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Phonological and Associative Inhibition in the Early Stages of English Word Identification: Evidence From Backward Masking

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The role of phonological information in English word identification and the activation pattern of phonological and associative dimensions were investigated with a backward-masking paradigm. Mask type (graphemic, homophonic, associative, unrelated word control, and nonletter #-baseline) and target exposure duration were manipulated. Graphemic and homophonic but not associative masks influenced target recognition at 28 ms, and homophonic masks inhibited recognition relative to graphemic masks. At 42 ms, homophonic masks facilitated recognition, and associates inhibited, rather than enhanced, recognition relative to word controls. These results suggest that phonological computation occurs before associative computation and that phonological inhibition arises from lexical competition. The phonological and associative inhibitory effects are interpreted in terms of the center-surround perceptual principle. In this interpretation, backward-masking conditions cause observers to seek orthographic rather than phonological codes.

Recent evidence for the hypothesis that phonological information plays a central role in word identification has come from a variety of tasks: semantic categorization (Van Orden, 1987; Van Orden, Johnston, & Hale, 1988; see also Peter & Turvey, 1994), backward masking (Berent & Perfetti, 1995; Perfetti, Bell, & Delaney, 1988), masked priming (e.g., Grainger & Ferrand, 1994), phonologically mediated priming (e.g., Lesch & Pollatsek, 1993; Lukatela & Turvey, 1994; Luo, 1996), letter search (e.g., Ziegler & Jacobs, 1995), and eye fixation times in reading (Henderson, Dixon, Petersen, Twilley, & Ferreira, 1995; Pollatsek, Lesch, Morris, & Rayner, 1992; Rayner, Pollatsek, & Binder, 1998). The results of these studies suggest that phonological codes provide early sources of constraint in printed English word recognition.

Brief exposure paradigms involving backward masking or priming in particular have provided evidence that phonological information is available within the first moments of visual identification. In a masked priming paradigm, for example, Perfetti and Bell (1991) presented a pseudoword prime for 25, 35, 45, 55, or 65 ms, followed immediately by a target presented for 30 ms and then a pattern mask, which was used to interrupt ongoing processing of the target word. Primes were graphemically similar or homophonic (i.e., both graphemically and phonemically similar) to the target or were unrelated to it. At 25 ms, the rate of target word identification was unaffected by a pseudohomophone prime (e.g., *creap* followed by the target *creep*) and by a graphemic prime (e.g., *crelp–creep*). By 35 ms, there was a large graphemic effect, but only a small and unreliable phonemic effect (relative to graphemic primes). By 45 ms, the phonemic effect was highly significant and did not increase further through 65 ms. These findings suggest that phonological information is available from pronounceable letter strings rapidly in a visual display. They also suggest that the patterns of graphemic and phonological activation go together over time, with graphemic information being only slightly stronger than phonemic information within the priming paradigm. Subsequent investigations have provided further evidence for the time course of phonological and orthographic computation in alphabetic (e.g., Ferrand & Grainger, 1993, 1994; Frost, 1994; Lukatela & Turvey, 1996; Rayner, Sereno, Lesch, & Pollatsek, 1995) and nonalphabetic (Perfetti & Tan, 1998; Tan, Hoosain, & Peng, 1995) writing systems.

The evidence for early phonology in brief exposure paradigms, however, has been established without a corresponding indicator of the time course of meaning activation. Because the backward-masking paradigm has been shown to be a powerful tool for investigating visual perception (see Turvey, 1973) and uncovering the timing asynchrony of the activation of various events in word recognition (Naish, 1980; Perfetti et al., 1988), it is a good candidate for examining meaning and form effects simultaneously, although, as with most paradigms, the interpretation of critical effects has been questioned (Brysbaert & Praet, 1992; Verstaen, Humphreys, Olson, & d'Ydewalle, 1995) and defended (Berent & Van Orden, 1996; Xu & Perfetti, in press). In English studies with this procedure, a target word is presented for a brief duration (around 30–65 ms), followed immediately by a pseudoword mask of about 30 ms and finally a pattern mask that ends the processing of letter strings. The observer immediately identifies the target, usually in writing. Because the data needed for identification are limited by the masking situation, this paradigm is

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assumed to tap early perceptual processes (e.g., Turvey, 1973). Moreover, a pattern mask appears to reduce or eliminate awareness of perceptual products (e.g., Forster & Davis, 1984; Fowler, Wolford, Slade, & Tassinary, 1981; Marcel, 1983).

Key results in the masking paradigm (e.g., Perfetti & Bell, 1991) are that (a) masking (interruption) effects are reduced when masks are graphemically similar to targets relative to control masks having no similarity to targets and (b) there is an additional reduction when masks are homophonic (i.e., both graphemically and phonologically similar) to targets, suggesting that orthographic and phonemic information is computed early in reading English. The assumption is that only if such information is already active can its reinstatement from the mask have any effect. The backward-masking paradigm has been applied to discovering the activation patterns of phonological and meaning codes in recognizing words from deep orthographies such as Chinese (Perfetti & Zhang, 1991, Experiment 1; Tan et al., 1995; Tan, Hoosain, & Siok, 1996) and Hebrew (Gronau & Frost, 1997).

As noted earlier, the previous English studies (e.g., Perfetti & Bell, 1991; Perfetti et al., 1988; Verstaen et al., 1995) with the backward-masking procedure have had the following two features: First, (meaningless) pseudowords are used as masks. The use of pseudowords can uncover the time course of activating graphemic and phonemic information, but it prevents the investigation of semantic and associative activation. As a consequence, although past research has demonstrated very early phonemic activation, it stops short of showing that phonology is activated before word meaning. Second, in all the aforementioned studies with such a paradigm, including investigations of Chinese, English, and Hebrew, no nonletter neutral masks were used as a baseline. The data from graphic, homophonic, and semantic masks are compared with the data from unrelated pseudoword masks. Because there is no baseline against which to compare performance on the unrelated string, the observed effects are potentially mixes of facilitation and inhibition (but see Jonides & Mack, 1984, for cautions about the use of neutral baselines).

