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## **Phonology and Orthography in Visual Word Recognition: Evidence from Masked Non-word Priming**

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Three lexical decision experiments in French investigated the effects of briefly presented forward-masked non-word primes on latencies to phonologically and/or orthographically related targets. At 64-msec prime presentation durations, primes that are pseudohomophones of the target produced facilitatory effects compared to orthographic controls, but these orthographically similar non-word primes did not facilitate target recognition compared to unrelated controls. These results were obtained independently of target word frequency and independently of the presence or absence of pseudohomophone targets in the experimental lists. With a 32-msec prime duration, on the other hand, pseudohomophone and orthographic primes had similar effects on target recognition, both producing facilitation relative to unrelated controls. The results are discussed in terms of the time course of phonological and orthographic code activation in the processing of pronounceable strings of letters.

An important current debate in the field of visual word recognition concerns the possible role of phonological information in the processing of isolated printed words. One view based on the fact that people learn to speak before they learn to read is that words are stored as phonological representations in memory, and therefore access to these representations must be phonologically mediated. In this case, visual word recognition would be essentially phonologically based, the printed word being translated into a phonological code before accessing the phonological representation for that word in the mental lexicon (Rubenstein, Lewis, &

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Rubenstein, 1971; Van Orden, 1987; Van Orden, Johnston, & Hale, 1988). The opposite view is that visual word recognition does not require access to phonological information and would, therefore, be accomplished on the basis of purely orthographic information, with no role played by phonology (Baron, 1973). In-between these two extremes lies the position that phonology is one of a number of sources of information used in the visual word recognition process (Meyer, Schvaneveldt, & Rudy, 1974; Waters & Seidenberg, 1985; Seidenberg, 1985).

### Homophone and Pseudohomophone Interference

One approach to the study of phonological influences on visual word recognition that is used to defend the position that lexical access is phonologically mediated takes advantage of the widespread homophony of the English language (e.g. MAID homophonic with MADE) and of the possibility of creating non-words that sound like English words (pseudohomophones, e.g. BRANE sounds like the word BRAIN). In their seminal study, Rubenstein et al. (1971) observed that lexical decision latencies are longer to the less frequent member of a heterographic homophone pair (e.g. SAIL-SALE) compared to words that are not homophones. This homophone interference effect arises, according to these authors, because words are stored as phonological representations in a mental lexicon ordered by frequency. Thus the first representation encountered in a frequency-ordered lexical search is the higher-frequency member of the homophone pair (SAIL in the above example). After a spelling verification and rejection of this word the search continues to the less frequent member (SALE), thus incurring slower recognition times for this word. However, Coltheart, Davelaar, Jonasson, and Besner (1977) failed to replicate this effect when controlling for frequency and part of speech in the homophones and their non-homophonic controls. They nevertheless observed a consistent pseudohomophone interference effect in the same experiment—that is, pseudohomophones (such as BRANE) took longer to reject in a lexical decision task than non-words that looked but did not sound like a word (e.g. SLINT)—an effect also observed by Rubenstein et al. (1971). When pseudohomophones are removed from the experimental lists, however, longer lexical decision latencies are observed to the less frequent members of homophone pairs (Davelaar, Coltheart, Besner, & Jonasson, 1978). These authors suggest that because the presence of pseudohomophones induces subjects to make more false positive errors, they might abandon a phonological encoding “strategy” to improve performance.

However, more recent experiments on homophone processing by Van Orden and his colleagues (Van Orden, 1987; Van Orden et al., 1988) provide evidence that phonological information is automatically (non-optionally) generated in visual word recognition. Van Orden (1987)

reported that subjects produced larger false positive error rates in a semantic categorization task when asked to say whether ROWS is A FLOWER (i.e. ROWS homophonic with category exemplar, ROSE), compared to whether ROBS (orthographic control) is a flower. These results suggest that the letter sequence ROWS has been encoded phonologically and is contacting the lexical representation for ROSE. This then gives rise to interference in subjects' decision-making, as ROSE is, indeed, a flower, whereas ROWS is not. Van Orden et al. (1988) replicated Van Orden's (1987) results and extended this finding to pseudohomophones (e.g. SUTE as AN ARTICLE OF CLOTHING). These results suggest that phonological encoding is not strategically variable as hypothesized by Davelaar et al. (1978), but that it is automatically generated in the processing of written words. Davelaar et al.'s results could be attributed to the strategic control of processing particular to the lexical decision task, such as a post-access spelling/sound check. More weight could be given to spelling or sound in this checking process, depending on the type of non-words in the experimental lists. Assigning more weight to spelling in the presence of pseudohomophone distractors, thus reducing errors on this type of non-word, would then lead to improved discriminability of homophone pairs (e.g. HARE-HAIR).

### Masked Phonological Priming

Further evidence for the automatic generation of phonological information during the processing of written words comes from priming experiments using visual masking procedures and very brief prime presentation durations. The advantage of using such procedures is that explanations of any priming effects observed in terms of variations in target predictability can generally be excluded. For the target to be predictable from the prime, the prime must be visible in the first instance.

