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The effects of orthographic neighborhood in reading and laboratory word identification tasks: A review

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This paper reviews recent research on the effects of "orthographic neighbors" (i.e., words that can be created by changing one letter of the stimulus item, preserving letter positions, see Coltheart et al., 1977) on reading and laboratory word identification tasks. We begin this paper with a literature review on the two basic "neighborhood" effects (neighborhood size and neighborhood frequency). This review shows that the number of higher frequency neighbors is inhibitory in reading. We also examine the influence of orthographic structure in form- and repetition-priming effects, which again suggests that orthographic neighbors seem to play an inhibitory role in the selection process. Finally, we discuss the empirical evidence in the context of current models of visual word recognition and reading.

Keywords: Orthographic neighborhood, lexical access, eye movements

Current models of visual word recognition assume that a word's identification is preceded by the activation of a set of candidates visually similar to the stimulus item. This assumption raises the following questions: i) what are the relevant *dimensions of lexical similarity* that determine which representations are sufficiently similar to the sensory stimulus to be activated?, and ii) do similarly spelled words *facilitate* or *inhibit* the processing of a given word? These questions are critical for the success or failure of the models because they determine which words are considered similar and, therefore, the cohort of words

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activated by a particular input. Undoubtedly, patterns of lexical similarity may provide insights into the organization of lexical and orthographic knowledge (see Andrews, 1996, 1997, for reviews).

The effects of neighborhood structure on performance in visual word identification tasks have been a focus of considerable interest for the last years (especially after the publications of the papers of Andrews, 1989, and Grainger, O'Regan, Jacobs, & Seguí, 1989), since they provide valuable information into the processes underlying word recognition. In this light, a growing body of data indicate that, upon the visual presentation of a word, similarly spelled words (the so-called "orthographic neighbors") affect the speed of lexical access. Virtually all these experiments have adopted Coltheart, Davelaar, Jonasson, and Besner's (1977) definition of an orthographic neighbor: any word that can be created by changing one letter of the stimulus word, preserving letter positions (e.g., *house* and *horde* are orthographic neighbors of *horse*).

Because of the need of integrate the experiments on this field, an exhaustive review of this literature was recently published by Sally Andrews in *Psychonomic Bulletin and Review* (Andrews, 1997; see also Grainger, 1992). Another paper simply reviewing these findings after such a short period is of little interest unless it may contribute in some way to resolving the remaining ambiguities (e.g., by adding a novel insight relative to the current empirical evidence or to theoretical interpretations of this evidence). (The interested reader is encouraged to read Andrews's paper before reading the present article.) To that end, the goal of this review is to add new empirical findings that —we believe— *essentially* modify some of Andrews' conclusions. The focus of the current review is on recent studies that have appeared in international peer-reviewed journals.

The two primary neighborhood variables that have been manipulated are (i) the number of neighbors (*neighborhood size or neighborhood density*), which is often referred to as *N*, and (ii) whether or not a word has higher frequency neighbors (*neighborhood frequency or neighbor frequency*). Andrews (1997) indicated that there were three main issue to be resolved regarding the empirical effects of orthographic neighborhood: 1) Is performance affected by neighborhood size, neighborhood frequency, or both? (Andrews' answer: performance is basically affected by N); 2) Are the effect of neighborhood size and/or frequency facilitative or inhibitory? (Andrews' answer: the effect of N is facilitative whereas the effect of neighborhood frequency is, if anything, task-specific in nature); and 3) Do these neighborhood effects reflect lexical retrieval mechanisms or task-specific processes? (Andrews' answer: The effect of N is genuine and probably reflects lexical access processes). These conclusions pose some problems for many activation-based models: We must bear in mind that a central claim of these models (e.g., interactive activation model, McClelland & Rumelhart, 1981; multiple read-out model, Grainger & Jacobs, 1996) is that word processing is based on a process of competition between simultaneously active candidates, with the selection decision being made as the activation of the node corresponding to the stimulus word emerges from among the rest of candidates. The presence of a genuine, facilitative effect of neighborhood size (or neighborhood frequency) could be taken as strong evidence against the lexical inhibition hypothesis.

