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Form-Based Priming in Spoken Word Recognition: The Roles of Competition and Bias

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Phonological priming of spoken words refers to improved recognition of targets preceded by primes that share at least one of their constituent phonemes (e.g., BULL–BEER). *Phonetic priming* refers to reduced recognition of targets preceded by primes that share no phonemes with targets but are phonetically similar to targets (e.g., BULL–VEER). Five experiments were conducted to investigate the role of bias in phonological priming. Performance was compared across conditions of phonological and phonetic priming under a variety of procedural manipulations. Ss in phonological priming conditions systematically modified their responses on unrelated priming trials in perceptual identification, and they were slower and more errorful on unrelated trials in lexical decision than were Ss in phonetic priming conditions. Phonetic and phonological priming effects display different time courses and also different interactions with changes in proportion of related priming trials. Phonological priming involves bias; phonetic priming appears to reflect basic properties of activation and competition in spoken word recognition.

In the 20 years since the publication of the work by Meyer and Schvaneveldt (1971), the literature on semantic priming has grown enormously. In comparison to the vast literature on semantic priming in visual and auditory word recognition (see Neely, 1991, for review), research on form-based priming has received little attention. *Form-based priming* is the term recently adopted (e.g. Forster, 1987; O'Seaghdha, Dell, Peterson, & Juliano, in press) for priming experiments in which the relation between primes and targets is defined in physical terms rather than abstract, knowledge-based terms. For example, whereas CAT and DOG might serve as a prime–target pair in a semantic priming experiment by virtue of their related meanings, CAT and CUP might serve as a prime–target pair in a form-based priming experiment by virtue of their common initial letter (in a visual task) or phoneme (in an auditory task). To the extent that form-based priming has been explored, almost all investigations have involved visual presentation of primes, targets, or both. In the present investigation, we were concerned with form-based priming of spoken words.

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The published literature that motivated the present research consists of four articles, which approximately exhausts the available literature on form-based priming of spoken words. Fortunately, although the auditory, form-based priming literature is sparse, the relevant issues are well-known and share much in common with previous studies of visual semantic and form-based priming. Examples of such common themes are the attentional versus automatic nature of priming effects and the time course of priming effects. Several important issues in auditory, form-based priming are unique, however, and may not be addressed by experimentation on visual or semantic priming. Included in this category are issues concerning the effects of phonetic activation on the recognition of phonetically similar words, the nature of similarity neighborhoods of spoken words, and the levels of representation that subserve spoken word recognition. The present investigation was concerned primarily with priming between phonetically and phonologically similar words. We begin with a brief review of the published data on auditory, form-based priming, with special focus on reports of "phonological priming." The results and conclusions of four studies are reviewed, although not in their exact chronological order of appearance in print. We begin with a discussion of research reported by Slowiaczek, Nusbaum, and Pisoni (1987), followed by discussions of research reported by Slowiaczek and Pisoni (1986), Goldinger, Luce, and Pisoni (1989), and Radeau, Morais, and Dewier (1989).

Slowiaczek, Nusbaum, and Pisoni (1987) reported the results of three phonological priming experiments intended to address predictions derived from the cohort theory of word recognition (Marslen-Wilson, 1987; Marslen-Wilson & Welsh, 1978). The methodology used by Slowiaczek et al. was roughly the same in all of their experiments, with slight variations necessitated by changes in stimulus materials. All three experiments measured the perceptual identification of primed and unprimed words in noise. In this methodology, an auditory prime was presented to subjects in the clear. Fifty milliseconds after the offset of the prime, an auditory target was presented in white noise. The subjects' task was to identify the target word; accuracy of identification was the dependent measure.

Several factors were manipulated in the Slowiaczek et al. (1987) experiments. In all three experiments, subjects identified four-phoneme, monosyllabic target words in two sessions, one in which the targets were presented alone in noise and one in which they were preceded by primes in the clear. The differences in identification accuracy between these sessions indicated the direction and magnitude of priming. Also, in all three experiments, targets were presented at one of five signal-to-noise ratios, ranging from −10 dB (SPL) to +10 dB (SPL), with 5-dB increments in between. Finally, in all three experiments, the degree of phonological overlap between primes and targets was varied, ranging from trials with zero shared phonemes between primes and targets to repetition trials with four shared phonemes. (An exception was Experiment 2, which contained no repetition trials.)

The differences across the three experiments conducted by Slowiaczek et al. (1987) were limited to the nature of the primes and targets and their phonological relations. In Experiment 1, primes and targets were all real words, and their shared phonemes were in word-initial positions. Results showed a pattern of facilitatory priming that increased both as the noise level increased and as the degree of phonological overlap between primes and targets increased. These results were consistent with predictions of cohort theory (and several other theories) concerning the residual activation levels of various members of the prime's cohort after their rejection by the word recognition system. According to cohort theory, phonological priming should be obtained between words sharing initial segments, at least for brief periods of time between presentations. In Experiment 2, pseudoword primes were used, and similar facilitatory priming effects were observed, although the magnitude of priming was attenuated. Finally, in Experiment 3, real-word primes and targets were used, but the shared phonemes between primes and targets were in word-final positions rather than word-initial positions. Facilitatory priming effects were observed in Experiment 3 as well.

From these data, Slowiaczek et al. (1987) concluded that word recognition involves the activation of a set of potential word candidates from which the recognized word is selected. Although support is provided elsewhere for this claim (e.g., Andrews, 1989; Pisoni & Luce, 1987), the phonological priming effect has remained controversial, both as an empirical result and as a theoretical issue. The controversy centers around the basis of the Slowiaczek et al. (1987) result as well as its generality across experimental contexts. The facilitatory phonological priming effect has proven difficult to replicate in reaction time tasks (Radeau et al., 1989; Slowiaczek & Pisoni, 1986), and some investigators have suggested that the effect may reflect biased or strategic processing by subjects rather than a "true" bottom-up priming effect (Goldinger et al., 1989; Radeau et al., 1989).

Slowiaczek and Pisoni (1986) conducted two auditory lexical decision experiments using priming procedures similar to those just described. For both words and nonwords, identical (repetition) primes caused reliable facilitation of lexical decisions. However, for prime–target pairs sharing one, two, or three phonemes, no facilitation was observed. This null result was obtained regardless of the duration of the interstimulus interval between primes and targets, which was either 50 or 500 ms. Slowiaczek and Pisoni (1986) interpreted the different patterns of results from the lexical decision and perceptual identification experiments as a reflection of inherent task differences rather than an indication that the perceptual identification data could be artifactual. Indeed, there are substantial task differences that may preclude the lexical decision task from revealing a genuine priming effect to which the perceptual identification task is more sensitive. Such task differences include the respective sizes of the response sets, the use of degraded versus nondegraded stimuli, and the different time pressures of the two tasks. For various reasons described by Slowiaczek and Pisoni, any of these factors may prevent subjects in a lexical decision task from using all information available in the primes and may thereby render the lexical decision task less sensitive to phonological priming. Alternatively, the null finding in lexical decision may reflect a true lack of phonological priming with the stimulus materials used. Because the perceptual identification task imposes no time constraints on subjects' responding, it may be possible and beneficial for subjects to use information about primes to infer the phonetic content of degraded targets. Such an account may explain why the facilitatory priming effect observed by Slowiaczek et al. (1987) increased when the targets were more degraded.

The merits of the arguments on both sides of this debate are considered more completely later in this article. For the present, suffice it to note that although the "guessing strategy" interpretation of the perceptual identification data is adequate, the null findings in lexical decision clearly provide no direct evidence one way or the other. Drawing any firm conclusion would entail not only a risky comparison across widely differing tasks and dependent measures but also a literal interpretation of a null result as a lack of effect. Although the validity of the phonological priming effect is questionable in light of the differences between the perceptual identification and lexical decision data, it would not be appropriate to dismiss the Slowiaczek et al. (1987) data without further investigation.

The nature of form-based priming for spoken words appears even more ambiguous upon consideration of recent findings reported by Goldinger, Luce, and Pisoni (1989). This investigation was motivated by a prediction derived from the neighborhood activation model of word recognition (Luce, 1986; Luce, Pisoni, & Goldinger, 1990). The neighborhood activation model is based on the concept of activation and competition among phonetically similar words in memory, and it predicts that form-based priming should inhibit target recognition. Like Slowiaczek et al. (1987), Goldinger et al. examined primed perceptual identification of words in noise. However, unlike Slowiaczek et al. (1987), Goldinger et al. did not examine *phonological* priming per se. Instead, they examined the effects of priming with prime–target pairs that were phonetically confusable when presented in noise but shared no common phonemes.[1]

Using phonetically related prime–target pairs and unrelated pairs to provide baseline recognition measures, Goldinger et al. (1989) observed reliable inhibitory priming effects. Targets were identified less accurately when they followed phonetically similar primes than when they followed phonetically unrelated primes. However, the inhibition effect was robust only in certain experimental conditions. Specifically, the effect was observed only in conditions with a brief, 50-ms interstimulus interval (ISI) between primes and targets. No effect of priming was observed with a longer, 500-ms ISI. Also, the inhibition was observed only for targets preceded by primes that were low-frequency words; no effect was observed for targets preceded by primes that were high-frequency words. Both of these constraints on the inhibitory priming effect were consistent with an account of word recognition based on activation and competition among words in memory. In conditions that allowed enough time for activation to dissipate (either because of the longer ISI or because of rapidly recognized high-frequency primes), the competition was eliminated before target presentation, and target recognition was independent of the priming manipulation.

The inhibitory priming of perceptual identification observed by Goldinger et al. (1989) is potentially contradictory to the facilitatory priming observed by Slowiaczek et al. (1987). This potential contradiction is introduced because both effects were explained in terms of residual activation in the lexicon from presentation of the prime. However, it is not clear that such opposite effects should be explained by a unitary mechanism. One can imagine such a situation in the context of, for example, an interactive-activation model of word recognition (McClelland & Rumelhart, 1981). In such a model, one would assume separate levels of representation for features, phonemes, and words. These levels pass excitatory activation to each other, and each level contains inhibitory lateral connections among its nodes. Consider possible effects of form-based priming in this interactive-activation model. For example, consider the recognition of the target word /bIn/ following either the prime /bæt/ (as in the Slowiaczek et al. experiments) or the prime /pæt/ (as in the Goldinger et al. experiments), especially with respect to the initial stop consonant /b/.

It is easy to verify that the interactive model can predict facilitation from phonologically overlapping primes and inhibition from phonetically similar, nonoverlapping primes. After successful recognition of the phonological prime /bæt/, the node for the phoneme /b/ would remain positively activated for some brief period, and the feature-to-phoneme and phoneme-to-word links for the phoneme node /b/ would remain activated as well. Both sources of excitation would encourage correct recognition of the /b/ in /bIn/, a priming effect analogous to the Slowiaczek et al. (1987) findings. Conversely, because /b/ and /p/ are phonetically similar, recognition of the phonetic prime /pæt/ would leave the node for the phoneme /b/ inhibited for some brief period, because the recognition of the /p/ in /pæt/ would require suppression, via inhibitory within-level connections, of the phoneme competitor /b/. This suppression of the node for the phoneme /b/ would imply inhibition of the target /bIn/, a priming effect analogous to the Goldinger et al. (1989) findings. Clearly, with changes in parameter settings, other patterns of priming are also possible.

This hypothetical interactive model demonstrates that the findings of Slowiaczek et al. (1987) and Goldinger et al. (1989) can be accommodated within a unitary framework.[2] Such an account is predicated, of course, on an assumption that both the facilitatory and inhibitory priming effects are true perceptual effects. Another possibility is that both of the effects are due to guessing strategies and that phonetic priming somehow encourages poor guessing. For example, subjects who hear targets incorrectly may perceive phonological relations between primes and targets and adopt a strategy to borrow phonemes from primes to generate responses to targets. However, the observation made by Goldinger et al. of no priming with a 500-ms ISI gives us little reason to assume subjects were acting strategically: It is unlikely that subjects would adopt a guessing strategy when primes and targets were separated by 50 ms but would abandon their strategy when primes and targets were separated by 500 ms. A third possibility is that the facilitatory effect is due to one process and the inhibitory effect is due to another, in contrast to the unitary, activation-based account offered in the interactive model just described. For example, inhibitory priming may be activation-based, and facilitatory priming may be due to subjects' biases or expectations. Unfortunately, comparison of the two studies is inconclusive on this issue. Although Goldinger et al. suggested that the Slowiaczek et al. data could reflect subject strategies, the differences between the studies preclude strong conclusions.

Radeau, Morais, and Dewier (1989) investigated the phonological priming effect further by conducting primed auditory lexical decision and auditory shadowing (naming) tasks. The lexical decision tasks conducted by Radeau et al. were similar in method to those conducted by Slowiaczek and Pisoni (1986) in that both used brief SOAs and nondegraded stimuli. The shadowing tasks were also similar in method, differing only in the response elicited from subjects. Accordingly, the data obtained by Radeau et al. bear close resemblance to those obtained by Slowiaczek and Pisoni. Like Slowiaczek and Pisoni, Radeau et al. observed no facilitatory phonological priming in any conditions of any experiment, with the exception of repetition priming. Indeed, just as Slowiaczek

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[1] The nature of the priming relations used in the present investigation defies precise terminology. Therefore, for the remainder of this article, we refer to priming relations such as those investigated by Goldinger, Luce, and Pisoni (1989) as *phonetic priming*, and we refer to priming relations such as those investigated by Slowiaczek, Nusbaum, and Pisoni (1987) with the typical label *phonological priming*. Our use of these terms is not meant to imply that the phonological priming relation is not phonetic as well; the labels are simply adopted for convenience.

[2] For the neighborhood activation model, the disparate patterns of results are not handled as easily if one assumes that both the facilitatory and inhibitory priming effects are free of perceptual or response strategies or both. See text for further discussion.

and Pisoni observed nonsignificant trends toward inhibitory priming in several conditions, Radeau et al. observed several significant effects of inhibitory priming. The inhibition increased as the phonological overlap between primes and targets increased, but only in the lexical decision experiments. In shadowing, significant inhibition was observed in one experiment and no effects of priming were observed in a second experiment.

In sum, using auditory lexical decision and shadowing tasks, Radeau et al. (1989) failed to replicate the Slowiaczek et al. (1987) finding of facilitatory phonological priming. Instead, they observed either effects of inhibition or no effects of priming at all. From these data, Radeau et al. drew two general conclusions. Their primary conclusion was that the phonological priming effect does not generalize across tasks, and they suggested that the facilitation observed by Slowiaczek et al. was due to a guessing strategy. Their second conclusion was methodological in nature: Radeau et al. suggested that the shadowing task may be used as a validating procedure in spoken word recognition experiments. According to Radeau et al., the results obtained in shadowing tasks can be used to diagnose effects obtained in tasks that may involve extensive postaccess processing (Balota & Chumbley, 1984).

Although both of the observations discussed by Radeau et al. (1989) may be correct—the Slowiaczek et al. (1987) data may be artifactual and the shadowing task may be our most veridical index of word recognition—the data reported by Radeau et al. do not strongly support either conclusion. With respect to the shadowing task, the patterns of data Radeau et al. observed in lexical decision and shadowing were quite similar to each other, aside from the inhibitory priming effects showing slightly greater magnitude and generality in lexical decision than in shadowing. These data, in turn, did not differ greatly from the lexical decision data reported by Slowiaczek and Pisoni (1986). As such, the shadowing task may not be superior to all other tasks used to investigate spoken word recognition.

With respect to the artifactual nature of the facilitatory priming effect, although failure to replicate the phonological priming effect with reaction time measures implies that the effect found in perceptual identification is due to a guessing strategy, the null results do not support any definitive conclusion. Failures of replication can occur for many reasons, especially across experimental methodologies and dependent measures, and must be interpreted modestly. The null findings reported by Radeau et al. fall into this category, so the status of the phonological priming effect remains ambiguous.

Indeed, in a recent investigation, Slowiaczek and Hamburger (1992) reported data from a primed shadowing task that are similar to the data reported by Radeau et al., but Slowiaczek and Hamburger offered a different interpretation. In experiments using both auditory and visual primes followed by auditory targets, Slowiaczek and Hamburger observed a consistent pattern of priming results: When primes and targets shared only an initial phoneme, facilitation of target shadowing was observed. As the number of shared phonemes increased to two or three phonemes, inhibition of target shadowing was observed. Finally, when primes and targets were identical, facilitation was observed again. Slowiaczek and Hamburger discussed these data in terms of an interactive-activation model, similar to the model sketched earlier, in which similar primes and targets may either facilitate each other or compete with each other depending on their degree of overlap. Of course, the adequacy of such a model of form-based priming will require further evaluation under a variety of testing conditions.

