CHAPTER 6

Neighborhood Effects in Visual Word Recognition and Reading

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Abstract

This chapter discusses research on how words that are orthographically (or phonologically) similar to a printed word influence the speed and accuracy of its encoding. The relevant set of words (the word's neighbors) was previously defined to be those lexical units differing from the target stimulus by a single letter in a given position. Recent evidence has revealed that a better definition of a word's neighborhood includes lexical units of different length and lexical units created by transpositions. The study of a word's neighborhood has revealed that that the activation of neighbors may interfere with the processing of the target words in word-identification tasks and during sentence reading, supporting the basic claims of interactive activation models. Some challenges to the current definitions of the sets of word neighborhoods are also examined, in particular the need to include differences between how consonants and vowels are encoded during word processing.

Key Words: word recognition, computational models, letter-position coding, consonant/vowel status, lexical decision, similarity metrics

Introduction

The examination of the nature of the underlying mechanisms that associate a printed word with its correct lexical unit (i.e., the process of lexical access) is one of the most basic issues in the research on reading. There are several reasons for this relevance. First, lexical access is a central component of sentence reading (Besner & Humphreys, 1991). Second, many reading disorders may originate from a deficient process of word identification (e.g., see Castles & Coltheart, 1993).

There is some agreement that when we identify a word in an alphabetic language, there is an early stage at which a number of similarly spelled lexical units to the printed stimulus (i.e., *neighbors*) are partially activated (or accessible). That is, during the process of visual word recognition there is a collection of lexical candidates that are similar (in some sense) to a given word and these candidates influence the ease with which the stimulus word is encoded or perceived. During the course of word processing, these lexical candidates are progressively deactivated until only one lexical unit remains active (i.e., the perceived word) (e.g., search model: Murray & Forster, 2004; Bayesian reader model: Norris, 2006; interactive activation model: McClelland & Rumelhart, 1981, and its successors: multiple read-out model: Grainger & Jacobs, 1996; dual route cascaded model: Coltheart, Rastle, Perry, Langdon, & Ziegler, 2001; spatial coding model: Davis, 2010). It is important to note here that there are other models that have a completely different metaphor for word identification, as in parallel distributed processing (PDP) models (Seidenberg & McClelland, 1989; see also Woollams, this volume).

The present chapter first examines the different metrics that have been proposed to define the set of a word's neighbors. It then examines whether a word's neighbors help or hinder during the process of word identification. Finally, it examines the limitations of current neighborhood metrics and suggests potential alternatives.

The Initial Definitions of the Set of a Word's Neighbors

One preliminary issue when studying the role of a word's neighbors during lexical access is to precisely define a word's neighborhood. If we use the characterization offered by Landauer and Streeter (1973, p. 120), "a similarity neighborhood will be defined as the set of words in the language from which a given stimulus word is indistinguishable after a specified loss of information about the stimulus word," then all lexical units in this set different from the target stimulus (specified by this criterion) are neighbors. Importantly, the influence of a word's neighbors on lexical access may be examined on two basic dimensions: (1) What is the influence of the number of the lexical units that compose the neighborhood (*neighborhood size*) on the processing of a given word? and (2) What is the influence of the frequency of the lexical units that compose the neighborhood (*neighborhood frequency*) on the processing of a given word?

The Initial Definitions of a Word's Neighborhood

In their seminal paper on word neighborhoods, Havens and Foote (1963) assumed that the set of a word's competitors (they used the term "competitors" rather than "neighbors") was composed of more frequent lexical units that shared all the letters but one with the target word, such that the differing letter should be an internal letter. Furthermore, this differing letter had to be visually similar to the original letter in terms of the ascending/neutral/descending pattern (e.g., *s* is a neutral letter, *d* is e an ascending letter, and *p* is a descending letter). For instance, *list* would be a close neighbor if of *lint*, as it is a high-frequency word that differs in a middle letter and the differing letter (*s*) keeps the same visual shape as the original letter (*n*; i.e., both are neutral letters). In contrast, lexical units such as *lift* and *line*, which also share three letters in the same position with *lint*, would not be close competitors. Havens and Foote (1963) did not provide a specific definition or weighting of the different grades of competitors, though.