In a primed perceptual identification task where both primes and targets were masked, Evett and Humphreys (1981) compared differences in performance between phonologically similar prime-target pairs (e.g. file-TILE) and unrelated controls (loft-TILE), as well as between orthographically similar but phonologically dissimilar prime-target pairs (e.g. couch-TOUCH) and unrelated controls (flown-TOUCH). They failed to observe any priming effect of the phonologically similar pairs over and above the orthographically similar controls. Nevertheless, in a subsequent study using the same paradigm, Humphreys, Evett, and Taylor (1982) established a facilitatory effect of phonological priming on target identification when primes were homophones of targets (e.g. maid-MADE). The important finding was that the phonological priming effects observed here occurred over and above any effects due to orthographic similarity between primes and targets (e.g. maze-MADE), suggesting an automatic phonological activation process in visual word recognition. In contrast,

Humphreys et al. (1982) demonstrated that non-words that sounded like the target did not produce a priming effect (e.g. BRANE did not facilitate the subsequent report of BRAIN any more than did the orthographic control BRANT). The authors therefore concluded that phonological priming is postlexical and occurs via a lexical route (see Humphreys & Evett, 1985, for a discussion on this point).

Nevertheless, more recent experiments contradict Humphreys et al.'s (1982) conclusion, suggesting instead that there is an automatic activation of prelexical phonology. Using a perceptual identification task in which the prime stimulus served as a backward mask for the target, Perfetti, Bell, and Delaney (1988) (see also Naish, 1980) reported phonological facilitation effects over and above purely orthographic effects. The percentage of correct identification for phonologically primed targets (e.g. MADE primed by a non-word mask that sounds like the target word, MAYD) was significantly higher than that obtained with orthographically primed targets (e.g. MADE primed by MARD). This facilitatory effect is explained by the authors in terms of a rapid activation of "phonetic units" by the corresponding "graphemic units", these phonetic units in turn increasing the activation level of any word units that contain them.

Recently, Lukatela and Turvey (1990a), using a similar backward masking paradigm, reported the same pattern of results for Serbo-Croatian. This language can be written in two different alphabets (Roman and Cyrillic) and therefore allows a complete separation of phonology and orthography. Using the lexical decision task, Lukatela and Turvey (1990b) and Lukatela, Carello, and Turvey (1990a) reported a facilitatory effect under forward masking conditions. When phonologically similar primes were presented very briefly with forward pattern masks, each prime differing from its target in alphabet and case (e.g. Cyrillic prime in lower case, Roman target in upper case), Lukatela and Turvey (1990b) found a facilitatory effect for phonologically similar non-word-word and word-non-word pairs. Lukatela et al. (1990a) also found a facilitatory priming effect with phonologically similar word-word pairs and non-word-non-word pairs.

These results seriously compromise Humphreys et al.'s (1982) conclusion that phonological priming is postlexical and occurs via a lexical route. Instead, the above experiments (Perfetti et al., 1988; Lukatela & Turvey, 1990a; Lukatela et al., 1990a; Van Orden, 1987) all converge to suggest that these facilitatory effects are due to the automatic, prelexical activation of phonological information. More recent research by Perfetti and his colleagues (Perfetti & Bell, 1991; Perfetti & Zhang, 1991) adds further support to this conclusion and indicates a possible source of the discrepancy between Humphreys et al.'s (1982) and Perfetti et al.'s (1988) results. Perfetti and Bell (1991) varied prime presentation duration in a forward-

masked primed perceptual identification task. At 35-msec prime durations (approximately the same as used by Humphreys et al., 1982), they replicated Humphreys et al.'s (1982) results, showing graphemic but not phonemic priming with non-word primes. With longer prime durations (up to 65 msec), graphemic priming remained constant, and a phonemic priming effect appeared over and above this graphemic effect.

The results of Perfetti and Bell (1991) therefore suggest that prime duration is critical in determining the presence of masked phonological priming. In the present experiments we attempt to replicate this phonological priming effect using RT in the lexical decision task as the dependent measure. Experiment 1 compares performance to French target words preceded by non-word primes that are either pseudohomophones of the target (e.g. *lont*-LONG, with identical pronunciations in French), orthographically related to the target (e.g. *lonc*-LONG), or unrelated to the target (e.g. *tabe*-LONG), using a 64-msec prime exposure. Experiment 2 tests the non-strategic nature of these phonological priming effects by repeating Experiment 1 with pseudohomophone targets added to the experimental lists. Experiment 3 tests the effects of reducing prime exposure to 32 msec on phonological and orthographic priming in the lexical decision task.

## EXPERIMENT 1

### Method

*Stimuli and Design.* Sixty word targets all 4 letters long were selected using French-language frequency counts (*Trésor de la langue Française*, 1971). Half had high printed frequencies (461 occurrences per million) and the remaining half low printed frequencies (17 occurrences per million). For each target word, 3 types of non-word prime were selected: (1) Non-word primes that were both orthographically related (differing by only one letter in any position) and homophonic with the target (e.g. *lont*-LONG); (2) non-word primes that were orthographically related (in the same way as category 1) but not homophonic with the target (e.g. *lonc*-LONG); (3) non-word primes that were unrelated to the target (e.g. *tabe*-LONG). Priming condition was crossed with target frequency in a 3×2 factorial design. Prime-target pairs were rotated across the priming conditions across three groups of subjects, such that no subject saw any single prime or target word more than once, but each subject received all three experimental conditions. Every subject saw 60 non-word-prime/word-target pairs, 10 from each condition. Sixty non-word-prime/non-word-target pairs were constructed for the purposes of the lexical decision task. In 20 of these pairs the non-word targets were primed by a non-word that was homophonic with and orthographically related to the target (e.g. *trat*-

TRAS); 20 other non-word targets were preceded by orthographically related non-homophonic non-word primes (e.g. clof-CLON), and 20 other non-word targets preceded by unrelated non-word primes (e.g. biam-SARS). Subjects were presented with 20 practice trials before doing the experiment proper. These consisted of 10 non-word-word and 10 non-word-non-word pairs, none of which appeared in the experimental trials, all 4 letters long and selected from the same frequency range as the experimental stimuli.

