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Masked Orthographic and Phonological Priming in Visual Word Recognition and Naming: Cross-Task Comparisons

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The effects of briefly presented, masked, and orthographically and/or phonologically related nonword primes on the recognition of subsequently presented target words were investigated in different experimental tasks. Robust effects of orthographic and phonological priming were observed in both the lexical decision and the perceptual identification tasks, with no such effects appearing in the word naming task, except for orthographic priming effects at the shortest prime exposures. Further investigation of this marked dissociation across experimental tasks showed that word naming is particularly sensitive to shared onsets in the masked priming paradigm and that robust rhyme priming does occur when primes and targets have different onsets. The lexical decision task, on the other hand, showed priming effects independently of whether prime and targets shared onsets. These results are discussed within the framework of a bimodal interactive activation model of visual word recognition and naming. © 1996 Academic Press, Inc.

A large amount of evidence recently has accumulated in favor of the hypothesis that phonological information generated from the printed word does influence early, automatic processes in visual word recognition (for recent reviews see Berent & Perfetti, 1995; Ferrand & Grainger, 1994; Lukatela & Turvey, 1994; Van Orden, Pennington, & Stone, 1990; Ziegler & Jacobs, 1995). These data have seriously compromised the hypothesis according to which only orthographic codes mediate contact with lexical representations in the recognition of printed words (e.g., Baron, 1973; Forster, 1976; Humphreys & Evett, 1985) and

Many of the ideas expressed in this article grew out of discussion with friends and colleagues. We acknowledge Arthur Jacobs and Ton Dijkstra as being the most influential as far as the bimodal IA model is concerned. David Balota, Glyn Humphreys, Georgije Lukatela, Ken Paap, and Arthur Samuel all provided excellent comments on earlier versions of this paper. We also thank Juan Segui for his invaluable comments on this work and Madeleine Leveillé for programming expertise. Address correspondence and reprint requests to Jonathan Grainger, CREPCO, Université de Provence, 29 Avenue Robert Schumann, 13621 Aix-en-Provence, France. E-mail: grainger@univ-aix.fr.

suggest on the contrary that phonology plays a central role in visual word recognition (e.g., Carello, Turvey, & Lukatela, 1992; Lukatela, Lukatela, & Turvey, 1993; Lukatela & Turvey, 1994; Van Orden et al., 1990; Rubenstein, Lewis, & Rubenstein, 1971). Recently, Lukatela, Van Orden, and their colleagues have cleverly pointed out that although there is now abundant evidence for the role played by phonological codes in visual word recognition, there is no clear-cut positive evidence for the role played by orthographic codes (other than subserving phonological code activation). Until now, the evidence in favor of direct orthographic mediation has generally taken the form of an absence of phonological effects (see Van Orden et al., 1992, for a discussion on this point). This is to be remedied in the present research where we examine how both phonological and orthographic codes influence performance in three of the most commonly used tasks in the study of visual word recognition.

Perhaps the clearest evidence in favor of an automatic prelexical coding of orthographic

and phonological information during visual word recognition has been provided by priming experiments using visual masking procedures and very brief prime presentation durations. The fact that subjects are typically unable to correctly identify primes in such presentation conditions allows one to reject interpretations of any priming effects observed in terms of task-specific strategies subjects may develop on detecting a relation between primes and targets (cf. Forster, 1993). In both the perceptual identification and lexical decision paradigms it has been shown that prime–target orthographic and/or phonological overlap influences target recognition. Thus, Evett and Humphreys (1981) demonstrated that word targets preceded by orthographically similar word primes (e.g., couch–TOUCH) are easier to recognize than those preceded by unrelated controls (e.g., flown–TOUCH). Related research (Humphreys, Evett, & Quinlan, 1990; Perfetti & Bell, 1991; Perfetti, Bell, & Delaney, 1988; Naish, 1980) has shown that target identification is also improved with orthographically similar nonword primes (e.g., mave–MOVE compared to fand–MOVE) and phonologically similar nonword primes (e.g., mayd–MADE compared to mard–MADE). These facilitatory effects of orthographic and phonological priming with nonword primes have also been observed with RT (reaction time) as the dependent measure in tasks such as lexical decision (Ferrand & Grainger, 1992, 1993, 1994; Forster, 1987; Forster, Davis, Schoknecht, & Carter, 1987; Sereno, 1991) and speeded naming (Forster & Davis, 1991; Sereno, 1991).

Nevertheless, nonword primes have not always produced phonological facilitation in the masked priming paradigm. Using the primed perceptual identification task, 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) but not when primes were pseudohomophones of targets (e.g., brane–BRAIN). The authors therefore concluded that phonological priming is mediated by direct orthographic access to lexical

representations. More recent research by Perfetti and his colleagues (Perfetti & Bell, 1991; Perfetti & Zhang, 1991) and by Ferrand and Grainger (1992, 1993, 1994) indicates, however, 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 from 25 to 65 ms in a forward-masked primed perceptual identification task. At 35-ms prime durations (approximately the same as those used by Humphreys et al., 1982), they replicated Humphreys et al.'s (1982) results, showing orthographic but not phonological priming with nonwords (see also Ferrand & Grainger, 1992, for similar results using the masked priming procedure with the lexical decision task at 33 ms prime duration). With longer prime durations (from 45 up to 65 ms), orthographic priming remained constant, and a phonological priming effect appeared over and above the orthographic effect. Ferrand and Grainger (1992, 1993) extended these results, varying prime exposure from 17 to 100 ms: phonological facilitation started to emerge only at exposures of 45–50 ms. The results of Perfetti and Bell (1991), and those of Ferrand and Grainger (1992, 1993), therefore suggest that prime duration is critical in determining the presence of masked phonological priming. Moreover, a very similar pattern of results has recently been obtained in an eye movement priming study where total gaze duration on the target word was the dependent variable (Rayner, Sereno, Lesch, & Pollatsek, 1995).

As argued by Lukatela et al. (1993) and Van Orden et al. (1990), however, the above studies provide unequivocal evidence for phonologically mediated access to lexical representations in memory, but do not allow one to conclude that a direct orthographic access is possible. While the effects of phonological prime–target overlap are measured against appropriate orthographic controls (e.g., mayd–MADE compared to mard–MADE), the effects of orthography are measured against an unrelated control (e.g., mave–MOVE compared to fand–MOVE). Thus the primes and targets in the orthographic priming condition vary not only in degree of ortho-

TABLE 1

Example of pairs used in Experiments 1 and 2	Shared letters ^a (%)	Shared phonemes ^a (%)
Orthographically dissimilar pseudohomophone prime (e.g., <i>nair</i> –NERF)	25	100
Orthographically similar pseudohomophone prime (e.g., <i>nert</i> –NERF)	75	100
Orthographically similar but nonhomophonic prime (e.g., <i>nerc</i> –NERF)	75	60

^a At identical positions.

graphic overlap but also in degree of phonological overlap. This implies that any differences observed could be attributed to variations in either orthographic or phonological prime–target overlap, or both. However, in a more recent study (Ferrand & Grainger, 1994) using French stimuli it has been possible to create prime–target pairs that allow one to separate out the effects of orthographic prime–target overlap from effects of shared phonology. We demonstrated that homophonic and orthographically similar nonword primes (e.g., *nert*–NERF) facilitated target recognition in the lexical decision task relative to homophonic but orthographically dissimilar nonword primes (e.g., *nair*–NERF; “*nert*” and “*nair*” are nonwords that French speakers would typically pronounce as the word NERF). These results clearly indicate that this facilitation effect is due to orthographic and not phonological overlap between prime and target. Since there is identical phonological prime–target overlap in these two conditions the only variable that distinguishes them is orthographic overlap. These results therefore provide strong support for the hypothesis that orthographic information plays an early role in visual word recognition and they stand in contradiction to the phonological recoding hypothesis.

Table 1 summarizes the logic underlying stimulus selection in the present article. In the stimulus set used by Ferrand and Grainger

(1992, 1993) effects of phonology are estimated by varying prime–target phonological overlap with orthographic overlap held constant. In another stimulus set used by Ferrand and Grainger (1994) effects of orthography are estimated by varying orthographic overlap with phonological overlap held constant. The present experiments were designed as a combination of these manipulations in order to isolate effects of orthography and phonology with a single set of stimuli. In French it is possible to create triplets of prime stimuli that vary in terms of both their orthographic relatedness and their phonological relatedness to the target word. Effects of orthography over and above phonology are evaluated by comparing performance to the same targets preceded by orthographically similar or dissimilar pseudohomophone primes as in Ferrand and Grainger (1994) (e.g., *nert*–NERF compared to *nair*–NERF, pronounced identically in French). Effects of phonology over and above orthography are evaluated by comparing performance to targets preceded by orthographically related primes that are or are not pseudohomophones of the target (e.g., *nert*–NERF compared to *nerc*–NERF, pronounced differently in French) as in Ferrand and Grainger (1992, 1993). The present experiments add a further improvement over previous investigations of orthographic and phonological priming by testing the same stimuli in three different experimental tasks.

