap between the orthographic error scores for word and nonword items is

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[6] We thank Seidenberg and McClelland (1989) for making these data available. Unfortunately we had no phonological error scores for a number of our words with small neighborhoods, because Seidenberg and McClelland (1989) did not train their model with these stimuli. Consequently, the pattern of phonological error scores for the small neighborhood word conditions should be interpreted with caution.

[7] Only the naming experiments were used for these analyses, because it is currently unclear how phonological error scores relate to lexical decision RTs (Fera & Besner, 1992). It should be noted, however, that the lexical decision RTs and the naming RTs in all our experiments showed similar patterns. We should also note that the patterns of orthographic error scores, which may be more relevant to lexical decision tasks, were similar to the patterns of phonological error scores.

too large to provide a basis for accurate lexical decisions. Although it is clear that the model is not the final answer, the basic principle embodied in it—that one is better at processing patterns seen many times before—is hard to dispute. Future versions of the model will presumably be more successful at overcoming the deficiencies identified by Besner and colleagues (see, e.g., Plaut, McClelland, & Seidenberg, 1992).

Conclusions

The purpose of this investigation was to determine the role that a word's orthographic neighborhood plays in lexical access and to examine the apparent empirical contradiction between neighborhood size and neighborhood frequency effects. Our results lend support to Andrews's (1989, 1992) claim that large neighborhoods facilitate the lexical access of low-frequency words; however, we were unable to replicate the inhibitory neighborhood frequency effect described by Grainger and colleagues (1989, 1990). Instead, we found that higher frequency neighbors facilitated the lexical access of low-frequency words and had no effect on the lexical access of high-frequency words. Serial-based models of lexical access will have great difficulty accommodating these results. Alternatively, with an appropriate set of assumptions, activation models such as the interactive-activation model of McClelland and Rumelhart (1981) or the PDP model of Seidenberg and McClelland (1989)[8] do appear to have the ability to account for the present findings.

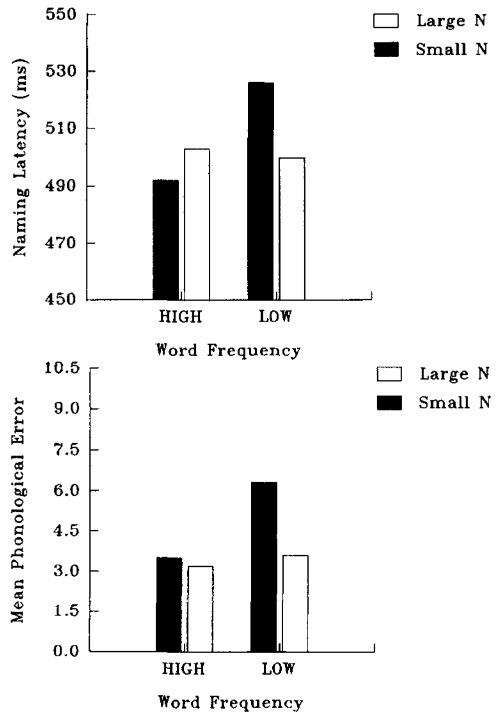

Figure 3. Mean response latencies and mean phonological error scores for the stimuli used in Experiment 3b. N = neighborhood size; HF = higher frequency.

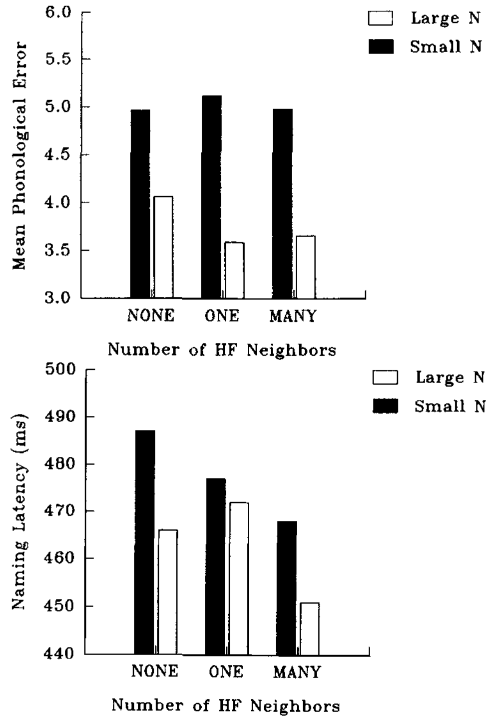

Figure 4. Mean response latencies and mean phonological error scores for the stimuli used in Experiment 4b. N = neighborhood size; HF = higher-frequency.

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[8] "Lexical access" does not, of course, exist as a concept in the Seidenberg and McClelland (1989) model because the model has no lexicon. In the framework of this model the term *lexical access* is simply taken to refer to the set of processes leading to a word's unique identification.