*Procedure.* Stimuli were presented in isolation at the centre of the display screen of an Olivetti M24 personal computer. The items appeared on the screen as green characters on a dark background. Each character (in upper case) covered approximately  $0.38^\circ$  of visual angle from a viewing distance of 60 cm, so that a four-letter word subtended about  $1.53^\circ$  of visual angle. The masked prime procedure with the lexical decision task used in the experiments of Forster and Davis (1984) was adopted here. Each trial consisted of the following sequence of three stimuli: first a forward mask consisting of a row of four hash-marks (####) was presented for 500 msec; this was immediately followed by presentation of the prime stimulus for 64 msec, which was immediately followed by presentation of the target stimulus, both presented at the same screen location as the mask. The target remained on the screen until subjects responded. Primes were always presented in lower case and targets in upper case in order to minimize physical overlap with orthographically related pairs. Subjects were instructed to respond as rapidly and as accurately as possible whether or not the letter string in upper case that remained on the screen was a French word. The existence of a prime stimulus was not mentioned. Subjects responded "yes" by pressing one of two response buttons with the forefinger of the preferred hand and "no" by pressing the other response button with the forefinger of the non-preferred hand. The next sequence followed after a 1-sec delay. Stimulus presentation was randomized, with a different order for each subject. Reaction times, measured from target onset until subjects' response, were accurate to the nearest millisecond.

*Subjects.* Thirty psychology students at René Descartes University, Paris, served as subjects for course credit. All were native speakers of French, with normal or corrected-to-normal vision.

## Results

Mean lexical decision latencies and percent errors are given in Table 1. The latencies were trimmed applying a 1000-msec cutoff (2.6% of the data rejected). Priming condition (pseudohomophone prime, orthographic prime, and unrelated control) and target frequency were entered as main

TABLE 1  
 Mean Lexical Decision Latencies<sup>a</sup> and Percentage of Errors<sup>b</sup> to Targets Preceded by Phonologically and/or Orthographically Related or Unrelated Non-word Primes in Experiment 1

<i>Condition</i>	<i>Example</i>	<i>RT<sup>a</sup></i>	<i>%ER<sup>b</sup></i>
<i>High-frequency words</i>			
Orthographically similar pseudohomophone prime	lont-LONG	582	5.33
Orthographically similar prime	lonc-LONG	601	5.66
Unrelated control	tabe-LONG	605	3.33
<i>Low-frequency words</i>			
Orthographically similar pseudohomophone prime	klan-CLAN	607	11.66
Orthographically similar prime	slan-CLAN	641	10.66
Unrelated control	jjnc-CLAN	644	12.66
<i>Non-word targets</i>			
Orthographically similar pseudohomophone prime	trat-TRAS	710	9.33
Orthographically similar prime	clof-CLON	692	5.0
Unrelated control	biam-SARS	697	3.7

<sup>a</sup>RT given in msec.

<sup>b</sup>%ER = percentage of errors.

Note: 64-msec SOA.

factors in an analysis of variance of the data for words targets. The non-word results were analysed separately, with priming condition as the main factor.

*Reaction-Time Data.* *F* values are reported by subject (*F*<sub>1</sub>) and by item (*F*<sub>2</sub>). There was a significant main effect of target frequency, *F*<sub>1</sub>(1, 27) = 31.51, *p* < 0.001 and *F*<sub>2</sub>(1, 58) = 11.12, *p* < 0.01; higher-frequency targets were responded to more rapidly than lower-frequency targets. There was also a main effect of priming condition, *F*<sub>1</sub>(2, 54) = 11.57, *p* < 0.001 and *F*<sub>2</sub>(2, 116) = 9.81, *p* < 0.001. Planned comparisons indicated that primes that were pseudohomophones of the target facilitated target recognition relative to the orthographic controls, *F*<sub>1</sub>(1, 27) = 15.76, *p* < 0.001 and *F*<sub>2</sub>(1, 58) = 15.12, *p* < 0.001, and relative to the unrelated controls, *F*<sub>1</sub>(1, 27) = 19.36, *p* < 0.001 and *F*<sub>2</sub>(1, 58) = 16.1, *p* < 0.001. Orthographically related primes, on the other hand, did not affect processing relative to the unrelated condition (*F*<sub>1</sub> < 1 and *F*<sub>2</sub> < 1). The Target Frequency × Priming Condition interaction was not significant [*F*<sub>1</sub>(2, 54) = 1.04 and *F*<sub>2</sub> < 1].



An analysis of variance on the non-word reaction times showed that priming condition did not significantly affect performance [ $F(2, 58) = 3.09$  and  $F2 < 1$ ]. There was, however, a trend for primes that were pseudohomophones of the target to slow non-word responses compared to orthographically related primes,  $F(1, 29) = 5.63$ ,  $p < 0.05$ , and  $F(1, 36) = 1.13$ .

