Published in final edited form as:

J Exp Psychol Learn Mem Cogn. 1987 January ; 13(1): 64–75.

Phonological Priming in Auditory Word Recognition

Louisa M. Slowiaczek, Howard C. Nusbaum, and David B. Pisoni

Indiana University

Abstract

Cohort theory, developed by Marslen-Wilson and Welsh (1978), proposes that a "cohort" of all the words beginning with a particular sound sequence will be activated during the initial stage of the word recognition process. We used a priming technique to test specific predictions regarding cohort activation in three experiments. In each experiment, subjects identified target words embedded in noise at different signal-to-noise ratios. The target words were either presented in isolation or preceded by a prime item that shared phonological information with the target. In Experiment 1, primes and targets were English words that shared zero, one, two, three, or all phonemes from the beginning of the word. In Experiment 2, nonword primes preceded word targets and shared initial phonemes. In Experiment 3, word primes and word targets shared phonemes from the end of a word. Evidence of reliable phonological priming was observed in all three experiments. The results of the first two experiments support the assumption of activation of lexical candidates based on word-initial information, as proposed in cohort theory. However, the results of the third experiment, which showed increased probability of correctly identifying targets that shared phonemes from the end of words, did not support the predictions derived from the theory. The findings are discussed in terms of current models of auditory word recognition and recent approaches to spoken-language understanding.

The perception and comprehension of spoken language involves a complex interaction among several different sources of linguistic information. To comprehend a sentence, a listener must analyze the phonetic, lexical, syntactic, semantic, and pragmatic information encoded in the speech waveform. Word perception is clearly a critical part of the comprehension process because words provide the interface between the perceptual processing of stimulus information and the conceptual interpretation of an utterance. In principle, it is possible to distinguish two functionally different processes that subserve word perception: *word recognition* and *lexical access*. Although there are no standard or widely agreed-upon definitions for these terms, we can define word recognition as the pattern recognition process that allows a listener to identify a spoken or printed stimulus as a word and lexical access as the process that mediates access to abstract knowledge (e.g., syntactic, semantic, pragmatic information) about a lexical entry (see Pisoni & Luce, in press). Note that making this theoretical distinction does not require that these processes operate as autonomous modules (cf. Fodor, 1983; Forster, 1978); rather it serves only to partition word perception into separate cognitive operations that are theoretically quite different.

Over the last few years, there has been an increased interest in the processes that mediate perception of spoken words (Cole, 1980; Cole & Rudnick, 1983) and three general findings have emerged from this work (see Cole & Jakimik, 1980; Foss & Blank, 1980; Grosjean,

Copyright 1987 by the American Psychological Association, Inc.

Correspondence concerning this article should be addressed to Louisa M. Slowiaczek, who is now at the Department of Psychology, Loyola University of Chicago, 6525 North Sheridan Road, Chicago, Illinois 60626; or to Howard C. Nusbaum, who is now at the Department of Behavioral Sciences, 5848 South University Avenue, University of Chicago, Chicago, Illinois 60637; or to David B. Pisoni, Speech Research Laboratory, Department of Psychology, Indiana University, Bloomington, Indiana 47405.

1980; Marslen-Wilson & Welsh, 1978). First, spoken words are recognized one at a time in the same temporal sequence in which they are produced (Cole & Jakimik, 1980). Second, the beginnings of words appear to be far more important for directing the recognition process than either the middles or the ends of words (Cole & Jakimik, 1980; Marslen-Wilson & Welsh, 1978; Nooteboom, 1981; Salasoo & Pisoni, 1985). Information encoded in the acoustic-phonetic structure at the beginning of a word apparently is given more weight in recognition than any other portion of a word. Finally, word perception results from an interaction between bottom-up pattern processing and top-down expectations derived from context and linguistic knowledge (Marslen-Wilson & Tyler, 1980). This finding suggests that word recognition and lexical access cooperate to specify word identity in the comprehension of fluent speech. This interaction between top-down and bottom-up processes allows listeners to identify words very quickly, even when the sensory input may be incomplete (Marslen-Wilson, 1984).

Recently, Marslen-Wilson and his colleagues have attempted to account for these general findings with a single theory of auditory word recognition called *cohort theory* (see Marslen-Wilson & Tyler, 1980; Marslen-Wilson & Welsh, 1978; Tyler & Marslen-Wilson, 1982a, 1982b). Cohort theory depicts word recognition as a two-stage process. In the first stage, a “cohort” of word candidates is activated using only the acoustic-phonetic information at the beginning of a word. These candidates are all the words in the lexicon that share the same initial sound sequence. For a stimulus word to be recognized, it must be contained within this initial set of word candidates. The second stage of cohort theory describes the process by which word candidates are eliminated from the original set. Members of the cohort are deactivated by a mismatch with acoustic-phonetic information later in the stimulus word or by a mismatch with expectations derived from linguistic context. As more of the signal is heard, more word candidates become inconsistent with sensory information and prior sentential context, and these candidates are eliminated from further consideration. At some point either before or at the end of the word, all candidates but one are deactivated, leaving the recognized word. The point at which a word diverges from all other words in the activated cohort has been called the *isolation point* or *uniqueness point* for that word (cf. Grosjean, 1980; Marslen-Wilson, 1984).

The main features of cohort theory can be summarized easily. A set of word candidates is activated by bottom-up processing of the sensory information contained in the initial part of the speech waveform. According to the theory, bottom-up processing therefore has priority in directing the word-recognition process (see Marslen-Wilson & Tyler, 1980; Tyler & Marslen-Wilson, 1982b)). Members of this word-initial cohort set are then deactivated by an interaction of top-down expectations and continued bottom-up processing of acoustic-phonetic information in the signal until a single candidate remains.

In addition, cohort theory makes several assumptions about the time course of auditory word recognition. First, as Marslen-Wilson and Welsh (1978) have stated, once a member of the pool of word candidates is eliminated, it “may remain activated for a short period thereafter” (p. 56). Second, Tyler and Marslen-Wilson (1982b; Marslen-Wilson, 1984) have argued that the auditory word recognition process is “optimally efficient.” Optimal efficiency in this context refers to the ability of the recognition system to reject possible word candidates at the earliest indication of inconsistency with the stimulus. Thus, a listener should be able to reject cohort members on the basis of the very first top-down or bottom-up mismatch of information.

These assumptions, taken together with the description of the recognition process in terms of candidate activation and elimination, make cohort theory a fairly complex and potentially powerful account of auditory word recognition. Although there have been some

experimental tests of cohort theory, these studies have focused on very broad and fairly general claims regarding the interaction between contextual expectations and sensory analysis (Marslen-Wilson & Tyler, 1980; Tyler & Marslen-Wilson, 1982a), or on claims related to optimal efficiency in recognition (Marslen-Wilson, 1984). None of the previous research has provided any empirical evidence to support the most basic claim of the theory, namely, that recognition depends on activation of a cohort of word candidates. In this article, we present the results of three experiments designed to test specific predictions regarding the activation of a cohort of word candidates sharing acoustic-phonetic information with the input stimulus. These experiments are only concerned with the bottom-up pattern matching operations in the recognition process described by cohort theory. That is, only the process of matching encoded sensory information to lexical representations is examined, in order to investigate the activation and deactivation of word candidates during recognition.