Because the question of guessing strategies is unresolved, especially in light of the Slowiaczek and Hamburger data, the possible nature of such a strategy also remains ambiguous. As Slowiaczek and Pisoni (1986) noted, the differences between perceptual identification and lexical decision entail not only response differences but stimulus differences as well. Accordingly, the nature of a bias in perceptual identification may assume different forms. It is plausible that a bias could develop as a true "guessing strategy," but it is also plausible that a bias could develop as a lower level perceptual criterion shift. That is, whereas the phonological prime may not increase bottom-up sensitivity to the related target, the facilitation effect may not necessarily reflect overt or intentional guessing strategies. Instead, the consistent relation between primes and targets may encourage a perceptual bias that need not be conscious or strategic (see McLean & Shulman, 1978).

Form-based priming effects, both the facilitatory phonological priming effect and the inhibitory phonetic priming effect, carry broad implications for theories of spoken word recognition. The presence and nature of priming effects may elucidate the organization of the mental lexicon, the units of lexical representation, and the processes of lexical activation, search, and competition. Determining the validity of the phonetic and phonological priming effects, as well as their underlying bases, is clearly relevant to the pursuit of an accurate model of lexical processing. The present experiments were conducted to provide direct evidence concerning the nature of the phonetic and phonological priming effects. Specifically, we sought to determine whether the facilitatory phonological priming effect is due to biased processing.

Our approach in this investigation involved juxtaposing the phonetic and the phonological priming tasks using a common pool of stimuli across a variety of experimental contexts. Two general aspects of our approach were particularly important: First, we assessed bias in phonological priming by comparing subjects' responses on the unrelated priming trials across conditions. If the phonological priming effect entails a "cost" for the unrelated trials of an experimental block, in terms of speed or accuracy, we will have some evidence that phonological priming involves bias. This research strategy is explained in greater detail below. Second, we compared the phonological and phonetic priming effects across several procedural manipulations. If both effects always occur or disappear in tandem under all procedural manipulations, we can assume that the effects are due to the same set of processes. If, however, the two effects pattern differently under various procedural manipulations, we can assume that the effects are due to differing underlying processes.

Experiment 1

In the semantic priming literature, a well-known index of strategic processing is the "cost" associated with recognition of targets preceded by unrelated primes. A typical pattern of data shows that, as recognition of targets preceded by semantic primes is improved relative to a baseline, recognition of targets preceded by unrelated primes is reduced relative to the same baseline, becoming either slower or less accurate (McLean & Shulman, 1978; Neely, 1991; Posner, 1982; Posner & Snyder, 1975a, 1975b; Shiffrin, 1988). Experiment 1 was designed to detect strategic processing via comparison of subjects' performance on unrelated priming trials. In Experiment 1, we juxtaposed the priming relations investigated by Slowiaczek et al. (1987) and Goldinger et al. (1989) with a common pool of stimulus materials in both conditions. Both conditions investigated perceptual identification of primed words presented in noise, but the priming relations varied across conditions.

The phonetic priming condition of Experiment 1 was a replication of the Goldinger et al. (1989) experiment in which half of the prime–target pairs presented to subjects were phonetically unrelated and half were phonetically similar but with no shared phonemes. The phonological priming condition of Experiment 1 was not an exact replication of the Slowiaczek et al. (1987) experiment but was analogous with respect to phonological overlap between primes and targets. To maintain consistency with the phonetic priming condition, half of the prime–target pairs in the phonological priming condition were phonetically unrelated, and the other half were related such that the prime and target in each pair contained the same initial phoneme. Thus, unlike the Slowiaczek et al. experiments, in which the degree of phonological overlap was a manipulated variable, in the phonological priming condition of Experiment 1, it was held constant at either one shared phoneme between primes and targets or none at all.[3] Also, following Goldinger et al., we used a constant signal-to-noise ratio of +5 dB (SPL) for target presentation.

The purpose of conducting Experiment 1 was not to simply replicate the previous experiments of Slowiaczek et al. (1987) and Goldinger et al. (1989) and show that "one phoneme makes all the difference" in converting an inhibition effect to a facilitation effect. Rather, the purpose was to detect strategic processing by subjects in the phonological priming condition. In both conditions of Experiment 1, the same target words and unrelated primes were used; only the related primes differed across conditions. Therefore, despite the differences in related trials, half of the trials in both conditions were identical. Analysis of these trials, either in absolute accuracy or in types of errors, provided an index of the effect of condition (phonetic vs. phonological priming) on the subjects' approach to the task. If there is no strategic processing in either condition, we assume that all experimental trials are independent of each other, and performance on the unrelated priming trials should be equivalent across conditions. If phonological priming encourages subject biases, however, strategic responding should be reflected by a change on the unrelated priming trials. Because the dependent measure in perceptual identification is the accuracy of identification responses, a strategy may be revealed by lower accuracy on these trials, systematic errors in subjects' guesses, or both. These measures of "cost" on unrelated trials served as our index of strategic processing across conditions of Experiment 1.

Method

Subjects. Eighty-eight Indiana University undergraduate students participated in Experiment 1 in partial fulfillment of the requirements for an introductory psychology course. Forty-four subjects participated in the phonological priming condition and 44 participated in the phonetic priming condition. No subject participated in both conditions of Experiment 1. All subjects were native speakers of English and reported no history of speech or hearing disorders.

Stimulus materials. One hundred sixty-eight phonetically related prime–target pairs were selected from a computerized lexical data base based on *Webster's Seventh New Collegiate Dictionary* (1967). In addition to the phonetically related primes, phonologically related and unrelated primes were selected for each of the 168 targets, for a total of 672 words. The phonetically related prime–target pairings were created by searching the data base for each target's nearest neighbor with no common phonemes (see Goldinger et al., 1989). Degrees of similarity between primes and their phonetically related targets were computed using confusion matrices for individual consonants and vowels at the signal-to-noise ratio used in the present study (see Luce, 1986, for a complete description). The phonologically related primes were selected for each target by searching the data base for each target's nearest neighbor with the same initial phoneme. The unrelated primes were selected by searching for words from neighborhoods that had approximately the same density as their prospective targets but were not phonetically confusable with the targets.[4] Table 1 shows examples of real-word and nonword targets with their respective phonologically related, phonetically related, and unrelated primes. Only real-word targets were presented in the perceptual identification experiments (Experiments 1 and 2); real-word and nonword targets were presented in the lexical decision experiments (Experiments 3, 4, and 5).

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[3] To the reader who is familiar with the data reported by Slowiaczek, Nusbaum, and Pisoni (1987), our selection of a constant one-phoneme overlap relation between primes and targets may seem odd. In their experiments, when targets were presented at a +5-dB signal-to-noise ratio (the noise level used in the present study), the one-phoneme overlap pairs showed little evidence of priming, which suggests that our selection of the one-phoneme overlap relation is inappropriate. However, there were several important reasons for the selection: Our primary goal was to compare phonological and phonetic priming, so it would clearly be inappropriate to manipulate a variable in one condition and not in the other. Constraints on stimulus selection for phonetic priming make manipulating degrees of similarity impossible, so no such manipulation was used in the phonological priming condition. The reasons for selecting the minimal, one-phoneme overlap relation were twofold: First, using minimal overlap provided a stronger test of the hypothesis that subjects can develop a strategy based on phonological relations between pairs of words. Second, the one-phoneme overlap relation made the phonological priming condition as similar as possible to the phonetic priming condition; the difference was confined to one phoneme. As such, comparisons across the conditions were more direct than they might have been if the priming relations were more disparate. Finally, the present experiments maintained more consistency in signal-to-noise ratio and phonological relations and also contained many more trials with the one-phoneme overlap relation than did the Slowiaczek et al. investigation. Therefore, despite the subtle priming relationship, the likelihood of observing reliable priming effects was greater in the present investigation than in the Slowiaczek et al. investigation.

[4] Given the nonintuitive nature of the similarity relations between phonetic primes and targets, we conducted a pilot experiment to ensure that related pairs, such as BULL–VEER, were more similar

The 672 words selected for Experiment 1 were subject to the following constraints: (a) All targets and unrelated primes were three phonemes in length and related primes were either two or three phonemes in length; (b) all words were monosyllabic; (c) all words were listed in the Kučera and Francis (1967) corpus; and (d) all words had a rated familiarity of 6.0 or above on a 7-point scale. These familiarity ratings were obtained in a previous study by Nusbaum, Pisoni, and Davis (1984). In that study, all words in *Webster's Pocket Dictionary* were presented visually to subjects for familiarity ratings. The rating scale ranged from *don't know the word* (1) to *recognize the word, but don't know its meaning* (4) to *know the word and its meaning* (7). The rating criterion of 6.0 and above was used to ensure that all words were familiar to subjects.

Two final constraints on stimulus selection concerned a balance of the structural characteristics of the words. Because Goldinger et al. (1989) observed that only low-frequency primes produced reliable inhibitory priming, only low-frequency words were used as related primes in Experiment 1. Also, because target word frequency and neighborhood density affect recognition accuracy (Goldinger et al., 1989), these structural variables were balanced in target selection. Four cells of prime–target pairs were created by orthogonally combining two levels (high and low) of target frequency and neighborhood density. Once prime–target pairs were separated according to these structural variables, the smallest cell contained 42 pairs. Prime–target pairs were removed from the other cells such that the remaining pairs had the highest possible similarity between phonetic primes and targets. The remaining 42 pairs in each cell represented an exhaustive set of all possible stimuli for the purposes of Experiment 1.

Because every target word had two corresponding primes (within either condition) and no subject was to be presented the same target twice, the stimuli for each condition were divided into two lists. Every subject in each condition responded to all 168 targets, but the related and unrelated primes varied across groups of subjects. For a given group, 84 targets were preceded by related primes, and 84 targets were preceded by unrelated primes. For another group, the pairings for all targets were reversed. An equal number of subjects in each condition were presented with each list.

All words were recorded on audiotape in a sound-attenuated booth by a male speaker with a midwestern dialect. All words were spoken in isolation. The stimuli were low-pass filtered at 4.8 kHz and digitized at a sampling rate of 10 kHz using a 12-bit analog-to-digital converter. All words were excised from the list using WAVES, a digitally controlled speech waveform editor on a PDP 11/34 computer (Luce & Carrell, 1981). Finally, all words were stored as digital stimulus files on a computer disk for presentation during the experiment.

to each other than unrelated pairs, such as GUM–VEER. Toward this end, we conducted a same–different experiment in which subjects were presented pairs of words and told to indicate as quickly as possible whether they heard the same word twice in a row or two different words. Half of the trials were "same" trials and half were "different" trials. Half of the "different" trials contained unrelated prime–target pairs, and half contained phonetically related prime–target pairs. Three conditions were tested, with 40 subjects per condition: In one condition, both words were presented in noise (conditions under which the confusion matrices were derived). In another condition, only the second word was presented in noise (conditions under which the priming experiments were conducted). In a third condition, both words were presented in the clear. In all three conditions, we found that "different" responses to phonetically related pairs (e.g., BULL–VEER) were reliably slower and less accurate than "different" responses to unrelated pairs (e.g., GUM–VEER). These findings show that although related pairs such as BULL–VEER may not sound particularly similar to each other, they are at least more similar to each other than their associated unrelated pairs.

Table 1
Examples of Stimuli for Perceptual Identification (Experiments 1 and 2) and Lexical Decision (Experiments 3, 4, and 5)

Target	Phonological prime	Phonetic prime	Unrelated prime
	Perceptual identification		
run	ram	lamb	bed
bone	bang	dung	lease
mush	mass	notch	surge
nerve	gnaw	mug	whose
gear	ghoul	yell	man
jar	jail	gall	phone
	Lexical decision		
run	ram	lamb	bed
bone	bang	dung	lease
mush	mass	notch	surge
/noik/	gnaw	mug	whose
/gour/	ghoul	yell	man
/jær/	jail	gall	phone

To ensure that all stimuli were equally intelligible, an additional group of 10 subjects identified all of the words in the clear. Words that were not correctly identified by at least 8 of 10 subjects were re-recorded and replaced with more intelligible tokens.

Procedure. Subjects were tested in groups of 6 or fewer. Each subject was seated in a sound-attenuated testing booth equipped with an ADM computer terminal and a pair of matched and calibrated TDH-39 headphones. The presentation of stimuli and collection of responses were controlled by a PDP 11/34 computer. All pairs of stimuli were presented in random order.

A typical trial proceeded as follows: A prompt appeared on the CRT screen that read "GET READY FOR NEXT TRIAL." Five hundred milliseconds after the prompt appeared, a prime was presented over headphones at 75 dB (SPL) in the clear. Immediately upon the offset of the prime, 70 dB (SPL) of continuous, band-limited white noise was presented. Fifty milliseconds after the onset of the noise, the target was presented at 75 dB (SPL), yielding a +5-dB signal-to-noise ratio. Fifty milliseconds after the offset of the target, the noise was discontinued. The subjects' task was to identify the target words as accurately as possible and type their responses on the ADM terminal keyboards. Subjects were provided 30 s to respond.

Results and Discussion

Overall results from Experiment 1 are presented first, then the phonetic and phonological priming conditions are analyzed independently. Comparisons across the conditions are presented last.

The percentage of correctly identified words was determined for each subject and each item. For a response to be considered correct, the entire response had to match the target exactly or be a homophone of the target (e.g., *one*, *won*). All simple spelling or typing errors, such as letter transpositions, were corrected prior to data analysis.

Figure 1 displays the results, in terms of percentage of correct target identification, of Experiment 1. Dark bars show performance for targets preceded by unrelated primes; light bars show performance for targets preceded by related primes. Results from the phonetic priming condition are shown on the left; results from the phonological priming condition are shown on the right.

A two-way analysis of variance (ANOVA; Condition × Relatedness) was performed on the mean percentages of correct responses. A significant main effect of condition was obtained in analyses based on data analyzed both by subjects, $F_1(1, 86) = 42.99$, $MS_e = 1.2974$, and by items, $F_2(1, 332) = 16.49$, $MS_e = 0.0479$.[5] (In all experiments reported throughout this article, all results reported are $p < .05$ or beyond except for specifically denoted null results). The overall accuracy was higher in the phonological priming condition than in the phonetic priming condition. No significant main effect of relatedness was observed, $F_1(1, 86) = 1.66$, $MS_e = 0.3802$, $p = .2012$; $F_2(1, 332) = 1.34$, $MS_e = 0.0479$, $p = .2486$. No net effect of relatedness was observed because the priming effects were in opposite directions across conditions, as reflected by a significant two-way Condition × Relatedness interaction, $F_1(1, 86) = 129.34$, $MS_e = 0.3802$; $F_2(1, 332) = 64.23$, $MS_e = 0.0479$.

Phonetic priming. A one-way ANOVA (Relatedness) was performed on the mean percentages of correct responses from the phonetic priming condition. A significant main effect of relatedness was observed, $F_1(1, 43) = 19.56$, $MS_e = 0.4394$; $F_2(1, 166) = 4.42$, $MS_e = 0.0469$. Targets preceded by unrelated primes were identified more accurately than targets preceded by phonetically related primes. The phonetic priming condition replicated the main finding reported by Goldinger et al. (1989). Phonetically related primes inhibited target identification relative to the identification of the same targets preceded by unrelated primes.

Phonological priming. A one-way ANOVA (Relatedness) was performed on the mean percentages of correct responses. A significant main effect of relatedness was obtained, $F_1(1, 43) = 110.84$, $MS_e = 0.2750$; $F_2(1, 166) = 15.08$, $MS_e = 0.0489$. Targets preceded by phonologically related primes were identified more accurately than targets preceded by unrelated primes. This facilitation essentially replicates the results reported by Slowiaczek et al. (1987). The question of major interest in Experiment 1, however, was not whether the priming effects could be replicated but whether the phonological priming effect could be attributed to a bias.

Comparison across conditions. As discussed earlier, the purpose of juxtaposing the phonetic and phonological priming conditions was to detect strategic processing by comparing performance on the unrelated trials across conditions. If subjects apply a perceptual or response bias in the phonological priming condition, their responses on the unrelated priming trials should be affected, either by lowering their overall accuracy (because the strategy would be misapplied on these trials) or by selectively modifying the content of their incorrect guesses. Comparison across the conditions shown in Figure 1 reveals a striking similarity in the overall accuracy on unrelated priming trials. As such, it is clear that we cannot detect any bias by comparing absolute percentage correct performance across conditions. Fortunately, the perceptual identification task provides a second dependent measure—the actual forms of the errors committed. Although there were no differences in overall error rates on unrelated priming trials across conditions, qualitative error analyses revealed an important difference between conditions.

Recall that the phonological overlap between primes and targets consisted of one phoneme in word-initial position. As such, if subjects were to develop a perceptual or response strategy, it would most likely conform to a rule such as "When in doubt, assume that the initial phoneme of the target was the same as the intial phoneme of the prime." Assuming that a strategy would adopt this form, we operationally defined *a biased response* as any error on an unrelated priming trial in which the erroneous response given by the subject contained the initial phoneme from the prime. Clearly, a certain number of errors with this form are likely to occur by chance, regardless of strategic processing. However, because the unrelated trials of Experiment 1 were identical in both conditions, a reliable increase in the frequency of biased responses in the phonological priming condition can only be attributed to strategic processing.

