Neighborhood density and neighborhood frequency effects in French spoken word recognition

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Abstract

According to activation-based models of spoken word recognition, words with many and high frequency neighbors are processed more slowly than words with few and low frequency neighbors. Because empirical support for inhibitory neighborhood effects comes mainly from studies conducted in English, the effects of neighborhood density and neighborhood frequency were examined in French. As typically observed in English, we found that words residing in dense neighborhoods are recognized more slowly than words residing in sparse neighborhoods. Moreover, we showed that words with higher frequency neighbors are processed more slowly than words with no higher frequency neighbors. Implications of theses results for spoken word recognition are discussed.

Index Terms: phonological neighbors, neighborhood density, neighborhood frequency

1. Introduction

A major issue in research on spoken word recognition concerns the process by which information in the speech signal is mapped onto representations of words in long-term memory. Clearly, the way in which human word recognition system deals with spoken language is remarkable, since word recognition occurs effortlessly and with few errors under a wide variety of conditions that could be disruptive. Indeed, words are often poorly pronounced and are generally perceived against a background of considerable ambient noise. Imperfections in the speech signal and environmental noise make it thus unlikely that only one lexical entry is activated when listeners attend to a spoken word [1]. In fact, contemporary models of spoken word recognition assume that the speech signal activates a number of similar sounding representations in memory, among which the system must choose (NAM, [1]; Shortlist, [2]; Trace, [3]). As a result, an issue of particular interest in the last few years has been how the identification of a word is affected by its phonological neighbors.

The phonological neighbors of a word are often defined as the set of words that can be formed by the addition, substitution, or deletion of one phoneme in the word [1]. For example, the word *CAT* has neighbors such as *SCAT* where a phoneme is added, *BAT*, *CUT*, *CAP* where a phoneme is substituted, and _at where a phoneme is deleted. The Neighborhood may thus vary on both the density and frequency of the words that comprise it. Since, in activation-based models of word recognition, lexical selection operates through a process of competition, in which the lexical units of the word and its neighbors compete against one another for recognition, the phonological neighbors and their characteristics play a decisive role in the selection of the target words. As a result, the presence of phonological neighborhood effects in word identification tasks is taken as evidence for the lexical competition mechanism embodied in these models.

Although the competition process is shared by all models of spoken word recognition, controversies remain about the precise mechanism by which competition is supposed to arise. In some models, such as Trace [3] and Shortlist [2], lexical competition is due to intra-level inhibition that operates between activated lexical entries. By this mechanism, not only the target word inhibits its phonological competitors, but the competitors themselves also send inhibition to the target word and thus reduce its activation level, causing slower recognition. As a result, the more competitors a target word has or the more frequent the competitors are, the more inhibition the target word receives (see [4] for simulations with the Trace model). In contrast, in the Cohort [5] or the NAM [1] models, lexical competitors have no direct influence on the activation level of the target word. Competition effects take place only at the decision stage of recognition where the existence of competitors slows down the process of discrimination among lexical candidates. For example, in NAM, the decision about the identity of the word depends on the ratio between the activation level of the target word to that of all other competitors. If the stimulus input results in a large number and frequent phonological neighbors, the probability of recognizing the stimulus word is low. At present, there is no definitive evidence to help distinguish between these accounts of lexical competition.

Whatever the precise mechanism by which competition is supposed to arise, the lexical competition process embraced in all models of spoken word recognition predicts inhibitory neighborhood effects. Compatible with this hypothesis, numerous studies have reported an inhibitory influence of neighborhood on spoken word recognition, in a variety of tasks. In a perceptual-identification task, in which participants hear a word mixed with noise and must type out the word they believe they heard, Luce and Pisoni [1] found that words with sparse and low frequency neighborhoods were identified more accurately than words with dense and high frequency neighborhoods. Measure of one-line processing such as auditory naming [1; 6], speeded same-different decision [7] and auditory lexical decision [1; 7] have also shown that phonological neighbors affect the speed with which spoken words are processed. In each of these tasks, it was observed that words with dense neighborhoods are responded to more slowly than words with sparse neighbohoods. Although few studies have examined the effect of neighborhood frequency, it was also found, in a lexical decision task, that competition is more intense when the average frequency of the neighbors is high [1], thus resulting in slower processing. The inhibitory influence of the neighborhood on spoken-word recognition has been observed for both monosyllabic [1] and bisyllabic words [8].

