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The density constraint also occurs with unmasked, visible primes in the lexical decision task

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RUNNING HEAD: The density constraint in the LDT

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Abstract

The presence of stronger masked repetition/form priming effects for words with few orthographic neighbors than for words with many orthographic neighbors has been called the density constraint (Forster et al., 1987; Perea & Rosa, in press). Previous research suggests that, when target words are presented for long enough to allow complete retrieval and conscious identification, form-priming effects with masked and unmasked primes may qualitatively differ (Forster & Veres, 1998; Segui & Grainger, 1990). To analyze this possibility, the relationships between repetition/form priming effects and neighborhood density were analyzed in a lexical decision experiment with visible, unmasked primes at a 300-ms stimulus-onset asynchrony. The results show that repetition and form priming effects are smaller for words with many orthographic neighbors. The implications of these results for determining how neighbors affect the identification of a word are discussed.

Keywords: Masked-priming, orthographic-neighborhood, lexical-decision, repetition-priming.

A growing body of data indicates that, upon the visual presentation of a target word, similarly spelled words become partially activated and affect the speed of lexical access (see Andrews, 1997, for a review). Previous research has found facilitative effects of the number of orthographic neighbors or N (i.e., the number of words that can be created by changing one letter of the stimulus word, preserving letter positions; see Coltheart, Davelaar, Jonasson, & Besner, 1977; e.g., horse and mouse are orthographic neighbors of house) in lexical decision and naming tasks, at least for low-frequency words (Andrews, 1997). However, there is controversy over whether these facilitative N effects in the lexical decision task —or in the naming task— are indexing the speed of lexical access or, instead, are reflections of a different, task-specific, process (e.g., a familiarity assessment in the lexical decision task, see Forster & Shen, 1996; Grainger & Jacobs, 1996; Pollatsek, Perea, & Binder, 1999). For instance, data from recent eye-movement studies suggest that the orthographic neighbors have an inhibitory influence in the processing of a target word in normal (silent) reading (Perea & Pollatsek, 1998; Pollatsek et al., 1999).

What is worse, replication failures with different set of words are not unusual, which suggests that some confounds may have occurred in the materials (see Forster & Shen, 1996). Priming techniques offer a powerful complement to single-word experiments, since the target materials are held constant across the priming conditions (Forster, 1998). In this context, the masked priming technique (Forster & Davis, 1984; Forster, 1998; Forster, Davis, Schoknecht, & Carter, 1987) has been the most fruitful paradigm to study competition processes at the earliest stages of word recognition. In this paradigm, the priming stimulus is presented briefly (30-66 ms) just prior to the target. The prime is preceded by a forward pattern mask and, under these conditions, the trace of the prime is relatively inaccessible to conscious report. Prior research with the masked priming technique has found that target words are primed by visually similar nonword primes (relative to an unrelated control condition), although these effects are restricted to low-N target words (Forster, 1987; Forster et al., 1987; Forster & Davis, 1991; Forster & Taft, 1994; Perea & Rosa, in press). Similarly, masked repetition priming effects are stronger for low-N words than for high-N words (Perea & Rosa, in press). The presence of stronger priming effects for low-N words than for high-N words has been called the density constraint (Forster et al., 1987; Forster & Taft, 1994).

As Forster and Veres (1998) indicated, the masked priming effect can be interpreted in terms of a resolution/verification process in which the rapid transition from the prime to the target prevents the resolution process for the prime from being completed. In the entry-opening model (Forster & Davis, 1984), the recognition process of a masked prime is somewhat noisy, and, when the prime has many similarly spelled words, the identification system may not always open the correct lexical entry (see Perea & Rosa, in press). Alternatively, in the framework of an interactive activation (IA) model (McClelland & Rumelhart, 1981; see also Grainger & Jacobs, 1996), the masked presentation of a nonword prime with many neighbors (e.g., tace) should produce a significant rise in activation level of its word neighbors (e.g., face, race, etc.), which could produce some amount of lexical inhibition from the target's similar words. In the case of target words with few neighbors, the activation from the target's similar words will be negligible and only facilitation —via sublexical activation from the letter level— would be obtained. That is, the density constraint seems to fall out as a natural consequence of the recognition process in an IA model.

