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EFFECTS OF MASKED REPETITION PRIMING AND ORTHOGRAPHIC NEIGHBORHOOD IN VISUAL RECOGNITION OF WORDS[1]

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Summary.—The role of orthographic neighborhood (neighborhood size and neighborhood frequency) in visual-word recognition was analyzed using the masked repetition-priming paradigm. Specifically, we varied stimulus-onset asynchrony (33, 50, and 67 msec.) and type of prime (identical, unrelated, unprimed) in a lexical-decision task. Analyses show additive effects of repetition and stimulus-onset asynchrony. Further, the unrelated condition overestimated the repetition effects relative to an unprimed condition. Facilitatory effects of neighborhood size and inhibitory effects of neighborhood frequency were also found. The results are interpreted in terms of current models of visual-word recognition.

Visual-word recognition is assumed to involve a series of highly efficient mechanisms capable of identifying and selecting a lexical unit from a large number of words similar to the stimulus in about 150 to 200 msec. (20). Thus, investigations of the effects of lexical similarity (or orthographic neighborhood) can provide insights into the processes underlying the recognition of words.

Models and Measures

Most current models of visual word-recognition (cf. 10 for review) assume that word-identification is preceded by a selection of the appropriate lexical item from a relatively small set of word candidates whose specifications are roughly consistent with the perceptual analysis of the stimulus word. Previous studies (1, 6, 10, 17) have equated the set of candidate words with the definition of orthographic neighbor (3): any word that can be created by changing one letter of the stimulus word, while preserving letter positions. In other words, the presentation of the word "house" would activate lexical units similar to that of "house" such as "horse," "mouse," etc.

Two basic measures of orthographic neighborhood have been proposed: neighborhood frequency and neighborhood size. Neighborhood size (or Colt-

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heart's N) refers to the number of orthographic neighbors of a given word, and it is an estimate of the initial cohort of candidates. Several investigations have shown a facilitatory effect of the number of neighbors on words in the lexical decision task (1, 2, 21, cf. 3) and the naming task (1, 2, 21). The effect of neighborhood frequency (11) indicates that words with neighbors which are more frequent than the stimulus word are recognized more slowly than are words without higher frequency neighbors. This effect has been found in lexical decision (10, 11, 13, cf. 8, 21), durations of eye gaze (11), and speeded identification tasks (13).

Serial models that assume higher frequency words in the set of candidates are checked before lower frequency words [search model (5) and activation-verification model (18)] predict an inhibitory effect of the number of higher frequency neighbors and a null effect of the number of neighbors *per se*. Activation models based on a competition among partially activated word units in which the most frequent words enjoy the most activation for a brief period of time, e.g., interactive activation (IA) model (16) can accommodate the inhibitory neighborhood frequency effects but not the facilitatory neighborhood size effects in the lexical decision task (14). Nonetheless, the multiple read-out model (12)—an expansion of the IA model—can predict both facilitatory effects of neighborhood size and inhibitory effects of neighborhood frequency in the lexical decision task depending on the depth of processing of the stimuli. Finally, the Seidenberg and McClelland model (23) predicts both facilitatory effects of neighborhood size and frequency (21).

Masked Repetition Priming and Orthographic Neighborhood

A useful tool to examine the influence of neighborhood on the process of word recognition is the masked priming paradigm (7). In this technique, a mask is presented for 500 msec. in the center of a computer screen and is immediately replaced by the prime (about 60 msec.), followed by the target. Using this technique, the effects of repetition and word frequency appear to be additive in the lexical decision task (7, 22, 24). In a series of experiments, Seguí and Grainger (22) found similar effects for repetition at a 60-msec. stimulus-onset asynchrony for high-frequency words without higher frequency neighbors and for low-frequency words with higher frequency neighbors. However, they also found significant inhibitory effects when primes were higher frequency neighbors of the target at the 60-msec. stimulus-onset asynchrony (but not when primes were lower frequency neighbors of the target), which suggests that neighborhood frequency could interact with repetition. Jacobs and Grainger (14) successfully simulated both experiments on the interactive activation model. The remaining question is whether or not at shorter stimulus-onset asynchronies, the prime remains more activated than its more frequent neighbors. In addition, serial search models (5, 7) assume that the presentation of the masked prime leaves the lexical representation of the prime in a moderately excited effect. Since that effect influences equally each word in the lexicon, it should be independent of word frequency or orthographic neighborhood. However, the fact that orthographic priming effects have been found especially for words with few neighbors (6) raises some doubts about the independence of orthographic neighborhood and repetition.

The present experiment analyzed the role of orthographic neighborhood (neighborhood size and frequency) in the masked repetition priming at several very short stimulus-onset asynchronies (33, 50, and 67 msec.) in the lexical decision task. Because the lexical processing of a given word can be altered by the existence of the prime word, we included a condition in which target words were preceded by a blank sequence (unprimed condition).

