Journal of Experimental Psychology:
Learning, Memory, and Cognition
1997, Vol. 23, No. 4, 857–871

0278-7393/97/$3.00

Effects of Orthographic Neighborhood in Visual Word Recognition: Cross-Task Comparisons

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Effects of orthographic neighborhood in visual word recognition in Spanish were examined in 5 paradigms: progressive demasking, standard lexical decision, lexical decision with blocking of neighborhood density, naming, and semantic categorization. The results showed inhibitory effects of neighborhood frequency in the progressive-demasking task, in both lexical-decision tasks, as well as for low-density words in the naming task, and for high-density words in the semantic-categorization task. Higher levels of neighborhood density produced an inhibitory trend in the progressive-demasking task, facilitation in lexical decision (significant only when neighborhood density was blocked), and a robust facilitation effect in naming (only for words with higher frequency neighbors). A global analysis across tasks and one simulation study helped outline some of the underlying task-specific and task-independent mechanisms.

It is a well established fact that words that are read more frequently (measured in terms of the number of occurrences in a given corpus) are recognized more rapidly and/or with fewer errors in the classical word-recognition paradigms than less frequently read words (see Balota, 1994, and Monsell, 1991, for a review). However, it has also been pointed out that the basis of this effect may not be the absolute frequency per se, but the relative frequency of a given target word in relation to orthographically similar words (e.g., Grainger, 1990; Havens & Foote, 1963). In line with this reasoning, many models of visual word recognition assume that words that are orthographically similar to a given target word will compete in some way in the recognition process, and that the degree of competition is a function of the relative frequency of the target word and its competitors (e.g., Forster, 1976; McClelland & Rumelhart, 1981; Norris, 1986; Paap, Newsome, McDonald, & Schvaneveldt, 1982).

It is commonly accepted (e.g., see Andrews, 1989; Forster, 1989; Grainger, 1992; Johnson & Pugh, 1994; Paap & Johansen, 1994) that at least for short words, an adequate approximation to orthographic similarity is the definition of an orthographic neighbor proposed by Coltheart, Davelaar, Jonasson, and Besner (1977): An orthographic neighbor is any word that can be created by changing one letter of the stimulus and preserving letter positions (e.g., *lift, list,* and *pint* are neighbors of *lint*). The index *N* is typically used to refer to the number of orthographic neighbors of a given word.

Prior studies have manipulated two variables related to the above definition of orthographic neighborhood. A number of researchers have explored the effects of having higher frequency orthographic neighbors, the so-called *neighborhood-frequency effect* (Grainger, O'Regan, Jacobs, & Seguí, 1989): Words with higher frequency neighbors are harder to recognize than words without higher frequency neighbors. This result has been observed with Dutch, English, French, and Spanish words in lexical decision (Grainger, 1990; Grainger & Jacobs, 1996; Grainger & Seguí, 1990; Grainger et al., 1989; Grainger, O'Regan, Jacobs, Seguí, 1992; Huntsman & Lima, 1996; Perea, 1993; Perea & Pollatsek, in press; however, see Forster & Shen, 1996, and Sears, Hino, & Lupker, 1995, for examples of studies using English stimuli that have not observed this pattern of results), with eye-gaze durations (Grainger et al., 1989; Perea & Pollatsek, in press), and with speeded-identification tasks (Grainger & Jacobs, 1996; Grainger & Seguí, 1990; Perea, 1993). This result is predicted by a number of models, both parallel models (the interactive-activation model, Jacobs & Grainger, 1992; McClelland & Rumelhart, 1981; the checking model, Norris, 1986) and serial models (Forster, 1976; Paap et al., 1982). In contrast, the neighborhood-frequency effect appears to be facilitatory in the naming task for words with many orthographic neighbors (Grainger, 1990; Sears et al., 1995), which could be explained in terms of pronunciation-specific processes rather than lexical access. Possibly, this facilitation occurs because orthographic neighbors generally have pronunciations that are similar to that of the stimulus

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This research was supported by Grants PB/93-0562 and PS/94-0193 from the Dirección General de Investigación Científica y Técnica, as well as by the Picasso Project Acción Integrada Hispano-Francesa HF-64-B, which supported our collaboration.

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word and therefore provide support for the stimulus word's pronunciation as predicted by analogy models of word naming (see Glushko, 1979; Grainger, 1990, 1992; Jared, McRae, & Seidenberg, 1990; Kay & Marcel, 1981; Taraban & McClelland, 1987).

Other studies have explored the influence of the number of neighbors of a given word (the *neighborhood-size effect* or *neighborhood-density effect*). Generally speaking, increasing the number of orthographic neighbors of word targets produces faster reaction times (RTs) and fewer errors in the lexical-decision task, whereas the same manipulation on nonword targets produces slower RTs and more errors (Andrews, 1989, 1992; Forster & Shen, 1996; Johnson & Pugh, 1994; Laxon, Coltheart, & Keating, 1988; Perea, 1993; Sears et al., 1995). The facilitatory effects of neighborhood density obtained with word stimuli in the lexical-decision task are sensitive to word frequency (effects are strongest with low-frequency words), the type of nonwords used as distractors, and task instructions stressing speed or accuracy (e.g., Andrews, 1989; Grainger & Jacobs, 1996).

Several studies have consistently found facilitatory effects of neighborhood density for low-frequency words in the speeded-naming task (e.g., Andrews, 1989, 1992; Peereman & Content, 1995; Sears et al., 1995). As with the facilitatory effect of neighborhood frequency also observed in this task, this effect can be explained in terms of phonological–articulatory processes specific to the naming task, such as the degree of consistency of the pronunciation of the orthographic rime (e.g., Jared et al., 1990; Treiman, Mullennix, Bijeljac-Babic, & Richmond-Welty, 1995). In regression analyses performed on two mega-studies of word naming, Treiman et al. (1995) did find some evidence of facilitatory effects of neighborhood density when effects of onset and rime consistency were partialed out. Nevertheless, it remains to be clearly demonstrated that the number of orthographic neighbors of monosyllabic English words can influence speeded word-naming performance over and above the effects of rime consistency (or other phonologically defined variables).

The present study provides a further investigation of the effects of neighborhood density and neighborhood frequency in four different experimental paradigms: speeded identification (the progressive-demasking task), word–nonword classification (the lexical-decision task), reading aloud (the naming task), and animal–nonanimal classification (the semantic-categorization task). The same set of word stimuli was tested in all experiments, thus allowing cross-task comparisons not only of the variables under study, but also of how the tasks cohere with respect to interitem variability. To this end, a final combined analysis over all experiments examined pairwise correlations between experiments, and a factor analysis examined possible groupings among the tasks. Such analyses should help isolate task-independent and task-specific processes underlying effects of orthographic neighborhood in visual word recognition.

One major problem faced by any researcher investigating visual word recognition concerns the selection of the appropriate task or tasks to test the proposed hypotheses. Until recently, a commonly adopted strategy was to use at least two classical paradigms (e.g., lexical decision and naming) and to check whether they produced the same pattern of results. If this was the case, then one concluded that the variable under study influences some process or processes common to both tasks and basic to visual word recognition. As the title of the present study suggests, we encourage the use of such cross-task comparisons, but they must be performed with care. In the absence of a strong theoretical analysis of the different tasks and how they relate to the hypothesized basic processes involved in visual word recognition (the analysis of *functional overlap* proposed by Jacobs & Grainger, 1994, and Grainger & Jacobs, 1996), these cross-task comparisons may lead to errors. Thus, for example, Andrews (1989, 1992) and Sears et al. (1995) found systematic facilitatory effects of neighborhood density on low-frequency words in both the naming and lexical-decision tasks and concluded that neighborhood density affects a process common to these tasks (often referred to as lexical access). In the present work, we argue that although certain similarities in the effects of orthographic neighborhood are observed across different tasks, these similarities cannot systematically be attributed to the operation of the same underlying mechanism.

Experiment 1: Progressive Demasking

Method

Participants. Twenty students from introductory psychology courses at the Universitat de València took part in the experiment either to earn extra course credit or to fulfill a course requirement.

Design and materials. A total of 64 two-syllable Spanish words (nouns or adjectives), all of them four or five letters long, were selected from the Universitat de València's computerized word pool (Algarabel, Ruíz, & Sanmartín, 1988) by combining two factors (neighborhood density: low-density words vs. high-density words; neighborhood frequency: words with higher frequency neighbors vs. words with no higher frequency neighbors) in a 2 × 2 within-subjects but between-materials design. The characteristics of the words are presented in Table 1. As is shown in the table, all words used were low-frequency words. Words were matched across conditions for syllable frequency, initial sound, and length. The complete set of materials is listed in the Appendix.

