

Phonetic priming effects in auditory word recognition

Joan A. Sereno and Allard Jongman

1. Introduction

The present research is concerned with the representation and access of lexical form during spoken language comprehension. We address the nature of the input representation, focusing on how lower-level acoustic-phonetic information is used to access lexical representations in spoken word recognition.

In general, the representation of a given lexical form may be a specific acoustic-phonetic realization of the input, or it may be a more abstract representation which is independent of various sources of acoustic variation such as the sex of the speaker or the rate at which the utterance was produced. Consider, for example, the phoneme /t/ in the words *top* and *stop*. Both words obviously contain a /t/ segment. Nevertheless, /t/ in *top* and /t/ in *stop* are quite distinct acoustically. The acoustic properties or features that make up these segments are different. The /t/ in 'top' is an unvoiced aspirated alveolar stop consonant and is transcribed in a narrow phonetic transcription as [t^h], whereas a /t/ which is not syllable-initial, as in 'stop', is an unvoiced unaspirated alveolar stop consonant and is transcribed as [t].

The question arises whether listeners in the process of spoken language comprehension make use of the difference in acoustic information between these two /t/ segments. Two opposing viewpoints are possible. Either the listener engages all available acoustic-phonetic information to segment words, or else the listener resorts to a segmental representation and uses an abstract representation in accessing the lexicon. When listeners hear an aspirated [t^h], is it the case that they retain the information that this segment is aspirated and that it therefore could only have occurred in syllable-initial position, or do listeners simply categorize this segment as a /t/ phoneme?

The present set of experiments addresses this issue using a priming paradigm. In priming experiments, the relationship between prime and target can be systematically varied. Ordinarily, there is a relationship of meaning (e.g., Meyer and Schvaneveldt, 1971), in which recognition of a target word preceded by an associatively related prime item is facilitated.

Relevant for the present research is the case when prime and target are related phonologically. The most extensively studied topic in this domain is rhyme priming (e.g.,

Meyer, Schvaneveldt, and Ruddy, 1974; Shulman, Hornak, and Sanders, 1978; Hillinger, 1980). In a visual lexical decision task, both Shulman et al. (1978) and Hillinger (1980) found that reaction time to a target item (e.g., *tribe*) is faster when preceded by a graphemically and phonologically related prime (e.g., *bribe*) compared to a control prime. This result suggests that both orthographic and phonological similarity facilitate responses to target items.

Additionally, it has been shown that this effect is not exclusively due to a purely visual effect of overlapping letters. Meyer et al. (1974) and Shulman et al. (1978) contrasted prime-target pairs that were both graphemically and phonologically related (e.g., *bribe-tribe*) to pairs that were only graphemically related (e.g., *freak-break*). Comparing these two conditions to their respective controls, they showed that reaction times to stimuli sharing only graphemic information were slower than those to stimuli sharing both graphemic and phonological information, suggesting that phonological as well as graphemic information is effective in priming.

In an attempt to separate the individual contributions of graphemic and phonological information to the priming effect, Hillinger (1980) used prime-target pairs that shared phonological but not graphemic information (e.g., *eight-mate*). For such phonologically similar but graphemically dissimilar pairs, Hillinger obtained as much facilitation as when prime and target shared both phonological and graphemic information, suggesting that phonological rather than graphemic overlap primarily contributes to the rhyme priming effect. Recently, however, Martin and Jensen (1988) failed to replicate these results and concluded that visual lexical decisions are made without phonological mediation.

Given such conflicting evidence for the role of graphemic and phonological information in visual rhyme priming, it is surprising that so few studies have investigated rhyme priming effects within an auditory paradigm. In a rare example, Burton (1989) obtained significant rhyme priming effects, relative to controls, for both word prime-target pairs (*bat-cat*) and nonword prime-target pairs (*gat-cat*) using an auditory lexical decision task. In these experiments, rhymes were kept orthographically similar since Seidenberg and Tanenhaus (1979) had previously found that orthographic differences did affect rhyme detection when stimuli were presented auditorily.

In general, rhyming can be defined in terms of a preponderant overlap of phonological information between prime and target, as in the rhyming pair *bribe-tribe*. It also involves coincidence at the *end* of words. This is intriguing in light of recent theories emphasizing the importance of information at word *onset*. A prominent theory of spoken word recognition is the Cohort Theory (Marslen-Wilson and Welsh, 1978; Marslen-

Wilson and Tyler, 1980; Marslen-Wilson, 1987). In the Cohort model, there is a continuous mapping of sensory input onto representations of lexical form, starting at word onset. A cohort of all word candidates beginning with the same acoustic-phonetic sequence is activated. Members of this cohort are progressively deactivated on the basis of incoming lower-level (acoustic-phonetic) and higher-level (semantic and syntactic) information until only the word to be recognized remains activated. According to the Cohort model, then, words are apprehended in a serial fashion beginning at their onset.

To test the claims of the Cohort model, Slowiaczek, Nusbaum, and Pisoni (1987) examined 'phonological priming' effects by varying the number of phonemes that prime and target shared. In contrast to previous studies investigating rhyme priming, the overlap in phonological information occurred starting from word *onset*. Slowiaczek et al. (1987) used an identification task in which subjects were to identify target words embedded in noise at various signal-to-noise ratios. These target words were preceded by prime words in the clear which shared zero, one, two, three, or all phonemes with the target, beginning at word onset. For example, for a given target (*dread*), the prime had either: 1) no phonemes in common (*scream*), 2) one phoneme in common (*dove*), 3) two phonemes in common (*drill*), 4) three phonemes in common (*dress*), or 5) all phonemes in common (*dread*). According to the Cohort model, one might expect an increase in facilitation to target items as the phonological overlap between prime and target increased. Overall, phonological priming did track phonological overlap between prime and target. However, no significant differences were obtained between unrelated primes and primes with one phoneme overlap, nor between primes with two and three phonemes in common. Thus, these results only tepidly support Cohort theory since priming was not observed when prime and target had one phoneme in common, and priming did not increase from two to three shared phonemes.

In a follow-up study using similar experimental conditions, Slowiaczek and Pisoni (1986)¹ found that facilitation occurred only in the identity condition in which prime and target shared all phonemes. In all other conditions, no facilitation was observed relative to the baseline condition (no phonemes in common). Instead of an identification task, Slowiaczek and Pisoni (1986) used an auditory lexical decision task. Based on their finding that partial phonological overlap did not facilitate responses to target items, Slowiaczek and Pisoni (1986) concluded that the Cohort model was not supported. Similar results from both lexical decision and shadowing experiments have also recently been reported (Radeau, Morais, and Dewier, 1989).

