Neighborhood frequency effects in visual word recognition: A comparison of lexical decision and masked identification latencies

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Recent research suggests that the time to recognize a visually presented word may be a function of not only the frequency of that word itself but also the frequencies of neighboring words. The concept of neighborhood refers here to the existence of physical similarities between words, in terms of, for example, orthographic or phonological information. In the present paper, we investigate one particular neighborhood of similarities, namely, orthographic similarities. Orthographic similarity between words refers more specifically to the number of letters shared by different words, the orthographic neighbors of a given word sharing the greatest number of letters with this word. The precise definition of orthographic neighborhood adopted here was first introduced by Coltheart, Davelaar, Jonasson, and Besner (1977). This particular definition is length-dependent and letter-position-specific, in that a given word’s orthographic neighbors are defined as all other words of the same length sharing all but one letter in the same position. This is obviously only one out of many possible definitions of orthographic neighborhoods, and as such it should only be considered a first approximation. Using such a definition, Coltheart et al. (1977) varied the number of orthographic neighbors (N) of word and nonword stimuli in a lexical decision task. They observed a significant interference effect of N on nonword latencies but no effect of N on word responses.

When one varies not merely the number of neighbors, however, but also the frequencies of these neighbors, interference effects are observed in word recognition. The first indications of such interference effects came from studies in which the ability or inability of word stimuli to evoke high-frequency competitive responses was manipulated. Thus, auditory thresholds (Savin, 1963) and visual thresholds (Havens & Foote, 1963) were higher for words that were similar to other high-frequency words, these higher frequency competitors tending to be produced in error at subthreshold presentations. Along a similar line of investigation, Treisman (1978) demonstrated that words with a low error-response frequency (i.e., words given rarely as errors in response to other words) were identified more accurately than words that appeared frequently as errors, the former tending not to have any close neighbors.

In more recent studies, stricter controls have been introduced, with independent manipulations of the frequency of the stimuli and the frequencies of their neighbors. Thus, Luce (1986) observed that perceptual identification scores in response to auditorily presented words varied as a function of a frequency-weighted neighborhood probability rule, which was calculated using the frequencies of a word’s phonological neighbors. In the visual modality, Chambers (1979) compared lexical decision latencies in response to words with higher frequency neighbors (defined in two distinct ways, as either transposition neighbors, such as BALE-able, or substitution neighbors, such as COLLAR-dollar) with lexical decision latencies in response to words with no higher frequency neighbors. Interference effects were observed only for transposition neighbors. Unfortunately, Chambers did not control for the presence of substitution neighbors in the transposition neighborhood condition (e.g., BALE-sale), so the effects observed cannot be unequivocally attributed to their higher frequency transposition neighbors. Also, the ab-
sence of an effect for the substitution neighbors may have occurred because these were all longer words (5–7 letters). More recently, Grainger, O'Regan, Jacobs, and Segui (1989) have demonstrated that lexical decision latencies and eye-gaze durations on isolated French words of four letters in length increase significantly as soon as the stimulus word has at least one higher frequency substitution neighbor. The data were obtained in conditions in which bigram frequency, number of neighbors, printed frequency, and familiarity were controlled across the different categories of stimuli.

This result, which we have termed the **neighborhood frequency effect**, is an important demonstration of interference between lexical representations competing for identification in the word-recognition process. This competition is described in terms of mutual inhibition between word-level nodes in the interactive activation model (McClelland & Rumelhart, 1981) or in terms of a frequency-ordered sequential search among word candidates in serial search (Forster, 1976) or serial verification (Becker, 1976; Paap, Newsome, McDonald, & Schvaneveldt, 1982) models of word recognition. In the interactive activation model, the inhibition acting on a given node is a function of the activation levels of all the other nodes at the same level; the higher the activation level of these nodes, the stronger the inhibition. In this model, the activation level of a given word node is determined by that word's frequency (translated into resting level activation) and the number of letters shared with the stimulus in the same position. Thus the nodes of high-frequency neighbors will have relatively high activation levels and will therefore generate more inhibition on the stimulus word, compared with the inhibition generated by the less activated nodes of low-frequency neighbors or high-frequency words that are not neighbors. In serial models, the candidate set is determined by physical similarity with the stimulus word (in the absence of context), so the stimulus word's orthographic neighbors will typically be a part of this set. As verification is performed in order of decreasing frequency, higher frequency neighbors will be checked and rejected before the stimulus word itself is reached. Each checking operation takes a certain amount of time, thus incurring a delay in the recognition of words with higher frequency neighbors as opposed to words with no higher frequency neighbors. Thus, both serial search models and the interactive activation model of word recognition can account for the neighborhood frequency effect.