Table 1
Characteristics of Words Used in Experiments 1–4

Word neighborhood and neighbor type	Word frequency		No. of neighbors		No. of HF neighbors	
	M	Range	*M*	Range	*M*	Range
LD neighborhood						
HF neighbors	9.6	2–20	2.3	1–3	1.3	1–2
No HF neighbors	10.7	4–21	1.9	1–3	0.0	0–0
HD neighborhood						
HF neighbors	9.6	2–16	7.7	6–11	1.4	1–2
No HF neighbors	11.0	2–21	7.0	5–12	0.0	0–0

Note. Mean word frequency was based on a count of 500,000 Spanish words (Juilland & Chang-Rodríguez, 1964). No. = number; LD = low density; HF = higher frequency; HD = high density.

Procedure. Participants were tested individually in a quiet room. Presentation of the stimuli and recording of latencies were controlled by an Apple Macintosh Plus computer. Words were presented in capital letters in the center of the computer screen. Identification latencies were collected by a microphone connected to a voice-activated key (Algarabel, Sanmartín, & Ahuir, 1989) interfaced with a digital input–output port of the computer. In each trial, there was a succession of target–mask cycles. On the first cycle, the target word was presented for 17 ms and immediately was replaced by a mask (#####) for 320 ms. After each two cycles (the third cycle, the fifth cycle, and so on), the presentation of the word was increased by 17 ms, and the presentation of the mask was decreased by 17 ms. There were no intervals between successive cycles. This succession continued until the participant read the word aloud.[1] Participants were instructed to say the word aloud as quickly and as accurately as possible. Each participant received 12 practice trials prior to the 64 experimental trials. The whole session lasted about 13 min.

Results and Discussion

The mean RT and error rate for the words in each experimental condition are presented in Table 2. Incorrect responses (6.6%) and RTs shorter than 300 ms or longer than 3,500 ms (0.6% of the data) were excluded from the latency analysis.[2] Mean RTs and error data were then submitted to separate analyses of variance (ANOVAs), with neighborhood frequency (words with higher frequency neighbors vs. words with no higher frequency neighbors) and neighborhood density (low-density words vs. high-density words) as variables. All data were subjected to two ANOVAs, one treating subjects as a random variable (F_1) and one treating items as a random variable (F_2).

The ANOVA on the mean latency data yielded a significant effect of neighborhood frequency, $F_1(1, 19) = 31.65$, $MSE = 9{,}733$, $p < .001$; $F_2(1, 60) = 5.59$, $MSE = 55{,}770$, $p < .03$. Words with higher frequency neighbors were identified more slowly than words without higher frequency neighbors. The main effect of neighborhood density approached the traditional criterion for significance in the by-subject analysis, $F_1(1, 19) = 4.25$, $MSE = 20{,}237$, $p = .053$; $F_2(1, 60) = 1.10$, $MSE = 55{,}770$. The interaction between neighborhood frequency and neighborhood density was not significant (both Fs < 1).

For errors, the only reliable effect was that of neighborhood frequency, $F_1(1, 19) = 10.27$, $MSE = 41$, $p < .005$; $F_2(1, 60) = 5.69$, $MSE = 58$, $p < .03$: Words without higher frequency neighbors were identified better than words with higher frequency neighbors.

Table 2
Mean Reaction Times (RTs; in Milliseconds) and Errors (in Percentages) in Experiment 1

	Neighborhood frequency				
	No HF neighbors		HF neighbors		
Neighborhood density	RT	Error (%)	RT	Error (%)	RT difference
Low	1,350	5.1	1,476	9.0	−126
High	1,417	4.4	1,540	9.7	−123
RT difference	−67		−64		

Note. HF = higher frequency.

A robust neighborhood-frequency effect was observed in both the RT data and the error data, thus replicating earlier work with the progressive-demasking paradigm (Grainger & Jacobs, 1996; Grainger & Seguí, 1990; Perea, 1993). That is, having high-frequency neighbors seems to interfere with the recognition of low-frequency stimulus words in such speeded-identification tasks. The subject analysis showed an inhibitory trend ($p = .053$) of neighborhood density, possibly due to the harder process of discrimination among lexical candidates for high-density words (see Snodgrass & Mintzer, 1993). In fact, one other recent study has reported robust inhibitory effects of neighborhood density in the progressive-demasking task (Van Heuven, Dijkstra, & Grainger, 1996). It therefore appears that the inhibitory trend of neighborhood density observed in the present data has found confirmation in other research.

Experiment 2: Lexical Decision

Method

Participants. A total of 21 students drawn from the same population as in the previous experiment took part in this experiment. None of them had participated in the previous experiment.

Design and materials. The design and stimuli were the same as in the previous experiment with the exception that 64 orthographically legal bisyllabic nonwords matched in length with the word stimuli were added for the purposes of the lexical-decision task. The nonwords were pronounceable and orthographically legal, and were constructed by changing one letter of a real Spanish word. Half of the nonwords had only 1 word neighbor, and the other half had many word neighbors ($M = 5.3$). The stimuli are listed in the Appendix.

Procedure. Participants were tested in groups of 2 or 3 in a quiet room. Presentation of the stimuli and recording of latencies were controlled by Apple Macintosh Plus microcomputers. On each trial, the sequence > < was presented for 300 ms in the center of the screen. Next, an uppercase letter string (word or nonword) was presented in the center of the screen until the participant's response. Participants were instructed to press one of two keys on the keyboard to indicate whether the letter string was a

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[1] Unlike previous studies that asked participants to press a button once they had identified the word and then to write the stimulus words (e.g., Grainger & Seguí, 1990), participants were instructed to pronounce the word aloud as accurately as possible, because the oral response might facilitate the participants' task as well as minimize the use of guessing strategies after pressing the button. Perea and Carreiras (1995) obtained similar results for syllable frequency, using the two types of answer (oral response vs. typing the word after pressing a button).

[2] For words, we used a cutoff of 3,500 ms for the progressive-demasking task (Experiment 1), a cutoff of 1,500 ms for the two lexical-decision tasks and the semantic-categorization task (Experiments 2, 3, and 5, respectively), and a cutoff of 800 ms for the naming task (Experiment 4). Other cutoff procedures (e.g., excluding RTs that are two or three standard deviations above or below a particular condition's mean, other fixed cutoffs, etc.) yielded an analogous pattern of results (see Ratcliff, 1993).

Spanish word or not. This decision was to be made as rapidly and as accurately as possible, with accuracy stressed more than speed. The intertrial interval was 1,500 ms. Each participant received 24 practice trials prior to the 128 experimental trials. The whole session lasted approximately 11 min.

Results and Discussion

The mean lexical-decision time and error rate for the stimuli in each experimental condition are shown in Table 3. For words, incorrect responses (3.2%) and RTs shorter than 300 ms or longer than 1,500 ms (1.7% of the data) were omitted from the latency analysis. As in Experiment 1, mean RTs and error data were submitted to separate ANOVAs, with neighborhood frequency and neighborhood density as within-subjects but between-items variables. For nonwords, incorrect responses (3.6%) and RTs shorter than 300 ms or longer than 2,000 ms (2.6% of the data) were omitted from the latency analysis. Mean RTs and error data were then submitted to separate ANOVAs, with neighborhood density (low vs. high) as a within-subjects but between-items variable.

The ANOVA on latency data for words revealed a main effect of neighborhood frequency, $F_1(1, 20) = 23.01$, $MSE = 1{,}756$, $p < .001$; $F_2(1, 60) = 8.44$, $MSE = 4{,}307$, $p < .01$, in which words without higher frequency neighbors were responded to faster than those with higher frequency neighbors. Neither the main effect of neighborhood density, $F_1(1, 20) = 1.23$; $F_2(1, 60) < 1$, nor the interaction between neighborhood density and neighborhood frequency (both Fs < 1) was statistically reliable.

Similarly, the ANOVA on error rates for words yielded a significant effect of only neighborhood frequency, $F_1(1, 20) = 5.51$, $MSE = 39$, $p < .03$; $F_2(1, 60) = 5.62$, $MSE = 30$, $p < .03$: Words without higher frequency neighbors were identified better than those with higher frequency neighbors.