However, as Slowiaczek and Pisoni (1986) suggest, the lack of phonological priming

(with the exception of the identity condition) might be due to the use of whole-word primes which created an inhibition effect, thereby obscuring priming that may have been present. Slowiaczek and Pisoni (1986) also invoked the notion of task demands to resolve the difference in results between their study and that of Slowiaczek et al. (1987). In order to recognize a word in the perceptual identification task, subjects were compelled to use the phonological information in the signal. Furthermore, the use of white noise in the perceptual identification task degraded stimulus information such that subjects attended inordinately to phonological cues. In the lexical decision task, this phonological information may already have been replaced by a more abstract lexical representation. Slowiaczek and Pisoni (1986) conclude, for these reasons, that the perceptual identification task may be more sensitive to phonological information than the lexical decision task.

In order to investigate partial phonological priming, we devised a technique which we will call 'phonetic' priming. Phonetic priming employs a priming paradigm in which subjects are to make a lexical decision to a target item when preceded by either a neutral or related prime item. Both prime and target are presented auditorily. However, in contrast to the traditional auditory priming paradigm, the prime consists of a single phonetic segment rather than a word or nonword. The phonetic priming paradigm offers several advantages. As with previous methodologies, this paradigm allows variation in overlap (e.g., initial, medial, or final) between prime and target. Importantly, however, using a single phonetic segment strips the prime of lexical status. Priming effects will therefore not be inhibited by the use of whole-word primes, as may have been the case in Slowiaczek and Pisoni (1986). Finally, presentation of a single phonetic segment for a limited duration substantially reduces the temporal interval between prime and target, enhancing sensitivity to early processes of auditory word recognition.

The next sections describe two experiments using the phonetic priming paradigm to test whether listeners are sensitive to isolated phonemic information during word recognition. The first experiment involves vowels in medial position while the second experiment focuses on fricatives in initial position.

2. Experiment 1 - Vowel Phonetic Priming

The purpose of this experiment was to determine whether a phonetic segment prime facilitates the response to a stimulus item containing that segment. In this experiment, an isolated vowel segment [e,a,o] preceded target items containing that vowel sound in medial position. Both word and nonword target items were employed and these stimuli

were presented to subjects in an auditory lexical decision task.

2.1 Method

2.1.1 Subjects. Thirty university students from the subject pool at the Max Planck Institute for Psycholinguistics were paid to participate in the experiment. All were native speakers of Dutch and reported no history of speech or hearing disorders.

2.1.2 Stimuli. Seventy-two stimuli (36 words and 36 nonwords) were used in this experiment. The 36 word stimuli were selected from the Dutch written word frequency norms collected by Uit den Boogaart (1975). All words were monosyllabic nouns, with 12 words containing the stressed vowel [e], 12 containing the stressed vowel [a], and 12 containing the stressed vowel [o].

The vowels [e,a,o] were chosen since they are monophthongal and are phonemically long (Cohen, Ebeling, Fokkema, and Van Holk, 1972; Trommelen and Zonneveld, 1979). In Dutch, only long vowels occur in syllable-final position while short vowels occur only in closed syllables. It is, therefore, possible for long vowels to occur in isolation while short vowels cannot. For this reason, only long vowels were used as primes in this experiment.

The vowels [e,a,o] can be categorized on the basis of features that make up these segments (Chomsky and Halle, 1968). Dutch vowels are voiced and they are typically defined in terms of the position of the articulators (the tongue and lips), with the dimensions height, backness, and roundness being most relevant. In this way, [e] can be described as [+high], [-back], [-round]; [a] as [-high], [+back], [-round]; and [o] as [+high], [+back], [+round].

Words in all vowel subgroups were matched for frequency (Uit den Boogaart, 1975). The mean frequency of occurrence per million for words containing [e], [a], [o] was 44, 37, and 47, respectively.

In addition, a set of 36 monosyllabic nonwords was constructed, one third of which contained the stressed vowel [e], one third [a], and one third [o]. All nonwords obeyed the phonotactic constraints of Dutch (see Bakker, 1971).

All word and nonword stimuli were consonant-initial, with a (C)CVC(C) structure, and they were matched for mean number of phonemes.

All subgroups were of comparable duration. For the word stimuli, durations for words containing [e], [a], and [o] were 477 ms, 476 ms, and 479 ms, respectively, while for the nonwords mean durations were 484 ms, 484 ms, and 485 ms, respectively.

Durations of the isolated prime vowels [e], [a], and [o] were 219 ms, 217 ms, and 220 ms, respectively.

2.1.3 Stimulus Preparation. All stimuli were recorded by a male speaker on a Revox B77 MK II tape recorder in a sound-proof booth (Philips amplisilence) using a Sennheiser MD211N microphone. The words and nonwords were read in a list and the prime segments were produced in isolation. The stimuli were digitized on a VAX750 computer at a sampling rate of 20 kHz with a 10 kHz low-pass filter setting. The stimuli were then excised using both auditory and visual criteria.

Three test conditions were constructed so that every subject heard all target items but no subject heard a target item more than once. Thus, in each condition there were 12 target words and 12 target nonwords each containing the vowel [e], [a], and [o]. All target words and nonwords were preceded by one of the priming vowel segments [e,a,o]. One third of these target items was preceded by a matching vowel prime and two thirds by a non-matching vowel prime.

Three experimental tapes (one for each condition) were prepared. On the second channel of each tape, a timing pulse was set concurrently with the acoustic onset of the target stimuli. This pulse served to start the clock of a MicroMax computer which stored responses and reaction times.

The stimuli were presented at a fixed rate with a prime stimulus followed by a target item. There was a 200 ms ISI between offset of the prime and onset of the target. Reaction times were measured from the onset of the target until a key press was made. Following the offset of the target, there was a 3 second silent interval until the next trial started. This sequence was repeated for each stimulus item.

2.1.4 Procedure. All subjects were tested individually in an auditory lexical decision task. The test tapes were played to subjects on a Revox B77 tape recorder using Sennheiser HD424 headphones. Subjects were told that on each trial they would hear a vowel sound (either [e], [a], or [o]) followed by a target stimulus, and that they were to identify the target stimulus as either a word or a nonword. Subjects were instructed to respond as quickly and accurately as possible to each target item. All responses were made by pressing one of two clearly marked buttons on a response box placed in front of the subject. Each trial was completed when subjects used the index finger of their preferred hand to press one of two equidistantly-placed response buttons. Following instructions, subjects were given a set of 10 practice items to introduce them to the procedure. These

practice items were not used in the experiment. The entire experiment lasted approximately 30 minutes.

3. Results

Mean lexical decision latencies and error rates for the different experimental conditions of Experiment 1 are given in Table 1. The data in all experiments were submitted to an analysis of variance (ANOVA) with both subjects (F1) and items (F2) as random variables. All means presented are taken from the subject analyses. There was a total of 72 errors in this experiment, representing 3.3% of all responses. All trials in which errors occurred were excluded from the reaction time analyses.