Thus, the main aim of the present experiments was to obtain information about the availability of associative meaning features to provide comparison with the time course of graphemic and phonemic information in the brief exposure masking paradigm. The secondary aim was to establish the mix of facilitative and inhibitory effects in the paradigm by use of a non–letter-string baseline.

There is reason to expect that word meaning can affect identification in brief exposure paradigms because semantic effects have been demonstrated at perceptual threshold levels in the priming paradigm (e.g., Balota, 1983) and at subthreshold in a pattern-masked lexical-decision task (e.g., Fowler et al., 1981; Marcel, 1983). Such results suggest that it might be difficult to find a moment at which formal (i.e., graphemic and phonemic) but not meaning information is available. However, there are theoretical grounds to expect a timing asynchrony of phonological and associative activation. In the resonance-coherence framework of Van Orden and Goldinger (1994), visual–phonological resonances cohere before visual–semantic resonances in word recognition (see also Stone & Van Orden, 1994). A fundamental feature of how writing systems are mapped to language indeed suggests a privilege of form–form relations, which approximate one-to-one mappings, over form–meaning relations, which are one-to-many mappings (Perfetti & Tan, 1998; Perfetti & Zhang, 1995). Therefore, the (graphic) form (phonological)–form relation is nearly deterministic at the word level, whereas the form–meaning relation is nondeterministic. The asymmetry of form–form and form–meaning connections may provide a basis for a timing asynchrony of phonological and meaning activation.

Nevertheless, meaning attributes of a word can be activated quite early, even if time lagged relative to form activation. According to the spreading activation hypothesis, once the meaning node of a word is activated, activation spreads along related meaning nodes automatically (e.g., Balota, 1983; de Groot, 1983; Neely, 1977). In the masking paradigm, the mask can be chosen so that it is likely to be among the nodes that are activated from the given target word. The activated associate word (the mask) will restimulate the target's meaning information (e.g., Jacobson, 1976). Therefore, it should enhance target processing relative to unrelated word controls. In the present experimental situation, associative masking may be expected to behave like what researchers call *retrospective* or *backward priming* in the literature on semantic priming (e.g., Hirshman & Durante, 1992; Peterson & Simpson, 1989; Van Voorhis & Dark, 1995).

As for formal information, the graphemic and phonemic constituents of words are closely linked in English because graphemes map onto phonemes in the spoken language. This fact allows the activation of graphemic and phonological information to rise in synchrony, even if there are differential strengths in the two types of activation at some points in time. (In contrast, the activation pattern in Chinese character identification may be one in which the graphic information and phonological information are asynchronous, reflecting the fact that Chinese graphemes map onto morphemic syllables rather than phonemes; see Leong, 1997; Perfetti & Tan, 1998). As noted earlier, graphemic and phonemic effects in English backward masking and priming have shown a strong temporal locking over a range of 25–65 ms when pseudowords served as masks or primes (Perfetti & Bell, 1991). Thus, our general expectation, even with real words, was that graphemic and homophonic masks should show temporally comparable patterns, even if the activation of graphemic information may be a bit stronger than the activation of phonological information in the earliest stage of processing.

Thus, to allow a comparison of the availability of graphemic, phonemic, and associative information, while also establishing a baseline to distinguish facilitation from inhibition, we used five mask types in our experiments: (a) a graphemically similar mask, visually similar but not homophonic to the target (e.g., *beach–bench*); (b) a homophonic mask, both graphemically and phonologically similar to the target (*beach–beech*); (c) an associate mask, associatively (and perhaps semantically) related but neither graphemically

nor phonologically similar to the target (*beach–sand*); (d) a word control, no similarity to the target (*beach–smell*); and (e) a non–letter-string baseline, a string of #s (*beach–#####*).

Finally, to observe a possible timing asynchrony of phonological and associative activation, we varied the exposure time of the target at 28 ms (Experiment 1) and 42 ms (Experiment 2) while holding the mask exposure duration constant at 28 ms. If phonological information is computed earlier than associative relations, we might find an effect from homophonic masks with an absence of associate masking effect at 28 ms. Because homophonic pairs in English tend to be both phonologically identical and graphemically similar, an incremental role for phonology is customarily based on comparisons of homophonic pairs and graphemic pairs. This comparison is a conservative one, in that the graphemes shared between a target and a nonhomophonic (grapheme) mask also entail shared phonemes. Indeed, some of the early effects of consonant graphemes, which would ordinarily be attributed to strictly graphemic factors, might be phonemic, according to Berent and Perfetti's (1995) two-cycles model. Nevertheless, because we could not control for consonant and vowel constituents while using real words, we adopted the customary conservative criterion for phonemic effects.

Experiment 1

In Experiment 1, we exposed a target for 28 ms, followed immediately by a mask of 28 ms, which in turn was replaced by a pattern mask. These parameters are at the lower end of the range that has established graphemic and phonemic effects in masking with pseudowords (e.g., Perfetti et al., 1988) to allow a window on early occurring effects.

Method

Participants. Forty University of Pittsburgh undergraduates participated in partial fulfillment of a course requirement. All were native English speakers and had normal or corrected-to-normal vision.