Frequency counts were conducted on the total number of errors on unrelated priming trials and also on errors that fit the definition of biased responses. In the phonetic priming condition, there were 1,801 errors committed on the unrelated priming trials, 116 of which were biased responses. In the phonological priming condition, there were 1,733 errors committed on the unrelated priming trials, 318 of which were biased responses.[6] This was nearly a three-to-one ratio of biased responses in the phonological priming condition to biased responses in the phonetic priming condition, and the difference was statistically reliable, $\chi^2(1, N = 88) = 115.24$. This difference provides evidence that subjects in the phonological priming condition did in fact learn the relevant relation between primes and targets during the course of the experiment and that they used this information, either in perception or response generation, on trials in which they were highly uncertain.[7]

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[5] Throughout all statistical analyses reported in this article, F_1 refers to subject analyses and F_2 refers to item analyses.

[6] On first consideration, the reader may be concerned by the small number of biased responses relative to the total number of errors. It is important to bear in mind, however, that stimuli for the unrelated prime–target pairs were selected to be as dissimilar as possible. Given the nature of these pairs, it is to be expected that, regardless of subject strategies, the absolute number of biased responses should remain small.

[7] Because Radeau, Morais, and Dewier (1989) suggested that subjects in the phonological priming task adopt a "guessing strategy," implying an intentional ploy, we administered a posttest questionnaire to all subjects after they participated in Experiment 1. The questionnaire contained several questions to determine whether the subjects had noticed systematic relations between primes and targets, what these relations were, and whether they had used this insight (or any other strategy) to help them identify the words presented in noise. The questionnaire data revealed that subjects in the phonological priming condition noticed the relevant relation between primes and targets (often reporting that they began with the same "letter"), but few subjects reported using any strategy. Moreover, most subjects denied that any strategic responding would be possible in the experiment. Clearly, this null finding of the questionnaire does not mean that no strategies were used by subjects, but it suggests that subjects did not use intentional "guessing strategies" per se. Instead, a perceptual criterion shift may account for the bias displayed in phonological priming.

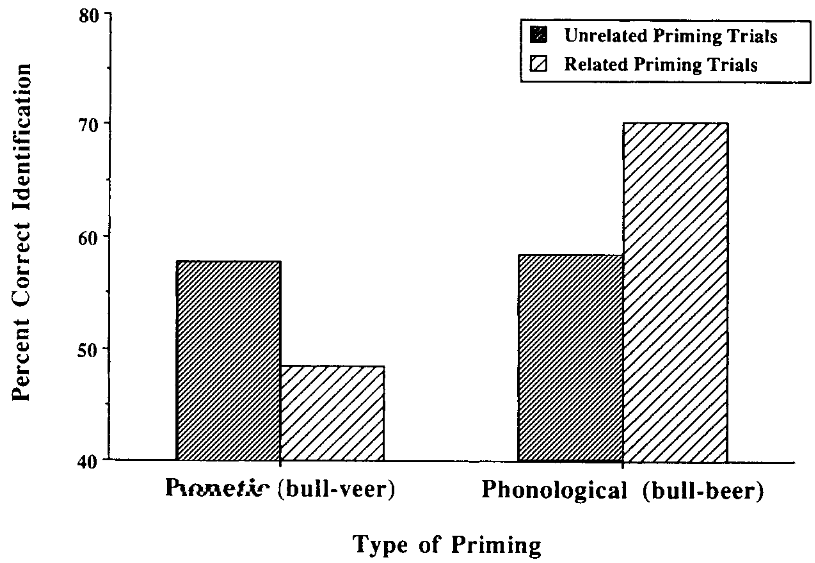

Figure 1. Mean percentages of correct target identification in Experiment 1. (Results from the phonetic priming condition are shown on the left; results from the phonological priming condition are shown on the right.)

Experiment 2

The results of Experiment 1 provide preliminary evidence that a bias is involved in the facilitatory phonological priming effect. We observed that phonological overlap between related primes and targets not only increased the probability of correctly identifying the targets but also reliably altered subjects' patterns of responding on the unrelated priming trials. However, the results of Experiment 1 do not allow us to conclude that the bias was entirely responsible for the phonological priming effect; bias may only exaggerate the effect. To investigate the role of bias further, we conducted Experiment 2.

Numerous experimental manipulations have been applied in studies of semantic priming to investigate the effects of biases on the magnitude of priming. The particular manipulation that we adopted in Experiment 2 was a change in the proportion of related priming trials within an experimental session. In Experiment 1, half of the trials in each condition were related priming trials and half were unrelated priming trials. In Experiment 2, the same stimulus materials and task were used, but the proportion of related trials was reduced from 50% to approximately 10% of all trials.

The relatedness proportion effect has been studied extensively in semantic priming experiments (e.g., den Heyer, Briand, & Dannenbring, 1983; Neely, Keefe, & Ross, 1989; Norris, 1987; Seidenberg, Waters, Sanders, & Langer, 1984). If there is an attentional component to the priming effect, the typical pattern of results shows that as the proportion of related trials is increased, the magnitude of the facilitatory priming effect is increased and the inhibition from unrelated primes is also increased. In Experiment 2, we used the relatedness proportion methodology to further investigate the role of bias in the phonological priming task. The logic of this experiment was straightforward: If there is a bias component to the phonological priming effect, the reduction of related trials should reduce the magnitude of the effect, although it may never be eliminated (Fischler, 1977). On the other hand, if the inhibition observed in the phonetic priming task is a product of low-level competition among activated words in memory, the change in relatedness proportion should not alter the magnitude of the effect.

Method

Subjects. Eighty-eight Indiana University undergraduate students participated in Experiment 2 in partial fulfillment of requirements for an introductory psychology course. Forty-four subjects participated in the phonetic priming condition, and another 44 subjects participated in the phonological priming condition. No subject participated in both conditions, and none of the subjects had participated in Experiment 1. All subjects were native speakers of English and reported no history of speech or hearing disorders.

Stimulus materials. A subset of the stimulus materials used in Experiment 1 was used in Experiment 2. All of the same target words and unrelated prime words were used. However, in either condition, only 40 of the related primes were used. The stimulus materials were organized into two lists. In both lists, the 40 relevant targets were included, but their associated primes were varied such that 20 targets in each list were preceded by related primes. An equal number of subjects were presented with each list. In this manner, we collected data for 40 relevant prime–target pairs, but any given subject received only 20 related priming trials. The 40 targets were selected subject to two constraints: First, we maintained control over the structural variables of target word frequency and neighborhood density. Second, we selected targets that displayed priming effects to a typical degree in Experiment 1, thus avoiding any targets that showed either unusually large or small priming effects.

Procedure. The procedures for Experiment 2 were identical to those for Experiment 1. As before, in one condition of Experiment 2 we used phonetically related prime–target pairs and in the other condition we used phonologically related prime–target pairs.

Results and Discussion

Overall results from Experiment 2 are presented first, then the phonetic and phonological priming conditions are analyzed independently. Comparisons across the conditions, and comparisons to Experiment 1, are presented last.

The procedures for scoring and analysis in Experiment 2 were identical to those described for Experiment 1. Figure 2 displays the results from both conditions of Experiment 2 juxtaposed against subsets of the data from Experiment 1. By comparing the same subsets of stimuli from both experiments, we can assess the effects of changing the proportion of related trials from 50% in Experiment 1 to approximately 10% in Experiment 2. The upper panel shows the results for the relevant subset of targets from the phonetic priming condition of Experiment 1 compared with the results for the same stimuli in Experiment 2. The lower panel shows the results for the relevant subset of targets from the phonological priming condition of Experiment 1 compared with the results for the same stimuli in Experiment 2. Although subjects performed 168 trials in each experiment, only the data for 40 trials per subject per condition per experiment are shown in Figure 2 (i.e., each bar in the figure represents 20 trials × 44 subjects). As before, dark bars show performance for targets preceded by unrelated primes and light bars show performance for targets preceded by related primes.

A two-way ANOVA (Condition × Relatedness) was performed on the mean percentages of correct responses from Experiment 2. A significant main effect of condition was observed, $F_1(1, 86) = 35.46$, $MS_e = 0.0126$; $F_2(1, 76) = 23.58$, $MS_e = 0.0155$. The overall accuracy was higher in the phonological priming condition than in the phonetic priming condition. A significant main effect of relatedness was also observed, $F_1(1, 86) = 6.07$, $MS_e = 0.0083$, $F_2(1, 76) = 7.55$, $MS_e = 0.0155$, reflecting the net phonetic priming effect after subtracting the smaller phonological priming effect. A signif-

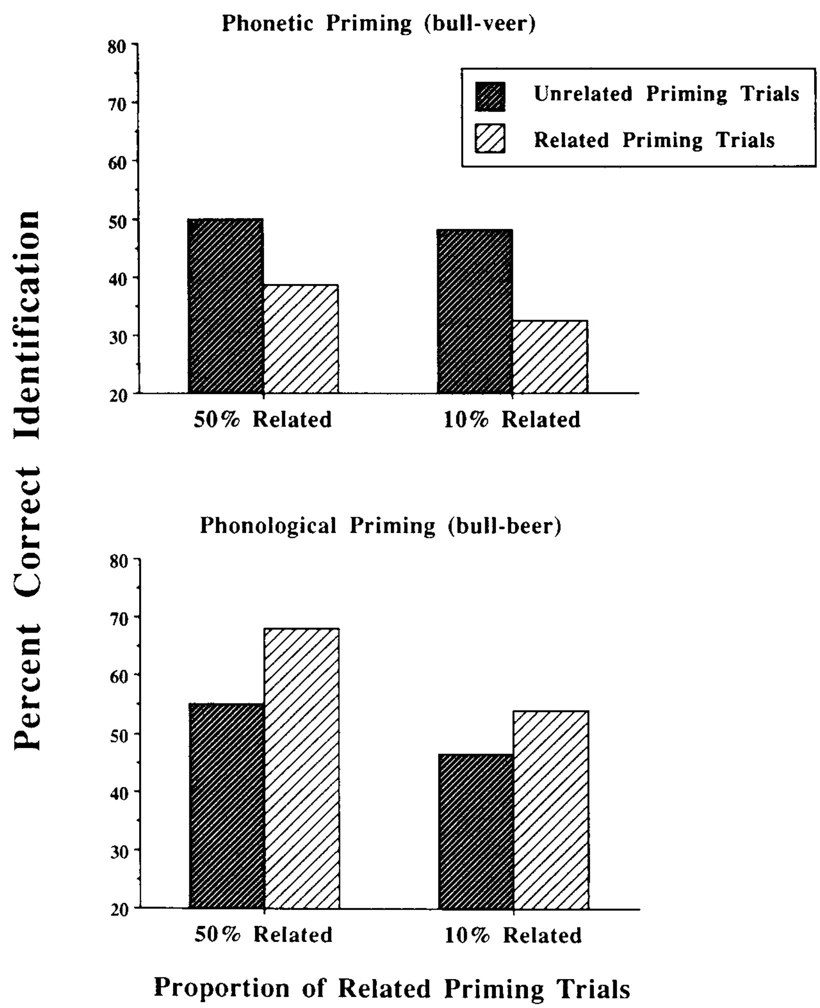

Figure 2. Mean percentages of correct target identification from Experiment 2 (10% Related) juxtaposed against subsets of data from Experiment 1 (50% Related). (The upper panel shows results for a subset of targets from the phonetic priming condition of Experiment 1 compared with results for the same stimuli in Experiment 2. The lower panel shows results for a subset of targets from the phonological priming condition of Experiment 1 compared with results for the same stimuli in Experiment 2.)

icant two-way Condition × Relatedness interaction was also observed, $F_1(1, 86) = 67.78$, $MS_e = 0.0083$, $F_2(1, 76) = 22.63$, $MS_e = 0.0155$, reflecting the opposite directions of priming across conditions.

Phonetic priming. A one-way ANOVA (Relatedness) was performed on the mean percentages of correct responses for the subset of relevant stimuli from the phonetic priming condition of Experiment 2. A significant main effect of relatedness was obtained, $F_1(1, 43) = 47.67$, $MS_e = 0.0020$; $F_2(1, 38) = 18.88$, $MS_e = 0.0433$. Targets preceded by unrelated primes were identified more accurately than targets preceded by phonetically related primes. To compare the results obtained in the phonetic priming condition of Experiment 2 with those obtained with the same stimuli in the phonetic priming condition of Experiment 1, we performed another ANOVA treating the experiments as a between-subjects variable. A significant main effect of experiment was observed, $F_1(1, 86) = 5.75$, $MS_e = 0.0178$; $F_2(1, 76) = 18.10$, $MS_e = 0.0322$, reflecting the overall lower performance in Experiment 2 than in Experiment 1. A significant main effect of relatedness was also observed, $F_1(1, 86) = 44.09$, $MS_e = 0.0112$, $F_2(1, 76) = 29.66$, $MS_e = 0.0322$, reflecting the consistent phonetic priming effect in both experiments. However, the important Experiment × Relatedness interaction was not significant, $F_1(1, 86) = 1.58$, $MS_e = 0.0112$, $p = .2128$, $F_2(1, 76) = 0.98$, $MS_e = 0.0322$, $p = .3258$, indicating that the change in proportion of related trials did not modify the inhibitory priming effect.

Phonological priming. A one-way ANOVA (Relatedness) was performed on the mean percentages of correct responses for the subset of relevant stimuli from the phonological priming condition of Experiment 2. A significant main effect of relatedness was obtained, $F_1(1, 43) = 20.80$, $MS_e = 0.0041$; $F_2(1, 38) = 14.05$, $MS_e = 0.0028$. Targets were identified more accurately when preceded by phonologically related primes than when preceded by unrelated primes. To compare the results obtained in the phonological priming condition of Experiment 2 with those obtained with the same stimuli in the phonological priming condition of Experiment 1, we conducted another ANOVA treating the separate experiments as a between-subjects variable. A significant main effect of experiment was observed, $F_1(1, 86) = 45.80$, $MS_e = 0.0119$, $F_2(1, 76) = 23.73$, $MS_e = 0.0030$, reflecting the overall lower performance in Experiment 2 than in Experiment 1. A significant main effect of relatedness was also observed, $F_1(1, 86) = 38.09$, $MS_e = 0.0019$, $F_2(1, 76) = 19.40$, $MS_e = 0.0030$, reflecting the consistent phonological priming effect observed across experiments. The important Experiment × Relatedness interaction was also significant, $F_1(1, 86) = 13.73$, $MS_e = 0.0019$, $F_2(1, 76) = 9.84$, $MS_e = 0.0030$. When fewer trials in the experiment contained the one-phoneme overlap relation, the priming effect was significantly reduced, although it was not eliminated.

Comparison across conditions. Experiment 2 was predicated on the assumption that decreasing the proportion of related trials would prevent subjects from developing any kinds of biases via learning during the experiment. To assess the validity of the manipulation, we examined the performance on the unrelated trials, as in Experiment 1. In Experiment 2, just as in Experiment 1, the absolute percentages of correct responses on the unrelated trials were remarkably similar across conditions. Accordingly, as before, the analyses we report were conducted on the actual forms of the errors rather than on the percentages. Frequency counts were conducted on the total number of errors on unrelated trials for the subset of 40 targets of interest for each condition (20 relevant unrelated trials per subject) and also on the number of biased responses defined by the criterion described for Experiment 1. In the phonetic priming condition, there were 226 errors committed on the relevant unrelated priming trials, 38 of which fit the criterion of biased responses. In the phonological priming condition, there were 233 errors committed, 57 of which were biased responses. Although this trend resembles that observed in Experiment 1, it was not a reliable difference, $\chi^2(1, N = 88) = 3.64$, $p > .05$. By this (admittedly weak) measure, although the facilitatory phonological priming effect remained reliable in Experiment 2, we cannot conclude that subjects generated their responses strategically.

A final analysis of the errors on unrelated priming trials involved comparison across Experiments 1 and 2. Examining first the phonetic priming conditions, in Experiment 1, we found a total of 161 errors were committed on the relevant subset of unrelated trials, 34 of which were biased responses. As mentioned earlier, in the phonetic priming condition of Experiment 2, the number of biased responses was 38 of 226 errors. By this measure, no difference was detected between the phonetic priming conditions of Experiments 1 and 2, $\chi^2(1, N = 176) = 0.88$, $p > .05$. In contrast, in the phonological priming condition of Experiment 1, 107 errors were committed on the relevant subset of trials, 49 of which were biased responses. In the phonological priming condition of Experiment 2, the number of biased responses was 57 of 233 errors. By this measure, bias in the phonological priming condition was significantly reduced by the diminished proportion of related trials, $\chi^2(1, N = 176) = 15.53$, $p < .01$, providing an indication that the manipulation was successful.