These models do, however, provide distinct predictions concerning the effects of word frequency when neighborhood frequency is controlled. Simulations run on a version of the interactive activation model provided in McClelland and Rumelhart (1988) indicate that word-frequency effects do obtain when neighborhood frequency is held constant. It should be noted that the parameters used in these simulations were the same as in the original model. Recognition latencies were measured as the number of processing cycles required for a given word node to reach a predetermined activation threshold (0.7). Serial search/verification models (Becker, 1976; Forster, 1976; Paap et al., 1982), on the other hand, predict an absence of word-frequency effects when neighborhood frequency is controlled. In these models, the word-frequency effect is in fact nothing more than an effect of neighborhood frequency, the two factors typically being confounded. Speed of recognition of a word is determined by the rank that this word occupies in the verification queue, and this rank is a function of the frequency of the word relative to the frequencies of all the other words in the set of candidates to be checked. Thus, less frequent words are recognized less rapidly, only because one or more higher frequency candidates have been checked beforehand. This means that once neighborhood frequency is held constant, there should no longer be any effect of stimulus word frequency. In other words, a low-frequency word with no higher frequency neighbors should be recognized as rapidly as a high-frequency word with no higher frequency neighbors (if possible confounding factors such as bigram frequency are controlled). This assumes, of course, that the definition of orthographic neighborhoods used here is a reasonable reflection of the candidate set in these models.

**EXPERIMENT 1**

**LEXICAL DECISION**

**Method**

**Stimuli.** From a computerized list of all four- and five-letter French words with their printed frequencies (Trésor de la langue Française, 1971), two stimulus sets were generated, consisting of words with no higher frequency orthographic neighbors and words with at least one higher frequency neighbor. **Neighborhood** was defined here as comprising all other words of the same length sharing all but one letter in the same position. These two categories of stimuli represent the factor neighborhood frequency. This factor was crossed with stimulus word frequency (medium or low) in a 2 × 2 factorial design. Stimuli were matched for printed frequency, average positional bigram frequency (token count), number of neighbors, and word length (four or five letters) across the two modalities of neighborhood frequency. Twenty words were selected for each of the four stimulus categories. The average frequencies of the low- and medium-frequency words were 45 occurrences per million and 333 occurrences per million, respectively (Trésor de la langue Française, 1971). The low-frequency and medium-frequency words were matched in terms of number of neighbors, number of higher frequency neighbors, and bigram frequency. Eighty pseudowords were constructed by randomly replacing a letter of a real word (other than one of the experimental words) with another letter to form an orthographically legal, pronounceable, meaningless letter string. Half of the pseudowords were four letters long and half were five letters long.

**Procedure.** Stimuli were presented in isolation on the center of the display screen of an Olivetti M24 personal computer. Subjects saw a fixation point for 500 msec, which was replaced by the stimulus centered on the fixation point. The stimulus remained on the screen until the subjects responded either "word" or "nonword" by pressing one of two response buttons. Positive responses were made with the forefinger of the preferred hand, and negative
responses with the forefinger of the other hand. The next sequence followed after a 1-sec delay. The subjects were instructed to respond as rapidly and accurately as possible. Stimulus presentation was randomized, with a different order for each subject.

Subjects. Twenty-five third-year psychology students at René Descartes University, Paris, took part in the experiment for course credit. All were native speakers of French, with normal or corrected-to-normal vision.

Results

All reaction times exceeding 1 sec (3.7% of the data) were excluded from the analysis of the correct responses to word stimuli. Means of the lexical decision latencies for correct responses and percent errors are given in Table 1. An analysis of variance was performed on the data, with neighborhood frequency and stimulus word frequency as principal factors.