Landauer and Streeter (1973) defined a word's neighborhood as the set of one-letter substitution neighbors. That is, two words are neighbors if they share the letters in all but one position. Albeit somewhat rudimentary, this is the definition that was later used in the influential study of Coltheart, Davelaar, Jonasson, and Besner (1977), and the number of orthographic neighbors of a word has commonly been termed *Coltheart's N*. Unlike Havens and Foote (1963), this definition does not take into account letter shape. This assumption is consistent with claims that word identification is mediated by abstract (i.e., case independent) letter units rather than by visual similarity (or letter shape), at least for skilled readers (see Rayner, McConkie, & Zola, 1980, for early evidence of the role of abstract letter/word representations in reading). In addition, the one-letter substitution characterization considers that all neighbors are equal regardless of whether the different letter is an external (i.e., initial or final) letter or a middle letter. This assumption was perhaps made more to keep the metrics as simple as possible rather than on the basis of empirical data. Indeed, there is evidence that shows that, as anticipated by Havens and Foote (1963), one-letter substitution neighbors that differ in an internal letter position are more perceptually similar to the target stimulus than lexical units that differ in an external letter position (see Perea, 1998). Both the Havens and Foote (1963) and Landauer and Streeter (1973) definitions also implicitly assume that the cognitive system initially encodes the number of letters of the target stimulus without noise, so that different-length lexical units (e.g., *house* and *hose*) are not part of the word's neighborhood. Furthermore, both Havens and Foote (1963) and Landauer and Streeter (1963) assume that, during word processing, letter-position coding operates without noise, so that *trail* would not be activated upon presentation of the word *trial* (i.e., they would not form part of the same neighborhood).

Thus, in the one-letter substitution definition from Landauer and Streeter (1973) and Coltheart et al. (1977), *clam* has *slam, cram, clad, clan, clap, claw*, and *clay* as orthographic neighbors. The idea here is that the number of orthographic neighbors (Coltheart's N = 7 in the case of *clam*) provides an initial index of the size (or density) of a word's neighborhood. That is, there are words with a large neighborhood (i.e., high-N words) such as *pale* (N=20), and words with a small neighborhood (i.e., low-N words) such as *trek* (N=1; its only neighbor is *tree*). Since the Coltheart et al. (1977) experiment, a number of experiments have examined the size of the orthographic neighborhood in a wide range of behavioral, eyetracking, and neurophysiological paradigms (see Andrews, 1989, 1992, 1997). Another way to examine the role of a word's neighbors in visual word recognition has been to examine not the number of neighbors per se but their frequency (see Grainger, O'Regan, Jacobs, & Segui, 1989). This is in line with the initial proposal of Havens and Foote (1963) of considering the pivotal role of higher-frequency competitors during visual word recognition. In this line of research, the basic comparison is between a set of words with stronger competitors (i.e., higher-frequency neighbors) and a set of words without strong competitors (i.e., no higher-frequency neighbors).

The First Expansion of the Neighborhood: Uncertainty in Letter-Position Coding

Research in the 1950s showed that participants could easily reproduce the base word upon the brief presentation of transposed-letter nonwords (e.g., *avitaion*; the base word is *aviation*) (see Bruner & O'Dowd, 1958), thus suggesting that nonwords created by transposing two letters resembled their original base words to a large degree. In more systematic research, Chambers (1979) and O'Connor and Forster (1981) examined the intricacies of letter-position encoding in chronometric word/nonword discrimination tasks (i.e., lexical decision), and found that transposed-letter nonwords like *mohter* produced a sizeable number of "word" responses (more than 20%). More recently, Vergara-Martínez, Perea, Gomez, and Swaab (2013) found that a relatively late electrophysiological component such as the N400 (a peak that occurs around 400 ms after stimulus presentation) was evoked similarly for high-frequency words and for their transposed-letter counterparts (e.g., *mother* and *mohter*) in two visual word recognition tasks (lexical decision and semantic categorization), whereas this did not occur for replacement-letter nonwords (e.g., *mopher*). The fact that nonwords created from transposing adjacent letters (e.g., *mohter*) are highly word-like suggests that the encoding of letter position and letter identity do not go hand in hand and that letter-position coding is quite flexible

The results described above pose problems for the orthographic coding scheme of the interactive activation model (McClelland & Rumelhart, 1981). The model was initially implemented with a basic vocabulary of words of four letters, in which letter position was assumed to be processed in the correct order. In the model, *slat* and *salt* would be no closer than *slat* and *scar* (i.e., two letters in common in the two pairs), so that the presence of letter transposition effects rules out this orthographic coding scheme. Additional research from Andrews (1996) and a myriad of experiments in the past decade (see Perea & Lupker, 2003, 2004) have helped refine the ideas of how letter-position coding is attained during visual word recognition. As a result, a number of models with a more flexible coding scheme have been proposed (see Frost, this volume; Kinoshita, this volume). The important issue here is that transposed-letter neighbors are also activated during visual word recognition and reading (e.g., *trial* would influence the processing of *trail*), so that a word's neighborhood should also include these lexical units within the set of candidates (see Acha & Perea, 2008b; Johnson, 2009 for evidence of an inhibitory effect of transposed-letter neighbors during normal reading).