The results and implications of Experiments 1 and 2 can be easily summarized: In Experiment 1, by comparing the responses given by subjects to the same unrelated prime–target pairs in different priming contexts, we obtained preliminary data suggesting that subjects in the phonological priming task adopt some form of strategy. This preliminary evidence was bolstered by the results of Experiment 2, in which the phonological priming effect was attenuated by reducing the proportion of related priming trials. In contrast, the inhibitory phonetic priming effect was not changed by reducing the relatedness proportion. The patterns of results observed across both experiments suggest that the facilitatory phonological priming effect reported by Slowiaczek et al. (1987) was due to more than simple residual activation among words in memory; a bias was apparently operative as well.

Questions remain, however, concerning the nature of phonological priming. We have obtained evidence that in perceptual identification, facilitatory phonological priming involves bias. However, we can neither conclude that the effect is purely a product of bias nor assess the nature of the bias. Comparison of the phonological priming conditions of Experiments 1 and 2 shows that an apparent elimination of bias reduces, but does not eliminate, the phonological priming effect. It is unknown whether the residual phonological priming effect was due to a bias that our measure could not detect or whether it was a "true" priming effect that was merely exaggerated by bias in Experiment 1. With regard to the nature of the bias, the perceptual identification paradigm alone cannot unambiguously inform us about the kind of bias or biases involved. As Slowiaczek and Pisoni (1986) pointed out, the perceptual identification task involves an open response set and no response time constraints, so subjects' performance may benefit from strategic, postaccess processing. As such, it is possible that the phonological priming effect or, indeed, both of the form-based priming effects discussed thus far are specific to the perceptual identification paradigm. In the next three experiments, we sought to assess the generality of the priming effects and to further explore the role of bias in phonological priming. Toward this end, we used an approach that was similar to that of the prior experiments, but we adopted the lexical decision methodology.

Experiment 3

Slowiaczek and Pisoni (1986) discussed three aspects of the perceptual identification methodology that could make it more sensitive to a priming manipulation than the lexical decision methodology, including the open response set, the freedom from time constraints, and the use of degraded stimuli. By switching from perceptual identification to lexical decision, we reduce the response set from the entire lexicon to two categories, and we introduce time constraints. However, in "typical" primed lexical decision experiments, such as those conducted by Slowiaczek and Pisoni (1986) and by Radeau et al. (1989), both primes and targets are presented in the clear. As such, these studies preclude systematic investigation of the roles of task characteristics and stimulus characteristics in the perceptual identification task. To rectify this oversight, we conducted a lexical decision experiment that manipulated stimulus degradation. In two conditions, all items were presented in the clear; in another two conditions, primes were presented in the clear and targets were presented in white noise.

Investigation of primed lexical decision to targets in noise is important for reasons other than satisfying our compulsion for systematicity. Our approach in this investigation of form-based priming has been to juxtapose the phonetic and phonological priming effects. When both the facilitatory and inhibitory priming effects are obtained, we compare performance on the unrelated trials of the respective conditions. Thus far, we have no reason to believe that either priming effect should occur when nondegraded targets are used; only null results have been obtained in phonological priming, and phonetic priming has not been investigated. We assume that the observation of priming effects is dependent on perceptual similarity between primes and targets. Recall that the primes and targets selected to study phonetic priming were words that contained segments that were empirically determined to be confusable, but only in noise. It is plausible that obtaining high perceptual similarity between these words, and therefore phonetic priming, is dependent on stimulus degradation.

In Experiment 3, we used priming relations similar to those used in the perceptual identification experiments. As before, we included phonetic and phonological priming conditions. Half of the conditions were conducted with all stimuli presented in the clear; half were conducted with targets presented in noise. In every condition, half of the targets were real words and half were nonwords. Also, half of the trials in each condition for each kind of target were related priming trials, and half were unrelated priming trials. All conditions used a primed lexical decision task, all primes were real words, and the primes and targets were separated by a 50-ms ISI.

Two possible outcomes of this experiment seemed most likely and are considered in turn: First, it was possible that no priming effects would be observed either with the targets in the clear (as reported earlier) or in noise. In this case, we would conclude that form-based priming effects are specific to the perceptual identification task and that they may not reflect general properties of spoken word recognition. The other possible result was that no priming effects would be observed with targets presented in the clear but that the effects would be observed with targets presented in noise. In this case, we would be in a position to assess the role of bias in phonological priming, as described earlier.

Method

Subjects. One hundred thirty-six Indiana University undergraduate students participated in Experiment 3 in partial fulfillment of the requirements for an introductory psychology course. Thirty-four students participated in each of four conditions: (a) phonetic priming, no noise; (b) phonological priming, no noise; (c) phonetic priming, noise; and (d) phonological priming, noise. No subject participated in more than one condition, and none had participated in either of the earlier experiments. All subjects were native speakers of English and reported no history of speech or hearing disorders.

Stimulus materials. The stimulus materials described in this section were used in all of the lexical decision experiments reported in the remainder of this article. Of the original 168 sets of stimulus groups (targets and their three associated primes) used in the perceptual identification experiments, 100 were used in the lexical decision experiments. In addition to the words selected earlier, 100 nonwords were generated. All nonwords were phonotactically legal, monosyllabic CVCs (consonant–vowel–consonant trigrams) and were recorded and prepared for presentation following the procedures described earlier (see *Stimulus materials,* Experiment 1). As in the perceptual identification experiments, each real-word and nonword target was paired with several real-word primes. Each target had a corresponding unrelated prime, a phonetically similar prime, and a phonologically related prime. These relations between primes and targets were maintained for both the real-word and nonword targets (see Table 1).

Because every target item had two corresponding primes (within any condition) and no subject was to be presented the same target item twice, the stimuli were divided into two lists. In each condition, every subject responded to all 200 targets, but the related and unrelated primes varied across groups of subjects. For a given group, 100 targets were preceded by related primes, and 100 targets were preceded by unrelated primes. For the next group, the specific pairings of primes and targets were reversed. An equal number of subjects were presented with each list. In this manner, all subjects were presented all targets, but the primes associated with those targets varied across groups.

Procedure. Subjects were tested in groups of 6 or fewer in a sound-attenuated room used for speech perception experiments. Each subject was seated in an individual booth equipped with a pair of matched and calibrated TDH-39 headphones and a two-button response box connected to a PDP 11/34 computer. Underneath each button on the response box, either a WORD or NONWORD label was situated. For all groups of subjects, the WORD response corresponded to the right-hand side of the response box, and the NONWORD response corresponded to the left-hand side of the response box. In addition to the two response buttons, a cue light was situated at the top of the response box to alert subjects when a trial was beginning. Subjects were instructed that they would hear brief English words followed by either a second English word or a nonword (examples provided were CAT versus GOIP). They were instructed to listen to each stimulus pair carefully and indicate whether the second item was a word or a nonword by pressing the appropriate button. The instructions stressed both speed and accuracy of responding.

Each trial of the experiment began with an illumination of the cue light at the top of the response box. The cue light remained on for 1 s to indicate that a stimulus pair was about to be presented over the headphones. Five hundred milliseconds after the offset of the cue light, a randomly selected prime was presented at 75 dB (SPL). Fifty milliseconds later, a word or nonword target was also presented at 75 dB (SPL) either in the clear or in 70 dB (SPL) of white noise, and the computer waited for all subjects to respond. Reaction times for each subject were recorded from the onset of the spoken target until the response was executed. After all subjects responded, a 500-ms intertrial interval elapsed, and then a new trial began. If 5 s elapsed on any given trial before all responses were collected, the computer recorded incorrect responses for the remaining subjects and began a new trial. The 200 experimental trials were preceded by 15 practice trials that were not included in the final data analysis. The practice list contained words and nonwords that were not drawn from any experimental condition.

Results and Discussion

Results are discussed first for the latency data, then for the accuracy data. Mean latencies of correct responses were calculated for each subject and for each item. Latencies shorter than 200 ms or longer than 1500 ms were excluded from calculations of means. The mean latencies for correct responses in all conditions are shown in Figure 3. The two left panels of Figure 3 display results from the phonetic priming conditions; the right panels display results from the phonological priming conditions. The upper panels display results from conditions that presented targets in the clear; the lower panels display results from conditions that presented targets in noise.

The latency data were first analyzed in a four-way ANOVA examining noise condition (clear vs. noise), type of priming (phonetic vs. phonological), target class (word vs. nonword),

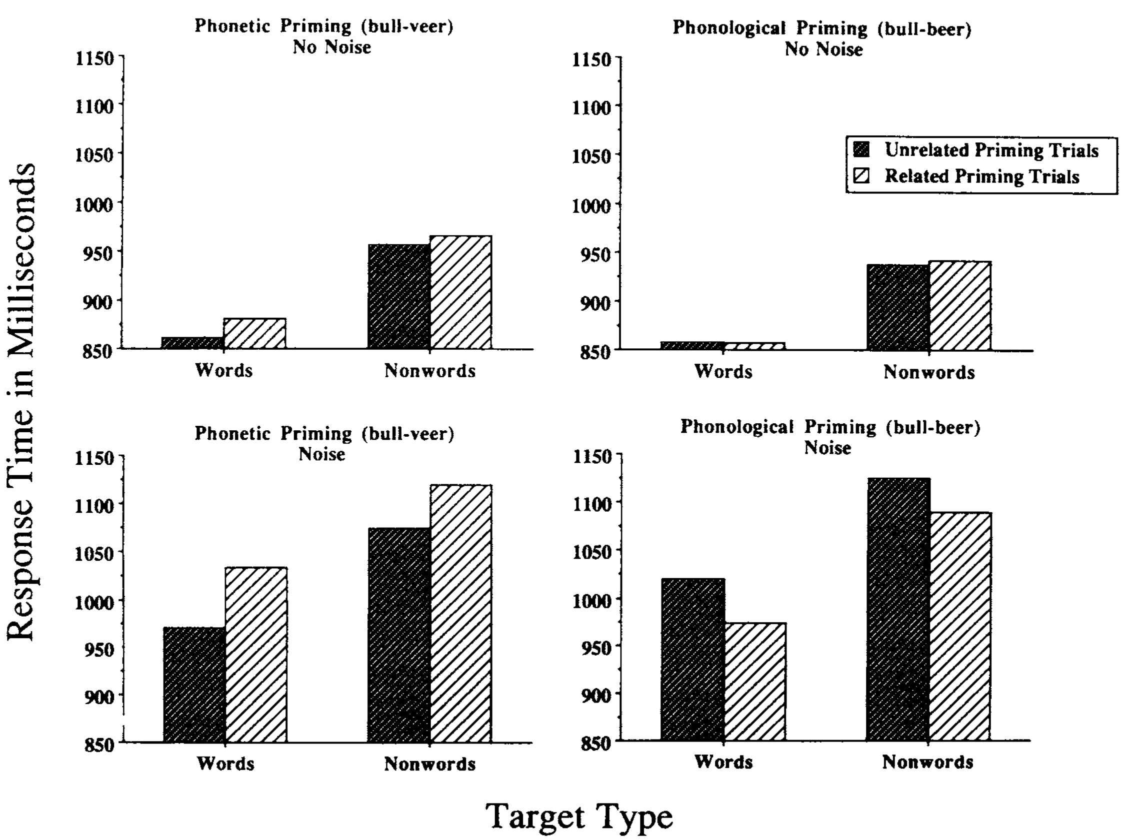

Figure 3. Mean latencies of correct responses in Experiment 3. (The left panels display results of phonetic priming; the right panels display results of phonological priming. The upper panels display results for targets presented in noise; the lower panels display results for targets presented in the clear.)

and relatedness (related vs. unrelated). A main effect of noise condition was observed, $F_1(1, 132) = 28.18$, $MS_e = 79{,}243.66$, $F_2(1, 784) = 622.04$, $MS_e = 3{,}092.96$, reflecting the faster responses to targets presented in the clear than to targets presented in noise. A main effect was also observed for target class, $F_1(1, 132) = 133.00$, $MS_e = 9{,}274.71$, $F_2(1, 784) = 449.07$, $MS_e = 3{,}092.96$, reflecting the faster responses to words than nonwords in all conditions. In addition to these main effects, two key interactions were observed. First, a significant two-way Type of Priming × Relatedness interaction was observed, $F_1(1, 132) = 18.27$, $MS_e = 4{,}815.93$, $F_2(1, 784) = 12.45$, $MS_e = 3{,}092.96$. This interaction reflects the opposite directions of priming in the phonetic and phonological priming conditions. Most important, a significant three-way Noise Condition × Type of Priming × Relatedness interaction was observed, $F_1(1, 86) = 12.66$, $MS_e = 4{,}815.93$, $F_2(1, 784) = 7.27$, $MS_e = 3{,}092.96$, showing that the disparate effects of phonetic and phonological priming were observed only when targets were presented in noise.

After the overall ANOVA was conducted, the specific effects of priming in all conditions were examined via post hoc analyses.[8] Tukey's honestly significant difference (HSD) analyses were conducted to compare latencies in related and unrelated priming trials. Significant effects of priming were observed in all conditions involving noise (lower panels of Figure 3). Significant facilitation was observed in phonological priming; significant inhibition was observed in phonetic priming. No significant effects of priming were observed in any conditions that presented targets in the clear.

Next, we discuss the accuracy data from Experiment 3. The mean error rates from all conditions are shown in Figure 4. The left panels display results from the phonetic priming conditions; the right panels display results from the phonological priming conditions. The upper panels display results from conditions that presented targets in the clear; the lower panels display results from conditions that presented targets in noise.

A four-way ANOVA (Noise Condition × Type of Priming × Target Class × Relatedness) was conducted on the mean error rates. A main effect of noise condition was observed, $F_1(1, 132) = 226.85$, $MS_e = 157.63$, $F_2(1, 784) = 219.50$, $MS_e = 230.66$, reflecting the more accurate responses to targets presented in the clear than to targets presented in noise. A main effect of type of priming was observed, $F_1(1, 132) = 4.03$, $MS_e = 157.63$, $F_2(1, 784) = 18.22$, $MS_e = 230.66$, reflecting the finding that subjects in the phonetic priming conditions responded more accurately in general than subjects in the phonological priming conditions. A main effect of relatedness was also observed, $F_1(1, 132) = 11.21$, $MS_e = 30.28$, $F_2(1, 784) = 4.41$, $MS_e = 230.66$, showing that responses on related priming trials were generally more accurate than responses on unrelated priming trials. In addition to the main effects, a significant two-way Noise Condition × Type of Priming interaction was observed, $F_1(1, 132) = 6.52$, $MS_e = 157.63$, $F_2(1, 784) = 4.53$, $MS_e = 230.66$, reflecting the finding that noise decreased accuracy more in the phonological priming/noise condition than in the phonetic priming/noise condition.

After the ANOVA was conducted, effects of priming were examined in closer detail. Tukey's HSD analyses revealed significant priming only in the phonological priming/noise condition. In this condition, significant facilitatory effects of priming were observed for both words and nonwords.

The major results of Experiment 3 are easily summarized: In the latency data, when all stimuli were presented in the clear, as in the earlier Slowiaczek and Pisoni (1986) and Radeau et al. (1989) experiments, no reliable effects of form-based priming were observed. Neither the inhibitory phonetic priming effect nor the facilitatory phonological priming effect was present.[9] However, when the targets were presented in white noise, as in the perceptual identification experiments, both form-based priming effects were reinstated. In the accuracy data, however, the only significant priming effect we observed was a facilitatory phonological priming effect found when targets were presented in noise.

Because reliable inhibitory and facilitatory priming effects were observed when targets were presented in noise, our next step involved an assessment of the role of bias in phonological priming. Recall that one index of biased processing in a priming experiment is the "cost" associated with unrelated trials presented in a biasing context. Figure 5 displays the results for all of the unrelated priming trials of Experiment 3. The data from the no-noise conditions are shown in the upper panel; the data from the noise conditions are shown in the lower panel. Data from the phonetic priming conditions are shown on the left side of each panel; data from the phonological priming conditions are shown on the right.

As Figure 5 shows, when targets were presented in the clear and no effects of priming were observed, the respective response latencies for words and nonwords were equivalent across the phonetic and phonological priming conditions. However, when targets were presented in noise and both priming effects were reinstated, the response latencies on unrelated priming trials to classify both words and nonwords

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[8] In the interest of brevity, we report in detail only the most relevant analyses concerning priming effects. In all conditions of all of the lexical decision experiments conducted, words were responded to more quickly than nonwords, and noise created slower and less accurate responses. Accordingly, we report these findings only in the overall ANOVAs. Also, although all comparisons reported were fully planned before the experiments were conducted, we assessed the critical effects of priming with conservative post hoc analyses. All null results from the post hoc analyses were also null results by more powerful planned comparisons.