Furthermore, although cohort theory is explicit about some aspects of spoken-word recognition, it is neutral with respect to the basic unit of information used to activate and deactivate cohort members. Marslen-Wilson and Welsh (1978) describe the activation of word candidates based on “acoustic-phonetic information” at the beginning of a word without stating explicitly the nature or size of the unit of information. In order to generate predictions about auditory word recognition, it is necessary to make some commitment to the basic unit of pattern-matching used during the recognition process. For the purposes of the present experiments, we assumed that word recognition is carried out by processing phonemes in the temporal order in which they are produced. Phonemes can be specified as linguistic constructs (although the relation between phonemes and the acoustic structure of speech is not completely understood), and a number of linguistic arguments can be cited to support the use of the phoneme as a basic unit of recognition in word perception (see Pisoni, 1981; Pisoni & Luce, in press).

Over the past few years, a large number of experiments have used a priming procedure to investigate the processes that mediate word perception. To date, this research has been concerned primarily with the influence of the meaning of a prime word on recognition of a target word (e.g., Meyer, Schvaneveldt, & Ruddy, 1975) or on the activation of different senses of a word during lexical access (e.g., Seidenberg, Tanenhaus, Leiman, & Bienkowski, 1982; Swinney, 1982). However, some priming research has examined the effects of phonological similarity on word recognition. Specifically, Meyer, Schvaneveldt, and Ruddy (1974) found facilitation to make a visual-lexical decision when pairs of words that rhyme (e.g., *bribe-tribe*) were presented to subjects. Meyer et al. (1974) visually presented stimulus items and found that subjects responded more rapidly to word pairs that were both graphemically and phonemically similar (*bribe-tribe*) than to control pairs (*break-ditch*). Moreover, Meyer et al. found slower response times when the pairs shared only graphemic similarity (*touch-couch*). Hillinger (1980) also found rhyming facilitation when the first item in a prime-target pair was presented auditorily and when the rhymes were graphemically dissimilar (*eight-mate*). Similarly, Jakimik, Cole, and Rudnicki (1985) found facilitation to make a lexical decision to auditorily presented monosyllabic words and nonwords only when the preceding polysyllabic words were related phonologically and orthographically (e.g., facilitation for *message-mess*, but not for *definite-deaf*). These studies suggest that the phonological representation of a prime word may facilitate recognition of a target word (also see Tanenhaus, Flanagan, & Seidenberg, 1980).

One characteristic of cohort theory suggests that phonological overlap between a prime and target word should influence auditory word recognition.¹ At the end of a stimulus, the amount of residual activation of a candidate depends on the point at which the candidate was eliminated from further consideration by the recognition system. For example, the word *dream* would be a member of the cohort activated by the word *dread only* for the first two

phonemes of the stimulus. The third phoneme, /e/, would deactivate the *dream* candidate. However, the residual activation associated with the *dream* candidate would be higher than the residual activation associated with *damp*, which would only be a member of the *dread* cohort for the first phoneme. The activation of former cohort members can be investigated by examining recognition of the targets *dream* or *damp* following the prime *dread*. A higher level of residual activation for a former cohort member should boost the activation of that word when it is actually presented as a stimulus following a prime. As the prime and target share more phonemes from the beginning of the words, recognition of the target should be enhanced compared to unprimed recognition of the same target. A model of cohort activation from which these basic predictions are derived has been developed by Nusbaum and Slowiaczek (1983).

At first glance, the prediction of phonological priming in auditory word recognition would seem to be addressed by previous research on priming in visual word recognition (e.g., Hillinger, 1980; Meyer et al., 1974). However, a number of differences exist between these previous studies and the present investigation. First, a major difference exists between previous research on visual word recognition and the present research on auditory word recognition, in that visually presented words are spatially distributed, whereas auditorily presented words are temporally distributed. Cohort theory is specifically a theory of auditory word recognition and therefore it makes no claim or prediction about word recognition when the entire pattern of a word is available at one time. Second, the primes and targets used by Meyer et al. (1974) and Hillinger (1980) rhymed, resulting in phonological similarity between a prime and target from the vowels to the ends of the items. Therefore, the phonological similarity between Meyer et al.'s prime-target pairs generally involved phonological overlap of more than 50% of each item (i.e., the final 75% of four phoneme prime-target items were similar and the final 66% of three phoneme items were similar). Moreover, in these studies the degree of phonological similarity was not systematically manipulated. In the present study we examined the effect of systematically varying the amount of phonological overlap between a prime and target by increasing the number of identical phonemes. The percentage of phonologically similar information between primes and targets in the present study varied from 0% to 100% of the items. Moreover, in visual rhyme priming studies, priming was based on overlap at the ends of the words, whereas the beginning of words are used in cohort theory to initiate recognition. Third, in the Jakimik et al. (1985) study, the targets were the first syllable of the primes item (e.g., *message-mess*, *napkin-nap*). Their results, therefore, may be due in part to overall syllabic similarity. The present study does not confound phonetic similarity with syllabic similarity. Finally, the present study uses a perceptual identification task, whereas previous studies have used lexical decision. (See Slowiaczek and Pisoni, 1986, for a discussion of differences between experimental tasks such as lexical decision and identification of words in noise.) Thus, although previous research has found some evidence for phonological priming in visual and auditory word recognition, the present research extends that work by (a) systematically varying the amount of phonological overlap, (b) using a different experimental task, and (c) testing a specific theory of auditory word recognition, cohort theory, by using auditorily presented stimulus items.

¹Although we are using the term *phonological priming* to describe the effects of the segmental structure of one word on the perception of a second word, it is not clear whether these effects are due to processing of abstract linguistic units such as phonemes or to processing of the acoustic-phonetic structure of these stimuli (see Klatt, 1980). The present experiments were not designed to dissociate the level of perceptual processing at which these effects occur, and thus we have no basis of determining which level of representation is involved in mediating these effects. For our purposes, it is sufficient to note that we are concerned with the effects of the internal segmental structure of one word on another, and we have adopted the convention of referring to these effects as phonological priming.

Experiment 1

To test whether word candidates sharing initial acoustic-phonetic information are activated early in the word-recognition process, an auditory word-recognition experiment was conducted in which subjects were required to identify isolated English words masked by white noise.² The target words were presented at five different signal-to-noise ratios. Subjects were tested in two sessions. In one session, each target word was preceded by a prime word that was presented without noise. The prime words were either identical to the target word, unrelated to the target word, or shared one, two, or three phonemes in common with the beginning of the target word. In a second session, subjects identified the same target words without presentation of the prime word.

Two specific predictions were investigated. First, if our assumptions regarding cohort activation are correct, we should observe a significant effect of priming on word identification accuracy. That is, accuracy should be greater in the primed session than in the unprimed session. Second, the magnitude of the observed priming effects should increase as the phonological overlap between the prime and target words increases.

Method

Subjects—Subjects were 60 undergraduate students who were obtained from a paid subject pool maintained in the Speech Research Laboratory at Indiana University. All subjects were paid \$4 for participation in the experiment. All subjects were native speakers of English with no reported history of hearing loss or speech disorder.