The Second Expansion of the Neighborhood: The Issue of Word Length

In a word identification task with masked stimuli, Grainger and Segui (1990) noted that a number of errors involved the addition or deletion of a letter (e.g., *votre* 'your' instead of *vote* 'vote'; *cuir* 'leather' instead of *cuire* 'to cook'). Grainger and Segui indicated that "competing units in the word-recognition process need not be of the same length" (p. 195), which echoed the research in auditory word recognition where a word's neighborhood is typically defined in terms of words in which one phoneme is substituted, added, or removed (see Luce & Pisoni, 1998). Later, more systematic research provided evidence that the processing of a printed word may be affected by lexical units that that differ in the number of letters: this is the case of the addition-letter neighbors (the addition-letter neighbor *slate* may influence the processing of the target word *slat*; see Davis & Taft, 2005; Davis, Perea, & Acha, 2009; de Moor & Brysbaert, 2000) and the deletion-letter neighbors (the deletion-letter neighbor *sat* may influence the processing of the target word *slat*; see Davis et al., 2009; Perea & Gomez, 2010).

Finally, syllable neighbors (i.e., lexical units that share a syllable in the same position with the target word, in particular the initial syllable) may also be activated. Syllable neighbors may be particularly relevant in those languages in which the syllable plays a major role in word identification (e.g., Spanish; see Carreiras, Álvarez, & de Vega, 1993; Perea & Carreiras, 1998). These neighbors may have the same length as the target word (e.g., *laca* and *lago* in Spanish) or may not (*laca* and *lavar*). In sum, a word's orthographic neighborhood can be composed of different types of neighbors: one-letter substitution neighbors (*slam* and six others for *slat*); transposed-letter neighbors (*salt*); addition-letter neighbors (*slate* and two others); deletion-letter neighbors (*sat*); and (possibly) syllabic neighbors.

One issue here is whether we can obtain a single, combined metric of a word's orthographic neighborhood. Davis (2005) proposed the use of *N** as the sum of all the one-letter substitution neighbors (i.e., Coltheart's N), transposed-letter neighbors, addition-letter neighbors, and deletion-letter neighbors. For example, in the case of *clam,* N* is 12+1+3+1=17. Although using Davis's combined set of neighbors as a metric may be considered as good initial approach, it is not free from shortcomings. One shortcoming is that it assigns the same weight to all types of neighbors, but there is evidence that some types of neighbors may be more equal than others (e.g., Davis et al., 2009; Duñabeitia, Perea, & Carreiras, 2009). Another shortcoming is that this measure tends to be zero (or close to zero) for relatively long words—as also occurs with Coltheart's N.

To overcome this latter limitation, a number of researchers have designed an alternate measure, *OLD20* (Yarkoni, Balota, & Yap, 2008). This measure is based on the Levenshtein distance between two words. The Levenshtein distance, a common measure in information theory, is the minimum number of single-letter changes (replacements, additions, deletions) required to change one word into the other. For instance, the Levenshtein distance between *hose* and (its one-letter substitution) neighbor *nose* is 1 (i.e., the replacement of *h* with *n*). Similarly, the Levenshtein distance between *hose* and (its addition-letter) neighbor *horse* is also 1 (i.e., addition of *r*). The OLD20 measure is defined as the mean distance, in terms of these single-letter changes, from each word relative its 20 closest Levenshtein neighbors. Thus, as occurs with N*, the OLD20 is a measure of the size of the orthographic neighborhood rather than a measure of the frequency of its members. Two advantages of this measure over either N* and N are the following: (1) while they all apply to long words, OLD20 is less likely to be 0; and (2) OLD20 allows a (more realistic) graded view of a word's neighbors (i.e., it is not only measuring whether two words are neighbors, but it is measuring how perceptually close two words are). Indeed, the OLD20 measure is rapidly becoming the most employed neighborhood measure in research on visual word recognition (Grainger, Dufau, Montant, Ziegler, & Fagot, 2012; see Vergara-Martínez & Swaab, 2012, for electrophysiological evidence of OLD20 effects).

