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Visual and phonological codes in letter and word recognition: Evidence from incremental priming

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Critical issues in letter and word priming were investigated using the novel *incremental priming technique*. This technique adds a parametric manipulation of prime duration (or prime intensity) to the traditional design of a fast masked priming study. By doing so, additional information on the time course and nature of priming effects can be obtained. In Experiment 1, cross-case letter priming (a–A) was investigated in both alphabetic decision (letter/non-letter classification) and letter naming. In Experiment 2, cross-case word priming was investigated in lexical decision and naming. Whereas letter priming in alphabetic decision was most strongly determined by visual overlap between prime and target, word priming in lexical decision was facilitated by both orthographic and phonological information. Orthographic activation was stronger and occurred earlier than phonological activation. In letter and word naming, in contrast, priming effects were most strongly determined by phonological/articulatory information. Differences and similarities between letter and word recognition are discussed in the light of the incremental priming data.

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The present study examines the visual processing of letter and word stimuli in an attempt to isolate any similarities and differences in the underlying mechanisms. One fundamental difference between letter and word recognition may lie in the involvement of phonological information. In word recognition, a large amount of evidence indicates that phonological information plays an early and automatic role in the recognition of printed words (e.g., Lukatela & Turvey, 1994; Perfetti & Bell, 1991; Perfetti, Bell, & Delaney, 1988; Peter & Turvey, 1994; Rayner, Sereno, Lesch, & Pollatsek, 1995; Ziegler & Jacobs, 1995; Ziegler, Van Orden, & Jacobs, 1997; for a review, see Frost, 1998). Some of this evidence comes from priming studies in which phonological overlap between a prime and a target facilitates recognition of the target (e.g., Ferrand & Grainger, 1992, 1993, 1994; Grainger & Ferrand, 1994, 1996; Humphreys, Evett, & Taylor, 1982; Lukatela, Frost, & Turvey, 1998). Moreover, studies that manipulated prime duration point to the possibility that orthographic and phonological processes follow different time course with orthographic information being accessed slightly faster than phonological information (e.g., Ferrand & Grainger, 1993, 1994; see also Perfetti & Tan, 1998).

In letter recognition, in contrast, it is much less clear whether phonological information plays a role, and it is still a matter of discussion as to which kind of evidence would unambiguously prove the involvement of phonological information. For example, Posner and Mitchell (1967) argued that cross-case priming (a–A) constitutes evidence for phonological processing (i.e., the involvement of a name code) because, in cross-case priming, primes and targets have the same name albeit a different visual shape. However, other studies that looked specifically for effects of phonetic/acoustic similarity in letter recognition typically failed to find such phonetic/acoustic effects (Arguin & Bub, 1995; Boles & Eveland, 1983; Carrasco, Kinchla, & Figueroa, 1988). Moreover, cross-case priming does not necessarily need to result from overlap in phonological information. It could result from primes activating abstract orthographic letter representations that are shared by both upper- and lower-case letters (e.g., Arguin & Bub, 1995). Another possibility would be that primes automatically and rapidly generate the opposite case in memory, without the mediation of a phonological code (Boles, 1992).

Interestingly, it turns out to be less important to decide which of the above mentioned accounts would best explain cross-case letter priming because cross-case priming effects seem to be difficult to obtain unless the task is naming. One of the few studies that obtained cross-case letter priming effects in a task that did not involve naming was by Jacobs and Grainger (1991). These authors obtained facilitatory cross-case priming effects in a letter–nonletter classification task (alphabetic decision task). However, this study confounded case format and visual similarity in that some prime–target pairs were visually similar (e.g., c–C) whereas others were not (e.g., a–A). Clearly, to make a case for cross-case priming that cannot be reduced to visual similarity between prime and target, only visually dissimilar primes (a–A) can provide conclusive evidence for the existence of abstract letter codes or the involvement of phonological information. In fact, when Arguin and Bub (1995) replicated Jacobs and Grainger's study with cross-case primes that were all visually dissimilar, the cross-case priming effects in the alphabetic decision task disappeared. The only situation in which Arguin and Bub found cross-case letter priming was when the task involved naming.

Recently, Bowers, Vigliocco, and Haan (1998) followed up on Arguin and Bub's (1995) finding. They investigated cross-case letter priming with both visually similar (SIM) and visually dissimilar (DIS) primes (e.g., SIM: x–X; DIS: a–A). Furthermore, they compared the effects across four different tasks: alphabetic decision, letter naming, vowel/consonant decision, and perceptual identification. Their striking finding was that whereas SIM letter priming was present in all tasks, DIS letter priming was present only in letter naming. This study clearly suggested that DIS letter priming can be obtained only when the task requires articulation (naming). The absence of cross-case priming effects in tasks other than naming casts doubts on the importance of phonological processes or abstract orthographic letter representations in letter recognition. This stands in sharp contrast to word recognition where both orthographic and phonological overlap have been shown to influence word recognition in tasks other than naming (e.g., Ferrand & Grainger, 1992, 1993, 1994; Grainger & Ferrand, 1994, 1996).

In the present research, we extended Bowers et al.'s (1998) study by investigating the time course and the nature of priming effects in letter and word recognition. For this purpose, we used the novel *incremental priming technique* (Jacobs, Grainger, & Ferrand, 1995). This technique adds a parametric manipulation of prime duration (or intensity) to the traditional design of a priming experiment. For this technique to work, one has to find a fairly short prime duration (or a low level of prime intensity) at which priming effects are minimal. This point is defined as the *within-condition baseline*. Then, prime duration or intensity is gradually increased (i.e., incremental priming). If performance improves with respect to this within-condition baseline, then the prime has facilitated target processing. If performance decreases, then the prime has inhibited target processing. Thus, priming is defined with respect to two baseline conditions: One is the within-condition baseline, the other is the traditional across-condition baseline.

The advantage of this technique is that it provides additional information on both the nature and the time-course of priming effects. For example, imagine we were interested in investigating phonological priming effects by using phonologically identical nonword primes in a masked priming situation (e.g., baik–BAKE). To estimate the size of the priming effect, one typically uses an unrelated condition as across-condition baseline (e.g., firt–BAKE). Any difference between the related and the unrelated conditions is interpreted as a net facilitatory priming effect. Incremental priming provides additional information by investigating how a prime affects target processing as it becomes increasingly available. For example, if the net priming effect were due to phonological overlap between prime and target, we would predict that with increasing prime availability target processing in the related condition would become faster (facilitation). However, if the net priming effect were due to competition from visual or phonological mismatch in the unrelated conditioned, then we would expect that with increasing prime availability, target processing in the unrelated condition would be slowed down (inhibition).

It is clear that incremental priming does not distinguish facilitation from inhibition in some absolute sense. However, incremental priming can offer additional information concerning the nature of priming effects. Take, for example, the homophone priming effects observed by Perfetti and Tan (1998) in a naming task. The homophone priming effect reflects the finding that naming latencies were faster when a target was preceded by its homophone mate (e.g., blew–BLUE) than when the target was preceded by a nonhomophonic control prime (e.g., cent–BLUE). In the General Discussion of their article, these authors discuss the possibility that their homophone priming effect was "less one of facilitation than of release from competition" (Perfetti & Tan, 1998, p. 111). Their argument was based on the fact that nonhomophonic control primes, contrary to homophonic primes, did not share the initial phoneme with the target. This mismatch in the unrelated condition may have resulted in naming competition at the level of articulatory outputs. Hence, their phonological effects could have been primarily a release-from-interference effect mediated through output phonology. Their data did not allow them fully to assess this possibility.