Materials—A set of 100 monosyllabic words was selected for use in the experiment.³ Each of the 100 target words was paired with each of five separate primes. The primes were all monosyllabic words related to the target words in the following five ways: (a) identical, (b) same first, second, and third phonemes as the target, (c) same first and second phonemes, (d) same first phoneme, and (e) no phonemes in common (unrelated prime). Table 1 lists some examples of word targets and their corresponding primes.

A male talker recorded the target and prime items in a sound-attenuated booth (Industrial Acoustics Corporation, Model No. 106648) on one track of an audio tape. The recordings were made using an Electro-Voice D054 microphone and an Ampex AG500 tape deck. The stimulus items were produced in the carrier sentence “Say the word _____ please” to control for the increase in durations that occur when words are recited in isolation. The stimulus items were then digitized at a sampling rate of 10 kHz using a 12-bit analog-to-digital converter, low-pass filtered at 4.8 kHz, and excised from the carrier sentence using a digitally controlled speech waveform editor (*WAVES*) on a PDP 11/34 computer (Luce & Carrell, 1981). The targets and their corresponding primes were stored digitally as stimulus files on a computer disk for later presentation to subjects in the experiment.

Procedure—Subjects were tested in groups of six or fewer. The presentation of stimuli was controlled by a PDP 11/34 computer. Subjects participated in two sessions of the experiment. In one session, the target words were presented in isolation. In the other session,

²It has been argued that experiments in which stimuli are degraded by noise force subjects to rely on strategies normally not operative during normal word-recognition processing. However, even under normal conversational circumstances, speech processing always involves background noise of varying degrees. Thus, there is some ecological validity to the basic task of word identification in noise, as it reflects the type of operations that may be required during “normal” conversation. Furthermore, no evidence is available to support the claim that the presence of noise in experimental situations creates context effects; instead, the presence of noise may simply reveal the recognition system’s sensitivity to context.

³To ensure that the stimuli could be identified accurately, 12 subjects were asked to identify the 100 target items presented without any noise. The stimuli were reported correctly at .95 probability in the clear.

each target word was preceded by a prime word. The subject's task in both sessions of the experiment was to identify the target word. Subjects participated in the second session immediately following participation in session one. The order of participation in the primed and unprimed sessions was counterbalanced across subjects.

All prime words were presented at 75 dB (SPL) without noise over a pair of TDH-39 headphones. In order to manipulate the range over which target items could be identified, each of the target words was presented at 85 dB mixed with white noise at one of five possible signal-to-noise ratios: +10, +5, 0, -5, and -10 dB. Subjects were asked to listen carefully to the target word presented in noise and to write the word on an answer sheet provided by the experimenter. During the primed session of the experiment, subjects were told to listen to both the prime and the target on each trial, but to respond only to the target word.

A typical trial sequence in the primed session proceeded as follows: First, a cue light was presented for 500 ms at the top of the subject's response box to indicate that the trial was beginning. Immediately following the cue light, the unmasked prime item was presented over the headphones. Then, 50 ms later, the target word was presented at one of the five signal-to-noise ratios. Subjects responded by identifying the target word in the noise. When the subject's response was complete, the subject pushed a button on the response box as a signal to the computer to initiate the next trial. A typical trial in the unprimed session proceeded in the same manner except the presentation of the prime was omitted from the trial sequence and the target word in noise occurred 50 ms after presentation of the cue light.

Each session of the experiment consisted of 100 trials. The target words were presented in random order in each session. During a given session, an equal number of target words (20) were presented at each of the signal-to-noise ratios. In addition, an equal number of words (20) were primed by each of the five prime types during the primed session. Subjects were never presented with the same target or prime item on any of the 100 trials in a particular session of the experiment, although the same target and signal-to-noise levels were used across the primed and unprimed sessions for a particular group of subjects. Across groups of subjects every target was presented at each signal-to-noise level and was primed by each prime type. However, all targets were not presented at all possible pairings of signal-to-noise level and prime type.

Results and Discussion

The percentage of words correctly identified was determined for each subject in each condition (prime type by signal-to-noise ratio) for the primed and unprimed sessions. Words were scored as correct only if the response matched the entire target word exactly. Omissions or additions of affixes were scored as incorrect. Words with alternate spellings that matched the target word phonetically were scored as correct (e.g., *steel*, *steal*). The percent correct word-recognition scores for individual subjects were averaged to determine the probability of correct identification over all subjects and a cumulative normal distribution was used to fit functions to these probability scores. The graphs produced as a result of fitting the probability scores are shown in Figure 1.

Each panel in Figure 1 represents a different prime-type condition. The data are plotted as the probability of correct identification across each of the five signal-to-noise ratios used in the experiment (-10, -5, 0, +5, +10). The crosses represent the probability of correct identification during the unprimed session; the squares represent the probability of correct identification during the primed session. The .50 probability of correct identification was chosen to compare the difference between the fitted functions for the primed and unprimed sessions. This is marked by the horizontal dotted line.

As illustrated in Figures 1a and 1b, there is no apparent difference for the functions obtained in the primed and unprimed sessions for the unrelated prime and the one-phoneme overlap conditions. However, when the prime overlapped with the target item by two, or three phonemes or was identical with the target (Figures 1c, 1d, and 1e, respectively), the functions for the primed and unprimed sessions showed progressively larger separation. Performance in the primed sessions was, in each case, higher than in the unprimed sessions.

An analysis of variance (ANOVA; session by prime type by signal-to-noise ratio) was performed on the percentage of words correctly identified for each subject in each of the conditions. The outcome of this analysis reflects the trends illustrated in Figure 1. Significant main effects of session, $F(1,59) = 98.64$, $MS_e = 767.98$, $p < .01$, prime type, $F(4, 236) = 35.75$, $MS_e = 765.56$, $p < .01$, and signal-to-noise ratio, $F(4, 236) = 813.69$, $MS_e = 399.67$, $p < .01$, were obtained. These main effects reveal that subjects performed significantly better at identifying words correctly in the primed session than in the unprimed session. Furthermore, subjects showed significant differences in the primed session as prime type varied. In addition, significant interactions of Session $\times$ Prime Type, $F(4, 236) = 61.11$, $MS_e = 294.52$, $p < .01$, Session $\times$ Signal-to-Noise $\times$ Ratio, $F(4,236) = 16.16$, $MS_e = 272.75$, $p < .01$, Prime Type $\times$ Signal-to-Noise Ratio, $F(4, 236) = 16.98$, $MS_e = 558.03$, $p < .01$, and Session $\times$ Prime Type $\times$ Signal-to-Noise Ratio, $F(16, 944) = 13.10$, $MS_e = 267.22$, $p < .01$, were also observed.

As expected, the Session $\times$ Prime Type interaction demonstrates that differences in correct identification across different prime types were only observed in the primed session of the experiment. The Session $\times$ Signal-to-Noise Ratio and the Prime Type $\times$ Signal-to-Noise Ratio interactions reveal that facilitation of identification due to phonological priming is greater at low signal-to-noise ratios than at high signal-to-noise ratios. This result is similar to the finding in semantic priming research that priming effects increase as stimuli are degraded (Meyer et al., 1975). The Session $\times$ Prime Type $\times$ Signal-to-Noise Ratio interaction is due to a very small difference in identification performance for different prime types during the unprimed and primed sessions at high signal-to-noise ratios, but a much greater difference in identification across conditions for low signal-to-noise ratios.

