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Mapping from Sound to Meaning: Reduced Lexical Activation in Broca's Aphasics

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Recent studies of lexical access in Broca's aphasics suggest that lexical activation levels are reduced in these patients. The present study compared the performance of Broca's aphasics with that of normal subjects in an auditory semantic priming paradigm. Lexical decision times were measured in response to word targets preceded by an intact semantically related prime word (''cat''–''dog''), by a related prime in which one segment was acoustically altered to produce a poorer phonetic exemplar (''c*at''–''dog''), and by a semantically unrelated prime (''ring''–''dog''). The effects of the locus of the acoustic distortion within the prime word (initial or final position) and the presence of potential lexical competitors (''cat'' → /gæt/ versus ''coat'' → ''goat'') were examined. In normal subjects, the acoustic manipulations produce a small, short-lived reduction in semantic facilitation irrespective of the position of the distortion in the prime word or the presence of a voiced lexical competitor. In contrast, Broca's aphasics showed a large and lasting reduction in priming in response to word-initial acoustic distortions, but only a weak effect of word-final distortions on priming. In both phonetic positions, the effect of distortion was greater for prime words with a lexical competitor. These findings are compatible with the claim that Broca's aphasics have reduced lexical activation levels, which may result in a disruption of the bottom-up access of words on the basis of acoustic input as well as increased vulnerability to competition between acoustically similar lexical items.

Key Words: Broca's aphasia; lexical access; acoustic variation.

The goal of the present study is to determine whether Broca's aphasics suffer from a deficit in lexical activation by examining how acoustic variation influences lexical access in these patients. In normal subjects, subphonetic variation, i.e., acoustic variation within a phonetic category, influences both the perception of speech sounds and the mapping from sound to lexical meaning. For example, variation in voice-onset time (VOT) within the voiceless phonetic category in initial stop consonants can produce a variety of perceptual effects, even when this variation is not sufficient to change the perception of the stop consonant from voiceless to voiced. In tests of phonetic discrimination, listeners judge both intact and reduced VOTs as belonging to the same phonetic category, but show longer reaction times to stimulus pairs that

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differ acoustically than to identical pairs (Pisoni & Tash, 1974; Utman, Blumstein, & Burton, 1998; Utman, 1997, 1998b). In addition, a reduction in VOT significantly slows the identification of initial stop consonants as members of the voiceless phonetic category, even though these segments are consistently identified as voiceless (Andruski, Blumstein, & Burton, 1994; Utman, 1998a). Further, in goodness rating tasks, listeners consistently rate segments with reduced VOTs as poorer exemplars of the voiceless phonetic category (Miller & Volaitis, 1989; Volaitis & Miller, 1992; Utman, 1998a). These findings suggest that phonetic categories have an internal structure that reflects within-category acoustic variation such that some tokens represent better acoustic exemplars of the intended phonetic category than others (cf. Samuel, 1982; Kuhl, 1991).

The interaction of phonetic category structure with lexical access in normal subjects has been examined in a number of studies using an auditory semantic priming paradigm. In this paradigm, a prime word containing a good or poor exemplar of a phonetic segment is paired with a semantically related target (e.g., ''cat''–''dog'' vs ''c*at''–''dog''), and the amount of semantic facilitation produced by these differing phonetic exemplars is compared relative to targets preceded by semantically unrelated primes (e.g., ''ring''–''dog''). The acoustic cues examined in these studies have included VOT in initial stop consonants (Andruski et al., 1994) and other cues to phonetic contrasts, such as phonation in the closure interval in voiced final stop consonants (Utman, 1997, 1998b). The results of these studies demonstrate that words containing poorer phonetic exemplars produce significantly less semantic facilitation than words containing good exemplars. Moreover, a reduction in priming emerges whether the prime stimulus has a voiced lexical competitor (e.g., ''coat'' → ''goat'') or not (e.g., ''cat'' → /gæt/), indicating that the effect observed for the poor exemplar prime stimulus reflects the bottom-up mapping from acoustics to lexical entries rather than competition at the lexical level. The effects of these acoustic manipulations are short-lived, emerging only at a brief interstimulus interval (ISI) of 50 ms. At a longer interval of 250 ms, no difference in semantic priming is observed between good and poor phonetic exemplars.

Effects similar to those described above emerge in normal subjects across a number of acoustic and phonetic conditions. They emerge for different acoustic cues (i.e., for both spectral and temporal parameters), across different types of phonetic segments (i.e., for both consonants and vowels), and in different phonetic environments (i.e., in both word-initial and word-final positions) (Utman, 1997, 1998b). Thus, within-category acoustic variation that produces a poorer phonetic exemplar reduces lexical activation in normal subjects. This variation is eventually accommodated by the language processing system with increased processing time.

Studies of lexical processing in aphasia have suggested that the mapping from sound to word meaning may be disrupted in patients with Broca's aphasia. Milberg, Blumstein, & Dworetzky (1988a, 1988b) examined the effects of phonological changes in the initial segment of a prime word on the amount of facilitation obtained to a semantically related target for normal subjects and aphasic patients. A paired lexical decision task was administered in which primes were either words semantically related to the target word (e.g., ''cat''–''dog'') or nonwords in which the initial segment differed from the related prime by either one phonetic feature (e.g.,''gat''–''dog'') or several phonetic features (e.g., ''wat''–''dog''). Normal subjects showed a monotonic decrease in semantic facilitation as a function of increased phonological distance from the related prime (Milberg et al., 1988a). That is, normal subjects showed the most facilitation for related word primes, less facilitation for primes that were changed by one feature, and the least facilitation for primes that were changed by more than two features. In contrast, nonfluent agrammatic aphasics (i.e., Broca's aphasics) showed significant facilitation only for semantically related prime words. They showed no priming for the phonologically altered prime stimuli (Milberg et al., 1988b).

A possible account of the pattern of performance obtained for Broca's aphasics may be described in terms of graded activation models of lexical access (e.g., McClelland & Elman, 1986; Elman, 1989). According to this approach, lexical entries may be more or less active depending on how well the input matches the target representation. Thus, in the case of normal subjects, an input that exactly matches its lexical representation will produce the most activation, whereas an input that differs by a single phonetic feature will produce less activation, and an input that differs by several features will produce even less activation. Words that are semantically related to that entry also become active through a process of spreading activation, although to a lesser extent than the original input lexical entry. The magnitude of semantic priming, then, will be greatest when the prime word phonologically matches its lexical entry, and it will decrease as a function of the phonological distance of the prime word from that entry. Milberg et al. (1988b) propose that Broca's aphasics suffer from a disturbance in the activation levels of lexical entries. As a result, although inputs that exactly match the phonological representation of a lexical entry may produce semantic priming in these patients, inputs that do not provide an exact match will fail to reach sufficient levels of activation to produce detectable priming. This account of the lexical processing disturbances of Broca's aphasics is compatible with evidence from other studies exploring lexical access in aphasic patients (cf. Kolk & van Grunsven, 1985).

It is important to note that not all aphasic patients demonstrate this pattern of performance. For example, Wernicke's aphasics show the same magnitude of semantic priming for phonologically altered primes (i.e., ''gat''–''dog'' and ''wat''–dog'') as they do for unaltered primes (i.e., ''cat''–''dog'') (Milberg et al., 1988b), and they show semantic priming effects in conditions where Broca's aphasics fail to do so (Milberg & Blumstein, 1981; Milberg, Blumstein, & Dworetzky, 1987). The lexical processing disturbance observed in Broca's patients, then, appears to reflect a specific aspect of the symptomatology of Broca's aphasia.

If it is the case that Broca's aphasics have reduced levels of lexical activation, the interaction of acoustic–phonetic processing with lexical access may be affected in these patients. Specifically, Broca's aphasics may be particularly vulnerable to variations in subphonetic acoustic information in the access of lexical entries. Recall that in normal subjects, subphonetic acoustic manipulations of prime words influence the amount of semantic facilitation obtained to related targets (Andruski et al., 1994; Utman, 1997, 1998b). Specifically, poorer exemplar prime stimuli reduce semantic priming. If Broca's aphasics have lowered activation of lexical candidates even in response to an intact acoustic input (Milberg et al., 1988b), then subphonetic acoustic differences manifested in poorer exemplar stimuli may result in an even greater reduction than shown for normal subjects, or potentially even a loss of semantic priming.

In order to investigate the effects of subphonetic acoustic differences on semantic priming, it is essential to determine whether Broca's aphasics can, in fact, perceive within-category acoustic differences as do normals or whether they have a speech perception impairment (cf. Yeni-Komshian & Lafontaine, 1983). To explore this issue, the performance of these patients on tests of phonetic discrimination and paired lexical decision is compared with earlier findings for normal subjects. In the phonetic discrimination task, acoustically manipulated words are paired with intact words and performance is compared to discrimination performance on acoustically identical pairs of words. In order to explore the effects of the acoustic manipulations on lexical access, these same acoustically manipulated and intact words also serve as primes and are paired with semantically related targets in a lexical decision task.

The performance of Broca's aphasics on these tasks might differ from that of normal subjects in a number of respects. For instance, Broca's patients may fail to demonstrate sensitivity to the subphonetic acoustic differences, in which case they should not show increased reaction times to pairs containing an altered stimulus in the discrimination task. Moreover, they should not show a reduction in semantic facilitation for altered as compared to unaltered prime words in the lexical decision task. Alternatively, Broca's aphasics may perform normally on the discrimination task. If this is the case, then the hypothesized deficit in lexical activation should result in either a greater reduction in semantic priming compared to normals or a loss of semantic priming altogether for acoustically manipulated primes.

The present investigation also considers the time course of speech perception and lexical access in these patients in relation to normal subjects by presenting stimulus pairs at ISIs of 50 and 250 ms in both the discrimination and lexical decision tasks. The time course of the effects of subphonetic differences on semantic priming is of particular interest, as some researchers have argued that lexical activation is slowed in Broca's patients (Swinney, Zurif, & Nicol, 1989; Prather, Shapiro, Zurif, & Swinney, 1991; Prather, Zurif, Stern, & Rosen, 1992; Swaab, Brown, & Hagoort, 1998). Thus, the early reduction in facilitation in response to altered prime words that emerges for normal subjects may be delayed in Broca's aphasics.

