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# The Effect of the Balance of Orthographic Neighborhood Distribution in VisualWord Recognition

Christelle Robert, Stéphanie Mathey & Daniel Zagar

## Abstract

The present study investigated whether the balance of neighborhood distribution (i.e., the way orthographic neighbors are spread across letter positions) influences visual word recognition. Three word conditions were compared. Word neighbors were either concentrated on one letter position (e.g., nasse/basselasse- tasse-masse) or were unequally spread across two letter positions (e.g., pelle/ celle-selle-telle-perle), or were equally spread across two letter positions (e.g., litre/ titre-vitre-libre-livre). Predictions based on the interactive activation model [McClelland & Rumelhart (1981). Psychological Review, 88, 375–401] were generated by running simulations and were confirmed in the lexical decision task. Data showed that words were more rapidly identified when they had spread neighbors rather than concentrated neighbors. Furthermore, within the set of spread neighbors, words were more rapidly recognized when they had equally rather than unequally spread neighbors. The findings are explained in terms of activation and inhibition processes in the interactive activation framework.

**Keywords** Word recognition; Orthographic neighborhood; Balance of neighborhood distribution; Interactive activation; Lexical decision

A number of studies have reported an effect of orthographic neighborhood (i.e., words sharing all but one letter with a stimulus word; Coltheart, Davelaar, Jonasson, & Besner, 1977) in visual word recognition. Nevertheless, inconsistent results have been found in the lexical decision task (LDT; for reviews, see Andrews, 1997; Mathey, 2001). In English, the effect of neighborhood density (i.e., the number of neighbors) is generally facilitatory on low-frequency words (e.g., Andrews, 1992), while it is difficult to observe in French (e.g., Grainger, O'Regan, Jacobs, & Segui, 1989). In contrast, an inhibitory effect of neighborhood frequency (i.e., the existence of at least one higher frequency neighbor) is usually reported in French (e.g., Grainger et al., 1989) but not in English (e.g., Forster & Shen, 1996). Even though a language-specific explanation has been proposed to reconcile these findings (Andrews, 1997), it is not sufficient to account for the whole pattern of discrepancies (Mathey 2001; Siakaluk, Sears, & Lupker, 2002). In order to shed more light on the orthographic neighborhood issue, the present study further investigated the effect of neighborhood distribution (P), which refers to the number of letter positions yielding at least one neighbor (Johnson & Pugh, 1994) and takes into account the neighborhood relationships that exist between the neighbors of the stimulus (Mathey & Zagar, 2000). More precisely, this study addresses the question of whether the balance of neighborhood distribution (i.e., the way neighbors are spread across the various letter positions) influences visual word recognition.

In order to examine whether the neighborhood relationships between the neighbors influence word recognition, Mathey and Zagar (2000) investigated the effect of neighborhood distribution when the number of neighbors was held constant (set at two). The authors ran simulations with the interactive activation model (IA; McClelland & Rumelhart, 1981) and showed that when word neighbors were spread across two letter positions (*P* = 2; e.g., flanc/blanc-franc), their inhibitory effect was less great than when they were concentrated on a single one (*P* = 1; e.g., firme/ferme-forme). The reason is that concentrated neighbors do not inhibit each other more than they inhibit the stimulus because they also reinforce each other at the letter level. On the contrary, spread neighbors strongly compete with each other because reinforcement at the letter level is not as great (they are not neighbors themselves), so the inhibition they exert on the stimulus word is reduced. Empirical data from the LDT confirmed the IA prediction. Other simulations run on artificial lexica (Mathey & Zagar, 2000) suggested that when the number of neighbors was greater than two, the neighborhood distribution effect varied as a function of the balance of the distribution; i.e., the way neighbors were spread across letter positions. To our knowledge, this prediction of the IA model has never been derived from a natural lexicon, nor has any experimental study been conducted to confirm the effect of the balance of the distribution. However, this issue is critical for assessing the mechanisms underlying lexical access. Specifically, the issue is to determine whether the neighborhood relationships that exist between the various neighbors of a stimulus word are involved in visual word recognition processes and should be taken into account in the models.