In recent theoretical work (Jacobs & Grainger, 1994; Grainger & Jacobs, in press), one of the present authors has defended a multitask, multilevel approach to modeling visual word recognition. The present article provides another application of this general research strategy, to be contrasted with other strategies that appear to be more representative at present. What one generally sees in the experimental literature is the assumption that the task being used (typically lexical decision or word naming) is a fairly direct reflection of normal word recognition processes. Although this attitude has already received considerable criticism (e.g., Balota & Chumbley, 1984), it still is widely adopted. In the face of criticisms with respect to one particular task (e.g., the

lexical decision task), authors will typically test the same stimuli with another, less criticized task (e.g., word naming), and if there is a certain amount of cross-task coherence then conclude that the effects picked up by the tasks do reflect basic processes in word recognition. This purely empirical multitask approach however, is doomed to failure in that different tasks may very well produce the same observable effects via very different mechanisms (e.g., neighborhood density effects in lexical decision and word naming; Grainger & Jacobs, in press). We need to know to what extent the functional mental structures involved in performing a given task overlap with those involved in normal word recognition, and how this functional overlap varies from task to task. Unfortunately, as pointed out by Jacobs and Grainger (1994) and Jacobs (1994), there is no theory-free way of determining this functional overlap. We require not only models of the psychological process under study (visual word recognition) but also models of the particular tasks used to investigate the target process, and we need to specify the overlap between the two. Figure 1 presents a possible starting point for such an enterprise (see Grainger & Jacobs, in press, for a more detailed analysis). Building on our previous work in this area (Ferrand, Grainger, & Segui, 1994; Grainger & Ferrand, 1994), the theoretical framework illustrated in Fig. 1 specifies the different informational codes generated on presentation of a visual or auditory stimulus. This specific architecture is currently being implemented and will be given a more complete description in a later report.

Within this theoretical framework it is hypothesized that responses in both the visual lexical decision and the perceptual identification tasks are based on activity in the orthographic lexicon (but see Grainger & Ferrand, 1994, for cases where decisions may be based on activity in the phonological lexicon). On the other hand, it is hypothesized that responses in the word naming task are governed by activity in articulatory output units, which receive excitatory input from all compatible lexical and sublexical units in the network. The bidirectional connections between ortho-

graphic and phonological units in the model allow it to handle the early effects of phonology observed in both the visual lexical decision and the perceptual identification tasks discussed above (and also to explain orthographic influences in auditory tasks, e.g., Dijkstra, Frauenfelder, & Schreuder, 1993; Seidenberg & Tanenhaus, 1979). The model clearly predicts that one should observe similar patterns of effects in these two tasks, due to the high degree of overlap in the hypothesized mental structures involved. With respect to the word naming task, however, it is clear that performance in this task will depend essentially on the structure of articulatory output units and how response criteria (for speeded naming) can be set on such units. The present experiments test the model's prediction that a similar pattern of orthographic and phonological priming effects should be observable in the lexical decision and perceptual identification tasks and show how performance in the word naming task is critically distinct from that observed in the two former tasks.

EXPERIMENT 1

Experiment 1 tests for effects of orthographic and phonological priming with primes presented for 43 ms in the lexical decision, perceptual identification, and speeded naming tasks. Pilot work indicated that (for the specific video display and stimulus contrast used in the present experiments) both orthographic and phonological priming should be observable at prime exposures of 43 ms with the lexical decision task.

Method

Subjects. Ninety psychology students at René Descartes University, Paris, France, served as subjects for course credit, 30 in each of the three different tasks (lexical decision, perceptual identification, and naming). All were native speakers of French, with normal or corrected-to-normal vision.

Stimuli and design. Exactly the same word targets and nonword prime stimuli were used for the three tasks. These consisted of 30 monosyllabic word targets all four letters long that were selected such that for each target

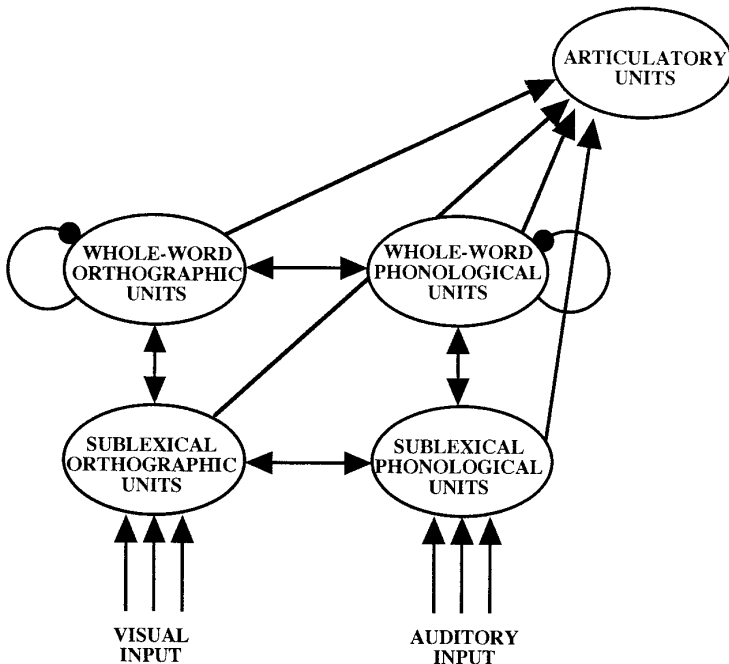


FIG. 1. A bimodal interactive activation model of word recognition and naming in which performance in visual and auditory word recognition tasks is determined essentially by the activation levels of units in the corresponding lexicon, whereas performance in the word naming task is conjointly determined by activity in sublexical and lexical representations.

word three types of nonword primes could be generated: (1) nonword primes that are orthographically unrelated (maximum one letter shared in the correct position) but homophonic with the target (e.g., *nair*–*NERF*); (2) nonword primes that are both homophonic with and orthographically similar (differing by one letter other than the first) to the target (e.g., *nert*–*NERF*); and (3) nonword primes that are orthographically related (differing by one letter other than the first) but not homophonic with the target (e.g., *nerc*–*NERF*). All prime stimuli had the same initial letter as the corresponding target word. The average printed frequency of the word targets was 260 occurrences per million (*Trésor de la langue Française*, 1971) and they had on average 5.9 orthographic neighbors. Prime–target pairs were rotated across the priming conditions using three groups of subjects (for each type of task) 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 nonword prime/word target pairs, 10 from each condition. A complete list of the stimuli is presented in Appendix A. Thirty nonword prime/nonword target pairs were constructed for the lexical decision task only. In 10 of these pairs the nonword targets were primed by a nonword that was homophonic with and orthographically related to the target (e.g., *jaud*–*JAUX*). Ten other nonword targets were preceded by orthographically dissimilar but homophonic nonword primes (e.g., *vaur*–*VORD*), and 10 other nonword targets were preceded by orthographically related but non-homophonic nonword primes (e.g., *cobe*–*COGE*). However, these 30 nonword/nonword pairs could not be rotated across the different priming conditions because of the limited number of such stimuli. Subjects were presented with 20 practice trials before doing the experiment proper. These consisted of 10 nonword/word pairs in the perceptual identification and naming tasks plus 10 nonword/nonword pairs in the lexical deci-

sion task, none of which appeared in the experimental trials, all four letters long and selected from the same frequency range as the experimental stimuli.

Procedure. Stimuli were presented in isolation on the center 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 uppercase) covered approximately 0.38° of visual angle from a viewing distance of 60 cm, so a four-letter word subtended about 1.53° of visual angle. Each trial consisted of the following sequence of three stimuli: First a forward mask consisting of a row of four hashmarks (####) was presented for 500 ms, this was immediately followed by the prime stimulus in lowercase letters for 43 ms, followed immediately by the target stimulus in uppercase letters, both presented in the same screen location as the mask. In the lexical decision and naming tasks the target remained on the screen until subjects responded either by pressing one of two response keys (word/nonword) or by reading aloud the target word. In the perceptual identification task targets were presented for 29 ms and immediately followed by a series of four hashmarks for 500 ms (pilot work indicated that response accuracy was about 60% in these conditions). Subjects were instructed to report the word in uppercase letters by typing their response using the computer keyboard. After checking their answer subjects initiated the next trial with the enter key. Primes were always presented in lowercase and targets in uppercase in order to minimize physical overlap with orthographically related pairs. The existence of a prime stimulus was not mentioned. In the lexical decision and naming tasks subjects were instructed to respond as rapidly and as accurately as possible. Reaction times, measured from target onset until subjects' response, were accurate to the nearest millisecond. Naming times were measured using a voice key connected to a Sennheiser MD211N microphone. Stimulus presentation was randomized, with a different order for each subject.