Despite its importance, there is one arguable limitation of the Levenshtein distance when describing a word's neighborhood: it weights single-substitutions more heavily than letter transpositions. That is, in this metric, *train* and *trail* (Levenshtein distance = 1; i.e., replacing *n* with *l*) is more closely related than *trial* and *trail* (Levenshtein distance = 2; i.e., replacing *i* with *a* and *a* with *i*). However, there is evidence that transposed-letter neighbors have a special status within a word's neighborhood so that they are more closely related than substitution-letter neighbors (see Duñabeitia et al., 2009; Gómez et al., 2008; Perea & Fraga, 2006). Although this issue does not affect the majority of orthographic systems, where the number of transposed-letter word pairs is usually very small (see Acha & Perea, 2008b; Andrews, 1996), it may be a relevant factor in those languages with a large set of transposed-letter word pairs (e.g., Semitic languages like Arabic and Hebrew; see Perea, Abu Mallouh, & Carreiras, 2010; Velan & Frost, 2007).

In this section, I have focused on orthographic measures of a word's neighborhood. Parallel measures have been proposed for phonological neighborhoods. Following the logic of the Landauer and Streeter (1973) definition, Yates, Locker, and Simpson (2004) defined "phonological neighbors as words that could be formed by changing only one phoneme of the target word" (p. 453). That is, the POLD20 is analogous to the OLD20 measure except that it deals with phonological rather than orthographic neighbors. While in a number of languages orthographic and phonological neighbors typically coincide (e.g., in Spanish), this is not always the case (e.g., in English). Given that the number of experiments that have manipulated a word's phonological neighborhoods in visual word recognition and reading is substantially smaller than the research on orthographic neighborhoods, the following section will focus primarily on the effects of orthographic neighborhoods. Nonetheless, recent experiments on the effects of phonological neighborhoods will be reviewed at the end of the section.

Do Neighbors Help or Hinder the Process of Word Identification?

The initial experiments on the role of a word's orthographic neighbors using response time tasks such as the lexical decision task (i.e., "is the stimulus a real word or not?") tested one basic assumption of the interactive activation model: the idea of competition at the lexical level via inhibitory links among the nodes that represented the lexical units. Specifically, in a lexical decision experiment, Grainger et al. (1989) compared the word identification times of a set of words with no higher frequency (one-letter substitution) neighbors and a set of words with at least one higher frequency (one-letter substitution) neighbor. Consistent with the predictions of the interactive activation model, they found that words with a higher frequency neighbor produced longer word identification times than the words with no higher frequency neighbors. This finding is not limited to laboratory word identification tasks, as it has been also replicated and generalized to sentence reading. In particular, fixation times on words with higher frequency neighbors are longer (and/or there are more regressions back to the target word) than the parallel measures for control words with no higher frequency neighbors, and this has been reported using different types of neighbors: one-letter substitution neighbors (Perea & Pollatsek, 1998; Slattery, 2009), transposed-letter neighbors (Acha & Perea, 2008b; Johnson, 2009), addition-letter neighbors (Davis, Perea, & Acha, 2009), and deletion-letter neighbors (Davis et al., 2009). Importantly, the sentence reading experiments have revealed that the effects of these higher-frequency neighbors tend to occur in relatively late measures (i.e., once the reader has left the target word, such as the fixation duration following the target word or the percentage of regressions back to the target word) rather than in early fixation measures (e.g., the initial fixation on the target word). This outcome is consistent with models of eye movement control (e.g., E-Z-Reader model; see Reichle, Rayner, & Pollatsek, 2003; Reichle & Sheridan, this volume; see also Johnson, Staub, & Fleri, 2012, for evidence of transposed-letter neighborhood effects in word reading by using response time distributions).

The previous paragraph offered evidence in favor of competitive effects at the lexical level during visual word recognition. However, Andrews (1989, 1992) found that low-frequency words with many (one-letter substitution) neighbors produced faster latencies in the lexical decision task than low-frequency words with few (one-letter substitution) neighbors. This finding seems to be at odds with the existence of competition at the lexical level, since one would have expected that having many neighbors would lead to more lexical competition (via inhibitory links) which, in turn, would lead to longer word identification times for high-N words. Indeed, simulations with the interactive activation model cannot capture that pattern of effects (see Grainger & Jacobs, 1996).