In order to examine the differences between the primed and unprimed sessions more closely, the data were collapsed over signal-to-noise ratio and the difference between primed and unprimed sessions was computed for each prime type. The means for the unprimed and primed sessions as well as the differences between them are provided in Table 2. Results of a one-way ANOVA on these difference scores revealed a significant effect of prime type, $F(4, 236) = 60.90$, $MS_e = .0119$, $p < .01$. A post hoc Newman-Keuls analysis supported the prediction that as the number of phonemes shared by the prime and target increased the probability of correct identification of words in noise would increase. Specifically, when primed with words that were unrelated to the targets or with primes that overlapped with targets by one phoneme, performance was significantly worse than in the other priming conditions. Unrelated primes and primes with only one phoneme overlap, however, did not produce significantly different priming effects. Also, primes that shared two or three phonemes with targets did not produce significantly different priming effects, although primes that were identical to targets produced significantly better identification than primes with zero, one, two or three phonemes overlap ($p < .01$, for all comparisons). Although the increase in the probability of correct identification across prime types was not a simple monotonic function of the number of shared phonemes between the prime and the target, a reliable increase in the probability of correct identification is nonetheless apparent across the different priming conditions.

The results of the first experiment support the predictions derived from cohort theory concerning the cohort activation process. Two specific predictions were verified. First, phonological priming improved identification of words presented in noise. Second, greater phonological overlap between prime and target items produced better word-identification performance. In addition, the largest change in the size of the priming effect occurred in the condition where the prime and target words were identical. Although cohort theory would only predict an advantage for identical prime-target pairs on the basis of the increase of similar phonemes between the prime and target by one (i.e., the theory would not predict an additional advantage for identical prime-target pairs beyond the increase in identical phonological information), the model of cohort activation developed by Nusbaum and Slowiaczek (1983) does predict such an advantage for identical pairs. Although it is possible that in addition to phonological priming some effect of semantic priming is operative in this case, it is noteworthy that the activation model of cohort theory could account for this result without recourse to semantic knowledge. The prediction is based only on the activation of lexical units from phonological information. More important, appeal to semantic priming cannot be used to account for the effects of primes that were semantically unrelated to targets, but shared two or three phonemes with the targets.

Taken together, these results clearly demonstrate that phonological overlap between prime and target words improves recognition of those target words as predicted and therefore support the cohort activation assumption. However, an alternative interpretation of these results is possible. Specifically, the prime simply could have produced a shift in the subjects' response criteria or induced some sort of guessing strategy. The basic question is really whether phonological priming effects are due to a response bias in a postperceptual decision process or result from changes in recognition processing. This concern is clearly illustrated in a study carried out by Pollack (1963), who reported that visually presenting zero, one, two, or three letters from the beginning of a spoken word masked by noise increasingly improved identification of the word as more letters were presented. Because there was no difference between pre- and postcuing conditions, Pollack concluded that the effect of the letter context was on response selection rather than perception. Although Pollack asserted that pre- and posttarget cuing comparisons can test for guessing strategies, it is not clear that a lack of difference between these conditions at short interstimulus intervals is strong evidence in support of sophisticated guessing. In interactive activation models (e.g., McClelland & Rumelhart, 1981), both cuing conditions should affect the pattern of activation in the lexicon for a target, although in somewhat different ways. Thus, the pattern of results in pre- and postcuing designs does not provide a strong test of guessing strategies for this class of models. Rather, it is necessary to consider how different guessing strategies might affect the pattern of subjects' responses.

Although it is possible that some subjects may have guessed in generating their responses on some trials in this experiment (as in most experiments), it is necessary to specify any guessing strategy in enough detail that it predicts only those results we obtained and excludes those we did not obtain. One possibility is that subjects may have used a very sophisticated guessing strategy in which the prime serves to constrain the set of alternative responses from which the target identification is selected. Another way to describe this strategy is that subjects select their responses from the set of candidates resulting from the intersection of the set of words in the lexicon that is similar to the prime and the set of words that is similar to the target. However, it is not clear that this sort of sophisticated guessing strategy is, in fact, "guessing." This description of a guessing strategy bears a striking resemblance to the operation of an interactive activation model of word recognition (McClelland & Rumelhart, 1981). When the prime is recognized by this type of recognition system, words that are similar to it will receive activation according to their similarity to the prime. When the target is processed, words that were activated by both the prime and the

target will have an activation advantage over words activated only by the target (i.e., “the rich get richer effect,” McClelland & Rumelhart, 1981). Thus, in an interactive activation model of word recognition, responses will be drawn from the intersection of prime-activated and target-activated candidates just as would be predicted by a sophisticated guessing strategy such as the one previously outlined. Without any further distinction between them, it is arbitrary to call one description “guessing” and the other “recognition.” In the present context, it is clear that the perceptual system is sensitive to the degree of phonological overlap between prime and target words and that it can make use of this information to improve recognition performance. This finding is entirely consistent with a model of cohort activation, and cannot be accounted for by any simple guessing strategy.

Experiment 2

Taken together, the results of the first experiment demonstrate that phonological priming can be obtained for identification of target words that share initial phonological information with prime words. These results support the activation assumption of cohort theory. An additional assumption incorporated in cohort theory is that phonological priming is independent of the lexical status of the prime. In our priming experiments, the prime serves as a source of phonemes to activate word candidates. Thus, as each phoneme in a stimulus word is recognized, word candidates that are inconsistent with the input are deactivated and consistent word candidates receive more activation. However, at no point in the recognition process is an explicit lexical decision about the input used to direct further processing. As a result, cohort theory suggests that phonological overlap between a nonword prime and a target word should produce effects on identification that are similar to the effects observed when the prime and target stimulus are both words. Moreover, this prediction is consistent with any model of auditory word recognition that involves activation of phoneme units (nodes) with word units during recognition (e.g., Elman & McClelland, 1986; McClelland & Elman, 1986).

To test this lexical status assumption, we conducted a second experiment in which the prime items were phonologically admissible pseudowords. As in Experiment 1, the primes shared three, two, or one initial phonemes with the target or they were unrelated to the target. Because of the difference in lexical status between primes and targets, the identical prime-target condition was impossible. If increased correct identification of targets for different prime types in the first experiment was a result of the match in phonological information between the beginning of primes and targets without consideration for the lexical status of the primes, we should expect to find similar results in an experiment using pseudoword primes that share the same initial phonological information with targets but do not have representations in the lexicon. Such a result would provide additional support for the activation of word units, on the basis of an analysis of the internal structure of words during auditory word recognition.

Method

Subjects—Subjects were 60 undergraduate students who were obtained from a paid subject pool maintained in the Speech Research laboratory at Indiana University. Subjects were paid \$3.50 for participation in the experiment. All subjects were native speakers of English with no reported history of hearing loss or speech disorder at the time of testing. None of the subjects in Experiment 2 had participated in the previous experiment.

