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## **Effects of Orthography Are Independent of Phonology in Masked Form Priming**

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Briefly presented forward-masked primes that share letters with a word target have been shown to facilitate performance in different word recognition tasks. However, in all the experiments that have previously reported these facilitatory effects, related primes not only shared more letters with the target than did unrelated primes (orthographic priming), but they also shared more phonemes (phonological priming). The stimuli used in the present experiments allow us to separate out the effects of orthographic priming from phonological priming. Varying prime exposure duration from 14 to 57 msec, it is shown that effects of orthography follow a distinct time-course from the effects of phonology, and that orthographic facilitation does not result from a confound with phonological prime-target overlap.

Perhaps the simplest way of describing a written word is as the ordered combination of its component letters (e.g. *white* = *W+H+I+T+E*). Many models of visual word recognition (e.g. Forster, 1976; McClelland & Rumelhart, 1981; Paap, Newsome, McDonald, & Schvaneveldt, 1982) assume that recognizing a printed word involves accessing such an orthographic description in memory. In such models, visual word recognition requires the preliminary processing of component letter identities and their position in the target string. These models clearly predict, therefore, that providing supplementary information about a target word's component letters should facilitate the recognition of this word. Research on orthographic priming effects in visual word recognition where prime stimuli share letters with the target provides support for such a conception of the word recognition process.

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## Masked Orthographic Priming

Perhaps the strongest evidence in favour of an automatic prelexical coding of orthographic information during visual word recognition has been provided by priming experiments using visual masking procedures and very brief prime presentation durations. The advantage of using such procedures is that strategic/predictive explanations of any priming effects observed can generally be excluded, as primes are barely visible. Priming effects observed with this paradigm are considered as automatic and not the result of subjects' intentional use of primes to predict following targets.

In primed perceptual identification paradigm where both primes and targets are masked and briefly presented in different case, the percentage of correct target identification has been shown to vary as a function of prime-target orthographic overlap (Evetts & Humphreys, 1981; Humphreys, Evett, Quinlan, & Besner, 1987). Thus, word targets preceded by orthographically similar word primes (e.g. *couch-TOUCH*) are easier to recognize than when preceded by unrelated controls (e.g. *flown-TOUCH*). Related research (Humphreys, Evett, & Quinlan, 1990; Naish, 1980; Perfetti & Bell, 1991; Perfetti, Bell, & Delaney, 1988) has shown that target identification is also improved with orthographically similar nonword primes (e.g. *mave-MOVE* compared to *fand-MOVE*). These facilitatory effects of orthographic priming with nonword primes have also been observed with reaction time (RT) as the dependent measure in the lexical decision task (Ferrand & Grainger, 1992, 1993; Forster, 1987; Forster, Davis, Schoknecht, & Carter, 1987; Sereno, 1991).

All these results, therefore, provide strong support for the hypothesis that orthographic information (information about a word's component letters and how they are combined) plays a primary role in visual word recognition. This position contrasts with the hypothesis that printed words are recognized by their global form (Johnson, 1977), and more particularly with the hypothesis that visual word recognition is essentially phonologically mediated (Rubenstein, Lewis, & Rubenstein, 1971; Spoehr & Smith, 1973). The latter hypothesis states that as spoken language ontogenetically precedes written language, words are represented phonologically and not orthographically in the mental lexicon, and therefore lexical access is necessarily phonologically mediated.

## Orthography and Phonology in Visual Word Recognition

Recently, a large body of evidence has been collected showing that phonological information influences performance in primed visual word recognition tasks such as perceptual identification (Lukatela & Turvey, 1990a; Perfetti & Bell, 1991; Perfetti et al., 1988), and lexical decision (Ferrand

& Grainger, 1992, 1993; Lukatela, Carello, & Turvey, 1990; Lukatela & Turvey, 1990b). In all the above-cited experiments, performance to word targets was superior when preceded by phonologically related primes (e.g. *mayd-MAID*) than when preceded by orthographic controls (e.g. *maid-MAID*). The above experiments all converge to suggest that these facilitatory effects are due to the automatic, prelexical activation of phonological information in visual word recognition. Thus, using a masked priming procedure with the lexical decision task, Ferrand and Grainger (1992) observed only orthographic facilitation and no phonological facilitation with a 32-msec prime duration. With 64-msec prime exposures, however, they replicated the existence of phonological priming previously observed in perceptual identification (Perfetti & Bell, 1991; Perfetti et al., 1988) and showed that this phonological facilitation obtains independently of the presence or absence of pseudohomophone targets in the experimental lists. This result suggests that these phonological facilitatory effects are indeed prelexical and not strategically driven.