The main goal of this study is to analyze whether the density constraint is affected by awareness of the prime. (This experiment is a replication of the masked priming experiments of Perea and Rosa, in press.) To that end, participants will be presented unmasked, visible primes before target presentation (at a 300 ms stimulus-onset asynchrony, SOA). Previous research suggests that, when target words are presented for long enough to allow complete retrieval and conscious identification, form-priming effects with masked and unmasked primes may qualitatively differ, at least when words are used as form-related primes (e.g., see Drews & Zwitserlood, 1995; Forster & Veres, 1998; Segui & Grainger, 1990). When a nonword prime is presented for a long duration, the entry-opening model indicates that no exact match to the stimulus will be discovered and the resolution process would not be completed until additional evidence becomes available as to which candidate is the best match (Forster & Veres, 1998). This means that, when the prime is a nonword, the candidate entries for the prime will remain in an "open" state for a longer period of time, which will result in form-priming. Consistent with this view, Forster and Veres (1998) found that, when nonwords were used as primes, reliable form-priming effects (e.g., univorse-UNIVERSE) were obtained both with masked and unmasked primes (37 vs. 58 ms, at a 60- and a 500-ms

SOA, respectively). However, when words were used as primes, only the masked condition yielded a reliable form-priming effect. With respect to the predictions concerning the repetition priming effect with visible, unmasked primes, Forster and Davis (1984) also indicated that a repeated word may increase the perceived familiarity of the word, which may in turn decrease decision time (see Balota & Chumbley, 1984). This process will probably benefit more low-N words than high-N words: high-N words already have a high value of perceived familiarity, and hence the added familiarity of a recent encounter may have little impact.

The most obvious way to model the contrast between masked and unmasked priming in an IA model would be to vary the length of time for which the prime is presented. However, merely increasing the duration of the prime does not appear to produce any qualitative change in the pattern of priming effects in the model (see Forster & Veres, 1998). The original IA model incorrectly predicts an inhibitory main effect of N (see Grainger & Jacobs, 1996), since low-N words in the model are more easily discriminated from the other candidates than high-N words. To cope with the facilitative effect N in the lexical decision task, an extension of the IA model has been proposed (the multiple read-out model, Grainger & Jacobs, 1996) that incorporates the possibility of making decisions on the basis of the familiarity of the letter string. The latency of the decision in the multiple read-out model depends on which criterion, the criteria set on individual word unit activity (the M criterion, as in the original IA model) or the criterion on summed lexical activity (the sum of activations of all word detectors activated above zero; the Σ criterion), is reached first. If a given stimulus generates a high level of lexical activity at the early stages of word recognition, the Σ decision criterion is lowered, and hence high-N words (but not low-N words) can give rise to fast positive responses generated by the Σ criterion. This strategy would facilitate the processing of high-N words, but it would not affect the low-N words because they would never trigger a fast “word” response. This way, a facilitative main effect of N with unrelated targets would be expected. More important, if this strategy can be applied to the high-N words across the three prime types, it might serve to attenuate any priming effects associated with the recognition of a specific word.

Experiment

Method

Participants. A total of thirty-three psychology students from the University of València took part in the experiment to fulfill a course requirement. All of them either had normal vision or vision that was corrected-to-normal and were native speakers of Spanish.

Materials. Ninety two-syllable Spanish words, all of them of five letters, were selected as word targets from the Spanish word pool (Alameda & Cuetos, 1995). (The stimulus set used in the present experiment is the same as the one used in Perea & Rosa, in press, Experiment 1.) Forty-five words had no orthographic neighbors and the other forty-five words had at least nine orthographic neighbors (Mean N=9.9, range: 9-15). All the target words were of low-frequency, with a mean frequency of 12 (range: 1-28) per two million words for the low-N words, and a mean frequency of 12 (range: 1-31) for the high-N words. For each word target, three primes were selected: 1) identity (e.g., tifus-TIFUS; the Spanish for typhus-TYPHUS); 2) substitution-nonword (e.g., tigus-TIFUS); 3) control-word (e.g., penco-TIFUS; penco is the Spanish for nag). The substitution-nonword condition prime was always a nonword one letter different from the target in a middle position. The control prime was matched on number of syllables, number of letters, and word frequency with the identity prime. None of the control primes shared any letters in common in the same position with its corresponding target.

In addition, we used ninety disyllabic nonword targets, all of them of five letters. In all cases, nonwords were orthographically legal and had been constructed by changing one middle letter from a Spanish word other than one in the experimental set. Nonword targets had a mean of 3.2 orthographic neighbors (range 1-7). Nonwords targets were preceded by related word primes (the ones that were used to create the nonwords), identical primes, or unrelated word primes.

Procedure. Participants were tested individually (or in groups of two) in a quiet room. Presentation of the stimuli and recording of reaction times were controlled by Apple Macintosh Plus microcomputers. On each trial, the sequence (> <) was presented for 500 ms, followed by a 100-ms blank. Then the prime stimulus was presented centered for a duration of 200 ms, followed by a 100-ms blank. Finally, an uppercase target item was presented centered, which remained on the screen until the participant's response. Participants were instructed to press one of two buttons on the keyboard to indicate whether the uppercase letter string was a legitimate Spanish word or not (“;” for yes and “z” for no). Participants were instructed to make this decision as quickly and as accurately as possible. Reaction times were measured from target onset until the participant's response. After an inter-trial interval of 1.5 sec, the next trial was presented. Prime-target pairs were counterbalanced across three experimental lists so that if the identical pair tifus-TIFUS was in the first list, TIFUS would be preceded by its unrelated word prime, penco in the second list, and by its form-related prime, tigus in the third list. Stimulus presentation was randomized, with a different order for each participant. Each participant received a total of 20 practice trials (with the same manipulation as in the experimental trials) prior to the 180 experimental trials. The whole session lasted approximately 14 min.