The ANOVA on RTs for nonwords showed that the main effect of neighborhood density was reliable, $F_1(1, 20) = 9.87$, $MSE = 6{,}829$, $p < .001$; $F_2(1, 60) = 15.32$, $MSE = 4{,}342$, $p < .001$: Nonwords from low-density neighborhoods were responded to faster than words from high-density neighborhoods. However, error rates did not show reliable differences.

In Experiment 2, we found a robust inhibitory effect of neighborhood frequency in the lexical-decision task, thus replicating the earlier studies of Grainger and his colleagues (Grainger, 1990; Grainger & Seguí, 1990; Grainger et al., 1989, 1992), as well as some very recent results (Huntsman & Lima, 1996; Perea & Pollatsek, in press). Huntsman and Lima (1996) performed post hoc analyses of their results to test for effects of neighborhood density and neighborhood frequency. As in the present study, they found a significant inhibitory effect of neighborhood frequency and a smaller, nonsignificant facilitatory effect of neighborhood density (see also Paap & Johansen, 1994, for similar post hoc analyses). On the other hand, the results of Experiment 2 stand as further contradictory evidence with respect to the recent studies of Sears et al. (1995) and Forster and Shen (1996). These authors systematically did not observe significant inhibitory effects of neighborhood frequency in the lexical-decision task. We return to such discrepancies in more detail in the General Discussion. Here we point out some of the most obvious ways in which the present experiment differs from these studies.

First of all, the language studied here (Spanish) has very consistent spelling-to-sound correspondences. This may have helped avoid possible contamination from uncontrolled phonological neighborhoods. Second, all the stimuli in the present experiments were controlled for syllable length and frequency (see Carreiras, Alvarez, & de Vega, 1993; Perea & Carreiras, in press), and were (except for two suffixed words) all monomorphemic nouns and adjectives. Finally, participants were encouraged to give preference to accuracy over speed to encourage responses based on unique word identification. The error rates to word (3.4%) and nonword stimuli (4.1%) were much lower than those observed by either Sears et al. (1995) or Forster and Shen (1996), which were generally above 10%. On this point, it should be noted that the average error rate reported in Huntsman and Lima's (1996) study was 3.2%. Also, it should be noted that the RTs obtained in our experiment were slower than those obtained in Forster and Shen's and in Sears et al.'s experiments. This suggests that the higher error rates in their studies were not simply due to the use of words of lower printed frequency.

On the other hand, there was only a small nonsignificant 7-ms facilitation for words from high-density neighborhoods in Experiment 2. Because our participants showed much higher levels of accuracy than participants in previous studies that have found a reliable neighborhood-density

Table 3
Mean Reaction Times (RTs; in Milliseconds) and Errors (in Percentages) for Words and Nonwords in Experiment 2

	Words						
	No HF neighbors		HF neighbors			Nonwords	
Neighborhood density	RT	Error (%)	RT	Error (%)	RT difference	RT	Error (%)
Low	681	1.7	731	5.9	−50	867	3.3
High	681	2.0	718	4.1	−37	924	4.9
RT difference	0		13			−57	

Note. HF = higher frequency.

effect in the lexical-decision task with low-frequency words (see Andrews, 1989, 1992; Forster & Shen, 1996; Sears et al., 1995), it would appear that stressing accuracy in the instructions to participants and using high-density nonwords reduces the facilitatory effects of neighborhood density (see Johnson & Pugh, 1994, for a similar argument and Huntsman & Lima, 1996, for a similar result). In line with this reasoning, Grainger and Jacobs (1996) have shown that reducing the degree of resemblance of the nonword stimuli and stressing speed over accuracy in a series of three lexical-decision experiments caused a decrease in the inhibitory effects of neighborhood frequency and an increase in the facilitatory effects of neighborhood density.

This pattern of effects was explained by Grainger and Jacobs (1996) within the framework of a revised interactive-activation model of orthographic processing in visual word recognition: the multiple read-out model. This model implements noisy response criteria set on individual word unit activity (the word detectors of the original interactive-activation model, McClelland & Rumelhart, 1981) and summed lexical activity (the sum of the activations of all word detectors activated above zero), to generate precise quantitative predictions concerning RTs to word stimuli in speeded-identification and lexical-decision tasks. The criterion set on word unit activity (M criterion) is thought to reflect unique word identification (or, more precisely, the correct matching of the stimulus to a whole-word orthographic description in memory), as required in perceptual-identification paradigms. The criterion set on summed lexical activity (Σ criterion) is thought to be operational in the lexical-decision task, inasmuch as it allows a fast, accurate discrimination of word stimuli from nonword stimuli. In an interactive-activation network, all word units inhibit each other (a principle referred to as *lexical inhibition* by Grainger & Jacobs, 1996), and the amount of inhibition is a function of the inhibiting unit's activation level. This explains why increasing the number and the frequency of orthographic neighbors produces inhibition in paradigms requiring unique word identification. On the other hand, when participants can base their responses on summed lexical activity, then facilitatory effects of orthographic neighbors can be observed. High-density words can give rise to fast positive responses generated by the Σ criterion. Moreover, in the multiple read-out model, correct responses to nonword stimuli are generated by a decision criterion set on the time dimension (i.e., a deadline mechanism). The value of this negative response criterion varies as a function of the summed activity of stimuli, with higher values being adopted in the presence of stimuli that generate high levels of global lexical activity. This mechanism captures the inhibitory effect of neighborhood density on responses to nonword stimuli in the lexical-decision task (Andrews, 1989; Coltheart et al., 1977; Sears et al., 1995).

Indeed, for the nonword stimuli tested in Experiment 2, we found the usual inhibitory effect of neighborhood density in the RT analysis, but not in the analysis of errors. Within the framework of the multiple read-out model, the absence of an effect in the errors to nonword stimuli follows from the use of a high Σ criterion for positive responses. The false-positive error rate increases as the Σ criterion is lowered. Therefore, the model predicts that experimental conditions that allow facilitatory effects of neighborhood density to emerge in the RTs to word stimuli should also allow inhibitory effects to appear in the error rates to nonword stimuli. This prediction was tested in Experiment 3.

Another interesting prediction of the multiple read-out model concerns what we refer to as a density-blocking manipulation:[3] presenting the high- and the low-density words in separate blocks with the same type of nonwords (i.e., mixed high and low density). The model predicts that the density-blocking manipulation should increase the size and stability of neighborhood-density effects. This follows from the fact that blocking the word stimuli by density (while keeping the nonword stimuli the same in each condition) allows a better discrimination of the word and nonword stimuli in terms of global lexical activity, in the blocked high-density condition. Thus, in Experiment 3, it was expected that the density-blocking manipulation should produce significant facilitatory effects of neighborhood density for the word stimuli (not robust in Experiment 2). Furthermore, as noted above, this should be accompanied by a significant inhibitory effect of neighborhood density in the error rates to nonwords (not observed in Experiment 2).

Experiment 3: Lexical Decision With Density Blocking

Method

Participants. A total of 40 students from the introductory courses at the Universidad de La Laguna received course credit for taking part in this experiment.

Design and materials. The design and experimental stimuli were the same as in the previous experiment, with the exception that the high- and low-density words were presented in two different blocks. Half of the low-density and half of the high-density nonwords were randomly selected to be presented in each block, so that the neighborhood-blocking manipulation concerned only the word stimuli. The two conditions of the neighborhood frequency variable were, of course, present in each block. In addition, 64 words and 64 nonwords of a length comparable to that of the experimental stimuli were constructed to act as prolonged practice trials for each blocking condition. Half of these words had small neighborhoods and preceded the block of experimental words with small neighborhoods. The other 32 words and 32 nonwords had large neighborhoods and preceded the block of experimental words with large neighborhoods. Half of the participants received the small-neighborhood block first and then the large-neighborhood block. The other half of the participants received the blocks in the opposite order.

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[3] Johnson and Pugh (1994) also used a presentation blocked by neighborhood density. However, in their experiments both the word and the nonword stimuli were blocked together by density. With respect to hypothetical criterion manipulations in the multiple read-out model (Grainger & Jacobs, 1996), the critical manipulation is to block the density of word stimuli while maintaining a mixed-density nonword background. Thus, in Experiment 3 only the word stimuli were blocked by density. The results obtained by Johnson and Pugh are commented on in the General Discussion.