This is where incremental priming can offer additional information. If facilitatory effects were due to release from inhibition,[1] then we would predict that inhibition in the unrelated (mismatch) condition should increase with increasing prime availability. The way to look at such inhibition is that in any priming situation, visual or linguistic mismatch between prime and target can result in a perturbation of performance. If the pertubation were due to a mismatch between prime and target, then this perturbation effect should increase with increasing prime availability (i.e., inhibition). If we obtain shorter reaction times for the related condition than for an inhibitory unrelated condition, then this positive priming effect can be seen as a release from this perturbation effect (release from inhibition). Finally, if the mismatch in the unrelated condition does not produce an inhibitory effect (no perturbation with increasing prime duration), then facilitation in the related condition could be seen as genuine facilitation. Knowing whether priming effects are due to facilitation, inhibition, or release from inhibition can be extremely useful for testing simulation models that allow a prime literally to inhibit or facilitate target performance (e.g., Coltheart, Woollams, Kinoshita, & Perry, 1999; Jacobs & Grainger, 1992; Jacobs, Rey, Ziegler, & Grainger, 1998).

In sum, the present experiments explore facilitatory and inhibitory processes in letter and word priming using the incremental priming technique. In Experiment 1, cross-case letter priming was investigated in both alphabetic decision and letter naming. In Experiment 2, this research was extended to word stimuli by investigating cross-case priming in lexical decision and word naming.

EXPERIMENT 1

Experiment 1 investigated whether evidence for cross-case letter priming could be obtained when the incremental priming technique was used. For this purpose, SIM and DIS primes were used in both alphabetic decision and letter naming. An identity condition and the traditional unrelated condition were added to form a total of four priming conditions: (1) physically identical (ID) primes (e.g., B–B); (2) SIM primes (e.g., c–C); (3) DIS primes (e.g., a–A), and (4) unrelated primes (e.g., x–T). Based on previous results (Arguin & Bub, 1995; Bowers et al., 1998), it was predicted that DIS primes should produce facilitation in naming but not in alphabetic decision. In contrast, ID and SIM primes should produce facilitation in both alphabetic decision and naming.

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[1] Because the priming literature refers more commonly to inhibition and facilitation to describe the nature of priming effects, we prefer to use the term "release from inhibition" rather than "release from competition".

Furthermore, it was of interest to us whether unrelated primes would actually produce within-condition inhibition with increasing prime duration or whether unrelated primes would provide a stable baseline. As mentioned above, this information is needed to decide whether inhibitory processes are at work in the unrelated condition.

METHOD

Subjects

Eight well-trained subjects,[2] all members of the Experimental Psychology Laboratory in Paris, took part in the study, four in each of the two tasks (go/no-go alphabetic decision and naming). All subjects reported normal or corrected-to-normal vision.

Apparatus, stimuli, and design

Stimulus presentation and response measurements were controlled by a standard PC using a monitor with a 70-Hz refresh rate (frame duration of approximately 14 ms). Stimuli were presented at a high contrast under photopic viewing conditions. Naming latencies were recorded to the nearest millisecond via a Sennheiser MD211 N microphone that was connected to the PC via an amplifier and voice key.

A total of 20 target letters were used in the experiment, 10 with similar lower- and upper-case versions (C, K, O, P, S, U, V, W, X, Z), and 10 with dissimilar lower- and upper-case versions (A, B, D, E, N, G, T, Y, Q, R). Target letters were presented in upper case and primes in lower case. Four different prime conditions were used: (1) ID: the prime was physically identical to the target (e.g., B–B); (2) SIM: prime and target had the same name and a similar shape (e.g., c–C, x–X); (3) DIS: prime and target had the same name but dissimilar shape (e.g., a–A, g–G); (4) UNREL: the prime was visually and nominally different from the target (e.g., x–T).

Because SIM target letters (e.g., C) could not be tested in the DIS condition (and vice versa), each target letter could occur in only three of the four priming conditions (three experimental lists): A SIM target letter, like C, could occur only in the ID condition (C–C), the SIM condition (c–C), and the UNREL condition (x–C), and not in the DIS condition. Similarly, a DIS target letter, like A, could occur only in the ID condition (A–A), the DIS condition (a–A), and the UNREL condition (x–A), and not in the SIM condition. Thus each target letter was tested in three of the four priming conditions. In addition, each target letter was tested at each of four different prime durations (14, 29, 43, and 57 ms). This resulted in the total number of 240 "yes" trials (20 target letters $\times$ 3 priming conditions $\times$ 4 prime durations). Subjects received all possible combinations of prime conditions and prime exposure duration in a random order, which was different for each subject. In addition, for the purpose of the alphabetic decision task, 240 "no" trials were added. The "no" trials consisted of letter primes followed by various keyboard characters (e.g., *, &, %, ?, >).

Procedure

In the go/no-go alphabetic decision task, subjects decided as rapidly as possible if the visually presented stimulus was a letter or a nonletter. If it was a letter, they pressed a response key on the computer keyboard. If not, they refrained from responding. In the naming task, they read aloud the

[2] As in previous studies (Arguin & Bub, 1995, Jacobs & Grainger, 1991; Jacobs et al., 1995; Ziegler, Rey, & Jacobs, 1998) we followed the psychophysical approach of using only a few subjects and a rather large number of trials.

name of the target letter. In both tasks, the sequence of events on each trial was as follows. A forward pattern mask (ALT 177 on PC keyboard) was presented on the centre of the screen for approximately 500 ms (35 frame durations). It was immediately replaced by the prime stimulus, which remained on the screen for one of four durations (14, 29, 43, and 57 ms). The prime was replaced by a backward mask presented for 14 ms. This backward mask was immediately followed by the target letter, which appeared in the same position as the prime. In both tasks, the target remained on the screen until subjects responded. Subjects were asked to respond as quickly as possible to the target. Alphabetic decision and naming latencies were measured between the onset of the target and the onset of the subject's response. Before the experimental session, subjects received 16 practice trials in the alphabetic decision task, which consisted of 8 "go" trials and 8 "no-go" trials. The 8 go trials contained two prime–target pairs from each priming condition (i.e., ID, SIM, DIS, UNREL). In the naming task, subjects received 8 practice trials, which consisted of two prime–target pairs from each priming condition.

Results

Table 1 gives the mean correct reaction times (RTs) and error rates for the four priming conditions for both the alphabetic decision and the letter-naming task. Because the error data represented less than 1% of all trials, they are not considered any further. Data analysis was based on correct responses only. The data were analysed using an analysis of variance (ANOVA) with subjects (F_1) and items (F_2) as random factor. In the subject analysis, prime type and prime duration were within-subject variables. In the item analysis, prime type was a between-item variable,[3] and prime duration was a within-item variable.