To address this issue, the present study focused on testing the effect of the balance of neighborhood distribution. The following three cases of neighborhood distribution were considered. In the first condition, the word neighbors were concentrated on a single letter position (*P* = 1; e.g., nasse/basse-lasse-tasse-masse). In the second condition, the word neighbors were unequally spread over two letter positions (P = 2; e.g., pelle/celle-selle-telle-perle). In the third, the word neighbors were equally spreadover two letter positions (*P* = 2; e.g., litre/titre-vitre-libre-livre).

According to Mathey and Zagar (2000), words should be more rapidly identified when their neighbors are spread across two letter positions (*P* = 2) rather than concentrated on a single one (*P* = 1), so a facilitatory effect of neighborhood distribution is expected. More importantly, when *P* = 2, an effect of the balance of neighborhood distribution should be found. Words should be more rapidly identified when their neighbors are equally rather than unequally spread across two ambiguous letter positions. In the IA framework, equally spread neighbors should compete more strongly with each other than unequally spread neighbors, so their inhibitory influence toward the stimulus word should be weakened to a larger extent. First, simulations were run with the IA model on French wordmaterials in order to determine whether the effects of neighborhood distribution and the balance of neighborhood distribution could be predicted by the model. Second, the word materials were presented in an LDT in order to test the model predictions.

## Simulation Study

### Method

*Stimuli* Forty-eight four- and five-letter words with low frequencies were selected using French-language frequency counts (Imbs, 1971). As can be seen in Fig. 1, three word conditions were set up by considering both neighborhood distribution (P) and the balance of neighborhood distribution. In the first condition, words had from three to five higher frequency neighbors (*M* = 3.50) that were concentrated on a single letter position (*P* = 1; e.g., nasse/basse-lassetasse masse). In the second condition, words had four higher frequency neighbors that were unequally spread over two letter positions (*P* = 2; e.g., pelle/celle-selletelle- perle). In the third, words had four higher frequency neighbors that were equally spread over two letter positions (*P* = 2; e.g., litre/titre-vitre-libre-livre). We manipulated the number of higher frequency neighbors since they are considered to be better predictors of word latencies than lower frequency neighbors (see also Mathey & Zagar, 2000).1 The main statistical characteristics of the materials are presented in Table 1. The total number of neighbors was controlled across the experimental conditions (*M* = 6.3, *F* < 1). Stimulus frequency (in log units) was matched across the word conditions, (*M* = 2.29,*F(*2, 45*)* = 1.46, *p* = .24), as was the cumulated higher frequency neighborhood frequency (in log units), (*M* = 4.12, *F* < 1).

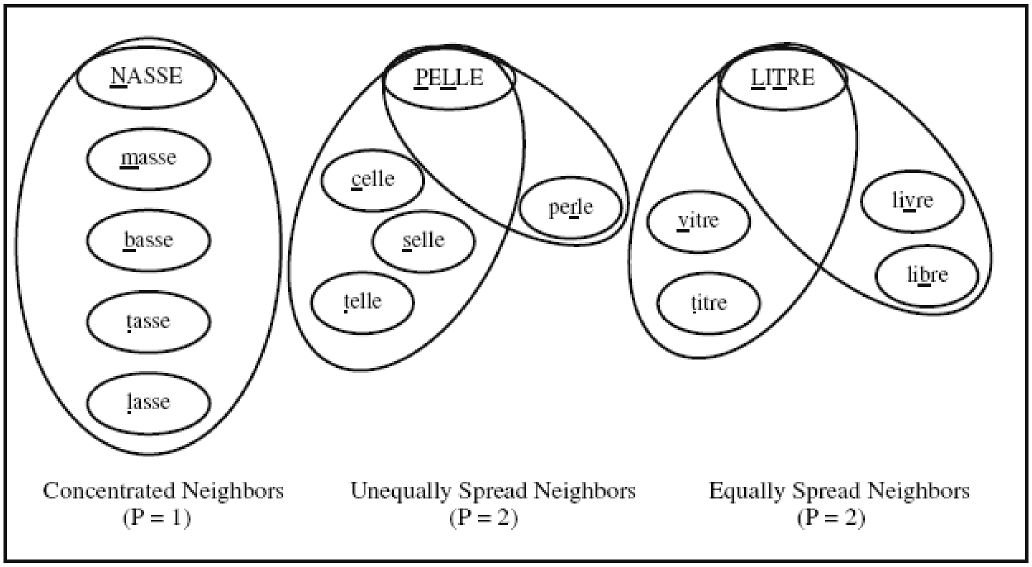

**Fig. 1** An example illustrating the experimental word conditions. The stimulus words are presented in upper-case letters and the word neighbors in lower-case letters. Ellipses represent the set of words that are neighbors themselves