Ferrand and Grainger (1992) interpreted this pattern of orthographic and phonological priming effects within the framework of a modified version of the interactive activation model initially developed by McClelland and Rumelhart (1981). The architecture of the model is characterized by a triangular organization, including a layer of sublexical orthographic units, a layer of sublexical phonological units, and a level of lexical representations (word level). This triangular organization involves direct connections from orthographic units to both word units and phonological units, phonological units also being directly connected to the word level. On presentation of a written word, the visual input activates a set of orthographic units (letters or letter clusters), which, in turn, send activation on to the word and phonological units that are directly linked to these activated orthographic units. In this way the build-up of activation at the lexical and phonological levels lags behind the build-up of activation at the orthographic level. This means that at very short prime exposures (e.g. 32 msec) only orthographic units will be sufficiently activated to facilitate subsequent target recognition. With longer prime exposures (e.g. 64 msec), however, both phonological and word units will be more activated and hence capable of influencing subsequent target recognition. Activated word units will inhibit target word recognition via within-level inhibition, whereas activated phonological units will provide facilitatory input to the target representation and hence facilitate recognition. Thus, at prime exposures of around 60 msec, facilitatory effects of phonological prime-target overlap are present, but the facilitatory effects of orthographic overlap are cancelled by lexical inhibition.

According to this conception of the visual word recognition process, orthographic information is fed directly into the mental lexicon without

any prior transformation into a phonological code. However, some authors (Lukatela & Turvey, 1991; Van Orden, Pennington, & Stone, 1990) have recently claimed that visual word recognition is entirely phonologically mediated. These authors propose that there is no direct link between orthographic units and word units, and in support of this they point out that in all the studies reporting facilitatory effects of orthographically related primes, these primes were also phonologically related to the targets. Thus, for example, in the experiments of Ferrand and Grainger (1992), at 32-msec prime exposures we claimed to have observed an orthographic facilitation effect, as orthographically related primes in French (e.g. *pien-PIED*) facilitated target recognition relative to unrelated controls (e.g. *tabe-PIED*). However, the orthographically related primes were also phonologically related to targets (even if *PIEN* and *PIED* are pronounced differently in French, they do share phonemes). This is problematical in that we cannot know if we have observed orthographic facilitation, phonological facilitation, or a combination of both. It is, however, unlikely to be a purely phonological effect, because the phonologically related pairs (*piez-PIED*, pronounced identically in French) did not add facilitation over and above the orthographically related condition (*pien-PIED*).

It is possible to isolate a purely orthographic effect with French stimuli by creating pairs of pseudohomophone stimuli that either are or are not orthographically related. This experiment was designed to test the effects of orthographic and phonological priming with briefly presented masked pseudohomophone primes through prime durations ranging from 14 msec to 57 msec. In order to isolate a pure effect of orthography, we compare performance to French target words preceded by pseudohomophone primes that are either orthographically related to the word target (e.g. *mert-MERE*, pronounced identically in French) or orthographically unrelated to the target (e.g. *mair-MERE*, pronounced identically in French). In French it is possible to create such pairs of pseudohomophones that vary in terms of their orthographic relatedness to the base word (*mert/mair/MERE*), which is almost impossible in English due to the greater number of spelling-to-sound irregularities in this language. An approximate English example would be "*cawl-CALL*" compared to "*korl-CALL*".

Table 1 summarizes the logic underlying stimulus selection in the present experiment. In the stimulus set used by Ferrand and Grainger (1992), a pure effect of phonology can be estimated as orthographic overlap is held constant while varying phonological overlap. In the stimulus set used in the present experiment, a pure effect of orthography can be estimated, as phonological overlap is held constant while varying orthographic overlap.

Experiment 1 traces the time-course of orthographic and phonological code activation in the early stages of visual word recognition using very short prime durations. Assuming that orthographic information contacts

TABLE 1

	<i>Shared Letters<sup>a</sup></i>	<i>Shared Phonemes<sup>a</sup></i>
<i>Examples of pairs in Ferrand &amp; Grainger (1992)</i>		
Orthographically similar pseudohomophone prime (e.g. <i>piez-PIED</i> )	75%	100%
Orthographically similar prime (e.g. <i>pien-PIED</i> )	75%	60%
Unrelated prime (e.g. <i>tabe-PIED</i> )	0%	0%
<i>Examples of pairs used in Experiment 1</i>		
Orthographically similar pseudohomophone prime (e.g. <i>mert-MERE</i> )	75%	100%
Orthographically dissimilar pseudohomophone prime (e.g. <i>mair-MERE</i> )	25%	100%
Unrelated prime (e.g. <i>toul-MERE</i> )	0%	0%

<sup>a</sup>At identical position.

lexical representations before phonological information does (Ferrand & Grainger, 1992), we are led to predict that the effects of prime-target orthographic overlap should appear earlier than the effects of phonological overlap. On the other hand, if we assume a primary role of phonology in visual word recognition, with little or no role played by orthography (as recently claimed by Lukatela & Turvey, 1991), we only expect to observe effects of phonological prime-target overlap and no effect of orthography throughout the four prime exposures.