To explain this apparent discrepancy, Grainger and Jacobs (1996) argued that the facilitative effect of the number of neighbors was due to task-specific factors in the lexical decision task. In particular, in their multiple read-out model, Grainger and Jacobs expanded the interactive activation model so that a "word" response in lexical decision could be generated not only on the basis of a word unit reaching a given level of activation (i.e., the original criterion in the interactive activation model) but also on the basis of a global activity criterion on the basis of the summed activation of the orthographic neighbors (the so-called Σ-criterion). This new model was able to capture simultaneously the facilitative effect of number of neighbors and the inhibitory effect of neighborhood frequency that occurs in lexical decision (Grainger & Jacobs, 1996; but see Wagenmakers, Ratcliff, Gomez, & McKoon, 2008). One prediction from the Grainger and Jacobs (1996) model is that, when the same words that produce a facilitative effect of neighborhood size in lexical decision are employed in a situation in which actual word identification is required (e.g., in sentence reading), the effect should become inhibitory. This prediction was later confirmed by Pollatsek, Perea, and Binder (1999).

Taken together, the above-cited evidence is consistent with models that assume that there is lexical competition among the neighboring units activated upon word presentation, such as the interactive activation model (or its successors). One limitation of the experiments that use two different sets of stimuli, such as those described above (e.g., words with higher frequency neighbors vs. words with no higher frequency neighbors; words from large neighborhoods vs. words from small neighborhoods) is that the control of some of the characteristics of the two sets of stimuli is not straightforward. One complementary way to examine the role of lexical competition during lexical access is to employ a priming procedure—in particular, *masked priming* (Forster & Davis, 1984; see also Grainger, 2008, for a review). The procedure of the masked priming technique is straightforward: after a 500-ms forward pattern mask (#####), the priming stimulus is presented briefly (around 30–50 ms), just prior to the target. Participants are required to make a response to the target stimulus (i.e., lexical decision, semantic categorization, or naming). Although the trace of the masked prime is (essentially) inaccessible to conscious report, the prime is capable of affecting the recognition of the target in lexical decision and other tasks. Unsurprisingly, the strongest positive priming effect is obtained when the prime is the same word as the target (faster response times to *house-HOUSE*, than to *ocean-HOUSE*), but masked priming effects also occur when the prime and target share an orthographic, phonological, morphological, or even a semantic relationship. The nature of masked priming is at an abstract level of representation, as masked priming effects are the same magnitude for pairs that are nominally and physically the same in lowercase and uppercase (e.g., *kiss-KISS*) and for pairs that are nominally (but not physically) the same in lowercase and uppercase (e.g., *edge-EDGE*) (see Bowers, Vigliocco, & Haan 1998; Perea, Jiménez, & Gómez, 2014). In contrast to single-word (or reading) experiments, the target materials in priming conditions (or in any other within-item manipulation) are held constant across the priming conditions. This avoids the problems of attempting to control for potential confounds in the selected stimuli (see Forster, 2000, for discussion), and it also allows for a within-item rather than a less powerful between-item analysis.

A number of masked priming experiments using the lexical decision task have provided converging evidence in favor of competition at the lexical level from a word's neighbors. Masked form priming effects on word targets usually differ depending on whether the prime stimulus is a word or not. Specifically, while the influence of word neighbor primes on target processing tends to be inhibitory, the influence of nonword neighbor primes tends to be facilitative (e.g., Carreiras & Perea, 2002; Davis & Lupker, 2006; Duñabeitia et al., 2009; Nakayama, Sears, & Lupker, 2011; Segui & Grainger, 1990). This applies to experiments using one-letter substitution neighbors and transposed-letter neighbors. This outcome fits quite well with the idea that a neighboring word prime exerts an inhibitory influence on the processing of the target word (via inhibitory links at the lexical level), while a neighboring nonword prime produces sublexical facilitation.

Further evidence that a word's neighbors may hinder its processing comes from the interaction between masked form/repetition priming and neighborhood density. Consider the effect of form priming with nonword primes (e.g., *honse-HOUSE* vs. *minve-HOUSE*). While form priming occurs for target words with few neighbors (low-N words), it is absent for target words with many neighbors (high-N words; Forster, Davis, Schoknecht, & Carter 1987; see also Perea & Rosa, 2000). Furthermore, a parallel effect occurs in repetition priming. The magnitude of masked repetition priming is larger for low-N words than for high-N words (Perea & Rosa, 2000). That is, high-N words benefit less from a repeated presentation of the same word than low-N words. In a series of three masked form/repetition priming lexical decision experiments testing with three different sets of stimuli varying in overall word frequency, Perea and Forster (in preparation) found that repetition priming in English was greater for low-N words (47, 49, and 52 ms) than for high-N words (31, 34, and 34 ms). Likewise, low-N words showed a significant form priming effect of approximately 25-30 ms in the three experiments (26, 25, and 29 ms), which is a bit less than half the size of the repetition priming effects for these same items—the form priming effect for high-N words was negligible across the three experiments (-2, 2, and 7 ms). Since the prime duration was 50 ms in these masked priming experiments, this means that low-N words, but not high-N words, obtained full benefit from the identity prime (i.e., a presumed advantage of around 50 ms of the identity over the unrelated priming condition; see Gomez, Perea, & Ratcliff, 2013, for a discussion of the nature of masked repetition priming effects) via inhibitory links from the preactivated lexical units in large neighborhoods. The basic conclusion from these experiments is that a high-N word receives less processing benefit from its previous masked presentation than a low-N word. Therefore, the modulation of masked form/repetition priming provides converging evidence in favor of those models that assume that there is competition at the lexical level.