Results

Mean lexical decision latencies and percentage errors in the lexical decision task, means of percentage correct whole-word report in the perceptual identification task, and mean naming latencies and corresponding percentage errors in the naming task are given in Table 2 for the three priming conditions tested in Experiment 1. The latencies were trimmed applying a 1000-ms cutoff (less than 2.5 and 1% of the data rejected for the lexical decision task and the naming task, respectively). The data of the three tasks (lexical decision, perceptual identification, and naming) were submitted to separate analyses of variance with priming condition (homophonic but orthographically dissimilar nonword prime, homophonic and orthographically similar nonword prime, and nonhomophonic but orthographically similar nonword prime) entered as the main factor. *F* values are reported by subject (*F*1) and by item (*F*2).

Lexical decision. Concerning reaction times, there was a significant main effect of priming condition, $F(2,54) = 14.27, p < .001$, and $F(2,58) = 7.2, p < .005$. Planned comparisons between orthographically similar pseudohomophone primes and orthographically dissimilar pseudohomophone primes (i.e., effects of orthographic priming) showed a 50-ms facilitation effect, $F(1,27) = 28.33, p < .001$; and $F(1,29) = 11.26, p < .005$. Planned comparisons between orthographically similar pseudohomophone primes and orthographically similar but nonhomophonic primes (i.e., effects of phonological facilitation) showed a 45-ms facilitation effect, $F(1,27) = 14.52, p < .001$; and $F(1,29) = 9.39, p < .005$. In an analysis of variance conducted on the error data, the main effect of priming condition failed to reach significance, $F(1) < 1$ and $F(2) < 1$. Response times to nonword targets were not affected by prime relatedness (735 ms in the orthographically dissimilar pseudohomophone prime condition, 739 ms in the orthographically similar pseudohomophone prime condition, and 739 ms in the orthographically similar but nonhomophonic prime condition, all *F*s < 1).

TABLE 2

MEAN RESPONSE TIME (IN MILLISECONDS) AND PERCENTAGE OF ERROR (IN PARENTHESES) IN THE LEXICAL DECISION AND NAMING TASKS AND PERCENTAGE CORRECT RESPONSES IN THE PERCEPTUAL IDENTIFICATION TASK FROM EXPERIMENT 1 (43 ms PRIME EXPOSURES)

Priming condition	Type of task		
	Lexical decision	Perceptual identification	Naming
Orthographically dissimilar pseudohomophone prime (e.g., <i>nair</i> -NERF)	642 (14.3)	50	584 (1.3)
Orthographically similar pseudohomophone prime (e.g., <i>nert</i> -NERF)	592 (12.0)	72	583 (1.0)
Orthographically similar but nonhomophonic prime (e.g., <i>nerc</i> -NERF)	637 (14.6)	55	580 (1.3)
Net orthographic priming effect	+50	+22	+1
Net phonological priming effect	+45	+17	-3

Perceptual identification. An analysis of variance performed on the percentage correct whole-word report mirrored the reaction times results of the lexical decision task. There was a significant main effect of priming condition, $F(1,27) = 17.92$, $p < .001$, and $F(2,58) = 18.44$, $p < .001$. Planned comparisons showed an orthographic facilitation effect (+22%), $F(1,27) = 34.79$, $p < .001$; and $F(2,29) = 39.67$, $p < .001$, as well as a phonological facilitation effect (+17%), $F(1,27) = 18.56$, $p < .001$, and $F(2,29) = 23.08$, $p < .001$.

Naming. An analysis of variance conducted on the naming latencies showed no main effect of priming condition, $F(1,27) < 1$ and $F(2,29) < 1$, and naming errors did not vary significantly across conditions, $F(1,27) < 1$ and $F(2,29) < 1$.

Discussion

The facilitatory effects of orthographic and phonological priming observed in the lexical decision and perceptual identification tasks are consistent with prior research testing the effects of orthography and phonology in visual word recognition (Evett & Humphreys, 1981; Ferrand & Grainger, 1992, 1993, 1994; Forster, 1987; Forster et al., 1987; Humphreys, Evett, Quinlan, & Besner, 1987; Humphreys et al., 1990; Perfetti & Bell, 1991; Perfetti et al., 1988; Sereno, 1991). The present results demonstrate effects of orthographic priming and phonological priming in the same experi-

ment with a prime exposure of 43 ms. The orthographic priming effects cannot be the result of a confound with phonological prime-target overlap, and the reverse is true for phonological priming effects that cannot be attributed to a confound with orthographic prime-target overlap. The results of the perceptual identification task mirrored the lexical decision task results. Within the theoretical framework presented in Fig. 1, this suggests that briefly presented letter strings activate sublexical orthographic and phonological units, which in turn affect the activation level of whole-word orthographic units. It is hypothesized that subjects' responses in the lexical decision and perceptual identification tasks are based on activity in the orthographic input lexicon (at least in the present experimental conditions).

The naming experiment, however, failed to provide evidence for either orthographic or phonological priming. A similar result had previously been reported by Peter, Lukatela, and Turvey (1990) using prime exposures of 150 ms. More recently, however, Lukatela and Turvey (1994) claim to have observed significant pseudohomophone priming effects in conditions very similar to those used in Experiment 1. It should nevertheless be noted that in these experiments the critical comparison between the pseudohomophone prime condition (e.g., *tode*-TOAD) and its orthographic

control (e.g., tods–TOAD) gave an average 6-ms pseudohomophone advantage across three different experiments using brief prime exposures. However, before concluding on this point, Experiment 2 provides a further investigation of orthographic and phonological priming in the naming task using both shorter (29 ms) and longer (57 ms) prime exposures.

EXPERIMENT 2

Method

Subjects. Forty-eight psychology students at René Descartes University, Paris, France, served as subjects for course credit, 24 in each of the two prime duration conditions (29 and 57 ms). All were native speakers of French, with normal or corrected-to-normal vision. None of these subjects had participated in the previous experiment.

Stimuli and design. The stimuli and design were the same as those used in Experiment 1, except that only the naming task was used and two prime durations were tested (29 and 57 ms). Thus, priming condition (within-subjects) was crossed with prime duration (between-subjects) in a 3×2 factorial design.

Procedure. This was the same as that used for the naming task in Experiment 1.

Results

Mean naming latencies and percentage errors are given in Table 3, for each prime duration. The latencies were trimmed applying a 1000-ms cutoff (1.2 and 1.4% of the data rejected for each prime duration, respectively). An analysis of variance was performed on the reaction time data with prime duration and priming condition entered as main factors.

There was a marginally significant effect of priming condition, $F(1,2,92) = 4.47, p < .05$; and $F(2,116) = 2.51, p < .10$, and a significant effect of prime duration, $F(1,1,46) = 5.32, p < .05$, and $F(2,1,58) = 64.79, p < .001$. More interestingly, prime duration significantly interacted with priming condition, $F(1,2,92) = 5.96, p < .005$, and $F(2,116) = 3.66, p < .05$. Planned comparisons between orthographically similar pseudohomophone primes and orthographically dissimilar pseu-

TABLE 3

MEAN NAMING LATENCIES (IN MILLISECONDS) AND PERCENTAGE OF ERRORS (IN PARENTHESES) FOR THE TWO PRIME DURATIONS IN EXPERIMENT 2

Priming condition	Prime duration (ms)	
	29	57
Orthographically dissimilar pseudohomophone prime (e.g., <i>nair</i> –NERF)	555 (1.3)	583 (1.7)
Orthographically similar pseudohomophone prime (e.g., <i>nert</i> –NERF)	528 (0.8)	582 (1.3)
Orthographically similar but nonhomophonic prime (e.g., <i>nerc</i> –NERF)	526 (0.8)	588 (1.7)
Net orthographic priming effect	+27	+1
Net phonological priming effect	–2	+6

dohomophone primes (i.e., effects of orthographic priming) showed a significant effect at 29 ms, $F(1,23) = 9.68, p < .005$, and $F(2,1,29) = 8.41, p < .01$, but not at 57 ms, $F(1) < 1$ and $F(2) < 1$. On the other hand, planned comparisons between orthographically similar pseudohomophone primes and orthographically similar but nonhomophonic primes (i.e., effects of phonological priming) failed to reach significance at both the 29- and 57-ms prime exposures (all F s < 1). In an analysis of variance conducted on the error data the main effect of priming condition was not significant at both the 26- and 57-ms prime exposure durations (all F s < 1).