We begin this article with a literature review on the two basic neighborhood effects (neighborhood size and neighborhood frequency). To anticipate, this review shows that the number of higher frequency neighbors is inhibitory in reading. After this, we examine the influence of orthographic structure in form- and repetition-priming, which again suggests that neighbors could play an inhibitory role in the selection process. Finally, we discuss the empirical evidence in the context of current models of visual word recognition and reading.

The effect of number of neighbors (*neighborhood size or neighborhood density*)

As Andrews (1997) indicated, most published experiments replicate the finding of facilitative effects of N on lexical decision and naming, albeit the effect seems to be restricted to low-frequency words. It may be of interest to note that such effects can be observed when neighborhood frequency (the number of higher frequency neighbors) is controlled (e.g., Carreiras, Perea, & Grainger, 1997; Forster & Shen, 1996; Perea, 1993; Sears, Hino, & Lupker, 1995), which implies that the number of lower frequency neighbors is *facilitative* in this task. In other words, the facilitative effects of neighborhood size in the studies that did not control for neighborhood frequency (e.g., Andrews, 1989, 1992) may have been caused by an increasing number of *lower* frequency neighbors (see Paap & Johansen, 1994; Pollatsek, Perea, & Binder, 1999).

Taken together, these results appear to rule out serial models of lexical access (e.g., search model, Forster, 1976; activation-verification model, Paap, Newsome, McDonald, & Schvaneveldt, 1992), since these models involve a search through the candidate set to find the actual lexical entry. This stage of lexical access would clearly be slowed down (if anything) by having to search for the correct lexical item among a greater number of competing candidates (i.e., neighbors). Furthermore, these results also call into question the role of lexical inhibition as the responsible factor for a highly efficient selection process in visual word recognition (as in activation-based models; e.g., McClelland & Rumelhart, 1981; Grainger & Jacobs, 1996).

One attempt to save these models from oblivion has been to explain the facilitative effects of N in the lexical decision task (or the naming task) as due to *task-specific* processes (e.g., see Grainger, 1990; Grainger & Jacobs, 1996). For instance, the effect of N is weaker when word-like nonwords are used as distractors (Andrews, 1992) and when speed is stressed over and above accuracy (Grainger & Jacobs, 1996), which suggests that the effect of N could be due to incomplete processing of the stimuli. In this light, the effect of N tends to be inhibitory in speeded identification tasks with the progressive demasking task (e.g., Alameda & Cuetos, 1997; Carreiras et al., 1997; van Heuven, Grainger, & Dijkstra, 1998). However, the story is much more complicated: Recent evidence suggests that the effect of N could be facilitative with other speed identification paradigms (e.g., see Grainger, Carreiras, & Perea, 2000; Sears, Lupker, & Hino, 1999). Likewise, the evidence of a neighborhood size effect in a semantic categorization task (e.g., is the word an animal?) has also yielded inconsistent results (see Carreiras et al., 1997; Forster & Shen, 1996; Sears et al., 1999).

Nonetheless, the conflict in the existing evidence could be more apparent than real. We must keep in mind that all of these above-cited studies involve making responses to isolated words, so that all contain components not used in normal (silent) reading. For that reason, it is of great interest to examine the effects of a word's neighbors in normal (silent) reading by examining the pattern of eye movements when target words, varying in neighborhood size, were embedded in neutral sentences (e.g., “He knew that the [icon,wand] with magic properties played a big role in the fable.”). As Pollatsek et al. (1999) indicated, if neighborhood size effects are found in normal (silent) reading, then one has clear evidence that these neighborhood effects are not restricted to laboratory word identification tasks, but are *actually* influencing reading. An additional reason for using the reading task to investigate neighborhood size —or neighborhood frequency— (besides the ecological validity) is that it offers a window on whether the effects observed occur relatively "early" or "late" in word identification. Because eye fixations in reading are relatively short (usually about 200-250 ms), one can examine whether effects are early (e.g., on the first fixation on the target word), intermediate (e.g., on later fixations on the target word: gaze durations), or late (e.g., on fixations after the target word has been left or on regressions back to the target word).