The effect of the location of the acoustic manipulation in the prime word on semantic facilitation in Broca's aphasics is also examined. The results for normal subjects indicate that subphonetic acoustic differences affect priming similarly for variations in the initial and final segments of CVC words (Andruski et al., 1994; Utman, 1997, 1998b). Nevertheless, the reduced initial activation levels observed in Broca's aphasics may interact with the locus of the acoustic–phonetic distortion such that acoustic variations at the onset of a word may prevent the activation of that lexical entry (cf. Milberg et al., 1988b). Thus, it may be difficult for the lexical processing system in Broca's aphasics to recover from the effects of initial distortion, especially at the short ISI. In contrast, distortions occurring late in a word may be encountered after the initial activation of the entry has occurred and may have a lesser effect on semantic priming than variations encountered early in the word. The effects of subphonetic acoustic variation on semantic priming in Broca's aphasics are examined for word-initial segments (Andruski et al., 1994) in Experiment 1 by investigating VOT as a cue to voicing in initial stop consonants and for word-final segments (Utman, 1997, 1998b) in Experiment 2 by investigating the effects of phonation during the closure interval on the perception of voicing in final stop consonants.

EXPERIMENT 1

Method

Subjects. Nine right-handed aphasic patients were recruited from the following facilities to participate in the present experiment: The Harold Goodglass Aphasia Research Center at the Boston Veterans Administration Medical Center, the Braintree Rehabilitation Hospital, the Roger Williams Hospital, the Department of Veteran Affairs Medical Center in Providence (RI), and the Rhode Island Hospital. All patients became aphasic as a consequence of stroke and were classified as Broca's aphasics according to the Boston Diagnostic Aphasia Exam (BDAE) (Goodglass & Kaplan, 1972). One patient performed at chance on both administrations of the lexical decision task and was excluded from analysis. This patient's information is therefore not included in Table 1. Of the eight remaining subjects, six were male and two were female, with an age range of 51 to 80 years and a mean age of 63.25 years. Table 1 provides a summary of age, etiology and lesion localization, as well as *z* scores for auditory comprehension and

TABLE 1
Patient Summary

ID	Experiment	Age at testing	Years postonset	Auditory comprehension	Fluency	Etiology	CT scan
S01	1, 2	51	2	+0.68	Nonfluent	CVA[a]	N/A[b]
S02	1, 2	57	1	+0.80	Nonfluent	CVA	Left motor cortex, sensory cortex, anterior PVWM,[c] posterior PVWM; inferior and superior parietal lobule; superior temporal gyrus; putamen
S03	1, 2	80	20	+0.75	Nonfluent	N/A	Left frontal lesion involving Broca's area with deep extension across to left frontal horn/lower motor cortex; part of left temporal lobe
S04	1, 2	54	9	+0.94	Nonfluent	N/A	Large insular lesion extending to temporal lobe, sparing Wernicke's and part of Broca's area
S05	1, 2	64	23	+0.78	Nonfluent	CVA	Left hemisphere lesion in Broca's area and white matter deep to it; lower two-thirds of premotor, motor, sensory cortex; white matter and PVWM deep to those areas
S06	1, 2	53	11	+0.63	Nonfluent	CVA	Left caudate and globus pallidus, anterior internal capsule to medial temporal cortex and insula, anterior PVWM
S07	1, 2	69	23	+0.88	Nonfluent	Hemorrhage	Left interior lesion, frontal to sylvian fissure, deep to ventricles
S08	1	78	20	+0.81	Nonfluent	CVA	Left hemisphere lesion in Broca's area, insula, putamen, white matter in supermarginal and angular gyrus areas
S09	2	44	6	+0.59	Nonfluent	Hemorrhage	N/A

[a] Cerebrovascular accident.
[b] Information not available.
[c] Periventricular white matter.

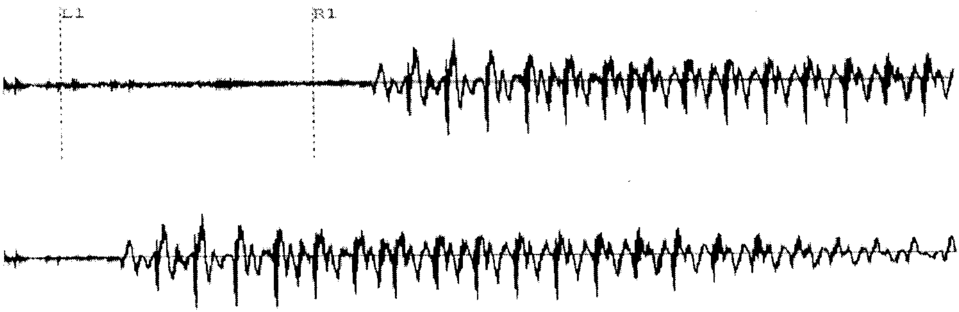

FIG. 1. Sample waveforms of intact (top panel) and altered (bottom panel) tokens for stimulus item ''pill'' (Experiment 1). Cursors demarcate the middle two-thirds of the VOT.

fluency rating according to the BDAE for the eight patients (identified in column 2 of Table 1, participants S01–S08) who participated in the experiment.

Stimuli. The stimuli in the present experiment were identical to those used in the lexical decision task of Andruski et al. (1994). The set of test primes consisted of 26 CVC(C) words with /p/, /t/, or /k/ in initial position (e.g., ''peace,'' ''tack,'' and ''cat''). For half of the test primes, a change in voicing of the initial segment resulted in a word (e.g., ''pill'' > ''bill''), and for the other half, a change in voicing resulted in a nonword (e.g., ''peace'' > /bis/). These prime words were paired with 26 semantically related target words (e.g., ''peace''–''war,'' ''tack''–''pin,'' and ''cat''–''dog'') for a total of 26 semantically related test pairs. The target words were also paired with 26 semantically unrelated primes (e.g., ''hip''–''war,'' ''race''–''pin,'' and ''fact''–''dog'') for a total of 26 semantically unrelated test pairs. The stimulus set also included the altered test primes from the Andruski et al. (1994) study. The VOTs of the semantically related primes were reduced by two-thirds, and these primes were paired with the related targets (e.g., ''p$^{-2/3}$eace''–''war,'' ''t$^{-2/3}$ack''–''pin,'' and ''c$^{-2/3}$at''–''dog'') for a total of 26 altered test pairs. Sample waveforms of intact and altered stimuli are shown in Fig. 1. For a complete description of the creation and editing of the test stimuli, see Andruski et al. (1994).

Distractor (nonword) targets consisted of 26 phonologically permissible strings that did not form a word in English (e.g., ''mish''). They were organized to parallel the real word priming conditions to avoid guessing strategies and to examine the effects of the acoustic manipulations on general processing time in the lexical decision task. Specifically, nonword targets were preceded by intact /p/-, /t/-, and /k/-initial prime words (e.g., ''pig''–''mish''), acoustically altered /p/-, /t/-, and /k/-initial prime words (e.g., ''p$^{-2/3}$ig''–''mish''), and prime words that did not begin with /p/, /t/, or /k/ (e.g., ''wing''–''mish''). The frequency of occurrence of the prime stimuli was controlled across the test and distractor sets (see Andruski et al., 1994, for details). Thus, the stimuli for the lexical decision task consisted of 78 test (word target) pairs (26 related, 26 altered, and 26 unrelated) and 78 distractor (nonword target) pairs (26 with /p/-, /t/-, or /k/-initial primes, 26 with altered primes, and 26 primes that did not begin with /p/, /t/, or /k/).

A paired discrimination task was also created using the altered and intact /p/-, /t/-, and /k/-initial prime words. The purpose of this task was to determine whether the patients perceived the altered stimuli as belonging to the same phonetic category as the intact stimuli (i.e., the voiceless category) and to ascertain whether the patients demonstrated perceptual sensitivity to the acoustic difference between intact and altered primes. The intact /p/-, /t/-, and /k/-initial words always served as the second item in each test pair in the discrimination task. Each intact word was preceded by an identical intact word (e.g., ''pill''–''pill''), an altered version of the same word (e.g., ''p$^{-2/3}$ill''–''pill''), or a counterpart word with an initial voiced stop (e.g., ''bill''–''pill''). Based on the Andruski et al. (1994) results, subjects were expected to respond ''SAME'' to pairs containing two intact words as well as to pairs containing an altered word and to respond ''DIFFERENT'' to pairs containing a voiced counterpart. Voiced counterpart pairs were presented twice to produce an equal number of expected ''SAME'' and ''DIFFERENT'' responses.

The digitized and edited stimuli from the Andruski et al. (1994) study were used in the creation of the test tapes. The stimulus pairs for both the lexical decision and discrimination tasks were tape recorded in random order with an intertrial interval (ITI) of 6000 ms. The stimuli were recorded onto one channel and a 50-ms tone occurring simultaneously with the onset of the target stimulus was recorded onto the other channel. Two test tapes were produced for each of the tasks of lexical decision and discrimination. For one set of test tapes, the stimulus pairs for both tasks were presented with an ISI of 50 ms [334- to 695-ms stimulus onset asynchrony (SOA)], and for the other set of tapes, the pairs were presented with an ISI of 250 ms (534- to 895-ms SOA).

Apparatus. The apparatus for the experiment consisted of a Sony Pro Walkman stereo tape recorder, a Pioneer SA 500A stereo amplifier, a Lafayette Instruments voice-activated relay, a Gerbrands millisecond timer, two sets of headphones, and a response board. The response board consisted of two keys, which were marked ''WORD'' and ''NONWORD,'' respectively, for the lexical decision task, and ''SAME'' and ''DIFFERENT,'' respectively, for the discrimination task. The output of the tape recorder was split so that the channel containing the tone was sent to the voice-activated relay. With the onset of the target word in each trial (i.e., the second item in each test pair), the tone activated the voice-activated relay, which in turn activated the millisecond timer. The timer was stopped when the subject pressed a key on the response board. The output of the channel containing the recorded stimuli was amplified with the stereo amplifier. The subject and the experimenter heard the amplified stimuli binaurally through sealed headphones and did not hear the tone at the onset of the target stimulus.

Procedure. Subjects were run individually in two sessions, each of which lasted approximately 45 min. In the first session, subjects received the lexical decision task at a single ISI (50 ms or 250 ms) followed by the discrimination task at the same ISI. In the second session, subjects received the lexical decision task at the other ISI followed by the discrimination task at the other ISI. Order of presentation of ISIs was counterbalanced across subjects. Both sessions were completed within 1 week for all subjects.