A three-way ANOVA (Lexical Status X Target Vowel X Prime Vowel) was conducted. Three effects were significant only in the subject analysis: a main effect for Lexical Status [$F(1,29)=8.20$, $MSe=8034$, $p<.008$; $F(1,66)=1.18$, $MSe=20982$, $p>.25$]; a main effect of Target Vowel [$F(2,58)=15.52$, $MSe=3465$, $p<.001$; $F(2,66)=1.25$, $MSe=20982$, $p>.25$]; and a Lexical Status X Target Vowel interaction [$F(2,58)=14.42$, $MSe=4216$, $p<.001$; $F(2,66)=1.17$, $MSe=20982$, $p>.30$]. However, none of these effects was significant in the item analysis and therefore they are not generalizable. There was also a significant Lexical Status X Target Vowel X Prime Vowel interaction in both subject and item analyses [$F(4,116)=3.68$, $MSe=4989$, $p<.007$; $F(4,132)=3.15$, $MSe=1720$, $p<.02$]. Mean reaction times for word and nonword stimuli are given in Table 1 for each target vowel preceded by each prime vowel. In general, identical vowels in prime and target words facilitated reaction time relative to non-identical controls while a contrasting pattern occurred for identical and non-identical vowels in nonwords.

Separate analyses were conducted on the words and nonwords. For the words, a two-way ANOVA (Target Vowel X Prime Vowel) revealed a main effect of Target Vowel only in the subject analysis [$F(2,58)=24.52$, $MSe=3443$, $p<.001$; $F(2,33)=1.96$, $MSe=18490$, $p>.15$]. There was a significant interaction between Target Vowel and Prime Vowel [$F(4,116)=3.70$, $MSe=6562$, $p<.007$; $F(4,66)=3.99$, $MSe=1839$, $p<.006$]. A posthoc Scheffe comparison revealed that reaction times to word stimuli (840 ms) preceded by a matching prime vowel were significantly faster than to word stimuli (870 ms) preceded by a non-matching prime vowel ($p<.05$).

For the nonwords, a two-way ANOVA (Target Vowel X Prime Vowel) revealed a main effect of Target Vowel only in the subject analysis [$F(2,58)=7.10$, $MSe=4237$, $p<.002$; $F(2,33)=.62$, $MSe=23473$, $p>.50$]. There were no other significant main

WORDS

target vowel	prime		
	[e]	[a]	[o]
[e]	854 (5.0)	861 (3.3)	875 (5.0)
[a]	917 (2.5)	860 (5.8)	889 (5.8)
[o]	819 (7.5)	857 (6.7)	807 (7.5)

NONWORDS

target vowel	prime		
	[e]	[a]	[o]
[e]	856 (0.8)	860 (0.0)	867 (4.2)
[a]	877 (2.5)	898 (0.8)	905 (0.0)
[o]	890 (0.8)	886 (0.0)	900 (1.7)

Table 1. Mean response latencies (ms) and error rates (percent) for word targets (top) and nonword targets (bottom) obtained in the vowel phonetic priming experiment (Experiment 1).

effects or interactions.

Further analyses were conducted in which the vowels were analyzed in terms of their distinctive features ([high], [back], and [round]). Both prime and target vowels were classified in this fashion. In these analyses, means were first calculated by collapsing over the relevant feature. Three separate ANOVAs, one for each feature contrast ([high], [back], and [round]), were then conducted. For example, for the feature [round], the vowels [e] and [a] (both unrounded vowels) were contrasted to the rounded vowel [o]. It should be noted that these are not optimal contrasts due to language constraints of Dutch. The two contrasting groups differ not only in terms of the vowel feature under consideration ([round]) but also in terms of the other defining vowel features ([high], [back]). None of the feature analyses revealed any significant differences. Reaction times to target stimuli preceded by a prime vowel that matched on one of these features were not significantly different from reaction times to target stimuli that did not match in terms of that same feature.

An analysis of the error data was also conducted. A three-way ANOVA (Lexical Status X Target Vowel X Prime Vowel) revealed a main effect of Lexical Status ($F(1, 29)=28.62$, $MSe=.14$, $p<.001$; $F(1, 66)=4.67$, $MSe=2.10$, $p<.03$). There were significantly more errors for word targets (59 errors) compared to nonword targets (13 errors). There were no other significant main effects or interactions.

4. Discussion

Experiment 1 showed that prior presentation of a vowel segment in isolation influenced the processing of a following target stimulus containing that vowel. This significant interaction between the prime vowel and the target vowel depended on the lexical status of the target. Reaction times to word targets with matching prime and target vowels were facilitated relative to word targets with non-matching prime and target vowels. This facilitation for target words with matching prime and target vowels depended on the exact identity of the vowel segment in the prime and target stimuli occurring in target-medial position. For the nonword stimuli, response times to nonword stimuli with matching prime and target vowels were not significantly different from responses to nonword stimuli with non-matching prime and target vowels.

Having obtained vowel phonetic priming, it was of interest to determine whether this effect could be generalized to other positions in the target stimulus. A second experiment investigating priming of segments in word-initial position was therefore conducted.

5. Experiment 2 - Fricative Phonetic Priming

The purpose of this experiment was to establish whether a phonetic segment prime facilitates the response to a stimulus item that contains that segment. In this experiment, a fricative segment [f,v,s,z] preceded target items containing that fricative sound in initial position. Both word and nonword target items were employed and these stimuli were presented to subjects in an auditory lexical decision task.

5.1 Method

5.1.1 Subjects. Forty university students from the subject pool at the Max Planck Institute for Psycholinguistics were paid to participate in the experiment. All were native speakers of Dutch and reported no history of speech or hearing disorders. None of these subjects had participated in the previous experiment.

5.1.2 Stimuli. One hundred twenty-eight stimulus items (64 words and 64 nonwords) were used in this experiment. The 64 word stimuli were selected from the Dutch written frequency norms of Uit den Boogaart (1975). One half of the words were monosyllabic nouns and the remaining half were bisyllabic nouns. All bisyllabic words had first-syllable stress. The word stimuli were equally divided into four subgroups in terms of their onset consonant, with 16 words each having an initial [f], [v], [s], or [z] fricative segment. None of the stimuli began with a consonant cluster and no stimulus contained any of the fricative segments [f,v,s,z] in non-initial position.

The consonants [f,v,s,z] can also be categorized on the basis of features that make up these segments (Chomsky and Halle, 1968). The segments [f,v] and [s,z] can be distinguished in terms of their place of articulation. [f] and [v] are characterized by the feature [-coronal] and are classified as labiodental fricatives whereas [s] and [z] share the feature [+coronal] and are classified as alveolar fricatives. In a similar fashion, the segments [f,s] and [v,z] are contrasted in terms of voicing. [f] and [s] are characterized as [-voice] and are classified as unvoiced fricatives whereas [v] and [z] share the feature [+voice] and are classified as voiced fricatives.