[9] Examination of Figure 3 shows that, although the effect was not reliable, there was a consistent trend toward an inhibitory phonetic priming effect even when targets were presented in the clear. As described earlier, the similarity between phonetic primes and targets was estimated by reference to confusion matrices for individual consonants and vowels presented in noise. Thus one would expect the perceptual similarity between primes and targets to be reduced when the signals are not degraded by noise. An analysis was performed on the data from the phonetic priming/no-noise condition in which the estimates of similarity between each prime–target pair were correlated with the magnitudes of their respective inhibitory priming effects. The resultant correlation was positive and significant: $r = .6881$; $F(1, 198) = 109.03$, $p < .01$. This finding indicates that the phonetic priming effect is not necessarily dependent on the use of noise per se but is merely dependent on perceptual similarity between primes and targets.

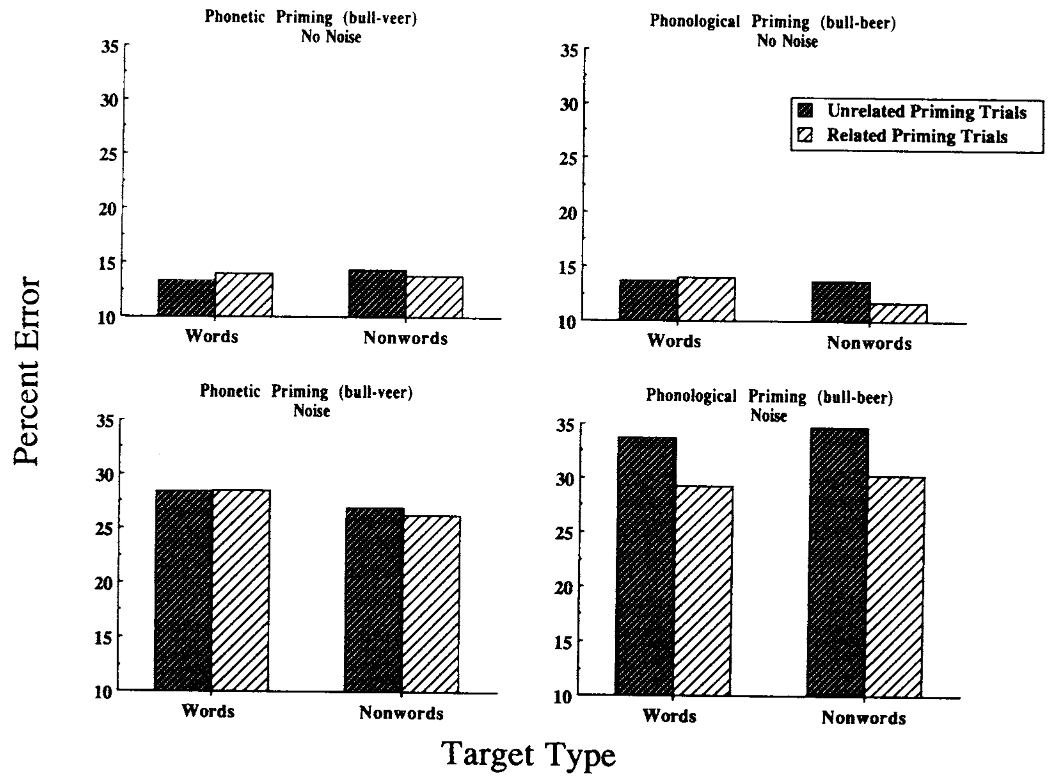

Figure 4. Mean error rates in Experiment 3. (The left panels display results of phonetic priming; the right panels display results of phonological priming. The upper panels display results for targets presented in noise; the lower panels display results for targets presented in the clear.)

were slower in the phonological priming conditions than in the phonetic priming conditions. A three-way ANOVA (Noise Condition × Target Class × Type of Priming) was conducted on the latency data of the unrelated trials. As expected, a significant main effect of noise condition was observed, $F_1(1, 132) = 25.43$, $MS_e = 44{,}622.82$, $F_2(1, 392) = 314.19$, $MS_e = 2{,}947.04$, reflecting the general slowing of responses to targets presented in noise. In addition, the expected main effect of target class was observed, $F_1(1, 132) = 68.87$, $MS_e = 9{,}846.16$, $F_2(1, 392) = 245.42$, $MS_e = 2{,}947.04$, showing that words were correctly classified faster than nonwords. Most important, a significant Noise Condition × Type of Priming interaction was observed, $F_1(1, 132) = 4.02$, $MS_e = 44{,}622.82$, $F_2(1, 392) = 32.77$, $MS_e = 2{,}947.04$, reflecting the slowing of responses in the phonological priming condition, relative to the phonetic priming condition, when targets were presented in noise.

The accuracy data for the unrelated trials mirrored the latency data shown in Figure 5. When targets were presented in the clear, responses on unrelated priming trials were equivalent across the phonetic and phonological priming conditions. When targets were presented in noise, however, responses on unrelated priming trials were less accurate in the phonological priming condition than in the phonetic priming condition. A three-way ANOVA (Noise Condition × Target Class × Type of Priming) was conducted on the accuracy data of the unrelated trials. A significant main effect of noise condition was observed, $F_1(1, 132) = 257.91$, $MS_e = 80.14$, $F_2(1, 392) = 100.09$, $MS_e = 259.93$, reflecting the reduction in accuracy of classifying targets presented in noise. In addition, a main effect of type of priming was observed, $F_1(1, 132) = 11.46$, $MS_e = 80.14$, $F_2(1, 392) = 11.75$, $MS_e = 259.93$, reflecting the generally higher accuracy found in the phonetic priming conditions. Most important, a significant Noise Condition × Type of Priming interaction was observed, $F_1(1, 132) = 12.31$, $MS_e = 80.14$, $F_2(1, 392) = 5.61$, $MS_e = 259.93$, reflecting the reduction of accuracy in the phonological priming condition, relative to the phonetic priming condition, when targets were presented in noise. In sum, subjects in the phonological priming condition were reliably slower and less accurate on the unrelated priming trials than subjects in the phonetic priming condition despite the use of identical stimuli in both conditions. It is clear that the facilitatory phonological priming effect entailed a "cost" for the unrelated priming trials, which implies the use of a bias (see Neely, 1991; Posner & Snyder, 1975a, 1975b).

Experiment 4

Experiment 3 revealed that reliable form-based priming effects can be observed using the lexical decision task. Apparently, stimulus characteristics are more important than task characteristics in producing the effects. We have observed reliable priming effects with the lexical decision task and have obtained evidence that the phonological priming effect entails a bias. Given the apparent qualitative differences between the facilitatory phonological and the inhibitory phonetic priming

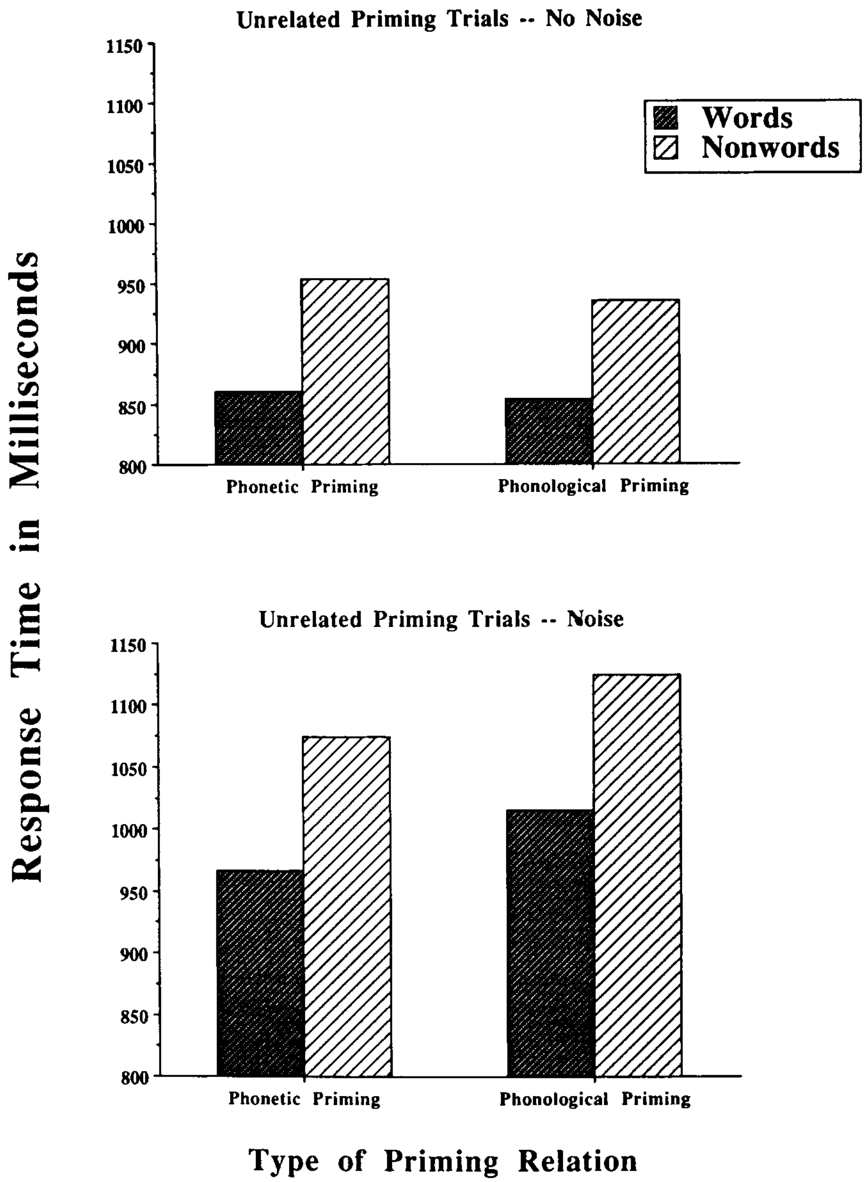

Figure 5. Mean latencies of correct responses on unrelated priming trials in Experiment 3. (The no-noise conditions are shown in the upper panel; the noise conditions are shown in the lower panel. The phonetic priming conditions are shown on the left side of each panel; the phonological priming conditions are shown on the right.)

effects, another important avenue of investigation involves the time course of the respective priming effects. In our earlier investigation of phonetic priming, Goldinger et al. (1989) found that the inhibitory priming effects observed when a short, 50-ms ISI was used were not found when a longer, 500-ms ISI was used. Goldinger et al. argued that if the phonetic priming effect were due to an ineffectual guessing strategy, changing the ISI by 450 ms would not be expected to modify the effect. The pattern of results was taken as evidence that the phonetic priming effect is due to transient competition among similar-sounding words in memory.

If we apply the reasoning used by Goldinger et al. (1989), we can derive another prediction regarding the differences between phonetic and phonological priming. Specifically, if the facilitatory phonological priming effect is the product of a bias, we should predict that the facilitatory effect will remain over a longer ISI than the 50-ms ISI used in our previous experiments. In contrast, the phonetic priming effect should not be observed in experiments using an ISI much longer than 50 ms.

In Experiment 4, we again used presentation of targets in noise, but with two longer ISIs.[10] As in Experiment 3, both

[10] Although we did not observe reliable priming effects in any of the earlier conditions that presented targets in the clear, we could not

phonetic and phonological priming conditions were included in Experiment 4. Both kinds of priming conditions were tested twice, once with a 500-ms ISI and once with a 1,500-ms ISI.

Method

Subjects. One hundred twenty Indiana University undergraduate students participated in Experiment 4 in partial fulfillment of requirements for an introductory psychology course. Thirty subjects participated in each of four conditions: (a) phonetic priming, 500-ms ISI; (b) phonetic priming, 1,500-ms ISI; (c) phonological priming, 500-ms ISI; and (d) phonological priming, 1,500-ms ISI. No subject participated in more than one condition, and none had participated in any of the earlier experiments. All subjects were native speakers of English and reported no history of speech or hearing disorders.

Stimulus materials and procedure. All stimulus materials and experimental procedures in Experiment 4 were the same as those in Experiment 3 except for procedural changes involving the use of noise and the ISI. Only noise conditions were examined in Experiment 4. Also, in two conditions of Experiment 4, a 500-ms ISI separated primes and targets; in the other two conditions, a 1,500-ms ISI separated primes and targets.

Results and Discussion

Results are discussed first for the latency data of Experiment 4, then for the accuracy data. Calculations of means followed procedures described in the discussion of results of Experiment 3. The mean latencies for correct responses in all experimental conditions are shown in Figure 6. The two left panels display results from the phonetic priming conditions; the right panels display results from the phonological priming conditions. The upper panels display results from conditions that used a 500-ms ISI; the lower panels display results from conditions that used a 1,500-ms ISI.

A four-way ANOVA (ISI × Type of Priming × Target Class × Relatedness) was conducted on the mean latencies of correct responses. A main effect of ISI was observed, $F_1(1, 116) = 7.78$, $MS_e = 55{,}263.01$, $F_2(1, 784) = 7.07$, $MS_e = 6{,}155.06$, reflecting the finding that responses were generally faster in conditions with the 500-ms ISI. A main effect was also observed for target class, $F_1(1, 116) = 219.10$, $MS_e = 8{,}834.55$, $F_2(1, 784) = 322.44$, $MS_e = 6{,}155.06$, reflecting the faster responses to words than nonwords in all conditions. Finally, a significant main effect of relatedness was also observed, $F_1(1, 116) = 14.72$, $MS_e = 4{,}615.85$, $F_2(1, 784) = 20.90$, $MS_e = 6{,}155.06$, reflecting the predominant effect of facilitatory phonological priming. In addition to the main effects, a significant two-way Type of Priming × Relatedness interaction was observed, $F_1(1, 116) = 33.82$, $MS_e = 4{,}615.85$, $F_2(1, 784) = 41.67$, $MS_e = 6{,}155.06$, reflecting the consistent priming effect found in phonological priming but not in phonetic priming.

As in Experiment 3, after the overall ANOVA was conducted, the effects of priming were examined in closer detail. Tukey's HSD analyses were conducted to compare latencies on related and unrelated priming trials. Significant effects of priming were observed in both phonological priming conditions (right-hand panels of Figure 6). Significant facilitation was observed with both the 500-ms and the 1,500-ms ISIs. No significant effects of priming were observed in the phonetic priming conditions.

Next, we discuss the accuracy data from Experiment 4. The mean error rates from all four conditions are shown in Figure 7. The left panels display results from the phonetic priming conditions; the right panels display results from the phonological priming conditions. The upper panels display results from conditions that used a 500-ms ISI; the lower panels display results from conditions that used a 1,500-ms ISI.

A four-way ANOVA (ISI × Type of Priming × Target Class × Relatedness) was conducted on the mean error rates. A main effect of ISI was observed, $F_1(1, 116) = 6.65$, $MS_e = 122.75$, $F_2(1, 784) = 9.40$, $MS_e = 180.33$, reflecting the higher accuracy in the 500-ms ISI conditions. Another main effect of type of priming was observed, $F_1(1, 116) = 4.90$, $MS_e = 122.75$, $F_2(1, 784) = 4.12$, $MS_e = 180.33$, reflecting the finding that subjects in the phonological priming conditions responded more accurately than subjects in the phonetic priming conditions. In addition to the main effects, a significant two-way Type of Priming × Relatedness interaction was observed, $F_1(1, 116) = 15.62$, $MS_e = 122.75$, $F_2(1, 784) = 14.03$, $MS_e = 180.33$. This interaction reflects the finding that priming effects were only consistently observed in the phonological priming conditions.

After the ANOVA was conducted, the specific effects of priming were assessed. Tukey's HSD analyses revealed a significant inhibitory priming effect for the nonwords in the phonetic priming/1,500-ms ISI condition, and significant facilitatory priming effects in all four phonological priming conditions. No other significant effects of priming were observed.

To summarize the results of Experiment 4, although the ISI was increased from 50 to 500 ms, and then again to 1,500 ms, reliable facilitatory effects of phonological priming were still observed in both response latency and accuracy of lexical decisions. These results are in marked contrast to the data obtained in the complementary phonetic priming conditions. As Goldinger et al. (1989) reported previously, no evidence of inhibitory phonetic priming was observed with an ISI of 500 ms. Similarly, no phonetic priming effect was observed with a 1,500-ms ISI. The phonetic and phonological priming effects are apparently dissociated not only by the bias detected in Experiments 1, 2, and 3 but also by their respective time courses. The most parsimonious account of this new result is to refer to the bias detected earlier: Phonological priming remains robust over long ISIs, whereas phonetic priming is eliminated. The data suggest that phonological priming is due to biases that are maintained throughout the experiment, whereas phonetic priming is due to transient competition that occurs only within trials.

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assume a priori that no effects would be observed when a longer ISI was used. The manipulation of the ISI could, conceivably, alter the way subjects approach the task and could change the pattern of results. In the interest of being thorough, we conducted an experiment including phonetic and phonological priming conditions, each using a 500-ms ISI and presentation of targets in the clear. The conditions included 32 and 30 subjects, respectively. As expected, no reliable priming effects were observed in either condition. From this point on, we conducted only experiments that included presentation of targets in noise.