METHOD

Subjects

Eighty-seven students from introductory psychology courses at the Universitat de València participated in the experiment to earn additional course credit.

Materials

A total of 45 Spanish words of four letters were compiled. There were 15 words in each level of orthographic neighborhood: Category 1, low-N words without higher frequency neighbors, Category 2, high-N words without higher frequency neighbors, and Category 3, high-N words with at least one higher frequency neighbor. The characteristics of the target words are presented in Table 1.

Forty-five nonwords of four letters were created to complete the stimuli for the lexical decision task. None of the targets (word or nonword) were orthographic neighbors to each other. Three conditions depending upon type of prime and target were used: identical, unrelated, and unprimed targets (a blank prime). Ninety unrelated word primes (always four letters long)

TABLE 1
CHARACTERISTICS OF TARGET WORDS USED IN THE EXPERIMENT

Word Class	Frequency, *f*		Coltheart's N		Number of High *f*	
	M	Range	*M*	Range	*M*	Range
Category 1	24.5	5–51	0.6	0–2	0.0	0–0
Category 2	24.6	6–47	7.8	5–11	0.0	0–0
Category 3	24.6	9–37	8.3	5–11	1.7	1–3

Note.—Frequency refers to the printed frequency based on a count of 500,000 Spanish words (14). Coltheart's N refers to the number of orthographic neighbors, and Number of high *f* refers to the number of higher frequency neighbors.

that did not share any letters in the same position with their respective targets were also selected. Pairs of prime and target were counterbalanced across three experimental lists. The font and size used for the stimuli were Courier 12 point.

Design

Stimulus-onset asynchrony (33, 50, and 67 msec.) was varied between subjects (27 subjects at 33 msec., 30 subjects at 50 msec., and 30 subjects at 67 msec.), whereas prime-target relatedness (identical, unrelated, unprimed) and orthographic neighborhood (Category 1, Category 2, and Category 3) were varied within subjects. Each subject was given a total of 90 experimental trials: 45 word-word trials (15 identical, 15 unrelated, and 15 unprimed pairs) and 45 word-nonword trials (15 unprimed and 30 unrelated pairs).

Procedure

Subjects were tested individually in a quiet room. Presentation of the stimuli and recording of reaction times were controlled by Apple Macintosh Plus microcomputers. On each trial, a forward mask (####) was presented for 500 msec. on the center of the screen. Next, the lowercase prime word (or a blank sequence in the unprimed trials) was presented in the center for 33, 50, or 67 msec. Primes were then replaced by the uppercase target item. Subjects were instructed to press one of two buttons on the keyboard (";" for yes and "z" for no) to indicate whether the uppercase string of letters was a Spanish word or not. This decision had to be done as quickly and as accurately as possible. When the subject responded, the target disappeared from the screen. After an intertrial interval of 1,500 msec., the next trial was presented. Subjects were not informed of the presence of lowercase words. Each subject received a total of 18 practice trials prior to the 90 experimental trials. The whole session lasted approximately 10 min.

Results

Plan of Analysis

Extreme reaction times (more than 2.0 standard deviations above or below the mean for that subject in all conditions) and incorrect responses were excluded from the analysis of latency. Analyses of variance were performed over both subjects and items.

Separate analyses were conducted for RT and errors in words, with stimulus-onset asynchrony (33, 50, and 67 msec.), orthographic relatedness (identical, unrelated, and unprimed), and orthographic neighborhood (Category 1, Category 2, and Category 3) as principal factors. Also, planned comparisons were carried out to analyze the separate effects of orthographic neighborhood: neighborhood size (Category 1 vs Category 2) and neighborhood frequency (Category 2 vs Category 3). The mean latencies for decisions and rates of error in each condition are displayed in Table 2.

TABLE 2
MEAN LEXICAL DECISION TIMES (IN MSEC.) AND PERCENTAGE OF ERRORS ON TARGET WORDS IN THE EXPERIMENT

Stimulus-onset Asynchrony	Prime-target Relatedness							
	Identical		Unrelated		Unprimed		Unrelated, Identical	Unprimed, Identical
	M_{Time}	% Error	M_{Time}	% Error	M_{Time}	% Error		
33 msec.								
Category 1	638	8.9	677	5.3	643	8.2	39	5
Category 2	620	3.0	661	0.7	630	1.5	41	10
Category 3	639	0.7	667	0.7	646	2.2	28	7
50 msec.								
Category 1	622	8.7	658	10.1	634	6.7	36	12
Category 2	611	1.3	626	4.0	612	2.0	15	1
Category 3	615	2.7	650	1.3	622	1.3	35	7
67 msec.								
Category 1	631	7.4	656	4.7	653	6.7	25	22
Category 2	606	2.0	661	2.7	627	2.7	55	21
Category 3	612	1.3	653	2.7	641	1.3	41	29