All subgroups were matched for word frequency on the basis of the frequency norms for Dutch (Uit den Boogaart, 1975). The mean frequency of occurrence per million for words beginning with [f], [v], [s], and [z] was 19, 23, 17, and 31, respectively.

Additionally, a set of 64 nonwords was constructed. One half of the stimuli was monosyllabic and one half bisyllabic. All bisyllabic nonwords were to be pronounced with first-syllable stress. These items were also equally divided in terms of their onset

consonant, with 16 nonwords each having an initial [f], [v], [s], or [z] fricative segment. All items obeyed the phonotactic constraints of Dutch (see Bakker, 1971).

Word and nonword stimuli were matched for mean number of phonemes. All subgroups were also of comparable duration. For the word stimuli, durations for words containing [f], [v], [s], and [z] were 611 ms, 556 ms, 607 ms, and 575 ms, respectively, while for the nonwords, mean durations were 619 ms, 599 ms, 628 ms, and 599 ms, respectively. Durations of the isolated prime fricative segments [f], [v], [s], and [z] were 196 ms, 195 ms, 198 ms, and 196 ms, respectively. It has previously been shown that listeners identify fricatives very accurately when presented with the frication noise in isolation (Jongman, 1989).

5.1.3 Stimulus Preparation. The stimuli were recorded, digitized, and excised as described in Experiment 1. For this experiment, four test conditions were constructed so that every subject heard all target items but no subject heard a target item more than once. Thus, in each condition there were 16 target words and 16 target nonwords each beginning with an initial [f], an initial [v], an initial [s], and an initial [z] fricative segment. All target words and nonwords were preceded by one of the fricative primes [f,v,s,z]. One fourth of these target items was preceded by a matching fricative prime and three fourths by a non-matching fricative prime.

Four experimental tapes (one for each condition) were then prepared. All stimulus presentation and response procedures were the same as those described in Experiment 1.

5.1.4 Procedure. All subjects were tested individually in an auditory lexical decision task. Subjects were told that on each trial they would hear an isolated fricative sound (either [f], [v], [s], or [z]) followed by a target, and that they were to identify each target as either a word or a nonword. All other experimental procedures were identical to those in Experiment 1. The entire experiment lasted approximately 30 minutes.

6. Results

Mean lexical decision latencies and error rates for the different conditions of Experiment 2 are given in Table 2. The total number of errors was 219, representing 4.3% of all responses. All trials in which errors occurred were excluded from the reaction time analyses.

A three-way ANOVA (Lexical Status X Target Fricative X Prime Fricative) was conducted. There was a significant main effect of Lexical Status [$F(1,39)=28.72$,

MSe=32939, $p<.001$; $F_2(1,120)=25.16$, MSe=19629, $p<.001$]. Responses to words (969 ms) were significantly faster than those to nonwords (1023 ms). A main effect was also obtained for Target Fricative [$F_1(3,117)=36.63$, MSe=7991, $p<.001$; $F_2(3,120)=6.10$, MSe=19629, $p<.001$]. A Newman-Keuls posthoc test showed that targets beginning with the fricative [f] (1034 ms) were significantly slower than targets beginning with the fricatives [v] (968 ms) ($p<.01$), [s] (1006 ms) ($p<.05$), and [z] (976 ms) ($p<.01$) and that targets beginning with the fricative [s] (1006 ms) were significantly slower than targets beginning with the fricatives [z] (976 ms) ($p<.05$) and [v] (968 ms) ($p<.05$). There were no other significant main effects or interactions.

Additional analyses of the data were conducted examining the contribution of phonetic features as contrasted to phonetic segments. The phonetic feature analysis of the data involved the following factors: Lexical Status (target is either a word or a nonword); Place (fricatives are categorized in terms of place of articulation, with [f,v] as labiodental and [s,z] as alveolar; and Voicing ([f,s] as voiceless and [v,z] as voiced)(e.g., Ladefoged, 1975). The latter two factors (Place and Voicing) were appropriate for classification of both primes and targets.

A five-way ANOVA (Lexical Status X Target Place X Target Voicing X Prime Place X Prime Voicing) yielded the following results. There was a main effect for Lexical Status [$F_1(1,39)=28.72$, MSe=32939, $p<.001$; $F_2(1,120)=25.16$, MSe=19629, $p<.001$]. As stated earlier, responses to words were significantly faster than to nonwords. A main effect also obtained for Target Voicing [$F_1(1,39)=65.22$, MSe=11369, $p<.001$; $F_2(1,120)=15.78$, MSe=19629, $p<.001$]. Responses to targets beginning with the voiced fricatives [v,z] (972 ms) were significantly faster than responses to targets beginning with the voiceless fricatives [f,s] (1020 ms). The only other significant finding was a Lexical Status X Target Place X Prime Place interaction [$F_1(1,39)=13.27$, MSe=6091, $p<.001$; $F_2(1,120)=8.55$, MSe=2424, $p<.004$]. As shown in Table 3, responses to word targets were facilitated when prime and target fricative shared the same place of articulation (962 ms) compared to a different place of articulation (976 ms), while an opposite pattern obtained for nonwords. Responses to nonword targets were inhibited when prime and target fricative matched in terms of place of articulation (1033 ms) relative to when they mismatched (1014 ms). There were no other significant main effects or interactions.

Separate analyses were then conducted on the word and nonword data. For the word stimuli, a two-way ANOVA (Target Fricative X Prime Fricative) was conducted. There was a significant main effect of Target Fricative [$F_1(3,117)=26.66$, MSe=6659,

WORDS

target onset	prime			
	[f]	[v]	[s]	[z]
[f]	1019 (5.6)	1001 (6.9)	1021 (8.1)	1016 (6.3)
[v]	949 (6.3)	931 (9.4)	967 (10.6)	958 (7.5)
[s]	973 (5.0)	974 (4.4)	972 (4.4)	966 (2.5)
[z]	940 (4.4)	954 (3.8)	939 (3.8)	919 (5.0)

NONWORDS

target onset	prime			
	[f]	[v]	[s]	[z]
[f]	1067 (4.4)	1056 (0.6)	1038 (0.6)	1054 (2.5)
[v]	1003 (1.9)	982 (2.5)	973 (0.0)	981 (1.3)
[s]	1022 (5.6)	1042 (6.3)	1052 (3.8)	1046 (3.8)
[z]	984 (2.5)	1015 (2.5)	1020 (1.9)	1034 (3.1)

Table 2. Mean response latencies (ms) and error rates (percent) for word targets (top) and nonword targets (bottom) obtained in the fricative phonetic priming experiment (Experiment 2).