Materials—A subset of 80 monosyllabic words was selected from the 100 target words used in Experiment 1. Each of the 80 target words was paired with each of four separate primes. The primes were all monosyllabic, phonologically permissible pseudowords related to the target words in the following four ways: (a) same first, second, and third phonemes as

the target, (b) same first and second phonemes, (c) same first phoneme, and (d) so phonemes in common (unrelated prime). Table 3 lists some examples of the word targets and their corresponding nonword primes used in Experiment 2.

The target words and nonword primes used in Experiment 2 were recorded, digitized, edited, and stored digitally for presentation to subjects using the same procedures described in Experiment 1.

Procedure—Subjects were tested in groups of six or fewer. The procedure was identical to that used in Experiment 1 with the following exceptions. First, during the primed session of the experiment each target word was preceded by a nonword prime. Second, only 80 trials were presented in each session of the experiment. An equal number of target words (16) were presented at each of the five signal-to-noise ratios in a particular session. In addition, an equal number of words (20) were primed by each of the four different prime types during the primed session. As in the first experiment, subjects were never presented with the same target word or nonword prime on any of the 80 trials in a particular session. However, the same target and signal-to-noise ratios were used across the primed and unprimed sessions for a particular group of subjects. Across groups of subjects every target word was presented at each signal-to-noise level and was primed by each prime type. However, all targets were not presented at all possible pairings of signal-to-noise level and prime type.

Results and Discussion

The percentage of words correctly identified was determined for each subject for each condition (prime type by signal-to-noise ratio) for the unprimed and primed sessions. The percentages of words correctly identified for individual subjects in various conditions were averaged to determine the overall probability of correct identification across all subjects and a cumulative normal distribution was used to fit functions to these probability scores. The graphs produced as a result of fitting the probability scores are shown in Figure 2. The data are plotted as in the first experiment.

Although some evidence of phonological priming is apparent in Figure 2, the results of the second experiment are different from those reported in Experiment I. An ANOVA (session $\times$ prime type $\times$ signal-to-noise ratio) was performed on the percentage of targets correctly identified by each subject under each of the conditions. The analysis revealed significant main effects of session, $F(1, 59) = 14.45$, $MS_e = 484.44$, $p < .01$, prime type, $F(3, 177) = 5.38$, $MS_e = 636.84$, $p < .01$, and signal-to-noise ratio, $F(4, 236) = 365.08$, $MS_e = 922.82$, $p < .01$. These results support the finding in the first experiment that subjects identify target words in the primed session better than target words in the unprimed session, that identification of target words was different across priming conditions, and that identification was better at high signal-to-noise ratios than at low signal-to-noise ratios. In addition, significant interactions of Session $\times$ Prime Type, $F(3, 177) = 6.96$, $MS_e = 278.76$, $p < .01$, Prime Type $\times$ Signal-to-Noise Ratio, $F(12, 708) = 11.51$, $MS_e = 659.96$, $p < .01$, and Session $\times$ Prime Type $\times$ Signal-to-Noise Ratio, $F(12, 708) = 2.65$, $MS_e = 235.67$, $p < .01$, were found.

The probability of correct word identification was averaged over signal-to-noise ratios. The means for the unprimed and primed sessions, as well as the difference between these means are listed in Table 4. Results of a one-way ANOVA on the difference between the primed and unprimed sessions for each prime type revealed a significant effect of prime type, $F(3, 177) = 6.34$, $MS_e = .0116$, $p < .01$. To compare the magnitude of the priming effect across different prime types, as in Experiment 1, a Newman-Keuls post hoc analysis was computed on the difference between the mean probability of correct identification for the primed and unprimed sessions at each of the four prime types. This analysis revealed no significant

differences in the magnitude of the priming effect for unprimed and primed sessions when the prime and target shared two phonemes, one phoneme, or were unrelated. However, when compared to the other prime types, a three-phoneme overlap between the prime and target produced a significant increase in the difference between the primed and unprimed sessions ($p < .05$).

In this experiment the priming effect was significant for only the three-phoneme overlap condition, suggesting that such effects are different or at least much smaller when the prime is a nonword compared to when it is a word. Although the priming effect was reliable in Experiment 2, the results suggest that the lexical status of the prime does appear to modulate the effects of phonological information in a prime on target identification. This effect may be due either to differences in the acoustic-phonetic structure of words and nonwords used in the experiment or to differences in recognition processing of word and nonword primes. Cohort theory suggests that the lexical status of the prime should not affect the activation of word candidates because the auditory word recognition system is sensitive to the degree of phonological overlap between successive items rather than to the lexical status of those items. Indeed, few, if any models of auditory word recognition make an explicit lexical decision prior to recognition. Therefore, most models of auditory word recognition, as well as cohort theory, may have to be modified to account for the apparent role of lexical status in word recognition.

One possible interpretation of the difference in magnitude between the results from Experiment 1 and those from Experiment 2 using nonword primes involves postulating an auditory word-recognition system that contains at least two levels of information: a phonemic level and a lexical level. In this type of system, phonological priming with a word prime could result from activation of information at both the phoneme and lexical levels. Moreover, feedback from the lexical level to the phonemic level would further enhance activation at the phonemic level (cf. McClelland & Elman, 1986; McClelland & Rumelhart, 1981). The smaller phonological priming effect observed with nonword primes, on the other hand, could be the result of activation of only phonemic information (because nonwords would not be represented at the lexical level).

Taken together, however, the facilitation we observed in identification of words masked by noise in Experiments 1 and 2 provides support for the presence of residual activation of the phonological forms of words in the lexicon as suggested by cohort theory. Moreover, the results of Experiment 2, though smaller in magnitude, still demonstrate that the initial stage of the auditory word recognition process is sensitive to the segmental structure of speech.

Experiment 3

An additional assumption of cohort theory is that a set of word candidates is activated based on word-initial acoustic-phonetic information. Although we obtained support for phonological activation of word candidates in the first two experiments, both outcomes did not establish that the phonological information used to activate words is restricted exclusively to word-initial position. According to cohort theory, activation of a cohort is based entirely on the initial phonemes of a word. A prime that differs from a target word in its initial sound sequence should not activate the target in the cohort of word candidates considered during recognition of the prime. As a result, the target would derive no residual activation from recognition of the prime and therefore the target should not be primed. In order to test this specific prediction, a third experiment was conducted in which word primes and word targets were selected so that the phonological overlap between primes and targets occurred at the ends of the words, as opposed to the beginnings of words as in the previous two experiments.

Method

Subjects—Subjects were 50 undergraduate students who were obtained from a paid subject file maintained in the Speech Research Laboratory. Subjects were paid \$3.50 for participation in the experiment. All subjects were native speakers of English with no reported history of hearing loss or speech disorder. None of the subjects used in this experiment had participated in Experiments 1 or 2.

Materials—A set of 75 monosyllabic words was selected for use in the experiment.⁴ Each of the 75 target words was then paired with each of five different prime words. The prime items were related to the target words by the number of phonemes that were shared from the end of the word. The primes were all monosyllabic words and included words that shared the following number of final phonemes with the phonemes at the end of the target: (a) identical (all phonemes the same), (b) final three phonemes the same, (c) final two phonemes the same, (d) final phoneme the same, and (e) no phonemes in common (unrelated prime). Table 5 lists some examples of the targets and their corresponding primes used in this experiment.