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(*Appendix A follows on next page*)

Appendix A

Words Used in Experiments 1 and 2

HF Words—Small N and No HF Neighbors	HF Words—Small N and HF Neighbors	HF Words—Large N and No HF Neighbors	HF Words—Large N and HF Neighbors
HUGE	TREE	DARK	CLAY
RICH	VOTE	RISE	DEEP
UNIT	FAIR	BORN	POOL
STEP	TERM	MAIN	SHOT
ARMY	DOWN	TALK	TEST
BLUE	WALK	SORT	GAME
CLUB	FIRM	ROAD	FEAR
HAIR	POOR	MEAN	LIST
KEPT	STOP	SOON	CENT
TYPE	FARM	FULL	WALL
PLAN	EASY	LOVE	REST
TOWN	SIZE	CALL	COLD
TURN	EVER	MISS	WORD
FREE	KNEW	SHOW	NAME
HALF	HOUR	ROLE	WIDE
RAFT	LOFT	BRAG	PELT
FUSE	VERB	SWAM	RINK
LIMB	PULP	GANG	HOOK
ACRE	DUAL	SLUM	CART
MONK	GENE	PUMP	HALT
CULT	DEAF	SLAB	WEEP
TROT	RUIN	PINT	RIPE
ACID	GOWN	GRIM	HEAP
DUMB	GLOW	PEAK	HIRE
HAWK	FUEL	BULK	LUNG
NUDE	TRAP	SPAN	BUNK
VEIN	STEM	SUNK	LAMP
TUBE	HORN	FLEW	FOIL
BOMB	FISH	PLOT	HANG
NAVY	PITY	SKIN	DOME

Appendix B

Words Used in Experiments 3a and 3b

HF Words—Small N	HF Words—Large N	LF Words—Small N	LF Words—Large N
PATH	SEAT	FIZZ	MITE
HUGE	MINE	COAX	RASH
DESK	SLOW	FLEA	LOOT
FILM	HILL	GASP	TANG
WALK	GAME	YOKE	MOLE
SIZE	FEAR	SNAG	SUCK
BOTH	FOOD	MESH	LASH
TYPE	RATE	NUMB	DAME
GIRL	FULL	SOAK	HOOT
HALF	REAL	TAUT	CAGE
BODY	WORD	ROSY	RAKE
NEXT	CASE	CLUE	HULL
FACT	HAND	QUIT	PILL
IDEA	HOME	EPIC	ROPE
MUCH	MUST	FLUX	TENT

Appendix C

Words Used in Experiments 4a and 4b

Words With No Neighbors	Small N and No HF Neighbors	Small N and 1 HF Neighbor	Small N and Many HF Neighbors
ENVY	RAFT	ANEW	VERB
IDOL	FUSE	WOLF	GAIT
OBEY	TAUT	LAMB	TRIO
HYMN	ACRE	OVAL	SIGH
ECHO	TROT	GENE	CALF
VOID	DUMB	LAZY	GREY
RELY	IDLE	KNIT	CURB
ODOR	HAWK	NORM	CLUE
LEVY	MONK	TOMB	GOWN
TAXI	NUDE	NEON	SOUP
EPIC	AUNT	FURY	FUEL
OKAY	FOLK	HORN	STEM
URGE	BOMB	GOLF	HOLY
GYRO	GALA	FISH	DISC

Large N and No HF Neighbors	Large N and 1 HF Neighbor	Large N and Many HF Neighbors
BRAG	PUMP	LUMP
PEER	PINK	SUNK
SLAB	SLUM	TIDE
PINT	BITE	BARK
GRIM	SCAR	LEND
PEAK	LAMP	RIPE
BULK	BUNK	KICK
SPAN	WHIP	LUNG
SLIM	RUSH	RAGE
GANG	FOIL	TILE
PLOT	BUCK	COLT
PATH	FLEW	POLE
MAIL	CORN	LEAN
USH	BUMP	TENT

Appendix D

Words Used in Experiment 5

Small N—No HF	Large N—No HF	Small N—HF	Large N—HF
GOLF	HINT	GENE	TRIM
TUBE	BRAG	VERB	LUMP
FUSE	PEER	DEAF	TIDE
CULT	SLAB	SIGH	HEAP
TROT	GRIM	CALF	LEND
DUMB	PEAK	GREY	RIPE
LIMB	BULK	CURB	KICK
HAWK	SPAN	CLUE	LUNG
MONK	SLIM	GOWN	RAGE
NUDE	GANG	SOUP	TILE
AUNT	PUMP	FUEL	COLT
FOLK	PATH	STEM	CORN
BOMB	MAIL	PULP	LEAN
VEIN	SKIN	FISH	FOIL

(Appendix E follows on next page)

Appendix E

Words Used in Experiment 6

Small N—No HF	Large N—No HF	Small N—HF	Large N—HF
PLEAD	JOLLY	WEAVE	SPILL
HARSH	SHINE	MARSH	SPIKE
GLOOM	METER	FROST	PEACH
BOOST	SCOUT	THIEF	SPICE
SPRAY	FREED	FLOUR	POKER
ALIEN	BORED	DENSE	BAKED
FLEET	SILLY	TOKEN	SLACK
GRAPH	WIPED	VOCAL	BLANK
LABEL	PITCH	REACT	PLATE
SOLVE	EAGER	LOYAL	TRACE
MERCY	LUNCH	AWAKE	TIGHT
SAUCE	BAKER	TREAT	SHOCK
EXACT	GRACE	YIELD	GRADE
PANEL	TASTE	MAYOR	PAINT
TRUST	SCALE	COUNT	PRIME

Words With No Neighbors

DIGIT	THEFT	FLUID	MERIT
BLIMP	VIRUS	CABIN	CLERK
FROZE	CRUDE	RANCH	PROOF
MAPLE	TWIST	FALSE	

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