## EXPERIMENT 1

### Method

*Subjects.* Eighty-four psychology students at René Descartes University, Paris, served as subjects for course credit, 21 in each of the four prime duration conditions (14-msec, 29-msec, 43-msec, and 57-msec). All were native speakers of French, with normal or corrected-to-normal vision.

*Stimuli and Design.* Thirty monosyllabic word targets all 4 letters long were selected such that for each target word 3 types of non-word prime could be generated: (1) non-word primes that are both homophonic with and orthographically similar (differing by only one letter) to the target

(e.g. *mert*–*MERE*); (2) non-word primes that are orthographically unrelated (maximum one letter shared in the correct position) but homophonic with the target (e.g. *mair*–*MERE*); (3) non-word primes that are unrelated (orthographically and phonologically) to the target (e.g. *toul*–*MERE*). The average printed frequency of the word targets was 260 occurrences per million (*Trésor de la langue Française*, 1971). Four prime durations were used: 14 msec, 29 msec, 43 msec, and 57 msec. Thus, priming condition (within-subjects) was crossed with prime duration (between-subjects) in a  $3 \times 4$  factorial design. Prime–target pairs were rotated across the priming conditions across three groups of subjects (for each prime duration) such that no subject saw any single prime or target word more than once, but each subject received all three priming conditions. Every subject saw 30 non-word–prime/word–target pairs, 10 from each condition. A complete list of the stimuli is presented in the Appendix. Thirty non-word–prime/non-word–target pairs were constructed for the lexical decision task. In ten of these pairs the non-word targets were primed by a non-word that was homophonic with but orthographically dissimilar to the target (e.g. *vaur*–*VORD*). Ten other non-word targets were preceded by orthographically related and homophonic non-word primes (e.g. *jaud*–*JAUX*), and ten other non-word targets preceded by unrelated non-word primes (e.g. *buir*–*COGE*). However, these 30 non-word/non-word pairs could not be rotated across the different priming conditions because of the limited number of such stimuli. As different non-word targets were tested in the different priming conditions, these data were not presented for analysis. 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 on the centre of the display screen of an AT286 personal computer with a 70-Hz refresh rate. The items appeared on the screen as white 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 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 Ferrand and Grainger (1992) 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 the presentation of the prime stimulus (for 14 msec, 29 msec, 43 msec or 57 msec), which was immediately followed by presentation of the target stimulus, both presented in 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.

## Results

Mean lexical decision latencies and percentages of errors are given in Table 2 for each prime duration. The latencies were trimmed applying a 1000-msec cutoff (2.5%, 2.2%, 1.9%, and 2.6% of the data rejected for each prime duration, respectively). An overall analysis of variance (ANOVA) of the RT data for word targets was performed with Priming Condition (homophonic and orthographically similar prime, homophonic but orthographically dissimilar prime, and unrelated prime) and Prime Duration entered as main factors. *F* values are reported by subject ( $F_1$ ) and by item ( $F_2$ ).

TABLE 2  
Mean Lexical Decision Latencies<sup>a</sup> and Percentage of Errors to Targets Preceded by Orthographically and/or Phonologically Related or Unrelated Non-word Primes Throughout the Four Prime Durations in Experiment 1

<i>Priming Condition</i>	<i>Prime Duration<sup>b</sup></i>			
	<i>14</i>	<i>29</i>	<i>43</i>	<i>57</i>
Orthographically similar pseudohomophone prime (e.g. <i>mer</i> - <i>MERE</i> )	559 (8.09)	591 (5.23)	569 (7.14)	601 (9.52)
Orthographically dissimilar pseudohomophone prime (e.g. <i>mair</i> - <i>MERE</i> )	570 (8.09)	618 (5.28)	575 (7.61)	596 (10.0)
Unrelated prime (e.g. <i>toul</i> - <i>MERE</i> )	573 (10.0)	644 (6.19)	594 (7.14)	637 (8.09)

<sup>a</sup>Decision latencies in msec.

<sup>b</sup>Prime duration in msec.

Note: Percentages of errors in parentheses.



There are significant main effects of Priming Condition,  $F_1(2, 144) = 19.41, p \ll 0.0001$  and  $F_2(2, 116) = 17.03, p \ll 0.0001$ , and of Prime Duration,  $F_1(3, 72) = 3.10, p < 0.05$  and  $F_2(3, 108) = 4.85, p < 0.005$ , and a significant Prime Duration  $\times$  Priming Condition interaction,  $F_1(6, 144) = 2.56, p < 0.05$  and  $F_2(6, 216) = 1.81$ . An ANOVA performed on the error data for the word targets showed no main or interaction effects, all  $F_s < 1$ .