The target and primes were recorded, digitized, edited, and stored digitally using the same procedures as those described in Experiment 1.

Procedure—Subjects were tested in groups of five or less. The presentation of stimuli and the collection of data were controlled by a PDP 11/34 computer. As in the previous experiment, subjects participated in two sessions: an unprimed session and a primed session. The subject's task in both sessions of the experiment was to identify the target word by typing a response on a computer terminal keyboard.

The procedures for Experiment 3 were identical to those described in Experiment 1 with the following exceptions. During the primed session of the experiment, a trial started with the presentation of the warning phrase "Get Ready for Next Trial" on the computer terminal positioned in front of the subject. 100 ms after the warning signal, the prime item was presented without noise. The target was presented at one of the five signal-to-noise ratios 50 ms after the offset of the prime. Subjects responded by typing the target word on the terminal keyboard. As the subject typed, the letters appeared on the computer terminal screen. When the subject pushed the return key on the keyboard, the computer initiated the next trial. A typical trial in the unprimed session proceeded in the same manner except the presentation of the prime was omitted from the trial sequence.

Each session of the experiment contained 75 trials. The order of the sessions (primed vs. unprimed) was counterbalanced across subjects. The target words were presented in random order in each session. An equal number of target words (15) were presented at each of the signal-to-noise ratios in a given session. In addition, an equal number of words (15) were primed by each of the five prime types during the primed session of the experiment. Subjects were never presented with the same target or prime on any of the 75 trials in a particular session of the experiment. A given group of subjects only heard a given target at one signal-to-noise ratio and paired with one prime type. Although targets were presented at all signal-to-noise ratios and with each of the five possible prime types across subjects, all targets were not presented at all possible pairings of signal-to-noise level and prime type.

⁴To ensure that the stimuli could be identified accurately, 10 subjects identified the 75 target items presented without any noise. The 75 target words were reported correctly at .95 probability in the clear.

Results and Discussion

The percentage of words correctly identified for each subject in each condition was determined as in Experiments 1 and 2. The probabilities of correct word identification in the experimental conditions were determined and a cumulative normal distribution was used to fit functions to these probability scores. The graphs produced as a result of fitting the probability scores are shown in Figure 3. The data are plotted as in the previous experiments.

As in the two previous experiments, the data in Figure 3 reveal differences in word identification in the primed and unprimed sessions of the experiment as the number of phonemes that overlap between the prime and the target increases. In this experiment, no difference in performance between the primed and unprimed sessions was observed for the unrelated prime-target pairs. However, for prime and target pairs that are identical, or pairs that share one phoneme, two phonemes, or three phonemes, the data reveal differences in word identification. An ANOVA (session $\times$ prime type $\times$ signal-to-noise ratio) revealed significant main effects of session, $F(1, 49) = 145.78$, $MS_e = 615.79$, $p < .01$, prime type, $F(4, 196) = 18.62$, $MS_e = 716.73$, $p < .01$, and signal-to-noise ratio, $F(4, 196) = 426.90$, $MS_e = 699.74$, $p < .01$. In addition, significant interactions were found for Session $\times$ Prime Type, $F(4, 196) = 48.96$, $MS_e = 388.28$, $p < .01$, Session $\times$ Signal-to-Noise Ratio, $F(4, 196) = 6.28$, $MS_e = 323.22$, $p < .01$, Prime Type $\times$ Signal-to-Noise Ratio, $F(16, 784) = 16.98$, $MS_e = 942.42$, $p < .01$, and Session $\times$ Prime Type $\times$ Signal-to-Noise Ratio, $F(16, 784) = 7.84$, $MS_e = 335.81$, $p < .01$. These results are generally consistent with those reported in Experiments 1 and 2.

The probability of correct word identification for the primed and unprimed sessions for each prime type was determined by averaging over signal-to-noise ratios and subjects. These means and the difference between the primed and unprimed sessions are listed in Table 6. A one-way ANOVA was conducted on the difference between the primed and unprimed sessions for each prime type. As in the previous experiments, this analysis revealed a significant main effect of prime type, $F(4, 196) = 50.32$, $MS_e = .0076$, $p < .01$. A Newman-Keuls analysis was computed on the differences between the probability of correct identification for the primed and unprimed sessions to determine which prime types differed significantly from each other in terms of the magnitude of priming between the primed and unprimed sessions. The results revealed that identification in the unrelated prime condition was not significantly different from performance in the one-phoneme overlap condition. Also, primes and targets that overlapped by one and two phonemes were not significantly different. However, performance in the unrelated prime condition was significantly worse than performance in conditions where primes and targets shared two or three phonemes or were identical. In addition, identification when primes and targets shared three phonemes and when primes and targets were identical differed significantly from all other priming conditions ($p < .01$, for all comparisons). Therefore, as the number of phonemes shared between the prime and target increased, the magnitude of the priming effect increased.

As in the first two experiments, we found evidence of phonological priming. However, in this experiment, the probability of correctly identifying a target increased as the phonological overlap between the prime and target increased from the ends of the items. These results demonstrate that listeners are sensitive to phonological overlap at the ends of words as well as to phonological overlap at the beginnings of words. The present findings are clearly inconsistent with one of the basic assumptions of cohort theory. That is, that the set of word candidates activated during recognition is determined solely by the initial sound sequence of the utterance. More important, these results call into question the presumed importance of word-initial phonological information in directing the word-recognition process.

Recent studies examining identification of spoken word fragments (Nooteboom, 1981; Salasoo & Pisoni, 1985) have demonstrated that listeners are indeed capable of identifying words from the information at the ends of those words. In addition, structural analyses of the phonotactic properties of words have revealed that word endings provide similar constraints on cohort size as word beginnings (Pisoni, Nusbaum, Luce, & Slowiaczek, 1985). It is advantageous, therefore, for any theory of word recognition to make use of the constraints provided by word-final as well as word-initial acoustic-phonetic information. As currently formulated, cohort theory, with its emphasis on the primacy of word-initial information in the recognition process, is unable to account for the present results or the findings reported by Nooteboom (1981) and Salasoo and Pisoni (1985).

General Discussion

On the basis of the assumption of residual activation of word units suggested by cohort theory, we generated and tested several explicit predictions regarding the activation process in auditory word recognition. First, of course, was the fundamental prediction that the phonological structure of an utterance can produce a priming effect. This prediction was supported by the finding that priming, based solely on phonological overlap, was obtained in all three experiments. These results provide strong evidence that listeners make use of and are sensitive to the internal segmental structure of a word during word recognition. Furthermore, our findings argue that spoken words are not processed as wholistic entities, but are, instead, recognized from an analysis of their internal segmental structures.