On the whole, the literature supports the key prediction of activation-based models that words with high density and high frequency neighboroods will be responded to more slowly and less accurately than words with low density and low frequency neighboroods. However, this support has come from studies conducted in English. To our knowledge, no study has reported an inhibitory effect of neighborhood, in other languages than English. More importantly, Vitevitch and Rodríguez [9] recently found exactly the opposite result with Spanish words. That is, Spanish words were recognized faster and more accurately when residing in a high density neighborhood. Such a contradictory result thus raises questions about whether the neighborhood does actually have the impact that the competitive activation models claim it does.

In the present study, we examined both the effects of neighborhood density and neighborhood frequency on the recognition of French words. One simple and convenient way often used to vary neighborhood frequency in visual word recognition research is to select pairs of words matched in neighborhood size, one with at least one higher frequency neighbor and the other without any higher frequency neighbor. Such a manipulation makes sense since in activation based- models, a higher frequency neighbor should compete more actively for final selection than should lower frequency neighbors. Although the effect of the number of higher frequency neighbors has not yet been examined in studies on spoken word recognition, this variable has proven to be important in determining the time course of visual word recognition. In particular, using monosyllabic French words, Grainger and collaborators [10] showed that visual word recognition is slow down by the presence of a neighbor of higher frequency than the stimulus words itself. The present study has thus two goals. The first is to examine how neighborhood density affects the performance in French. The second is to examine the effect of the presence of higher frequency neighbors than the stimulus words itself, while controlling for neighborhood density.

2. Experiment 1

The performance of French listeners in an auditory lexical decision task was compared on three sets of words. In the first set, words occurred in a sparse neighborhood and none of the neighbors was of higher frequency than the stimulus word itself. In the second set, words occurred in a dense neighborhood and again none of the neighbors was of higher frequency than the stimulus words. The comparison between the first and the second sets allows us to assess the effect of neighborhood density. Finally, in the third set, words occurred in a dense neighborhood and half of the neighbors were of higher frequency than the stimulus words. The comparison between the second and the third sets allow us to evaluate the effect of neighborhood frequency, regardless of neighborhood density.

2.1. Method

2.1.1. Participants

Twenty-three students at the University of Geneva participated in the experiment for course credits. All were native speakers of French and reported no hearing or speech disorders.

2.1.2. Materials

Three sets of 12 monosyllabic words, three to four phonemes in length, were selected from VOCOLEX, a lexical database for the French language [11]. In the first set, words had on average 4.17 neighbors, none of which was of higher frequency than the word itself. In the second set, words had in average 12.08 neighbors. As in the first set, none of which was more frequent than the word itself. Finally, in the last set, words had in average 13.08 neighbors and 6 of which, on average, were of higher frequency than the words itself.

The second and the third sets of words were equivalent in neighborhood density ($F < 1$). The three sets were matched in terms of phonological length (number of phonemes), uniqueness point and word frequency. Item characteristics are summarized in Table 1. For the purpose of the lexical decision task, 36 nonwords were created by changing the last phoneme of the test words, to make sure that participants wait until the end of the words to give their responses.

Table 1. *Characteristics of the words used in Experiment 1 (mean values)*

	Sets		
	First	Second	Third
Neighborhood Density	4.17	12.08	13.08
Neighbors Frequency[1]	2.76	2.98	4.13
Number of higher frequency neighbors	0	0	6
Frequency[1]	3.89	3.92	3.41
Number of phonemes	3.75	3.67	3.67
Uniqueness point	4.17	4.42	4.58

Note: [1] in logarithm

2.1.3. Procedure

The stimuli were recorded by a female native speaker of French on a digital audio tape recorder. The items were digitized at a sampling rate of 44 kHz with 16-bit analog to digital recording. The participants were tested in a sound attenuated booth and stimuli were presented over headphones at a comfortable sound level. The presentation of the items was controlled by a personal computer. Participants were asked to make a lexical decision as quickly and accurately as possible with “word” responses using their dominant hand on a button-box that was placed in font of them. Response times (RTs) were recorded from the onset of stimuli. An intertrial interval of 2000 ms elapsed between the end of one trial and the beginning of the next. The participants began the experiment with 16 practice trials.