Discussion

Experiment 2 demonstrates that facilitatory effects of orthographic priming can be observed in the naming task with 29-ms prime exposures, whereas effects of prime–target phonological overlap are absent at both 29- and 57-ms prime exposures. Thus, the only priming effect obtained with the word naming task in Experiments 1 and 2 is an effect of prime–target orthographic overlap with 29-ms prime exposures. The absence of priming effects in all the other conditions tested with

the naming task is discussed in the following. However, before examining the implications of these results, a series of supplementary analyses is presented in order to check whether phonological priming effects in word naming did appear in some specific conditions hidden by the global analyses.

Further Analyses of Experiments 1 and 2

Three different factors, word frequency, subject rapidity, and the homophonic status of target words, were analyzed. Since priming effects often interact with target word frequency (low frequency targets generally being more sensitive to priming), it is important to know whether any such interaction occurred in the present experiments, with phonological priming emerging with low frequency targets in the word naming task, for example. The effects of word frequency were analyzed by comparing performance to the 10 most frequent target words (average frequency of 538 occurrences per million) and the 10 least frequent words (average frequency of 15 occurrences per million) in a by-item analysis. The main effect of word frequency was never significant in the word naming task at all the prime exposures (all $F_s < 1$) and this factor never interacted with priming condition (all $F_s < 1$). In the word naming task the effects of phonological priming never exceeded 5 ms in magnitude, never interacted with word frequency, and were nonsignificant for both the low and the high frequency targets at all prime exposures (all $F_s < 1$). The effects of orthographic priming were nonsignificant in the word naming task except at the 29-ms prime exposure, $F(1,9) = 5.38$, $p < .05$, and did not interact with word frequency at each exposure duration (all $F_s < 1$). There was a significant main effect of word frequency in the lexical decision task. $F(1,18) = 7.61$, $p < .05$, which did not interact with priming condition ($F < 1$). Orthographic and phonological priming effects were very similar in size across the high and low frequency targets. This was also true in the perceptual identification task, although the main effect of word frequency was not statistically significant, $F(1,18) = 1.97$.

Subject rapidity may also be a factor that

influences the emergence of priming effects, in that slow subjects may provide more time for such effects to develop. It is therefore important to test whether any interaction between priming and subject rapidity arose in the present experiments. The performance of the 10 fastest subjects was compared to the performance of the 10 slowest subjects in the word naming task at each exposure duration. Fast subjects were on average 128 ms faster than the slow subjects, $F(1,18) = 63.42$, $p < .001$, and this factor did not interact with priming condition at any of the prime exposures (all $F_s < 1$). The effects of phonological priming were never greater than 8 ms in size (all $F_s < 1$), and as in the previous analysis, the effects of orthographic priming were robust only at 29-ms prime exposures with similar effects for the fast and slow subjects. Exactly the same pattern of results was obtained in the lexical decision task with practically identical orthographic and phonological facilitation effects for the fast and slow subject groups.

Finally, since many of the target words tested in Experiments 1 and 2 are heterographic homophones, it is important to know whether such target homophony might have reduced any priming effects, via the simultaneous activation of competing orthographic representations, for example. The performance on 10 target words that were homophones of another French word was compared to 10 nonhomophone targets matched approximately in terms of printed frequency. In the word naming task there was no main effect of this factor, $F < 1$, and no interaction with priming condition at any of the prime exposures (all $F_s < 1$). This was also true for both the lexical decision and the perceptual identification tasks of Experiment 1, with very similar orthographic and phonological priming effects occurring for the homophone and the nonhomophone targets.

The results of these supplementary analyses clearly indicate that orthographic and phonological priming effects are independent of word frequency, subject speed, and target homophony in the three tasks used in Experiments 1 and 2. The striking dissociation be-

tween the presence of phonological priming effects in the lexical decision and perceptual identification tasks on the one hand, and the systematic absence of such effects in the word naming task on the other hand, therefore would appear to be a robust phenomenon that requires an adequate explanation. The rest of this article is dedicated to such an enterprise.

Orthographic Priming

The main result from Experiment 2 is the observation of orthographic facilitation measured relative to phonological controls in conditions (29-ms prime exposures) where there are nonsignificant effects of phonology when these are measured relative to appropriate orthographic controls. These results observed in the naming task are a direct replication of the results from Ferrand and Grainger (1994, Experiment 2B) observed in the lexical decision task. A similar result also has been obtained recently by Ferrand et al. (1994) with a different stimulus set designed to compare word and picture naming. It should also be pointed out that effects of orthographic priming tend to diminish as prime exposure duration is increased in the lexical decision task (Ferrand & Grainger, 1992, 1993). Thus the absence of an effect of orthographic priming at the 57-ms prime duration of Experiment 2 conforms to prior results obtained with the lexical decision task.

Thus Experiments 1 and 2 clearly demonstrate effects of orthographic priming relative to appropriate phonological controls in the lexical decision, perceptual identification, and word naming tasks. Although the use of phonological controls is, in our opinion, a major improvement on prior studies of orthographic priming, one other problem remains to be solved in future research. This concerns the possible confound between prime–target orthographic overlap (number of shared letters) and some measure of prime–target featural overlap. Nevertheless, a number of experiments do suggest that degree of featural overlap cannot account for all the orthographic priming effect. Thus, for example, Grainger and Jacobs (1993) demonstrated that both repetition priming effects and partial-word prim-

ing effects were insensitive to whether the prime and target were presented in the same case (e.g., TA%LE–TABLE vs TA%LE–table). Since featural overlap will always be larger in the same case condition this result suggests that abstract representations above the feature level subtend these priming effects. Furthermore, in some recent research comparing word and picture naming Ferrand et al. (1994) observed significant effects of orthographic priming in word naming with 29-ms prime exposures and with prime and target stimuli separated by a 14-ms pattern mask. Since pattern masks are themselves composed of visual features that should interfere with any featural representation activated by the prime stimulus, this result suggests once more that some higher level representation (resistant to pattern masking) underlies orthographic priming effects.

However, recent work by Davis and Forster (1994) has shown that although the legibility of a superimposed image of the prime and target (always orthographically unrelated) does not affect subjects' performance in the lexical decision task, it does have a significant influence on performance in the perceptual identification task. This result would appear to suggest the existence of low-level featural priming in this particular task. This, however, does not necessarily imply that effects of orthographic priming observed with this task can be reduced to feature priming. Davis and Forster did not actually test for effects of orthographic priming while controlling for prime–target legibility. On this point, it should be noted that Humphreys et al. (1990) have demonstrated that it is the relative position rather than the absolute position of shared letters in the prime and target stimuli that critically determines orthographic priming effects (e.g., BVK primes BLACK). Although featural representations could be coded for relative position in a word (e.g., vertical line at initial position), it does seem intuitively more likely that this type of relative position coding be achieved at the letter level. Nevertheless, intuition aside, further empirical work is required on this point and we have recently launched a project aimed specifically at evalu-

ating featural versus orthographic interpretations of these form priming effects.

Phonological Priming

The failure to observe any phonological priming effect in the naming task using prime durations ranging from 29 to 57 ms would, contradictory to the predictions of our model, appear to suggest that there is a minimal influence of prelexically generated phonology on the time to name written words. Certainly, the fact that significant effects of orthographic priming are observed at the 29-ms prime duration of Experiment 2 would suggest that the naming task is sensitive to form priming effects with very brief prime exposures. The problem is therefore to explain why phonological priming effects do not appear with longer prime exposures (as is observed in lexical decision and perceptual identification). The explanation for the absence of phonological priming in the naming task to be offered here is based on previous observations of an *onset effect* on word naming latencies in conditions similar to the present experiments with 60-ms prime exposures (Forster & Davis, 1991). Naming responses are faster when the onset of the prime (the initial consonant cluster) matches that of the target, even if it is the only resemblance between the prime and the target, compared to when the prime stimuli have a different onset. It might therefore be the case that more subtle effects of prime–target phonological overlap are somehow masked by the effects of shared onsets. This would arise in a system that assigns more weight to the initial components of the stimulus in the generation of an articulatory response. This hypothesis was tested in Experiment 3 by disrupting the onsets of prime stimuli (the initial letters were replaced by a % sign).