Reaction time data. There was a significant main effect of stimulus word frequency \(F(1,24) = 14.45, p < .001\), medium-frequency words being responded to on an average of 20 msec more rapidly than low-frequency words. The main effect of neighborhood frequency was also significant \(F(1,24) = 7.83, p < .01\). Thus, subjects were responding on an average of 16 msec more slowly to words with at least one higher frequency neighbor than to words with no higher frequency neighbors. There was no interaction between stimulus word frequency and neighborhood frequency \(F < 1\).

Error data. The analysis of variance on the error means closely mirrors the reaction time results. There was a significant main effect of stimulus word frequency \(F(1,24) = 43.08, p < .001\), with low-frequency words producing more errors than medium-frequency words did, and there was a significant main effect of neighborhood frequency \(F(1,24) = 9.33, p < .01\). The interaction between stimulus word frequency and neighborhood frequency was not significant \(F(1,24) = 1.89\), but a larger effect of neighborhood frequency was obtained with the low-frequency words \(F(1,24) = 6.23, p < .05\) than with the medium-frequency words \(F(1,24) = 1.13\).

Discussion

The effects of neighborhood frequency reported in Grainger et al. (1989) were successfully replicated here over a larger population of words of varying length and frequency. These results add further support for the hypothesis that multiple lexical representations compete for identification in visual word recognition.

Table 1

<table>
<thead>
<tr>
<th>Stimulus Word Frequency</th>
<th>No Higher Frequency Neighbors</th>
<th>At Least One Higher Frequency Neighbor</th>
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</thead>
<tbody>
<tr>
<td></td>
<td>RT</td>
<td>PE</td>
</tr>
<tr>
<td>Low</td>
<td>608</td>
<td>7.4</td>
</tr>
<tr>
<td>Medium</td>
<td>588</td>
<td>2.2</td>
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The fact that significant word-frequency effects were observed in conditions where the effects of neighborhood frequency had been neutralized was correctly predicted by the interactive activation model. On the other hand, this constitutes a highly compromising result for current formulations of serial search/verification models of visual word recognition. In these models, word-frequency effects are determined uniquely by the order in which candidates are checked. Thus, words with the same rank in this checking queue (i.e., with the same number of higher frequency neighbors) should be identified with the same speed, independently of their absolute frequencies. This apparently is not the case. These models therefore need to situate word-frequency effects at another stage in the word-recognition process, either before or after the serial checking stage. Thus, for example, checking order could be a function of relative activation level rather than simply relative frequency. This could be easily implemented in the activation-verification model (Paap et al., 1982), by setting an activation threshold for verification, word candidates being checked as soon as their activation threshold reaches this criterion level. If we now consider word frequency to be represented in terms of the resting level activation of word representations (as in the interactive activation model), then the order in which candidates will be checked becomes a function of their absolute frequencies as well as of the frequencies of the other candidates. More frequent words will reach the verification threshold more quickly than less frequent words will.

The effects of neighborhood frequency and stimulus word frequency observed in Experiment 1 were, nevertheless, fairly small in magnitude. Concerning the small size of the word-frequeny effect, compared with what has been obtained in traditional observations of this effect, it should be noted that past research investigating word frequency effects in visual word recognition probably confounded word frequency and neighborhood frequency. In other words, the low-frequency words in these experiments would tend to have higher frequency neighbors, whereas the high-frequency words would tend not to have higher frequency neighbors. If one compares the values obtained in these precise cells in Experiment 1 (low-frequency words with at least one higher frequency neighbor, compared with medium-frequency words with no higher frequency neighbors), one will observe a 36-msec effect that is comparable to traditional word-frequency effects obtained with the lexical decision task (cf. Gordon, 1983). This point is discussed more fully by Grainger (in press), in a comparison of word-frequency and neighborhood frequency effects in lexical decision and word naming.