2.2. Results and Discussion

For each participant, RTs longer than 1,200 msec were excluded from the analyses (2.7 %). Incorrect responses were also removed from the RT analyses. The mean RTs and error rates in each condition are presented in Table 2. Because few errors occurred (less than 5%), analyses were performed on RTs only. Analyses of variance (ANOVAs) by participants (*F1*) and by items (*F2*) were performed, and planned comparisons were carried out for the relevant category pairs. To factor out the effect of word duration on reaction times, the duration of each word was subtracted from each subject's reaction times to that word [1].

Table 2. *Mean Reaction Times (in ms), Standard Deviation for Correct Responses and Error Rates (in %) in each condition of Experiment 1.*

	RTs		
Item sets	M	SE	Error
First (sparse & no HF)	140	66	2.0
Second (dense & no HF)	204	73	4.0
Third (dense & HF)	202	75	4.0

Note: HF = higher frequency neighbors

The 64-msec difference between the first and second sets (effect of neighborhood density) was significant both by subjects and by items [$F_1(1,22) = 68.91$, $p < .001$; $F2\ (1,33) = 4.99$, $p < .05$], as was the 62-msec difference between the first and third sets [$F_1(1,22) = 39.48$, $p < .001$; $F2\ (1,33) = 4.76$, $p < .05$]. The 2-msec difference between the second and third sets (effect of the presence of more frequent neighbors) was not significant [$Fs < 1$].

Experiment 1 provided clear cut data on the effects of the neighborhood in French. The significant increase in reaction times from the first and second sets of words suggests that neighborhood density per se affects lexical decision performance in French. Such an observation confirms and extends to another language than English the previous findings that the phonological neighbors inhibit the word identification process [1; 6; 7; 8]. The absence of a significant increase between the second and the third sets indicates that the presence of higher frequency neighbors does not further increase the processing difficulty. We cannot, however, firmly conclude on the basis of this experiment, that the presence of higher frequency neighbors does not increase interference. Indeed, the effect of having higher frequency neighbors was assessed with words residing in high density neighborhoods. Because targets with many competitors are already subject to a greater degree of competition, the lexical decision task may be too insensitive to detect the additional competition caused by the presence of higher frequency neighbors. In Experiment 2, we re-examined the effect of the presence of higher frequency neighbors, but under a condition where the amount of competition coming from the whole set of candidates is relatively low.

3. Experiment 2

In this experiment, we examined the effect of having higher frequency neighbors with words residing in low density neighborhoods. The performance in a lexical decision task on two sets of words was compared. In the first set, words have no higher frequency neighbors. In the second set, at least one neighbor was of higher frequency than the stimulus word.

3.1. Method

3.1.1. Participants

Twenty-six students were recruited from the same pool as in Experiment 1.

3.1.2. Materials

Two sets of 10 monosyllabic words, three to four phonemes in length, were selected. In the first set, words had on average 4.2 neighbors, none of which was of higher frequency than the word itself. In the second set, words had on average 4.3 neighbors and 1.4 of which, on average, were of higher frequency than the words itself.

The two sets of words were equivalent in neighborhood density ($F < 1$) and were matched in terms of phonological length (number of phonemes), uniqueness point and word frequency. Item characteristics are summarized in Table 3. For the purpose of the lexical decision task, 20 nonwords were created by changing the last phoneme of the test words.

Table 3. *Characteristics of the words used in Experiment 2 (mean values)*

	Sets	
	First	Second
Neighborhood Density	4.20	4.30
Neighbors Frequency[1]	2.70	4.15
Number of higher frequency neighbors	0	1.40
Frequency[1]	3.88	3.86
Number of phonemes	3.80	3.70
Uniqueness point	4.10	4.30

Note: [1] in logarithm

3.1.3. Procedure

The procedure was the same as in Experiment 1.