In the lexical decision task, subjects were instructed that they would hear pairs of stimuli. Some of these stimuli would be real words in English and some of them would be nonsense words. The subjects' task was to decide whether the second item in each pair was a real word. If the second member of the pair was a real word, subjects were to press the ''WORD'' key, and if it was not, subjects were to press the ''NONWORD'' key. Examples of both word (''cat''–''ring'') and nonword (''pig''–''mish'') target test pairs were spoken by the experimenter. A practice test consisting of 12 pairs from the test series (2 unaltered, 2 altered, 2 unrelated, and 6 nonword pairs) was administered to familiarize subjects with the procedure. If a subject performed at or below chance on the practice test, the practice series was repeated until performance exceeded chance. The test series was then administered.

In the discrimination task, subjects were told that they would hear pairs of real words and nonsense words. For some pairs, the items would be the same, and for others, the items would be slightly different. Examples of both same (''cat''–''cat'') and different (''bill''–''pill'') test pairs were spoken by the experimenter. If the items were the same, subjects were to press the ''SAME'' key, and if they were different, subjects were to press the ''DIFFERENT'' key. A practice test consisting of eight pairs from the test series (two identical, two altered, and four voicing contrast pairs) was administered to familiarize subjects with the procedure. If a subject performed at or below chance on the practice test, the practice series was repeated until performance exceeded chance. The test series was then administered.

In both the lexical decision and discrimination tasks, responses were made with the subjects' preferred hand (in some cases the nondominant hand), which was allowed to rest between the keys after each trial. Subjects were instructed to respond as quickly as possible and to respond even if they were unsure of their answer. Responses and reaction times were recorded by the experimenter for both tasks.

Results

Discrimination task. The results of the discrimination task were scored for responses (''SAME'' and ''DIFFERENT'') and reaction times. Reaction times that were more than 2 *SD* from the mean for each subject in each condition were excluded from analysis. The raw reaction times for each subject were log normalized and averaged across conditions prior to statistical analysis to reduce the amount of variability in the reaction time data.

The percentage of ''SAME'' and ''DIFFERENT'' responses across conditions are shown in Table 2. The pattern of performance at both ISIs indicates that in general patients perceived both intact and altered items as belonging to the same phonetic category. Patients appear to have experienced some difficulty in discriminating the voiced counterparts from the voiceless stimuli at the 50 ms ISI, as only three of the eight patients produced more than 66% correct ''DIFFERENT'' judgments in response to test pairs containing a voiced counterpart. This was not the case at the 250 ms ISI: seven of the eight patients tested produced more than 66% correct ''DIFFERENT'' judgments. Responses to identical pairs were quite accurate at both ISIs, as all but one of the eight patients responded ''SAME'' to these pairs more than 85% of the time.

In order to examine in more detail the effect of the acoustic manipulation on pho-

TABLE 2
Means (and Standard Deviations) of the Percentages of ''SAME'' and ''DIFFERENT'' Responses in the Discrimination Task (Experiment 1)

ISI	Response	Altered (''p$^{-2/3}$ill''–''pill'')	Unaltered (''pill''–''pill'')	Counterpart (''bill''–''pill'')
50 ms	''SAME''	84.13 (7.81)	93.27 (5.72)	32.69 (17.74)
	''DIFFERENT''	11.06 (8.58)	3.37 (3.81)	63.46 (16.67)
250 ms	''SAME''	80.77 (9.64)	92.79 (5.61)	24.52 (11.75)
	''DIFFERENT''	14.42 (9.59)	1.92 (4.11)	72.60 (11.62)

Note. Due to rounding and nonresponses, percentages within a condition may not sum to 100.

netic discrimination, reaction times and accuracy were compared for ''SAME'' responses to identical pairs and pairs containing an altered stimulus. To determine whether lexical competition influenced phonetic discrimination in these patients, the effect of the acoustic manipulation was compared across items for which a change in the voicing of the initial segment would produce a real word or a nonword. These data are shown in Table 3.

The percentage of ''SAME'' responses to identical pairs and pairs containing an acoustically altered stimulus and the reaction times to these responses were analyzed in three-way analyses of variance (ANOVAs) with ISI (50 ms vs 250 ms), Acoustic Manipulation (Altered vs Unaltered), and Lexical Competitor (Competitor vs No Competitor) as within-subjects factors. Means comparisons were conducted on the accuracy and reaction time data as planned contrasts (Altered vs Unaltered) in a general linear model. The results of these analyses are shown in Table 4. A highly significant main effect of Acoustic Manipulation was obtained in both the accuracy and reaction time analyses. Patients produced significantly fewer ''SAME'' responses to pairs containing an altered stimulus than to acoustically identical pairs (six of eight patients), and reaction times were significantly slower for pairs containing an altered stimulus than for acoustically identical pairs (eight of eight patients). This finding indicates that patients were perceptually sensitive to the reduction in VOT in word-initial stop consonants.

No significant main effects of ISI or Lexical Competitor emerged in either the reaction time or accuracy analyses, and there was no interaction of either of these factors with Acoustic Manipulation. However, a significant three-way interaction was obtained in the analysis of ''SAME'' responses. Planned means comparisons revealed

TABLE 3
Means (and Standard Deviations) of the Percentages of ''SAME'' Responses and Reaction Times in Milliseconds for ''SAME'' Responses in the Discrimination Task (Experiment 1)

ISI	Lexical competitor	Acoustic manipulation	% ''SAME'' responses	RTs (ms) to ''SAME'' responses
50 ms	Competitor	Altered	85.71 (10.10)	990 (279)
		Unaltered	91.07 (8.32)	821 (178)
	No competitor	Altered	82.29 (9.38)	961 (305)
		Unaltered	95.83 (6.30)	796 (178)
250 ms	Competitor	Altered	79.46 (9.69)	905 (194)
		Unaltered	93.75 (5.96)	795 (150)
	No competitor	Altered	82.29 (12.15)	914 (250)
		Unaltered	91.67 (7.72)	768 (155)

TABLE 4

Results of Statistical Analyses (ANOVAs and Means Comparisons) for the Discrimination Task (Experiment 1)

Effect		Main		× Lexical competitor		× Acoustic manipulation		× Acoustic manipulation × lexical competitor	
Measure		% SAME	RT	% SAME	RT	% SAME	RT	% SAME	RT
ISI	$F(1, 7)$	2.55	1.44	<0.01	0.94	0.73	0.29	**6.38***	0.51
Acoustic manipulation	$F(1, 7)$	**13.56****	**14.34****	0.21	<0.01	—	—	—	—
Lexical competitor	$F(1, 7)$	0.06	1.98	—	—	—	—	—	—

Comparison			Altered vs unaltered	
Measure			% SAME	RT
50 ms ISI	Competitor	$F(1, 7)$	**4.27** ~ (p = .07)	**8.45***
	No competitor	$F(1, 7)$	**27.29****	**4.59** ~ (p = .06)
250 ms ISI	Competitor	$F(1, 7)$	**30.37****	**3.37** ~ (p = .10)
	No competitor	$F(1, 7)$	**13.08****	**6.25***

Note. Bold entries indicate significant or marginally significant effects.

* $p < .05$.

** $p < .01$.

~ $p < .1$.

TABLE 5
Percentage of Correct Responses in the Lexical Decision Task
(Experiment 1)

ISI	Lexical competitor	Acoustic manipulation	% Correct
50 ms	Competitor	Unaltered	91.07 (6.33)
		Altered	91.07 (6.33)
		Unrelated	93.75 (7.08)
	No competitor	Unaltered	92.71 (6.95)
		Altered	93.75 (5.89)
		Unrelated	91.67 (6.30)
250 ms	Competitor	Unaltered	87.50 (5.05)
		Altered	86.61 (16.39)
		Unrelated	85.71 (7.64)
	No competitor	Unaltered	87.50 (8.91)
		Altered	89.58 (7.39)
		Unrelated	90.63 (8.26)

a highly significant difference in ''SAME'' responses between identical pairs and pairs containing an altered stimulus in all conditions *except* at the 50 ms ISI for items with a lexical competitor. Reaction times were slower overall in this condition, and this increase in processing time may have attenuated the effect of the acoustic manipulation on ''SAME'' responses. However, there was a significant difference in reaction times to identical pairs and pairs containing an altered stimulus in this condition, indicating that patients were sensitive to the acoustic difference in all conditions irrespective of the presence of a lexical competitor.

Taken together, the results of the analyses of ''SAME'' responses and reaction times demonstrate that patients were perceptually sensitive to the acoustic difference between altered and intact VOTs at both the 50- and 250-ms ISIs, and in general both types of stimulus were identified as belonging to the same phonetic category. Further, the results revealed no consistent difference in perceptual sensitivity to the acoustic manipulation as a function of lexical competitor.

Lexical decision task. The results of the lexical decision task were scored for both accuracy and reaction time. The percentages of correct ''WORD'' responses across conditions are shown in Table 5. Reaction times that were more than 2 *SD* from the mean for each subject in each condition were eliminated from analysis. The raw reaction times for each subject were log normalized and averaged across conditions prior to statistical analysis. Mean reaction times across all conditions are plotted in Fig. 2. Three-way repeated-measures ANOVAs were performed on the accuracy and reaction time data with ISI (50 ms vs 250 ms), Prime Condition (Related vs Altered vs Unrelated), and Lexical Competitor (Competitor vs No Competitor) as within-subjects factors. Means comparisons were performed on the reaction time data as planned contrasts (Altered vs Unaltered, Unaltered vs Unrelated, and Altered vs Unrelated) in a general linear model. Similar analyses were also conducted for ''NONWORD'' responses, but no significant effects emerged. The results for ''WORD'' responses are shown in Table 6.