Planned comparisons between orthographically similar pseudohomophone primes and orthographically dissimilar pseudohomophone primes (i.e. effects of orthographic priming) showed a significant (or marginally significant) effect for prime exposures up to and including 29 msec: at 14 msec,  $F_1(1, 18) = 3.25$  and  $F_2(1, 27) = 3.61$ ; at 29 msec,  $F_1(1, 18) = 5.64, p < 0.05$  and  $F_2(1, 27) = 8.09, p < 0.01$ ; at 43 msec and 57 msec all  $F_s < 1$ . On the other hand, planned comparisons between orthographically dissimilar pseudohomophone primes and unrelated controls (i.e. effects of phonological priming—see Table 2) showed a significant effect at prime exposures from 29 msec to 57 msec; at 14 msec, both  $F_s < 1$ ; at 29 msec,  $F_1(1, 18) = 11.26, p < 0.005$  and  $F_2(1, 27) = 4.42, p < 0.05$ ; at 43 msec,  $F_1(1, 18) = 4.91, p < 0.05$  and  $F_2(1, 27) = 6.97, p < 0.05$ ; at 57 msec,  $F_1(1, 18) = 14.94, p < 0.005$  and  $F_2(1, 27) = 14.45, p < 0.001$ .

Figure 1 shows the variations in net facilitation as a function of prime duration and illustrates the interaction between priming effects and exposure duration. As can be seen in this figure, there is a relatively steady increase in the size of phonological priming effects with longer prime exposures, whereas the effects of orthographic priming increase from 14 msec to 29 msec and then decrease with longer prime exposures.

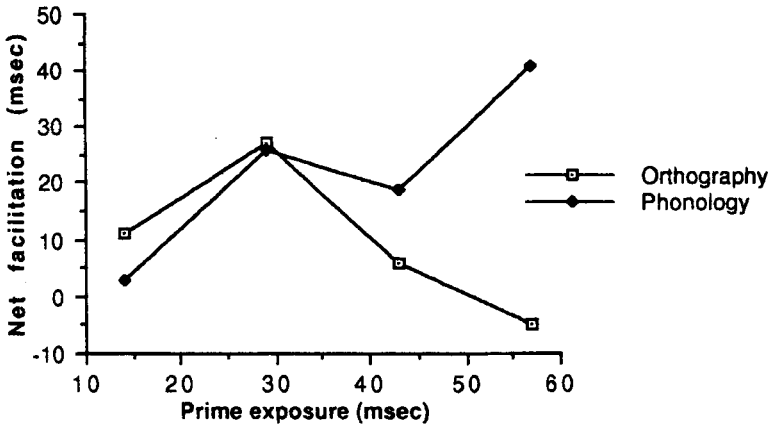


FIG. 1. Net effects of orthographic priming (orthographically related primes compared to their phonological controls) and phonological priming (phonologically related primes compared to unrelated controls) as a function of prime exposure duration in Experiment 1.

## Discussion

The facilitatory effects of orthographic priming observed here are consistent with previous research testing the effects of orthographically related non-word primes on visual word recognition (Evelt & Humphreys, 1981; Ferrand & Grainger, 1992, 1993; Forster, 1987; Forster et al., 1987; Grainger & Jacobs, 1993; Humphreys et al., 1987, 1990; Perfetti & Bell, 1991; Sereno, 1991). More importantly, the present results demonstrate that these facilitatory orthographic priming effects are not simply the result of a confound with phonological prime–target overlap. The fact that homophonic and orthographically similar pairs (e.g. *mert*–*MERE*) facilitate target recognition relative to homophonic but orthographically dissimilar pairs (e.g. *mair*–*MERE*) at 29-msec prime exposures clearly indicates that this facilitation effect is due to orthographic and not phonological overlap between prime and target (see Table 1). As there is identical phonological prime–target overlap in these two conditions, the only variable that distinguishes them is orthographic overlap. These results, therefore, support the hypothesis that both orthographic and phonological information play a fundamental role in the process of visual word recognition and that lexical representations can be accessed on the basis of both types of code.