*Error Data.* An analysis of variance performed on the error data for the word targets showed a significant effect of target frequency,  $F(1, 27) = 19.88$ ,  $p < 0.001$ ; lower-frequency targets produced more errors than higher-frequency targets. The effect of priming condition and the Priming Condition  $\times$  Target Frequency interaction were not significant (both  $F_s < 1$ ). There was a significant effect of priming condition on errors to the non-word targets,  $F(2, 58) = 5.86$ ,  $p < 0.05$ . Primes that were pseudohomophones of the targets caused significantly more errors than either orthographically related primes,  $F(1, 29) = 5.21$ ,  $p < 0.05$ , or unrelated primes,  $F(1, 29) = 7.89$ ,  $p < 0.025$ . The orthographically related primes did not affect performance compared to the unrelated primes [ $F(1, 29) = 1.35$ ].

## Discussion

The results of Experiment 1 show clear facilitatory effects of masked pseudohomophone primes on lexical decision latencies to word targets. The present experiment confirms the existence of phonological priming, with prime exposures of about 60 msec previously observed in perceptual identification (Perfetti et al., 1988; Perfetti & Bell, 1991). These results therefore provide further support for the general hypothesis that phonological information is rapidly and automatically generated in the processing of pronounceable strings of letters.

Contrary to the results of Perfetti et al. (1988) and Perfetti and Bell (1991), however, we failed to observe any facilitation from orthographically related primes in Experiment 1. In related unpublished work on orthographic priming with non-word primes, orthographically related primes did not affect target processing at a 64-msec SOA, but inhibitory effects appeared with longer prime exposures. This pattern of orthographic and phonological priming can be accommodated within the framework of the interactive activation model (McClelland & Rumelhart, 1981) in the manner described in Figure 1.

First, the model must be extended to form a triangular structure of sublexical orthographic units linked to their corresponding phonological units, both of which are directly connected to word units that contain them (cf. Rumelhart & McClelland, 1982; Lukatela, Carello, & Turvey, 1990b). Within this framework, connections between word units are uniquely

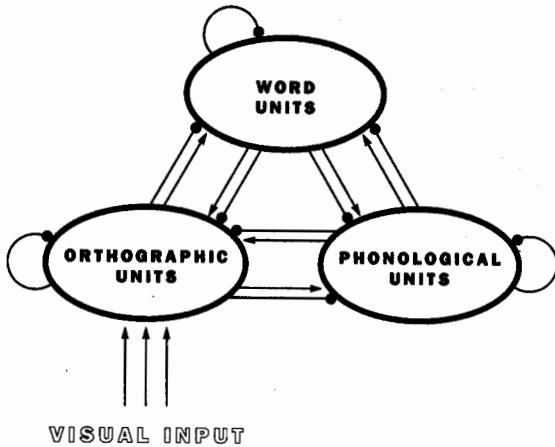


FIG. 1. A possible extension of the interactive activation model (adapted from McClelland & Rumelhart, 1981) where visual input from a given letter string activates a set of orthographic units (letters or letter clusters), which, in turn, send activation on to both word units and phonological units.

inhibitory (within-level inhibition), whereas connections between different types of unit (orthographic, phonological, word) are primarily facilitatory (between-level facilitation). This structure then allows a precise analysis of the time-course of information flow during the word-recognition process, and more particularly the interaction between the early development of feedforward between-level facilitation and the later build-up of within-level inhibition.

Orthographic units activated by the visual input will simultaneously feedforward activation to both word and phonological units. Phonological units then feedforward activation to the word level, and while this facilitatory flow of information from the phonological to the word level is occurring, within-level inhibition is also developing at the word level from units directly activated by orthographic information. Lexical-level inhibition is primarily a function of prime-target orthographic overlap (the target word's letters continue to sustain activation of lexical representations already activated by the prime stimulus) and is therefore approximately equivalent for the orthographically related and pseudohomophone primes. As the pseudohomophone primes add extra feedforward phonological facilitation compared to the orthographically related primes, then in conditions where between-level orthographic facilitation is cancelled by within-level lexical inhibition, the pseudohomophone primes continue to facilitate target recognition.

The fact that pseudohomophone primes tended to have an inhibitory effect on non-word responses provides further support for the above

explanation. The interactive activation framework can easily be extended as a model of lexical decision by implementing a criterion level of activation of a given word unit necessary to trigger a "yes" response (Grainger, 1990; Jacobs & Grainger, in press) and by implementing a variable deadline necessary to trigger "no" responses (Coltheart et al., 1977). This temporal threshold could be set as a function of the degree of word-level activity in the model in the initial processing cycles. Pseudohomophone primes would cause a greater increase in the activation level of a particular lexical representation than would orthographically related primes. This would then facilitate the recognition of this particular word, as it would take less time to reach a critical activation level for identification. On the other hand, the more lexical representations are activated during the processing of a non-word target, the more difficult it would be to respond "no" in the lexical decision task.

## EXPERIMENT 2

If the pseudohomophone priming observed in Experiment 1 is indeed a prelexical effect resulting from the automatic activation of sublexical phonological units, then it should not be influenced by the type of non-word foils used in the lexical decision task. Thus, the presence of pseudohomophones as target stimuli should not influence the facilitation observed in Experiment 1. This was tested in Experiment 2 by introducing pseudohomophones among the non-word targets with the same word targets as Experiment 1.