Table 4
Mean Reaction Times (RTs; in Milliseconds) and Errors (in Percentages) for Words and Nonwords in Experiment 3

Neighborhood density	Words					Nonwords	
	No HF neighbors		HF neighbors		RT difference		
	RT	Error (%)	RT	Error (%)		RT	Error (%)
Low	677	2.6	719	4.0	−42	806	4.8
High	659	2.9	701	5.6	−42	854	8.4
RT difference	18		18			−48	

Note. HF = higher frequency.

Procedure. This was identical to that of Experiment 2 except that the experiment was divided into a series of four parts (two experimental blocks plus the corresponding practice trials).

Results and Discussion

The mean lexical-decision time and error rate for the stimuli in each experimental condition are shown in Table 4. For words, incorrect responses (4.2%) and RTs shorter than 300 ms or longer than 1,500 ms (0.9% of the data) were omitted from the latency analysis. As in Experiment 2, mean RTs and error data were submitted to separate ANOVAs, with neighborhood frequency and neighborhood density as within-subjects but between-items variables. For nonwords, incorrect responses (6.3%) and RTs shorter than 300 ms or longer than 2,000 ms (0.7% of the data) were omitted from the latency analysis.[4] Mean RTs and error data were then submitted to separate ANOVAs, with neighborhood density (low vs. high) as a within-subjects but between-items variable.

The ANOVA on latency data for words revealed a main effect of neighborhood frequency, $F_1(1, 38) = 59.16$, $MSE = 1{,}173$, $p < .001$; $F_2(1, 59) = 9.71$, $MSE = 5{,}821$, $p < .005$, in which words without higher frequency neighbors were responded to faster than those with higher frequency neighbors.[5] The main effect of neighborhood density was also reliable in the analysis by subjects, $F_1(1, 38) = 4.62$, $MSE = 2{,}738$, $p < .05$; $F_2(1, 59) = 2.22$, $MSE = 5{,}821$, $p = .14$. Words from large neighborhoods were responded to faster than words from small neighborhoods. The interaction between neighborhood density and neighborhood frequency (both Fs < 1) was not statistically reliable. The ANOVA on error rates for words yielded a significant effect only of neighborhood frequency, $F_1(1, 38) = 8.59$, $MSE = 23$, $p < .01$; $F_2(1, 59) = 4.68$, $MSE = 33$, $p < .04$: Words without higher frequency neighbors were identified better than those with higher frequency neighbors. Neither the main effect of neighborhood density, $F_1(1, 38) = 2.20$, $MSE = 22$; $F_2(1, 59) = 1.19$, $MSE = 33$, nor the interaction between neighborhood density and neighborhood frequency (both Fs < 1) was statistically reliable.

The ANOVA on RTs for nonwords showed that the main effect of neighborhood density was reliable, $F_1(1, 39) = 52.37$, $MSE = 887$, $p < .001$; $F_2(1, 52) = 9.27$, $MSE = 3{,}956$, $p < .003$: Nonwords from low-density neighborhoods were responded to faster than nonwords from high-density neighborhoods. Also, the ANOVA on error rates showed that nonwords from low-density neighborhoods were responded to more accurately than those from high-density neighborhoods, $F_1(1, 39) = 11.90$, $MSE = 22$, $p < .002$; $F_2(1, 52) = 2.53$, $MSE = 67$, $p = .1179$.

Experiment 3 demonstrated, once again, a robust inhibitory effect of neighborhood frequency, thus replicating the results obtained in the previous experiments as well as in the prior studies of Grainger and his colleagues (Grainger, 1990; Grainger & Seguí, 1990; Grainger et al., 1989, 1992). Also, the density-blocking manipulation allowed us to obtain a facilitatory effect of neighborhood density that was robust in the analysis by subjects. An 18-ms facilitation for words from high-density neighborhoods was obtained in this experiment compared with the nonsignificant 7-ms effect observed in Experiment 2.

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[4] Because of an error, the data from five nonwords were not collected by the program. Because these five nonwords were always the same, from the high-density neighborhood condition, another five nonwords chosen ramdomly were skipped from the analysis.

[5] A word (i.e., *lema*) with a large neighborhood and higher frequency neighbors showed a high percentage of errors (43%); it is possible that this was because a similar nonword (i.e., *plema*) was included in the preceding practice block, because *lema* did not produce such high errors in any of the other experiments. Before removing the data corresponding to this word, the mean RT for that condition was 700 ms, and the mean percentage of errors was 8.5%. The pattern of results of the latency data without removing that word was identical to that shown in the text. The main effect of neighborhood frequency was reliable, $F_1(1, 38) = 59.27$, $MSE = 1{,}169$, $p < .001$; $F_2(1, 60) = 10.67$, $MSE = 5{,}812$, $p < .005$, as was the main effect of neighborhood size in the analysis by subjects, $F_1(1, 38) = 4.65$, $MSE = 2{,}731$, $p < .05$; $F_2(1, 60) = 1.90$, $MSE = 5{,}812$. The interaction between neighborhood size and neighborhood frequency (both Fs < 1) was not statistically reliable. As for the error rates, without removing the word, there was a main effect of neighborhood frequency, $F_1(1, 38) = 21.19$, $MSE = 23$, $p < .001$; $F_2(1, 60) = 4.84$, $MSE = 79$, $p < .04$. The main effect of neighborhood size was also reliable in the by-subjects analysis, $F_1(1, 38) = 9.88$, $MSE = 22$, $p < .004$; $F_2(1, 60) = 2.20$, $MSE = 79$, as was the interaction between those variables, $F_1(1, 38) = 6.12$, $MSE = 28$, $p < .05$; $F_2(1, 60) = 1.64$, $MSE = 79$.

According to the multiple read-out model (Grainger & Jacobs, 1996), blocking the word stimuli by neighborhood density allows participants to adjust the Σ response criterion. With only high-density words in the list, the Σ criterion can be lowered, thus producing a global decrease in RTs to word stimuli and an increase in the false-positive error rate (errors to nonwords). However, because words with higher frequency neighbors also tend to generate higher levels of global lexical activity than words without higher frequency neighbors, the robust inhibitory effect of neighborhood frequency obtained in Experiment 3 appears to contradict this theoretical position. The simulation study presented below demonstrates that a critical value of the Σ criterion can be found that discriminates between increasing neighborhood density and the presence or absence of higher frequency neighbors, thus allowing the multiple read-out model to capture this pattern of effects.

The error rates in Experiment 3 are comparable to those obtained in Experiment 2 and in other experiments that have demonstrated inhibitory neighborhood-frequency effects (e.g., Grainger et al., 1989; Huntsman & Lima, 1996). These error rates are much lower than those obtained in lexical-decision experiments showing strong facilitatory effects of neighborhood density in the absence of inhibitory effects of neighborhood frequency (e.g., Andrews, 1989, 1992; Forster & Shen, 1996; Sears et al., 1995). Because the average RTs in Forster and Shen's (1996) and Sears et al.'s (1995) lexical-decision experiments were faster than those obtained in the present experiments (see also Huntsman & Lima, 1996), it appears that participants in the former studies were stressing speed over accuracy in their lexical-decision performance. In the multiple read-out model, stressing speed over accuracy leads to increased use of the Σ criterion, thus providing one possible explanation for such discrepancies in the experimental literature.

For nonwords, we found the usual inhibitory effect of neighborhood density in the RT data and in the error rates, replicating the results obtained in previous studies (e.g., Andrews, 1989; Coltheart et al., 1977; Forster & Shen, 1996; Sears et al., 1995). The presence of inhibitory effects of neighborhood density in the error rates for nonword stimuli (absent in Experiment 2) was another clear prediction of the multiple read-out model that finds confirmation in the experimental data. In the following simulation study, we tested the model's ability to accommodate the variations across Experiments 1–3 in the effects of neighborhood density and frequency on the mean RT of correct responses to word stimuli.

Simulation Study

The multiple read-out model (Grainger & Jacobs, 1996) explains the increase in facilitatory effects of neighborhood density on correct RTs to word stimuli across Experiments 1–3 as the result of increased use of the Σ criterion compared with the M criterion in generating a correct positive response. Because perceptual-identification tasks such as the progressive-demasking task used in Experiment 1 explicitly require a unique identification response, participants cannot base their response on summed lexical activity. On the other hand, as argued above, a positive lexical-decision response can be made on this basis, and the resulting pattern of effects is likely to reflect a combination of unique word identification and summed lexical activity. The density-blocking manipulation of Experiment 3 allowed a greater reliance on the Σ criterion relative to the M criterion, in the blocked high-density condition. This was tested in a series of three simulations involving increased use of the Σ criterion.