3.2. Results and Discussion

RTs were analyzed according to the same criteria as in Experiment 1. 3% of the data were rejected. Mean RTs and error rates in each condition are presented in Table 4. Because few errors occurred (less than 5%), analyses were performed on RTs only.

Table 4. *Mean Reaction Times (in ms), Standard Deviation for Correct Responses and Error Rates (in %) in each condition of Experiment 2.*

	RTs		
Item sets	M	SE	Error
First (sparse & no HF)	112	84	2.0
Second (sparse & HF)	175	80	4.0

Note: HF = higher frequency neighbors

The 63-msec between words with no higher frequency neighbors and those with higher frequency neighbors was significant both by subjects and by items [($F_1(1,25) = 83.05$, $p < .001$); $F_2(1,18) = 4.32$, $p = .05$]. Hence, it appears that the presence of higher frequency neighbors also inhibits word identification process, at least when the words have relatively few neighbors, and thus are prone to little competition from the entire set of neighbors. Further studies are needed to directly examine the interaction between neighborhood frequency and neighborhood density.

4. Discussion

A key prediction of activation-based models of spoken word recognition is that words in dense and high frequency neighborhoods will be processed more slowly than words in sparse and low frequency neighborhoods. This hypothesis is a consequence of the lexical competition mechanism embodied in these models: Words with dense and high frequency neighbors receive more competition than words with sparse and low frequency neighbors, requiring thus more time to be selected. The existence of an inhibitory neighborhood effect in word identification tasks is thus a critical test of the model's assumption that competitive activation is central to lexical selection.

The results of the present study showed that French words residing in dense neighborhoods were recognized slower than words residing in sparse neighborhoods. Moreover, they showed that words with higher frequency neighbors are processed more slowly than words with no higher frequency neighbors. To our knowledge, these findings are the first to demonstrate that neighborhood density and neighborhood frequency influence spoken word recognition in French, and are consistent with previous studies in English [1]. The present research thus provides further evidence that lexical competition is involved in the word recognition process.

As we have seen, Vitevitch and Rodríguez [9] recently found that, in auditory lexical decision task, Spanish words with dense neighborhoods were recognized more quickly than Spanish words with sparse neighborhoods. It appears thus that the neighborhood differently affects processing from one language to another. Differential effects of the neighborhood were also found in visual word recognition. While the neighborhood seems to be mostly facilitatory in English, they tend to be absent or inhibitory in French. According to Ziegler and Perry [12], the facilitatory neighborhood effect in English is due to the fact that most neighbors in English share the same orthographic rime as the target word. Differences in word length between Spanish and English have been envisaged by Vitevitch and Rodríguez [9] to account for the differential effects of the neighborhood on spoken word recognition in these two languages. Hence, the differences in processing observed across languages probably result from the many differences that exist between the languages. Further cross-linguistic studies are necessary to have a better understanding of how and why phonological similarity may differentially affect processing in different languages as a function of their particular characteristics.

As it was the case in the research in visual word recognition [10], our study showed an effect of the presence of higher frequency neighbors than the stimulus word itself. As Grainger and collaborators pointed out [10], the manipulation of the number of higher frequency neighbors should prove useful to address some important areas of research in word recognition. For example, an issue that could be examined via this effect concerns the relative importance of word-initial and word-final information in lexical access. In particular, given the sequential nature of the speech signal, it might be that the information carried out by the beginning of the words is more important than that carried out by the end of words [see 13]. By examining fluctuations in the magnitude of the neighborhood frequency effect as a function of the phoneme position at which the stimulus word and its higher frequency neighbors differ (substituted neighbors on the initial phoneme, substituted neighbors on the final phoneme), it might be possible to determine which types of phonological neighbors have the more impact on word identification.

To sum-up, this research brings further evidence that, at least in French, lexical competition constitutes the core mechanism of auditory word recognition process. Moreover, as we have indicated, the neighborhood frequency effect observed in the present study should prove to be a useful experimental tool to examine important areas of research in spoken word recognition.

5. References

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