In Experiment 2, we introduced a technique designed to be maximally sensitive to the effects of word frequency and neighborhood frequency. The technique involves artificially slowing down the rate of availability of stimulus information. According to activation-based models of word recognition, this should slow down the rise in activation level of word representations. In this way, the im-
portance of differences in resting level activation would be accentuated and more time would be available for competitional processes to operate before identification. We therefore expected to observe larger effects of both word frequency and neighborhood frequency, using this technique.

**EXPERIMENT 2**

**PROGRESSIVE DEMASKING**

In Experiment 2, we introduced a technique that appeared particularly appropriate for the study of neighborhood effects in word recognition. This technique is a variation of the "continuous threshold latency identification" task developed by Feustel, Shiffer, and Salasoo (1983). It involves increasing the signal-to-noise ratio, the signal being a word and the noise a pattern mask, until the signal becomes identifiable by the subject. This increase in signal-to-noise ratio is produced by gradually increasing stimulus duration while simultaneously reducing the duration of the accompanying pattern mask. Initially, subjects only see the pattern mask, but gradually the stimulus "appears out of the mask." The subjects simply have to press a response button when they have identified the stimulus. This method therefore allows the measurement of an identification latency, as well as the collection of data concerning the nature and quantity of erroneous responses. In order to simplify terminology, we shall refer to this particular technique as the progressive demasking paradigm and to the latency data obtained with the technique as masked identification latencies.

**Method**

**Stimuli.** These remained the same as in Experiment 1, except that no pseudowords were required here.

**Procedure.** Stimuli were presented in uppercase on the center of the display screen of an Olivetti M24 personal computer. Each presentation cycle was composed of a given stimulus word, followed immediately by a pattern mask of four or five hash marks (depending on the length of the stimulus word). On each progressive cycle, the presentation of the stimulus was increased by 16 msec and the presentation of the mask decreased by 16 msec. The total duration of each cycle remained constant at 336 msec. Thus, each trial consisted of a succession of cycles in which stimulus presentation increased and mask presentation decreased. On the first cycle of each trial, stimuli were presented for 16 msec and the mask for 320 msec; on the second cycle, stimuli were presented for 32 msec and the mask for 304 msec; and so forth. There was no interval between cycles. This succession of cycles continued until the subject pressed a response key on the computer keyboard to indicate that he or she had recognized the stimulus word. Response latencies accurate to the nearest millisecond were measured from the beginning of the first cycle until the subject's response. The subjects were instructed to focus on the center of the visual display and to press the response key with the forefinger of their preferred hand as soon as they had recognized a word. They then had to type in the identified word, using the keyboard of the computer. A press of the return key then initiated the following trial. The subjects were asked to check carefully that they had correctly typed the word before initiating the following trial.

**Subjects.** Twenty-five third-year psychology students from René Descartes University participated in the experiment for course credit. All were native speakers of French with normal or corrected-to-normal vision, and none had taken part in the previous experiment.

**Results**

Means of the latencies for correctly identified words and percent errors in the different stimulus categories are given in Table 2. The data were submitted to an analysis of variance, with stimulus word frequency and neighborhood frequency as the principal factors. No reaction time cutoffs were used here before data analysis, given the absence of any extreme values relative to the means.

**Reaction time data.** Significant main effects were observed for both stimulus word frequency \([F(1,24) = 21.49, p < .001]\) and neighborhood frequency \([F(1,24) = 35.70, p < .001]\). There was a significant interaction between neighborhood frequency and stimulus word frequency \([F(1,24) = 5.53, p < .05]\). This interaction reflects the fact that a 313-msec neighborhood interference effect was observed for low-frequency words \([F(1,24) = 25.77, p < .001]\), with a smaller 122-msec effect being observed for medium-frequency words \([F(1,24) = 6.94, p < .025]\). It also reflects the fact that word-frequency effects are stronger for the words with higher frequency neighbors \([F(1,24) = 15.62, p < .001]\) than for the words with no higher frequency neighbor \([F(1,24) = 3.97]\), the magnitudes of the effects being 267 and 76 msec, respectively.