Materials. Each of 35 targets was paired with five masks: a graphemic word mask, a homophonic word mask, a meaning associate mask, an unrelated word mask, and a #-control mask. Most targets and masks were identical in number of letters, although in a few cases the lengths were different between targets and masks. The mean frequency of targets was 52.9 (SD = 77.3) per million (Francis & Kucera, 1982). The mean frequencies of the four sets of word masks were 33 (SD = 53), 35 (SD = 37), 41 (SD = 37), and 34 (SD = 36), respectively.

Visual similarity. To ensure that differences between graphemic and homophonic masks were unrelated to variations in visual similarity (VS), we controlled similarity across two sorts of masks using a procedure devised by Lesch and Pollatsek (1993). Estimates of VS were calculated as the averages of the following two indexes: (a) the fraction of letters shared between the two words regardless of position and (b) the fraction of shared letters that occur in the same position within the two words. To illustrate, for the words *hare* and *hair,* the first fraction is ¾ = 0.75 and the second fraction is ¾ = 0.5. Therefore, the VS index for the two words would be (0.75 + 0.5)/2 = 0.625. When the numbers of letters in the two words were not the same, we used the average letter number of the two words as the denominator. The mean ratings of VS for the graphemic and homophonic pairs were 0.693 (SD = 0.11) and 0.687 (SD = 0.11), respectively.

Evaluation of associative strength. To select associate masks, we asked 20 undergraduates of the University of Pittsburgh, all native English speakers, to look at the meaning of each target word and write down the first word that came to mind. The highest associate for each target was selected as the mask provided that this associate was given by at least 20% of the participants. The association strength ranged from 20% to 88%, with a mean of 41% (SD = 17%).

Design. All participants received all five mask types in a within-subject design. Participants were divided into five groups of eight such that target–mask pairings were counterbalanced across the five groups, with each group viewing a given target with just one of its five masks. For each group of participants, the stimulus pairs were presented in random order. In addition to 35 pairs of experimental stimuli, there were another 30 pairs of unrelated words and 5 pairs of word targets and #-masks used as fillers. Therefore, each observer viewed 70 pairs of items in all.

Procedure. An IBM-compatible computer connected to a screen with a refresh rate of 14 ms was used to control the experimental trials. The target and mask were presented in white against a black background. Participants were seated approximately 50 cm from the screen in a dimly lit room. Each word subtended about 0.8° of visual angle in height and 1.38°–2.52° in width (depending on the number of letters).

The presentation sequence of the target and mask on each trial is illustrated in Figure 1. Each trial began with a fixation cross displayed at the center of the screen for 1,000 ms. After the offset of the fixation, a target was presented for 28 ms and was immediately followed by a word or nonletter mask exposed for 28 ms in the same location as the target. The mask was immediately replaced by a pattern mask, #####, which occupied about the same space as the word and was presented for 1,500 ms. All stimuli were exposed at the center of the computer screen. Participants were informed about the sequence of stimuli and required to write down the target immediately. The intertrial interval was 3 s.

Each participant received 30 practice trials before the experimental trials. In this practice, all target–mask pairs had no graphemic, phonemic, or semantic similarity. Each mask was exposed for 28 ms before being replaced by a pattern mask of 1,500 ms. The presentation times of targets were decreased gradually from 70 to 28 ms. Participants were run individually, and the total experiment lasted approximately 20 min.

Results

The mean percentage of correctly identified target items in each of the five mask conditions is shown in Figure 2. The effect of mask type was significant by observers, $F1(4, 156) = 75.50, p < .001, MSE = 56.18$, and by items, $F2(4, 136) = 79.22, p < .001, MSE = 64.02$. The unrelated word controls produced significant inhibition relative to #-controls, $F1(1, 39) = 238.98, p < .001, MSE = 115.20$, and $F2(1, 34) = 258.11, p < .001, MSE = 131.66$.

Planned comparisons were made for each of the three key conditions (i.e., graphemic, homophonic, and associate masks) against both word controls and nonletter controls. The effect of graphemic masks was not significant relative to #-controls ($F1$ and $F2 < 1$). Graphemic masks, however, facilitated target identification relative to word controls, $F1(1, 39) = 158.91, p < .001, MSE = 112.81$, and $F2(1, 34) = 241.50, p < .001, MSE = 126.23$. Homophonic

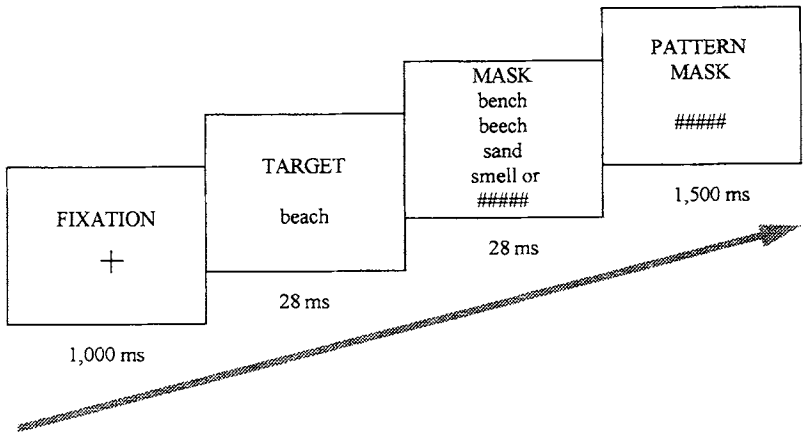

Figure 1. Paradigm used in Experiment 1. Observers were asked to write down the target.