### Method

*Stimuli and Design.* The design was identical to Experiment 1, and the stimuli were the same as in Experiment 1, except that pseudohomophones were introduced in the experimental lists as non-word targets. Thirty new non-word-non-word pairs were therefore constructed using pseudohomophones as targets. In ten of these pairs the pseudohomophone targets were primed by orthographically similar non-words that were homophonic with the target (e.g. *coue*-*COUS*, both of which are not French words and are pronounced identically to the French word *COUP*). Ten other pseudohomophone targets were primed by orthographically similar non-words (e.g. *labe*-*LARE*), and ten other pseudohomophone targets were primed by unrelated non-words (e.g. *fien*-*RAIS*). Thirty other non-word targets were presented in the same three priming conditions as the pseudohomophone targets.

*Procedure.* This was identical to Experiment 1.

*Subjects.* Thirty psychology students at René Descartes University, Paris, served as subjects for course credit. All had normal or corrected-to-normal vision and were native speakers of French. None of these subjects had participated in Experiment 1.

## Results

Mean lexical decision latencies and percent errors are given in Table 2. The latencies were trimmed applying a 1000-msec cutoff (3.1% of the data rejected). Priming condition (pseudohomophone prime, orthographic prime, and unrelated control) and target frequency were entered as main factors in an analysis of variance of the word data. The non-word results were analysed separately with priming condition and type of non-word (pseudohomophone or not) as main factors.

TABLE 2

Mean Lexical Decision Latencies<sup>a</sup> and Percentage of Errors<sup>b</sup> to Targets Preceded by Phonologically and/or Orthographically Related or Unrelated Non-word Primes with Pseudohomophone Distractors in Experiment 2

<i>Condition</i>	<i>Example</i>	<i>RT<sup>a</sup></i>	<i>%ER<sup>b</sup></i>
<i>High-frequency words</i>			
Orthographically similar pseudohomophone prime	lonc-LONG	587	5.33
Orthographically similar prime	lonc-LONG	608	7.76
Unrelated control	tabe-LONG	603	2.0
<i>Low-frequency words</i>			
Orthographically similar pseudohomophone prime	klan-CLAN	619	14.0
Orthographically similar prime	slan-CLAN	640	13.66
Unrelated control	jinc-CLAN	638	11.33
<i>Pseudohomophone non-word targets</i>			
Orthographically similar pseudohomophone prime	coue-COUS	777	20.0
Orthographically similar prime	labe-LARE	738	15.7
Unrelated control	fien-RAIS	750	20.0
<i>Non-word targets</i>			
Orthographically similar pseudohomophone prime	trat-TRAS	701	5.0
Orthographically similar prime	clof-CLON	680	5.0
Unrelated control	biam-SARS	704	6.3

<sup>a</sup>RT given in msec.

<sup>b</sup>%ER = percentage of errors.

Note: 64-msec SOA.

*Reaction Time Data.* There was a significant main effect of target frequency,  $F_1(1, 27) = 36.0$ ,  $p < 0.001$  and  $F_2(1, 58) = 10.42$ ,  $p < 0.01$ , higher-frequency targets were responded to more rapidly than lower-frequency targets. There was also a main effect of priming condition,  $F_1(2, 54) = 5.68$ ,  $p < 0.01$  and  $F_2(2, 116) = 6.52$ ,  $p < 0.01$ . Planned comparisons indicated that pseudohomophone primes facilitated target recognition relative to the orthographic controls,  $F_1(1, 27) = 10.41$ ,  $p < 0.01$  and  $F_2(1, 58) = 11.72$ ,  $p < 0.005$ , and to the unrelated controls,  $F_1(1, 27) = 6.04$ ,  $p < 0.05$  and  $F_2(1, 58) = 7.65$ ,  $p < 0.01$ , whereas orthographically related primes did not affect processing relative to the unrelated condition [ $F_1(1, 27) < 1$  and  $F_2(1, 58) < 1$ ]. There was no interaction between target frequency and priming condition [ $F_1(2, 54) < 1$  and  $F_2(2, 116) < 1$ ].

An analysis of variance on the non-word reaction times showed that pseudohomophone targets were responded to more slowly than non-homophonic non-word targets,  $F_1(1, 29) = 33.29$ ,  $p < 0.001$  and  $F_2(1, 48) = 12.07$ ,  $p < 0.01$ . There was also a significant main effect of priming condition in the subject analysis,  $F_1(2, 58) = 4.51$ ,  $p < 0.05$  and  $F_2(2, 54) = 2.80$ . Planned comparisons indicated that primes that were pseudohomophones of the targets tended to slow non-word responses compared to orthographically related primes,  $F_1(1, 29) = 10.54$ ,  $p < 0.01$ , and  $F_2(1, 36) = 3.31$ . Priming condition did not interact with type of non-word [ $F_1 < 1$  and  $F_2 < 1$ ].