WORDS

target onset	prime	
	labiodental [f,v]	alveolar [s,z]
labiodental [f,v]	975 (7.0)	991 (8.1)
alveolar [s,z]	960 (4.4)	949 (3.9)

NONWORDS

target onset	prime	
	labiodental [f,v]	alveolar [s,z]
labiodental [f,v]	1027 (2.3)	1012 (1.1)
alveolar [s,z]	1016 (4.2)	1038 (3.1)

Table 3. Mean response latencies (ms) and error rates (percent) for word targets (top) and nonword targets (bottom) obtained in the fricative phonetic priming experiment (Experiment 2) for the feature analysis.

$p < .001$; $F_2(3,60) = 3.10$, $MSe = 23878$, $p < .033$]. A Newman-Keuls posthoc test revealed that word targets beginning with the fricative [f] (1014 ms) were significantly slower than word targets beginning with the fricatives [v] (951 ms) ($p < .01$), [s] (971 ms) ($p < .05$), and [z] (938 ms) ($p < .01$).

The word data were also analyzed in terms of phonetic features. A four-way ANOVA (Prime Place X Prime Voicing X Target Place X Target Voicing) yielded the following results. There was a main effect of Target Voicing [$F_1(1,39) = 64.04$, $MSe = 5777$, $p < .001$; $F_2(1,60) = 6.52$, $MSe = 23878$, $p < .02$]. Responses to word targets beginning with the voiced fricatives [v,z] (945 ms) were significantly faster than those to word targets beginning with the voiceless fricatives [f,s] (993 ms). There was a significant interaction of Target Place X Prime Place [$F_1(1,39) = 4.10$, $MSe = 6625$, $p < .05$; $F_2(1,60) = 3.69$, $MSe = 2775$, $p < .05$]. For words, reaction times to targets beginning with the labiodental fricatives [f,v] were facilitated when preceded by primes beginning with the labiodental fricatives [f,v] (975 ms) as compared to primes beginning with the alveolar fricatives [s,z] (991 ms), and reaction times to targets beginning with the alveolar fricatives [s,z] were facilitated when preceded by primes beginning with the alveolar fricatives [s,z] (949 ms) as compared to primes beginning with the labiodental fricatives [f,v] (960 ms).

For the nonwords, a two-way ANOVA (Target Fricative X Prime Fricative) revealed a main effect of Target Fricative [$F_1(3,117) = 19.16$, $MSe = 7830$, $p < .001$; $F_2(3,60) = 3.79$, $MSe = 15381$, $p < .02$]. A Newman-Keuls posthoc test revealed that nonword targets beginning with the fricative [v] (985 ms) were significantly faster than nonword targets beginning with the fricatives [f] (1054 ms) ($p < .01$) and [s] (1041 ms) ($p < .05$).

For the feature analysis of the nonword data, a four-way ANOVA (Target Place X Target Voicing X Prime Place X Prime Voicing) was conducted. A main effect was found for Target Voicing [$F_1(1,39) = 33.14$, $MSe = 11211$, $p < .001$; $F_2(1,60) = 10.02$, $MSe = 15381$, $p < .002$]. Reaction times to nonword targets with voiced fricatives [v,z] (999 ms) were significantly faster than to nonword targets with voiceless fricatives [f,s] (1048 ms). There was also a significant interaction of Target Place X Prime Place [$F_1(1,39) = 6.29$, $MSe = 8947$, $p < .02$; $F_2(1,60) = 5.06$, $MSe = 2073$, $p < .03$]. For nonwords, reaction times to targets beginning with the labiodental fricatives [f,v] were inhibited when preceded by primes beginning with the labiodental fricatives [f,v] (1027 ms) as compared to primes with the alveolar fricatives [s,z] (1012 ms), and reaction times to targets beginning with the alveolar fricatives [s,z] were inhibited when preceded by primes beginning with the alveolar fricatives [s,z] (1038 ms) as compared to primes with

labiodental fricatives (1016 ms).

An analysis of the error data was also conducted. A three-way ANOVA (Lexical Status X Target Fricative X Prime Fricative) revealed a main effect of Lexical Status ($[F(1,39)=20.40, MSe=.28, p<.001; F(1,120)=5.58, MSe=2.30, p<.02]$). There were significantly more errors for word targets (150 errors) compared to nonword targets (69 errors). There were no other significant main effects or interactions.

The error data were also analyzed in terms of phonetic features. A five-way ANOVA (Lexical Status X Target Place X Target Voicing X Prime Place X Prime Voicing) revealed a significant main effect for Lexical Status, identical to the segment analysis reported above. There were no other significant main effects or interactions.

7. Discussion

Experiment 2 produced the expected effect of lexical status wherein words were recognized faster than nonwords. In addition, reaction times to both words and nonwords beginning with voiced fricatives [v,z] were faster compared to words and nonwords beginning with voiceless fricatives [f,s]. While this latter effect might seem puzzling, a simple explanation may be found in terms of stimulus duration. The mean duration of target items beginning with [v,z] (582 ms) was significantly shorter than that of targets beginning with [f,s] (617 ms) [$t=2.37, df=126, p<.02$]. Since there was a significant correlation between stimulus duration and reaction time (Pearson correlation, $r=.5043, p<.001$), the difference in reaction time found between voiced and voiceless target items may be due to the 35 ms difference in stimulus duration.

More importantly, however, the fricative priming experiment showed that prior presentation of a fricative segment in isolation influenced the processing of the following target stimulus. For word targets, reaction times to target words with matching prime and target fricative segments were *facilitated* compared to word targets with non-matching prime and target fricatives. Conversely, reaction times to target nonwords with matching prime and target fricative segments were *inhibited* compared to nonword targets with non-matching prime and target fricatives.

However, this facilitation for target words and inhibition for nonwords with matching prime and target fricatives did not depend on the exact identity of the fricative segment in the prime and target stimuli. Instead, it was based on a match in terms of place of articulation, regardless of voicing. When the initial consonant of prime and target shared the same place of articulation, responses to target words were facilitated and responses to target nonwords were inhibited relative to a non-matching baseline.

8. General Discussion

The present study describes two auditory lexical decision experiments using a phonetic priming paradigm. Both experiments showed that prior presentation of an isolated phonetic segment affected responses to targets containing an identical or similar segment. Facilitation was observed for word targets with matching prime and target phonetic segments, and an opposite effect obtained for nonword targets with matching prime and target phonetic segments. The results for the word stimuli will first be considered, followed by the nonword data.