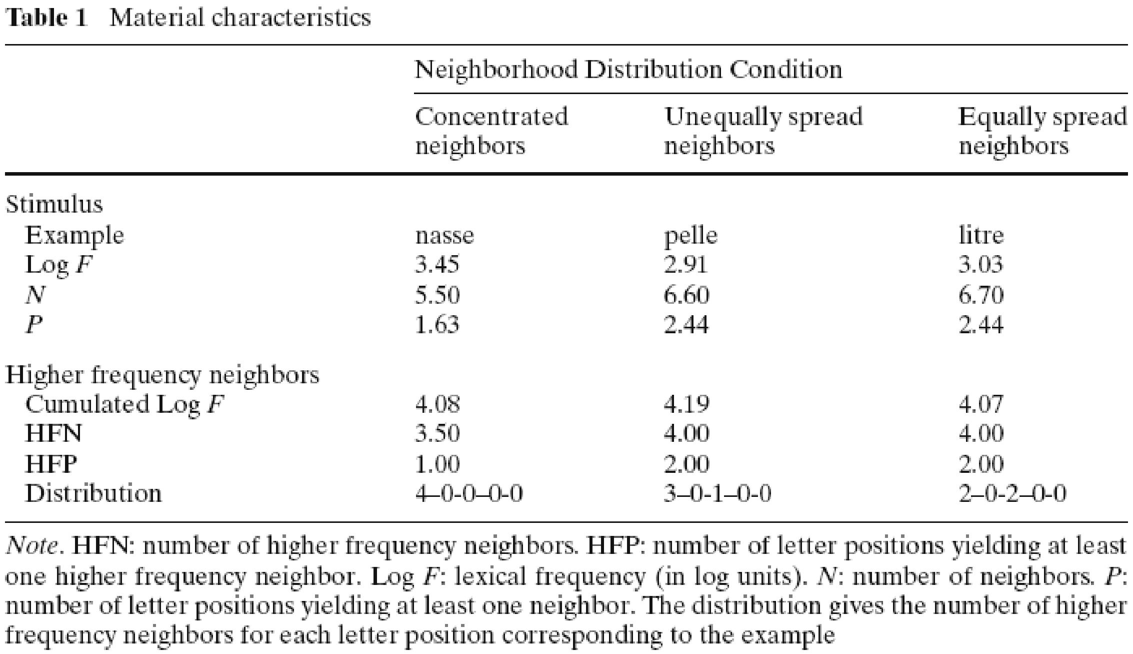

**Table 1** Material characteristics

| | Neighborhood Distribution Condition | | |
|---|---|---|---|
| | Concentrated neighbors | Unequally spread neighbors | Equally spread neighbors |
| Stimulus | | | |
| Example | nasse | pelle | litre |
| Log *F* | 3.45 | 2.91 | 3.03 |
| *N* | 5.50 | 6.60 | 6.70 |
| *P* | 1.63 | 2.44 | 2.44 |
| Higher frequency neighbors | | | |
| Cumulated Log *F* | 4.08 | 4.19 | 4.07 |
| HFN | 3.50 | 4.00 | 4.00 |
| HFP | 1.00 | 2.00 | 2.00 |
| Distribution | 4–0-0–0-0 | 3–0-1–0-0 | 2–0-2–0-0 |

*Note*. HFN: number of higher frequency neighbors. HFP: number of letter positions yielding at least one higher frequency neighbor. Log *F*: lexical frequency (in log units). *N*: number of neighbors. *P*: number of letter positions yielding at least one neighbor. The distribution gives the number of higher frequency neighbors for each letter position corresponding to the example

## *Procedure*

Simulations were run with the IA model (McClelland & Rumelhart, 1981) on two separate lexica of four- and five-letter French words. The default parameters provided byMcClelland andRumelhart (1981)were used for the simulations run on the 4-letter-word lexicon. The adjustment proposed by Grainger and Jacobs (1996) was used for the simulations run on the five-letter-word lexicon. Stimulus activation level along with its summed neighborhood activation level were collected at cycle 17 (around the end of stimulus processing; see Mathey&Zagar, 2000). Also, the number of processing cycles for words to reach a decision criterion (.70) was recorded and converted into reaction times using the equation proposed by Jacobs and Grainger (1992).