*Error Data.* An analysis of variance performed on the errors to word targets showed a significant effect of target frequency,  $F(1, 27) = 25.43$ ,  $p < 0.0001$ , and a significant main effect of priming condition,  $F(2, 54) = 3.63$ ,  $p < 0.05$ . Both of the related conditions produced more errors than did the unrelated condition. The Target Frequency  $\times$  Priming Condition interaction was not significant [ $F(2, 54) < 1$ ]. An analysis of the errors to the non-word targets showed that pseudohomophones produced more errors than non-pseudohomophone targets,  $F(1, 29) = 74.1$ ,  $p < 0.001$ . The main effect of priming condition on errors to the non-word targets was not significant [ $F(2, 58) = 1.94$ ]; neither was the interaction between these two factors [ $F(2, 58) = 1.13$ ].

## Combined Analysis of Experiments 1 and 2

In order to examine the effects of adding pseudohomophones to the experimental lists on responses to word targets, a combined analysis of the RT data from Experiments 1 and 2 was performed with presence or absence of pseudohomophones as a between-subjects factor. This analysis showed a main effect of priming condition,  $F_1(2, 116) = 16.1$ ,  $p < 0.001$  and  $F_2(2, 116) = 10.3$ ,  $p < 0.001$ , a main effect of target frequency,

$F_1(1, 58) = 68.1, p < 0.001$  and  $F_2(1, 58) = 21.3, p < 0.001$ , and no effect of adding pseudohomophones to the experimental lists [ $F < 1$ ]. None of the interactions between these three factors was significant [all  $F_s < 1$ ]. An analysis of the error rates from both experiments showed a significant main effect of frequency,  $F(1, 58) = 41.92, p < 0.001$ . None of the other main or interaction effects was significant.

## Discussion

In Experiment 2 pseudohomophone primes continued to facilitate target recognition, even with pseudohomophone targets present in the experimental lists. These pseudohomophone targets were nevertheless responded to more slowly and less accurately than non-homophonic non-words. This result suggests therefore that these facilitatory pseudohomophone priming effects are indeed prelexical effects that are uninfluenced by the type of non-word distractors.

The significant priming effect on the error data to word targets observed in Experiment 2 goes against the RT results. A closer examination of Table 2 indicates, however, that this cannot be attributed to speed-accuracy trade-offs. Where facilitatory effects of phonological priming were observed in the RT data (pseudohomophone prime versus orthographic controls), there was a corresponding decrease in the error rates. On the other hand, where error rates increased the most (orthographically related primes versus unrelated controls), there was also a slight increase in RT.

The inhibitory effects of orthographic prime/target overlap observed in the error data of Experiment 2 could be the result of within-level inhibition from lexical representations that are partially activated by the prime. Within the framework described in Figure 1, this lexical level inhibition builds up once information has been fed forward from sublexical orthographic units and therefore takes longer to develop than between-level orthographic facilitation. According to this analysis, decreasing prime duration should decrease inhibition, thus allowing between-level orthographic facilitation to appear. Moreover, according to the time course analysis presented in the discussion of Experiment 1, with shorter prime exposures between-level phonological facilitation should no longer be observable (Perfetti & Bell, 1991). Experiment 3 tests these predictions.

## EXPERIMENT 3

### Method

*Stimuli and Design.* The design and stimuli were the same as in Experiment 1.

*Procedure.* The same procedure as Experiment 1 was used, except that the SOA was reduced to 32 msec.

*Subjects.* Thirty psychology students at René Descartes University, Paris, served as subjects for course credit. All had normal or corrected-to-normal vision and were native speakers of French. None of these subjects had participated in the previous experiments.

## Results

Mean lexical decision latencies and percent errors are given in Table 3. The latencies were trimmed applying a 1000-msec cutoff (2.9% of the data rejected). Priming condition (pseudohomophone prime, orthographic prime, and unrelated control) and target frequency were entered as main factors in an analysis of variance of the word data. The non-word results were analysed separately, with priming condition as main factor.

*Reaction Time Data.* There was a significant main effect of target frequency,  $F(1, 27) = 44.88, p < 0.001$  and  $F(1, 58) = 10.55, p < 0.005$ , higher-frequency targets being responded to more rapidly than lower-

TABLE 3

Mean Lexical Decision Latencies<sup>a</sup> and Percentage of Errors<sup>b</sup> to Targets Preceded by Phonologically and/or Orthographically Related or Unrelated Non-word Primes in Experiment 3

<i>Condition</i>	<i>Example</i>	<i>RT<sup>a</sup></i>	<i>%ER<sup>b</sup></i>
<i>High-frequency words</i>			
Orthographically similar pseudohomophone prime	lont-LONG	558	4.0
Orthographically similar prime	lonc-LONG	563	7.33
Unrelated control	tabe-LONG	593	7.33
<i>Low-frequency words</i>			
Orthographically similar pseudohomophone prime	klan-CLAN	599	13.0
Orthographically similar prime	slan-CLAN	604	14.0
Unrelated control	jinc-CLAN	620	15.33
<i>Non-word targets</i>			
Orthographically similar pseudohomophone prime	trat-TRAS	656	10.7
Orthographically similar prime	clof-CLON	638	6.0
Unrelated control	biam-SARS	633	3.0

<sup>a</sup>RT given in msec.

<sup>b</sup>%ER = percentage of errors.