Results

Incorrect responses (6.9% for words and 3.4% for nonwords) were excluded from the latency analysis. To avoid the influence of outliers, all reaction times more than 2.0 standard deviations above or below the mean for each participant in all conditions were also excluded from the latency analysis. Mean reaction times and percentage errors on word responses were submitted to an analysis of variance (ANOVA), with N (low-N words, high-N words), Prime type (identical, form-related, unrelated), and List (list 1, list 2, list 3) as factors. The factor ‘List’ was included in the ANOVA to extract the variance due to the lists (see Pollatsek & Well, 1995). List was a nonrepeated measures factor in the analysis by participants ($F1$), whereas N and Prime type were within-participants factors. In the analysis by items ($F2$), List and N were the nonrepeated measures factors. The statistical analysis of the nonwords was identical to that of the words, except that N was not included as a factor. Significance levels were less than .05 unless otherwise noted. The mean lexical decision time and the error rate on the stimulus words and nonwords in each experimental condition is displayed in Table 1.

Insert Table 1 about here

Word targets. The ANOVAs on the latency data showed that the main effect of prime type was significant, F1(2,60)=135.78, F2(2,168)=117.82, and so was the main effect of N, F1(1,30)=18.70, F2(1,84)=5.74. The influence of the prime was modulated by N, as reflected by the interaction between these two factors, F1(2,60)=29.11, F2(2,168)=11.02. This interaction reflected that the effect of N was facilitative for the unrelated targets (58 ms), F1(1,30)=31.79, F2(1,84)=21.45, but not for the form-related targets (8 ms), both Fs<1, or the identical targets (-5 ms), both Fs<1. The Prime type x N interaction also reflected that repetition priming effects differed as a function of N, F1(1,30)=29.81, F2(1,84)=17.71: repetition priming effects (relative to the unrelated control condition) were stronger for low-N words (143 ms), than for high-N words (90 ms). Finally, form-priming effects also differed as a function of N, F1(1,30)=11.26, F2(1,84)=14.89: form-priming effects occurred for low-N words (45 ms), F1(1,30)=22.23, F2(1,84)=19.92, but not for high-N words (-5 ms), both Fs<1.

The ANOVAs on the error data showed that the main effect of prime type was significant, F1(2,60)=10.40, F2(2,168)=7.69. The main effect of N was significant only in the analysis by participants, F1(1,30)=6.18, F2(1,84)=1.31, p>.15. The interaction between Prime Type and N was significant in the analysis by participants, F1(2,60)=3.18, but not in the analysis by items, F2(2,168)=2.09, p>.15. This interaction reflected an effect of prime type for low-N words, F1(2,60)=12.41, F2(2,168)=8.85, but not for high-N words, F1(2,60)=1.37, F2(1,84)=0.94.

Nonword targets. The latency analysis showed that the effect of prime type was statistically significant, F1(2,60)=31.09, F2(2,174)=44.02. Pairwise comparisons among means with Fisher's LSD procedure revealed that nonwords preceded by identical primes were responded to 41 ms faster than nonwords preceded by unrelated primes, F1(1,30)=35.70, F2(1,87)=40.09. Also, the 61 ms effect of form priming was significant, F1(1,30)=58.72, F2(1,87)=74.10. Finally, nonwords preceded by form-related primes were responded to 20 ms faster than nonwords preceded by identical primes, F1(1,30)=5.12, F2(1,87)=8.23. The ANOVA on the error data did not show any significant effects.

One could argue that we would need an unrelated nonword prime as a baseline for form priming for word targets —and for identity priming for nonword targets— because participants might make implicit lexical decisions to the prime (i.e., a nonword prime might have slowed response times to word targets because of the activation of two conflicting responses). However, for reasons having to do with design efficiency (i.e., to limit the number of priming conditions), these conditions were not included. Furthermore, even if such a bias might have somehow affected response latencies, it could not explain the density constraint for the identity condition. In addition, we would like to note that the lexical status of the unrelated prime does not appear to influence decision time with visible, unmasked primes (e.g., Bourassa & Besner, 1998; Zeelenberg, Pecher, de Kook, & Raaijmakers, 1998) or with masked primes (e.g., see Bourassa & Besner, 1998; Perea, Fernández, & Rosa, 1998). In fact, response competition effects at short SOAs only seem to occur when the instructions emphasize the importance of the prime (Zeelenberg et al., 1998).