EXPERIMENT 3

In Experiment 3 the same set of prime–target pairs as that used in Experiments 1 and 2 was used with a single modification: the initial letters of all prime stimuli were replaced by the % sign (e.g., %air–NERF). These stimuli were tested in both a word naming and a lexical decision experiment. It is

hypothesized that the absence of an onset effect in these conditions should allow phonological priming effects to emerge in word naming. Moreover, these particular stimuli allow us to test whether the phonological priming effects observed in Experiment 1 and by Ferrand and Grainger (1992, 1993, 1994) and Perfetti and Bell (1991) generalize to conditions where primes are not pseudohomophones of targets (in all previous experiments when primes shared phonology with targets they were pseudohomophones of the targets).

Method

Subjects. Sixty psychology students at René Descartes University, Paris, France served as subjects for course credit, 30 in the lexical decision task and 30 in the naming task. All were native speakers of French, with normal or corrected-to-normal vision. None of these subjects had participated in the previous experiments.

Stimuli and design. The design was identical to that in Experiment 1 and the stimuli were the same as those used in Experiment 1, except that the first letter of each prime was replaced by a percent sign (%). Three types of nonword primes resulted from this modification: (1) rhyming primes orthographically unrelated to the target (e.g., %air–NERF); (2) rhyming primes orthographically related to the target (50% of letters shared; e.g., %ert–NERF); and (3) nonrhyming primes orthographically related to the target (e.g., %erc–NERF).

Procedure. The procedure was the same as the lexical decision and naming tasks in Experiment 1 using the same prime exposure of 43 ms.

Results

Mean lexical decision latencies and percentage errors and mean naming latencies and percentage errors for each priming condition are given in Table 4. The latencies were trimmed applying a 1000-ms cutoff (less than 3 and 1% of the data rejected for the lexical decision task and the naming task, respectively). The data from the two tasks (lexical decision and naming) were submitted to sepa-

TABLE 4

MEAN LEXICAL DECISION AND NAMING LATENCIES (IN MILLISECONDS) AND PERCENTAGE OF ERRORS IN EXPERIMENT 3 (43 ms PRIME EXPOSURE)

Priming condition	Lexical decision	Naming
Rhyming but orthographically unrelated prime (e.g., %air-NERF)	622 (11.6)	564 (1.0)
Rhyming and orthographically related prime (e.g., %ert-NERF)	609 (9.0)	557 (1.0)
Non-rhyming but orthographically related prime (e.g., %erc-NERF)	654 (12.6)	585 (1.3)
Net orthographic priming effect	+13	+7
Net phonological priming effect	+45	+28

rate analyses of variance. Priming condition (rhyming but orthographically unrelated prime, rhyming and orthographically related prime, and nonrhyming but orthographically related prime) was entered as the main factor.

Lexical decision. Concerning reaction times, there was a significant main effect of priming condition, $F1(2,54) = 21.19$, $p < .001$, and $F2(2,58) = 14.28$, $p < .001$. Planned comparisons between rhyming and orthographically related primes and nonrhyming but orthographically related primes (i.e., phonological priming) showed a 45-ms facilitation effect, $F1(1,27) = 54.25$, $p < .001$, and $F2(1,29) = 43.97$, $p < .001$. On the other hand, planned comparisons between rhyming and orthographically related primes and rhyming but orthographically unrelated primes (i.e., orthographic priming) failed to reach significance, $F1(1,27) = 4.08$, $p = .053$, and $F2(1,29) = 2.97$. In an analysis of variance performed on the error data, the main effect of priming condition failed to reach significance, $F1(2,54) = 1.06$ and $F2(2,58) = 1.21$. The main effect of priming condition in an analysis

of the nonword reaction times failed to reach statistical significance, both F s < 1 (731 ms in the rhyming but orthographically unrelated prime condition, 739 ms in the rhyming and orthographically related prime condition, and 737 ms in the nonrhyming but orthographically related prime condition).

Naming. Concerning naming latencies, there was a significant main effect of priming condition, $F1(2,54) = 14.19$, $p < .001$, and $F2(2,58) = 3.19$, $p < .05$. Planned comparisons between rhyming and orthographically related primes and nonrhyming but orthographically related primes (i.e., phonological priming) showed a 28-ms facilitation effect, $F1(1,27) = 25.06$, $p < .001$, and $F2(1,29) = 5.53$, $p < .05$. On the other hand, planned comparisons between rhyming and orthographically related primes and rhyming but orthographically unrelated primes (i.e., orthographic priming) failed to reach significance, $F1(1,27) = 3.39$ and $F2(1,29) < 1$. An analysis of variance on the naming errors showed no main effect of priming condition, $F1 < 1$ and $F2 < 1$.

Discussion

The results from Experiment 3 clearly support the hypothesis according to which the onset effect masks more subtle phonological priming effects in the naming task. Replacing the initial letter of prime stimuli with a % sign (e.g., %ert-NERF) led to significant effects of phonological priming in conditions (43-ms prime exposures) where complete prime stimuli (e.g., nert-NERF) did not produce such an effect. On the other hand, the size of the rhyme priming effect observed in the lexical decision task in Experiment 3 is identical to the size of the pseudohomophone priming effect observed in Experiment 1, thus suggesting that shared onsets have little effect on form priming in the lexical decision task. The results of the naming task are consistent with those obtained by Bowey (1990, 1993) using a similar partial-word priming procedure but with longer prime exposures (120–150 ms). Bowey found that the prior presentation of a portion of a target word facilitated word naming when the prime was either the onset of

the target (e.g., br–brand) or the rhyme of the target (e.g., aze–gaze). Our own results show clear effects of phonological rhyme units (%ert–NERF) measured against appropriate orthographic controls (%erc–NERF) in the naming task.

The fact that the effects of orthographic priming were not significant in Experiment 3 is likely to be due to the reduction in orthographic overlap between primes and targets (50% in Experiment 3 compared to 75% in Experiment 1). Finally, the fact that partial-word phonologically related primes facilitate naming and lexical decision latencies demonstrates that effects of prime–target phonological overlap in the masked priming paradigm are not limited to the case of primes being pseudohomophones of the targets. This result adds further support to an interpretation of masked phonological priming effects as reflecting the automatic generation of prelexical phonology from the printed word (Perfetti et al., 1988).

EXPERIMENT 4

Experiment 4 was designed to provide further data to help elucidate the precise nature of onset effects in masked form priming. The results from Experiment 3 demonstrate that when prime stimuli do not share their onset with target words significant effects of phonological priming are observed in the word naming task. This result therefore adds support to an interpretation of the absence of such effects in Experiments 1 and 2 as being due to shared onsets producing maximal form priming in the word naming task (just how this could arise is examined under the General Discussion). The fact that orthographic and phonological priming effects do appear in the lexical decision and perceptual identification tasks would be because shared onsets have little influence on form priming observed with such tasks. On this point it should be noted that Forster and Davis (1991) have previously reported a failure to observe onset effects in a masked prime experiment using the lexical decision task. If this argument is correct, then in the word naming task prime stimuli that share only onsets with target words should produce priming ef-

fects comparable in magnitude to those produced by orthographically similar pseudohomophone primes. In the lexical decision task, on the other hand, shared onset primes should have no effect on target recognition latencies relative to an unrelated prime condition. This was tested in Experiment 4 where the homophonic and orthographically related primes from Experiments 1 and 2 (e.g., nert–NERF) were compared to a shared onset prime condition (e.g., nise–NERF) and an unrelated prime condition (e.g., fise–NERF) in both the lexical decision and the naming tasks.

Method

Subjects. Forty-eight psychology students at René Descartes University, Paris, France, served as subjects for course credit, 24 in the lexical decision task and 24 in the naming task. All were native speakers of French with normal or corrected-to-normal vision, and none had participated in the previous experiments.

Stimuli and design. The same word targets as those used in the previous experiments were used. Three types of nonword prime were generated for each target word: (a) nonword primes that are both homophonic with and orthographically similar to the target (e.g., nert–NERF, as in Experiment 1); (b) nonword primes that share only the same initial sound with the target (e.g., nise–NERF); and (c) nonword primes that are orthographically and phonologically unrelated to the target (e.g., fise–NERF). A complete list of these stimuli is presented in Appendix B.

Procedure. The procedure was the same as the lexical decision and naming tasks used in Experiment 1 using a prime exposure of 43 ms.

Results

Mean lexical decision latencies and percentage errors and mean naming latencies and percentage errors for each priming condition are given in Table 5. The latencies were trimmed applying a 1000-ms cutoff (less than 2 and 1% of the data rejected for the lexical decision task and the naming task, respectively). The data from the two tasks (lexical

TABLE 5

MEAN LEXICAL DECISION AND NAMING LATENCIES (IN MILLISECONDS) AND PERCENTAGE OF ERRORS IN EXPERIMENT 4 (43 ms PRIME EXPOSURE)

Priming condition	Lexical decision	Naming
Orthographically similar pseudohomophone prime (e.g., nert-NERF)	615 (10.8)	518 (1.0)
Same initial sound prime (e.g., nise-NERF)	660 (13.7)	519 (1.0)
Unrelated control prime (e.g., fise-NERF)	664 (14.8)	548 (1.5)
Net orthographic and phonological priming effect	+49	+30
Net onset priming effect	+4	+29

decision and naming) were submitted to separate analyses of variance. Priming condition (orthographically similar pseudohomophone prime, same initial sound prime, and unrelated control prime) was entered as the main factor.