In the accuracy analysis, the main effect of ISI was marginally significant, indicating that reaction times tended to be slower overall at the 50-ms ISI. No other significant main effects emerged, and there were no significant interactions. The reaction time analysis revealed a significant main effect of Prime Condition, indicating that the prime conditions were successful in influencing reaction times to targets. This effect is discussed in further detail below. There was also a significant main effect

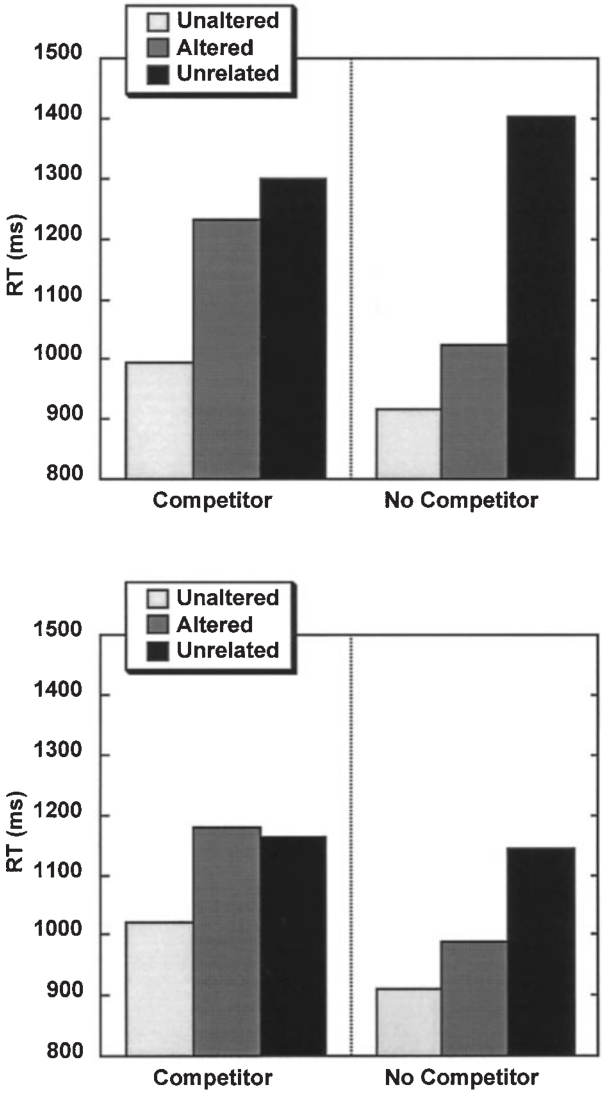

FIG. 2. Reaction times to correct responses to word targets across prime conditions in the lexical decision task as a function of lexical competitor (Experiment 1). Results for the 50-ms ISI are shown in the top panel and those for the 250-ms ISI in the bottom panel.

of Lexical Competitor such that reaction times were slower overall when the prime had a potential competitor at the lexical level. A similar effect was obtained for normal subjects in response to these stimuli in the previous study (Andruski et al., 1994). No significant main effect of ISI emerged.

In addition to the observed main effects, there was a significant ISI × Prime Condition interaction in the reaction time analysis, suggesting that priming effects were larger overall at the 50-ms ISI than at the 250-ms ISI. A comparison of least-squares means revealed significantly longer reaction times to Unrelated targets at the 50-ms ISI than at the 250-ms ISI ($p < .05$), but no significant effect of ISI on reaction times in the Related or Altered conditions. Thus, response times were significantly slower in the Unrelated condition at the 50-ms ISI than at the 250-ms ISI.

A highly significant Prime Condition × Lexical Competitor interaction also

TABLE 6
Results of Statistical Analyses (ANOVAs and Means Comparisons) for the Lexical Decision Task (Experiment 1)

Effect	Main		× Lexical competitor		× Prime condition		× Prime condition × lexical competitor	
Measure	% Correct	RT	% Correct	RT	% Correct	RT	% Correct	RT
ISI	*F*(1, 7) **5.43**~ (p = .05)	*F*(1, 7) 0.19	*F*(1, 7) 0.54	*F*(1, 7) 1.49	*F*(2, 14) <0.01	*F*(2, 14) **4.98***	*F*(2, 14) 0.83	*F*(2, 14) 0.11
Prime condition	*F*(2, 14) 0.08	*F*(2, 14) **16.41****	*F*(2, 14) 0.14	*F*(2, 14) **12.42****	—	—	—	—
Lexical competitor	*F*(1, 7) 3.07	*F*(1, 7) **20.72****	—	—	—	—	—	—

Comparison			Altered vs unaltered	Unaltered vs unrelated	Altered vs unrelated
50-ms ISI	Competitor	*F*(1, 14)	**35.30****	**42.76****	0.36
	No competitor	*F*(1, 14)	**12.97****	**103.80****	**43.38****
250-ms ISI	Competitor	*F*(1, 14)	**17.58****	**9.67****	1.17
	No competitor	*F*(1, 14)	**5.82***	**40.77****	**15.79****

Note. Bold entries indicate significant or marginally significant effects.
* $p < .05$.
** $p < .01$.
~ $p < .1$.

emerged in the reaction time data. This interaction is of particular interest, as no such effect was obtained for normal subjects. An examination of the means comparisons for primes with no lexical competitor reveals a similar pattern to that obtained for normal subjects. Reaction times were significantly faster to targets preceded by both altered and unaltered related primes than to targets preceded by unrelated primes. Thus, semantic priming was obtained for both unaltered and altered primes. However, reaction times were significantly slower for targets preceded by altered primes than by unaltered primes, indicating that altered primes produced significantly less semantic priming than unaltered primes.

In contrast, the pattern of results for primes with a lexical competitor differed from that obtained for normal subjects. Whereas reaction times were significantly faster to targets preceded by related (unaltered) primes than by unrelated primes, this effect did not emerge for targets preceded by altered primes. In fact, there was no significant difference in reaction times between altered and unrelated primes. Thus, when the prime word had a lexical competitor, semantic facilitation emerged only for unaltered prime words, and no facilitation emerged for altered prime words. There was no significant Prime Condition × Lexical Competitor × ISI interaction, indicating that this pattern of results did not differ across ISI conditions. This indicates that the effect of the acoustic manipulation on semantic priming did not change as a function of increased processing time.

Before considering the implications of these results, it is important to note that all target items were presented three times each within an experimental session (once in each prime condition in the lexical decision task). This repeated-measures design was chosen so that each item would serve as its own control in terms of length, frequency, and phonetic content. However, it is possible that the repetition of targets affected the pattern of results. To explore this question, mean reaction times were calculated for the first occurrence of each target at each ISI. This substantially reduced the number of observations within each condition such that it was no longer possible to compare reaction times as a function of Lexical Competitor. Nevertheless, it was possible to examine the effects of Prime Condition on reaction times. These data are plotted in Fig. 3.

A two-way ANOVA was performed on the reaction time data with ISI (50 ms vs 250 ms) and Prime Condition (Related vs Altered vs Unrelated) as within-subjects

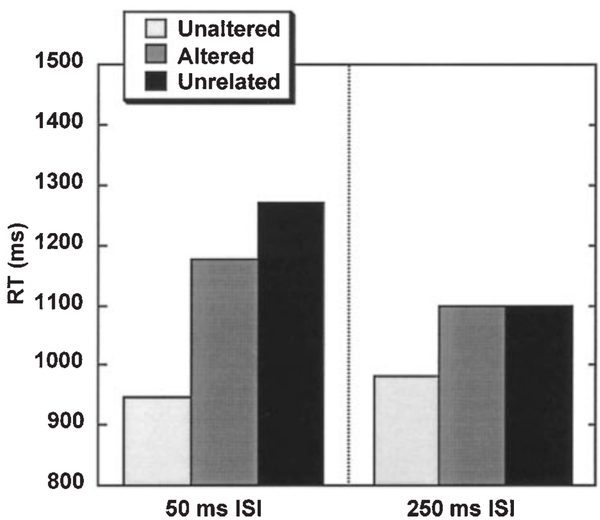

FIG. 3. Reaction times to correct responses to the first occurrence of word targets across prime conditions (Experiment 1).

TABLE 7
Results of Statistical Analyses (ANOVAs and Means Comparisons) for the First Occurrence of Targets in the Lexical Decision Task (Experiment 1)

Effect		Main		× Prime condition
ISI		F(1, 7) 0.66		F(2, 14) 0.28
Prime condition		F(2, 14) **5.10***		—
Comparison		Altered vs unaltered	Unaltered vs unrelated	Altered vs unrelated
50-ms ISI	F(1, 14)	**17.29****	**23.06****	0.41
250-ms ISI	F(1, 14)	**6.68***	**6.09***	0.01

Note. Bold entries indicate significant or marginally significant effects.
* $p < .05$.
** $p < .01$.

factors. Means comparisons were performed on the reaction time data as planned contrasts (Altered vs Unaltered, Unaltered vs Unrelated, and Altered vs Unrelated) in a general linear model. The results of these analyses are shown in Table 7. A significant main effect of Prime Condition emerged. Planned comparisons revealed a significant semantic facilitation effect at both ISIs such that reaction times were significantly faster to targets preceded by related (unaltered) primes than by unrelated primes. Further, the difference between reaction times to targets in the unaltered and unrelated conditions was highly significant at both ISIs, and there was no significant difference between the altered and unrelated conditions. Thus, altered primes failed to produce semantic facilitation at either ISI. There was no significant main effect of ISI, and no Prime Condition × ISI interaction, indicating that this pattern of results did not differ across ISIs. This pattern of results is compatible with the findings obtained for the entire dataset, suggesting that the observed effects were not influenced by the repetition of targets.

Discussion

The results of the discrimination task demonstrate that the Broca's patients were perceptually sensitive to the acoustic difference between altered and intact stimuli at both ISIs. Subjects demonstrated significantly fewer ''SAME'' responses and significantly longer reaction times to ''SAME'' responses for pairs containing an altered stimulus than to acoustically identical pairs. Further, the findings indicate that the subjects perceived both altered and intact stimuli as belonging to the same phonetic category. Thus, the performance of Broca's aphasics on this task was similar to that of normal subjects in previous investigations (Andruski et al., 1994; Utman et al., 1998).

In contrast, the results obtained for Broca's aphasics in the lexical decision task was markedly different from the previous findings for normal subjects (Andruski et al., 1994). First, the effects of subphonetic acoustic differences on semantic facilitation did not change over time for Broca's aphasics, as they do for normal subjects. In addition, the amount of semantic facilitation obtained in response to an altered prime differed according to whether the prime had a competitor at the lexical level. If the altered prime did not have a lexical competitor (e.g., ''peace'' > /biys/), a significant reduction in facilitation emerged at both ISIs. However, if the altered prime had a lexical competitor (e.g., ''pill'' > ''bill''), no facilitation emerged at either ISI.