The classic between-condition priming effects were assessed in planned comparisons between the related (ID, SIM, and DIS) and the unrelated priming conditions (UNREL). The within-condition priming effects were analysed in separate ANOVAs for each prime condition, with prime duration as a single within-subject and within-item factor. These analyses assessed whether RTs significantly increased or decreased with prime duration. For all other comparisons, 95% within-subject confidence intervals (CIs) according to Loftus and Masson (1994) were computed. The values of these CIs are given in Figures 1 and listed in Table 1.

The incremental priming technique provides information on the nature and time course of priming effects by using the shortest possible prime duration of 14 ms as the within-condition baseline for each priming condition. In all of the following figures, net priming effects are presented with respect to this within-condition baseline. The values above the zero-line thus indicate that target processing was inhibited (longer RTs) compared to the within-condition baseline; values below that line indicate that target processing was facilitated (faster RTs).

[3] Notice that it would have been possible to perform the item analysis using a 2 × 3 ANOVA with similarity (DIS vs. SIM) as between-item factor and prime type (ID vs. CASE vs. UNREL) as a within-item factor. However, we decided to go with the less powerful between-item design and a single four-level factor in order to be compatible with the subject analysis, which required a single four-level factor.

TABLE 1
Mean correct reaction times[a] and confidence intervals (CIs) for the four prime types and the four prime durations in the alphabetic decision and the letter-naming task of Experiment 1

		Prime duration				
	Prime type	*14*	*29*	*43*	*57*	*CIs*
Alphabetic decision	ID (B–B)	376	370	360	363	8.2
	SIM (c–C)	381	364	364	372	8.4
	DIS (a–A)	379	377	389	395	7.6
	UNREL(x–T)	385	394	405	421	9.9
Letter naming	ID (B–B)	499	494	491	491	6.0
	SIM (c–C)	502	505	501	512	5.2
	DIS (a–A)	505	511	509	517	8.2
	UNREL (x–T)	514	538	557	573	8.6

[a] In ms.

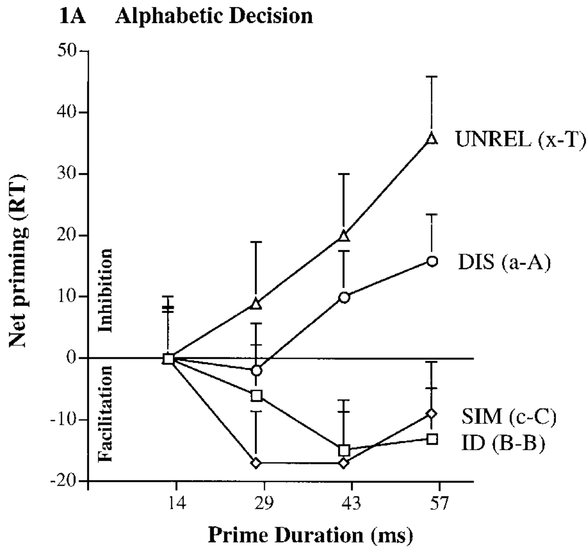
Alphabetic decision

Figure 1A illustrates the net within-condition priming effects and corresponding within-subject CIs. The overall analysis exhibited a significant main effect of prime type, $F_1(3, 9) = 10.7$, $p < .01$, and $F_2(3, 56) = 18.6$, $p < .001$, and a significant interaction between the effects of prime type and prime duration, $F_1(9, 27) = 5.8$, $p < .001$, and $F_2(9, 168) = 3.7$, $p < .001$. The main effect of prime duration was not significant, $F_1(3, 9) = 2.4$, $p > .05$, and $F_2(3, 168) = 1.8$, $p > .20$.

With regard to the classic between-condition priming effects, planned comparisons between related and unrelated conditions revealed significant effects of ID priming, $F_1(1, 9) = 26.6$, $p < .001$, and $F_2(1, 56) = 26.3$, $p < .001$; SIM priming, $F_1(1, 9) = 21.1$, $p < .001$, and $F_2(1, 56) = 27.1$, $p < .001$; and DIS priming, $F_1(1, 9) = 6.9$, $p < .05$, and $F_2(1, 56) = 8.9$, $p < .01$. The difference between SIM and DIS primes was significant by items but only marginally significant by subjects, $F_1(1, 9) = 3.8$, $p < .08$, and $F_2(1, 56) = 3.7$, $p < .05$. There was no significant difference between SIM and ID primes (all Fs < 1).

With regard to the within-condition priming effects, ID primes produced a facilitatory trend that was significant by items but not by subjects, $F_1(3, 9) = 2.1$, $p > .17$, and $F_2(3, 57) = 2.9$, $p < .05$. SIM primes produced facilitatory within-condition priming effects that were significant by items but only marginally significant by subjects, $F_1(3, 9) = 3.1$, $p < .10$, and $F_2(3, 27) = 5.7$, $p < .01$. Both DIS and UNREL primes produced inhibitory effects, which were significant by subjects and items: DIS, $F_1(3, 9) = 5.56$, $p < .05$, and $F_2(3, 27) = 10.7$, $p < .001$; UNREL, $F_1(3, 9) = 19.49$, $p < .001$, and $F_2(3, 57) = 56.3$, $p < .001$.

The overall picture that emerges from this analysis can be summarised as follows. ID (A–A), SIM (c–C), and DIS (a–A) primes facilitated target processing with respect to the traditionally used unrelated condition (across-condition baseline). However, with respect to the within-condition baseline, only ID and SIM primes produced facilitatory priming



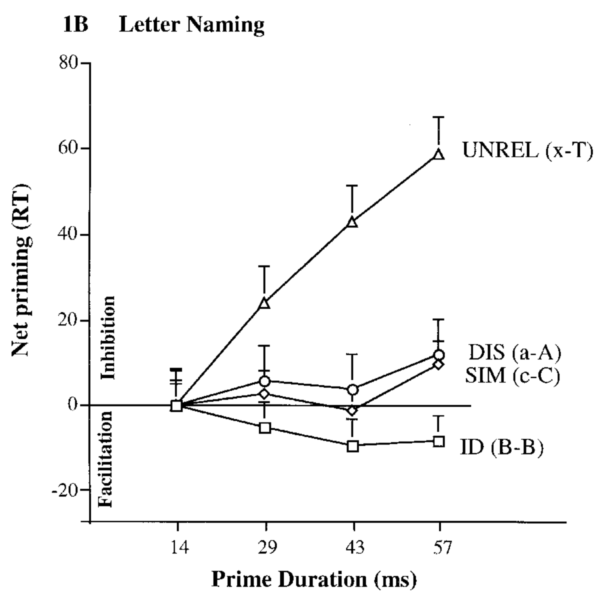


Figure 1. Facilitatory and inhibitory net priming effects with respect to the within-condition baseline for each priming condition at four different prime durations (14, 29, 43, and 57 ms) in Experiment 1. Around each data point, 95% within-subject confidence intervals according to Loftus and Masson (1995) are given. Panel A shows priming in the alphabetic decision task (letter/nonletter classification). Panel B shows priming in the letter-naming task.

effects that were significant in the item analysis. In contrast, both DIS and UNREL primes produced significant within-condition inhibition (increased latencies with increased prime duration).