Lexical decision. Concerning reaction times, there was a significant main effect of priming condition, $F(2,42) = 10.34$, $p < .001$, and $F(2,58) = 4.72$, $p < .02$. Planned comparisons indicated that orthographically similar pseudohomophone primes facilitated target recognition relative to both the same initial sound primes, $F(1,21) = 19.49$, $p < .001$, and $F(2,1,29) = 9.88$, $p < .005$, and the unrelated control primes, $F(1,21) = 10.34$, $p < .005$, and $F(2,1,29) = 5.14$, $p < .05$. On the other hand, planned comparisons between same initial sound primes and unrelated control primes failed to reach significance (both $F_s < 1$). In an analysis of variance performed on the error data, the main effect of priming condition failed to reach significance, $F(2,42) = 1.19$ and $F(2) < 1$. The main effect of priming condition failed to reach significance in an analysis of the nonword reaction times, $F(2,54) = 1.04$ and $F(2) < 1$ (761 ms in the orthographically similar pseudohomophone prime condition, 768 ms in the same initial sound prime condition, and 770 ms in the unrelated control condition).

Naming. Concerning naming latencies, there was a significant main effect of priming condition, $F(2,42) = 19.49$, $p < .001$, and $F(2,58) = 3.99$, $p < .05$. Planned comparisons indicated that orthographically similar pseudohomophone primes facilitated target naming relative to unrelated control primes, $F(1,21) = 29.69$, $p < .001$, and $F(2,1,29) = 7.21$, $p < .05$. Same initial sound primes also facilitated target naming relative to unrelated control primes, $F(1,21) = 25.39$, $p < .001$, and $F(2,1,29) = 5.75$, $p < .05$, whereas the difference between same initial sound primes and orthographically similar pseudohomophone primes was not significant, $F(1) < 1$ and $F(2) < 1$. In an analysis of variance performed on the error data, the main effect of priming condition failed to reach significance, $F(1) < 1$ and $F(2) < 1$.

Discussion

The results from Experiment 4 clearly demonstrate that primes that share their onset (same initial sound) with targets produce facilitation effects that are comparable to those obtained with orthographically and phonologically related primes in the speeded naming task. On the other hand, shared onsets had no effect on lexical decision latencies to target words when compared to unrelated controls. These results therefore add further support to our interpretation of the observed absence of form priming effects in the word naming task in Experiment 1 as being due to shared onsets maximally facilitating the target naming process.

EXPERIMENT 5

Experiment 5 examines a more general theoretical issue concerning the precise nature of onset effects in the masked priming paradigm. Forster and Davis (1991) interpret the effect of shared onsets in the naming task as an inhibitory rather than a facilitatory phenomenon. According to these authors, shared onsets do not facilitate target pronunciation, but rather it is the different onset condition that interferes in generating a naming response (the response competition hypothesis). Furthermore, Forster and Davis argue that the re-

response competition generated by different onset primes in the naming task masks other form priming effects. This is of course diametrically opposed to the hypothesis developed here according to which primes that share onsets with target words produce a maximum facilitation effect that prevents more subtle form priming effects from emerging. Clearly, the fact that phonological priming of word naming was observed in Experiment 3 when primes did not share their onsets with targets, and not in Experiments 1 and 2 when primes did share their onsets with targets, would appear to be evidence favorable to the present hypothesis. Experiment 5 tests the alternative interpretations of the onset effect in word naming discussed above by comparing a shared onset condition (e.g., *nise*-NERF) with both a different onset condition (e.g., *fise*-NERF) and a different a non letter onset condition (e.g., %*ise*-NERF). Assuming that a % sign could only very weakly activate any given letter representation via some shared visual features, response competition should diminish in this condition.

Method

Subjects. Twenty-four psychology students at René Descartes University, Paris, France, served as subjects for course credit. All were native speakers of French, with normal or corrected-to-normal vision, and none had participated in the previous experiments.

Stimuli and design. In Experiment 5 the homophonic and orthographically related primes from Experiment 4 were replaced by unrelated primes with a % sign in initial position (nonletter initial primes), thus giving the three following prime conditions: (a) nonword primes that have the same initial sound as the target (e.g., *nise*-NERF); (b) nonword primes that are orthographically and phonologically unrelated to the target (e.g., *fise*-NERF); and (c) nonword primes with a nonletter onset that are orthographically and phonologically unrelated to the target (e.g., %*ise*-NERF). A complete list of these stimuli is presented in Appendix B.

Procedure. The procedure was the same as

TABLE 6

MEAN NAMING LATENCIES (IN MILLISECONDS) AND PERCENTAGE OF ERRORS IN EXPERIMENT 5 (43 ms PRIME EXPOSURE)

Priming condition	Naming
Same initial sound prime (e.g., <i>nise</i> -NERF)	568 (1.5)
All different prime (e.g., <i>fise</i> -NERF)	599 (2.0)
Nonletter onset prime (e.g., % <i>ise</i> -NERF)	591 (1.8)

that used for the naming tasks in the previous experiments using a prime exposure of 43 ms.

Results

Mean naming latencies and percentage errors for each priming condition are given in Table 6. The latencies were trimmed applying a 1000 ms cutoff (less than 1% of the data rejected). The data were submitted to an analysis of variance with priming condition (same initial sound prime, all different unrelated prime, and nonletter onset unrelated prime) entered as the main factor.

There was a significant main effect of priming condition, $F1(2,42) = 15.03$, $p < .001$, and $F2(2,58) = 11.79$, $p < .001$. Planned comparisons indicated that same initial sound primes facilitated target naming relative to all different primes, $F1(1,21) = 26.43$, $p < .001$, and $F2(1,29) = 19.09$, $p < .001$, and relative to nonletter onset primes, $F1(1,21) = 21.41$, $p < .001$, and $F2(1,29) = 8.88$, $p < .01$. However, the difference between all different primes and nonletter onset primes was not significant, $F1(1,21) = 1.75$ and $F2(1,29) = 3.01$. In an analysis of variance performed on the error data, the main effect of priming condition failed to reach significance, $F1 < 1$ and $F2 < 1$.

Discussion

The results from Experiment 5 stand in contradiction to the response competition hypothesis of Forster and Davis (1991). Although same onset primes (e.g., *nise*-NERF) significantly facilitated target pronunciation relative to a nonletter onset prime (e.g., %*ise*-NERF), the different onset prime condition (e.g., *fise*-

NERF) was not significantly slower than the nonletter onset condition. Moreover, there was no evidence of response competition in the small number of errors produced by our subjects. It should be pointed out, however, that the prime exposures used by Forster and Davis were slightly longer than those in the present experiments (60 compared to 43 ms). Thus, the observed absence of response competition in the different onset condition in Experiment 5 may well be due to the shorter prime exposures used. Nevertheless, the important point is that the presence of shared onsets between primes and targets in the present experiments appears to produce a strong facilitation effect that makes it difficult to observe more subtle form priming effects in the word naming task. With longer prime exposures (around 60 ms), it would appear from Forster and Davis' (1991) observations that an inhibitory (response competition) component is also present in the onset effect. We are currently pursuing our investigations of facilitatory and inhibitory onset priming effects using a radically different approach referred to as the incremental priming technique (Jacobs, Grainger, & Ferrand, 1995). By gradually increasing the intensity of the prime stimulus across different priming sessions one can observe the growth of facilitation or inhibition of priming effects with respect to a zero intensity baseline. This approach therefore provides an interesting solution to the delicate problem of deciding the appropriate baseline for measuring priming effects. It should provide very useful information with respect to the precise nature of onset effects in primed word naming.