Method

Design and materials. The design was the same as that used in the previous experiments, and the stimuli were the same as the word stimuli tested in Experiments 1–3.

Procedure. Spanish four- and five-letter lexica were constructed for the present simulations. All four-letter Spanish words with frequencies of at least two per million were included ($N = 877$), and their printed frequency was transformed into resting-level activation following McClelland and Rumelhart (1981). The five-letter lexicon was composed of all five-letter Spanish words with a frequency of four or more per million ($N = 974$). Exactly the same parameter settings as were used in the interactive simulations (i.e., with word–letter feedback) reported by Jacobs and Grainger (1992) were adopted here. All the word stimuli tested in the present experiments were presented to the model on 20 occasions, and the number of cycles to reach a prespecified noisy decision criterion was recorded. The number of cycles was then averaged over the 20 simulation runs for each experimental condition. One simulation was run with only the M (word unit activity) criterion. Two further simulations were run with both the M and the Σ criteria, with increasingly lower values of the latter.

Results and Discussion

In Table 5, the average number of cycles to reach a positive response criterion (either M or Σ) is given for each experimental condition for each of the simulations. One can

Table 5
Mean Number of Cycles to Reach a Positive Response Criterion for the Words in Each Experimental Condition in Three Simulations Run on the Multiple Read-Out Model With Decreasing Values of the Σ Criterion

	Neighborhood frequency		
Neighborhood density	No HF neighbors	HF neighbors	Difference
Simulation 1			
Low	17.8	19.0	−1.2
High	18.2	19.2	−1.0
Difference	−0.4	−0.2	
Simulation 2			
Low	17.9	19.2	−1.3
High	18.0	18.9	−0.9
Difference	−0.1	0.3	
Simulation 3			
Low	18.0	18.9	−0.9
High	17.5	18.6	−1.1
Difference	0.5	0.3	

Note. HF = higher frequency.

immediately see from Table 5 that the model captures the inhibitory neighborhood effects observed in the progressive-demasking task when only the M criterion was adopted (Simulation 1). Increasing the use made of the Σ criterion in the following simulations (Simulations 2 and 3) caused a gradual decrease in average RT and, of more importance, produced a change in the pattern of neighborhood effects. Although the inhibitory effects of neighborhood frequency remained fairly stable across simulations, the effects of neighborhood density switched from inhibition to facilitation.

To provide a quantitative fit between the simulation and the experimental data, the effect sizes were calculated from the means per experimental condition (i.e., neighborhood-density effect for words with no higher frequency neighbors, neighborhood-density effect for words with higher frequency neighbors, neighborhood-frequency effect for low-density words, neighborhood-frequency effect for high-density words) and were expressed as a percentage of the average RT of the two conditions used to calculate the effect size. Using the percent net effects solved the problem of comparing effect sizes obtained in paradigms with very different average RTs, and also provided one solution to the problem of comparing empirical and simulation data. The resulting 12 data points (4 effects per experiment) correlated very highly with the effect sizes produced in the simulations ($r = .92$), and the linear regression ($y = 1.12x - .49$, where y represents the empirical effect size and x represents the simulation effect size) showed that predicted effect sizes were of the same order of magnitude as the observed effects. Furthermore, when absolute RTs were used to fit the model data (Simulations 2 and 3) to the lexical-decision data (means per condition), the resulting correlation was .99 ($N = 8$).

Thus, one can conclude that the results obtained in the progressive-demasking task and the two lexical-decision experiments were well captured by simulations run on the multiple read-out model. In the following experiments, we tested the same set of word stimuli in two other paradigms, speeded naming and semantic categorization, which were previously used to examine the effects of orthographic neighborhood in visual word recognition.

Experiment 4: Naming

In a recent study examining the factors that influence speeded word naming in English, Treiman et al. (1995) found little effect of neighborhood density over and above the effects of phonologically defined variables (onset and rime consistency). Because the printed frequency of orthographic neighbors was not examined in that study, it may be the case that stronger effects of orthographic neighborhood on word naming would appear with higher frequency neighbors. The Spanish words tested in the present experiments all had consistent pronunciations and were controlled for syllable frequency. Thus, any effects of orthographic neighborhood in the present experiments cannot be attributed to variation in phonological consistency.

Method

Participants. Twenty students from introductory psychology courses at the Universitat de València took part in the experiment for course credit. None of them had taken part in the previous experiments.

Design and materials. The design and stimuli were the same as those in Experiment 1.

Procedure. The computer and voice-activated key were the same as those used in Experiment 1. Standard speeded-naming procedures were applied. Words were presented one at a time in uppercase in the center of the screen, and participants were instructed to read the words aloud as rapidly and as accurately as possible. Both mispronunciations and hesitations were considered errors. Each participant received 12 practice trials prior to the 64 experimental trials. The whole session lasted approximately 7 min.

Results and Discussion

The mean RT and error rate for the words in each experimental condition are presented in Table 6. Incorrect responses (0.3%) and RTs shorter than 300 ms or longer than 800 ms (1.5% of the data) were excluded from the latency analysis. Because very few errors were recorded, only response latency is considered. Mean RTs were submitted to two ANOVAs, with neighborhood frequency and neighborhood density as within-subjects but between-materials variables.

The ANOVA on the naming latency data did not yield any significant main effects of neighborhood frequency, $F_1(1, 19) = 3.04$, $MSE = 216$, $p < .10$; $F_2 < 1$, or neighborhood density, $F_1(1, 19) = 2.27$, $MSE = 479$; $F_2(1, 60) = 1.53$, $MSE = 560$. However, the interpretation of both effects must be tempered in light of the reliable interaction between the two variables, $F_1(1, 19) = 16.06$, $MSE = 279$, $p < .001$; $F_2(1, 60) = 5.90$, $MSE = 560$, $p < .02$. This interaction reflects the fact that effects of neighborhood density were facilitatory for words with higher frequency neighbors, $F_1(1, 19) = 19.20$, $MSE = 260$, $p < .001$; $F_2(1, 60) = 6.72$, $MSE = 560$, $p < .02$, but not for words without higher frequency neighbors, $F_1(1, 19) = 1.16$, $MSE = 498$, $F_2 < 1$. It also reflects the fact that the effects of neighborhood frequency were inhibitory for low-density words, $F_1(1, 19) = 16.03$, $MSE = 267$, $p < .002$; $F_2(1, 60) = 5.33$, $MSE = 560$, $p < .03$, whereas there was a slight facilitatory trend for high-density words, $F_1(1, 19) = 3.76$, $MSE = 228$, $p < .07$; $F_2(1, 60) = 1.27$, $MSE = 560$.

Table 6
Mean Reaction Times (RTs; in Milliseconds) in Experiment 4

	Neighborhood frequency		
Neighborhood density	No HF neighbors	HF neighbors	RT difference
Low	528	549	−21
High	536	527	9
RT difference	−8	22	

Note. HF = higher frequency.

In this experiment, there was an inhibitory effect of neighborhood frequency for words from small neighborhoods. Apparently, the speeded naming of isolated words (mean $N = 2.1$) is affected by inhibition from othographically similar higher frequency words. It seems that the more isolated a word is in terms of its orthographic neighborhood, the more the speed of the naming process depends on the activation level of the stimulus word itself (see Grainger, 1990). Sears et al. (1995, Experiment 2) also found a similar inhibition for low-frequency words from low-density neighborhoods. Additionally, there was a facilitatory effect of neighborhood density for words with higher frequency neighbors similar to that obtained by Sears et al. in their Experiment 2 (although Experiment 4 in the same study did not produce this pattern).

These results suggest that orthographic neighborhood has a significant influence on word-naming latencies over and above any effects due to the consistency of sublexical spelling-to-sound correspondences (Treiman et al., 1995). These results were obtained in Spanish, a language with highly consistent spelling-to-sound correspondences, and with bisyllabic word stimuli that were carefully controlled for syllable frequency. However, the pattern of orthographic neighborhood effects obtained in word naming is quite different from that obtained in either of the two lexical-decision experiments or the progressive-demasking task. The naming RTs showed an interaction between neighborhood density and neighborhood frequency which was not present in the first three experiments. We interpret this different pattern of effects in terms of the influence of pronunciation-specific processes in word naming.