**Error data.** An analysis of variance on the error means indicated a significant main effect of neighborhood frequency \([F(1,24) = 8.50, p < .01]\) but no effect of stimulus word frequency \((F < 1)\). There was a trend toward an interaction between stimulus word frequency and neighborhood frequency \([F(1,24) = 3.24]\). As with the reaction time data, this trend toward an interaction reflects the fact that the effects of neighborhood frequency appear to have been stronger for low-frequency than for medium-frequency words, 3.6% more errors being produced in response to low-frequency words with a higher frequency neighbor than in response to low-frequency words with no higher frequency neighbor \([F(1,24) = 20.68, p < .001]\), whereas only 0.8% more errors were produced in response to medium-frequency words with a higher frequency neighbor compared with medium-frequency words with no higher frequency neighbor \((F < 1)\).

The nature of the progressive demasking task allows a qualitative as well as a quantitative analysis of the error

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<td></td>
<td>RT PE</td>
<td>RT PE</td>
</tr>
<tr>
<td>Low</td>
<td>1,982 2.2</td>
<td>2,295 5.8</td>
</tr>
<tr>
<td>Medium</td>
<td>1,906 2.8</td>
<td>2,028 3.6</td>
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data. In many cases, subjects did respond incorrectly with a higher frequency neighbor (according to our operational definition). Thus, for example, 3 subjects reported having identified ELLE (she or her) rather than the stimulus word ELFE (elf), and 7 subjects reported having identified BILLE (ball bearing) instead of BIL (ball). More importantly, however, a number of the errors were of a different nature, the most common being the insertion of an additional letter. Some examples of this type of error are: COEUR (heart) instead of COUR (court), COMPTE (count, the verb) instead of COMTE (count, the person), CUIVRE (copper) instead of CUIRE (to cook), VOTRE (your) instead of VOTE (vote). In several cases, the errors corresponded to the removal of one letter (e.g., CUIR, leather, instead of CUIRE, to cook). In general, the majority of errors (76.2%) involved a single letter (substitution, addition, or removal). Of the remaining errors, 17.5% involved the transformation of two letters, and only 6.3% involved more than two letters. The type of errors produced by our subjects also supports the hypothesis that the printed frequency of a given word strongly determines its competitiveness in word recognition. Thus, the average frequency of the reported errors was 1,896 occurrences per million, compared with an average frequency of 153 occurrences per million for the stimuli on which the errors were produced.

Discussion

The results of the progressive demasking paradigm indicate that this technique is indeed more sensitive to lexical factors such as word frequency and neighborhood frequency than the lexical decision task is. In general, concerning the role played by the two main experimental factors, the results of Experiment 2 parallel those observed in Experiment 1 while being larger in magnitude and statistically more robust. Expressed in terms of percent average response time, the effects of neighborhood frequency increased from 2.6% in lexical decision to 10.6% in the progressive demasking paradigm. Similarly, stimulus word-frequency effects increased from 3.3% in Experiment 1 to 8.4% in Experiment 2.

The results of Experiment 2 add more support to the generalizability of the neighborhood frequency effect across different tasks. Moreover, the data support our proposition that the progressive demasking technique should prove to be a valuable tool in the investigation of such effects. The analysis of the error responses indicated which competing units occasionally managed to beat the stimulus word in the process of selection for identification. These turned out to be, in a majority of cases, precisely our hypothesized higher frequency neighbors. In the errors where this was not in fact the case, the responses proved to be higher frequency neighbors of another type, typically words with one letter added (e.g., VOTE–votre). This tendency suggests that competing units in the word-recognition process need not be of the same length. This point has already been considered by Luce (1986), whose neighborhood probability rule includes neighbors differing by the removal or addition of one phoneme (in auditory word recognition). Obviously, future experiments should test this possibility by controlling these two kinds of neighborhood. It would also be interesting in these experiments to examine whether presentation blocked by word length would affect interference from neighbors of a different length.

As in Experiment 1, word frequency continued to affect response times and error rate when neighborhood frequency was controlled. This therefore contributes further evidence suggesting the need to modify current formulations of serial search models. In Experiment 2, however, the effects of word frequency did interact with neighborhood frequency, low-frequency words producing larger neighborhood frequency effects than medium-frequency words did. This had already been observed in the error data of Experiment 1, although the interaction was not statistically significant. We therefore need to clarify why the particular conditions of the progressive demasking paradigm produced an interaction between word frequency and neighborhood frequency that was absent in the lexical decision latency data.