In Experiment 1, a vowel segment [e,a,o] facilitated responses to target words containing an identical vowel segment as compared to responses to target words containing a non-identical vowel segment. This facilitation was based on the exact identity between prime and target vowel. This result clearly shows the effectiveness of phonetic priming as a novel procedure to test phonetic and phonological aspects of word recognition processes. First, primes consisted of brief, vowel segments, approximately 200 ms in duration, thereby allowing a substantially reduced temporal interval between prime and target. By restricting the stimulus onset asynchrony (SOA) in such a manner, a relatively early stage of word recognition could be investigated (see, e.g., Sereno, 1991). But the more important promise of such a methodology concerns the nature of the prime. Since the prime is a phonetic segment, it is not encumbered with lexical status. In fact, phonetic priming was observed even in the 'less-phonetically-sensitive' lexical decision task. The present results suggest that the difference in results between Slowiaczek et al. (1987) and Slowiaczek and Pisoni (1986) may not be due exclusively to task differences. In contrast to Slowiaczek and Pisoni (1986), the present results indicate that the lexical decision task can be used to tap into a level at which phonological information has not yet been replaced by a more abstract lexical representation. Since, in the present study, phonetic priming was observed using isolated phonetic segments, the lack of partial phonological priming as reported by Slowiaczek and Pisoni (1986) may have been primarily caused by inhibition due to the use of whole word or nonword primes, as the authors themselves have suggested.

In Experiment 2, fricative primes [f,v,s,z] speeded reaction times to word targets containing a similar fricative in initial position. This priming effect, however, was based on a partial overlap of features rather than an exact identity between prime segments and target stimuli. This featural priming appeared only when prime and target fricative shared the same place of articulation and did not depend on a match in terms of voicing. That is, labiodental fricatives primed target words beginning with labiodental fricative segments

and alveolar fricatives primed target words beginning with alveolar fricative segments.

These results suggest that subphonemic or featural rather than phonemic or segmental information may play the more important role in lexical access. This finding is supported by the recent research of Marslen-Wilson and Warren (1990) and Lahiri and Marslen-Wilson (1991). Marslen-Wilson and Warren (1990), for example, contrasted a 'segmental' and a 'featural' hypothesis. The segmental hypothesis assumes that phonetic cues are integrated pre-lexically. Lexical access is then mediated by resulting segmental labels. In the featural hypothesis, phonetic cues are integrated at the lexical level. That is, featural information available in the speech signal is directly projected onto the lexicon. Using a lexical decision task in which subjects responded to cross-spliced stimuli with conflicting phonetic cues to place of articulation, Marslen-Wilson and Warren (1990) obtained evidence in favor of the featural hypothesis. They concluded that features are extracted at a pre-lexical level and mapped directly onto lexical representations. The present fricative priming results also suggest that priming is based on the extraction of featural information.

Some recent speech production experiments (Meyer and Gordon, 1985) provide data consistent with the hypothesis that phonetic features are involved in the mechanisms that underlie speech processing. In these experiments, subjects either produced two CV syllables (e.g., [ba], [da]) in sequential order (the primary response) or they produced these two CV syllables in the reverse order (the secondary response). Meyer and Gordon (1985) found longer latencies and more errors when the consonants of the secondary response pair were related (that is, when they shared either a place of articulation feature or a voicing feature) relative to an unrelated control condition. These results suggest that phonetic features play a significant role in the programming and execution of speech sounds. Yaniv, Meyer, Gordon, Huff, and Sevald (1990) also provide additional supportive data for a phonetic feature analysis by examining vocal responses to syllable pairs which contrasted in terms of their medial vowels.

However, Gordon and Meyer (1984) and Meyer and Gordon (1984), using a slightly different experimental procedure, found that shared voicing features influenced response latencies more than shared place of articulation features, suggesting that some features may be more salient than others (see also Miller and Nicely, 1955). Unfortunately, no concrete explanation was given for the differences among experiments. Moreover, other researchers (e.g., Peters, 1963; Shepard, 1972; MacNeilage and Ladefoged, 1976; Pisoni, 1978) have reported that place and voicing features participate equally or even that place of articulation features may be more salient than voicing features in their contribution

to speech perception. It is clear that more research is needed to obtain converging evidence for the status of the features of voicing and place of articulation in the perception and production of speech.

If fricative priming is based on an overlap of features, a question that remains is why no identity priming is observed. When prime and target fricative are identical, they share information about both place and voicing. With identity priming, an increase rather than a decrease in facilitation could be expected. The lack of identity priming in Experiment 2 may be compatible with certain recent developments in phonological theory. One such development is a phonological theory of underspecification which argues that segments are underspecified in their underlying phonological representation (e.g., Archangeli, 1984). That is, instead of all featural information being specified for a particular segment, only the *marked, distinctive* information (i.e., the minimal information necessary to distinguish the segment from all other segments in the language) for that segment is listed in its underlying representation. Based on data from a wide variety of languages, underspecification theory claims that for the feature [voice], for example, only the marked value (i.e., the presence of voicing), represented as [+voice], is specified (Mester and Ito, 1989). In the underlying representation, then, both [v] and [z] are specified as [+voice] whereas [f] and [s] are unspecified and, as such, are underlyingly ambiguous with respect to voicing.

In the context of the present experiment, such an account implies that segments may not necessarily be better primes than a subset of their features. When hearing [f] or [s], for example, the listener cannot be sure about the voicing status of these segments since they are unspecified. In contrast, place of articulation always provides an unambiguous cue to the segment's identity. Since [f,v,s,z] are all underlyingly specified in terms of place of articulation but only [v,z] are underlyingly specified in terms of voicing, priming may be observed based on a match in terms of place of articulation rather than a match in both place and voicing.

The fact that identity priming rather than feature priming obtained for the vowels can also be explained within a theory of phonological underspecification. In this theory, there is an asymmetry in the feature specification of [f,v,s,z] such that all these fricatives are underlyingly specified in terms of place of articulation but all are not specified in terms of voicing. However, for the vowels [e,a,o], there can be no such asymmetry. The features [high], [back] and [round] are all underlyingly specified, since they are necessary to distinguish among these three vowels. For the vowels, then, since all features are underlyingly specified, priming is expected to be observed when all features overlap

(identity priming), rather than when a subset of these features overlap.

Finally, priming was observed when the matching phonetic segment occurred in either word-medial (Experiment 1) or word-initial (Experiment 2) position. The existence of both medial and initial priming suggests that matching segments at either location facilitate lexical access processes. These findings may be compatible with results of Cutler (1976) and Cutler and Norris (1988) who suggest that a lexical search is initiated on the basis of the strong syllable in a word. Specifically, Cutler and Norris (1988) showed that word detection is delayed when the word consists of two strong syllables, but not when it consists of a strong followed by a weak syllable. They view their data as supporting a model in which only strong syllables trigger a lexical search.

In the present two experiments, the primed phonetic segments always occurred in the strong syllable of the target stimulus. In Experiment 1, only monosyllabic stimuli were used, and in Experiment 2, all bisyllabic stimuli were of the strong-weak type. Thus, both the medial vowel and the initial fricative priming results are compatible with a model in which lexical access is initiated by the strong syllable in a word. However, to explicitly evaluate Cutler's strong syllable proposal, additional experiments would have to be conducted using polysyllabic target stimuli in which the primed segment occurs in either the strong or the weak syllable.