The effects of orthographic neighborhood on word-naming performance observed in Experiment 4 can be easily accommodated by analogy models of word naming (Glushko, 1979; Kay & Marcel, 1981; Taraban & McClelland, 1987). More precisely, in Taraban and McClelland's (1987) model, the quality of the synthesized pronunciation is a function of the number and the frequency of all activated word stimuli that share pronunciation (articulatory) units with the target word. According to this analysis of word naming, there are precisely two situations that produce fast RTs in the speeded-naming task: (a) when a single word rapidly reaches a high activation level (i.e., fast unique word identification), and (b) when unique word identification is slow but many other strongly activated words contribute to articulatory unit activity. Our theoretical analysis of performance in the progressive-demasking task (Experiment 1) can help us isolate these two conditions. Low-density words with no higher frequency neighbors suffered the least lexical inhibition from simultaneously activated word units and gave rise to the fastest RTs in the progressive-demasking task. The high-density words with higher frequency neighbors, on the other hand, suffered the most lexical inhibition from simultaneously activated word units and therefore gave rise to the slowest RTs. It is these two extreme conditions that should give the fastest RTs in the naming task. Indeed, the fastest naming latencies in the present experiment were given to (a) low-density words with no higher frequency neighbors (528 ms), and (b) high-density words with higher frequency neighbors (527 ms).

Experiment 5: Semantic Categorization

In a recent article, Forster and Shen (1996) tested for effects of neighborhood density and neighborhood frequency in both the lexical-decision and semantic-categorization tasks. Effects of neighborhood density significantly interacted with task. Facilitatory effects were observed in the lexical-decision task, but these effects disappeared in the semantic-categorization task. The effects of neighborhood frequency were not robust in either task. Because, according to Forster and Shen, semantic categorization requires unique word identification, the absence of inhibitory neighborhood effects in this task is critically damaging for the lexical-inhibition hypothesis implemented in the interactive-activation model (McClelland & Rumelhart, 1981) and in its successors (Jacobs & Grainger, 1992; Grainger & Jacobs, 1996). One problem with Forster and Shen's study that was addressed in Experiment 5, was the relatively weak manipulation of number of orthographic neighbors (maximum $N = 4$) in their experiment. The progressive-demasking results of our Experiment 1 indicate that maximum inhibition occurs in high-density words (average $N = 7.7$, see Table 1) having higher frequency neighbors. Thus, Experiment 5 provides a further examination of orthographic neighborhood effects in the semantic-categorization task with a more extreme manipulation of neighborhood density.

Method

Participants. A total of 46 students drawn from the same population as in the previous experiment participated in this experiment. None of them had taken part in the previous experiments.

Design and materials. The design was the same as that in Experiment 1. A total of 122 words were used as stimuli: 61 animal names and 61 nonanimal names. The nonanimal names were drawn from the set of words used in the previous experiments; the set included only 3 words closely related to animals (*garra, pardo,* and *rapaz*). The animal names were new words, which were four and five letters long to match the length of the nonanimal names. The animal names included mammals, birds, reptiles, amphibians, insects, and fish, but excluded humans. Participants were explicitly instructed about the type of words they would see.

Procedure. The procedure was similar to that in Experiment 2, except that only word trials were presented. The task was to press one of two keys on the keyboard to indicate whether the word was an animal name. Each participant received 24 practice trials (12 animal words and 12 nonanimal words) prior to the 122 experimental trials (61 animal word and 61 nonanimal word trials randomly presented).

Results and Discussion

The mean RT and error rate for the nonanimal words in each experimental condition are presented in Table 7. These were the same set of nonanimal words used in the prior experiments. Incorrect responses (2.1%) and RTs shorter than 300 ms or longer than 1,500 ms (less than 1% of the

Table 7
Mean Reaction Times (RTs; in Milliseconds) and Errors (in Percentages) for Words in Experiment 5

	Neighborhood frequency				
	No HF neighbors		HF neighbors		
Neighborhood density	RT	Error (%)	RT	Error (%)	RT difference
Low	727	3.3	713	0.7	14
High	706	3.1	742	3.1	−36
RT difference	21		−29		

Note. HF = higher frequency.

data) were excluded from the latency analysis. Mean RTs and error data were submitted to separate ANOVAs, with neighborhood frequency and neighborhood density as within-subjects but between-materials variables.

The ANOVA on the latency data showed a significant inhibitory effect of neighborhood frequency in the by-subjects analysis, $F_1(1, 45) = 4.86$, $MSE = 1{,}071$, $p < .05$; $F_2 < 1$. The neighborhood-density effect was not significant in either the subject or the item analysis, $F_1(1, 45) = 1.07$, $MSE = 723$; $F_2 < 1$. Finally, the interaction between both variables was significant, $F_1(1, 45) = 39.95$, $MSE = 707$, $p < .0001$; $F_2(1, 57) = 4.02$, $MSE = 2{,}767$, $p < .05$, reflecting the fact that the effects of neighborhood frequency were inhibitory for high-density words, $F_1(1, 45) = 29.05$, $MSE = 992$, $p < .001$; $F_2(1, 57) = 4.10$, $MSE = 2{,}767$, $p < .05$, but not for low-density words, which showed a facilitatory trend that was significant in the analysis by subjects, $F_1(1, 45) = 5.85$, $MSE = 785$, $p < .05$; $F_2 < 1$. In addition, the effects of neighborhood density were inhibitory for words with higher frequency neighbors only in the analysis by subjects, $F_1(1, 45) = 29.05$, $MSE = 992$, $p < .001$; $F_2(1, 57) = 3.37$, $MSE = 2{,}767$, $p < .08$, and were facilitatory for words without higher frequency neighbors also only in the analysis by subjects, $F_1(1, 45) = 11.45$, $MSE = 850$, $p < .005$; $F_2 < 1$.

The ANOVA on error rates yielded a significant interaction between neighborhood density and frequency only in the analysis by subjects, $F_1(1, 45) = 5.32$, $MSE = 13$, $p < .05$; $F_2 < 1$, reflecting a facilitatory trend of neighborhood frequency for low-density words in the analysis by subjects, $F_1(1, 45) = 14.32$, $MSE = 9$, $p < .001$; $F_2(1, 57) = 1.46$, $MSE = 30$, and an inhibitory trend of neighborhood density for words with higher frequency neighbors also only in the analysis by subjects, $F_1(1, 45) = 8.00$, $MSE = 15$, $p < .01$; $F_2(1, 57) = 1.30$, $MSE = 30$. The other simple effects were not significant.

The results of the semantic-categorization task again showed an inhibitory effect of neighborhood frequency in the case of words with many orthographic neighbors. It should be noted that this was precisely the condition that gave the slowest RTs in the progressive-demasking paradigm. According to our analysis of performance in this task, the high-density words with higher frequency neighbors represented the case with the highest levels of lexical inhibition in the present set of stimuli, and therefore produced the slowest unique identification times.

The results of Experiment 5 show a nonsignificant (by-items) facilitatory effect of neighborhood frequency in low-density words, which is comparable to that observed by Forster and Shen (1996). The comparable means from Forster and Shen's study are given by the average of the one, two, and three to four neighbor neighborhood-density conditions (because our low-neighborhood-density condition ranged from one to three neighbors). The mean RT was 644 ms for words without higher frequency neighbors and 639 ms for words with higher frequency neighbors, giving a nonsignificant 5-ms facilitation in their study. As noted above, our results show that inhibitory effects of neighborhood frequency do appear in the semantic-categorization task in words with larger orthographic neighborhoods ($N > 5$).

Although the semantic-categorization data confirm the presence of inhibitory effects of higher frequency neighbors (at least in the high-density condition), the overall pattern varied considerably with respect to the pattern obtained in the four previous experiments. Most important is the different pattern of effects observed in the progressive-demasking and semantic-categorization tasks. Effects of neighborhood frequency and neighborhood density interacted in the semantic-categorization task but did not interact in the progressive-demasking task. Such divergences in performance in these two tasks suggest that unique word identification was not the only mechanism generating responses in either or both of these tasks. Some alternative mechanisms are proposed in the General Discussion, following a joint analysis of all five experiments that examines more closely the similarities and differences in these data patterns.

Global Analyses of Experiments 1–5

Table 8 presents the Pearson correlations between mean RT per item ($N = 61$)[6] obtained in the different tasks used in Experiments 1–5. Obviously the two lexical-decision experiments are most strongly correlated (.72). What is more interesting, however, is the very strong correlation between the progressive-demasking task of Experiment 1 and the lexical-decision task of Experiment 2 (.57). This point is extremely important with respect to recent criticisms of inhibitory effects of orthographic neighborhood obtained with the progressive-demasking task (e.g., Forster & Shen, 1996). RTs in the semantic-categorization task correlate significantly with all tasks except word naming. Word-naming RTs correlate significantly only with RTs in the two lexical-decision experiments.