masks inhibited target recognition relative to #-controls, $F1(1, 39) = 12.27, p < .002$, $MSE = 11.25$, and $F2(1, 34) = 7.21, p < .02$, $MSE = 11.20$. When compared with word controls, however, homophonic masks showed facilitation, $F1(1, 39) = 114.48, p < .001$, $MSE = 54.45$, and $F2(1, 34) = 83.36$, $p < .001$, $MSE = 66.06$. Associate masks produced inhibition relative to #-controls, $F1(1, 39) = 157.49, p < .001$, $MSE = 105.80$, and $F2(1, 34) = 194.97$, $p < .001$, $MSE = 120.91$. There was no reliable difference between associate masks and unrelated word controls. Moreover, the identification difference between graphemic and homophonic conditions was significant, $F1(1, 39) = 10.79, p < .003$, $MSE = 10.51$, and $F2(1, 34) = 8.35, p < .01$, $MSE = 9.66$, indicating that graphemic masks produced more facilitation than did homophonic masks (relative to word controls). Also, there was a significant difference between homophonic and associate conditions, $F1(1, 39) = 75.11, p < .001$, $MSE = 48.05$, and $F2(1, 34) = 69.84, p < .001$, $MSE = 58.51$.

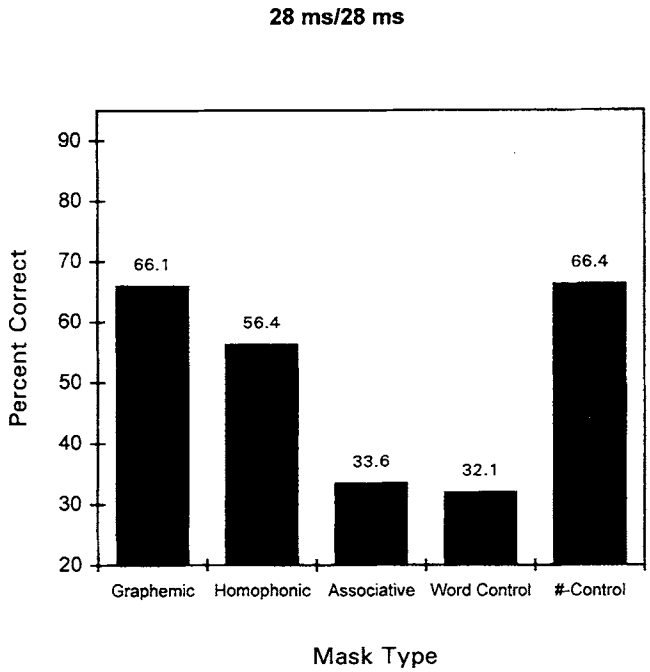

Figure 2. Mean percentages of correctly identified targets as a function of mask type. The target and mask were each exposed for 28 ms, followed immediately by a pattern mask of 1,500 ms.

These analyses revealed an additional graphemic effect beyond the phonemic effect and an absence of an associative masking effect. To verify that these effects did not depend on the few cases in which targets and masks were unequal in number of letters, we further examined just those trials on which the lengths were identical among targets and masks. There were 26 targets that had the same word length as graphemic masks, homophonic masks, as well as word controls. For these 26 targets, identification accuracies in the graphemic and homophonic conditions were 64.9% and 57.7%, respectively. The 7.2% difference was significant, $F(1, 25) = 3.98$, $MSE = 4.33$, $p = .05$. A further assessment of length difference effects with mask type (graphemic and homophonic) and word length (same and different) as main factors indicated a mask type effect, $F(1, 33) = 9.41, p < .004$, $MSE = 10.82$, but no word length effect ($F < 1$) or interaction, $F(1, 33) = 1.21, p = .28$, $MSE = 1.39$. Thus, the difference between graphemic and phonemic masks was general across length variation in target–mask pairings.

For the associative masks, for which length variation was more common, we compared 12 target–mask pairs with the same word length and 23 other pairs with different lengths. The identification rates in the same-length and different-length conditions were 32.3% and 34.8%, respectively, $F(1, 33) = 2.39, p = .13$, $MSE = 1.32$. Thus, regardless of length variations across target–mask pairings, associative masks led to an identification rate comparable to that for word control masks (32.1%).

Discussion

The results of this experiment are straightforward. First, there was no facilitative effect of any letter string mask

relative to the #-baseline. Thus, the basic effect of a letter-string mask under the exposure conditions of Experiment 1 may be interpreted as inhibitory. This suggests that reductions in the effects of various types of letter string masks should be understood as a release from inhibition caused by a following letter string rather than a strictly facilitative effect.[1] Whether our interpretation should also be imposed on previous studies using pseudowords rather than words remains to be determined.

Equally important, however, is that the basic inhibition produced by a word mask is dramatically reduced by formal similarity between the target and mask. Graphemic masks produced a large (34%) facilitative effect relative to unrelated word controls. Perhaps surprisingly, this formal similarity effect was somewhat less for homophone masks, which produced significantly lower identification than did graphemic masks (56.4% vs. 66.1%).

In contrast to the facilitative effects of formal similarity, relative to unrelated words, associative relatedness provided no effect (i.e., no release from the inhibition resulting from a word associate). This suggests that at least the type of associative meaning relations tapped in our association task is not available to processing within 28 ms.

Thus, the pattern of results strongly confirms an early stage of word identification dominated by formal word constituents, with limited access to nonformal meaning constituents. Masking a word during the early moments of identification interrupts the processing of these formal constituents. Reinstating the formal constituents reduces the effects of the interruption, but reinstating nonformal meaning features may not. The null effect from meaning masks was consistent with Naish's (1980) finding of an absence of semantic masking effects. At a somewhat later stage, we should expect things to be different. In particular, nonformal meaning features should start to be available from the target word in interaction with encoded graphic and phonological form information, even if the latter is incomplete.