It is important to emphasize that these effects do not reflect a difference in perceptual sensitivity to the acoustic difference at the phonetic level: in the discrimination task, subjects showed no consistent difference in sensitivity to the acoustic manipulation between words that had a lexical competitor and words that did not. Further, there were no significant effects of the acoustic manipulations on reaction times to nonwords, so the observed effects cannot be attributed to a general increase in processing time in response to the altered prime stimuli. Rather, the results indicate that, when there is no lexical competitor present, subphonetic acoustic differences affect lexical activation similarly in Broca's aphasics and normal subjects, although for Broca's aphasics these effects do not diminish over time. However, unlike normal subjects, in the presence of a lexical competitor, an altered prime fails to produce sufficient lexical activation to prime a related target.

Before attempting to provide a comprehensive account of the above findings, it is necessary to determine whether similar effects emerge for within-category manipulations in other phonetic contrasts and phonetic positions. Experiment 2 examined the role of closure phonation in the perception of consonant voicing in word-final position in Broca's aphasics.

EXPERIMENT 2

Method

Subjects. Seven of the eight patients from Experiment 1 also participated in Experiment 2 (all patients except participant S08). In addition, one patient who did not participate in Experiment 1 (participant S09) was included in Experiment 2. Table 1 provides a summary of age, etiology and lesion localization, as well as *z* scores for auditory comprehension and fluency rating according to the BDAE for each patient who participated in the experiment (see column 2 of Table 1). Of the eight subjects, five were male and three were female, with an age range of 44 to 80 years and a mean age of 59 years.

Stimuli. The stimuli were identical to those used in the discrimination and lexical decision tasks in previous experiments conducted with normal subjects (Utman, 1997, 1998b). For the lexical decision task, the set of prime words consisted of 18 CVC words ending in voiced stop consonants (e.g., ''robe,'' ''lid,'' and ''bug''). Six of the prime words ended in /b/, 6 ended in /d/, and 6 ended in /g/. Further, for half of the prime words, a change in the voicing of the final consonant resulted in a word (e.g., ''robe'' → ''rope'') and for the remaining prime words a change in final consonant voicing resulted in a nonword (e.g., ''tub'' → ''tup''). The presence or absence of a lexical competitor was counterbalanced across places of articulation. The prime words were paired with semantically related target words (e.g., ''robe''–''dress,'' ''lid''–''top,'' and ''bug''–''ant''), resulting in a set of 18 semantically related word pairs. A list of CVC words was then generated that were semantically unrelated to the target words, and these words were paired with the targets (e.g., ''nut''–''dress,'' ''joke''–''top,'' and ''thief''–''ant''), resulting in a set of 18 semantically unrelated word pairs. The stimulus set also included the altered primes from the Utman (1997, 1998b) studies. For each of these stimuli, the glottal phonation in the closure interval of the voiced final stops was replaced by silence of equal duration. Sample waveforms of intact and altered stimuli are shown in Fig. 4. For a complete description of the creation and editing of the test stimuli, the reader may refer to Utman (1997, 1998b). These primes were paired with the related targets, for a total of 18 altered test pairs.

Nonword distractor targets consisted of 18 phonologically permissible CVC strings that did not form a word in English (e.g., ''wuck''). As in Experiment 1, these were placed in similar prime conditions to the test targets to avoid guessing strategies and to examine the effects of the acoustic manipulations on general processing time in the lexical decision task. Thus, one list of distractor primes consisted of 18 CVC words ending in voiced stop consonants (e.g., ''cab,'' ''maid,'' and ''pig'') and 18 altered versions of these primes. As with the test primes, for half of the distractor prime words, a change in the voicing of the final consonant would result in a word (e.g., ''cab'' → ''cap'') and for the remaining prime words a change in final consonant voicing would result in a nonword (e.g., ''bib'' → ''bip''). The presence or absence of a lexical competitor was counterbalanced across places of articulation. These distractor primes were matched for frequency with the related test primes such that there were an equal number of high-(>500), medium-(50–500), and low-(<50) frequency words (Francis & Kučera, 1982). The second list of distractor primes consisted of 18 CVC words that did not end in a voiced stop consonant (e.g., ''cave''). These were matched for frequency with the unrelated test primes such that there were

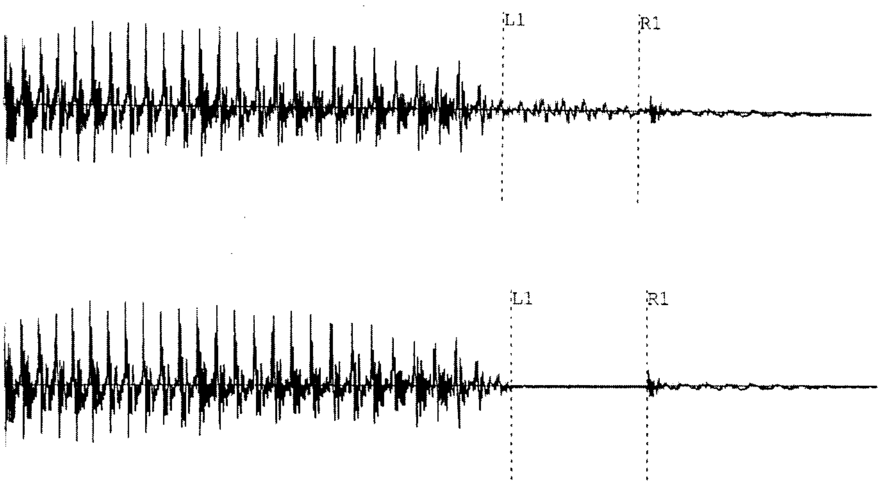

FIG. 4. Sample waveforms of intact (top panel) and altered (bottom panel) tokens for stimulus item ''bug'' (Experiment 2). Cursors demarcate the consonant closure interval.

an equal number of high-(>500), medium-(50–500), and low-(<50) frequency words (Francis and Kučera, 1982). The two lists of distractor primes were paired with the nonword targets (e.g., ''pig''–''wuck,'' ''pig$_{-vd}$''–''wuck,'' and ''cave''–''wuck'') for a total of 36 distractor pairs.

Thus, the complete stimulus set for the lexical decision task consisted of 72 test items (18 semantically related primes with unaltered final stops, 18 semantically related primes with altered final stops, 18 semantically unrelated primes, and 18 word targets) and 72 distractor items (18 primes with unaltered final voiced stops, 18 primes with altered final voiced stops, 18 primes without final voiced stops, and 18 nonword targets). Each target appeared 3 times, preceded by 1 occurrence of each prime type, for a total of 54 test pairs and 54 distractor pairs.

The paired discrimination task included the altered and intact prime words and an additional list of stimuli consisting of the voiceless counterparts of the prime words (e.g., ''rope,'' ''lit,'' and ''buck''). The intact voiced-final prime words always served as the second item in each test pair in the discrimination task. Each intact word was preceded by an identical intact word (e.g., ''bug''–''bug'') and altered version of the same word (e.g., ''bug$_{-vd}$''–''bug'') or a counterpart word with a final voiceless stop (e.g., ''buck''–''bug''). As in Experiment 1, subjects were expected to respond ''SAME'' to pairs containing two intact words as well as to pairs containing an altered word and to respond ''DIFFERENT'' to pairs containing a voiceless counterpart. Counterpart pairs were presented twice to produce an equal number of expected ''SAME'' and ''DIFFERENT'' responses. The digitized and edited stimuli from Utman (1997, 1998b) were transferred to a Keynote 486SL Notebook PC-compatible laptop computer with a Pro Audio Spectra audio card for presentation to subjects.

Apparatus. The apparatus for the experiment consisted of the Keynote 486SL computer, a response box, and a set of headphones. The response box consisted of two keys, which were marked ''WORD'' and ''NONWORD,'' respectively, for the lexical decision task, and ''SAME'' and ''DIFFERENT,'' respectively, for the discrimination task.

Procedure. The lexical decision and discrimination tasks were administered in the same manner described under Experiment 1. The practice test for the lexical decision task consisted of 12 pairs from the test series (2 unaltered, 2 altered, 2 unrelated, and 6 nonword pairs). The practice test for the discrimination task consisted of 8 pairs from the test series (2 identical, 2 altered, and 4 counterpart pairs). Subjects were given up to 6000 ms to respond, with a minimum interval of 1000 ms after their response before the onset of the next trial. The stimulus pairs for both tasks were presented with an ISI of 50 ms (443- to 798-ms SOA) or 250 ms (693- to 1048-ms SOA). Order of presentation of ISI conditions was counterbalanced across subjects. Responses and reaction times were recorded by the Keynote 486SL computer that controlled the experiment.

Results

Discrimination task. As in Experiment 1, the results of the discrimination task were scored for responses (''SAME'' and ''DIFFERENT'') and reaction times. Reaction times that were more than 2 *SD* from the mean for each subject in each condition

TABLE 8
Means (and Standard Deviations) of the Percentage of ''SAME'' and ''DIFFERENT'' Responses in the Discrimination Task (Experiment 2)

ISI	Response	Altered (''$\text{rag}_{[\text{-vd}]}$''–''rag'')	Unaltered (''rag''–''rag'')	Counterpart (''rack''–''rag'')
50 ms	''SAME''	93.06 (7.12)	96.53 (2.88)	19.10 (10.33)
	''DIFFERENT''	4.17 (5.75)	0.69 (1.96)	77.08 (10.68)
250 ms	''SAME''	91.67 (6.64)	94.44 (5.94)	26.04 (15.14)
	''DIFFERENT''	4.17 (7.72)	3.47 (6.60)	71.18 (13.02)

Note. Due to rounding and nonresponses, percentages within a condition may not sum to 100.

were excluded from analysis. The raw reaction times for each subject were log normalized and averaged across conditions prior to statistical analysis.

The percentages of ''SAME'' and ''DIFFERENT'' responses across conditions are shown in Table 8. The pattern of performance across conditions indicates that in general patients identified both intact and altered items as belonging to the same phonetic category. Seven of eight patients at the 50-ms ISI and five of eight patients at the 250-ms ISI produced more than 66% correct ''DIFFERENT'' judgments in response to test pairs containing a voiced counterpart. As in Experiment 1, reaction times and accuracy were compared for ''SAME'' responses to identical pairs and pairs containing an altered stimulus as a function of lexical competitor, so that the effect of the acoustic manipulation on phonetic perception could be examined more closely. These data are shown in Table 9.