## EXPERIMENT 2

One aspect of the results of Experiment 1 that requires clarification is the observation of orthographic and phonological effects of equivalent magnitude at 29-msec prime exposures. The significant phonological facilitation observed in this condition is at odds with other studies that report an absence of phonological priming at such short prime durations (Ferrand & Grainger, 1992; Perfetti & Bell, 1991). However, unlike the Ferrand and Grainger (1992) study, the effects of phonology were not measured against an appropriate orthographic control in Experiment 1, as orthographic effects were of principal interest here. As can be seen in Table 1, primes not only shared more phonemes with targets but also more letters with targets (25% more) in the phonological priming condition compared to the unrelated condition. This is remedied in Experiment 2, where we introduce the appropriate orthographic controls for measuring effects of phonological prime–target overlap while maintaining the appropriate phonological controls for measuring effects of orthography. It is hypothesized that with the appropriate controls at 29-msec prime exposures, significant orthographic facilitation will be observed in the absence of phonological facilitation.

As Experiment 2 adopts a different procedure from Experiment 1, the original stimuli from Experiment 1 were re-tested in Experiment 2A in exactly the same conditions as the new set of stimuli tested in Experiment 2B. In the new stimulus set the unrelated primes of Experiment 1 are replaced by primes that are orthographically related to but not pseudohomophones of the targets (e.g. *merq-MERE*). Effects of orthography are evaluated by comparing performance to the same targets preceded by orthographically similar or dissimilar pseudohomophone primes, as in Experiment 1 (e.g. *mert/mair/MERE*), whereas effects of phonology are evaluated by comparing performance to targets preceded by orthographically related primes that are or are not pseudohomophones of the target (e.g. *mert/merq/MERE*).

## Method

*Subjects.* Four well-trained subjects, all members of the Laboratory of Experimental Psychology, René Descartes University, participated in both Experiments 2A and 2B. One of the well-trained subjects was the first author. All were native speakers of French, with normal or corrected-to-normal vision.

*Stimuli and Design.* The stimuli of Experiment 2A were the same as in Experiment 1. In Experiment 2B, however, the unrelated control primes from Experiment 1 were replaced by non-word primes that were orthographically related (differing by only one letter in any position) but not homophonic with the target (e.g. *merq-MERE*). This is also true for the primes associated with non-word targets. A complete list of the stimuli is presented in the Appendix. Subjects were tested repeatedly on all three experimental lists in each sub-experiment (counterbalancing prime-target combinations) in the six possible orders at a single prime exposure (29 msec). Thus each subject ran 18 experimental sessions over several days for each sub-experiment, giving a total of 36 sessions. Participation in Experiments 2A and 2B was separated by several months.

*Procedure.* This was the same as in Experiment 1, except that only one prime exposure was tested (29 msec).

## Results

Mean lexical decision latencies and percentages of errors are given in Table 3. The latencies were trimmed applying a 800-msec cutoff (less than 1% of the data rejected). An ANOVA of the reaction time data for word targets was performed with priming condition entered as the main factor. The repeated experimental sessions were taken as a random variable

TABLE 3  
Mean Lexical Decision Latencies<sup>a</sup> and Percentage of Errors<sup>b</sup> in  
Experiments 2A and 2B

<i>Priming Conditions</i>	<i>Example</i>	<i>RT</i>	<i>%ER</i>
<i>Experiment 2A</i>			
Orthographically similar pseudohomophone prime	<i>mert-MERE</i>	423	4.16
Orthographically dissimilar pseudohomophone prime	<i>mair-MERE</i>	446	4.58
Unrelated prime	<i>toul-MERE</i>	467	7.36
<i>Experiment 2B</i>			
Orthographically similar pseudohomophone prime	<i>mert-MERE</i>	433	4.72
Orthographically dissimilar pseudohomophone prime	<i>mair-MERE</i>	452	9.31
Orthographically similar but nonhomophonic prime	<i>merq-MERE</i>	438	7.08

<sup>a</sup>Decision latencies (RT in msec).

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

*Note:* 29-msec prime exposure.

grouped by subject. *F* values are reported by subject ( $F_1$ ) and by item ( $F_2$ ). Separate ANOVAs were run for Experiments 2A and 2B.

*Experiment 2A.* There is a significant main effect of Priming Condition,  $F_1(2, 136) = 110.15$ ,  $p < 0.001$  and  $F_2(2, 54) = 50.74$ ,  $p < 0.001$ . Planned comparisons between orthographically similar pseudohomophone primes and orthographically dissimilar pseudohomophone primes (i.e. effects of orthographic priming) show a 23-msec facilitation effect,  $F_1(1, 68) = 73.32$ ,  $p < 0.001$  and  $F_2(1, 27) = 41.3$ ,  $p < 0.001$ . Planned comparisons between orthographically dissimilar pseudohomophone primes and unrelated controls (i.e. effects of phonological priming) show a 21-msec facilitation effect,  $F_1(1, 68) = 50.53$ ,  $p < 0.001$  and  $F_2(1, 27) = 17.14$ ,  $p < 0.001$ . The Priming Condition  $\times$  Repetition interaction is not significant, all  $F_s < 1$ .