The matrix in Table 8 indicates a substantial degree of correlation for several pairs of tasks. This suggests that there may be some underlying dimensions that could more

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[6] Sixty-four words were used in the different experiments, except in the semantic-categorization task, in which only 61 words were tested, because 3 of the 64 words were closely related to animals. Because of that, correlations between tasks are based on those 61 words.

Table 8
Pearson Correlations Coefficients Among the Experimental Tasks

Task	PDT	LDT	LDT(b)	Naming
LDT	.57**			
LDT(b)	.44**	.72**		
Naming	.07	.32**	.36**	
Sem-cat	.29*	.34**	.37**	.25

Note. PDT = progressive-demasking task; LDT = lexical-decision task; LDT(b) = lexical-decision task with density blocking; Sem-cat = semantic-categorization task.
$^*p < .05$. $^{**}p < .01$.

compactly explain the overall variance in the data of the present study. Factor analysis has been used in many psychological studies to identify underlying dimensions. Table 9 presents a summary of a principle-components factor analysis with varimax rotation performed on the interrelation among the mean RTs to words in the five experiments. Three orthogonal factors emerged from the analysis. Factor 1 accounted for 52% of the variance in the data; Factor 2 accounted for 19%, followed by 15% for Factor 3. The progressive-demasking task and the two lexical-decision experiments were clearly the three highest loaded variables on Factor 1. The second factor included the naming task, and the third factor included the semantic-categorization task.

The immediately obvious interpretation of these three factors is in terms of the distinction between orthographic (Factor 1), phonological–articulatory (Factor 2), and semantic (Factor 3) processing. The distribution of the loadings of these three factors suggests that each task was principally sensitive to one type of information, but was also influenced to a lesser extent by the two other types of information. The negative weighting of Factor 2 (phonological–articulatory codes) in the progressive-demasking task suggests that this factor is picking up the contribution of many simultaneously activated word units to articulatory output activity (see our analogy-based interpretation of the word-naming results above). The negative weighting therefore reflects the higher levels of lexical inhibition provoked by many simultaneously activated word units when unique word identification is required. Moreover, this interpretation can also account for the relatively high positive weighting of Factor 2 in the density-blocked lexical-decision experiment, because many simultaneously activated word units produce higher global levels of lexical activity.

Table 9
Factorial Analysis for the Three Factors Corresponding to Reaction Time in the Experimental Tasks

Task	Factor 1	Factor 2	Factor 3
PDT	.82	−.18	.15
LDT	.90	.16	.12
LDT(b)	.80	.31	.19
Naming	.15	.95	.11
Sem-cat	.21	.12	.97

Note. PDT = progressive-demasking task; LDT = lexical-decision task; LDT(b) = lexical-decision task with density blocking; Sem-cat = semantic-categorization task.

General Discussion

The main goal of the present research was to compare effects of orthographic neighborhood in the different experimental paradigms typically used to investigate visual word recognition. Inhibitory effects of both neighborhood frequency and density appeared in the progressive-demasking task (Experiment 1). The inhibitory effects of neighborhood frequency remained robust in the lexical-decision task (Experiments 2 and 3). These effects were also observable, albeit to a lesser degree, in the naming and semantic-categorization tasks (Experiments 4 and 5). In the naming task, only low-density words showed an inhibitory effect of neighborhood frequency, whereas in the semantic-categorization task this was true only for the high-density words. The inhibitory trend of neighborhood density observed in the progressive-demasking task turned to facilitation in the lexical-decision task (and was robust only with the density-blocking manipulation). Facilitatory effects of density were also observed in the naming task, but only for words with higher frequency neighbors. On the other hand, there was a trend toward an inhibitory effect of neighborhood density in words with higher frequency neighbors in the semantic-categorization task.

The multiple read-out model of orthographic processing in visual word recognition (Grainger & Jacobs, 1996) captures the variations in effects of orthographic neighborhood across Experiments 1–3. The simulation study demonstrated that increasing the use made (lowering the critical value) of a response criterion on the basis of summed lexical activity (the Σ criterion) transformed the inhibitory effects of neighborhood density into facilitatory effects. The multiple read-out model implements the lexical-inhibition hypothesis of interactive-activation networks (McClelland & Rumelhart, 1981). In this framework, the orthographic neighbors of a target word are the most activated of all words activated by the target and therefore produce the greatest lexical inhibition during target-word processing. However, the same simultaneously activated word units that provoke inhibition on the target word when unique word identification occurs can produce exactly the opposite effect when participants are able to respond correctly before identifying the target word. This is the case when participants base their positive responses on total lexical activity rather than on unique word identification in the lexical-decision task.

Strategic Influences on Effects of Orthographic Neighborhood

The present series of experiments included a density-blocking manipulation intended to exaggerate the facilitatory effects of the number of orthographic neighbors in the lexical-decision task. Within the framework of the multiple read-out model, it was predicted that blocking word stimuli by neighborhood density (high or low), while having both high- and low-density nonwords in each block, should allow increased use of the Σ criterion in the blocked high-density condition. This should therefore enhance the facilitatory effects of neighborhood density on correct responses to word stimuli while increasing the number of false-positive errors to high-density nonword stimuli. Both predictions were supported by the experimental data.

Johnson and Pugh (1994) had previously performed a density-blocking manipulation in the lexical-decision task. However, their density blocking involved both the word and the nonword stimuli. In other words, high-density words were presented mixed with high-density nonwords in one list, and low-density words were mixed with low-density nonwords in a separate list. This type of blocking manipulation produced very different results from those obtained in the present study. (In what follows, we consider only the pronounceable nonword condition tested by Johnson & Pugh, 1994.) This distinct pattern of effects is, however, exactly what one would predict on the basis of strategic influences on use made of the Σ criterion in the multiple read-out model. High-density nonwords generate more global lexical activity than low-density nonwords. The same is true for word stimuli, but to a much lesser extent than for nonwords, because the activation level of the stimulus word itself contributes considerably to overall summed lexical activity in the model. Thus, blocking low-density words with low-density nonwords allows a much greater use of the Σ criterion (the distributions of summed lexical activity for words and nonwords are further apart) than when high-density words are blocked with high-density nonwords. This therefore gives rise to a pattern of results that is the direct opposite of that obtained in the present study. Facilitatory effects of neighborhood density appeared only in the mixed-density condition of Johnson and Pugh's study. On the other hand, neighborhood density had an inhibitory influence in the blocked presentation conditions. Such inhibitory effects of neighborhood density arise when use of the Σ criterion is made impossible by the very high levels of global activity generated by the nonword stimuli.

The present study therefore suggests that effects of orthographic neighborhood in the various tasks used to study visual word recognition can vary from being facilitatory to being inhibitory as a function of the extent to which participants base their responses on unique word identification. Grainger and Jacobs (1996) have provided further evidence in favor of this approach by systematically varying nonword context and task instructions in a lexical-decision experiment investigating effects of orthographic neighborhood. Our results showed that as wordlikeness of nonword stimuli decreased and the task instructions stressed speed over accuracy, inhibitory effects of neighborhood frequency diminished. In a similar vein, Sears et al. (1995) also increased how wordlike their nonwords were (by using nonwords with many word neighbors) in an attempt to provoke an inhibitory effect of neighborhood frequency in the lexical-decision task (see also Forster & Shen, 1996). Neither Sears et al. nor Forster and Shen (1996) observed such an effect, and thereby did not replicate the numerous studies purporting to do so (including the present one). Grainger and Jacobs have shown, however, that the high-density nonwords used by Sears et al. do not generate high enough levels of summed lexical activity in the multiple read-out model to totally prohibit use of the Σ criterion.