In this light, Pollatsek et al. (1999; Experiments 1-2) found a facilitative effect of N in the lexical decision task, whereas these same items yielded an inhibitory effect in normal silent reading. The fact that the effects of increasing N in the lexical decision data were opposite to those in the reading data, even though the same stimuli were used in the two experiments, casts doubts on the use of the lexical decision task as a tool for assessing the effects of orthographic neighborhood (see Pollatsek et al., 1999). For instance, participants in a lexical decision experiment can correctly respond "word" to a low-frequency word on the basis of incorrect retrieval of a more frequent (activated) neighbor (Andrews, 1996). As a result, the lexical decision task could exaggerate the magnitude of the effect of N for low-frequency words. Finally, we should note that Pollatsek et al. (1999; Experiment 3) found that increasing the number of lower frequency neighbors of a word apparently had an initial facilitative effect in normal reading (in the probability of skipping the target word), which is probably related to the fact that the number of lower frequency neighbors is facilitative in the lexical decision task (see *Conclusions*).

The effect of neighborhood frequency (or neighbor frequency)

In a number of reports, Grainger and colleagues (e.g., Grainger et al., 1989, 1992; Grainger, 1990; Grainger & Jacobs, 1996; Grainger & Seguí, 1990; see Carreiras et al., 1997, for evidence of this effect in Spanish) showed that the important neighborhood variable in visual word recognition was not the number of neighbors *per se*, but the *frequency of a word's neighbors relative to its own frequency*. Specifically, Grainger and colleagues found that the presence of a higher frequency word in a word's orthographic neighborhood delays lexical access, presumably because these high-frequency words had to be evaluated first (in serial models), or because they would inhibit the processing of the lower frequency neighbors (in activation-based models).

However, Sears et al. (1995) and Forster and Shen (1996) failed to obtain this pattern of effects in the lexical decision task in English, which cast doubts on the reliability of the effect. (The experiments of Grainger and colleagues were run in French and Dutch.) Nonetheless, the recent results of Perea and Pollatsek (1998) and Pollatsek et al. (1999) clearly indicate that the number of higher frequency neighbors inhibit lexical access in normal reading. (We should note that these experiments were run in English.) Furthermore, Perea and Pollatsek (1998) also found the effect in the lexical decision task (see also Huntsman & Lima, 1996). They concluded that this inhibition from the higher frequency neighbors could be conceptualized as a competition process among lexical entries.

One difference between the Perea and Pollatsek (1998) lexical decision experiment and those of Forster and Shen (1996) and Sears et al. (1995), which did not observe reliable inhibitory effects of neighborhood frequency, is that the higher frequency neighbors in the Perea and Pollatsek study always differed from the target word in a middle letter (e.g., *spice,* whose higher frequency neighbor is *space*), which should have increased the inhibitory effect of these neighbors by increasing the confusability with the target. Keep in mind that many views of word identification posit that interior letters are processed less well, and hence neighbors that differ from a lexical item by an interior letter are likely to be more interfering than a neighbor that differs on either the first or last letter of the word (see Grainger & Seguí, 1990; Perea, 1998). In addition, the percentage of errors in the Perea & Pollatsek experiment was smaller than in the Forster and Shen (1996) and Sears et al. (1995) experiments, which might reflect "deeper" processing of the stimuli in the Perea and Pollatsek experiment (see Snodgrass & Mintzer, 1993).

To summarize, the overall reading data indicated that the effects of having a higher frequency neighbor occurred late in lexical processing and were inhibitory. Interestingly, the effect of neighborhood frequency seems to be cumulative in reading, as deduced by the *post hoc* analyses of the reading data of Pollatsek et al. (1999) and Perea and Pollatsek (1998). (Nonetheless, the effect of neighborhood frequency does not seem to be cumulative in the lexical decision task, see Grainger et al., 1989; Perea & Pollatsek, 1998.) Finally, we should note that the neighborhood frequency effect appears to be facilitative 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 word and therefore provide support for the stimulus word's pronunciation as predicted by analogy models of word naming (see Carreiras et al., 1997; Glushko, 1979; Grainger, 1990).