GENERAL DISCUSSION

The results from the present experiments provide further evidence that orthographic and phonological codes are separate sources of input to lexical representations during visual word recognition. Masked, briefly presented (43 ms) primes that were orthographically and/or phonologically related to target words facilitated target recognition relative to appropriate controls in both the lexical decision and the perceptual identification tasks. This stands as clear evidence against theories that postu-

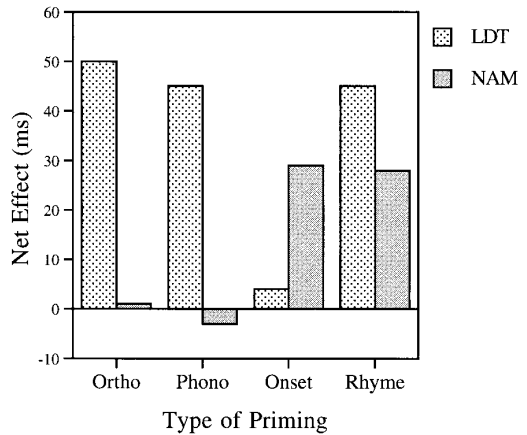


FIG. 2. Summary of the net priming effects obtained in the lexical decision and naming tasks with 43-ms prime exposures. Ortho, orthographic priming in Experiment 1; Phono, phonological priming in Experiment 1; Rhyme, phonological priming with deleted onset in Experiment 3; Onset, onset priming in Experiment 4.

late that lexical representations are contacted on the basis of one type of code only. In the word naming task, on the other hand, prime-target orthographic overlap facilitated target naming latencies only at 29-ms prime exposures, whereas phonological prime-target overlap failed to produce facilitation at all of the prime exposures tested (29, 43, and 57 ms). This failure to observe orthographic and phonological priming in the word naming task in conditions where clear effects are obtained in the lexical decision and perceptual identification tasks was shown to be due to the strong facilitation produced by shared onsets on word naming latencies. When prime stimuli share orthography and/or phonology with the target but do not share the same initial consonant, the word naming task produces effects comparable to those obtained in the lexical decision task.

The main results obtained with the lexical decision and word naming tasks are summarized in Fig. 2. The strong dissociation among orthographic, phonological, and onset priming effects in the two tasks is evident in this figure. Clearly, such a pattern of results provides strong constraints for any attempt to develop an account of visual word recognition that integrates data from the various laboratory tasks

used in this domain. A general framework for developing such a model was presented in the Introduction (Fig. 1). In the following, we examine the potential for such a framework to accommodate the pattern of effects observed in the present experiments.

At a general level of evaluation, the bimodal property of the model allowed it to correctly predict that both orthography and phonology provide separate sources of information input to lexical representations, as suggested by the results in the present experiments. Further evidence in favor of this position is available from other experimental paradigms. Pollatsek, Lesch, Morris, and Rayner (1992) have shown that parafoveal previews that are homophones of target words facilitate target recognition (measured in terms of naming latencies and eye fixation durations) and that the orthographic similarity between previews and targets also influences subjects' performance (see also Rayner et al., 1995). In the semantic categorization task, false positive responding is influenced not only by phonological similarity to correct responses but also by orthographic similarity (Coltheart, Patterson, & Leahy, 1994; Wydell, Patterson, & Humphreys, 1993; Van Orden, 1987), although some form of spelling check might be able to explain these effects (Van Orden, 1987). All these results converge to suggest that lexical representations can be activated by both orthographic and phonological codes. Let us now examine how well our model can accommodate the data concerning masked form priming in visual word recognition and naming.

Masked Priming and Word Recognition

In previous discussions of how the interactive activation framework captures both facilitatory and inhibitory form priming effects in visual word recognition (Grainger, 1992; Grainger & Jacobs, 1993; Jacobs & Grainger, 1992) two basic components of these effects, (1) between-level bottom-up facilitation, and (2) within-level lexical inhibition, were distinguished. Following this distinction, the net priming effect in the masked priming paradigm is thought to be a function of (a) the

extent to which any of the representations (sublexical or lexical) subtending target recognition are preactivated by the prime stimulus, and (b) the extent to which any lexical representations, other than the target word itself, are preactivated by the prime stimulus and continue to be activated during target processing. Thus all form priming effects are seen as resulting from a facilitation and an inhibition component the relative size of which will determine whether the net effect is positive or negative.

Applying this analysis of form priming effects within the framework described in Fig. 1 shows that the bimodal model correctly predicts variations in orthographic and phonological priming as a function of prime exposure duration (Ferrand & Grainger, 1992, 1993, 1994; Perfetti & Bell, 1991). The facilitatory effects of orthographic prime-target overlap develop earlier than the effects of phonological overlap. Moreover, as the effects of phonology begin to emerge the effects of orthography tend, on the contrary, to disappear. This aspect of the results can be explained by the build up of within-level inhibition between orthographic word units while activation is building up at the level of sublexical phonological units (sublexical orthographic units send activation simultaneously to whole-word orthographic units and sublexical phonological units). The early effects of orthographic prime-target overlap are explained by the prime stimulus activating sublexical orthographic units that are subsequently involved in target recognition. Sublexical phonology will have received little activation input after 29 ms of prime processing, but with longer prime exposures these too benefit from preactivation and thus facilitate subsequent target recognition. While sublexical phonological facilitation is developing, however, orthographic word units other than the target word also increase in activation level thus cancelling the facilitatory effects of prime-target orthographic overlap. Thus, for example, if the prime-target pair were *blun*-*BLUR*, facilitation will result from the prime sharing 75% of the target's component letters (in the correct position), but inhibition will develop from the

conjoint activation of competing word units such as BLUE (cf. Grainger, 1990; Grainger, O'Regan, Jacobs, & Segui, 1989; Grainger & Jacobs, 1993; Jacobs & Grainger, 1992; Segui & Grainger, 1990).

In some recent experiments using the backward masking paradigm of Perfetti et al. (1988), Verstaen, Humphreys, Olson, and d'Ydewalle (1995) have shown that when subjects received only homophone targets orthographic but no phonological priming effects are found. Also, when homophone targets are presented in the first half of an experiment the absence of phonological priming transfers to nonhomographic targets in the second half of the experiment. The authors conclude that phonological priming is sensitive to whether the experimental procedure encourages the use of phonological information. Within the framework of the bimodal interactive activation model, an absence of phonological priming effects would arise if subjects placed more reliance on the activity of sublexical orthographic codes (i.e., letter representations) when giving their response in a perceptual identification task (cf. Grainger & Jacobs, 1994). This would occur with homophone targets as the result of two conjointly operating mechanisms: increased inhibition in the orthographic lexicon and ambiguous information provided by the phonological lexicon. According to our model, when the target is a homophone (e.g., BEAR) then all the corresponding whole-word orthographic units (BEAR, BARE) will be activated upon presentation of a pseudohomophone prime (BAIR). Since all units within the same representational level mutually inhibit each other, the target word BEAR will be inhibited by its orthographic mate (BARE). This will be particularly true for the lower frequency member of the pair, thus explaining why target homophony did not influence performance in the present experiments (the homophone targets were generally the higher frequency member of the pair). Moreover, in the case of homophone targets, read-out from the phonological lexicon will provide ambiguous information (the different possible spellings) and this ambiguity will force subjects to pay more

attention to letter level information in order to disambiguate the information provided by the phonological lexicon.

Masked Priming and Word Naming

The word naming results from the present experiments can be summarized as follows. (1) At the shortest prime exposures (29 ms) shared orthography between prime and target facilitated word naming, whereas shared phonology had no detectable effect. This particular result recently has been replicated in a related series of experiments using different stimuli (Ferrand et al., 1994), and exactly the same pattern of effects previously had been observed with the lexical decision task (Ferrand & Grainger, 1992, 1993). (2) At longer prime exposures (43 and 57 ms), primes that had the same initial sound as targets (shared onsets) produced maximal facilitation above which additional orthographic and phonological overlap had no effect. (3) When the initial letters of prime stimuli were replaced by a % sign, the word naming task showed the same pattern of orthographic and phonological priming as the lexical decision task with 43-ms prime exposures.

The strong facilitation effect of shared onsets observed in the word naming task is predicted by dual-route models that postulate a serial grapheme-to-phoneme (GPC) conversion process (e.g., Coltheart, Curtis, Atkins, & Haller, 1993). In such models, the time constraints of masked priming would allow only the onset pronunciation to be generated, thus giving rise to the observed dominance of onset effects in the word naming task. Compared to the serial GPC translation procedures used in the dual-route model of Coltheart et al., however, the model outlined in Fig. 1 uses a parallel activation process from perceptual input units to articulatory output units (cf. Norris, 1994). Seriality is introduced in the model in the way articulatory units are selected for output. One means of producing this desired seriality is for the articulatory units to become maximally active in order, moving from the beginning to the end of the word. This could be achieved by means of a differential left-to-right weighting of the connection strengths

between perceptual units and articulatory units as in Houghton's (1990) model.¹ This also would allow the model to capture the recent observation that regularity effects in word naming decrease as the position of the irregularity moves from the beginning to the end of the word (Coltheart & Rastle, 1994; Content, 1991; Content & Peereman, 1992).