Letter naming

Figure 1B presents the net within-condition priming effects and corresponding CIs in the naming task. The overall ANOVA exhibited significant main effects of prime type, $F_1(3, 9) = 17.6$, $p < .001$, and $F_2(3, 56) = 20.9$, $p < .001$, and prime duration, $F_1(3, 9) = 6.1$, $p < .05$, and $F_2(3, 168) = 14.2$, $p < .001$, and a significant interaction between the effects of prime type and prime duration, $F_1(9, 27) = 19.7$, $p < .001$, and $F_2(3, 168) = 16.4$, $p < .001$.

With regard to the classic between-condition priming effects, planned comparisons between related and unrelated conditions revealed significant effects of ID priming, $F_1(1, 9) = 47.6$, $p < .001$, and $F_2(1, 56) = 58.1$, $p < .001$; SIM priming, $F_1(1, 9) = 28.7$, p .001, and $F_2(1, 56) = 23.5$, $p < .001$; and DIS priming, $F_1(1, 9) = 21.8$, $p < .001$, and $F_2(1, 56) = 19.1$, $p < .001$. The difference between SIM and DIS primes was not significant (both Fs < 1). Similarly, the difference between ID and SIM primes failed to reach significance, $F_1(1, 9) = 2.3$, $p > .15$, and $F_2(1, 56) = 1.9$, $p > .15$.

With regard to the within-condition priming effects, the facilitatory trend for ID primes failed to reach significance, $F_1(3, 9) = 1.8$, $p > .10$, and $F_2(3, 57) = 0.88$. Similarly, neither SIM nor DIS primes produced a significant within-condition priming effect, all ps $> .10$. However, UNREL primes produced significant inhibitory effects, which increased with increasing prime duration, $F_1(3, 9) = 28.27$, $p < .001$, and $F_2(3, 57) = 68.2$, $p < .001$.

The above analyses confirmed that with respect to the unrelated cross-condition baseline, ID, SIM, and DIS primes produced strong facilitatory priming effects. However, no difference was obtained between SIM and DIS primes. Physically identical primes produced slightly greater priming than SIM primes, although this difference failed to reach significance. With respect to the within-condition baseline, one can clearly see that unrelated primes (x–T) produced strong inhibitory effects that increased fairly linearly with increasing prime duration. ID primes produced non-significant facilitatory trends, whereas SIM and DIS primes produced no within-condition effects.

Discussion

The major result of Experiment 1 can be summarised as follows. In the alphabetic decision task, unrelated pairs (x–T) produce massive within-condition inhibition (up to 40 ms), whereas physically primes produce a 15-ms trend towards within-condition facilitation, which was not significant by subjects. With regard to the critical DIS priming condition, the data seem to suggest that there is a small but reliable DIS priming effect (faster latencies in the DIS condition than in the UNREL condition). However, when this effect is evaluated against the within-condition baseline, it becomes clear that the effect is not genuinely facilitatory (faster latencies with increased prime duration) but rather inhibitory. Taking these results together, it therefore seems that whenever prime and target are visually different, the mismatch between them generally produces strong inhibition. However, this inhibition is reduced when prime and target have the same name although a different shape (a–A). Thus, DIS priming effects can be obtained. They emerge as a release from inhibition compared to an even more inhibitory unrelated condition. The existence of DIS priming effects in alphabetic decision stands in contrast to recent studies that failed to find reliable DIS priming effects in alphabetic decision (Arguin & Bub, 1995; Bowers et al., 1998). However, none of these studies used the probably more sensitive incremental priming technique.

In perfect agreement with these studies, however, our results exhibit strong SIM priming effects (c–C) in alphabetic decision. These effects were much larger than the DIS priming effects and were slightly facilitatory when assessed against the within-condition baseline. In fact, in the alphabetic decision task, SIM priming was as strong as identity priming. In sum, in alphabetic decision, there is a small release from inhibition for DIS primes. SIM primes benefit from a strong release from inhibition, which turns into facilitation. The difference between SIM and DIS primes suggests that visual shape information plays a major role in the alphabetic decision task.

Turning to letter naming, the pattern for DIS and SIM priming is different from the alphabetic decision task. Now, DIS primes produce as much priming as do SIM primes. Interestingly, with respect to the within-condition baseline, DIS and SIM priming does not increase with increased prime duration. Conversely, latencies in the unrelated condition increase fairly linearly with increased prime duration—that is, a strong inhibitory effect in the unrelated condition. DIS, SIM, and ID primes do not show this inhibitory pattern. Thus with respect to the unrelated condition, there is a release from inhibition. However, for none of those primes does the release from inhibition turn into within-condition facilitation. In sum, unrelated primes produce a large amount of inhibition, which increases fairly linearly with prime duration. When primes and targets share the same name (regardless of whether they have the same shape), inhibition is released, and SIM and DIS primes produce fairly similar priming effects. The presence of DIS priming in naming is consistent with the prior work of Arguin and Bub (1995) and Bowers et al. (1998).

As can be seen in the letter-naming results, the strength of the incremental priming technique is that it sheds light on the nature of the priming effects. Had we conducted a traditional priming study with only one prime duration and the unrelated condition as baseline, we could have concluded only that both DIS and SIM primes produce massive facilitation (60 ms). Incremental priming allows us to go one step further as it reveals that neither SIM nor DIS priming increases with increased prime duration. Instead, unrelated primes produce increasingly strong inhibition with increasing prime duration. Thus, one is tempted to conclude that the nature of the strong cross-case priming effect in letter naming is due to strong inhibition from unrelated primes rather than facilitation from related primes. This is completely consistent with an articulatory explanation of priming effects in letter naming (Bowers et al., 1998), in which competition between articulatory motor programs due to mismatch in the unrelated condition would be responsible for priming effects.

Given the differences in DIS and SIM priming across alphabetic decision and naming, one tentative conclusion would be that when the task requires articulation, DIS priming is as strong as SIM priming. This suggests that phonological, rather than visual, overlap determines the size of cross-case priming effects in naming. In contrast when the task is alphabetic decision, DIS priming is much smaller than SIM priming, which suggests that visual rather than phonological information determines the size of cross-case priming effects in alphabetic decision.

EXPERIMENT 2

From Experiment 1, it appears that visual processing dominates alphabetic decision whereas phonological processing dominates letter naming. In order to investigate whether similar processes underlie word recognition, Experiment 2 investigated visual-orthographic and phonological priming in lexical decision and word naming using the incremental priming task. Previous priming studies found that under certain conditions visual-orthographic overlap can facilitate performance (for a review, see Forster & Taft, 1994). A number of studies also reported that phonological overlap can facilitate performance (Ferrand & Grainger, 1992, 1993, 1994; Humphreys et al., 1982; Lukatela et al., 1998). However, other studies reported null effects of phonological overlap or even inhibitory effects for rhyme overlap (Colombo, 1986; Lukatela & Turvey, 1996). As none of these studies used the incremental priming technique, Experiment 2 used this technique to evaluate the relative influence of orthographic and phonological information in visual word perception.