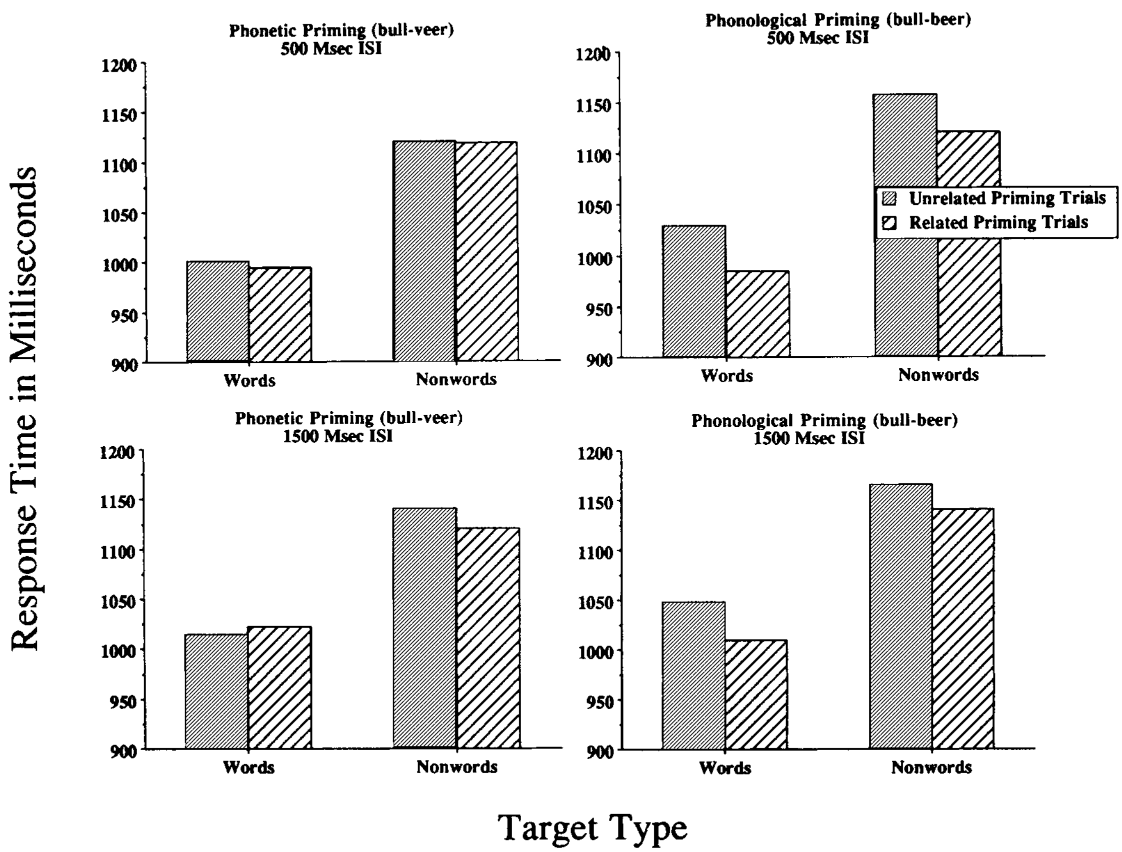

Figure 6. Mean latencies for correct responses in Experiment 4 (ISI = interstimulus interval). (The left panels display results of phonetic priming; the right panels display results of phonological priming. The upper panels display results for the 500-ms ISI; the lower panels display results for the 1500-ms ISI.)

Experiment 5

As in the earlier experiments, Experiment 4 suggests that the phonological and phonetic priming effects do not reflect differing properties of a unitary model of spoken word recognition. Instead, the effects appear to be qualitatively different from each other. In Experiment 2, we attempted to eliminate the bias component of the phonological priming effect by reducing the proportion of related priming trials. In the perceptual identification task, this manipulation reduced, but did not eliminate, the phonological priming effect. In Experiment 5, we attempted once again to eliminate the bias component of the phonological priming effect by applying the relatedness proportion manipulation in the lexical decision paradigm.

The predictions for Experiment 5 were straightforward because we assumed that the relatedness proportion manipulation succeeds in eliminating bias in phonological priming. In Experiment 2, we found that phonetic priming was unaffected by reducing the proportion of related priming trials. Accordingly, we predicted that the manipulation would not affect phonetic priming in Experiment 5. However, we still predicted that, as before, increasing the ISI would eliminate the phonetic priming effect. Predictions for the phonological priming effect were more difficult because of the residual effects of priming observed in Experiment 2 despite the reduction of related priming trials. If the phonological priming effect is completely due to bias, and if the manipulation is indeed successful in eliminating bias, we would expect the phonological priming effect to be eliminated at both levels of the ISI.

Like all of our earlier experiments, Experiment 5 juxtaposed phonetic and phonological priming conditions. We also manipulated the ISI between primes and targets. In two conditions, a 50-ms ISI was used; in the other two conditions, a 500-ms ISI was used. In all four conditions, the proportion of related priming trials was reduced to 10% of all trials, in contrast to the 50% proportions used earlier.

Method

Subjects. One hundred sixty Indiana University undergraduate students participated in Experiment 5 in partial fulfillment of requirements for an introductory psychology course. Forty students participated in each of four conditions: (a) phonetic priming, 50-ms ISI; (b) phonetic priming, 500-ms ISI; (c) phonological priming, 50-ms ISI;

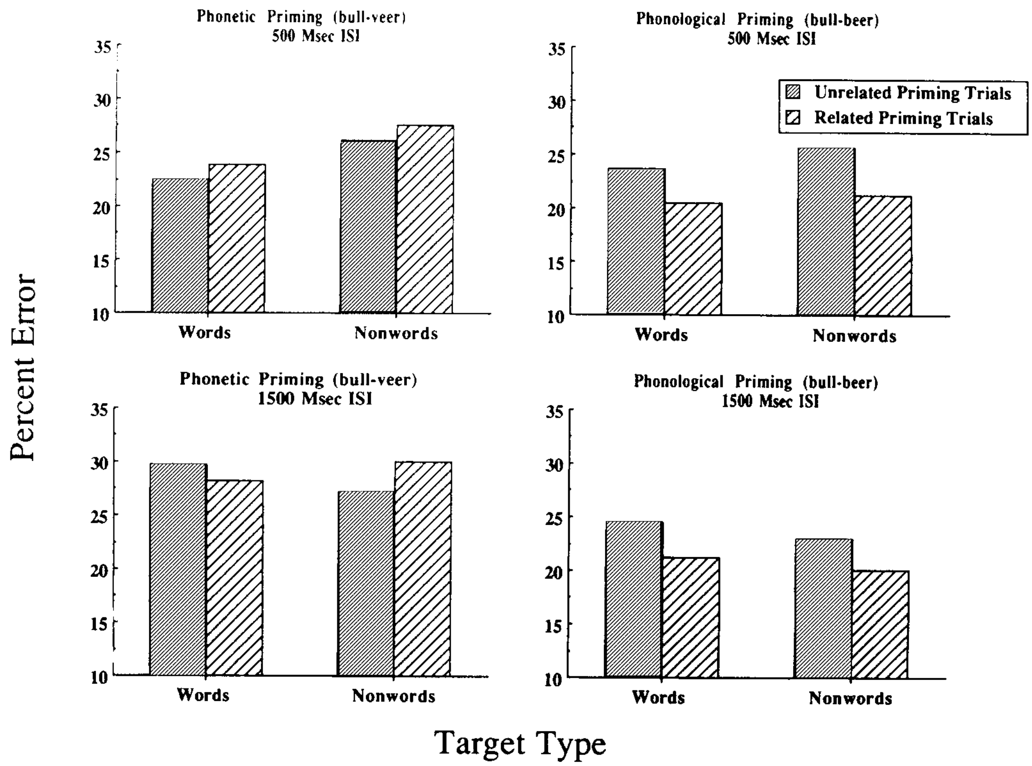

Figure 7. Mean error rates in Experiment 4 (ISI = interstimulus interval). (The left panels display results of phonetic priming; the right panels display results of phonological priming. The upper panels display results for the 500-ms ISI; the lower panels display results for the 1500-ms ISI.)

and (d) phonological priming, 500-ms ISI. No subject participated in more than one condition, and none had participated in any of the earlier experiments. All subjects were native speakers of English and reported no history of speech or hearing disorders.

Stimulus materials and procedure. All stimulus materials and experimental procedures used in Experiment 5 were the same as those used in Experiment 4 except for the relatedness proportions and procedural changes involving the ISI. As before, all subjects performed 200 primed lexical decision trials. Half of the related and unrelated trials presented word targets and half presented nonword targets. However, whereas the earlier experiments used 100 related priming trials and 100 unrelated priming trials, Experiment 5 used 20 related priming trials and 180 unrelated priming trials. Of the 20 related trials, 10 involved word targets and 10 involved nonword targets. Forty targets were selected to constitute the relevant trials in Experiment 5: Half of the 40 targets were presented in related priming pairs for one group of subjects; the other half of the 40 targets were presented in related pairs for the next group. As in Experiment 2, the prime–target pairs selected for the relevant subset were those that displayed typical phonetic and phonological priming effects in the earlier experiments. No targets that displayed unusually large or small priming effects were selected for the relevant subset. In two conditions of Experiment 5, a 50-ms ISI separated primes and targets; in the other two conditions, a 500-ms ISI separated primes and targets.

Results and Discussion

Results are discussed first for the latency data of Experiment 5, then for the accuracy data. Mean latencies of correct responses were calculated for each subject and for each item with the procedures used in Experiments 3 and 4. However, data from only the relevant 40 targets were used to calculate means for the analyses. The mean latencies for correct responses from all conditions are shown in Figure 8. The two left panels display results from the phonetic priming conditions; the right panels display results from the phonological priming conditions. The upper panels display results from conditions that included a 50-ms ISI; the lower panels display results from conditions that included a 500-ms ISI.

As in the earlier experiments, the mean latencies of correct responses were first analyzed in a four-way ANOVA (ISI × Type of Priming × Target Class × Relatedness). A main effect of ISI was observed, $F_1(1, 156) = 44.48$, $MS_e = 71{,}503.30$, $F_2(1, 144) = 92.31$, $MS_e = 8{,}805.65$, reflecting the faster responses in the 50-ms ISI conditions than in the 500-ms ISI conditions. A main effect was also observed for target class, $F_1(1, 156) = 94.09$, $MS_e = 7{,}480.59$, $F_2(1, 144) = 112.01$, $MS_e = 8{,}805.65$, reflecting the faster responses to words than nonwords in all conditions. Moreover, a significant main effect of relatedness was obtained, $F_1(1, 156) = 22.88$, $MS_e = 5{,}591.21$, $F_2(1, 144) = 19.82$, $MS_e = 8{,}805.65$, reflecting the general inhibitory effect of priming shown in Figure 8.

In addition to the main effects, one key significant interaction and one key nonsignificant interaction were observed. First, a significant two-way ISI × Relatedness interaction was observed, $F_1(1, 156) = 6.95$, $MS_e = 5{,}591.21$, $F_2(1, 144) =$

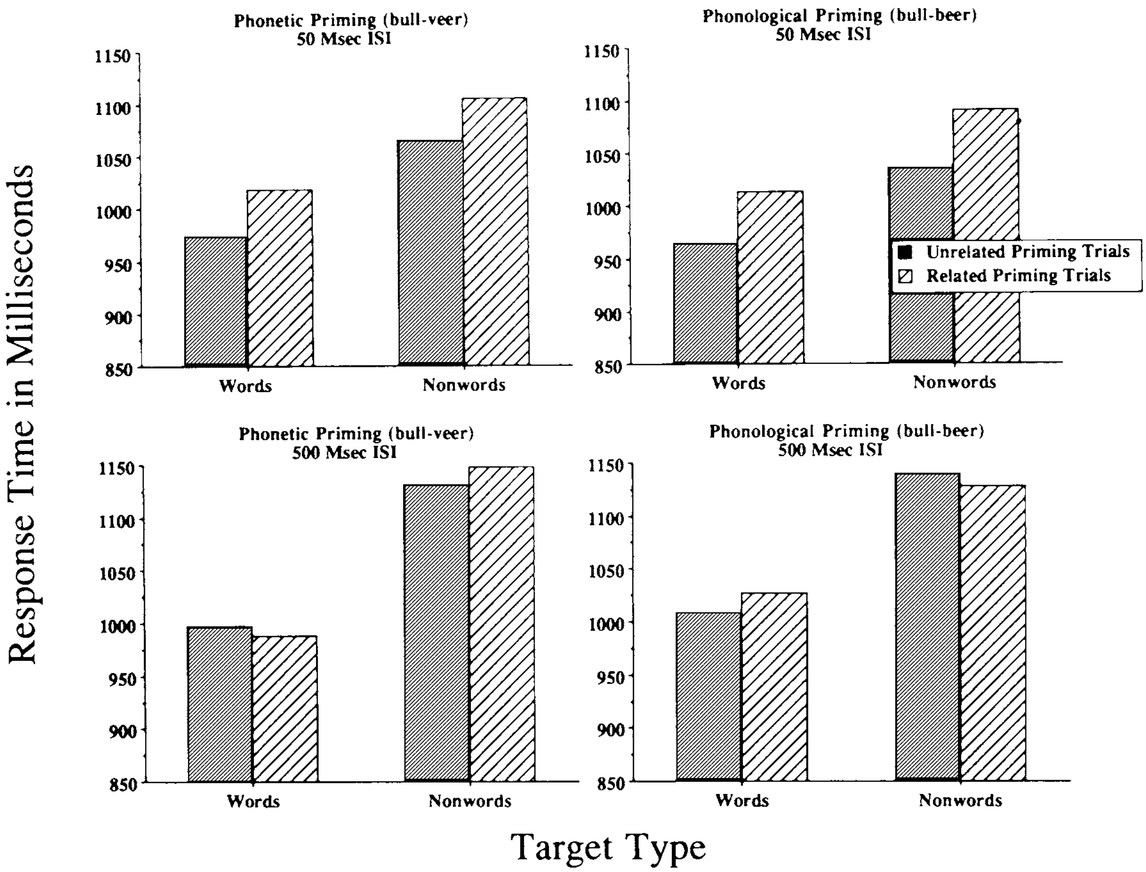

Figure 8. Mean latencies for correct responses in Experiment 5 (ISI = interstimulus interval). (The left panels display results of phonetic priming; the right panels display results of phonological priming. The upper panels display results for the 50-ms ISI; the lower panels display results for the 500-ms ISI.)

6.60, MS_e = 8,805.65, reflecting the finding that priming effects were present only in the conditions with the 50-ms ISI. Second, the critical two-way Type of Priming × Relatedness interaction was not significant. This null effect reflects the finding that the priming effects were in the same direction in both the phonetic and the phonological priming conditions: Inhibition priming was observed in both contexts.

After the overall ANOVA was conducted, the effects of priming were assessed in detail. Tukey's HSD analyses revealed significant inhibitory priming effects in all conditions with a 50-ms ISI regardless of the type of priming. No significant effects of priming were observed in any of the conditions with a 500-ms ISI.

Figure 9 displays mean response times from Experiment 5 juxtaposed against data for the same stimuli from the 50-ms ISI condition of Experiment 3 and the 500-ms ISI condition of Experiment 4. The two left panels display results from the phonetic priming conditions; the right panels display results from the phonological priming conditions. The upper panels display results from conditions that included a 50-ms ISI; the lower panels display results from conditions that included a 500-ms ISI. As this figure shows, the phonological priming effect for these stimuli was clearly reversed when the proportion of related trials was reduced to 10% of all trials.

Four separate ANOVAs were conducted to assess the effect of reducing the proportion of related trials in each condition. Although each 2 × 2 × 2 ANOVA examined relatedness proportion, relatedness, and target type, we report only the important Relatedness Proportion × Relatedness interactions. In the phonetic priming/50-ms ISI condition (upper left panel of Figure 9), no significant Related Proportion × Relatedness interaction was observed, $F_1(1, 71) = 2.02$, $MS_e = 13{,}443.10$, $p > .05$; $F_2(1, 77) = 1.99$, $MS_e = 2{,}265.40$, $p > .05$. Similarly, in the phonetic priming/500-ms ISI condition (lower left panel of Figure 9), no significant interaction was observed, $F_1(1, 67) = 0.87$, $MS_e = 13{,}321.09$, $p > .05$; $F_2(1, 77) = 1.11$, $MS_e = 4{,}510.53$, $p > .05$. In the phonological priming/50-ms ISI condition (upper right panel of Figure 9), a significant Relatedness Proportion × Relatedness interaction was observed, $F_1(1, 71) = 133.95$, $MS_e = 20{,}023.11$, $F_2(1, 77) = 192.31$, $MS_e = 1{,}185.04$, reflecting the opposite directions of priming across relatedness proportions. Also, in the phonological priming/500-ms ISI condition (lower right panel of Figure 9), a significant Relatedness Proportion × Relatedness interaction was observed, $F_1(1, 67) = 17.82$, $MS_e = 19{,}019.23$, $F_2(1, 77) = 23.02$, $MS_e = 6{,}612.01$, reflecting the finding that significant priming was observed only in the condition with 50% related trials.