Homophonic masks were not as effective as graphemic masks in releasing the inhibition of a mask, despite the fact that their graphemic similarity to the target was equal to that of the graphemic masks. Thus, we are in the paradoxical position of having to conclude that identification of the target was affected by phonology (the only difference between graphemic and homophone masks) based on relative *inhibition* rather than *facilitation.* The paradox arises because in previous research with pseudowords, homophonic masks produced higher rates of identification than did graphemic masks (Perfetti & Bell, 1991; Perfetti et al., 1988; Verstaen et al., 1995). It is possible that words and pseudowords produce different outcomes as masks, with words providing word-specific competition with the target. Thus, a lowered rate of identification with a homophone mask relative to a graphemic mask might reflect stronger competition between two lexical items that happen to be homophones compared with two that just share letters. This extra competition would arise from the phonological information initiated by viewing the target word and reinstated by the mask, with spelling information inadequately encoded to verify one form over the other. With the target and mask each exposed for 28 ms, there is little opportunity for the spelling of the target to be verified in the sense suggested by Rubenstein, Lewis, and Rubenstein (1971) and Van Orden (1987). The mask may well interrupt this spelling check with incompatible information (Paap, Newsome, McDonald, & Schvaneveldt, 1982). If so, then one might expect the occasional reports of masks rather than targets (errors) to be more frequent in the homophone condition. However, reports of masks were relatively low and without reliable variation across mask types: 10.7% (graphemic), 12.5% (homophonic), 11.8% (associate), and 10.4% (word control), respectively. The difference between graphemic and homophonic masks was nonsignificant ($F < 1$). Thus, the strong possibility that lexical-level competition is a factor in word masking that produces additional phonological inhibition by homophones lacks clear evidence from the error rates. More certainly, we can conclude that phonological information incremental to graphemic information was activated by the target–mask sequence. This conclusion is required to explain any difference between grapheme and phoneme masks, whatever its direction.

In summary, the results demonstrate that the basic effect of a word mask without formal similarity to a target is one of inhibition relative to #-baseline. The role of formal similarity in releasing the inhibition confirms the dominant role played by graphemic and phonological forms in the first few milliseconds of identification. Indeed, it appears that the orthographic constituents provide the only reliable source of information in the earliest phases when the observer's task requires perceptual identification in a data-limited situation. The activation of phonological information has clearly occurred in these early stages, but whether it assists or hinders identification in a masking situation hinges on additional factors.

Experiment 2

In Experiment 2 we extended the exposure duration of the target to 42 ms to allow an increased opportunity for an associative effect to emerge and to further track the homophonic inhibition discovery of Experiment 1. If this inhibition reflects the lack of opportunity for a spelling check before

[1] Previous studies using different neutral baselines have produced different patterns of findings (e.g., de Groot, Thomassen, & Hudson, 1982; Forster, 1981; see Jonides & Mack, 1984). To test whether our argument that the basic effect of a letter-string mask may be explained as inhibitory can generalize to other neutral baseline conditions, we ran an additional experiment using three types of neutral masks (i.e., X, $, and #s) and the first 33 targets appearing in the Appendix. Twenty-one participants were divided into three groups of seven such that target–mask pairs were counterbalanced across the three groups, with each group viewing a given target with just one of its three neutral masks. The procedure was identical to that used in Experiment 1. The identification rates of targets under the three mask conditions were 67.5%, 68.4%, and 66.7%, respectively. There was no significant difference among mask types ($F1$ and $F2 < 1$). Thus, it seems that identification accuracies were higher in neutral baseline situations than in letter-string mask conditions.

interruption by the mask, then increasing only the duration of the target but not the mask may eliminate the effect.

Method

Participants. Forty University of Pittsburgh undergraduates participated in this experiment. All were native English speakers and had normal or corrected-to-normal vision. They received course credit for their participation. None of these individuals had participated in the previous experiment.

Materials, design, and procedure. The materials, design, and procedure were the same as in Experiment 1, except that the exposure duration for a target was extended to 42 ms.

Results

The target identification rates are shown in Figure 3. There was a significant effect of mask type, $F1(4, 156) = 16.86, p < .001, MSE = 19.71$, and $F2(4, 136) = 14.80, p < .001, MSE = 21.53$. Interestingly, unrelated word controls did not inhibit target processing relative to #-controls ($F1$ and $F2 < 1$).

Planned comparisons indicated that graphemic masks facilitated target identification relative to #-controls, $F1(1, 39) = 6.78, p < .02, MSE = 9.11$, and $F2(1, 34) = 6.52, p < .02, MSE = 9.66$, and relative to word controls, $F1(1, 39) = 5.12, p < .03, MSE = 7.20$, and $F2(1, 34) = 3.79, p < .06, MSE = 6.91$. Homophonic masks also significantly facilitated target recognition relative to #-controls, $F1(1, 39) = 35.67, p < .001, MSE = 35.11$, and $F2(1, 34) = 27.86, p < .001, MSE = 37.16$, and relative to word controls, $F1(1, 39) = 24.50, p < .001, MSE = 31.25$, and $F2(1, 34) = 19.18, p < .001, MSE = 31.56$. Associate masks produced inhibition relative to unrelated word controls, $F1(1, 39) = 5.88, p < .03, MSE = 6.61$, and $F2(1, 34) = 7.13, p < .02, MSE = 8.93$. This inhibitory effect relative to #-controls was marginally significant, $F1(1, 39) = 3.61, p = .065, MSE = 5.00$, and $F2(1, 34) = 3.95, p = .055, MSE = 6.30$. In contrast to Experiment 1, homophonic masks produced a facilitation relative to graphemic masks, $F1(1, 39) = 11.15, p < .003, MSE = 8.45$, and $F2(1, 34) = 9.04, p < .006, MSE = 8.93$.