Experiment 2 takes advantage of the possibility that, in French, identical phonology can be spelled in many different ways (for a statistical analysis, see Ziegler, Jacobs, & Stone, 1996). This property made it possible to create for the same target word (e.g., NERF) nonword primes that were (1) phonologically identical and orthographically similar (nert–NERF), (2) phonologically identical but orthographically dissimilar (nair–NERF), and (3) phonologically dissimilar but orthographically similar (narf–NERF). These conditions were recently used in a fast-masked priming study by Grainger and Ferrand (1996). They found that at a prime duration of 43 ms, both orthographic and phonological overlap between a prime and a target facilitated lexical decision and perceptual identification but not naming. However, the absence of priming effects in the naming task was due to the strong facilitation produced by shared onsets. That is, a phonologically identical prime–target pair (e.g., nert–NERF) shared the same onset (n-) as a phonologically different prime–target pair (e.g., narf–NERF). Thus, strong facilitation from identical onsets masked any other potential priming effect. As the incremental priming technique allows us to investigate the temporal development of priming effects within the same condition, this technique was applied to investigate how orthographic and/or phonological overlap affect priming in lexical decision and naming.

Method

Subjects

Eight well-trained subjects, all members of the Experimental Psychology Laboratory in Paris, took part in the study, four in each of the two tasks (lexical decision and naming). All subjects had normal or corrected-to-normal vision.

Apparatus, stimuli, and design

The apparatus was identical to that of Experiment 1. The critical stimulus set consisted of 30 monosyllabic four-letter target words taken to a great extent from a study by Grainger and Ferrand (1996). Target words were chosen so that for each target word three types of nonword primes could be generated: (1) O+P+, that is, nonword primes that were both orthographically similar (differing by only one letter other than the first) and phonologically identical to the target (e.g., nert–NERF); (2) O−P+, that is, nonword primes that were orthographically dissimilar (they shared only one letter in one position with the target) but phonologically identical to the target (e.g., nair–NERF); and (3) O+P−, that is, nonword primes that were orthographically similar but not phonologically identical to the target word (e.g., narf–NERF).

Target words were taken from a broad frequency range (between 1.5 and 5,168 occurrences per million) with a median frequency of 93 occurrences per million according to a French frequency count (Imbs, 1971). Target words had on average 5.9 orthographic neighbours. Pseudohomophone status (i.e., phonological identity) was evaluated by asking 20 judges to read aloud pseudohomophones that were embedded in a list of pronounceable nonwords. For an item to be selected as a pseudohomophone, 15 of the judges must have pronounced it as its corresponding baseword.

In the lexical decision task, all nonword primes had the same initial letter as the corresponding target word (e.g., nert, nair, narf). In the naming task, however, the initial letter of the nonword prime was replaced by a percentage sign (e.g., %ert, %air, %arf). This was done to ensure that potential priming effects were not inflated by facilitatory priming effects that occur when primes and targets share the same onset (e.g., Bowey, 1990, 1993; Forster & Davis, 1991; Grainger & Ferrand, 1996).

Prime–target pairs were rotated across the priming conditions to produce three experimental lists, such that each target word was presented once in one of the three priming conditions in each list. Thus, NERF was primed by *nert* in List 1, NERF was primed by *nair* in List 2, and NERF was primed by *narf* in List 3. Four different prime durations were used (14, 29, 43, and 57 ms, corresponding to 1–4 frame durations). Subjects received the 12 possible combinations of list and prime exposure duration in a random order that was different for each subject.

Procedure

Subjects were seated in front of a standard PC that controlled stimulus presentation and response measurements. Stimuli were presented in isolation on the centre of the computer screen with a 70-Hz refresh rate (frame duration of approximately 14 ms). The items appeared on the screen as white characters on dark background. Each trial consisted of the following sequence of events: (1) A forward mask consisting of a row of four hash-marks was presented for 500 ms; (2) the forward mask was replaced by the prime stimulus in lower-case letters, which remained on the screen for one of the four prime durations; (3) the prime was replaced by a backward mask presented for 14 ms, which was immediately followed by the target stimulus in upper-case letters. Primes, masks, and targets were presented in the same screen location. The target remained on the screen until subjects responded. In order to minimize physical overlap with orthographically related pairs, primes were always presented in lower-case and targets in upper-case letters. Subjects were instructed to respond as rapidly and accurately as possible. In the lexical decision task, they were asked to indicate by pressing one of two response keys (word/nonword) whether the letter string in upper case was a French word. In the naming task, they were asked to read aloud the target word. The existence of a prime stimulus was not mentioned. In both tasks, the target remained on the screen until subjects responded. The interval between two trials was 1 s. Stimulus presentation was randomized for each subject.

Subjects received 20 practice trials. These consisted of 20 nonword prime/word target pairs in the naming task and both 10 nonword prime/word target pairs and 10 nonword prime/nonword target pairs in the lexical decision task. None of the training items appeared in the experimental trials. Training items were all four letters long and from the same frequency range as the experimental stimuli.

Results

Table 2 gives the mean correct RTs and error rates for the three priming conditions (i.e., O+P+, O−P+, and O+P−) for both lexical decision and naming. Errors were evenly distributed across conditions in the lexical decision task and virtually absent in the naming task (less than 0.5%); they were not considered for further analyses. Data analysis was based on correct responses only. In the lexcial decision task, nonword data ("no" trials) were not taken into consideration. The data were submitted to subject and item ANOVAs with prime type and prime duration as factors. Planned comparisons assessed whether the differences between the three prime types were statistically significant. Furthermore, separate ANOVAs for each prime type investigated whether priming effects systematically increased or decreased with prime duration. The analyses are presented separately for lexical decision and naming.

Lexical decision

Net within-condition priming effects for the three priming conditions are presented in Figure 2A. The data exhibited a main effect of prime duration that was significant by subjects and items, $F_1(3, 9) = 55.6$, $p < .001$, and $F_2(3, 87) = 110.6$, $p < .001$. The main effect of prime type was significant by items but only marginally significant by subjects, $F_1(3, 9) = 4.5$, $p < .10$, and $F_2(3, 87) = 44.9$, $p < .001$. Most important, there was a

TABLE 2
Mean correct reaction times[a], confidence intervals (CIs), and errors for the three prime conditions and the four prime durations in Experiment 2

		Prime duration[a]								
		14		*29*		*43*		*57*		
	Prime Type	*RT*	*Error*	*RT*	*Error*	*RT*	*Error*	*RT*	*Error*	*CIs*
Lexical decision	O−P+	492	3.33	470	3.33	456	4.17	447	2.50	8.2
	O+P−	489	1.67	439	2.50	443	3.30	438	5.00	9.4
	O+P+	488	5.00	434	3.33	422	2.50	417	1.67	11.0
Naming	O−P+	419		416		406		401		9.4
	O+P−	417		413		427		416		6.6
	O+P+	416		408		393		385		8.2

[a] In ms.
Note: O−P+: Orthographically dissimilar pseudohomophone prime (e.g., nair–NERF);
O+P−: Orthographically similar non-homophonic prime (e.g., narf–NERF);
O+P+: Orthographically similar pseudohomophone prime (e.g., nert–NERF).