Discussion

The results of this experiment are clear-cut. As in the masked priming experiments of Perea and Rosa (in press), 1) repetition priming effects are greater for low-N words than for high-N words, and 2) only low-N words yield form priming effects. Taken together, the present results strengthen the view that orthographic structure plays an important role in visual word recognition.

Not surprisingly, the magnitude of the unmasked repetition priming is dramatically increased relative to the masked priming experiments (the masked priming effects were about 35 and 70 ms for the high-N words and the low-N words, respectively; see Perea & Rosa, in press), as is the interaction with N. Under these conditions, repetition priming effects are too large to be interpreted as changes in lexical access times: Lexical decision times do not merely reflect speed in lexical access but episodic memory effects as well (e.g., perceived familiarity). Repeated items presumably have a high familiarity value than unrelated items, which may have aided the decision process to word stimuli in the lexical decision task. Interestingly, any changes in familiarity produced by priming should have opposite effects on responding “word” vs. “nonword” to the degree that familiarity is being used by the participants to make their lexical decisions (Balota & Chumbley, 1984). This explanation could readily account for the fact that facilitation of nonword targets was less for identity priming than for form-priming (see Table 1).

In addition, there is little change in the magnitude of the form priming effect, or its interaction with N, relative to the masked priming experiments (the effect was negligible for the high-N words and it was about 30-35 ms for the low-N words; see Perea & Rosa, in press). There is therefore no evidence of either qualitative differences between the effects of conscious and unconscious nonword primes, or of differences in the magnitude of the form priming effect at different prime exposures (see also Forster & Veres, 1998). The striking similarity of the pattern of form-priming effects across this range of exposure durations appears to imply that a form-related prime exerts the same influence on target identification whether it has been exposed for a very short interval, or for long enough to allow complete retrieval and conscious identification of the prime.

What are the implications of the present experiment for determining the locus of the neighborhood density effect on word identification? The fact that no reprocessing benefit from the form-related primes (relative to the unrelated control condition) was 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. In other words, it seems that competition between word units does appear to play a significant role in lexical access, as predicted by activation-based models of visual word recognition. (In these models, the lack of an inhibitory effect of N in a single-word lexical decision task would occur because lexical decisions can be made on the basis of the familiarity of the letter-string, see Grainger & Jacobs, 1996). Alternatively, in the framework of the entry-opening model, it could be argued that some processes could be abbreviated or omitted, leading to a process benefit for repeated words (Forster & Davis, 1984). As Forster and Davis indicated, the post-access orthographic check could be dispensed for repeated items, since it is highly unlikely that the same incorrect candidate entry is accessed twice. The savings will be greater for the low-N words, because the added familiarity of a recent encounter may have little impact for the —already familiar— high-N words.

Finally, there is another way of viewing the pattern of data of the present experiment. The interaction between repetition/form priming and neighborhood density also involved a neighborhood attenuation effect: the effect of N occurred for the unrelated targets (58 ms), but not for the form-related targets (8 ms), or the identical targets (-5 ms). In this light, it could be argued that the effect of N in the baseline condition could have been exaggerated by the presence of “related” primes. For instance, participants might have tried to anticipate unsuccessfully what word the prime comes from in a high-N condition (which causes inhibition in the unrelated high-N condition), whereas it would be relatively easy to anticipate the target word in a low-N condition. However, the magnitude of the facilitative effect of N in the baseline condition is similar to that found with the masked priming technique —in which expectancy processes are not operative— or with a single-word paradigm with a similar set of items (about 45-55 ms; Perea & Rosa, 1999, in press). Instead, 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 matters, it is the presence or absence of form-related or identical primes.

In sum, although activation-based models and the entry-opening model use quite different procedures to generate a set of candidates, both families of models seem to capture the basic pattern of effects obtained in the present experiment. Current research in our lab is focused on the density constrain in the naming task. If perceived familiarity is the only factor responsible for the density constraint, N should not affect the effect of repetition/form-priming in naming.

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Authors' notes

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Table 1

Mean lexical decision times (in ms) and percentage of errors (in parentheses) on word and nonword targets in the experiment

	Type of prime				
	Repeated	Form-Related	Unrelated	Rep. Priming	Form Priming
Words					
Low-N	632 (3.8)	730 (9.5)	775 (10.9)	143 (7.1)	45 (1.4)
High-N	637 (4.4)	722 (5.9)	717 (6.9)	90 (2.5)	-5 (1.0)
Nonwords	764 (3.2)	744 (3.2)	805 (3.6)	41 (0.4)	61 (0.4)

Note: Rep. Priming refers to the difference between the unrelated and the identical condition and Form priming refers to the difference between the unrelated and the form-related condition.