Both the vowel and the fricative phonetic priming experiments showed a contrasting pattern of results in the word targets as compared to the nonword targets with regard to matching and non-matching phonetic features. These results can be interpreted in terms of current interactive-activation models of word recognition (Elman and McClelland, 1984; McClelland and Elman, 1986). In such models, processing units or nodes have excitatory connections between levels and inhibitory connections within levels. Depending on the input, these connections either raise or lower activation levels. Thus, phoneme nodes, for example, have excitatory connections to word level nodes, with the strength of the connections depending on whether the phoneme is present or absent in the word. Phoneme nodes also have inhibitory connections to each other.

The present phonetic priming results can be interpreted within such a framework. Upon hearing the fricative phoneme [s], for example, activation is transmitted from the appropriate [s] phoneme node to higher level word nodes containing that phoneme (e.g., sin, salt, sofa, saint, sad, etc.). Activation of these word nodes is thus raised toward their threshold, thereby increasing the probability that a word node containing the fricative phoneme [s] will exceed its threshold and be activated. Word nodes with non-matching consonants do not have raised activation levels, thus requiring more confirmatory input

evidence to reach threshold. Therefore, reaction times to words with matching phonemes will be facilitated relative to reaction times to words with non-matching phonemes.

The story for nonword stimuli is initially similar to that for nonwords but, ultimately, different effects occur since no word nodes are activated. As stated earlier, presentation of the [s] phoneme will produce activation at the word level for words that contain the [s] phoneme. However, when a nonword stimulus is then presented, although, initially, there are raised activation levels for word nodes containing the [s] phoneme, these raised activation levels at the word level do not facilitate a nonword response to nonwords containing the [s] phoneme compared to nonwords which do not contain the [s] phoneme. In fact, raised activation levels for word nodes have generally been found to inhibit nonword responses. For example, both Coltheart, Davelaar, Jonasson, and Besner (1977) and Luce (1986) demonstrated that the number and nature of the words activated by a nonword stimulus influenced reaction time. Specifically, nonwords in high density and high frequency word neighborhoods were responded to more slowly than nonwords in low density and low frequency word neighborhoods. These results suggest that for nonword stimuli, activation of related words does not make responses faster or easier. Rather, activation of word neighbors at the word level appears to inhibit nonword responses. In the context of the present set of experiments, for nonword stimuli, the initial facilitation (that is, a lowered threshold) resulting from a matching phoneme between prime and target is nullified by raised activation of word neighbors which ultimately inhibits nonword responses. In fact, following the presentation of the [s] phoneme, reaction times to nonwords containing the [s] phoneme are inhibited relative to reaction times to nonwords that do not contain the [s] phoneme. Thus, over time, response latencies to word stimuli with a matching phonetic segment are facilitated as a result of activation of word neighbors while nonwords with a matching phonetic segment are inhibited.

Our results, however, suggest that this processing takes place at the featural level rather than at the phonemic level. In vowels, clusters of features equal phonemes but with the fricative consonants, due to underspecification of phonemes in terms of their features, there is not a complete mapping of feature bundles and phonemes. Similar to Stevens' (1986) model of speech perception in which features are directly mapped onto lexical representations, the present results suggest that no intermediate segmental analysis is made prior to access of the phonological representation in the lexicon. Instead, featural information is extracted from the speech signal and immediately transmitted to the lexicon, where it is mapped onto the appropriate featural phonological representation (see, for

example, Lahiri and Jongman, 1990).

Interestingly, for the initial fricative phonetic priming experiment, facilitation of matching prime-target fricative segments obtained for words and an inhibitory effect of matching prime-target fricative segments was observed for nonwords. However, for the medial vowel phonetic priming experiment, facilitation of matching prime-target vowel segments was observed in the word stimuli but no effect of matching prime-target vowel segments was found for the nonword stimuli. The differences found in the behavior of the matching and non-matching nonwords for the fricative and vowel phonetic priming experiments may reflect the importance of onset information in lexical access processes (Marslen-Wilson and Welsh, 1978; Marslen-Wilson, 1984; Marslen-Wilson, 1987). When *initial* phonetic information precedes target presentation, there is significant inhibition of nonword targets with matching phonetic segments due to the substantial activation of word neighbors (that is, word candidates with matching initial phonetic segments). However, since medial phonetic information may not be as effective as onset cues in analyzing the sensory input due to the inherent temporal nature of speech, prior presentation of medial phonetic information may also be not as effective in inhibiting nonword targets with matching phonetic segments. The different behavior of the nonword stimuli in the fricative and vowel phonetic priming experiments may provide some support for the notion that in auditory word recognition, onset information has privileged status and seems to have priority in directing word recognition processes.

9. Conclusions

The vowel phonetic priming experiment and the fricative phonetic priming experiment showed that priming based on phonetic overlap can be observed in an auditory lexical decision task. The phonetic priming paradigm provides a tool to investigate how lower-level acoustic-phonetic information is used to access lexical representations in spoken word recognition. The present results suggest that phonetic features rather than segments are active in lexical access. In future experiments, we hope to test this claim in more detail by systematically varying the acoustic-phonetic overlap between prime and target segments. Such manipulations will enable us to investigate the role of fine-grained, acoustic-phonetic information (for example, coarticulatory cues or allophonic information) in lexical access processes.

10. Acknowledgements

The authors would like to thank Dave Balota, Ino Flores d'Arcais, Howard Kurtzman, and Aditi Lahiri for helpful discussions and Cisca Custers, Henning Reetz, Toine Thissen, Jeroen van de Weijer, and Annemie Witjes for technical assistance.

11. Footnotes

1. Slowiaczek and Pisoni (1986) discuss the results of Slowiaczek, Nusbaum, and Pisoni as reported in an unpublished manuscript. This manuscript was later published as Slowiaczek et al. (1987).