The previous paragraphs focused on the impact of orthographic neighbors in visual word recognition. A less studied issue has been the examination of the impact of phonological neighbors in visual- word recognition. Indeed, most of the current (implemented) models of visual word recognition focus on the orthographic level of processing (e.g., spatial coding model, Davis, 2010). However, several studies have examined the influence of a word's phonological neighbors in visual word recognition and reading while controlling for the word's orthographic neighbors. Yates et al. (2004) reported that words with many phonological neighbors were responded to faster in a (visual) lexical decision task than the words with few phonological neighbors. Subsequently, Yates, Friend, and Ploetz (2008) examined whether this facilitative effect could be generalized to a normal reading situation.

In particular, Yates et al. conducted a sentence reading experiment in which a target word (with many/few phonological neighbors) was embedded in each sentence. The results were mixed. While they found shorter first-fixation times on the target words with many phonological neighbors than on the words with few phonological neighbors, this facilitative effect vanished in other eye movement measures such as gaze durations (i.e., the sum of all fixations on the target word before leaving it) and total times (i.e., the sum of all fixations on the target word including regressive fixations). Thus, while there were some hints that at some processing level, a word's phonological neighbors may have had a facilitative influence on the target word, the evidence was not decisive. Clearly, an important topic for future research is to examine in detail the impact of both orthographic and phonological neighbors in visual word recognition and reading across a range of languages.

Does the Consonant/Vowel Status Matter in a Word's Neighborhood?

A neglected issue in most studies on neighborhood effects is the distinction between consonants and vowels. The reason is that most influential models of visual word recognition assume that there is no distinction between the consonant/vowel status of printed letters (e.g., interactive activation model, McClelland & Rumelhart, 1981; spatial coding model, Davis, 2010; Bayesian reader model, Norris, 2006; open bigram model, Grainger & van Heuven, 2003; SERIOL model, Whitney, 2001; overlap model, Gomez et al., 2008). Therefore, in these models, neighbors that differ in one vowel such as *list* and *lost* are perceptually as close as neighbors that differ in one consonant such as *list* and *lift*.

However, a large body of research has revealed that, in various languages, consonants and vowels are not processed in exactly the same way (see Caramazza, Chialant, Capasso, & Miceli, 2000; Mehler, Peña, Nespor, & Bonatti, 2006). In particular, it has been claimed that consonants are more relevant than vowels for access to the mental lexicon, whereas vowels are more relevant for conveying grammatical information (Mehler et al., 2006). Indeed, when using shortcuts in text messages, we tend to omit the vowels rather than the consonants and the resulting words can be easily reproduced (see Perea, Acha, & Carreiras, 2009, for eyetracking evidence). With respect to the specific issue of consonants and vowels and orthographic neighborhoods, an important piece of evidence is the masked priming lexical decision experiment of New, Araujo, and Nazzi (2008). The two critical priming conditions were a consonant-preserving condition (e.g., *duvo-DIVA; apis-OPUS*) and a vowel-preserving condition (e.g., *rifa-DIVA; onub-OPUS*). For adult readers, consonant-preserving primes facilitated target processing to a larger degree than the vowel-preserving primes. Indeed, the response times in the vowel-preserving priming condition did not differ significantly from those of an unrelated priming condition (e.g., *rufo-DIVA; anib-OPUS*). In a recent series of experiments, Soares, Perea, and Comesaña (2014) replicated the New et al. finding in another language (Portuguese) with adult readers and also extended the finding of a consonant/vowel difference to developing readers (grade 5 children).