The progressive demasking paradigm involves reducing the rate at which sensory information becomes available, thus slowing down the recognition process. Within the serial search/verification framework, this should provide the system with the opportunity of executing several verification cycles. If verification order is considered to be a function of the relative frequencies of the candidate representations, then it is the number of higher frequency neighbors of the stimulus word that should determine recognition latencies. The number of higher frequency neighbors was, however, approximately equivalent for the low- and medium-frequency words, so this factor cannot explain the observed interaction. Nevertheless, the effects of absolute stimulus word frequency on the size of neighborhood interference effects can be accommodated by the proposed modification of these models in which verification order is determined by relative activation level rather than relative frequency. If activation level is computed on the basis of word frequency (resting level activation) and compatibility with the stimulus, the stimulus representation will always have a faster rise in activation level than its competitors, due to the greater input of sensory information. If verification order is determined by the order in which lexical representations reach a given activation level, then high-frequency neighbors may well be the first representations to be checked. However, the stimulus word itself will soon reach this criterion level of activation, the rapidity at which this occurs being determined by its resting level activation. In the nondegraded conditions of Experiment 1, the rise in activation of the stimulus representation may be so fast that differences in rest-
ing level activation become negligible, both medium- and low-frequency stimuli becoming the most activated representation after an initial erroneous verification of one higher frequency neighbor. However, in the degraded conditions of Experiment 2, differences in resting level activation may well become critical with the reduced rate of rise in activation. In these conditions, low-frequency words may take long enough to reach the verification threshold to allow the execution of several verification cycles on higher frequency neighbors.

Although it is impossible to test the interactive activation model without running simulations, it is not intuitively implausible that slowing down the rate in rise of activation of word nodes could provoke differential interference effects for low- and medium-frequency words. Lower frequency words will be subject to inhibition from competing units over longer periods, and they will produce less inhibition on their competitors than medium-frequency words will. This therefore suggests that they should be subject to larger neighborhood interference effects than medium-frequency words are. In normal presentation conditions, these differential effects may be unobservable. The progressive demasking technique appears to be one way of exaggerating these effects, by artificially slowing the rate of rise in activation level of lexical representations.

GENERAL DISCUSSION

The present experiments provide data supporting the generalizability of the neighborhood frequency effect across words of different length and frequency and in different experimental tasks. Experiment 2 introduced a task that proved to be particularly sensitive to neighborhood interference and particularly valuable for providing information on the nature of the competing units hypothetically responsible for this interference.

The data from both tasks support the general hypothesis that multiple representations are contacted during the visual recognition of isolated words, and that these representations may interfere in the identification of the stimulus word. The data suggest that the nature of the representations contacted by a given stimulus word is at least partly determined by their orthographic overlap with this word. The data also indicate that the competitiveness (capacity for interference) of these representations is stronger when the stimulus word has a low absolute frequency, in conditions providing sufficient time for such differences to appear.

One interesting aspect of the data concerns the various types of error response given in the progressive demasking paradigm. These errors confirm that words of the same length sharing all but one letter in the same position (e.g., ELFE-elle) are strong competitors in the identification process. They also suggest, however, that some competition is occurring for words differing from a higher frequency word by the addition of a single letter (e.g., VOTE-votre). It is clear that future research can use the neighborhood frequency effect to examine more precisely the parameters determining the nature of these competing units.

Within this line of research, one obviously important area for further study concerns the position specificity of letters (see, e.g., Chambers, 1979) and the position of letter change between the stimulus word and its neighbors. Thus it remains to be seen whether higher frequency transposition neighbors (differing by the order of two adjacent letters, such as BALE-able) would be produced in error in the progressive demasking paradigm. Concerning the importance of the position of letter change between the stimulus and its higher frequency neighbors, it has already been pointed out that seven of our subjects reported identifying BIBLE instead of the stimulus word BILLE. The fact that BIBLE was reported and never VILLE (town) may be an indication that neighbors differing by internal letters are more competitive than neighbors differing by the initial letter. Also, concerning the relative importance of word-initial and word-terminal information in visual word recognition, Grainger (1988) has shown that neighborhood frequency effects are comparable for words whose higher frequency neighbor differs by the first letter (e.g., RIND-find) and for words whose higher frequency neighbor differs by the last letter (e.g., BLUR-blue). This suggests that, at least for short words, word-initial and word-terminal information have equal weight in the word-recognition process.

