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The role of lexical competition and acoustic–phonetic structure in lexical processing: Evidence from normal subjects and aphasic patients

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Abstract

This study examined the effects that the acoustic–phonetic structure of a stimulus exerts on the processes by which lexical candidates compete for activation. An auditory lexical decision paradigm was used to investigate whether shortening the VOT of an initial voiceless stop consonant in a real word results in the activation of the lexical–semantic network of its voiced competitor, i.e., does acoustically modified *time* prime *penny* via *dime*. Results for normal subjects showed semantic priming for related pairs and mediated priming for voiced competitors, consistent with cascade models of language processing allowing for interaction between phonological and semantic levels of processing. Although Broca's aphasics showed semantic priming (*dime* primed *penny*), they failed to show priming in the context of a lexical competitor. These results are consistent with the hypothesis that these patients have a lexical processing deficit characterized by an overall reduction in lexical activation.

Keywords: Mediated priming; Lexical competition; Lexical activation; Acoustic–phonetic structure; Broca's aphasia

1. Introduction

In recent years, a great deal of research has explored the dynamics of lexical activation in both normal subjects and aphasic patients. Much of this research has been devoted to elucidating the processes by which sound structure is mapped to lexical form and determining how and in what ways phonetic and phonological variability affects lexical access. The focus on phonetic and phonological variability has been motivated in part by the fact that the speech signal that the listener receives is inherently 'noisy'. Not only is spoken language presented in a noisy medium, but there is also a great deal of variability in the speech production process itself. For example, there is variability within a speaker in producing exemplars of a phonetic category such as voicing in stop consonants. Despite the range of voice-onset time (VOT) values associated with the voiced and voiceless phonetic categories, the perception of such phonetic categories of speech and subsequent word forms appears to be remarkably robust and highly stable. The question then is whether the mapping from sound structure to lexical form is influenced by the variability of acoustic phonetic structure or alternatively whether this variability is 'cleaned up' in the process of phonetic categorization and hence does not affect lexical access.

Results of research in the normal literature as well as investigations with aphasic patients have suggested that lexical access is affected by both phonological and

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phonetic factors. Studies with normal subjects have shown that nonword stimuli that have been derived by altering the initial consonant of real words can facilitate lexical decision judgments for targets that are semantically related to the real word base (Connine, Blasko, & Titone, 1993; Milberg, Blumstein, & Dworetzky, 1988a). Moreover, the magnitude of priming elicited by these nonwords varies as a function of the phonological distance between the nonword prime and its real word derivative. For example, systematically less semantic priming is obtained for *wat–dog* than for *gat–dog* compared to *cat–dog*.

Similar effects have emerged when the acoustic–phonetic structure of phonetic categories has been manipulated. When the VOT of an initial voiceless stop consonant of a prime word has been shortened, reduced levels of semantic priming are observed. For example, the acoustic modification of the [k] in *cat* (henceforth denoted by the presence of an asterisk after the initial consonant, e.g., *c*at*) results in significantly less semantic priming for *dog* than that elicited by an unmodified exemplar of *cat* (Andruski, Blumstein, & Burton, 1994). In this case, the acoustically modified initial consonant is still perceived as a voiceless stop consonant by listeners, but it is a poorer exemplar of the voiceless phonetic category. These semantic priming effects have emerged when the acoustic manipulation has occurred in different phonetic positions (initial and final) and with different types of acoustic–phonetic manipulations (temporal and spectral) (Kessinger, 1998; Utman, 1997; Utman, Blumstein, & Sullivan, 2001). These results indicate that within phonetic category acoustic variation affects access to lexical–semantic information as a function of the 'goodness' of fit or prototypicality of the acoustic–phonetic exemplar to its phonetic category (Utman et al., 2001).

Taken together, the patterns of performance observed in both conditions of phonological and phonetic variation suggest that lexical activation is graded and is influenced by the phonetic/phonological distance between sound structure input and lexical form (Andruski et al., 1994; Connine et al., 1997). Moreover, these findings indicate that the nature of the phonetic-phonological input affects not only the activation of lexical form, but also influences the activation of the lexical network itself. That is, phonological and acoustic–phonetic variation in the speech input results in a reduction in the activation of a lexical candidate, which in turn results in a decrease in the activation of its associated lexical–semantic network.

The proposal that the activation of a lexical candidate is graded has important implications for the architecture of the lexical processing system, for it suggests that the phonetic-phonological input may also influence the activation of lexical competitors to a particular lexical item. That is, if activation of lexical form is graded and the extent of that activation varies as a function of phonetic-phonological similarity to a lexical entry, then phonetically–phonologically similar lexical competitors should also be partially activated. The extent of that activation should be dictated by the phonetic-phonological distance of the speech input from the lexical form of the competitor. A number of models of lexical access allow for graded activation of phonetic and phonological features and lexical competition via interactive activation in mapping from sound structure to lexical form. These include the Cohort model (Gaskell & Marslen-Wilson, 1999; Marslen-Wilson, 1987; Marslen-Wilson & Welsh, 1978); TRACE (Elman & McClelland, 1986; McClelland & Elman, 1986), and Shortlist (Norris, 1994). However, what is not clear is whether the influence of phonetic-phonological factors on lexical competition percolates throughout the lexical–semantic network. That is, does the partial activation of the lexical form of these competitors also partially activate their lexical–semantic network(s) as well?