## Results

Mean activation levels and mean simulated response latencies averaged over words are presented in Table 2. Student *t* tests were performed on the item mean response latencies.[2] The neighborhood distribution effect was tested by comparing words with concentrated neighbors (*P* = 1) with words with spread neighbors (*P* = 2). The effect of the balance of neighborhood was examined for words with spread neighbors

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[1] According to Grainger et al. (1989), only orthographic neighbors that are of higher frequency than the stimulus influence decision latencies of French words.

[2] Item analyses were conducted on the simulated data for two reasons. First, it is the only way to test the reliability of the effects predicted by the IA model. Second, items can be considered as a random factor here since the number of stimuli presenting the same lexical characteristics can be increased ad infinitum in the IA model by using artificial lexica.

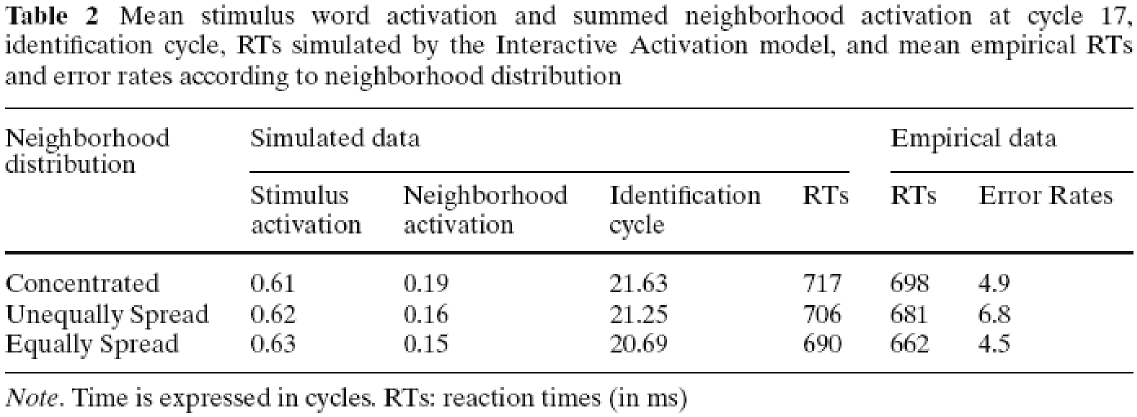

**Table 2** Mean stimulus word activation and summed neighborhood activation at cycle 17, identification cycle, RTs simulated by the Interactive Activation model, and mean empirical RTs and error rates according to neighborhood distribution

| Neighborhood distribution | Simulated data | | | | Empirical data | |
|---|---|---|---|---|---|---|
| | Stimulus activation | Neighborhood activation | Identification cycle | RTs | RTs | Error Rates |
| Concentrated | 0.61 | 0.19 | 21.63 | 717 | 698 | 4.9 |
| Unequally Spread | 0.62 | 0.16 | 21.25 | 706 | 681 | 6.8 |
| Equally Spread | 0.63 | 0.15 | 20.69 | 690 | 662 | 4.5 |

*Note*. Time is expressed in cycles. RTs: reaction times (in ms)

(*P* = 2) by comparing words with equally spread neighbors with words with unequally spread neighbors. As expected, the results indicated an effect of neighborhood distribution, $t(46) = 2.71$, $p < .01$.Wordswere 19ms faster to reach the decision criterionwhen their neighbors were spread across two letter positions rather than concentrated on a single one. Indeed, on cycle 17, words with spread neighbors (level of activation = 0.63) were more activated than words with concentrated neighbors (level of activation = 0.61). The reason was that the concentrated neighbors (level of activation = 0.19) were more activated than the whole set of spread neighbors (level of activation = 0.16), so the inhibition they exerted on the stimulus word was greater. The most important finding is that the IA model predicted an effect of the balance of neighborhood distribution, $t(30) = 2.15$, $p < .05$.Words were 16ms faster to reach the decision criterion when their neighbors were equally rather than unequally spread across the letter positions. On cycle 17, words were actually more activated when they had equally rather than unequally spread neighbors (level of activation = 0.63 vs. 0.62, respectively), given that their neighbors were less activated (level of activation = 0.15 vs. 0.16, respectively).