Note: 32-msec SOA

frequency targets. There was also a main effect of priming condition,  $F1(2, 54) = 7.77$ ,  $p < 0.01$  and  $F2(2, 116) = 9.09$ ,  $p < 0.001$ . Planned comparisons indicate that pseudohomophone primes facilitated target recognition relative to the unrelated controls,  $F1(1, 27) = 26.98$ ,  $p < 0.001$  and  $F2(1, 58) = 20.94$ ,  $p < 0.001$ . Orthographically related primes also facilitated target recognition relative to unrelated controls,  $F1(1, 27) = 4.81$ ,  $p < 0.05$ , and  $F2(1, 58) = 9.09$ ,  $p < 0.005$ . However, pseudohomophone primes did not produce facilitatory effects over and above orthographically related primes [ $F1(1, 27) = 1.74$  and  $F2(1, 58) < 1$ ]. There was no Target Frequency  $\times$  Priming Condition interaction [ $F1(2, 54) = 1.24$  and  $F2(2, 116) < 1$ ].

An analysis of variance on the non-word reaction times (using a 1500-msec cutoff eliminating 0.6% of the data) showed a significant effect of priming condition in the subject analysis,  $F1(2, 58) = 4.97$ ,  $p < 0.05$  and  $F2(2, 54) = 2.80$ . The only planned comparison to reach significance by both subject and item was the difference between pseudohomophone primes and unrelated primes,  $F1(1, 29) = 7.36$ ,  $p < 0.05$ , and  $F2(1, 36) = 7.01$ ,  $p < 0.05$ .

*Error Data.* An analysis of variance performed on the error rates to word targets showed a significant effect of target frequency,  $F(1, 27) = 20.76$ ,  $p < 0.001$ ; lower-frequency targets produced more errors than did higher-frequency targets. The effect of priming condition and the interaction between these two factors were not significant [ $F(2, 54) = 1.66$  and  $F(2, 54) < 1$ , respectively]. There was a significant effect of priming condition on errors to the non-word targets,  $F(2, 58) = 8.74$ ,  $p < 0.01$ . Primes that were pseudohomophones of the targets caused significantly more errors than did either orthographically related primes,  $F(1, 29) = 5.06$ ,  $p < 0.05$ , or unrelated primes,  $F(1, 29) = 20.16$ ,  $p < 0.01$ . The orthographically related primes did not affect performance compared to the unrelated primes [ $F(1, 29) = 2.99$ ].

### Combined Analysis of Experiments 1 and 3

In order to provide a more direct examination of the influence of prime presentation duration on orthographic and phonological priming effects on word recognition, a combined analysis of the RT data from Experiments 1 and 3 was performed with prime duration (32 msec or 64 msec) as a between-subjects factor. There were main effects of priming condition,  $F1(2, 116) = 22.7$ ,  $p < 0.001$  and  $F2(2, 116) = 12.5$ ,  $p < 0.001$ , and target frequency,  $F1(1, 58) = 80.9$ ,  $p < 0.001$  and  $F2(1, 58) = 21.9$ ,  $p < 0.001$ . Prime duration did not significantly affect RTs [ $F1(1, 58) = 2.3$  and  $F2 < 1$ ] but did significantly interact with priming condition,  $F1(2, 116) = 4.1$ ,  $p < 0.05$  and  $F2(2, 116) = 5.7$ ,  $p < 0.05$ . None of the



other interactions was significant. Planned comparisons indicated that prime duration interacted with the effects of phonological priming,  $F(1, 58) = 6.6, p < 0.05$  and  $F(1, 58) = 5.2, p < 0.05$ , and the effects of orthographic priming,  $F(1, 58) = 5.4, p < 0.05$  and  $F(1, 58) = 4.7, p < 0.05$ . An analysis of the error data showed a significant main effect of target frequency,  $F(1, 58) = 40.1, p < 0.001$ . None of the other main or interaction effects was significant.

## Discussion

Reducing the prime duration to 32 msec produced significant facilitatory effects of orthographically related non-word primes. On the other hand, pseudohomophone primes no longer produce significant facilitation over and above their orthographic controls while continuing to produce facilitation to the unrelated controls. Within the framework presented in Figure 1, this result suggests that after 32 msec of prime processing the activation levels of sublexical orthographic units have become strong enough to produce clear facilitatory effects on subsequent target identification. On the other hand, the feedforward of activation from these orthographic units to both lexical and phonological units has not yet become strong enough to produce clear influences on target recognition.

It is, nevertheless, evident from both the error data to word targets and the RT and error data to non-word targets (Table 3) that some influences of phonological activation do remain at 32-msec prime exposures. Non-word targets continued to be harder to reject when primed by a pseudohomophone, thus suggesting that these primes were producing more lexical-level activation. This would also explain why fewer errors occurred to word targets preceded by pseudohomophone primes compared to the orthographically related primes.

## GENERAL DISCUSSION

The results of the present experiments may be summarized as follows. When prime stimuli were presented for 64 msec, orthographically related non-word primes (e.g. lonc-LONG with distinct pronunciations in French) did not facilitate target recognition relative to unrelated non-word prime controls. On the other hand, non-word primes that were both orthographically related and homophonic with the target (e.g. lont-LONG, pronounced identically in French) facilitated target recognition relative to both the orthographically related and unrelated non-word primes. These effects were not conditioned by target frequency and remained unaffected by the presence of pseudohomophones as non-word targets. When prime stimuli were presented for 32 msec, non-words that were homophonic with targets

did not produce facilitation over and above the orthographically related non-words. However, both these conditions produced facilitatory effects relative to the unrelated condition. The different effects of prime exposure on orthographic and phonological priming are presented in Figure 2.