The reaction time and accuracy data were analyzed in three-way repeated-measures ANOVAs with ISI (50 ms vs 250 ms), Acoustic Manipulation (Altered vs Unaltered), and Lexical Competitor (Competitor vs No Competitor) as within-subjects factors. Means comparisons were conducted on the accuracy and reaction time data as planned contrasts (Altered vs Unaltered) in a general linear model. The results of these analyses are shown in Table 10. There was a marginally significant main effect of Acoustic Manipulation in the reaction time analysis, such that reaction times were slower overall to pairs containing an altered stimulus than to acoustically identical pairs. Seven of the eight patients showed this pattern, indicating that in general patients were sensitive to the acoustic difference between altered and unaltered primes, although the overall effect failed to reach significance. No significant main effects of ISI or Lexical Competitor emerged in either the reaction time or accuracy analyses.

TABLE 9
Means (and Standard Deviations) of the Percentage Correct and Reaction Times in Milliseconds for ''SAME'' Responses in the Discrimination Task (Experiment 2)

ISI	Lexical competitor	Acoustic manipulation	% ''SAME'' responses	RTs (ms) to ''SAME'' responses
50 ms	Competitor	Altered	93.06 (8.27)	833 (180)
		Unaltered	97.22 (5.14)	877 (261)
	No competitor	Altered	93.06 (8.27)	948 (338)
		Unaltered	95.83 (5.75)	839 (129)
250 ms	Competitor	Altered	88.89 (5.94)	887 (240)
		Unaltered	93.06 (5.75)	761 (94)
	No competitor	Altered	94.44 (8.40)	852 (122)
		Unaltered	95.83 (8.27)	803 (107)

TABLE 10
Results of Statistical Analyses (ANOVAs and Means Comparisons) for the Discrimination Task (Experiment 2)

Effect		Main		× Lexical competitor		× Acoustic manipulation		× Acoustic manipulation × lexical competitor	
Measure		% SAME	RT	% SAME	RT	% SAME	RT	% SAME	RT
ISI	$F(1, 7)$	0.85	0.62	**3.94**~ (p = .08)	0.94	0.04	**5.50***	0.04	**5.99***
Acoustic manipulation	$F(1, 7)$	3.10	**4.55**~ (p = .07)	0.66	0.54	—	—	—	—
Lexical competitor	$F(1, 7)$	1.58	0.96	—	—	—	—	—	—

Comparison			Altered vs unaltered	
Measure			% SAME	RT
50-ms ISI	Competitor	$F(1, 7)$	0.67	1.25
	No competitor	$F(1, 7)$	1.51	**5.60***
250-ms ISI	Competitor	$F(1, 7)$	1.51	**10.13****
	No competitor	$F(1, 7)$	0.17	3.14

Note. Bold entries indicate significant or marginally significant effects.
* $p < .05$.
** $p < .01$.
~ $p < .1$.

A marginally significant ISI × Lexical competitor interaction was obtained in the accuracy analysis, suggesting a tendency toward fewer ''SAME'' responses for items with a lexical competitor at the 250-ms ISI than at the 50-ms ISI. There was also a significant ISI × Acoustic Manipulation interaction in the reaction time data, indicating that the overall effect of the acoustic manipulation was greater at the 250-ms ISI than at the 50-ms ISI. In addition, a significant ISI × Acoustic Manipulation × Lexical Competitor interaction emerged in the reaction time data. Planned comparisons revealed that, at the 50-ms ISI, reaction times were significantly slower to pairs containing an altered stimulus than to unaltered pairs in the No Competitor condition, but not in the Competitor condition. At the 250-ms ISI, a similar effect emerged in the Competitor condition, but not in the No Competitor condition. This interaction is considered further below in the discussion of the lexical decision data.

In summary, patients showed a weak sensitivity to the acoustic manipulation in the discrimination task. While the overall effect of the acoustic manipulation on reaction times was marginally significant, such that on average listeners were slower to respond ''SAME'' to pairs containing an altered stimulus than to acoustically identical pairs, this effect failed to reach significance in all conditions.

Lexical decision task. The results of the lexical decision task were scored for accuracy and reaction time. The percentages of correct ''WORD'' responses are shown in Table 11. Reaction times that were more than 2 *SD* from the mean for each subject in each condition were eliminated from analysis. The raw reaction times for each subject were log normalized and averaged across conditions prior to statistical analysis. Mean reaction times across all conditions are plotted in Fig. 5. Three-way repeated-measures ANOVAs were performed on the accuracy and reaction time data with ISI (50 ms vs 250 ms), Prime Condition (Related vs Altered vs Unrelated), and Lexical Competitor (Competitor vs No Competitor) as within-subjects factors. Means comparisons were performed on the reaction time data as planned contrasts (Altered vs Unaltered, Unaltered vs Unrelated, and Altered vs Unrelated) in a general linear model. Similar analyses were conducted on ''NONWORD'' responses, but no significant effects emerged. The results for ''WORD'' responses are shown in Table 12.

A significant main effect of Prime Condition emerged in both the reaction time and accuracy analyses. The main effects of ISI and Lexical Competitor were not significant, and there were no significant interactions. Planned comparisons per-

TABLE 11
Percentage of Correct Responses in the Lexical Decision Task (Experiment 2)

ISI	Lexical competitor	Acoustic manipulation	% Correct
50 ms	Competitor	Unaltered	81.94 (15.64)
		Altered	84.72 (18.72)
		Unrelated	75.00 (12.94)
	No competitor	Unaltered	94.44 (5.94)
		Altered	88.89 (10.29)
		Unrelated	73.61 (14.47)
250 ms	Competitor	Unaltered	86.11 (15.43)
		Altered	87.50 (12.51)
		Unrelated	86.11 (7.86)
	No competitor	Unaltered	91.67 (5.14)
		Altered	90.28 (11.01)
		Unrelated	86.11 (9.85)

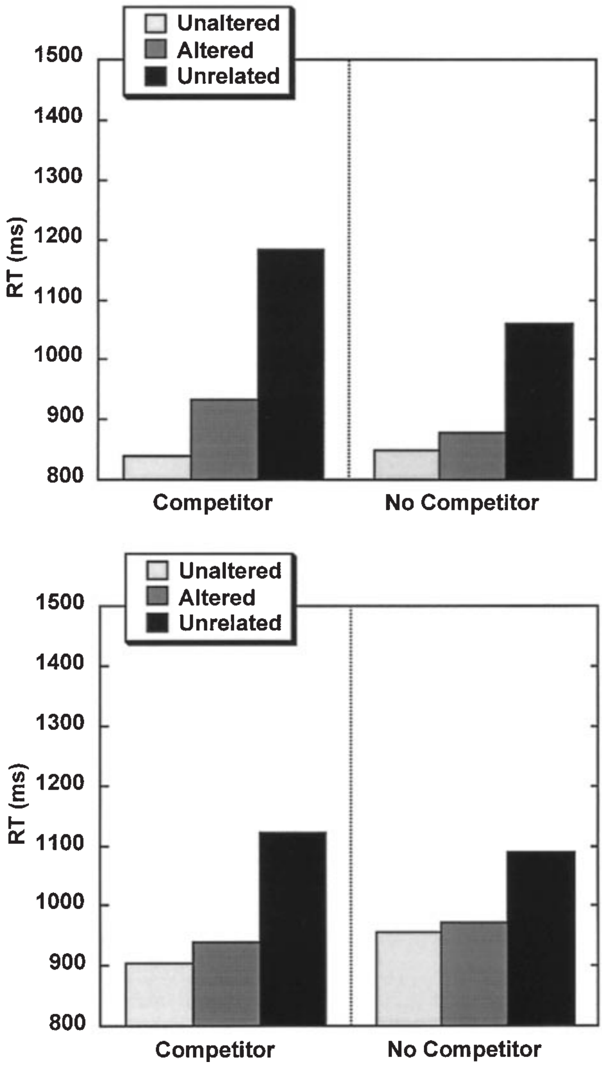

FIG. 5. Reaction times to correct responses to word targets across prime conditions in the lexical decision task as a function of lexical competitor (Experiment 2). Results for the 50-ms ISI are shown in the top panel and for the 250-ms ISI in the bottom panel.

formed on the reaction time data revealed that participants were significantly slower to respond to targets preceded by unrelated primes than by intact or altered primes. In addition, a marginally significant difference between the altered and unaltered conditions emerged in the reaction time analysis at the 50-ms ISI for primes with a lexical competitor. This difference indicates that there was a weak reduction in semantic facilitation for altered primes with a lexical competitor at the 50-ms ISI. No difference between the altered and unaltered conditions emerged at the 250-ms ISI.

To determine whether the pattern of results was influenced by the repetition of targets, mean reaction times were calculated for the first occurrence of each target at each ISI as a function of Prime Condition. These data are plotted in Fig. 6.

A two-way ANOVA was performed on the reaction time data with ISI (50 ms vs 250 ms) and Prime Condition (Related vs Altered vs Unrelated) as within-subjects factors. Means comparisons were performed on the reaction time data as planned

TABLE 12
Results of Statistical Analyses (ANOVAs and Means Comparisons for Reaction Time Data) for the Lexical Decision Task (Experiment 2)

Effect	Main		× Lexical competitor		× Prime condition		× Prime condition × lexical competitor	
Measure	% Correct	RT	% Correct	RT	% Correct	RT	% Correct	RT
ISI	*F*(1, 7) 2.61	*F*(1, 7) 0.96	*F*(1, 7) 0.42	*F*(1, 7) 2.43	*F*(2, 14) 2.28	*F*(2, 14) 1.39	*F*(2, 14) 0.29	*F*(2, 14) 0.14
Prime condition	*F*(2, 14) **7.82****	*F*(2, 14) **13.96****	*F*(2, 14) 2.04	*F*(2, 14) 2.38	—	—	—	—
Lexical competitor	*F*(1, 7) 2.46	*F*(1, 7) 1.02	—	—	—	—	—	—

Comparison			Altered vs unaltered	Unaltered vs unrelated	Altered vs unrelated
50-ms ISI	Competitor	*F*(1, 14)	**3.51**~ (p = .08)	**34.96****	**16.32****
	No competitor	*F*(1, 14)	0.26	**14.60****	**10.94****
250-ms ISI	Competitor	*F*(1, 14)	0.14	**14.04****	**11.40****
	No competitor	*F*(1, 14)	<0.01	**5.94***	**5.96***

Note. Bold entries indicate significant or marginally significant effects.
* $p < .05$.
** $p < .01$.
~ $p < .1$.