12. References

- Archangeli, D. (1984). *Underspecification in Yawelmani phonology*. Doctoral dissertation, Cambridge: MIT.
- Bakker, J.J.M. (1971). *Constant en variabel. De fonematische structuur van de Nederlandse woordvorm*. Asten: Schriks Drukkerij.
- Burton, M.W. (1989). Associative, mediated, and rhyme priming. Unpublished Doctoral Dissertation, Brown University.
- Chomsky, N., & Halle, M. (1968). *The sound pattern of English*. New York: Harper and Row.
- Cohen, A., Ebeling, C.L., Fokkema, K., & Van Holk, A.G.F. (1972). *Fonologie van het Nederlands en het Fries*. 's-Gravenhage: Martinus Nijhoff.
- Coltheart, M., Davelaar, E., Jonasson, J.T., & Besner, D. (1977). Access to the internal lexicon. In S. Dornic (Ed.), *Attention and Performance VI*. Hillsdale, N.J.: Erlbaum.
- Cutler, A. (1976). Phoneme-monitoring reaction time as a function of preceding intonation contour. *Perception & Psychophysics*, 20, 55-60.
- Cutler, A., & Norris, D. (1988). The role of strong syllables in segmentation for lexical access. *Journal of Experimental Psychology: Human Perception and Performance*, 14, 113-121.
- Elman, J.L., & McClelland, J.L. (1984). The interactive activation model of speech perception. In N. Lass (Ed.), *Language and Speech*. New York: Academic Press.
- Gordon, P.C. & Meyer, D.E. (1984). Perceptual-motor processing of phonetic features in speech. *Journal of Experimental Psychology: Human Perception and Performance*, 10, 153-178.

- Hillinger, M.L. (1980). Priming effects with phonemically similar words: The encoding-bias hypothesis reconsidered. *Memory & Cognition*, 8, 115-123.
- Jongman, A. (1989). Duration of frication noise required for identification of English fricatives. *Journal of the Acoustical Society of America*, 85, 1718-1725.
- Lahiri, A., & Jongman, A. (1990). Intermediate level of analysis: features or segments? *Journal of Phonetics*, 18, 435-443.
- Lahiri, A., & Marslen-Wilson, W.D. (1991). The mental representation of lexical form: A phonological approach to the recognition lexicon. *Cognition*, 38, 245-294.
- Ladefoged, P. (1975). *A course in phonetics*. New York: Harcourt Brace Jovanovich.
- Luce, P.A. (1986). Neighborhoods of words in the mental lexicon. *Research on Speech Perception, Technical Report No. 6*. Bloomington: Speech Research Laboratory.
- MacNeilage, P.F., & Ladefoged, P. (1976). The production of speech and language. In E.C. Carterette & M.P. Friedman (Eds.), *Handbook of Perception*, Vol. 7. New York: Academic Press.
- Marslen-Wilson, W.D. (1987). Functional parallelism in spoken word-recognition. In U. Frauenfelder & L.K. Tyler (Eds.), *Spoken word recognition*. Cambridge: MIT Press.
- Marslen-Wilson, W.D., & Tyler, L.K. (1980). The temporal structure of spoken language understanding. *Cognition*, 8, 1-71.
- Marslen-Wilson, W.D., & Warren, P. (1990). Lexical integration of phonetic cues. Submitted for publication.
- Marslen-Wilson, W.D., & Welsh, A. (1978). Processing interactions during word-recognition in continuous speech. *Cognitive Psychology*, 10, 29-63.
- Martin, R.C., & Jensen, C.R. (1988). Phonological priming in the lexical decision task: A failure to replicate. *Memory & Cognition*, 16, 505-521.
- McClelland, J.L., & Elman, J.L. (1986). The TRACE model of speech perception. *Cognitive Psychology*, 18, 1-86.
- Mester, R.A., & Ito, J. (1989). Feature predictability and underspecification: Palatal prosody in Japanese mimetics. *Language*, 2, 258-293.
- Mey, J.L. (1968). A case of assimilation in Modern Dutch. *Acta Linguistica Hafniensia*, 11, 123-145.
- Meyer, D.E., & Gordon, P.C. (1984). Dependencies between rapid speech perception and production : Evidence for a shared sensory-motor voicing mechanism. In H. Bouma & D. G. Bouwhuis (Eds.), *Attention and Performance X*. Hillsdale, N.J.: Erlbaum.

- Meyer, D.E., & Gordon, P.C. (1985). Speech production : Motor programming of phonetic features. *Journal of Memory and Language*, 24, 3-26.
- Meyer, D.E., & Schvaneveldt, R.W. (1971). Facilitation in recognizing pairs of words: Evidence of a dependence between retrieval operations. *Journal of Experimental Psychology*, 90, 227-234.
- Meyer, D.E., Schvaneveldt, R.W., & Ruddy, M. (1974). Functions of graphemic and phonemic codes in visual word recognition. *Memory & Cognition*, 2, 309-321.
- Miller, G.A., & Nicely, P.E. (1955). An analysis of perceptual confusions among some English consonants. *Journal of the Acoustical Society of America*, 27, 338-352.
- Peters, R.W. (1963). Dimensions of perception of consonants. *Journal of the Acoustical Society of America*, 35, 1985-1989.
- Pisoni, D.B. (1978). Speech perception. In W.K. Estes (Ed.), *Handbook of learning and cognitive processes*. Hillsdale: Erlbaum.
- Radeau, M., Morais, J., & Dewier, A. (1989). Phonological priming in spoken word recognition: Task effects. *Memory & Cognition*, 17, 525-535.
- Seidenberg, M. & Tanenhaus, M. (1979). Orthographic effects on rhyme monitoring. *Journal of Experimental Psychology: Human Learning and Memory*, 5, 546-554.
- Sereno, J.A. (1991). Graphemic, associative, and syntactic priming effects at a brief stimulus onset asynchrony in lexical decision and naming. *Journal of Experimental Psychology: Learning, Memory, and Cognition*, 17, 459-477.
- Shepard, R.N. (1972). Psychological representation of speech sounds. In E.E. David & P.B. Denes (Eds.), *Human communication : A unified view*. New York: McGraw-Hill.
- Shulman, H.G., Hornak, R., & Sanders, E. (1978). The effects of graphemic, phonetic, and semantic relationships on access to lexical structures. *Memory & Cognition*, 6, 115-123.
- Slowiaczek, L.M., & Pisoni, D.B. (1986). Effects of phonological similarity on priming in auditory lexical decision. *Memory & Cognition*, 14, 230-237.
- Slowiaczek, L.M., Nusbaum, H.C., & Pisoni, D.B. (1987). Phonological priming in auditory word recognition. *Journal of Experimental Psychology: Learning, Memory, and Cognition*, 13, 64-75.
- Stevens, K.N. (1986). Models of phonetic recognition II: An approach to feature-based recognition. In P. Mermelstein (Ed.), *Proceedings of the Montreal satellite symposium on speech recognition*. Montreal: ICA.

Trommelen, M., & Zonneveld, W. (1979). *Inleiding in de generatieve fonologie*. Muiderberg; Coutinho.

Uit den Boogaart, P.C. (1975). *Woordfrequenties in geschreven en gesproken Nederlands*. Utrecht: Oosthoek, Scheltema, & Holkema.

Yaniv, I., Meyer, D.E., Gordon, P.C., Huff, C.A., & Sevald, C.A. (1990). Vowel similarity, connectionnist models, and syllable structure in motor programming of speech. *Journal of Memory and Language*, 29, 1-27.