It is the goal of this research to examine whether the acoustic–phonetic manipulation of an initial voiceless stop consonant in a real word will partially activate its phonetically contrasting lexical competitor and lexical–semantic network. If this is the case then a prime stimulus such as *t*ime*, in which the voice-onset time of the initial voiceless stop is shortened and hence is closer to the voiced phonetic category [d], should partially activate the lexical representation for 'dime', which in turn should partially activate its lexical–semantic network. Thus, *t*ime* should prime *penny*, but the magnitude of priming for *penny* should be significantly less than it would be if the prime stimulus were *dime*, which contains a good exemplar of the voiced phonetic category.

There are some data that are consistent with the view that lexical competition influences the dynamics of lexical activation. Andruski et al. (1994) showed an effect of competitor status in a study investigating the effects of acoustic manipulation of phonetic category structure on the magnitude of semantic priming in a lexical decision task. In this study, the VOT of initial voiceless stop consonants was shortened by two-thirds in the stimulus primes, and the effects of these manipulations on reaction time latencies to semantically related targets were explored. Results showed that reaction time latencies were slower overall when the prime stimulus had a voiced lexical competitor compared to when the prime stimulus did not have a voiced lexical competitor. Thus, reaction time latencies were slower for the prime-target pair *pear–fruit* (*bear* is a voiced lexical competitor to *pear*) than they were for the prime-target pair *cat–dog* (*cat* has no voiced lexical competitor, i.e., *gat*). Similar findings were obtained by Utman (Utman, 1997; Utman et al., 2001) in exploring the effects of manipulating other acoustic cues to voicing in different phonetic contexts.

Stronger evidence for the influence of competition on the dynamics of lexical activation comes from a series of experiments with Broca's aphasic patients exploring the influence of acoustic–phonetic variability on lexical access (Utman et al., 2001). These experiments were based on Andruski et al. (1994) and investigated the effects of within phonetic category (VOT) manipulations on semantic priming in Broca's aphasics. The results showed that when the prime stimulus did not have a voiced lexical competitor, Broca's aphasics exhibited patterns of semantic priming similar to those seen with normal subjects. Phonetically altered *c*at* showed a significant reduction in the magnitude of priming for *dog*. However, when the prime stimulus had a voiced lexical competitor, semantic priming was completely lost for the Broca's aphasics. Phonetically altered *p*ear* (with the lexical competitor *bear*) failed to prime the semantically related word *fruit*. The presence of a lexical competitor resulted in the loss of semantic priming when the initial voiceless stop consonant of the prime stimulus was a poorer exemplar of the voiceless phonetic category. Importantly, the patients perceived the initial consonant of the acoustically modified stimulus prime as voiceless, indicating that the failure to show priming under conditions of lexical competition was not due to a problem in perceiving the phonetic attributes of the phonetically altered prime stimuli.

These results were interpreted in relation to a general theoretical framework and computational model that built on a number of the principles and assumptions of earlier models of lexical access (e.g., TRACE, Cohort, LAFS, Shortlist, and Neighborhood Activation) and extended them within a self-organizing dynamical system (McNellis & Blumstein, 2001). This model was developed to account for the patterns of performance of both normal subjects and aphasic patients in a series of lexical processing experiments (see Blumstein & Milberg, 2000). The simulations of the model were based on the theoretical assumption that Broca's and Wernicke's patients have deficits in the dynamics of lexical activation, and that Broca's aphasics, in particular, have reduced lexical activation. Because of lowered activation levels overall, bottom-up activation levels for acoustically manipulated prime stimuli are not sufficient to overcome lexical competition and hence semantic priming is lost.

The current study is designed to investigate the ways in which the dynamics of lexical activation are influenced by the sound structure of speech, and specifically to examine the effects that subphonetic variation exerts on the processes by which lexical candidates compete for activation. To this end, we will investigate whether the acoustic–phonetic structure of a lexical stimulus can influence the activation level of a competing lexical candidate. Specifically, we will examine whether alterations in the VOT of an initial voiceless stop consonant in a real word will result in the activation of the lexical–semantic network of its voiced lexical competitor.

The intention to explore patterns of priming in the presence of lexical competition rests on the assumption that an acoustic–phonetic exemplar that is nearer to a phonetic category boundary will partially activate the contrasting phonetic category and associated lexical representation. However, it is also possible that even a good exemplar of a phonetic category may partially activate its contrasting phonetic category and its associated lexical competitor. If this is the case then a good exemplar of *time* should prime *penny* via the voiced lexical competitor *dime*.