Another piece of information relevant to the importance of the consonant/vowel status of letters comes from the masked priming lexical decision experiments with nonword partial primes conducted by Duñabeitia and Carreiras (2011). They found that partial primes composed of consonants were more effective than partial primes composed of vowels (i.e., faster response times to *csn-CASINO* than to *aio-CASINO*). Furthermore, letter transposition effects differed for consonant and vowel transpositions: *caniso* and *casino* are perceptually closer than *anamil* and *animal*, as deduced from the fact that a target word like *CASINO* is identified more rapidly when preceded by the transposed-letter nonword *caniso* than when preceded by the replacement-letter nonword *caviro*, whereas the parallel difference is absent for the transposition/replacement of two vowels (i.e., similar word identification times for *anamil-ANIMAL* and *anomel-ANIMAL*; Perea & Lupker, 2004; see also Lupker, Perea, & Davis, 2008).

Therefore, the current measures of a word's neighborhood should be expanded to account for the consonant/vowel distinction. As stated above, current computational models of visual word recognition do not account for these consonant/vowel differences. One straightforward option would be to give a differential weight to consonantal modifications in OLD20 distance metrics. With the advent of big databases of identification times for thousands of words in different languages (e.g., Balota et al., 2007), it should be easy to test whether a modified OLD20 (or POLD20) measure that weights changes in consonants and vowels differently offers better fits than the current OLD20 measure. At the same time, it may be important to examine whether assigning higher weights to external letters than to internal letters may also provide a better fit. In turn, between the external letters, the beginning letter may also be assigned higher weights than the end letter.

Conclusions and Future Directions

Experimentation on the impact of a word's neighborhood during lexical access in laboratory word identification tasks (either in single-presentation or masked priming paradigms) and in silent reading (via eyetracking) has provided evidence of competition at the lexical level, thus providing empirical support to the claims of interactive-activation models. Despite the limitations of neighborhood metrics, the basic findings that were obtained with the one-letter substitution neighbors in the 1970s and 1980s have been extended—with appropriate adjustments—to other types of neighbors.

One final issue that deserves some comment is to what degree a word's neighborhood during reading is influenced by properties of the visual-attentional system that were ignored in the models that were discussed. As indicated above, the OLD20 measure has the limitation that letter transpositions involve two steps while a single addition, deletion, or replacement only involve one step and evidence reveals that transposed-letter neighbors are very close to the target word (i.e., more so than one-letter substitution neighbors). This phenomenon may be related to how the visual system encodes letter position: Perceptual uncertainty regarding letter position has been posited to originate from noise in encoding position at the visual level (Gomez et al., 2008). As such, it also appears when coding sequences of geometrical objects (García-Orza, Perea, & Estudillo, 2011) and when reading musical notes in a staff (Perea, García-Chamorro, Centelles, & Jiménez, 2013). Indeed, when the same materials that in the visual modality produce a transposed-letter effect (e.g., *cholocate* is error-prone when presented visually) are presented in a tactile modality such as Braille, the transposed-letter effect vanishes (Perea, García-Chamorro, Martín-Suesta, & Gómez, 2012). Therefore, research in modalities other than the visual, such as research in Braille, may be informative to find out which aspects of the reading process, including the definition of a word's neighbors, are modality-independent and which aspects are modality-specific (see Perea, Jiménez, Martín-Suesta, & Gómez, 2014 for a comparison of sentence reading in sighted vs. Braille readers).

An important issue for further research is how a word's neighborhood evolves in developing readers. Castles, Davis, Cavalot, and Forster (2007; see also Acha & Perea, 2008a; Soares et al., 2014) have claimed that the organization of the neighborhood varies as a function of reading skill across primary school children. In their *lexical tuning* hypothesis, Castles et al. indicated that the orthographic recognition system is initially coarsely tuned and that it becomes more and more precise with increased reading skill. Consistent with this view, Castles et al. (2007) found large effects of masked form priming close in size to those of identity priming in beginning readers. In older children they found the expected advantage in effect size of identity priming over form priming that occurs in adult readers. Therefore, the definition of a word's neighborhood in children may reflect more flexible coding of letter identity and letter position. More research should examine in detail the relationship between reading level and word neighborhoods.

Another relevant issue is how a word's neighborhood is affected by the existence of two (or multiple) lexicons in bilinguals. There is evidence that, in bilinguals, presentation of a word activates similarly spelled words in the bilingual's two languages, as predicted by interactive activation models. In particular, the Bilingual Activation Model (Dijkstra, van Heuven, & Grainger, 1998) can successfully deal with many of the intricacies of bilingual word recognition (see Grainger, Midgley, & Holcomb, 2010 for a review of recent research).