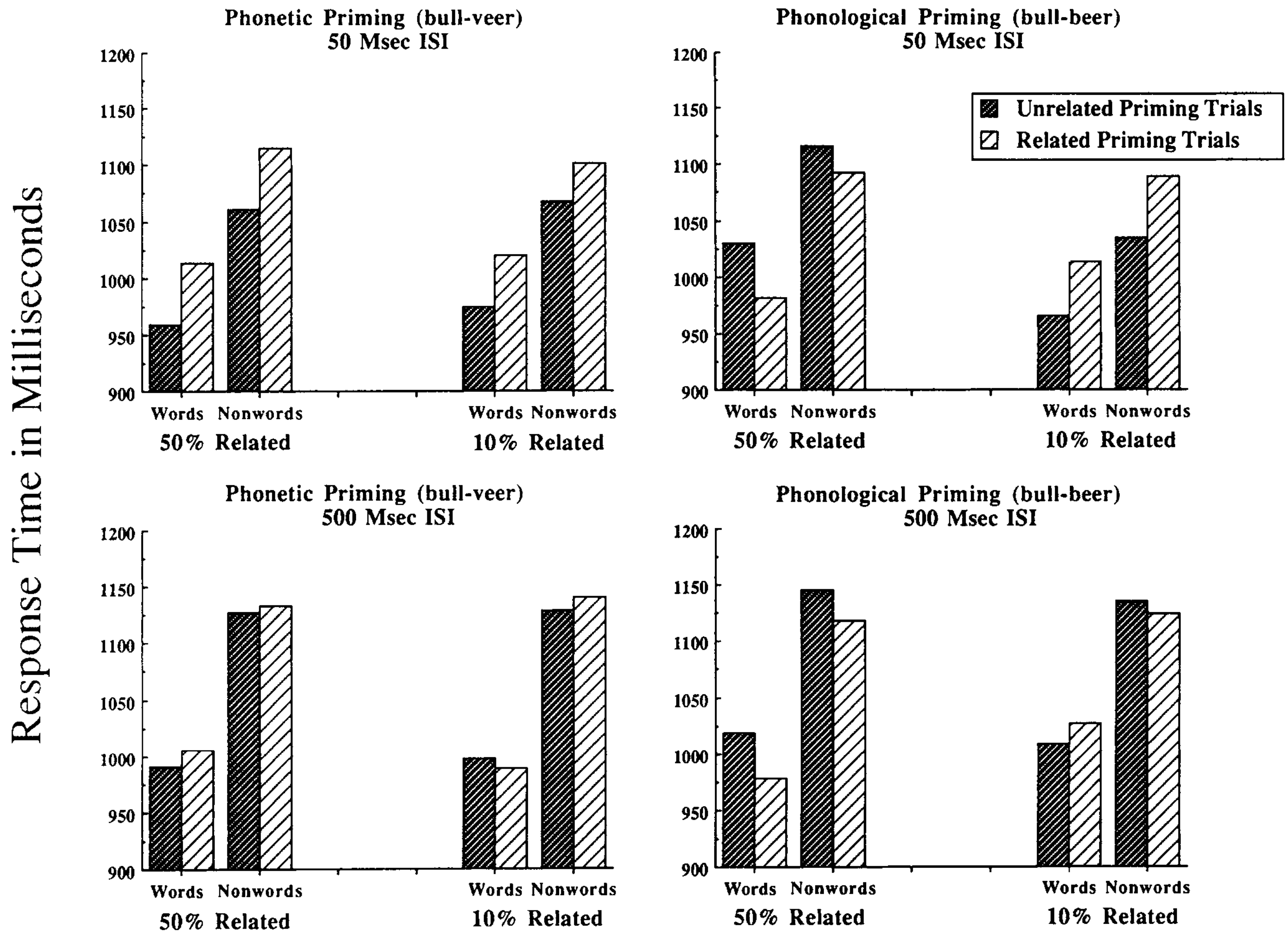

Figure 9. Mean percentages of correct target identification from Experiment 5 (10% Related) juxtaposed against subsets of data from Experiments 3 and 4 (50% Related). (The upper panel shows results for a subset of targets from the 50-ms ISI [interstimulus interval] conditions of Experiment 3 compared with results for the same stimuli in Experiment 5. The lower panel shows results for a subset of targets from the 500-ms ISI conditions of Experiment 4 compared with results for the same stimuli in Experiment 5.)

Finally, we discuss the accuracy data from Experiment 5. The mean error rates from all four conditions are shown in Figure 10. The two left panels display results from the phonetic priming conditions; the right panels display results from the phonological priming conditions. The upper panels display results from conditions that included a 50-ms ISI; the lower panels display results from conditions that included a 500-ms ISI.

A four-way ANOVA (ISI × Type of Priming × Target Class × Relatedness) was conducted on the mean error rates. A significant main effect of type of priming was observed, $F_1(1, 156) = 33.60$, $MS_e = 110.90$, $F_2(1, 144) = 26.12$, $MS_e = 55.02$, reflecting the finding that subjects in the phonetic priming conditions responded more accurately in general than subjects in the phonological priming conditions. No other significant main effects or interactions were observed.

After the overall ANOVA was conducted, the specific effects of priming were assessed in all conditions. Several significant priming effects were obtained, although no consistent pattern emerged. Tukey's HSD analyses revealed significant priming effects in the following conditions: In the phonetic priming/50-ms ISI condition, a significant facilitatory priming effect was observed for nonwords. In the phonological priming/50-ms ISI condition, a significant inhibitory priming effect was observed for words and a facilitatory priming effect was observed for nonwords.

The major results of Experiment 5 are in marked contrast to the results of the earlier experiments. Once the proportion of related trials in the experiment was reduced from 50% to 10% of all trials, the phonological priming effect showed a pattern like the phonetic priming effect. Specifically, the effect became inhibitory rather than facilitatory. Moreover, like the phonetic priming effect, the inhibitory phonological priming effect was transient and was eliminated when a 500-ms ISI was used. The apparent elimination of bias in Experiment 5 dramatically altered the nature of the phonological priming

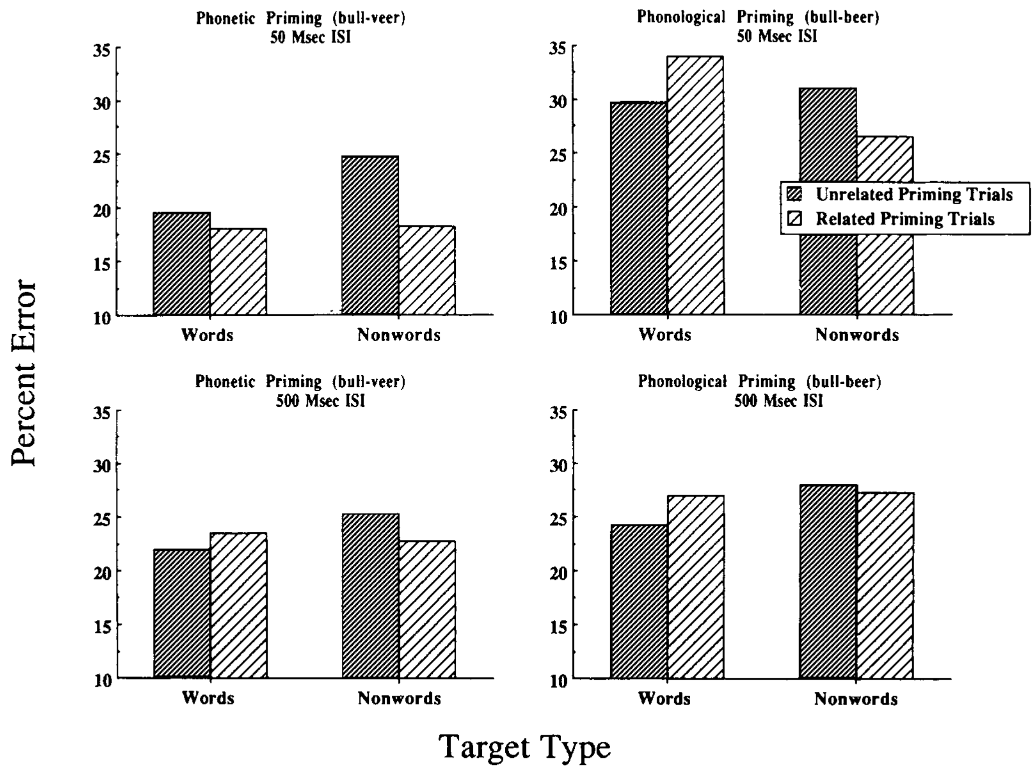

Figure 10. Mean error rates in Experiment 5 (ISI = interstimulus interval). (The left panels display results of phonetic priming; the right panels display results of phonological priming. The upper panels display results for the 50-ms ISI; the lower panels display results for the 500-ms ISI.)

effect. This is an especially interesting finding in light of Experiment 2, in which it was found that the relatedness proportion manipulation in perceptual identification was not sufficient to eliminate the facilitatory phonological priming effect.

General Discussion

The present investigation was conducted to examine the underlying nature of both facilitatory and inhibitory form-based priming of spoken words. Our primary goal was to determine whether the contrasting priming effects reported by Slowiaczek et al. (1987) and Goldinger et al. (1989) were both due to a unitary priming process or whether they were somehow qualitatively different. Specifically, we sought to assess the role of bias in phonological priming. We have reported many results, so a brief review of the major findings precedes theoretical considerations.

In the perceptual identification experiments (Experiments 1 and 2), we replicated the findings reported by Slowiaczek et al. (1987) and Goldinger et al. (1989), but we also obtained further results suggesting that the phonetic and phonological priming effects are fundamentally different. First, when the proportions of related and unrelated priming trials were 50% in both the phonetic and phonological priming conditions, comparison of subjects' responses to a common set of unrelated prime–target pairs showed that subjects in the phonological priming condition developed a bias that systematically altered the content of their responses. Second, when the proportions of related trials were reduced to approximately 10% of all trials, the magnitude of the facilitatory phonological priming effect was significantly reduced, but the inhibitory phonetic priming effect remained unchanged. These findings distinguish the phonetic and phonological priming effects above and beyond stimulus differences.

In the lexical decision experiments (Experiments 3, 4, and 5), we again replicated both the facilitatory and inhibitory priming effects, albeit only when degraded targets were presented. And, as in the perceptual identification experiments, we observed several patterns of data suggesting that the two priming effects are fundamentally different. First, in Experiment 3, when noise was used and priming effects were obtained, comparison of subjects' responses on the unrelated priming trials again revealed that the facilitatory phonological priming effect incurs a "cost" and, therefore, entails a bias. In Experiment 4, further evidence of a bias in phonological priming was provided by the observation that the phonological priming effect remained robust when the ISI was increased to 500 ms and also to 1,500 ms. In contrast, as reported by Goldinger et al. (1989), the phonetic priming effect was eliminated when the ISI was increased. Finally, in Experiment 5, we found that reducing the proportion of related priming trials not only reduced the phonological priming effect but actually reversed it. For the subset of trials that were phonological priming trials, significant inhibition of target classification was observed. Once again, changing the proportion of related priming trials did not alter the phonetic priming effect. Finally, like the phonetic priming effect, the inhibition effects found in the phonological priming conditions of Experiment 5 were short-lived effects that disappeared when a 500-ms ISI was used.

Our results suggest that the underlying mechanisms of inhibitory phonetic priming and facilitatory phonological priming are qualitatively different. The inhibition effect in phonetic priming (and in phonological priming in Experiment 5) appears to be caused by bottom-up, transient competition among words in memory. On the other hand, the facilitation effect in phonological priming appears to be caused by a perceptual or response bias that lasts longer than the residual activation from the primes. The longevity of the phonological priming effect and its influence on unrelated priming trials imply that the facilitation from phonological priming is due to learning during the experiment. Indeed, once the bias was eliminated by reducing the proportion of related trials (Experiments 2 and 5), the phonological priming effect was reduced in perceptual identification and was reversed in lexical decision.

One issue that remains unresolved is the nature of the bias in phonological priming. Specifically, we may have discovered either a perceptual bias or a response bias. Either interpretation of the bias is available, but they are not equally supported by the data and they are not equally interesting in any theoretical sense. Given the null results from lexical decision reported by Slowiaczek and Pisoni (1986) and their own null findings, Radeau et al. (1989) suggested that the phonological priming effect in perceptual identification was due to a "guessing strategy." This seems to imply a conscious and intentional response selection strategy applied by subjects after perceptual processing has been completed. With this form of response bias, it is assumed that subjects resolve the target word presented in noise to the best of their ability, given only the bottom-up acoustic–phonetic information, and then later "fill in" any missing information by applying their strategy.

Another type of bias that could explain the phonological priming effect is a perceptual bias. The concept of perceptual bias has been widely discussed in regard to speeded classification (e.g., LaBerge, LeGrand, & Hobbie, 1969; LaBerge & Tweedy, 1964), visual search (e.g., Shiffrin & Schneider, 1977), memory search (e.g., Neisser, 1967), and recently with regard to stimulus similarity relations and classification (Nosofsky, 1991; see also Shepard, 1957). Perceptual biases have been described in theories of word recognition as well. For example, perceptual biases have been depicted as changes in resting activation levels or recognition thresholds and also as criterion shifts in a perceptual decision system (Becker, 1980; Luce, 1986; Morton, 1969; Nakatani, 1973; Treisman, 1978a, 1978b). Note that the term *perceptual decision system* implies that the word recognition system entails a decisional system that is not available to the listener's conscious experience or control. The word frequency effect is an obvious example of this kind of perceptual bias. In Morton's (1969) logogen model, word frequency directly modifies the recognition thresholds of word nodes, and in the neighborhood activation model (Goldinger et al., 1989; Luce, 1986; Luce et al., 1990), word frequency influences the decision criteria of word decision units.

The example of word frequency as a perceptual bias is intended to address the special status of one stimulus over another and does not directly relate to the kind of perceptual bias that would alter subjects' behavior over the course of an entire experiment. With respect to the present research, a perceptual criterion shift of a more unilateral nature could be hypothesized. By simply noticing that primes and targets sometimes shared initial phonemes, subjects could develop an expectancy of the relationship and induce a "perceptual assumption" that favors interpretation of degraded stimuli via knowledge of the primes (Becker & Killion, 1977). Because the bias would correctly apply only on related priming trials, this perceptual bias would easily predict the facilitatory phonological priming effect as well as the "cost" on unrelated priming trials.

We do not have sufficient evidence to determine whether the bias in phonological priming is better characterized as a perceptual or a response bias. Perhaps the only empirical reason to interpret the present data in terms of a perceptual bias was provided by subjects' responses to the questionnaires administered in Experiment 1 (see Footnote 7). Although the phonological priming effect was large and the associated bias was evident, very few subjects were able to articulate a reasonable strategy. Many subjects reported that they noticed the shared phonemes between primes and targets, but few reported exploiting this information in any active or conscious sense. This conforms well to the kind of perceptual bias described by McLean and Shulman (1978); the bias is developed via learning but still asserts its influence automatically. Another reason to interpret the observed bias as a perceptual bias is more pragmatic—a perceptual bias is an interesting tool for theoretical analysis in models of word recognition.

In the following discussion, we consider several models of word recognition, with special emphasis on models of spoken word recognition. First, we evaluate models in terms of their ability to account for inhibitory priming effects. Because inhibitory priming is a special case of lexical competition, we evaluate models in terms of their treatment of competition among words in memory. Second, we evaluate models in terms of their abilities to develop perceptual biases.

Effects of Lexical Competition

A basic finding of the present research is that form-based priming of spoken words is essentially inhibitory in nature. A related finding is that a bias may develop and override the competitive effects. The inhibitory priming effect shows that similar-sounding words activate each other in memory and that this activation yields competition among words for recognition. As discussed by Goldinger et al. (1989), this finding is inconsistent with several contemporary models of word recognition. To accommodate the priming results, a model must meet two design specifications: The model must assume that similar words activate each other in memory (or at least that recognition of any given word is influenced by the presence of similar words), and the model must include some competitive processes. As it turns out, these requirements are not met by several well-known models in the word recognition literature (see Luce et al., 1990).

Morton's logogen theory of word recognition (Morton, 1969, 1979) proposes that word recognition is mediated via a system of *logogens*, passive sensing devices that represent words and operate by simultaneously monitoring bottom-up sensory information and top-down contextual information. Once a logogen accumulates sufficient evidence that its particular word is present in the signal, its activation level surpasses a threshold and the word is "recognized." By assuming that logogens are privileged to top-down information, logogen theory can account for context effects. By assuming that each logogen's recognition threshold is modified by word frequency, logogen theory can account for frequency effects. With respect to lexical competition or priming effects, however, Morton's theory assumes that logogens are independent processing units. As such, logogen theory incorporates no mechanism for lexical competition effects or, therefore, inhibitory priming effects.