Analysis of Response Time

The main effect of relatedness was significant ($F1_{2,168}=45.56$, $MSe=1805$, $p<.001$, $F2_{2,108}=23.38$, $MSe=546$, $p<.001$). *HSD* Tukey tests showed that unrelated targets were responded to more slowly than repeated targets (657 vs 634 msec., $p<.05$). Moreover, the latter conditions were responded to more slowly than unprimed targets (621 msec.). The effect of repetition across the three stimulus-onset asynchronies (33, 50, and 67 msec.) relative to unrelated targets was 36, 29, and 40 msec., respectively. In contrast, the repetition effect relative to unprimed targets was significant only at the 67-msec. stimulus-onset asynchrony (24 msec.; $F1_{1,29}=11.96$, $MSe=2172$, $p<.002$; $F2_{1,36}=9.76$, $MSe=414$, $p<.004$), but not at the 33- and 50-msec. stimulus-onset asynchronies (in both cases, 7 msec., $p>.20$). The main effect of orthographic neighborhood was also significant ($F1_{2,168}=13.71$, $MSe=1452$, $p<.001$; $F2_{2,108}=7.92$, $MSe=546$, $p<.001$). No other effects were significant.

Planned comparisons[2] showed reliable effects of neighborhood size ($F1_{1,84}=24.61$, $MSe=1606$, $p<.001$; $F2_{1,72}=12.82$, $MSe=671$, $p<.001$) and neighborhood frequency ($F1_{1,84}=9.26$, $MSe=1401$, $p<.004$; $F2_{1,72}=8.28$, $MSe=325$, $p<.006$).

Analysis of Errors

The analysis of variance showed a reliable effect of orthographic neigh-

[2]Since there were no signs of an interaction between orthographic neighborhood and repetition, we analyzed the over-all effects of orthographic neighborhood (not only for the unprimed condition).

borhood ($F1_{2,168}=36.60$, $MSe=72.7$, $p<.001$; $F2_{2,108}=17.33$, $MSe=26.5$, $p<.001$). No other effects were significant.

Planned comparisons showed a significant effect of neighborhood size ($F1_{1,84}=35.74$, $MSe=98.6$, $p<.001$; $F2_{1,72}=16.34$, $MSe=36.3$, $p<.001$): words from small neighborhoods were responded to less accurately than words from large neighborhoods (7.4% vs 2.2%). The effect of neighborhood frequency was not significant ($F1_{1,84}=1.37$; $F2<1.00$).

Discussion

The main finding of this study is that, as with word frequency and repetition (7, 22, 24), masked priming effects did not differ as a function of neighborhood size or frequency at several very short stimulus-onset asynchronies (33, 50, and 67 msec.). A pilot experiment carried out in our lab at the 67-msec. stimulus-onset asynchrony also gave a similar pattern of results (19).

To explain how this result can be accommodated in the interactive activation model (16) we carried out a series of simulations on the same stimuli used in our experiment. The results showed no interaction between orthographic neighborhood and repetition at very short stimulus-onset asynchronies (19). In addition, if search models assume that priming by repetition is a lexical effect, e.g., via a file "relatively" open when an entry has been accessed (7), the effect of repetition should be independent of orthographic neighborhood.

As predicted by most current models of visual word recognition [however, see the simulations on the Seidenberg and McClelland (23) model (21)], inhibitory effects of neighborhood frequency were found in the latency analysis. That is, higher frequency neighbors appear to interfere with the processing of their less frequent neighbors. In addition, we also found facilitatory effects of number of neighbors on the lexical decision task (1, 2, 21). However, when the same materials were used in speeded identification tasks, the effect of neighborhood size was not significant (19), whereas there were inhibitory effects of neighborhood frequency. Possibly, the facilitation of number of neighbors in the lexical decision task may be interpreted in terms of decisions based on the familiarity of the letter sequence rather than on a lexical access (12, 17, 25).

One final methodological note, using the unrelated condition as a baseline overestimated the repetition effect in masked repetition priming at short stimulus-onset asynchronies relative to that in an unprimed condition. Inhibitory effects of unrelated targets relative to unprimed targets appeared even at the 33-msec. stimulus-onset asynchrony, although the absence of a blank interval between the forward mask and the target might have enhanced the inhibitory effect of the prime in the unrelated condition. Thus, it appears that an analysis in terms of costs and benefits of primes on the perceptual system is needed (4), and we should be very cautious in interpreting masked priming effects as facilitatory or inhibitory.

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