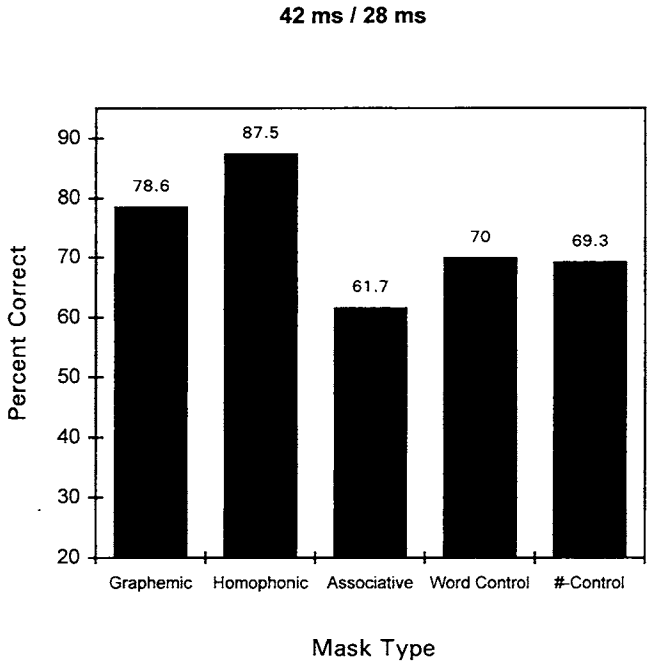

Figure 3. Mean percentages of correctly identified targets as a function of mask type. The target and mask were exposed for 42 and 28 ms, respectively, followed immediately by a pattern mask of 1,500 ms.

As in Experiment 1, additional analyses of target–mask length confirmed the generality of the masking effects across length variations in target–mask pairings. For 26 targets that had the same length as masks in the graphemic and homophonic conditions, the identification rates were 77.9% and 85.6%, respectively, $F(1, 25) = 5.57, p < .03, MSE = 4.92$. In addition, a Mask Type (graphemic and homophonic) × Word Length (same vs. different) analysis of variance showed a mask type effect, $F(1, 33) = 8.70, p < .007, MSE = 8.72$, with no word length effect, $F(1, 33) = 1.68, p = .20, MSE = 2.20$, and no Length × Mask Type interaction ($F < 1$). For associate masks, the identification accuracy was 63.5% when they had the same word length as targets and 60.9% when they had different length ($F < 1$).

To compare the masking effects in the two exposure durations of Experiments 1 and 2, we conducted an analysis of exposure duration (i.e., 28/28 ms and 42/28 ms) and mask type (i.e., graphemic, homophonic, associate, word control, and #-baseline). Both exposure duration and mask type were significant: for exposure duration, $F1(1, 78) = 209.63, p < .001, MSE = 251.22$, and $F2(1, 34) = 181.67, p < .001, MSE = 288.93$; for mask type, $F1(4, 312) = 57.27, p < .001, MSE = 54.78$, and $F2(4, 136) = 63.24, p < .001, MSE = 61.95$. More interesting was a significant Exposure Duration × Mask Type interaction, $F1(4, 312) = 22.06, p < .001, MSE = 21.10$, and $F2(4, 136) = 18.39, p < .001, MSE = 23.60$. Additional analyses indicated that for grapheme and homophone masks, the Exposure Duration × Mask Type interaction was significant, $F1(1, 78) = 21.84, p < .001, MSE = 18.91$, and $F2(1, 34) = 20.94, p < .001, MSE = 18.58$. Moreover, the Exposure Duration × Associate Mask versus Word Control interaction was also significant, $F1(1, 78) = 5.49, p < .03, MSE = 4.56$, and $F2(1, 34) = 6.87, p < .02, MSE = 6.01$.

Discussion

Three important departures from the results of Experiment 1 were observed: First, the inhibitory effect of words lacking formal similarity (control masks) disappeared. Second, the inhibitory effect of homophone masks relative to graphemic masks turned to facilitation. Third, associative masks, which showed no effect at 28 ms, produced inhibition relative to unrelated word controls.

If we compare across experiments, we must conclude that an additional 14 ms of processing brings about changes in the formal and associative attributes available to the identification process. A word lacking formal similarity is no longer

inhibitory because 42 ms is sufficient to bring about a more stabilized representation than can survive a challenge from competing letters. Masking still interrupts the process, but a letter string is no more disruptive than a pattern mask.

The nearly 9% facilitation effect of a homophone mask relative to a grapheme mask, in contrast to an inhibition effect at 28 ms, may stem from the same source. Because the representation is more stable, competition between competing forms is won increasingly by the target word form. By the longer duration, the phonological information that led initially both to activation of word forms consistent with the graphemic input (phonological activation) and to high competition between alternative orthographic forms of a single phonological word form (phonological competition) now has only its basic activation function to reveal.

Perhaps most interesting is the discovery that associate masks inhibited target identification at 42 ms. Whatever the mechanisms for semantic effects observed in other paradigms, such as the spreading activation models (see Neely, 1991) or compound-cue models (Ratcliff & McKoon, 1988), it is not clear how such mechanisms by themselves would lead to inhibition. Indeed, even in the masking paradigm, results with semantic masks have produced facilitation (Jacobson, 1976) or no effect (Naish, 1980), but not inhibition. Dimensions (e.g., associative or semantic) of word meaning may be different between our experimental materials and those used by other researchers. Naish (1980), for example, used semantic masks without an evaluation of target–mask association strength. Target–mask pairs in our meaning-related condition, however, were of high associative strength.