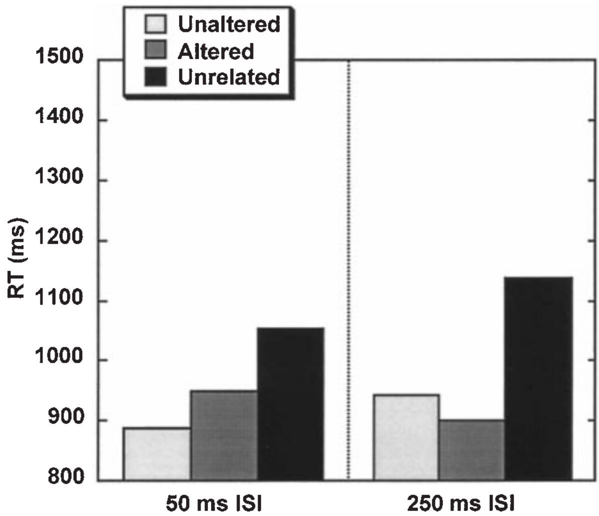

FIG. 6. Reaction times to correct responses to the first occurrence of word targets across prime conditions (Experiment 2).

contrasts (Altered vs Unaltered, Unaltered vs Unrelated, and Altered vs Unrelated) in a general linear model. The results of these analyses are shown in Table 13. A significant main effect of Prime Condition emerged. Planned comparisons revealed significant semantic facilitation overall at the 250-ms ISI such that reaction times were significantly faster to targets preceded by related (altered and unaltered) primes than by unrelated primes. However, at the 50-ms ISI, the difference between unaltered (related) and unrelated prime conditions was only marginally significant, and there was no significant difference between the altered and unrelated prime conditions. No significant difference emerged between the altered and unaltered prime conditions at either ISI. Thus, the statistical effects were weaker for this subset of the data than for the entire dataset, particularly at the 50-ms ISI. However, the pattern of results was similar in both analyses, suggesting that the observed effects were not influenced by the repetition of targets.

TABLE 13
Results of Statistical Analyses (ANOVAs and Means Comparisons) for the First Occurrence of Targets in the Lexical Decision Task (Experiment 2)

Effect		Main		× Prime condition
ISI		(1, 7) 0.14		(2, 14) 1.41
Prime Condition		(2, 14) **3.34**~ (p = .06)		—
Comparison		Altered vs unaltered	Unaltered vs unrelated	Altered vs unrelated
50-ms ISI	$F(1, 14)$	1.19	**3.83**~ (p = 0.07)	0.75
250-ms ISI	$F(1, 14)$	0.43	**6.16***	**9.84****

Note. Bold entries indicate significant or marginally significant effects.
* $p < .05$.
** $p < .01$.
~ $p < .1$.

Discussion

In the discrimination task, patients showed a weak sensitivity to the acoustic manipulation such that the presence of the manipulation significantly influenced reaction times in some conditions and not in others. However, this pattern of results was not reflected in the lexical decision task. Specifically, at the 50 ms ISI, the effect of the acoustic manipulation failed to reach significance in the discrimination task for items with a lexical competitor. Nevertheless, a marginally significant reduction in semantic facilitation emerged for primes with a lexical competitor in the lexical decision task. Indeed, six of the eight patients showed this pattern of results, suggesting that the presence of a lexical competitor in combination with the acoustic manipulation resulted in a reduction in semantic priming. In contrast, the acoustic manipulation had a significant effect on reaction times for items with no lexical competitor in the discrimination task, but these items did not produce a significant reduction in semantic facilitation in the lexical decision task. The overall pattern of results for both tasks at the 50-ms ISI suggests that in general patients were sensitive to the acoustic difference between altered and unaltered stimuli, but that the acoustic manipulation influenced semantic facilitation only when the prime word had a lexical competitor. At the 250-ms ISI, there was no difference in the amount of semantic facilitation obtained for altered and unaltered prime words and no apparent effect of lexical competition.

The performance of Broca's aphasics in Experiment 2 is similar in many respects to the previous results obtained for normal subjects. Nonetheless, some differences also occurred, particularly at the 50-ms ISI (Utman, 1997, 1998b). At the 50-ms ISI, normal subjects showed a reduction in the magnitude of semantic facilitation as a function of the acoustic manipulation. This effect emerged whether or not there was a lexical competitor. In contrast, for Broca's aphasics, the influence of subphonetic manipulations on priming emerged weakly only when there was a lexical competitor. By 250 ms, similar to normal subjects, Broca's aphasics showed significant priming for both acoustically altered and unaltered primes. Further, there was no influence of the acoustic manipulations on the magnitude of semantic priming, nor was there an influence of lexical competitor on the emergence of semantic priming.

GENERAL DISCUSSION

The purpose of the present experiments was to determine whether subphonetic (within-category) acoustic variation affects the access of lexical-semantic information in Broca's aphasics. Of particular interest were the influence of lexical competition and the locus of acoustic variation on the mapping from sound to meaning.

In general, the pattern of results obtained for Broca's aphasics in the discrimination task was similar to that obtained for normal subjects. Broca's patients perceived the acoustically altered stimuli as belonging to the same phonetic category as the intact stimuli. Additionally, they showed perceptual sensitivity to within-phonetic-category acoustic manipulations. Specifically, reaction time latencies to ''SAME'' responses for discrimination pairs that differed acoustically were significantly slowed compared to acoustically identical pairs. These effects emerged for acoustic manipulations of voice-onset time in voiceless stop consonants in initial position (Experiment 1) and for the acoustic manipulation of closure phonation in voiced stop consonants in final position (Experiment 2). Further, although the size of these effects varied across conditions, there was no consistent relationship between the presence of a lexical competitor and the patients' perceptual sensitivity to the acoustic manipulation. Thus, like normal subjects, aphasic patients showed perceptual sensitivity to these acoustic differences irrespective of the type of acoustic information being manipulated or the position of the manipulation in the word. These findings lend further support to the view that the basis for lexical processing impairments in Broca's aphasics cannot be attributed to a more fundamental deficit in the processing of the sounds of speech.

The results of the lexical decision tasks in Experiments 1 and 2 reveal that phonetic category structure affects lexical access in Broca's patients. Both Broca's aphasics and normal subjects show a reduction in the magnitude of semantic priming in response to prime words containing poor phonetic exemplars. However, the nature of this reduction in priming differs substantially across the two groups. In normal subjects, poorer phonetic exemplars have a small and short-lived effect on priming, irrespective of the presence of potential lexical competitors or the position of the acoustic manipulation in the prime word (Andruski et al., 1994; Utman, 1997, 1998b). In contrast, semantic priming in Broca's aphasics is influenced by competition at the lexical level as well as by the locus of the acoustic distortion in the word. Further, unlike normal subjects, Broca's patients showed no significant difference in the pattern of results across ISIs, indicating that the time course of lexical activation is differentially affected in these patients.

Manipulations of word-initial acoustic information result in a markedly different pattern of performance in the lexical decision task for Broca's aphasics than for normal subjects. Normal subjects show a reduction in the magnitude of semantic priming for altered primes at the 50-ms ISI, but not at the 250-ms ISI, irrespective of the presence of a lexical competitor (Andruski et al., 1994; Utman, 1997, 1998b). The performance of Broca's aphasics differed from this pattern in two respects. First, the presence of a lexical competitor had a significant effect on the pattern of priming obtained for altered primes. For altered prime words without a lexical competitor, Broca's patients showed reduced semantic facilitation (similar to normal subjects), whereas for altered prime words with a lexical competitor, facilitation was entirely eliminated. Second, the patterns of priming that emerged for these patients did not change over time.

The pattern of results for normal subjects shown in previous studies (Utman, 1997, 1998b) for word-final acoustic manipulations were the same as those obtained for acoustic alterations in initial position. Namely there was a reduction in the magnitude of semantic priming at the 50-ms ISI which disappeared by 250 ms. Moreover, these results were obtained irrespective of the presence of a lexical competitor. The results of Experiment 2 show that at the 50-ms ISI, Broca's aphasics demonstrate a marginally significant reduction in priming for word-final subphonetic variation, and only for prime words in which a change in the identity of the manipulated segment would result in a real word. As with normal subjects, no difference in priming was obtained between altered and intact variants at the 250-ms ISI. Thus, the effects of word-final acoustic manipulations on priming are less reliable in Broca's aphasics than in normal subjects and emerge weakly only when there is competition at the lexical level.

How can this complex pattern of results be accommodated under current accounts of lexical processing in Broca's aphasia? Previous studies involving normal subjects (Andruski et al., 1994; Utman, 1997, 1998b) have schematized the results in terms of a graded activation framework, illustrated in Fig. 7.