## Experiment

### Method

#### *Participants*

Thirty-eight students from the University of Bordeaux with normal or corrected-to-normal vision volunteered to participate. All were native French speakers.

#### *Stimuli*

The same 48 targets as in the simulation study were used. Forty-eight pseudowords of four or five letters were added for the purposes of the LDT. All were pronounceable and orthographically legal.

### *Procedure*

A standard LDT was used. A central fixation point was presented for 500 ms. Then, the stimulus in lowercase letters appeared and remained on the screen until the participant responded or until 2500 ms had elapsed. Participants were instructed to decide as quickly and as accurately as possible whether the stimulus wasa word or not by pressing one of two buttons on a response box. “Yes” responses (for words) were given with the dominant hand and “no” responses (for pseudowords) with the other hand. Tone feedback was provided when participants failed to respond or when the time limit was reached. All participants performed 16 practice trials before the experimental trials in a random order. Reaction times (RTs in ms) were measured from stimulus onset until the participant responded.

## Results

To avoid the influence of outliers, RTs below 300 ms or above 1500 ms were excluded from the analyses (1.30 % of the data). Three words were eliminated per condition because of their high error rates (more than 35%). Mean correct response latencies and error rates averaged over participants are presented in Table 2. Student *t* tests were performed on the participant means.[3] The neighborhood distribution effect was tested by comparing words with concentrated neighbors ($P$ = 1) with words with spread neighbors ($P$ = 2). The effect of the balance of neighborhood distribution was tested within the set of spread neighbors, by comparing words with equally spread neighbors with words with unequally spread neighbors. Analysis of the RTs showed a reliable effect of neighborhood distribution, $t(37) = 3.00$, $p < .01$.Words were 16ms faster to recognize when their neighbors were spread across two letter positions rather than concentrated on a single one.Asignificant effect of the balance of the distribution was also found, $t(37) = 2.34$, $p < .05$. Words were 19 ms faster to recognize when their neighbors were equally rather than unequally spread across the letter positions. No effect was significant in the error analysis.

## **Discussion**

The present study provides further evidence regarding the influence of neighborhood relationships between the orthographic competitors in visual word recognition when the number of neighbors is held constant. First, a facilitatory neighborhood distribution effect was observed. Words were recognized faster when their neighbors were spread across two letter positions ($P$ = 2) rather than concentrated on a single one ($P$ = 1).

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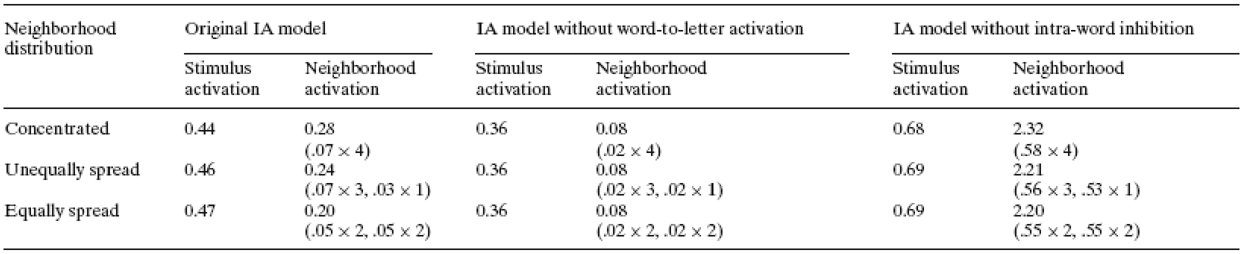
[3] On the basis of the work by Raaijmakers, Schrijnemakers, and Gremmen (1999; Raaijmakers, 2003;Wike & Church, 1976), item analyses are inappropriate in the present experiment. First, the materials were selected because they satisfied an extensive set of criteria. Second, items were matched across the three experimental conditions (for a similar approach, see Siakaluk et al., 2002). However, as requested by one anonymous reviewer, we have performed unilateral Student *t* tests on the item mean empirical response latencies. The effect of neighborhood distribution was marginally reliable, $t(37) = 1.49$, $p = .07$, and the effect of the balance of the distribution was not significant, $t < 1$.