An ANOVA performed on the error data for the word targets shows a significant main effect of Priming Condition,  $F_1(2, 136) = 5.28$ ,  $p < 0.01$  and  $F_2(2, 54) = 4.83$ ,  $p < 0.05$ . Planned comparisons show only a significant effect of phonological facilitation,  $F_1(1, 68) = 5.99$ ,  $p < 0.05$  and  $F_2(1, 27) = 9.37$ ,  $p < 0.01$ . None of the other effects is significant.

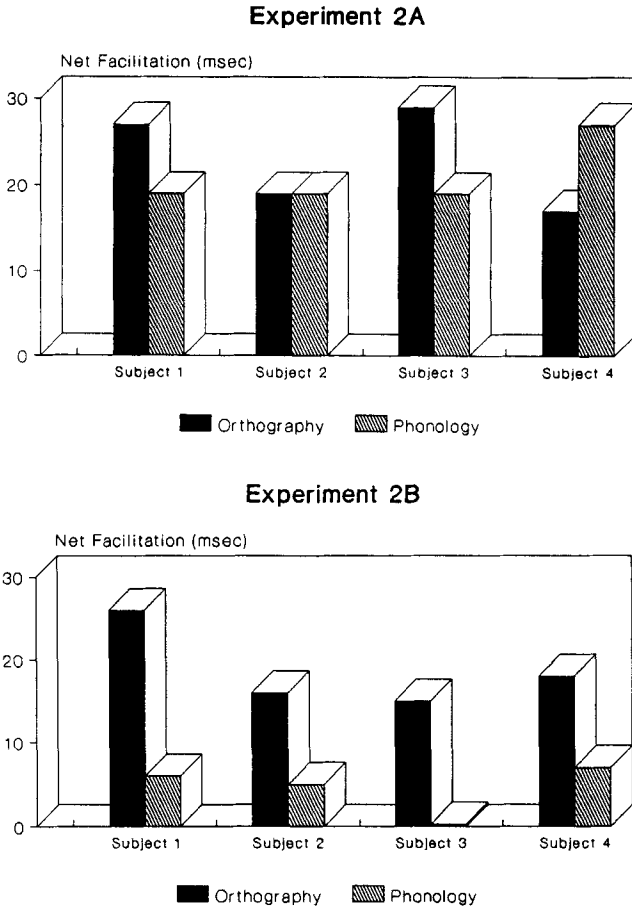


FIG. 2. Net orthographic priming effects in milliseconds measured against phonological controls in Experiments 2A and 2B (29-msec SOA) and net phonological priming effects measured against an unrelated control (Experiment 2A) and against an orthographic control (Experiment 2B). Effects are given separately for each of the four subjects.

*Experiment 2B.* There is a significant main effect of Priming Condition,  $F_1(2, 136) = 25.09$ ,  $p < 0.001$  and  $F_2(2, 54) = 3.79$ ,  $p < 0.05$ . Planned comparisons between orthographically similar pseudohomophone primes and orthographically dissimilar pseudohomophone primes (i.e. effects of orthographic facilitation) show a 19-msec facilitation effect,  $F_1(1, 68) = 47.67$ ,  $p < 0.001$  and  $F_2(1, 27) = 4.92$ ,  $p < 0.05$ . On the other hand, planned comparisons between orthographically similar pseudohomophone primes and orthographically similar but non-homophonic primes (i.e. effects of phonological facilitation) failed to reach significance,  $F_1(1, 68) =$

3.16 and  $F_2(1, 27) < 1$ . The Priming Condition  $\times$  Repetition interaction is not significant, all  $F_s < 1$ .

An ANOVA performed on the error data for the word targets mirrored the RT results. The main effect of Priming Condition is significant,  $F_1(2, 136) = 25.09$ ,  $p < 0.001$  and  $F_2(2, 54) = 9.38$ ,  $p < 0.001$ . Planned comparisons show a significant facilitatory effect of orthographic priming,  $F_1(1, 68) = 47.67$ ,  $p < 0.005$  and  $F_2(1, 27) = 15.51$ ,  $p < 0.001$ , but no effect of phonological priming,  $F_1(1, 68) = 3.16$  and  $F_2(1, 27) = 1.59$ . None of the other effects is significant, all  $F_s < 1$ .