The density constraint in priming experiments

Andrews (1997) did not examine any priming experiments in her review. The argument was the following: the effects of target neighborhood characteristics might reflect different mechanisms in the single-word paradigm and in the priming paradigm. Specifically, in the single-word paradigm, the issue concerns whether partial activation of neighboring words that were never presented influences responses to the target word. In the priming paradigm, an item is explicitly activated and the effect on target performance is measured. Obviously, the fact that neighborhood size modulates the strength of priming between similarly spelled words *does not necessarily imply* that neighborhood size modulates the time taken to access those words (see Andrews, 1996; Forster & Shen, 1996; Perea & Rosa, in press).

But this is not the whole story. Prior research with the masked priming technique has found that target words are primed by orthographically similar nonword primes (relative to an unrelated control condition), although these effects are restricted to target words extracted from small neighborhoods in both lexical decision (*the density constraint effect*; e.g., Forster, Davis, Schocknecht, & Carter, 1987; Forster & Taft, 1994; Perea & Rosa, 2000a, 2000b) and naming tasks (e.g., Forster & Davis, 1991). More important, repetition priming effects are also greater for words with few neighbors than for words with many neighbors (Perea & Rosa, in press, 2000). The interaction between repetition/form priming and neighborhood size also involves a neighborhood attenuation effect: the effect of N occurs for the unrelated targets, whereas it is dramatically reduced for the form-related targets or the identical targets (Perea & Rosa, in press, 2000a, 2000b).

The fact that no reprocessing benefit from the form-related primes (relative to the unrelated control condition) is obtained for high-N target words strongly suggests that some inhibition among lexical units takes place for these words: nonword primes presumably activate several lexical representations, and lateral inhibition at the lexical level cancels out any sublexical facilitation from the related target. Alternatively, it could be argued that high-N words experience a benefit from co-activated neighbors (or, in other metaphors, from their overlapping connections with other similarly spelled words) when they are presented alone, that low-N words experience only when preceded by a "related" prime. In other words, it is not the single-word vs. priming paradigm issue that seems to matter, it is the *presence* or *absence* of form-related or identical primes (Perea & Rosa, 2000a, 2000b).

We believe that these findings clearly stress the role of competitive process in visual word recognition. Although we acknowledge Andrews's claim concerning the fact that the single-word paradigm and in the priming paradigm might reflect different mechanisms, it is not clear to us how to interpret these priming results in a framework in which lateral inhibition does not play an important role.

CONCLUSIONS

The present review suggests that neighborhood frequency seems to play an important role in visual word recognition and reading (as suggested by Grainger and colleagues), whereas the status of neighborhood size is not entirely convincing (at least in normal silent reading). Furthermore, there is the question of how to vary neighborhood size when controlling neighborhood frequency: what does one keep constant, the mean frequency of the neighbors, the frequency of the highest frequency neighbor, or something else?

We believe that neighborhood effects are best interpreted in the framework of a two-stage model such as the E-Z Reader model of eye movements (Reichle, Pollatsek, Fisher, & Rayner, 1998). This model posits that the signal to leave a word —which is the primary determinant of gaze duration— is not completion of lexical access (“lexical completion stage”), but only a partial stage of lexical processing, called a "familiarity check". As Reichle et al. pointed out, such a division was necessary in the model to predict a variety of phenomena, most notably "spillover" effects (i.e., effects that occur once the reader has left the target word). As a result, this model predicts that the time to complete lexical access is not only reflected in first fixation durations and gaze durations, but also in the duration of "spillover" fixations and even in some regressions back to the target word (as actually occurs in Perea & Pollatsek, 1998, Experiment 2).

We would like to note that the distinction between matching on the basis of global familiarity (i.e., the overall similarity of an input pattern to the collective content of the internal lexicon) and retrieval through integration (i.e., unique word identification) is common in many models of memory (see Reichle et al., 1998). Although the following argument could be considered speculative, we believe that this "familiarity check" might serve as a signal of "word-likeness" of the stimulus in a lexical decision task. After all, the average participant is not used to read nonwords (or to perform lexical decisions) in her/his daily life, and s/he may well take into account some information used in normal reading. In this way, recognition of words with many similarly spelled words would be facilitated relative to words with few similarly spelled words, as actually occurs in the lexical decision task. For instance, in the multiple read-out model (Grainger & Jacobs, 1996), lexical decisions can be made on the basis of summed lexical activation in the lexicon, which explains the facilitative effect of N for words. Interestingly, the reading data of Pollatsek et al. (1999, Experiment 3) suggested that there may be facilitative effects early in processing due to having more lower frequency neighbors when the number of higher frequency neighbors was held constant. Specifically, the skipping data of Pollatsek et al. (1999; Experiment 3) indicated that more lower frequency neighbors facilitate the encoding of *something*, but not necessarily the target word.