Forster's (1976) search model assumes that word recognition is accomplished via a frequency-ordered search through "bins." The search model, like logogen theory, has some difficulty accounting for phonetic priming effects. Like Klatt's lexical access from spectra (LAFS) model of spoken word recognition (Klatt, 1979), Forster's search model primarily addresses the comparison of a stimulus to lexical memory, not the comparison of one presented stimulus to another. However, in recent work on orthographic priming, Forster, Davis, Schoknecht, and Carter (1987; see also Forster, 1987) described form-based priming effects that are observed only when masked primes are presented. Forster et al. suggested that priming occurs with masked primes because incomplete prime processing leaves representations "open" and therefore subject to priming effects. In the present research, however, all primes were spoken in the clear and were presumably recognized before target presentation. Therefore, the search model explanation seems incomplete for these data.

Given the nature of the phonetic priming effect (transient competition from weakly related items), a more basic criticism is that the search metaphor seems less appropriate than the activation metaphor. Several modifications to incorporate the concept of activation into the search model have been suggested. The activation-verification model (Paap, McDonald, Schvaneveldt, & Noel, 1987; Paap, Newsome, McDonald, & Schvaneveldt, 1982) combines activation of similar candidates with serial search. As we discuss further on, the activation-verification model is one of several models that can handle the present findings comfortably. Also, as Segui and Grainger (1990) noted, Forster (1987) recently suggested that lexical representations may be "open" or "closed" to varying degrees. Representations may be only partially opened following presentation of a masked stimulus. Because no match of the stimulus can be found in the lexicon, representations that are partially consistent with the input are left partially open for some period of time. This modification closely approximates the concept of continuous activation values, and it may allow the model to account for some of the present findings.

The models that handle the present findings most comfortably are models that incorporate activation of lexical candidates and competition among those candidates. Several models that fit these requirements are the neighborhood activation model, the activation-verification model, an interactive-activation model, Norris's checking model, and the revised cohort theory. As it turns out, although these models differ in specific details, all share a core set of assumptions regarding lexical competition. Moreover, most of these models also include mechanisms to develop perceptual biases.

In our earlier report on phonetic priming, we argued in support of the neighborhood activation model to account for effects of lexical competition (Luce, 1986; see also Goldinger et al., 1989, Luce et al., 1990). In the neighborhood activation model, a spoken stimulus is assumed to activate a set of acoustic–phonetic patterns in memory. All acoustic–phonetic patterns, regardless of their correspondence to real words, are activated in proportion to their similarity to the input. The activated patterns then activate, in turn, a set of word decision units that correspond only to real words in the lexicon. The neighborhood activation model is assumed to work with a continuous temporal sequence, as in cohort theory. As the stimulus is resolved in time, the word decision units monitor the activation of their given words and determine if their candidates surpass a recognition threshold. Like logogens, the decision units are biased by higher level lexical information, such as word frequency and context. Unlike logogens, however, decision units also monitor the overall activity level of the system, so a lexical candidate can only reach threshold by surpassing the activation levels of its competitors.

Because the neighborhood activation model assumes that any activated candidate constitutes a competitor for target recognition, it easily predicts inhibitory priming effects as well as inhibitory neighborhood effects (Luce et al., 1990). In the case of phonetic priming, the residual activation from a recently presented prime raises the baseline activity level of the system of decision units. Accordingly, the decision system is likely to select an incorrect word or take longer to select the correct word. Also, by assuming that word decision units are biased by higher level information, such as word frequency, the neighborhood activation model easily explains the development of a bias. Perceptual biases are a natural aspect of the model's normal operation; incorporating a new bias to accommodate phonological priming relations requires no basic modification.

A second model that is compatible with the present findings is the activation-verification model (Paap et al., 1982, 1987; see also Becker, 1976, 1980; Becker & Killion, 1977). In the verification model, presentation of a prime induces generation of an "expectancy set" consisting of words related to the prime. When the target is presented, two processes occur. In one process, the target word activates a subset of lexical candidates in memory to be submitted for serial verification (the usual sequence of word recognition in the verification model). At the same time, a second process that uses attention compares information in the visual store with the words in the expectancy set. If comparison yields a match with a member of the expectancy set, a response can be quickly executed. However, if no match is found, the entire expectancy set is exhaustively searched before attention can return to the target's own verification set. Taken together, these two processes are able to predict the complementary benefits and costs in priming.

The activation-verification model also has several components that allow it to account for the present data. Within the activation-verification framework, the phonetic priming effect is easily explained via the competitive activation account offered by Goldinger et al. (1989). Moreover, the verification model is assumed to apply perceptual biases whenever a context is available. The context surrounding a word (in our case, a prime) is assumed to influence the membership of the expectancy set. The effect of the expectancy set is to bypass exhaustive processing by the perceptual system in instances of facilitation and to induce unnecessary processing in instances of inhibition. Becker and Killion (1977) suggested that "if subjects can be induced to expect one of a small set of stimuli, to the exclusion of others, then the expected stimulus may benefit from the by-passing of feature extraction, whereas the unexpected stimuli may not" (p. 400). Clearly, an expectancy process of this kind may underlie the bias demonstrated in the present research.

Another model that accommodates the present data is Norris's (1986) plausibility-checking theory, which bears close resemblance to the neighborhood activation model and to the activation-verification model. Visual word recognition occurs in Norris's model as follows: Perceptual evidence for activated candidates in memory accumulates in proportion to their similarity to the stimulus, with the perceptual evidence for each candidate weighted according to word frequency. Once the set of candidates is activated, each candidate is checked to determine its plausibility in the context of the prime (or sentence). The plausibility check adjusts the recognition criteria for the words in the set; candidates that are consistent with the prime are facilitated and inconsistent candidates are inhibited. Like the neighborhood activation model and the activation-verification model, Norris's model is well-equipped to address the results of the present research. The model proposes a set of activated competitors to yield inhibition, and the model also uses perceptual biases in its common operation. Also, Norris's (1987) idea of shifting perceptual criteria during priming predicts both the benefits and costs of a perceptual bias rather elegantly.

The models that have received the majority of empirical and theoretical attention in recent years are interactive-activation, or connectionist, models of learning and perception. This is a wide class of models, but many share basic components that are germane to the present discussion. Among word recognition models, these basic components include massive interconnectivity among represented units, facilitative activation that spreads between levels of representation, and competitive activation that spreads within levels of representation. With these basic properties, models such as the TRACE model of speech perception (McClelland & Elman, 1986) and the interactive-activation model of visual word recognition (McClelland & Rumelhart, 1981) easily predict effects of lexical competition. Perceptually similar words activate each other in proportion to their similarity, and competition suppresses all but the best-fitting word to the input. As such, priming and neighborhood effects emerge from such models naturally.

We note, however, that priming is not easily implemented in the TRACE model of speech perception and spoken word recognition. Because speech is a temporally distributed signal, TRACE assumes multiple representations of all units, with separate representations included for each "time slice" of the model's operation. As such, TRACE contains no mechanism for words to influence each other across time delays. Despite this implementational difficulty with TRACE, it is possible that a modified version could predict priming effects. Indeed, Slowiaczek and Hamburger (1992) freely discussed the possibilities of a generic connectionist model to account for auditory phonological priming effects.

Peterson, Dell, and O'Seaghdha (1989; see also O'Seaghdha et al., in press) have recently described a connectionist model that combines elements of Dell's (1986) spreading activation model of speech production and McClelland and Rumelhart's (1981) model of word recognition. The Peterson et al. model contains levels of representation corresponding to letters, words, and phonemes (the model was designed to simulate the visual primed pronunciation task), and it contains excitatory and inhibitory connections between levels of nodes. Presentation of a prime in the model leaves a configuration of activation in the network and also activates an "episodic note" that remains activated for a variable amount of time depending on the frequency of the prime. If the subsequent target shares features with the prime, the episodic node is activated and it reactivates the constituents of the prime (see Jordan, 1986). In this manner, the network "remembers" the prime, which then influences target recognition and pronunciation.

Of particular interest to the present discussion is that the Peterson et al. model was applied to the form-based priming task, and it simulated patterns of data similar to the present data. Colombo (1986) showed that orthographic priming, which typically results in facilitation of target recognition (e.g., Meyer, Schvaneveldt, & Ruddy, 1974), can sometimes result in inhibition as well, depending on the relative frequencies of primes and targets. The Peterson et al. model reproduces the complex pattern of data by assuming that facilitatory priming arises at the lexical level and that inhibitory priming arises as a function of competition at the phonological level (see O'Seaghdha et al., in press, for expanded discussion).

Connectionist models of word recognition raise several intriguing questions about the present data, including the role of separate levels of representation in the dichotomous effects of form-based priming. We have little doubt that the data patterns of the present study could be successfully reproduced by an interactive model. A question remains, however, regarding the development of a bias. To accurately reflect the present data, an important modification to an interactive model should address the role of selective attention or expectancy in creating the facilitatory priming effect. In its current form, the Peterson et al. model (as well as the generic model that Slowiaczek and Hamburger, 1992, discussed) treats both the facilitatory and inhibitory priming effects as products of bottom-up processing. We know that all priming effects are not created equal. To remain faithful to the present data, some form of attention, perhaps implemented in the model by the selective heightening of word nodes, should be added (see Phaf, Van Der Heijden, & Hudson, 1990).

A final model that fares rather well with the present findings is the revised cohort theory (Marslen-Wilson, 1987, 1989, 1990). In the original description of cohort theory (Marslen-Wilson & Welsh, 1978), the theory relied on a strict matching procedure applied to a sequential speech input. As soon as any lexical candidate deviated from the input, it was eliminated from the cohort. Eventually, as bottom-up and top-down constraints eliminated candidates, only the "recognized" word remained in the cohort. In recent revisions of the cohort theory, Marslen-Wilson has maintained several assumptions while loosening others. The aspects of the model that remain from its original description include the following: The word-initial cohort can only be established via bottom-up input, the cohort is pared down by left-to-right mismatches with bottom-up information, and word beginnings are vital to fluent recognition.

The assumptions of cohort theory that have been revised include the following: The theory now assumes continuous matching, so candidates are activated in proportion to their match with the input. Also, the theory now incorporates frequency effects via changes in lexical activation functions. Perhaps most critically, the revised cohort theory acknowledges the importance of what Marslen-Wilson called the "contingency of perceptual choice" and the nature of the "competitor environment." In fact, the revised cohort theory closely resembles the neighborhood activation model—evidence for a particular lexical pattern accumulates during temporal processing of the signal, and a selection mechanism must determine when one candidate has sufficiently diverged from its competitors. These assumptions of the revised cohort theory were also proposed in the neighborhood activation model (Luce, 1986; Luce et al., 1990), in which word decision units evaluate the presence of any given word relative to the presence of its neighbors (as Forster, 1989, noted, distinguishing among particular models of lexical access is becoming increasingly difficult).

Because the revised cohort theory includes processes of activation and competition, it contains the necessary elements to address the present findings. If the model can assume that the prime is a legitimate competitor for the target, and if the model can assume that the prime is still active when the target is presented, it can account for inhibitory priming. Note that the latter of these conditions would not be met by the "optimally efficient" cohort theory that Marslen-Wilson (1987, 1989, 1990) recently described. Marslen-Wilson described competition effects as so transient that they disappear by the end of the word (indeed, he only finds competition effects using a cross-modal priming technique that assesses competition early in lexical processing). By this strong assumption, cohort theory would not predict inhibitory priming. We note, however, that this is a shortcoming of an assumption, not an inherent flaw of the model.

Another problem may be cohort theory's ability to develop a perceptual bias. Because cohort theory is intended to perform with "optimal efficiency," Marslen-Wilson assumed an active role of context in reducing the cohort to a single candidate. Given this powerful role of top-down knowledge, cohort theory should accommodate a perceptual bias quite easily. Although the machinery is in place, however, another assumption in the revised cohort theory (Marslen-Wilson, 1987) is that context biases selection by positively activating patterns that are already active from bottom-up input. Context is no longer considered a viable means of excluding members of the cohort; it serves instead to "pull" contextually appropriate words further from their competitors in the cohort. Although this innovation allows the revised cohort theory to predict accurate perception of words in garden-path sentences, it does not easily predict the costs associated with the perceptual bias found in the present investigation or in many semantic priming experiments (see Neely, 1991). A contextual influence that does not inhibit inconsistent candidates does not easily predict the symmetric cost–benefit nature of bias effects in priming experiments.

Modality Differences in Priming and Neighborhood Effects

The preceding discussion included models of both visual and auditory word recognition without consideration of the assumptions involved. We did not provide such unitary treatment because we believe processing is equivalent across modalities; our purpose was merely to sample the literature on word recognition. Because models of visual word recognition in the literature far outnumber models of spoken word recognition, we included visual models to be thorough. This pedagogical device, taken in the context of our data, raises a final issue for the present discussion.

It is frequently suggested that the same underlying processes mediate the recognition of printed and spoken words. Many articles describing models of lexical access simply diagram a system with both input modalities channeled into a central set of processors. Examples may be seen in articles by Morton (1969), Forster (1976), McClelland and Rumelhart (1981), and Seidenberg and McClelland (1989). Indeed, Bradley and Forster (1987) strongly advocated treating visual and auditory word recognition within a single theory. We are sympathetic with such a view and we believe that basic processes of memory and categorization must apply to all forms of word recognition. However, our present data and recent data on neighborhood effects force several inconsistencies into the picture.

In recent experimentation on neighborhood effects in word recognition, an asymmetry has emerged between the visual and auditory modalities. Andrews (1989) reported several lexical decision and naming experiments on visually presented words that varied in frequency and neighborhood density. In all experiments, a pattern emerged showing that low-frequency words from dense neighborhoods were recognized more quickly than low-frequency words from sparse neighborhoods. High-frequency words were unaffected by differences in neighborhood density, presumably because their recognition is already advantaged relative to other words in the lexicon. Andrews's research demonstrates that the presence of many neighbors can facilitate visual word recognition.

Precisely the opposite finding of neighborhood density is observed in auditory word recognition. Luce (1986) assessed word frequency and neighborhood density effects in auditory perceptual identification, lexical decision, and naming experiments. In all experiments, high neighborhood density inhibited word recognition. Moreover, the inhibition was greater for low-frequency words than for high-frequency words. In later research, Goldinger et al. (1989) replicated the inhibitory neighborhood density effect in perceptual identification, and Goldinger (1989) replicated the effect in lexical decision and naming. In sum, neighborhood density affects word recognition in opposite manners across modalities.

Because form-based priming is a means of invoking lexical interactions, it is not surprising that priming effects resemble neighborhood effects; an asymmetry between modalities also appears in form-based priming effects. Segui and Grainger (1990; see also Grainger, 1990) recently described several orthographic priming experiments that produced a complex pattern of results: When unmasked primes were shown for 350 ms, low-frequency primes interfered with recognition of high-frequency targets. When masked primes were shown for 60 ms, high-frequency primes interfered with recognition of low-frequency targets. Segui and Grainger found that degraded, high-frequency primes inhibit target identification. In the present data, and also in the data reported by Goldinger et al. (1989), we found that low-frequency primes inhibit recognition of degraded targets.[11] The asymmetry across modalities is apparent.

These asymmetries across the visual and auditory modalities are not easily explained by any model that assumes a unitary set of processes operates on all lexical stimuli. Many models incorporate the simplifying assumption that speech is converted to a string of phonemes, which is then treated as a string of letters. Perhaps more sophisticated thought is required. The different effects of similarity neighborhoods may reflect different optimization strategies: The facilitatory effect of dense orthographic neighborhoods may be a by-product of a system optimized to process spatial, relatively invariant stimuli. The inhibitory effect of dense phonetic neighborhoods may be a by-product of a system optimized to process temporal, variable stimuli. A powerful connectionist model could certainly mimic this asymmetry, but a principled theoretical account may not come as easily. We hope that other researchers will explore these phenomena and use them as tools to develop more sensitive theories of visual and auditory word recognition.

Conclusions

In summary, the present investigation was designed to further examine the phonological priming effect, first described by Slowiaczek et al. (1987) and summarily dismissed by Radeau et al. (1989). Our results show that, as Radeau et al. suggested, the phonological priming effect involves more than simple activation among words in memory; a bias is clearly involved as well. For the present, evaluating theories of spoken word recognition on the basis of the phonological priming effect may not be appropriate. In contrast to the phonological priming effect, the phonetic priming effect does not appear to involve bias. The competition and inhibition revealed via phonetic priming appear to directly reflect basic principles of spoken word recognition. These principles are best captured by models of word recognition that incorporate activation and competition among sets of similar lexical candidates.

[11]Another apparent asymmetry between the present data and those of Segui and Grainger (1990) concerns the time course of priming effects. Segui and Grainger observed priming only with their longer stimulus onset asynchrony (SOA), and we observed priming effects only with our shorter ISI. However, because spoken words are distributed over time, our actual "SOA" between related segments of primes and targets may be quite comparable to the SOA used by Segui and Grainger.

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