Let us now examine how the bimodal model, in principle, could accommodate the form priming effects observed in the word naming task from the present experiments. In our general description of the model, it was hypothesized that speeded word naming responses could be triggered once a critical number of articulatory units have been selected for output. Now, when prime stimuli are presented very briefly (29 ms), according to the analysis of form priming effects in word recognition presented above, only sublexical orthographic units are significantly activated at this point. This results in prime-target orthographic overlap producing facilitation effects in the word naming task (Experiment 2; Ferrand et al., 1994) comparable to those obtained in the lexical decision and perceptual identification tasks (Ferrand & Grainger, 1992; Perfetti & Bell, 1991). However, with prime exposures long enough to activate sublexical phonological units and whole-word orthographic units (43 ms), articulatory units are also being significantly activated by the prime stimulus. The serial nature of articulatory unit activation implies that at such prime exposures only articulatory units corresponding to word onsets have been significantly activated (and possibly already

selected for output). On presentation of a target word with the same onset as the prime stimulus the onset unit will be rapidly selected, thus allowing a faster selection of successive output units. Consequently, the critical number of units that needs to be selected for initiating a naming response will be attained more rapidly. However, when onsets are deleted from the prime stimuli as in Experiment 3, on presentation of the target word, onset unit activation will be at resting level and therefore a maximum of processing time will be available before a naming response criterion is reached. This will therefore allow other sublexical and lexical units that were preactivated by the prime stimulus to influence target naming latencies, thus accounting for the reappearance of orthographic and phonological priming when primes do not share onsets with targets.

There is, however, one situation tested in other experiments (e.g., Ferrand et al., 1994; Lukatela & Turvey, 1994) where word naming latencies have been significantly influenced by briefly presented masked primes. That is the case where the prime stimulus is the same word as the target. These repetition priming effects observed by Ferrand et al. (1994) at 29-ms prime exposures can be explained within the framework of the bimodal model as a case of maximal orthographic priming. Two points suggest that this is the case: (a) the fact that the size of orthographic priming effects obtained in the same experimental conditions with four to five letter words (where primes shared 75–80% of the target's letters) were approximately 75% of the size of repetition priming effects in stimuli of the same length (where primes shared all of the target's letters); and (b) the fact that the size of repetition priming effects increased with word length in the word naming task. Increasing word length might force subjects to wait for a larger number of articulatory units to be sufficiently activated before triggering a naming response. This would therefore allow a greater influence of orthographic priming.

¹ Other means of achieving sequential selection of articulatory output units may of course be possible. What interests us here, however, are the consequences of such seriality for the model's ability (independently of its precise implementation) to accommodate the results obtained in the word naming task. It should be noted, however, that since articulatory output is **necessarily** sequential, this cannot be considered an ad hoc addition to the model. What is important is that we are claiming that onset effects observed in the word naming task arise at the level of articulatory encoding and not during perceptual processing.

Onset Effects in Perception and Production

In the present experiments, when prime stimuli had the same onset as targets, word naming responses were facilitated relative to both a different onset prime and a prime beginning with a % sign. This suggests that the effects of shared onsets in masked form priming with the word naming task are facilitatory. Indeed, the fact that the two latter priming conditions did not produce a significant difference in naming latencies suggests that there was no inhibition from different onset primes at the 43-ms prime exposures in the present experiments (here we assume that an initial % sign will generate very little initial letter activity). This is confirmed by the observed absence of any mispronunciations of the target involving substitution of the prime's onset. The fact that Forster and Davis (1991) did observe such mispronunciations with slightly longer prime exposures than those in the present experiments, suggests that an inhibitory component of onset effects arises when sufficient time is given for prime processing. This critical prime exposure would correspond to the time necessary for the articulatory unit corresponding to the prime's onset to have been selected for output.

As mentioned in the preceding discussion, the serial GPC route of dual-route models (e.g., Coltheart et al., 1993) offers one possible explanation for onset effects in word naming. One simply has to postulate that with brief enough prime exposures the GPC procedure has had time only to compute the initial phoneme of the prime. However, in order to explain the effects of masked phonological priming within the dual-route framework one also has to postulate that the sublexical phonology generated by GPC rules also influences performance in tasks such as lexical decision and perceptual identification. In other words, one is led to incorrectly predict that onset effects also occur in such tasks. Dual-route models, however, could, get around this problem by allowing visual word recognition to be influenced by another form of sublexical phonology, thus leaving the GPC route uniquely devoted to

pronunciation. Nevertheless, the clear dissociation between the presence of strong onset effects in word naming and the almost total absence of such effects in lexical decision implies that these effects are located at an articulatory rather than a perceptual level of processing. Since articulatory output is necessarily sequential, it would appear likely that the mechanism used to introduce such seriality in pronunciation would also be responsible for onset effects. In the word naming component of the bimodal model sketched in the present article, it is the combination of such a serial output mechanism with the decision criterion used to initiate a speeded naming response that explains onset effects in word naming.

Finally, it is interesting to note a parallel in the language production literature where the importance of word onsets (or the *initialness effect* as it is referred to by Dell, Juliano, & Govindjee, 1993) has long been considered as one of the critical constraints for any model of language production (e.g., MacKay, 1972; Shattuck-Hufnagel, 1987). The original interactive activation model of Dell (1986) did not include a within-syllable ordering mechanism, but later developments of this type of model (e.g., Houghton, 1990) and other connectionist models (e.g., Dell et al., 1993) have incorporated such a mechanism. In the production literature, the importance of word onsets can be seen in the analyses of speech errors showing that word-initial consonants are more likely to participate in phonological errors than word-final ones (Stemberger, 1983). Further evidence is provided by the experiments of Meyer (1991) where subjects had to produce monosyllabic words in response to a previously learned prompt. Response times were faster when the list of words to be uttered shared the same onset but not when they shared the same rhyme (compared to a condition where the words shared neither onset nor rhyme). The results of Meyer (1991) therefore provide experimental confirmation of the dominant role of word onsets in speech production. One fruitful area for further research involves comparing naming performance in

the standard word naming task with performance in production tasks such as picture naming (e.g., Ferrand et al., 1994). Such comparisons should help dissociate effects

due to phonology generated from the printed word (input phonology) and effects due to phonology generated explicitly for an articulatory response (output phonology).

APPENDIX A: STIMULI USED IN EXPERIMENTS 1 AND 2

French word target	Homophonic and orthographically similar prime	Homophonic but orthographically dissimilar prime	Nonhomophonic but orthographically similar prime
FAIM	fain	fint	faic
LENT	lens	lamp	lene
BORD	bore	baur	borl
PAIR	peir	pers	plir
BEAU	bhau	baut	blau
TORT	tors	taur	torc
THYM	thyn	tein	thyr
NERF	nert	nair	nerc
TAUX	taud	tots	tauf
BAIN	baim	bint	bair
VENT	vens	vamd	vene
ZINC	zint	zein	zine
NORD	nore	naur	norc
VERS	verd	vair	verg
LAI	lais	lets	lain
FORT	fore	faur	fork
MAIN	maim	mins	maig
MAUX	maut	meau	maul
SAIN	saim	sint	saie
FAIT	faie	fets	fail
DENT	dens	damp	dene
VAIN	vaim	vint	vail
SORT	sore	saur	sora
MERE	mert	mair	merq
BAIE	bait	bets	bair
ROSE	roze	rauz	rove
SOLE	sols	saul	solt
FILS	fiss	phys	firs
FAUX	faud	fots	fauc
BANC	bant	bemp	bane

APPENDIX B: STIMULI USED IN EXPERIMENT 4

French word target	Homophonic and orthographically similar prime	Same initial sound prime	Unrelated control prime
FAIM	fain	fule	dule
LENT	lens	lade	pade
BORD	bore	beil	reil
PAIR	peir	pive	tive
BEAU	bhau	bour	nour
TORT	tors	tume	lume
THYM	thyn	toul	doul
NERF	nert	nise	fise
TAUX	taud	tene	lene
BAIN	baim	borl	porl
VENT	vens	vure	lure
ZINC	zint	zare	vare
NORD	nore	naig	jaig
VERS	verd	vule	sule
LAI	lais	lenf	benf
FORT	fore	feul	deul
MAIN	maim	mibe	sibe
MAUX	maut	mude	lude
SAIN	saim	solt	molt
FAIT	faie	forg	porg
DENT	dens	dour	gour
VAIN	vaim	vine	bine
SORT	sore	sape	bape
MERE	mert	maul	faul
BAIE	bait	boun	loun
ROSE	roze	ranc	danc
SOLE	sols	sanr	banr
FILS	fiss	feul	beul
FAUX	faud	firk	mirk
BANC	bant	bive	pive

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