If this interpretation is correct, it would suggest that the inhibitory effects of having higher frequency neighbors probably occur late in word processing, as competition is resolved to enable unique word identification (see Perea & Pollatsek, 1998, Pollatsek et al., 1999, for some evidence for this from eye-movement recordings). Interestingly, there appeared to be two groups of readers in the Perea and Pollatsek reading experiment: one group had many more regressions back to the words with higher frequency neighbors than to the control words but had somewhat shorter gaze durations on the words with higher frequency neighbors; the other group had about equal numbers of regressions back to the two classes of target words, but had longer gaze durations (and longer "spillover" durations) for the words with higher frequency neighbors. In this light, one simple possibility for how the familiarity check stage might vary in this fashion, hinted at earlier, would be that the signal to move the eyes is that total excitation in the lexicon has crossed some threshold, but that some participants would have lower thresholds than other participants.

Nonetheless, as Reichle et al. (1998) pointed out, the division of lexical access into two discrete processing "stages" was a modeling convenience; and the authors remained neutral about whether there really were two discrete stages that could be conveniently mapped into components of word processing models or whether the "familiarity check stage" was merely a partially completed state of lexical access that could be somehow read by a decision stage (e.g., an assessment that excitation in the lexicon has crossed a threshold). Instead, the model should be considered as a guide to further experimentation (see Pollatsek et al., 1999). In this light, the eye movement record allows one to interpret certain effects as occurring "earlier" (e.g., skipping data) and other effects as occurring "later" (regressions data).

In addition, it has been suggested that part of the discrepancies in studies on orthographic neighbors could be due to the particular definition of orthographic neighbor: We must keep in mind that the definition proposed by Coltheart et al. (1977) is letter-position-specific and length-dependent. However, recent research on lexical similarity challenges the position independence assumption (e.g., *trial* interferes the processing of *trail*; see Andrews, 1996; Perea, Rosa, & Gómez, 2000). Furthermore, words which share a syllable, but have different number of letters, seem to be activated during the process of word recognition ("syllabic neighbors"; e.g., the Spanish word *casa* interferes the processing of *caco*; Carreiras, Álvarez, & de Vega, 1993; Perea & Carreiras, 1998; see also Domínguez, de Vega, & Cuetos, 1997, for evidence of syllabic priming effects).

It could also be argued that the fact that words in Romance languages are primarily multisyllabic and highly regular in their stress-to-sound correspondences may well lead to the emergence of different lexical structures and different coding schemes, and this may be a reason why there have been a number of failures to replicate orthographic neighborhood effects found in French or Spanish. Grainger and Jacobs (1998) suggested that precise orthographic information in Romance languages may be coded in sublexical units such as morphemes or syllables. For instance, Ziegler and Perry (1998) suggested that the frequency of the body (i.e., the number of words that share the same orthographic rime) may play a role in English, at least in the lexical decision task. Specifically, Ziegler and Perry (1998) showed that, when words are matched for N, the effects of body neighbors are facilitative. Interestingly, when words are matched for the effect of body neighbors, the effects of N are not significant. As a result, the facilitative effects of N in English (with the lexical decision task) could have been due to the confounding between N and the frequency of body neighbors (see Ziegler & Perry, 1998).