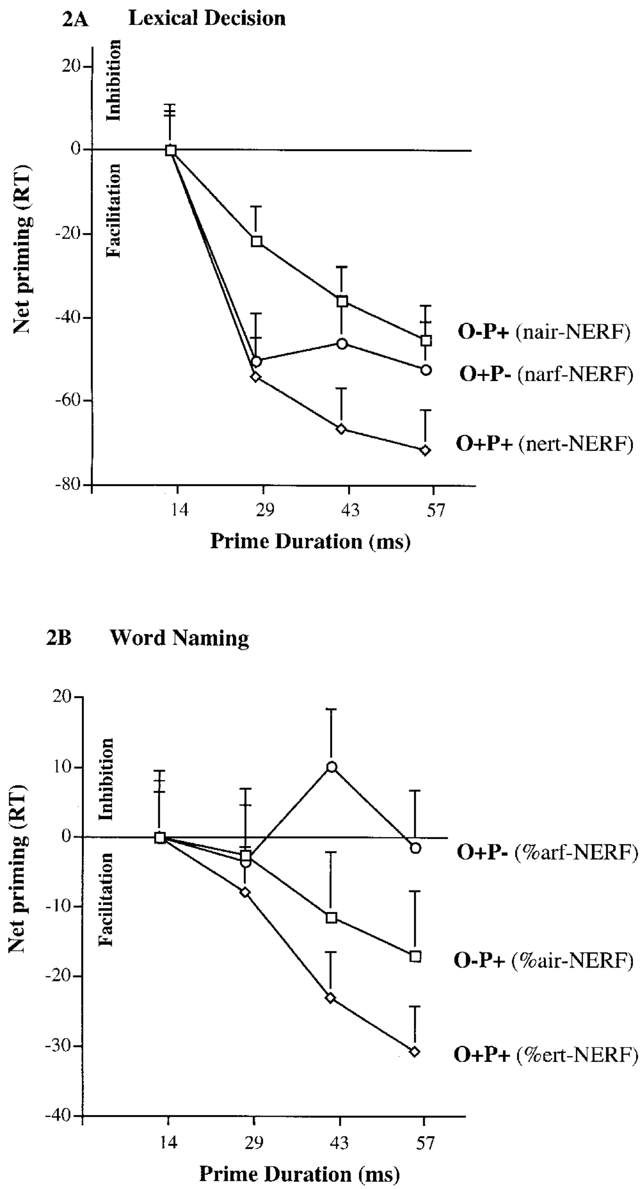


Figure 2. Facilitatory and inhibitory net priming effects with respect to the within-condition baseline in lexical decision (Panel A) and naming (Panel B) for each priming condition at four different prime durations (14, 29, 43, and 57 ms) in Experiment 2 along with 95% within-subject confidence intervals.

significant interaction between the effects of duration and prime type, suggesting that primes were differently effective across the four prime durations, $F_1(6, 18) = 4.7$, $p < .05$, and $F_2(6, 174) = 5.1$, $p < .001$.

To assess differences between prime types, means comparisons were performed separately for each prime duration. Only those comparisons that were significant by subjects and items are reported. As expected, at 14 ms, the differences between prime types were not significant (all Fs < 1). At 29 ms, both O+P+ and O+P− differed significantly from O−P+, $F_1(1, 18) = 23.8$, $p < .05$, $F_2(1, 174) = 44.6$, $p < .05$, and $F_1(1, 18) = 17.9$, $p < .05$, $F_2(1, 174) = 28.6$, $p < .05$, respectively. At 43 ms, O+P+ differed significantly from the other two prime types, which did not differ from one another: O+P+ vs. O−P+, $F_1(1, 18) = 20.93$, $p < .05$, $F_2(1, 174) = 33.5$, $p < .05$; O+P+ vs. O+P−, $F_1(1, 18) = 8.4$, $p < .05$, $F_2(1, 174) = 14.2$, $p < .05$. Similarly, at 57 ms, O+P+ differed significantly from the other two prime types: O+P+ vs. O−P+, $F_1(1, 18) = 16.2$, $p < .05$, $F_2(1, 174) = 25.8$, $p < .05$; O+P+ vs. O+P−, $F_1(1, 18) = 7.4$, $p < .05$, $F_2(1, 174) = 13.6$, $p < .05$.

As in previous analyses, within-condition priming effects were assessed in separate ANOVAs for each prime type with prime duration as single factor. These analyses showed that all three prime types produced significant facilitation—that is, shorter RTs with increasing prime duration: O+P+, $F_1(3, 9) = 38.9$, $p < .001$, and $F_2(3, 87) = 90.7$, $p < .001$; O−P+, $F_1(3, 9) = 13.6$, $p < .001$, and $F_2(3, 87) = 15.7$, $p < .001$; O+P−, $F_1(3, 9) = 15.9$, $p < .001$, and $F_2(3, 87) = 53.8$, $p < .001$.

As seen in Figure 2 and confirmed in the analyses, at shorter prime durations (29 ms), greater priming was obtained when primes and targets shared either orthographic or both orthographic and phonological overlap than when they shared only phonological overlap. At longer prime durations (43 and 57 ms), greater priming was obtained when primes and targets were both orthographically and phonologically related than when they were only orthographically or only phonologically related. In contrast to the alphabetic decision task, all three prime types produced reliable facilitatory priming effects when the within-condition was used as the baseline. Besides these overall facilitatory trends, there is a pattern of non-linearity in the lexical decision data that deserves attention. In the orthographic condition (O+P−, narf–NERF), maximum priming is already obtained at the 29-ms prime duration and does not further increase for longer prime durations. Furthermore, at this duration, orthographic priming is as strong as ortho-phonological priming (O+P+, nert–NERF) and maximally different from phonological priming (O−P+, nair–NERF).

Naming

Figure 2B presents the net within-condition priming effects and CIs for the three priming conditions in the naming task. The ANOVAs showed that all main effects and interactions were significant by subjects and items: duration: $F_1(3, 9) = 4.9$, $p < .01$, and $F_2(3, 87) = 12.4$, $p < .001$; prime type: $F_1(3, 9) = 7.6$, $p < .01$, and $F_2(3, 87) = 21.1$, $p < .001$, and Duration × Prime Type: $F_1(6, 18) = 4.5$, $p < .05$, and $F_2(6, 174) = 6.1$, $p < .001$.

As with the lexical decision results, to assess differences between prime types, means comparisons were performed separately for each prime duration. No significant differences between prime types were found at the two shortest prime duration (all Fs < 1.6, p > .20). At 43 ms, significant differences were found between all prime types: O+P+ vs. O−P+: $F_1(1, 18) = 5.4$, $p < .05$, $F_2(1, 174) = 7.9$, $p < .05$; O+P+ vs. O+P−: $F_1(1, 18) = 35.3$, $p < .05$, $F_2(1, 174) = 51.5$, $p < .05$; O+P− vs. O−P+: $F_1(1, 18) = 12.9$, $p < .05$, $F_2(1, 174) = 19.1$, $p < .05$. Similarly, at 57 ms, significant differences were found between all prime types: O+P+ vs. O−P+: $F_1(1, 18) = 7.4$, $p < .05$, $F_2(1, 174) = 10.1$, $p < .05$; O+P+ vs. O+P−: $F_1(1, 18) = 27.5$, $p < .05$, $F_2(1, 174) = 40.4$, $p < .05$; O+P− vs. O−P+: $F_1(1, 18) = 6.3$, $p < .05$, $F_2(1, 174) = 10.1$, $p < .05$.