One possibility to consider is that the direction of the associative relationship in our experiments was not conducive to facilitation in the masking paradigm. Associative strength was high from target to mask, but not necessarily high from mask to target. One might argue that a mask-to-target direction is more appropriate for masking if the mask's effect is to reinstate partially activated information from the target. The target–mask direction might preactivate the mask and make it more likely for the observer to report masks rather than targets. However, the error rates give no particular support to this reasoning. The rate of mask report was nearly the same for associative masks as for other mask types: Graphemic, homophonic, associative, and unrelated word control masks produced mask identification rates of 7.5%, 10.7%, 10%, and 9.3%. Nevertheless, these data argue against only an incidental aspect of the "wrong direction" explanation. The possibility that mask–target association strength needs to be high to capture the mechanism underlying masking effects remains. However, other investigations with the priming paradigm have found backward semantic facilitation when the direction of association is target to prime but not prime to target (e.g., Peterson & Simpson, 1989; Seidenberg, Waters, Sanders, & Langer, 1984).

An important observation on this associative inhibition effect, whatever its underlying mechanism, is that it must reflect the activation of some nonformal (associative) information. Just as homophones can produce competition at the lexical level (Experiment 1), so can meaning associates. However, it takes more processing time on the target to activate any meaning information, so the effects were delayed until 42 ms. Note that whether facilitation or inhibition, any difference between associative and unrelated word masks must arise through the target–mask nonformal relationships. Thus, we must conclude that associative or meaning information is available quickly in these conditions, although not as quickly as phonological information. We summarize the effects of different masks at 28- and 42-ms durations in Figure 4 as facilitation and inhibition (relative to unrelated word controls).

General Discussion

The results of these experiments confirm the dominant role of form information in word identification, suggesting a slightly later availability of the kind of nonformal associative information allowed here. It remains to be seen whether other kinds of meaning effects might be observed in masking at shorter exposures, given the fact that different dimensions of word meaning (e.g., semantic or associative) may be accessed asynchronously (e.g., Lupker, 1984; Shelton & Martin, 1992; Tan et al., 1996).

At a more general level, the observed asynchrony between phonological information and meaning information follows the asymmetry of form–form relations and form–meaning relations. Orthographic forms more deterministically connect to phonological forms than they do to meaning. This asynchrony has also been observed in Chinese studies with the primed naming task (Perfetti & Tan, 1998) and the backward-masking procedure (Tan et al., 1996).

We note again that the evidence for early phonological computation rests in these experiments on an inhibition effect observed at 28 ms as well as on a facilitation effect observed at 42 ms. Researchers using pseudoword masks

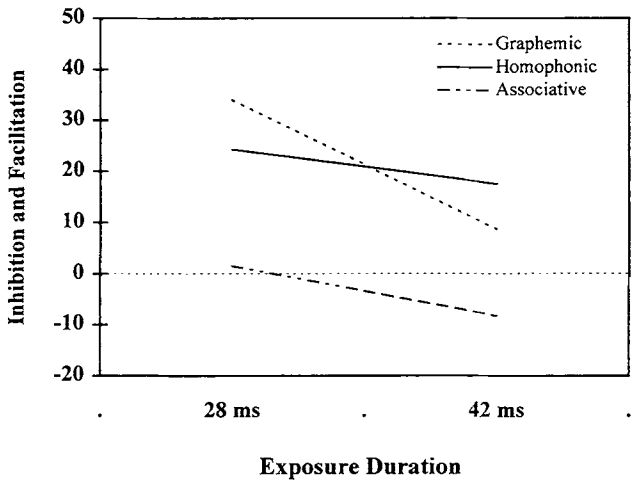

Figure 4. Facilitation (>0) and inhibition (<0) in percentage for each mask type relative to unrelated word controls in Experiments 1 and 2. In Experiment 1, the target and mask were each exposed for 28 ms. In Experiment 2, the target and mask were presented for 42 and 28 ms, respectively.

have reported facilitative effects of homophonic masks (e.g., Perfetti et al., 1988; Verstaen et al., 1995; Xu & Perfetti, in press). As we discussed previously (Experiment 1), it remains likely that word and nonword masks lead to different processes, especially at the stage of selection among activated word competitors. The possibility is that the effects of phonology have two aspects, an early activation based on sublexical components and a later lexical component. The first component's activation is always facilitative. The second, the lexical component, can be either facilitative or inhibitory depending on other factors. This account is consistent with the results of auditory and visual form priming showing lexical-level phonological inhibition (e.g., Colombo, 1986; Lupker & Colombo, 1994; O'Seaghdha, Dell, Peterson, & Juliano, 1992; Slowiaczek & Hamburger, 1992). We also emphasize that the results in Experiment 2 for graphemic and homophone masks replicate the results of pseudoword masking experiments (e.g., Perfetti et al., 1988). The sublexical facilitative component was, according to the present argument, present at the shorter duration but was partly obscured by lexical-level inhibition.

An important characteristic of brief display procedures is also highlighted by these results. Given a data-limited display in which a mask terminates a briefly exposed target, there is a premium placed on attending to the letters in the display. In effect, the graphemic string in the target is the only reliable source of information for the task the observer has to perform; a following word mask not only terminates processing of the input, but it also adds its own noise. A homophone mask adds not random noise but misleading information caused by pronunciation because it provides an alternative spelling for that pronunciation. Under such conditions, an effect of information in the mask is likely to be nonstrategic: There is more reason to try to ignore the mask than to try to use it. If so, the effect of homophonic masks can be taken as reflecting automatic as well as rapid phonological computation. Phonology, whether it helps or hinders in a specific case, is a constituent of visual identification, and its activation appears to be nonoptional. Phonological inhibition in backward masking has also been reported by Berent and Van Orden (1996) in a situation in which observers were discouraged to use phonology. These examples of phonology evidenced through inhibition are not easily explained by the strategy hypotheses (e.g., Brysbaert & Praet, 1992, Verstaen et al., 1995) without additional assumptions.