These data replicate previous findings by Mathey and Zagar (2000) and extend the neighborhood distribution effect to words with more than two neighbors. Second and more importantly, an effect of the balance of the distribution was observed. The neighborhood distribution effect was found to be greater when the neighbors were equally rather than unequally spread across the ambiguous letter positions;The IA model simulations run on the word materials were shown to correctly predict the results found in the LDT. More precisely, the model accounted for both an effect of neighborhood distribution and of the balance of neighborhood distribution. In fact, the simulated data demonstrated that the level of stimulus activation depended on the level of summed neighborhood activation. First, concentrated neighbors were activated more than spread neighbors (level of activation = 0.19 vs. 0.16, respectively). When a stimulus word has concentrated neighbors, these neighbors reinforce each other at the letter level (see also Mathey & Zagar, 2000). Given that the amount of inhibition exerted by a word is a function of its activation level, the inhibition concentrated neighbors exert on the stimulus word is great. However, when a stimulus has spread neighbors, the neighbors compete with each other because the reinforcement at the letter level is less great. The inhibition they exert on the stimulus word is therefore weakened. Second, within the set of spread neighbors, unequally spread neighbors were activated more than equally spread neighbors (level of activation = 0.16 vs. 0.15). In fact, when the stimulus word has unequally spread neighbors, the two sets of neighbors are unbalanced, so they do not compete with each other strongly enough to reliably weaken their inhibitory influence on the stimulus word. However, when the stimulus word has equally spread neighbors, the two sets of neighbors are balanced and therefore they inhibit each other to the same extent. Consequently, the amount of inhibition they exert on the stimulus is considerably weakened. These data therefore provide evidence that the stimulus neighbors inhibit each other to a varying extent depending on their neighborhood relationship. In order to clarify the mechanisms that are responsible for the present findings, further IA simulations were run with an artificial lexicon that was constructed to represent the experimental word conditions used in the present study (see Mathey & Zagar, 2000). This four-letterword lexiconwas reduced to the representations of three low-frequency stimulus words (with a resting activation level of −0.9) and the representations of their four higher frequency neighbors (with a resting activation level of −0.1). The only variable that was manipulated was the way the neighbors were spread across letter positions. Neighbors were either concentrated on a single letter position, or were unequally spread across two letter positions, or were equally spread across two letter positions. Simulations were then run with the original IA model and with two versions of the IAmodel in which either the word-to-letter activation or the intraword inhibition parameter was set to zero (Andrews, 1992; Zagar&Mathey, 2000). In doing so, the purposewas to disentangle the respective role of word-to-letter activation and intra-word inhibition mechanisms in the present findings. Because words reached their asymptotic activation earlier when the lexical inhibition parameter was cut off, levels of activation were taken at cycle 14. The results are presented in Table 3. First, the model without word-to-letter activation showed that the levels of activation of the stimulus (= 0.36) and its neighbors (= 0.08) were strictly identical across the three neighborhood distribution conditions. In addition, the levels of summed neighborhood activation were very low compared with those observed in the original IAmodel. These findings clearly indicate that the inhibitory effect of neighborhood is amplified by the word-to-letter activation mechanism, which is furthermore responsible for the amount of summed neighborhood activation when neighborhood distribution is varied. Second, in the model without intra-word inhibition, the level of neighborhood activation depended on the way the neighbors were spread across letter positions. In particular, the level of summed neighborhood activation was proportional to the number of neighbors that were also neighbors themselves, increasing from 0.53 to 0.58 when the number of neighbors per letter positions increased from one to four. Inaddition, a facilitatory effect of neighborhood distributionwas produced so that words with spread neighbors (level of activation = 0.69) were more activated than the word with concentrated neighbors (level of activation = 0.68).

**Table 3** Stimulus word activation and summed neighborhood activation for words at cycle 14 simulated by the original IA model, the IA model without word-to-letter activation, and the IA model without intra-word inhibition, when included in an artificial lexicon, according to neighborhood distribution



| Neighborhood distribution | Original IA model | | IA model without word-to-letter activation | | IA model without intra-word inhibition | |
|---|---|---|---|---|---|---|
| | Stimulus activation | Neighborhood activation | Stimulus activation | Neighborhood activation | Stimulus activation | Neighborhood activation |
| Concentrated | 0.44 | 0.28<br>(.07 × 4) | 0.36 | 0.08<br>(.02 × 4) | 0.68 | 2.32<br>(.58 × 4) |
| Unequally spread | 0.46 | 0.24<br>(.07 × 3, .03 × 1) | 0.36 | 0.08<br>(.02 × 3, .02 × 1) | 0.69 | 2.21<br>(.56 × 3, .53 × 1) |
| Equally spread | 0.47 | 0.20<br>(.05 × 2, .05 × 2) | 0.36 | 0.08<br>(.02 × 2, .02 × 2) | 0.69 | 2.20<br>(.55 × 2, .55 × 2) |