To assess within-condition priming effects, separate ANOVAs were performed for each prime type with prime duration as single factor. These analyses showed that only O+P+ primes produced facilitatory effects that were significant by subjects and items, $F_1(3, 9) = 14.4$, $p < .001$, and $F_2(3, 87) = 20.9$, $p < .001$. Facilitatory trends were also obtained for O−P+. However, those were significant by items but not by subjects, $F(3, 9) = 2.2$, $p > .10$, and $F_2(3, 87) = 5.8$, $p < .01$. Finally, RTs in the O+P− condition showed no significant duration effect in either analysis.

Together, the analyses showed that both types of phonologically identical primes (O+P+ and O−P+) facilitated naming latencies. Of these, primes that were both orthographically and phonologically related (O+P+) produced significantly stronger facilitation than primes that were phonologically identical but orthographically dissimilar (O−P+). Orthographically similar primes that were not phonologically related (O+P−) did not produce significant within-condition facilitation. If anything, they showed an inhibitory trend at a prime duration of 43 ms.

Discussion

The present results can be summarized as follows: Primes that share both orthography and phonology with the target (O+P+, nert–NERF) produce facilitatory priming effects in both lexical decision and naming. For the other two priming conditions, there is a remarkable dissociation across tasks: Whereas priming in the orthographic condition (O+P−, narf–NERF) is stronger than priming in the phonological condition (O−P+, nair–NERF) in lexical decision, these effects are reversed in naming. In fact, orthographic primes did not produce within-condition facilitation at all but within-condition inhibition at 43-ms prime duration. Thus, from the overall picture, one could conclude that both orthographic and phonological overlap can produce facilitatory priming effects in lexical decision. In naming, however, phonological overlap is necessary to obtain facilitatory priming, whereas orthographic overlap in the absence of phonological overlap does not produce facilitation (but inhibition at certain durations).

In this global picture, there are two interesting details that deserve further discussion. Both concern non-linear patterns in the orthographic priming condition (O+P−, narf–NERF). First, in lexical decision, priming in the orthographic condition reaches its maximum effect already at the first critical prime duration (29 ms). At this short duration, phonological overlap does not add anything to the amount of priming obtained by orthographic overlap. However, with increasing prime duration, orthographic priming does not increase any further whereas phonological priming increases steadily with increasing prime duration. This pattern clearly supports the idea that orthographic and phonological activation follow distinct time courses with orthographic information being activated faster than phonological information (see Ferrand & Grainger, 1993). Given that in the orthographic priming condition the consonantal skeleton is typically maintained (narf–NERF), the non-linear pattern in this condition is also consistent with the finding of Berent and Perfetti (1995) that, during early processing cycles, consonants showed earlier priming than vowels. The second non-linearity is also obtained for the orthographic condition but in naming. Here, the orthographic primes produce inhibition at 43 ms. It thus seems that at the duration at which phonological overlap between prime and target starts to produce facilitatory priming effects in phonologically related conditions (i.e., at 43 ms), phonological mismatch produces the strongest inhibition in the phonologically unrelated condition.

The present naming results are somewhat inconsistent with Lukatela and Turvey's (1996) finding of inhibition for rhyme primes (e.g., HOSE–NOSE) and Forster and Davis' (1991) failure to find rhyme priming for orthographically dissimilar rimes (e.g., STAKE–BREAK). Note, however, that in contrast to these authors, we primed targets only with the rhyme (e.g., %ERF), thus replacing the onset with a percentage sign (for a similar procedure see Bowey, 1993, and Grainger & Ferrand, 1996). Thus, it is possible that the contradictory results are due to the fact that in our study the onset was replaced by a non-alphabetic character (e.g., %ose–NOSE), whereas in Lukatela and Turvey's study prime and target contained different onsets (e.g., hose–NOSE). If we take our strong inhibitory pattern in the unrelated condition to suggest that different onsets produce strong inhibition, the failure to find facilitatory rhyme effects is quite plausible. More work is needed to investigate whether facilitation from rhymes can occur when prime and targets have different onsets (e.g., nose–HOSE). At present, our results join those of Bowey (1993) and Grainger and Ferrand (1996) to suggest that sharing a rhyme in the absence of conflicting onsets facilitates naming.

GENERAL DISCUSSION

The present study used the incremental priming technique to investigate similarities and differences in letter and word recognition. To facilitate the comparison between these two domains, we used similar letter and word recognition tasks that should draw upon similar processes; on the one hand alphabetic decision and letter naming, on the other hand lexical decision and word naming. The global picture that emerges from this comparison could be sketched in the following way. Priming in the alphabetic decision task seems to rely primarily on visual shape overlap between prime and target. This is indicated by both virtually identical facilitatory priming in the SIM and ID condition and large priming differences between the SIM and the DIS condition. In contrast to previous studies (Arguin & Bub, 1995; Bowers et al., 1998), the present study found small but reliable DIS priming effects in the alphabetic decision task. They emerge as a release from inhibition (e.g., Perfetti & Tan, 1998). Such inhibition seems to be generally obtained for two completely unrelated items. Why have previous studies failed to find DIS priming effects in the alphabetic decision task? One possibility is that the incremental priming technique, thanks to the parametric manipulation of prime duration and the large number of trials per condition, is more likely to pick up subtle DIS priming effects in alphabetic decision than does the traditional fast masked priming technique.

In contrast to alphabetic decision, priming in letter naming seems to rely primarily on articulatory information. This is indicated by identical priming effects for both DIS and SIM primes. In particular, given that latencies in the unrelated condition increase steadily with prime duration, it seems that the origin of this priming effect lies in the articulatory mismatch between primes and targets in the unrelated condition. This finding is consistent with previous proposals (Arguin & Bub, 1995; Bowers et al., 1998).

In lexical decision, in contrast to alphabetic decision, not only visual-orthographic overlap but also phonological overlap affect the size of the priming effect. That is, primes with minimal visual but maximal phonological overlap (nair–NERF) produce reliable facilitatory priming effects. However, there seem to be differences in the time course of orthographic and phonological activation, with orthographic priming being stronger at shorter prime durations and phonological priming being stronger at longer prime durations (see also Ferrand & Grainger, 1993, 1994; Lukatela et al., 1998; Perfetti & Tan, 1998). Similar to letter naming, the word-naming results suggest that phonological overlap is necessary to obtain facilitatory priming effects in naming, at least, when these effects are assessed against the within-condition baseline. With respect to the within-condition baseline, orthographic overlap in the absence of phonological overlap produces not facilitation but inhibition at an intermediate prime duration.