Second, cohort theory suggests that the residual activation of a word unit depends on the point at which the word is eliminated from the active cohort of potential word candidates. Thus, it follows directly that increasing the phonological overlap between the beginnings of prime and target items should increase residual activation of the target unit, thereby increasing the priming effect. Our results supported this prediction by showing that the magnitude of priming in word identification depends on the number of phonemes shared between prime and target words. This was true, although to a smaller degree, even when the primes were pseudowords. The fact that the priming effect was smaller for pseudoword primes, however, suggests that models of word recognition must account for the role that lexical status plays in the recognition process.

Finally, cohort theory predicts that phonological priming should depend on overlap in the segments only at the beginnings of prime and target items and not at their endings. This prediction is a direct consequence of the most fundamental assumption of cohort theory that the entire set of word candidates considered for recognition is determined solely by acoustic-phonetic information at the beginning of a word. Thus, if prime and target words begin with different sound sequences, the target word should not be contained within the initial cohort of word candidates activated by the prime. As a result, there should be no residual activation for the word unit corresponding to the target word and therefore, no priming should be observed.

Our finding that significant priming effects were obtained when the prime and target words shared phonological information in their endings clearly contradicts the fundamental assumption of cohort theory that word-initial acoustic-phonetic information is the sole determinant of the cohort of word candidates considered during recognition. Instead, it appears that listeners use both word-initial *and* word-final information in the recognition process. This conclusion is supported by the results of several recent studies showing that listeners can identify words using only word-final information (Nooteboom, 1981; Salasoo & Pisoni, 1985). Thus, it appears that listeners are able to take advantage of the rich and redundant structural properties of words and do not restrict recognition processing

exclusively to word-initial information. The only advantage for word-initial information in speech perception may simply be a temporal one: The beginnings of words are heard first and therefore receive the most processing. As a consequence, word beginnings may have the earliest impact on the recognition process. But other parts of words are also informative and provide important structural constraints on the organization of words in the lexicon (see, Pisoni et al., 1985).

Given these results, it is appropriate to consider how other theories of auditory word recognition might account for the effects of phonological overlap in priming. Surprisingly, most of the current theories of auditory word recognition are incapable of handling the present results. First, in order for any priming effects to be obtained, it is necessary for a theory to retain some memory or trace of the presentation of a word immediately after the word is recognized. For example, in Forster's (1978) autonomous search theory and Klatt's lexical access from spectra (LAFS; 1980), the recognition process entails only the comparison of stimulus information with stored lexical representations. No mechanisms exist to store or record previous comparisons in these accounts of word recognition.

Morton's (1969) logogen theory is unfortunately too vague about the specific computational processes and features used in spoken-word recognition to derive specific predictions regarding phonological priming. In logogen theory, computational units representing words count the features of a stimulus that they match. However, if the features are phonemes, there is no way to distinguish *pot* from *top* because there is no temporal order inherent in phonemes. If the recognition features are syllables, on the other hand, it is not clear how phonological priming could occur at all. If the units are morphemes, as Murrell and Morton (1974) suggest, it is also difficult to account for the present findings and the specific effects of phonological similarity which is defined over phoneme-sized units.

Recently, McClelland and Elman (1986) have proposed an interactive activation model of auditory word recognition called *TRACE*. In this model, auditory features extracted from a stimulus activate phoneme units, which in turn activate lexical units. Competition among alternative interpretations of a section of an utterance and feedback between levels of representation control the recognition process. In *TRACE*, different portions of an utterance activate different word units. Because different lexical representations are assumed in *TRACE* for each temporal segment of the waveform, *TRACE* is unable to account for the priming effects observed in the present experiments. *TRACE* could be modified to account for the phonological priming results observed here by including in the model phoneme and word type nodes to coordinate priming effects between successive presentations of words. However, the ramifications of such a modification for other aspects of the *TRACE* model are unclear until a simulation is constructed. However, it is important to note that although *TRACE* cannot account for priming per se, it does predict that listeners can use any part of a word for directing the recognition process. Thus, *TRACE* is capable of recognizing a word from its ending, provided that the ending is sufficiently distinctive.

Considering the present findings, it is important to generalize our phonological priming results to tasks other than word identification and investigate other prime-target relations. However, the present priming results demonstrate the potential utility of this procedure as a means of investigating the time course of auditory word recognition. Although there have been numerous studies in the literature on visual word recognition in reading, considerably less attention has been paid to the problem of auditory word recognition and the processes of spoken-language understanding. A great deal more research on auditory word recognition still remains to be done before a more complete picture of the structures and processes used in speech perception and spoken-language understanding emerges. On the basis of the results of the present studies, it does seem clear that a set of hypothesized word candidates is

activated during word recognition. These word candidates appear to share phonological properties with other words in a narrowly denned region of phonetic space in the lexicon. According to this approach, words are not viewed simply as discrete, unrelated stimuli, but instead represent points in a complex multidimensional space that defines the sound patterns of words in a language. A large body of data from studies of speech errors, language development, and perceptual confusions in noise is consistent with this view of the structure of the lexicon (see Pisoni & Luce, in press).

Acknowledgments

The research reported here was supported by National Institute of Health Grant NS-12179 to Indiana University in Bloomington.

We would like to thank Paul A. Luce for his assistance in recording the stimuli.

References

- Cole, RA. Perception and production of fluent speech. Hillsdale, NJ: Erlbaum; 1980.
- Cole, RA.; Jakimik, J. A model of speech perception. In: Cole, RA., editor. Perception and production of fluent speech. Hillsdale, NJ: Erlbaum; 1980. p. 133-163.
- Cole RA, Rudnicki AI. What's new in speech perception? The research and ideas of William Chandler Bagley, 1874–1946. *Psychological Review*. 1983; 90:94–101. [PubMed: 6342015]
- Elman, JL.; McClelland, JL. Exploiting lawful variability in the speech wave. In: Perkell, JS.; Klatt, DH., editors. Variability and invariance of speech processes. Hillsdale, NJ: Erlbaum; 1986. p. 360-385.
- Fodor, JA. The modularity of mind. Cambridge, MA: MIT Press; 1983.
- Forster, KI. Accessing the mental lexicon. In: Walker, E., editor. Explorations in the biology of language. Montgomery, VT: Bradford Books; 1978. p. 139-174.
- Foss DJ, Blank MA. Identifying the speech codes. *Cognitive Psychology*. 1980; 12:1–31. [PubMed: 7351123]
- Grosjean F. Spoken word recognition processes and the gating paradigm. *Perception & Psychophysics*. 1980; 28:267–283. [PubMed: 7465310]
- Hillinger ML. Priming effects with phonemically similar words: The encoding-bias hypothesis reconsidered. *Memory & Cognition*. 1980; 8:115–123.
- Jakimik J, Cole RA, Rudnicki AI. Sound and spelling in spoken word recognition. *Journal of Memory and Language*. 1985; 24:165–178.
- Klatt, DH. Speech perception: A model of acoustic-phonetic analysis and lexical access. In: Cole, RA., editor. Perception and production of fluent speech. Hillsdale, NJ: Erlbaum; 1980. p. 243-288.
- Luce, PA.; Carrell, TD. Creating and editing waveforms using WAVE. (Research on Speech Perception, Progress Rep. No. 7). Bloomington, IN: Speech Research Laboratory, Department of Psychology, Indiana University; 1981.
- Marslen-Wilson, WD. Function and process in spoken word recognition: A tutorial review. In: Bouma, H.; Bouwhuis, DG., editors. Attention and performance X. Control of language processes. Hillsdale, NJ: Erlbaum; 1984. p. 125-150.
- Marslen-Wilson WD, Tyler LK. The temporal structure of spoken language understanding. *Cognition*. 1980; 8:1–71. [PubMed: 7363578]
- Marslen-Wilson WD, Welsh A. Processing interactions and lexical access during word recognition in continuous speech. *Cognitive Psychology*. 1978; 10:29–63.
- McClelland JL, Elman JL. The TRACE model of speech perception. *Cognitive Psychology*. 1986; 18:1–86. [PubMed: 3753912]
- McClelland JL, Rumelhart DE. An interactive activation model of context effects in letter perception: Part 1, An account of basic findings. *Psychological Review*. 1981; 88:375–407.
- Meyer DE, Schvaneveldt RW, Ruddy MG. Functions of graphemic and phonemic codes in visual word recognition. *Memory & Cognition*. 1974; 2:309–321.