In addition to the manipulation of certain variables that may exaggerate (or mask) the effects of neighborhood size (or neighborhood frequency), we believe that future research should also go beyond the traditional experiment with two groups of items (e.g., low-N vs. high-N words). One such possibility is the use of parametric approach, in which three or more "neighborhood" conditions are tested (e.g., 0, 1, 2, 3-4 neighbors; see Forster & Shen, 1996). Another possibility is to examine of role of neighborhood distribution in visual word recognition. For instance, Mathey and Zagar (2000) recently found that words with two higher frequency "twin" neighbors (e.g., *firme*: *ferme*, *forme*) have longer lexical decision latencies than words with two higher frequency "single" neighbors (e.g., *foire*: *boire*, *faire*). In addition, as Forster (1998) pointed out, replication failures with different set of words are not unusual, which suggests that some confounds may have occurred in the materials. Priming techniques offer a powerful complement to single-word experiments, since the target materials are held constant across the priming conditions (Forster, 1998; Perea & Rosa, 1999a). However, it could be argued that the effects of target neighborhood characteristics might reflect different mechanisms in the single-word paradigm and in the priming paradigm (Andrews, 1997). For that reason, it may be of interest to held constant the stimuli, in a single-word paradigm, while manipulating some other factors (e.g., using an unfamiliar format). For instance, Perea and Rosa (1999b) failed to find a facilitative effect of N on low-frequency words in a lexical decision task when the items were presented in aLteRnAtInG-CaSe, which is consistent with the view that participants may make lexical decisions on the basis of visual familiarity (see Bodner & Masson, 1997).

Nonetheless, we acknowledge that this is not the whole story. How can we cope with the facilitative effect of N in perceptual identification or semantic-categorization tasks reported in several experiments? Undoubtedly, it is not easy to account for this pattern of results as mere reflections of a task-specific process. For instance, as indicated earlier, Grainger et al. (2000) found a facilitative effect of N with the luminance increment paradigm (a speeded perceptual-identification task), whereas these same items had yielded an inhibitory effect of N with the "classical" progressive demasking task. We believe that these facilitative effects of N will probably reflect top-down reinforcement of sublexical processing from whole-word representations (see Andrews, 1989, 1992, 1997; Grainger et al., 2000; Sears et al., 1999). Of course, the issue is whether implemented models of visual word recognition can accommodate the two types of effects (facilitative and inhibitory) at the same time. These models should be able to cope with the fact that *both* (inhibitory) lexical inhibition and (facilitative) lexical-sublexical feedback play a major role in identifying words. Interestingly, Andrews (1996) found that transposed-letter (TL) neighbors (*trial* and *trail*) cause inhibition, whereas "standard" neighbors (*train* and *trail*) cause facilitation in a naming task. Andrews suggested that TL interference effects could reflect lateral inhibition, whereas the facilitative effect of N could reflect excitatory feedback between the letter and word level. Undoubtedly, these findings provide empirical constraints that can be used to evaluate future specifications of models of visual word recognition and can be considered as a challenge for model builders.

Finally, a caveat: There is the likely possibility that, given the growing body of data concerning orthographic neighborhood effects, some of the conclusions of the present paper should be revised shortly. Nonetheless, the fact that faster and more powerful computers are designed everyday does not encourage customers to wait indefinitely until the "ultimate" computer is available on the market. Clearly, more research is needed to shed more light on the nature of the discrimination of lexical symbols in the internal lexicon.

RESUMEN

Los efectos de "vecindad" ortográfica en lectura y en tareas de reconocimiento de palabras: Una revisión. En este trabajo se ofrece una revisión de la literatura reciente sobre los efectos de "vecindad" ortográfica (esto es, del papel de las palabras que pueden ser creadas alterando una letra de la palabra-test, preservando las posiciones de las otras letras; Coltheart et al., 1977) en lectura y en tareas de reconocimiento visual de palabras. En primer lugar, se efectúa una revisión sobre los dos efectos más importantes de "vecindad" ortográfica: el tamaño de vecindad y la frecuencia de vecindad, en la que se muestra el papel inhibidor de los vecinos de alta frecuencia en la lectura. Seguidamente, se examina la influencia de la estructura ortográfica en los efectos de repetición y facilitación ortográfica, en la que de nuevo se aprecia el papel inhibidor de las palabras vecinas. Finalmente, se analiza la evidencia empírica de los efectos de vecindad ortográfica en el contexto de los modelos de lectura y reconocimiento visual de palabras.

Palabras clave: Vecindad ortográfica, acceso al léxico, movimientos oculares

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