The results of the present experiments contradict serial search/verification models where the order in which candidates are checked is uniquely a function of their relative frequencies. This class of model incorrectly predicted an absence of word-frequency effects in words with equivalent neighborhood frequencies. It could of course be argued that although the words used in the present experiments were controlled for one specific definition of neighborhood, they differed in terms of another, more appropriate, definition of neighborhood. Since bin composition has never been fully specified in Forster's model, it is not clear to what extent the definition used here is appropriate. This definition is likely, however, to be appropriate for the activation verification model, which adopts an initial letter-position-specific activation mechanism. In order to account for this result, a modified version of the activation-verification model has been proposed, in which verification order is determined by the order in which representations reach a criterion level of activation. If we assume that word-frequency effects reflect variations in resting level activation, then more frequent words would reach the verification threshold more rapidly than less frequent words. This accounts for the existence of word-frequency effects independently of neighborhood frequency.

It is important that future research continue to attempt to discriminate between interactive activation and activation-verification models of word recognition. One impor-
tant distinguishing prediction concerns the cumulative effects of number of higher frequency neighbors. Thus, the activation-verification model clearly predicts that neighborhood interference should increase as a function of the number of higher frequency neighbors, since each of these neighbors will provoke an erroneous verification cycle, thus producing an extra delay in recognition. On the other hand, the interactive activation model predicts no increase in interference with greater numbers of higher frequency neighbors (this prediction has been obtained on the basis of simulations run on the model). Grainger et al. (1989) failed to observe any evidence of a cumulative effect of higher frequency neighbors, neighborhood interference being dependent on the existence of at least one higher frequency neighbor but not increasing with several higher frequency neighbors. These results were inconclusive, however, since the words with several higher frequency neighbors had higher bigram frequencies than did the words with only one higher frequency neighbor. Thus, any additional interference could have been cancelled by a counteracting facilitatory effect of bigram frequency. Grainger (in press) has controlled for bigram frequency between these two critical categories and observed a nonsignificant trend toward an effect of number of higher frequency neighbors in the lexical decision task. This result therefore provides support for the interactive activation model and contradicts the predictions of serial models.

Nevertheless, in the modified version of the activation-verification model presented here, it may be the case that, in the recognition of nondegraded short words, the buildup of sensory information is too rapid to require the use of more than one verification cycle. Thus, a single verification cycle would be long enough for sufficient sensory information to accumulate for the stimulus word to become the most activated representation. One would then predict that in situations in which the collection of sensory information lasts longer (i.e., with the progressive demasking technique), several cycles will be performed, and an effect of number of higher frequency neighbors should be observable. We are currently running experiments to test these predictions, using the progressive demasking technique in comparison with lexical decision, with degraded and nondegraded stimuli.

We are also currently using the masked priming paradigm (Forster & Davis, 1984; Forster, Davis, Schoknecht, & Carter, 1987) as an alternative means of testing hypotheses about competitive processes in word recognition. In a recent study (Segui & Grainger, in press), we obtained data supporting an activation-based account of such processes. Thus, preactivating a target word’s higher frequency neighbor by the brief masked presentation of this neighbor accentuated its interfering capacity in the processing of the target. In order to explain these results, we suggested incorporating relative activation level as the factor that determines verification order in verification models, in much the same way as has been suggested here in order to account for the present set of results. The collation of data from different paradigms should be decisive in the testing and refining of current models of word recognition.

In this exploratory study, the progressive demasking technique has proved its utility as a means of investigating neighborhood frequency effects in visual word recognition. The use of this task in future experimentation in this field should help clarify the finer details of the competitive processes operating between lexical representations during word recognition. At present, it would appear that activation-based models of visual word recognition are most capable of explaining the effects of neighborhood interference.

REFERENCES


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