## Discussion

Experiment 2 replicates the most important result of Experiment 1 while using a psychophysical approach with a small number of highly trained subjects. Orthographic facilitation measured relative to phonological controls is observed in conditions (29-msec prime exposures) where there are non-significant effects of phonology when these are measured relative to appropriate orthographic controls. The absence of phonological priming at 29-msec prime exposures is consistent with the results of Ferrand and Grainger (1992), Perfetti and Bell (1991), and Humphreys, Evett, and Taylor (1982). Most importantly, using RT in the lexical decision task as the dependent measure, Experiment 2 provides a direct replication of Perfetti and Bell's (1991) results (with 35-msec prime exposures) showing orthographic effects in the absence of phonological effects in a primed perceptual identification task. Moreover, this experiment provides the appropriate phonological control to ensure that these facilitation effects are, indeed, orthographic in origin.

The contrasting effects of phonologically related primes in Experiments 2A and 2B underlines the importance of the baseline control condition from which these effects are evaluated. In Experiment 2A these effects were evaluated relative to an unrelated prime condition (e.g. *mair*-*MERE* compared to *toul*-*MERE*), whereas in Experiment 2B effects of phonology were evaluated using a more appropriate orthographic control (e.g. *mert*-*MERE* compared to *merq*-*MERE*). The fact that significant priming effects were observed in Experiment 2A and not in 2B indicates that these effects are due to the extra orthographic overlap between primes and targets in the phonologically related condition of Experiment 2A (the same argument applies for the 29-msec exposure duration of Experiment 1).

Figure 2 shows the net effects of orthographic and phonological priming observed for each of the four subjects tested in Experiments 2A and 2B. As can be seen from this figure, the effects of orthographic priming are very stable across subjects and sub-experiments (this is also true for the error data, which mirror the RT results), whereas the effects of phono-

logical priming are greatly reduced in Experiment 2B when more appropriate orthographic controls are used. Thus Experiment 2 constitutes another successful application of psychophysical methodology combined with the masked priming paradigm in the study of visual word recognition (see also Grainger & Jacobs, 1991; Grainger & O'Regan, 1992).

## GENERAL DISCUSSION

The results of the present experiments provide clear evidence that visual word recognition is directly influenced by orthographic information. If contact with the mental lexicon only occurred via a phonological code, then significant facilitation from orthographically related primes relative to phonological controls should never have been observed, as the phonological information shared by prime and target is identical in both cases. It is nevertheless clear that phonology also influences the early phases of visual word recognition. Experiment 1 illustrates the different time-courses of these two codes (Figure 1), and Experiment 2 demonstrates that with appropriate orthographic controls phonological priming is absent at 29-msec prime exposures, whereas orthographic priming is already robust. With longer prime exposures phonological facilitation continues to develop as the effects of orthographic prime-target overlap tend to inhibition (see also Ferrand & Grainger, 1993).

These results can be interpreted within the framework of a modified interactive activation model (McClelland & Rumelhart, 1981) discussed in the Introduction (see also Ferrand & Grainger, 1992). Within this framework, connections between word units are uniquely inhibitory (within level inhibition), whereas connections between different types of units (orthographic, phonological, word) are primarily facilitatory (between level facilitation). This framework incorporates the basic principle that the build-up of phonological information lags behind the build-up of orthographic information, while adding the important feature that when phonological information starts to provide feed-forward excitatory input to the lexicon, within-level inhibition is developing at the word level. As we do not have an implemented version of this model at present (but see Jacobs & Grainger, 1992), the following analysis is only an approximate application of the model to the present set of data.

After 14 msec of processing on the prime stimulus, orthographic units are starting to be activated. This leads to a slight (non-significant) facilitation in the recognition of target words that share orthographic information with primes. On the other hand, phonological units are not sufficiently activated after 14 msec of processing to affect the subsequent recognition of the target. With extended processing on the prime (29 msec), the facil-

itatory effects of orthographic priming develop and become statistically robust, while the facilitatory effects of phonological priming only start to emerge and are not yet significant (Experiment 2; Ferrand & Grainger, 1992). As processing on the prime continues, word units receive more and more excitatory input from both orthographic and phonological units. The rise in activation of all word units other than the target word itself results in increased inhibition during target processing, thus producing longer recognition latencies. This increase in lexical inhibition with longer prime exposures counteracts the otherwise facilitatory effects of orthographic prime–target overlap. However, while lexical inhibition is gradually cancelling the facilitatory effects of orthographic prime–target overlap, phonological units are providing more and more excitatory input to the target word representation, thus giving rise to an increase in the facilitatory effects of prime–target phonological overlap.