*Note*. Time is expressed in cycles. Activation of the four neighbors for each ambiguous letter position is given in parentheses

This seems to be due to a pure effect of word-to-letter activation (see also Andrews, 1992), since spread neighbors reinforce each of the four letters of the stimulus whereas the concentrated neighbors only reinforce three out of the four letters of the stimulus. Finally, comparing the data of the two previous models with those of the original IA model provided further evidence for the above conclusions. That is, the level of summed neighborhood activation varied as a function on the way the neighbors were spread across letter positions. Also, the stimulus word activation depended on both the amount of inhibition sent by the neighbors and the magnitude of word-to-letter activation. In summary, these simulation data clearly indicate that both word-to-letter activation and lexical inhibition are critical mechanisms underlying the effects of neighborhood distribution and of the balance of neighborhood distribution.

The present research also has strong implications concerning the interpretation of orthographic neighborhood effects in visual word recognition. As already mentioned, investigations of neighborhood density and neighborhood frequency effects have yielded inconsistent findings (for reviews, see Andrews, 1997; Mathey, 2001). According to Andrews (1997; see also Ziegler & Perry, 1998), these conflicting data are due to cross-language differences in orthographic–phonological mapping. In line with this idea, it could also be the case that neighborhood structure is language-specific. A consideration of the neighborhood statistics of four- and five-letter words in the English and the French languages may be instructive in this regard. The statistics of English were taken from Andrews' (1997) analysis of 1.895 four-letter words and

2.895 five-letter words. The statistics of French were computed on 1.065 four-letter words and 2.435 five-letter words from the Brulex database (Content, Mousty, & Radeau, 1990). In both languages, five-letter words tend to have similar neighborhood statistics (in English, $N$ = 2.3 and $P$ = 1.5; in French $N$ = 2.4 and $P$ = 1.3). However, English four-letter words have twice as many neighbors ($N$ = 7.2) as French ones ($N$ = 3.5), so neighborhood distribution is also higher in English ($P$ = 2.5) than in French ($P$ = 1.7). This evaluation of cross-language neighborhood statistics may therefore provide a possible explanation to some empirical contradictions concerning the neighborhood effect, in particular concerning four-letter words. However, a completely language-specific explanation is clearly not sufficient to account for the whole pattern of empirical findings. First, no cross-linguistic difference concerning the neighborhood characteristics was found for the set of five-letter words. Second, inconsistent neighborhood effects have also been reported between studies that were conducted in the same language (e.g., Forster & Shen, 1996; Siakaluk et al., 2002; for a review see Mathey, 2001). Whatever the language in which the study is carried out, another possible account to reconcile inconsistent neighborhood effects lies in the lack of control of the neighborhood relationships between the neighbors in previous experiments. When a word hasmore than one neighbor, the neighborhood effect is more complex than the simple influence of the neighbors toward the stimulus word. In particular, Mathey and Zagar (2000; Zagar & Mathey, 1999,2000) have accumulated empirical and theoretical evidence showing that the neighborhood effect varies as a function of the nature of the relationships between the various neighbors. These authors therefore contend that the lack of consensus concerning the neighborhood effect in visual word recognition might be due to inhibition between the neighbors of stimulus words. The results of the present study further support this view by showing that the neighborhood distribution effect varies as a function of the balance of neighborhood distribution. By generalizing this phenomenon, either a facilitatory or an inhibitory neighborhood effect can be observed. Interestingly, simulations run with the IA model correctly predicted such effects when the neighborhood relationships between the competitors of the word were varied (Mathey & Zagar, 2000;Zagar & Mathey, 1999 , 2000).

In conclusion, the present findings highlight the importance of neighborhood relationships between orthographic competitors in visual word recognition. In particular, they suggest that the exact distribution of the neighbors across letter positions modulates the neighborhood effect via mutual inhibition and word-to-letter activation. For future studies using the neighborhood effect as an index to investigate word processing, it therefore appears fundamental to control the way neighbors are spread across letter positions.

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