### Masked Phonological Priming

The fact that non-word primes that were homophonic with word targets facilitated target processing compared to orthographic controls (Experiments 1 and 2) provides further support for the general hypothesis that phonological information is rapidly and automatically generated in the processing of pronounceable strings of letters. This result corroborates prior observations of facilitatory pseudohomophone priming using the perceptual identification task (Naish, 1980; Perfetti et al., 1988; Perfetti & Bell, 1991). The fact that these effects can be observed in the lexical decision task, and independently of the presence or absence of pseudohomophone targets, is an indication of their robustness. Lukatela et al. (1990a) have also demonstrated facilitatory priming in the lexical decision task with phonologically related non-word primes that were orthographically distinct (written in a different alphabet) from the targets. All these results taken together strongly suggest that phonological information is generated extremely rapidly during the processing of pronounceable strings of letters and that this information influences the word-recognition process. The fact that phonological facilitation practically disappeared

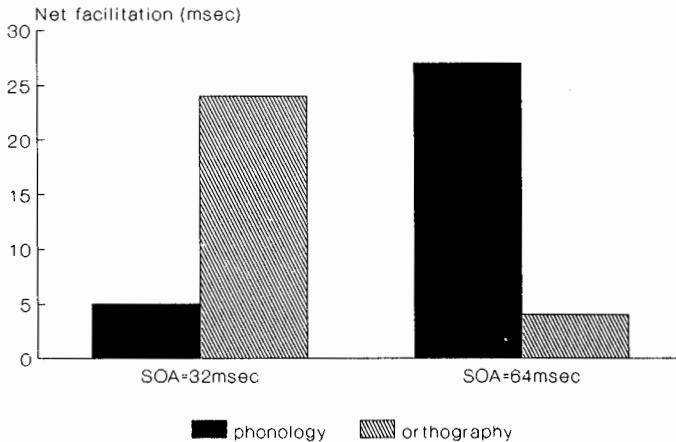


FIG. 2. Net priming effects in milliseconds observed in Experiment 1 (64-msec SOA) and Experiment 3 (32-msec SOA) to targets preceded by phonologically related primes (compared to orthographic controls) and orthographically related primes (compared to unrelated controls).

when prime presentation duration was reduced to 32 msec (Experiment 3) places a lower temporal limit on the build up of phonological information in the particular presentation conditions used in the present experiments.

### Masked Orthographic Priming

Briefly presented masked orthographically related non-word primes did not affect lexical decision latencies to high and low frequency targets at a 64-msec SOA, whereas the same primes produced facilitatory effects at a shorter 32-msec SOA. In related unpublished work we observed the same null effect of orthographically related non-word primes at a 64-msec SOA while demonstrating that with longer SOAs (100 msec and 350 msec) the same non-word primes produced inhibitory effects. Thus, the general picture that emerges from the SOA manipulations in these experiments and the present study is that orthographically related non-word primes tend to produce facilitatory effects with very brief prime durations, while inhibitory effects develop with longer SOAs.

Within the framework of the interactive activation model (McClelland & Rumelhart, 1981) presented in Figure 1, within-level effects are uniquely inhibitory, but between-level effects can be both facilitatory and inhibitory. Thus, if the prime stimulus activates sublexical information (orthographic and/or phonological) shared by the target word, then target processing will be facilitated. At the same time, prime stimuli that share sublexical information with the target will also activate lexical representations similar to the target, thus leading to within-level inhibition during target processing. Thus, according to this view of the visual word recognition process, facilitatory effects should develop with shorter prime durations, whereas inhibitory effects will tend to develop as prime presentation duration increases. This relationship between prime duration and type of effect (inhibition or facilitation) has been observed for orthographically related non-word primes. The same pattern of results has also been observed with orthographically related word primes in recent experimental work in our laboratory. With SOAs varying from 16 msec to 80 msec, orthographically related word primes produced increasing inhibition relative to unrelated controls.

One final discrepancy with other data that can be explained within the interactive activation framework concerns the degree of orthographic overlap between prime and target. In the present experiments all the stimuli were four letters long. Using the same experimental procedures but with longer stimuli (e.g. *bontrast-CONTRAST*), Forster, Davis, Schoknecht, and Carter (1987) demonstrated significant facilitatory effects at a 64-msec SOA. This result has been replicated more recently by Sereno (1991) with a similar paradigm and stimuli of similar length (e.g. *wondow-WINDOW*). With these stimuli orthographic overlap (expressed as the per-

centage of letters in the target that are shared by the prime) is at 83–88%, whereas in our experiments the overlap is only 75%. It is clear within the interactive activation framework that facilitatory form priming effects should be a function of prime–target overlap. More direct evidence for such a relationship has been provided by Humphreys, Evett, and Quinlan (1990). These authors directly manipulated prime–target overlap in the primed perceptual identification paradigm of Evett and Humphreys (1981). The results demonstrated that priming effects increased non-linearly as a function of both the number and the position of the shared letters.

## Conclusions

The present results are a modest contribution to the growing literature on masked form priming effects in visual word recognition. They demonstrate the robustness of the phenomenon observed in this field of research across different languages and experimental paradigms. At the theoretical level, the present article has shown the utility of the interactive activation model as a general framework for understanding these phenomena. The implementation of sublexical phonological units and their connections with corresponding orthographic units should figure among the future developments of this type of model.

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