Beyond this global picture, there are two quantitative comparisons that can be made concerning the results obtained with letter stimuli (Experiment 1) and those concerning word stimuli (Experiment 2). First of all, using the across-condition measure at the longest prime exposure duration, we systematically observed stronger effects of visuo-orthographic similarity compared to phonological similarity in the decision tasks (32 ms vs. 23 ms, respectively), whereas the opposite was true in the naming tasks: 21-ms effects of visuo-orthographic similarity compared with 43-ms effects of phonological similarity in the naming tasks.[4] This task-specific dissociation between the effects of orthographic and phonological priming was assessed in a two-way ANOVA with similarity (orthographic vs. phonological) and task (decision vs. naming) as independent variables. The cross-over interaction between the effects of similarity and task was significant, $F_1(1, 7) = 7.72$, $p < .05$, and $F_2(1, 39) = 37.4$, $p < .001$, suggesting that visual-orthographic overlap was more important in the decision tasks, whereas phonological overlap was more important in the naming tasks. This quantitative comparison corroborates Bowers et al.'s (1998) conclusion that visual orthographic information provides the strongest source of priming in alphabetic decision and lexical decision, whereas phonological information provides the strongest source of priming in naming.

The second interesting comparison that can be made across Experiments 1 and 2 is that naming latencies were systematically slower than alphabetic decision latencies when the stimuli were letters (513 vs. 382 ms), but naming latencies were systematically faster than lexical decision latencies when the stimuli were words (409 vs. 452 ms). The reliability of this dissociation was confirmed in a two-way ANOVA by a significant cross-over

[4] Effects of visual overlap in the letter experiments are obtained by subtracting mean RTs in the ID condition (A–A) from mean RTs in the DIS condition (a–A), whereas effects of phonological overlap are obtained by subtracting mean RTs in the DIS (a–A) from mean RTs in the UNREL condition (x–T). In the word experiments the corresponding subtractions are O+P+ from O−P+, and O+P+ from O+P− (see Tables 1 and 2).

interaction between the effects of task (naming vs. decision) and stimulus type (letter vs. words), $F_1(1, 7) = 965.6$, $p < .001$, and $F_2(1, 48) = 1{,}927.6$, $p < .001$. This result points to a fundamental difference between how letters and words can be read aloud. As there is no such thing as sub-letter phonology, letter naming is necessarily based on recognition of the appropriate letter. On the other hand, it is a well-established fact that word stimuli can be read aloud using sub-lexical spelling-to-sound correspondences (for a review, see Andrews & Scarratt, 1998). Therefore, word pronunciations may be initiated before the stimuli have been fully identified. One consequence of this is that naming latencies for words can be faster than lexical decision latencies for the same words. In contrast, because letter stimuli necessarily require full identification before they can be read aloud, naming latencies for letters are slower than alphabetic decision latencies. The same dissociation can be found in reading Chinese, where, contrary to English, lexical decision latencies are typically faster than naming latencies (e.g., Hoosain & Osgood, 1983). The similarity in the overal latency pattern between Chinese character recognition and letter recognition is not surprising because character naming, like letter naming, requires the character to be fully identified before pronunciation can be initiated. This is the case because phonology is not systematically represented at the sub-character level (e.g., Perfetti & Tan, 1998; Tan, Hoosain, & Peng, 1995; Tan, Hoosain, & Siok, 1996).

It remains to be discussed whether incremental priming can truly distinguish facilitation from inhibition. As mentioned before, it became clear to us that neither incremental priming nor any other priming technique can provide a natural "neutral" condition, an absolute baseline that truly distinguishes facilitation from inhibition. The major advantage of the incremental priming technique is that it adds a parametric manipulation to the traditional priming design. By doing so, it can provide additional information on the nature of priming effects and their underlying mechanisms. If with increasing prime availability performance decreases, then it is plausible that competitive processes are at work. This seems to be the case in all of our unrelated conditions where latencies increase linearly with increasing prime duration, as if the mismatch between primes and targets on both visual and linguistic dimensions resulted in a perturbation of performance. This perturbation becomes stronger as primes become more available. If visual or linguistic overlap reduces the perturbation effect, we can speak of release from inhibition (Perfetti & Tan, 1998). If performance improves with increasing prime duration, it seems that cooperative processes are stronger than competitive processes.

To illustrate how incremental priming can provide additional constraints on isolating the locus of priming effects, take the onset effect in naming. This effect reflects the finding that performance in the naming task is better when prime and target share the onset (initial phoneme) than when they do not share the same onset (Forster & Davis, 1991). It is possible that the effect arises from two different sources: (1) competition between different onsets in the unrelated condition and (2) facilitation from identical onsets in the related condition. The incremental priming technique provides some information to disentangle, or at least quantify, the contribution of each possibility. If the locus of the effect is competition in the unrelated condition due to articulatory mismatch, then the perturbation effect should increase with increasing prime activation. If, however, the locus of the effect is facilitatory due to the articulatory match in the related condition, then performance should increase with increasing prime duration in the absence of an inhibitory effect in the unrelated condition. Again, in some absolute sense, it may not appear important to know whether the effect is due to articulatory mismatch in the unrelated condition or to articulatory match in the related condition. However, such data seem to be crucial for evaluating and developing computational models that can predict not only differences between related and unrelated conditions but also the temporal development of priming effects within each condition. In this respect, incremental priming may provide a valuable tool to understand better some of the basic mechanisms underlying priming.

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APPENDIX

Item-specific lexical decision and naming latencies averaged across all prime exposures for the three priming conditions of Experiment 2

	LDT			Naming		
Target	O− P+	O+P−	O+P+	O−P+	O+P−	O+P+
FAIM	440	430	427	413	427	396
LENT	459	463	441	394	405	401
BORD	449	446	440	412	442	405
PAIR	480	447	448	411	432	409
BEAU	448	460	449	414	425	423
TORT	452	457	455	415	429	397
THYM	472	451	436	409	460	413
NERF	491	473	451	401	410	398
TAUX	475	449	433	407	428	409
BAIN	452	432	453	413	430	421
TANT	495	469	454	423	419	411
ROSE	451	449	428	400	433	374
NORD	465	446	429	419	409	383
VERS	444	445	438	419	409	391
LAID	472	469	444	401	393	402
FORT	484	458	449	416	419	397
MAIN	448	459	419	416	414	389
MAUX	476	468	444	414	415	383
SAIN	471	447	450	424	412	395
FAIT	467	449	424	432	438	399
VEAU	451	453	440	402	421	415
VAIN	474	474	463	409	412	393
SORT	474	452	433	398	384	392
MERE	468	456	439	406	407	408
BAIE	499	446	459	435	436	399
MAIS	475	432	442	407	398	399
SOLE	473	468	440	394	398	394
FILS	467	440	431	406	427	393
CORS	481	487	447	409	430	423
MORT	458	444	443	403	408	400

Note: O−P+: Orthographically dissimilar pseudohomophone prime (e.g., nair–NERF);
O+P−: Orthographically similar non-homophonic prime (e.g., narf–NERF);
O+P+: Orthographically similar pseudohomophone prime (e.g, nert–NERF).

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