One possible discrepancy with other data that can be explained within the interactive activation framework concerns the type of priming effects (facilitation or inhibition) observed in the masked form priming literature. As pointed out in a recent review of the subject, Grainger (1992) reports that when primes are *word neighbours* of the target, they tend to produce inhibitory effects that are strongest when the prime is more frequent than the target (Grainger, Colé, & Segui, 1991; Segui & Grainger, 1990). However, when the primes are *non-word neighbours* of the target, they tend to facilitate target processing (as shown in the present experiments; see also Ferrand & Grainger, 1992, 1993; Forster et al., 1987; Sereno, 1991). The interactive activation model can accommodate both inhibitory effects and facilitatory effects. With brief prime presentation durations, only sublexical units will be significantly activated at target onset, particularly when the prime is a non-word or a low-frequency word. In this case, there is not enough activity generated at the lexical level to provoke within-level inhibition, thus allowing sublexical facilitatory effects to emerge (as shown here and by Ferrand & Grainger, 1992, 1993). As primes activate word units other than the target word itself more and more compared to target-word activation (with increased prime frequency relative to target frequency and/or greater prime exposure durations) then lexical level inhibition increases, thus cancelling sublexical facilitation.

In conclusion, it appears that the extended architecture of the interactive activation model presented by Ferrand and Grainger (1992) provides a coherent account of the results of the present experiments. More precisely, it captures the time lag between the influence of orthographic and phonological information (estimated at approximately 30 msec) in visual word recognition, and the fact that phonology continues to facilitate while the effects of orthography turn to inhibition. From a methodological point of view, the masked priming paradigm has provided a sensitive means of



studying the time-course of these different effects. Future research using this technique should allow us to specify more precisely the type of orthographic and phonological units that subtend visual word recognition.

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## APPENDIX

<i>French Word Target</i>	<i>Homophonic and Orthographically Similar Prime</i>	<i>Homophonic but Orthographically Dissimilar Prime</i>	<i>Unrelated Control</i>	<i>Orthographic Control (Experiment 2B)</i>
FAIM	<i>fain</i>	<i>fint</i>	<i>peul</i>	<i>faic</i>
LENT	<i>lens</i>	<i>lamp</i>	<i>dile</i>	<i>lene</i>
BORD	<i>bore</i>	<i>baur</i>	<i>reil</i>	<i>borl</i>
PAIR	<i>peir</i>	<i>pers</i>	<i>fule</i>	<i>plir</i>
BEAU	<i>bhau</i>	<i>baut</i>	<i>moir</i>	<i>blau</i>
TORT	<i>tors</i>	<i>taur</i>	<i>seil</i>	<i>torc</i>
THYM	<i>thyn</i>	<i>tein</i>	<i>vure</i>	<i>thyr</i>
NERF	<i>nerd</i>	<i>nair</i>	<i>tabe</i>	<i>nerc</i>
TAUX	<i>taud</i>	<i>tots</i>	<i>lenf</i>	<i>tauf</i>
BAIN	<i>baim</i>	<i>bint</i>	<i>neul</i>	<i>bair</i>
VENT	<i>vens</i>	<i>vamd</i>	<i>dise</i>	<i>vene</i>
ZINC	<i>zint</i>	<i>zein</i>	<i>doir</i>	<i>zine</i>
NORD	<i>nore</i>	<i>naur</i>	<i>geuf</i>	<i>norc</i>
VERS	<i>verd</i>	<i>vair</i>	<i>doin</i>	<i>verg</i>
LAID	<i>lais</i>	<i>lets</i>	<i>clon</i>	<i>lain</i>
FORT	<i>fore</i>	<i>faur</i>	<i>sate</i>	<i>fork</i>
MAIN	<i>maim</i>	<i>mins</i>	<i>nour</i>	<i>maig</i>
MAUX	<i>maut</i>	<i>meau</i>	<i>lide</i>	<i>maul</i>
SAIN	<i>saim</i>	<i>sint</i>	<i>bive</i>	<i>saie</i>
FAIT	<i>faie</i>	<i>fets</i>	<i>dien</i>	<i>fail</i>
DENT	<i>dens</i>	<i>damp</i>	<i>nise</i>	<i>dene</i>
VAIN	<i>vaim</i>	<i>vint</i>	<i>dour</i>	<i>vail</i>
SORT	<i>sore</i>	<i>saur</i>	<i>beil</i>	<i>sora</i>
MERE	<i>mert</i>	<i>mair</i>	<i>toul</i>	<i>merq</i>
BAIE	<i>bait</i>	<i>bets</i>	<i>pien</i>	<i>bair</i>
JEUN	<i>jein</i>	<i>jaim</i>	<i>lade</i>	<i>jeln</i>
SOLE	<i>sols</i>	<i>saul</i>	<i>neur</i>	<i>solt</i>
FILS	<i>fiss</i>	<i>phys</i>	<i>clat</i>	<i>firs</i>
FAUX	<i>faud</i>	<i>fots</i>	<i>sule</i>	<i>fauc</i>
BANC	<i>bant</i>	<i>bemp</i>	<i>fure</i>	<i>bane</i>