Nevertheless, the studies by Sears et al. (1995) and Forster and Shen (1996) highlighted the difficulty of establishing in exactly which conditions the higher frequency neighbors of a given stimulus word will produce detrimental performance relative to words without such higher frequency neighbors. There are a number of factors that have not been systematically controlled in the experiments investigating effects of orthographic neighborhood, such as morphological status (simple or complex), syntactic category (or at a more general level, closed-class vs. open-class words), phonological neighborhood, syllable frequency (see Carreiras et al., 1993; Perea & Carreiras, in press), to name but a few factors that might turn out to be important. Concerning the effects of phonological neighborhood, as previously noted in the *Results and Discussion* section of Experiment 2, in languages with fairly regular spelling-to-sound correspondences such as Spanish and French, the orthographic neighbors of a given target word are generally also phonological neighbors. This is not the case in English where a given spelling sequence can often be given different pronunciations. Thus, the word *deaf* has at least two higher frequency neighbors (*dear* and *leaf*) with a different vowel sound. This is important in light of recent work on phonological influences in visual word recognition, showing that phonological codes are generated very rapidly from a pronounceable string of letters (Ferrand & Grainger, 1992, 1993; Perfetti & Bell, 1991; Ziegler & Jacobs, 1995). How such phonological inconsistency in the target word's orthographic neighborhood affects purely orthographic effects remains to be clarified (see Pugh, Rexer, & Katz, 1994, for a demonstration of the effects of phonological inconsistency in the lexical-decision task). What is important here is that not controlling for such phonological neighborhoods may contaminate the effects of orthographic neighborhood in languages, such as English, with relatively inconsistent spelling-to-sound correspondences.

Cross-Task Comparisons

One major prediction resulting from the above theoretical analysis is that inhibitory effects of orthographic neighborhood should predominantly arise in experimental conditions encouraging unique word identification. In line with this reasoning, the majority of studies to date that have investigated effects of orthographic neighborhood using perceptual-identification paradigms (Bozon & Carbonnel, in press; Grainger & Jacobs, 1996; Grainger & Seguí, 1990; Snodgrass & Mintzer, 1993; Van Heuven et al., 1996), including the present Experiment 1, have shown inhibition. These perceptual-identification paradigms all require the unique identification of an orthographic form (an ordered sequence of letters). It is the process of isolating a unique whole-word orthographic representation in memory that is hypothesized to be sensitive to the simultaneous activation of orthographically similar words.

Within the framework of the multiple read-out model (Grainger & Jacobs, 1996), perceptual-identification tasks are thought to represent the "purest" measure of time to identify a whole-word orthographic form. Although data-limited versions of such tasks are possibly subject to guessing strategies, we think that the progressive-demasking variant provides an excellent means of avoiding this problem. If participants were to guess in this task, not only would error rates be much higher, but one would also predict that neighborhood frequency would exert a facilitatory effect on RTs. If participants tried to guess what the stimulus word was and to respond as soon as any word came to mind, then low-frequency stimuli with high-frequency neighbors would be responded to more rapidly than low-frequency stimuli without high-frequency neighbors.

Within this theoretical framework, any divergence in the pattern of neighborhood effects obtained in other experimental tasks can be interpreted in terms of processes that are specific to that particular task. In the preceding discussion, variations in the effects of orthographic neighborhood in the two lexical-decision experiments were assigned to the operation of a mechanism whereby a positive lexical-decision response can be triggered when a critical level of global lexical activity is reached (the Σ criterion). In what follows, we examine some possible task-specific mechanisms that may operate in the word-naming and semantic-categorization tasks.

In our discussion of the results of our factor analysis across all tasks (Table 9), we proposed that the two factors isolating the word-naming (Factor 2) and semantic-categorization (Factor 3) tasks reflect the operation of phonological–articulatory and semantic processing, respectively. In line with this reasoning, we presented an interpretation of the word-naming data based on an analogy model where speed of pronunciation is determined by activity in articulatory output units. In the specific model of word naming we discussed, whole-word orthographic units send activation to articulatory output units (see also Grainger & Ferrand, 1996). In this way, articulatory output (and therefore naming latency), is sensitive to orthographic neighborhoods. As argued in the *Results and Discussion* section of Experiment 4, articulatory unit activity rises rapidly either when a single word unit rises rapidly in activation (the small neighborhood, no high-frequency neighbor condition), or when many word units rapidly attain high activation levels (the large neighborhood, high-frequency neighbor condition). The latter mechanism is valid only to the extent that the simultaneously activated words share articulatory units (such as phonologically defined onset and rime units: Treiman et al., 1995) with the stimulus word, which was the case in the present experiments.

Following our explanation of the word-naming data, a model of performance in the semantic-categorization task would involve postulating a response criterion set on some dimension of semantic information (such as "animalness" in the present study). If all whole-word orthographic units that are activated by the stimulus send activation onto semantic units (as would be the case in cascaded interactive-activation networks), then the resulting effect on the critical semantic dimension for the task being performed will depend on the semantic descriptions of each simultaneously activated word.

However, in the present semantic-categorization experiment (see also Forster & Shen, 1996), critical words were nonexemplars of the target category and therefore generated negative responses. In line with the multiple read-out model of lexical decision (Grainger & Jacobs, 1996), such negative responses could be triggered by a temporal deadline. In other words, participants would respond *no* when a critical level of activity on the animalness dimension was not reached before a predetermined time limit. As in the lexical-decision model, the average value of this time criterion could vary as a function of the amount of animalness activity generated in early phases of processing. In such a model, the relative animalness of nonexemplar words would therefore influence negative semantic-categorization RTs. As a simple test of this hypothesis, we collected animalness ratings (on a 10-point scale: *not at all animal-like* to *very animal-like*) for the stimuli of the semantic-categorization task. These ratings correlated positively with both semantic-categorization RT ($r = .29$, $p < .05$) and error rate ($r = .28$, $p < .05$). Although these correlations are rather small (accounting for only 8% of the variance in the data), they do provide some initial support for the above analysis of the semantic-categorization task. Clearly, only future work devoted specifically to the semantic-categorization task will help clarify our understanding of performance in this task.

The conclusion we wish to draw here is that the diversity in the patterns of effects observed across experiments in the present study may reflect the fact that these different tasks are maximally sensitive to different types of variables. The global analysis across tasks suggests that this is indeed the case. Therefore, the moral of the present study is that one must take care in choosing the appropriate task to investigate a given variable. Of course, there is no theory-free way of determining whether a task is appropriate or not. The concept of functional overlap, as discussed by Jacobs and Grainger (1994) and Grainger and Jacobs (1996), provides one solution to this problem. If one has a precise model of the phenomenon under study (visual word recognition), a precise model of the task in question, and therefore a clear understanding of the functional overlap between the two, then the appropriateness of the task will be immediately evident.

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Appendix

Items Used in the Experiments (Nonexemplars in Experiment 5)

LD neighborhood						HD neighborhood					
HF neighbors			No HF neighbors			HF neighbors			No HF neighbors		
Word	*f*	No. of neighbors	Word	*f*	No. of neighbors	Word	*f*	No. of neighbors	Word	*f*	No. of neighbors
Words											
trono	8	3	vasco	4	2	barro	8	10	pila	6	8
dique	5	2	tesis	21	2	tubo	12	7	voto	12	10
vapor	14	1	bomba	5	3	velo	11	7	tropa	4	8
vicio	9	2	vigor	11	2	banco	16	6	pinar	5	8
buque	20	1	pesca	10	2	banda	8	8	pardo	7	12
clave	7	3	cauce	7	3	canal	6	7	garra	2	7
copla	9	3	culto	17	1	callo	16	11	cañón	9	6
auto	17	3	oral	5	1	alba	14	6	azar	18	7
olor	16	2	indio	5	1	hilo	10	10	altar	9	5
rubor	6	1	leve	8	1	sazón	10	6	ropa	19	6
rapaz	4	2	ruta	12	2	renta	9	6	ruso	8	7
yeso	13	3	joya	6	3	fino	12	7	seco	18	7
fase	13	3	fuga	12	1	solar	7	11	ruido	18	6
furia	7	2	cine	20	2	lema	7	8	limón	5	5
goro	3	3	leche	19	3	cerco	6	6	latín	15	5
magno	2	2	motor	9	1	manga	2	7	moral	21	5
LD neighborhood						HD neighborhood					
Nonwords											
edón		disón	buhe		rosol	vifo		sebio	pufa		casgo
adal		modín	onzo		tesva	tefa		veral	geba		sulva
etel		pegol	isfa		visfa	savo		muria	tuye		juelo
sadi		melún	rufe		ergia	pane		pavio	ceya		barpa
esfo		tapez	urle		fovor	sare		sivio	zobo		cibra
rege		cafor	rive		vesbo	tafo		mevia	pibo		nuego
maclo		dilor	hicro		cempo	sodia		cania	focha		manfo
tecro		orroz	murjo		harbo	cutil		racio	bruzo		lebra

Note. Nonwords were used in Experiments 2 and 3. LD = low density; HD = high density; HF = higher frequency; No. = number.

Received August 11, 1995
Revision received October 2, 1996
Accepted October 17, 1996 ■