- Meyer, DE.; Schvaneveldt, RW.; Ruddy, MG. Loci of context effects in visual word recognition. In: Rabbitt, PMA.; Dornic, S., editors. *Attention and performance V*. New York: Academic Press; 1975. p. 98-118.
- Morton J. Interaction of information in word recognition. *Psychological Review*. 1969; 76:165–178.
- Murrell GA, Morton J. Word recognition and morphemic structure. *Journal of Experimental Psychology*. 1974; 102:963–968.
- Nooteboom SD. Lexical retrieval from fragments of spoken words: Beginnings versus endings. *Journal of Phonetics*. 1981; 9:407–424.
- Nusbaum, HC.; Slowiaczek, LM. An activation model of the cohort theory of auditory word recognition; Paper presented at the Sixteenth Annual Meeting of the Society for Mathematical Psychology; Boulder, Colorado. 1983 Aug.
- Pisoni, DB. In defense of segmental representations in speech processing; Paper presented at the meeting of the Acoustical Society of America; Ottawa, Ontario, Canada. 1981 May.
- Pisoni DB, Luce PA. Acoustic-phonetic representations in word recognition. *Cognition*. (in press).
- Pisoni DB, Nusbaum HC, Luce PA, Slowiaczek LM. Speech perception, word recognition and the structure of the lexicon. *Speech Communication*. 1985; 4:75–95.
- Pollack I. Message uncertainty and message reception: III. Effect of restriction of verbal context. *Journal of Verbal Learning and Verbal Behavior*. 1963; 1:392–395.
- Salasoo A, Pisoni DB. Sources of knowledge in spoken word identification. *Journal of Memory and Language*. 1985; 24:210–231.
- Seidenberg MS, Tanenhaus MK, Leiman JM, Bienkowski M. Automatic access of the meanings of ambiguous words in context: Some limitations of knowledge-based processing. *Cognitive Psychology*. 1982; 14:489–537.
- Slowiaczek LM, Pisoni DB. Effects of phonological similarity on priming in auditory lexical decision. *Memory & Cognition*. 1986; 14:230–237.
- Swinney, DA. The structure and time-course of information interaction during speech comprehension: Lexical segmentation, access, and interpretation. In: Mehler, J.; Walker, ECT.; Garrett, M., editors. *Perspectives on mental representation*. Hillsdale, NJ: Erlbaum; 1982. p. 151-167.
- Tanenhaus MK, Flanagan HP, Seidenberg MS. Orthographic and phonological activation in auditory and visual word recognition. *Memory & Cognition*. 1980; 8:513–520.
- Tyler LK, Marslen-Wilson W. Conjectures and refutations: A reply to Norris. *Cognition*. 1982a; 11:103–107. [PubMed: 7198950]
- Tyler, LK.; Marslen-Wilson, W. Speech comprehension processes. In: Mehler, J.; Walker, ECT.; Garrett, T., editors. *Perspectives on mental representation*. Hillsdale, NJ: Erlbaum; 1982b. p. 169-184.

Figure 1.

Results displaying the probability of correct identification of target words presented at various signal-to-noise ratios in Experiment 1. [Crosses in each panel represent unprimed trials and squares represent primed trials when prime-target overlap equals (a) 0 phonemes, (b) 1 phoneme, (c) 2 phonemes, (d) 3 phonemes, and (e) identical.]

Figure 2.

Results displaying the probability of correct identification of target words presented at various signal-to-noise ratios in Experiment 2. [Crosses in each panel represent uprimed trials and squares represent primed trials when prime-target overlap equals (a) 0 phonemes, (b) 1 phoneme, (c) 2 phonemes, and (d) 3 phonemes.]

Figure 3.

Results displaying the probability of correct identification of target words presented at various signal-to-noise ratios in Experiment 3. [Crosses in each panel represent unprimed trials and squares represent primed trials when prime-target overlap from the end of the words equals (a) 0 phonemes, (b) 1 phoneme, (c) 2 phonemes, (d) 3 phonemes, and (e) identical.]

\$watermark-text

\$watermark-text

\$watermark-text

Table 1

Examples of Word Targets and Word Primes Used in Experiment 1

Number of phonemes shared by prime and target					
Target	0	1	2	3	All
still	dream	sand	stamp	stiff	still
sense	lift	safe	said	send	sense
dread	scream	dove	drill	dress	dread
bald	peck	bank	bought	balls	bald

Table 2

Probability of Correct Identification of Target Words as a Function of Session and Number of Phonemes Shared by Prime and Target: Experiment 1

Number of shared phonemes	Session		Δ
	Unprimed	Primed	
0	.440	.435	-.005
1	.485	.498	.013
2	.492	.590	.098
3	.478	.603	.126
All	.485	.756	.271

Table 3

Examples of Word Targets and Nonword Primes Used in Experiment 2

Target	<u>Number of phonemes shared by prime and target</u>			
	0	1	2	3
place	/dist/	/pem/	/plik/	/plef/
blood	/griks/	/bls/	/blif/	/blʌn/
brown	/glaks/	/bef/	/brIf/	/brauk/
hint	/blaf/	/hob/	/hIg	/hInd/

Table 4

Probability of Correct Identification of Target Words as a Function of Session and Number of Phonemes Shared by Prime and Target: Experiment 2

Number of shared phonemes	Session		Δ
	Unprimed	Primed	
0	.494	.506	.012
1	.543	.557	.014
2	.495	.524	.029
3	.461	.548	.087

\$watermark-text

\$watermark-text

\$watermark-text

Table 5

Examples of Word Targets and Word Primes Used in Experiment 3

Target	Number of phonemes shared by prime and target				
	0	1	2	3	All
hand	fret	dried	send	sand	hand
cold	smug	find	filled	gold	cold
flock	grime	steak	stock	block	flock
trees	plaid	halls	skis	breeze	trees

Table 6

Probability of Correct Identification of Target Words as a Function of Session and Number of Phonemes Shared by Prime and Target: Experiment

Number of shared phonemes	Session		Δ
	Unprimed	Primed	
0	.447	.452	.005
1	.447	.485	.038
2	.410	.485	.075
3	.404	.571	.167
All	.416	.728	.313