The argument that graphic identities are sought by observers in these viewing situations may be related to the center-surround perceptual principle proposed by Carr and Dagenbach (1990; Dagenbach, Carr, & Barnhardt, 1990; Dagenbach, Carr, & Wilhelmsen, 1989; see also Barnhardt, Glisky, Polster, & Elam, 1996; Stolz & Besner, 1997). According to this principle, the perceptual mechanism can enhance the processing of the information it is focused on (i.e., center) while suppressing other information (i.e., surround) to enhance processing of a weakly activated item. This principle provides a possible account of the inhibition that occurs following attempts to retrieve weakly activated information of the same type that is subsequently inhibited. We think that this principle may also account for the inhibition effect that occurs after attempts to retrieve a different type of weakly activated information. In our experimental situations, the orthographic code of targets is focused; the phonological code is in the "surround" and is dampened. The appearance of inhibition effects depends both on the activation state of sought-for orthographic codes as well as on the subthreshold activation state of surrounding phonological codes. When phonological information is weakly activated and may compete with graphemic information, the perceptual mechanism will suppress its activation, resulting in an inhibitory effect. The phonological facilitation obtained in our experiment would be attributable to an unsuccessful suppression of activated phonology.

The center-surround theory was developed in the context of experimental conditions in which semantic primes inhibit, rather than facilitate, lexical decisions of targets (e.g., Carr & Dagenbach, 1990; Dagenbach et al., 1989). This hypothesis can also explain our associative inhibition effect despite differences in paradigms. As argued earlier, the sought-for codes in the backward-masking situations are graphemic units. Associative nodes, like phonological units, are in the surround of processing and will be suppressed once they are weakly activated. Note that when some nonvisual dimension of a word (e.g., associative relationship) is not aroused at all, as in the 28-ms exposure of Experiment 1, the center-surround mechanism does not need to suppress associative nodes. Therefore, at this duration there was no inhibitory associative masking.

In summary, the critical argument is that in the backward-masking task, observers try to focus on graphemic information in the display, not on phonological information. When the task is identification of words in noise, the visual display provides the sought-for information in its position-ordered letters. This creates conditions for inhibition of other types of information.

Finally, we emphasize again that the results of the experiments force a recognition that unrelated words and nonletter #-masks lead to different levels of performance at some sufficiently short duration. At 28 ms, a word lacking formal similarity to the target inhibited target identification beyond its mere interruption of processing. That this inhibition disappeared by 42 ms suggests some rapid stabilization of word representation over the 14 additional ms. However, we do not wish to emphasize precise timing parameters as the key to masking effects. As Xu and Perfetti (in press) reported, the emergence of graphemic and phonemic mask effects with pseudowords is a function of display parameters relative to identification thresholds. With real words rather than pseudowords as masks, although they may produce a more complex pattern because of lexical inhibition effects, a similar dependence on identification thresholds rather than specific durations should also be expected.

Conclusion

The early stages of word identification are dominated by form over meaning, consistent with the identification-with-

phonology hypothesis and theoretical proposals concerning the rapid convergence of orthographic with phonological information (Van Orden & Goldinger, 1994) and the asymmetry of form–form and form–meaning relations (Perfetti & Tan, 1998). The results of masking experiments with real word masks converge with those using pseudoword masks on key points (e.g., evidence for early phonology) but differ in some important aspects. The key difference is the discovery of an early stage of inhibition of real word homophone masks, which may be due to lexical-level competition enhanced by homophones. Associative masking does occur in this paradigm, but the results of the present experiments suggest that meaning effects begin later than form effects and emerge as inhibition rather than facilitation. Methodologically, the results suggest that (central) masking processes can be effectively used as a window on basic perceptual identification processes.

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Appendix

Items Used in This Study

Targets	Homophones	Graphemes	Associates	Word controls	#-Controls
bale	bail	bald	hay	stew	####
barren	baron	burden	desert	offers	#####
beach	beech	bench	sand	smell	#####
beat	beet	belt	win	stem	####
bread	bred	breed	butter	quote	#####
cent	sent	cant	penny	lafe	####
cereal	serial	central	milk	indeed	######
cord	chord	card	rope	oral	####
doe	dough	dye	deer	nap	###
feet	feat	fret	toes	rash	####
fowl	foul	folk	bird	keys	####
hare	hair	hire	rabbit	swim	####
heal	heel	hell	wound	clay	####
heard	herd	heed	noise	lakes	#####
medal	meddle	media	gold	depot	#####
miner	minor	meter	coal	snack	#####
pail	pale	pall	bucket	fink	####
paste	paced	pests	glue	haunt	#####
paws	pause	pays	dogs	sank	####
pear	pair	peer	fruit	rite	####
plane	plain	plank	fly	hired	#####
pore	pour	pure	skin	wage	####
rose	rows	rise	flower	fell	####
sail	sale	salt	boat	pick	####
seams	seems	slams	dress	diets	#####
sell	cell	sill	buy	bind	####
sign	sine	sing	stop	host	####
sweet	suite	suits	candy	cable	#####
tale	tail	tall	story	pure	####
team	teem	term	sport	rock	####
tired	tide	tile	shoe	array	#####
toad	towed	told	frog	rare	####
throne	thrown	throat	king	aspect	######
week	weak	walk	month	poet	####
wine	whine	wind	grape	kill	####

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