According to this approach, lexical entries may be more or less active depending on the extent to which the acoustic input constitutes a good match with the stored representation. Activation is passed on to semantically related words in the lexical network in a graded manner (cf. Milberg, Blumstein, Katz, Gershberg, and Brown, 1995). Lexical entries with higher activation levels will inhibit the activation of potential competitors and will pass activation downward to compatible segments at a phonetic level of representation. Thus, over time, feedback within and between levels

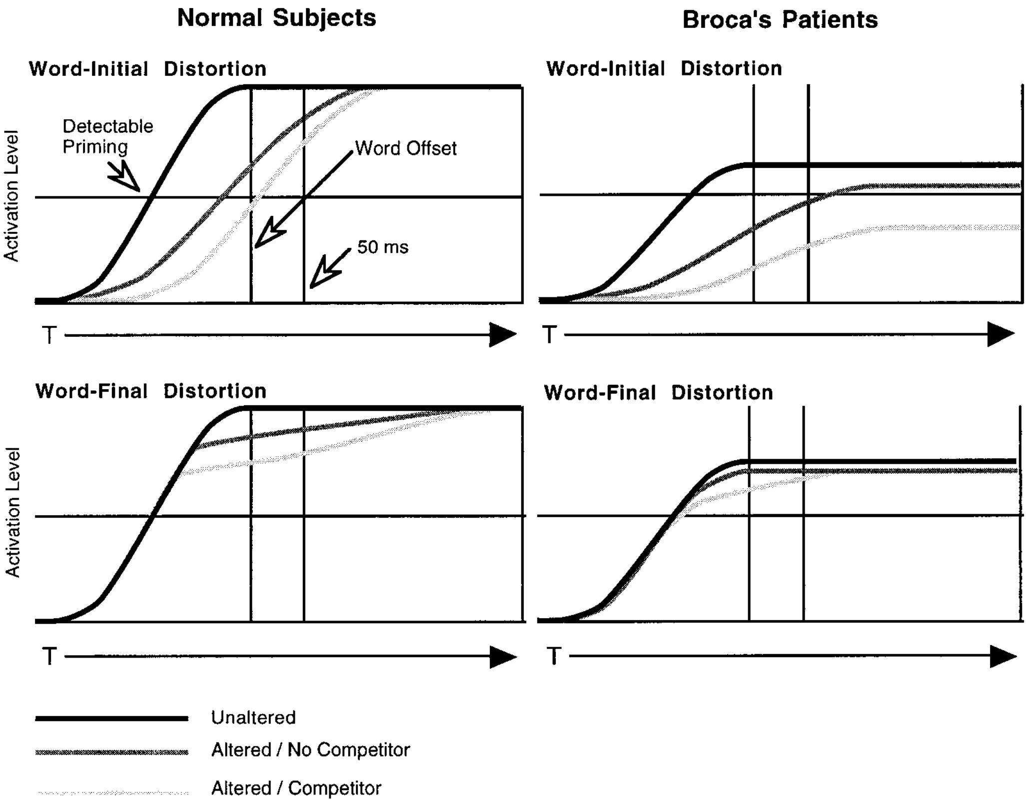

FIG. 7. Schematic representation of activation levels of the most compatible lexical entry in response to intact and distorted inputs for normal subjects (left panels) and Broca's aphasics (right panels). The upper panels represent activation levels for stimuli with acoustic distortion at word onset, and the lower panels represent activation levels for stimuli with acoustic distortion after word onset.

of representation serve to boost the activation level of the lexical entry most compatible with the acoustic input. The goal of the lexical processing system under this approach is to settle on the most compatible lexical candidate.

This framework accounts for the different patterns observed for normal subjects at the 50-ms and 250-ms ISIs. At the short ISI, an altered prime produces less lexical activation than an intact prime, and this difference is reflected in the spread of activation to related targets. Thus, altered primes produce less semantic facilitation than unaltered primes at the 50-ms ISI. At the longer ISI, top-down feedback has had time to operate on the initial activation levels produced by the altered prime and has increased the activation of the most compatible lexical entry to its asymptotic level. In other words, the lexical processing system has had sufficient time to settle on the most compatible lexical candidate. Thus, altered primes produce the same amount of semantic facilitation as intact primes at the 250-ms ISI.

The activation of lexical entries also needs to be considered as a continuous mapping of the acoustic input onto lexical representations (cf. Marslen-Wilson, 1993; Lahiri & Marslen-Wilson, 1991, 1992). Evidence from normal subjects suggests that lexical activation levels are continuously changing as a function of the available acoustic input even before the offset of the word (e.g., Warren & Marslen-Wilson, 1987). Potential candidates that are less compatible with the acoustic input are gradually eliminated as increasing portions of the acoustic signal are perceived (Warren & Marslen-Wilson, 1987). With increasing acoustic information, the activation level of the most compatible candidate may be differentiated from that of its competitors (cf. McClelland & Elman, 1986; Marslen-Wilson, 1993), allowing the lexical processing system to settle on that candidate.

In normal subjects, both intact words and words containing distorted segments activate an array of potential lexical candidates from the onset of the word. The activation level of these candidates is influenced by additional acoustic input and by the operation of feedback mechanisms (cf. Marslen-Wilson, 1993). Acoustic distortion that produces a poorer phonetic exemplar in any segmental position in the spoken word will result in reduced lexical activation. However, the locus of the acoustic distortion in the word will affect the point in time at which the activation levels of altered and unaltered inputs begin to separate. Thus, words with distorted final segments activate an initial array of candidates more strongly because the initial segment of these items is intact, although the occurrence of an acoustic manipulation late in the word will nevertheless result in less activation of the target than an intact input. However, since lexical representations are strongly activated in general in normal subjects, the most compatible candidate with the acoustic input will produce semantic priming regardless of the position of the acoustic distortion. Over time, feedback mechanisms will operate on the activation level of this candidate until it is maximally activated.

The results from the aphasic patients can be accounted for within this framework as well. As discussed above, a number of researchers have proposed that lexical activation levels are reduced in Broca's aphasics relative to normal subjects (Milberg & Blumstein, 1981; Blumstein, Milberg, & Shrier, 1982; Milberg et al., 1987, 1988a, 1988b, 1995). Because of lowered activation levels overall, bottom-up activation levels for words with an acoustic distortion in the initial segment may not be sufficient to overcome lexical competition (see Fig. 7). That is, the acoustically distorted prime weakly activates its lexical entry as well as its lexical competitor. Because the activation level of the lexical candidate is not sufficiently high, it will fail to be differentiated from the activation of potential competitors (e.g., acoustically modified ''pear'' partially activates ''pear'' as well as its competitor ''bear''). As a consequence, the lexical processing system will not be able to settle on the most compatible lexical candidate, and therefore semantically related targets may fail to produce detectable semantic priming. In contrast, lexical entries without a competitor (e.g., ''peace'') will not be inhibited by the presence of such a competitor and hence are sufficiently activated even by a distorted input to produce semantic priming.

That the influence of phonetic distortion on the patterns of semantic priming in Broca's aphasics emerges particularly under conditions of lexical competition lends further support to the view that the locus of the patients' deficit is in the lexical processing system itself and not in the mapping from sound structure to lexical form. In normal subjects, graded input to the lexical-semantic system does not have a disproportionate effect on words with competitors. These words might take slightly longer to settle into a stable state in the normal language processing system, as suggested in Fig. 7, but bottom-up activation levels are sufficiently high to inhibit the activation of competitors, even when the input is degraded. Effects of competition only begin to emerge when lexical activation levels are reduced, so that degraded words fail to achieve sufficient activation to overcome competition.

It is of interest that Broca's aphasics do not appear to be able to compensate for the acoustic distortions in initial position as do normal subjects over longer ISIs. These findings lend further support to the view that the activation levels of lexical entries are reduced in Broca's aphasics. As described above, once a lexical entry becomes active, it will pass activation downward to compatible segments at a phonetic level of representation. Thus, over time, feedback between levels of representation will serve to neutralize the within phonetic category, acoustic effects. Because the asymptotic level of activation of lexical entries is reduced in Broca's aphasics, the lexical processing system is unable to reach a sufficiently high level of activation to compensate for the effects of the phonetic distortion, particularly when the distortion occurs at word onset.

Because words with an acoustic distortion in the final segment have higher initial activation levels than words with distorted onsets, the bottom-up activation level of the target lexical item may be sufficiently activated in Broca's patients to produce semantic priming before the distorted final segment is encountered. Thus, semantic priming emerges consistently for words with distorted final segments. Further, word-final distortions may have less of an effect on priming in these patients than in normal subjects, particularly in the absence of lexical competitors, as the activation level of the most compatible candidate may serve to override the effect of the acoustic distortion by the time it is encountered.

The current proposal may account for the apparent slowed rise-time of lexical activation that some researchers have observed in Broca's patients (Swinney et al., 1989; Prather et al., 1991, 1992). Specifically, if initial activation levels are reduced, a longer time interval may be required for activation to build up sufficiently to feed activation back to lower levels of representation (cf. Milberg et al., 1995). However, once this time interval has passed and the feedback criterion is exceeded, these patients may more closely resemble normal subjects in their pattern of performance on tests of lexical processing. Nevertheless, it is important to point out that the results of the present experiments do not support an account of lexical processing in Broca's aphasia in terms of a general slowing of lexical access. If access to lexical entries were simply delayed in Broca's aphasics, their pattern of performance should have been similar to that of normal subjects in the present experiments, but emerging over a longer time course. Instead, Broca's patients show a markedly different overall pattern of performance than normal subjects and still do not show normal patterns of priming even at the longer ISI. The possibility that a different pattern might emerge at an ISI longer than 250 ms is a topic for future research.

The account of the results outlined above is framed in terms of the levels of lexical-semantic activation produced by altered and unaltered primes. However, it is important to point out that the pattern of results observed in Broca's aphasics may also reflect a disturbance in activation at the level of lexical form, i.e., the phonetic or orthographic representations of words. Poorer exemplars may produce weaker activation of word form representations, and this weak activation is passed on to the lexical-semantic level. Under this view, an altered prime with no competitors overcomes the phonetic degradation and settles into a stable state more rapidly than an altered prime with competitors, and this is reflected in both the form and meaning representations.

Alternatively, the lexical processing disturbance in Broca's patients may not reflect reduced activation levels, but may suggest an impairment in the selection of the appropriate item from an array of active candidates. Recent evidence has suggested that the left inferior frontal gyrus, particularly Brodmann's areas 44, 45, and 46, may be implicated in lexical selection as opposed to lexical retrieval (e.g., Thompson-Schill, Swick, Farah, D'Esposito, Kan, & Knight, 1998). The performance of Broca's aphasics in the present experiment is consistent with this view to some extent. Altered primes activate a greater number of potential competitors because the altered segment is closer to a phonetic category boundary. If Broca's are impaired in lexical selection, they should have more difficulty in choosing an item from a larger array of competitors. However, it is not clear under this account how the failure to choose between multiple active candidates would prevent the spread of lexical activation to related items in the semantic network.

In conclusion, the results of the present experiments demonstrate that Broca's aphasics are sensitive to subphonetic acoustic variation in the perception of phonetic segments and in the mapping from acoustic inputs to lexical entries. In addition, the findings support previous accounts of the lexical processing deficit in Broca's aphasia in terms of lowered activation levels. This deficit interacts with the position of acoustic variation in a word such that Broca's patients are particularly sensitive to distortions in word-initial position relative to word-final distortions. Finally, the reduction in lexical activation levels renders Broca's aphasics more vulnerable to competition between acoustically similar candidates in the access of lexical representations.

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