Most of the research summarized above has been conducted in languages that employ the Latin script. In languages that employ the second most widely used alphabetic script in the world, Arabic (e.g., Arabic, Persian, Urdu, Uyghur), the specific shape of each letter form depends on whether it is connected to the neighboring letters. Arabic is a semicursive script that is read from right to left in which, for instance, the shape of the letter *nūn* (n in the Buckwalter transliteration) differs depending on whether it is connected to its both contiguous letters (middle form: -ن-), when it is only connected to the previous letter (initial form: ن-), when it is only connected to the following letter (final form: -ن), and when it is not connected to the neighboring letters (isolated form: ن). While some letters in Arabic can connect with the following letter, others cannot, thus potentially creating graphemic chunks, as in the word شراع ('sail', $rAE in the Buckwalter transliteration; $=/ʃ/, r=/r/, A=/aː/, and E=/ʕ/ in IPA notation), in which the two initial letters are connected, and the two final letters are isolated—note that, as indicated above, Arabic is read from right to left. The position-dependent allography of the words' constituent letters in Arabic script influences the structure of a word's neighborhood (see Friedmann & Haddad-Hanna, 2012 for evidence in Arabic; see also Yakup, Abliz, Sereno, & Perea, 2014 for evidence in Uyghur). These two studies revealed that the words لهمت ('slowed', tmhl in the Buckwalter transliteration) and لمهت ('neglect', thml), which share the letter-position allographs (note that the transliterations of the phonemes m [-م] and h [-ه] are both in their middle form positions in the two words) are orthographically closer than the words عارش ('sail', transliterated as $rAE) and عراش ('street', $ArE) that do not share the letter-position allographs (the transliteration of the phoneme A is in isolated form in $rAE [ا] and final form in $ArE [-ا], whereas the transliteration of the phoneme r is in final form in $rAE [-ر] and in isolated form in $ArE [ر]).

Further research should also examine how a word's neighborhood is characterized in alphabetical languages that employ tones as markers, such as Thai (see Winskel & Perea, 2014 for an examination of orthographic/phonological effects of tone markers in Thai). Importantly, the nature of Thai orthography, in which words are not separated by blank spaces, may also lead to letter coding processes that differ from those in Indo-European languages (see Winskel, Perea, & Peart, 2014). For example, during sentence reading, the degree of disruption of reading transposed-letter nonwords is similar for internal and initial transposed-letter nonwords in Thai (Winskel, Perea, & Ratitamkul, 2012), whereas it is more disruptive for the initial letter position than for internal positions in Indo-European languages (see White, Johnson, Liversedge, & Rayner, 2008).

Finally, it seems likely that there is some sort of neighborhood effect (or effects) in nonalphabetic languages like Chinese and Japanese. That is, because research in alphabetic languages has shown, there are clear inhibitory effects in encoding words coming from competing similar words that are neighbors, it seems likely that there will be similar effects in nonalphabetic languages. This means that an important question is how a word's neighborhood can best be defined in these nonalphabetic languages. Consider the case of Chinese. There is the complex issue in Chinese of what a word is, and there is far from universal agreement as to which two- to four-letter sequences of Chinese characters are words. As a result, research on Chinese neighborhood effects has begun by exploring neighborhood effects in Chinese characters. Given that the majority of Chinese characters can be decomposed into a semantic radical that provides a clue to meaning and a phonetic radical that provides a clue to pronunciation, a preliminary way to examine a character's neighborhood in Chinese is by separating phonetic radical neighborhoods (i.e., characters that share the phonetic radical) and semantic radical neighborhoods (i.e., words that share the semantic radical; see Li, Bi, Wei, & Chen, 2011 for recent research on phonetic radical neighborhoods). An alternative way to define a word's neighborhoods in Chinese is by taking into account the similarity at the stroke level. In particular, Wang, Jing, Weijin, Liversedge, and Paterson (in press) defined stroke neighbors in Chinese as characters that could be formed by substituting, adding, or deleting one or more character strokes. Their rationale was that a character's strokes could be considered analogous to letters in words, whereas radicals could be considered more analogous to morphemes. Importantly, Wang et al. (in press) found an inhibitory stroke neighborhood effect in masked priming and normal reading. Thus, these data paralleled the effects reported in alphabetic languages (see also Nakayama et al., 2011 for a similar finding in the syllabic script Kana). Although further research is needed to establish firm conclusions regarding the nature of lexical competition during visual word recognition, the data so far from Chinese and Japanese suggests that these processes may be common across alphabetic and nonalphabetic languages.

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