Such mediated priming effects have been very difficult to demonstrate and have emerged inconsistently. Most studies have explored mediated priming at the lexical–semantic level by investigating whether a semantic associate of one word will prime an indirectly associated word or concept, i.e., will *lion* prime *stripes* via the semantically related word *tiger* (Balota & Lorch, 1986; McNamara & Altarriba, 1988). Only a few studies have explored semantic-phonological mediation, i.e., will *pen* prime *inch* through *ink*, and results show that it too is at best a weak effect (cf. McKoon & Ratcliff, 1992; O'Seaghdha & Marin, 1997). Indeed, pilot experiments with normal subjects using the same methods and ISIs as those used in Experiment 1 failed to show mediated priming when the prime stimulus was a good exemplar of its phonetic category, i.e., *time* failed to prime *penny* (via *dime*). However, it is possible that the presentation of a prime stimulus which is closer in acoustic-space to a phonological competitor will result in mediated semantic priming. It is the purpose of Experiment 1 to explore this question in normal subjects. It is hypothesized that mediated priming effects will emerge under such conditions. In contrast, it is expected that owing to reduced lexical activation that Broca's aphasics will fail to show mediated priming. Experiment 2 will investigate this question.

An auditory lexical decision priming paradigm will be used in which real word target stimuli (e.g., *penny*) will be preceded by real word prime stimuli in three priming conditions. In the related condition, the prime stimuli will be semantically related to the target and begin with a voiced stop consonant (e.g., *dime*). In the modified competitor condition, the prime stimuli will be voiceless competitors to the prime stimuli in the related condition. They will not be semantically related to the target, and the VOT of the initial voiceless stop will be shortened by 2/3 (e.g., *t*ime*). In the neutral condition, the prime stimuli will be real words that are neither semantically nor phonologically related to the target (e.g., *nose*). To explore the time course of the priming effects, two interstimulus (ISI) intervals will be used: 50 and 250 ms. Andruski et al. (1994) showed that for normals the effects of the acoustic manipulations on the magnitude

of semantic priming were short-lived. They occurred at 50 ms and disappeared by 250 ms. However, for Broca's aphasic patients, the effects of acoustic manipulations persisted across the two ISI conditions (Utman et al., 2001).

For all subjects, a phonetic discrimination post-test will also be given to ensure that despite the VOT manipulations, the acoustically modified prime stimuli are perceived as beginning with voiceless stop consonants. In other words, *t*ime* should be perceived as *time* and not *dime*. It is also important to determine whether subjects show perceptual sensitivity to the subphonetic acoustic differences. A failure to show sensitivity would suggest that listeners perceive the acoustically modified stimuli as containing a good exemplar of the voiceless phonetic category. In that case, a failure to show priming for *t*ime–penny* could be because a good exemplar of [t] does not sufficiently activate [d] and hence *dime*. If subjects are sensitive to the subphonetic acoustic differences, they should show increased error rates and/or reaction time latencies in making same/different discrimination judgments to pairs of words in which one of the items has been acoustically manipulated (e.g., *t*ime–time*) compared with pairs in which the items are acoustically identical (e.g., *time–time*). Previous studies have shown that Broca's and Wernicke's aphasics, as well as normal subjects, are perceptually sensitive to such within phonetic category distinctions (Aydelott & Blumstein, 1995; Kessinger, 1998; Utman et al., 2001).

2. Experiment 1

Experiment 1 investigated the hypothesis that in normal subjects acoustic–phonetic modifications to a lexical stimulus will influence the activation of the lexical–semantic network of its lexical competitor. If this is the case, acoustically modified competitor *t*ime* should prime *penny*, but the magnitude of priming should be less than that for *dime–penny*. Experiment 1a explored this hypothesis using a 50 ms ISI and Experiment 1b used a 250 ms ISI. In all other ways the two experiments were the same.

2.1. Method

2.1.1. Participants

Thirty-two students at Brown University were paid to participate in this study. All participants were native speakers of English with no known hearing impairments. Sixteen subjects were tested at the 50 ms ISI and the other sixteen were tested at the 250 ms ISI.

2.1.2. Stimuli

Twenty-one real-word targets were preceded by real-word primes in three conditions (see the Appendix). These three conditions constituted the test trials. In the first condition (*Related*), the prime stimulus was semantically related to the target and began with a voiced stop consonant (/b/, /d/, or /g/), e.g., *dime–penny*. Seven of the stimuli began with [b], seven with [d], and seven with [g]. In the second condition (*Modified competitor*), each prime stimulus was derived from the voiceless competitor of one of the voiced prime stimuli in the first condition, but the voice-onset time (VOT) of the initial voiceless stop was reduced by 2/3, e.g., *t*ime–penny*. The modified competitor prime stimuli were semantically unrelated to the target. In the third condition (*Neutral*), the real-word prime was both phonologically and semantically unrelated to the target, e.g., *nose-penny*.

Three equivalent distractor conditions were constructed. Twenty-one phonologically permissible strings that did not form words in English served as nonword targets. These words were similar in phonological shape to the real-word targets. In a fashion analogous to the three priming conditions described above, these nonword targets were either preceded by real words beginning with /b/, /d/, or /g/ (e.g., *gauge–shenny*), by the acoustically modified voiceless competitors of these real words (e.g., *c*age–shenny*), or by real words that did not begin with /b/, /d/, or /g/ (e.g., *fat–shenny*).

The lexical frequency of the primes was controlled across the test and distractor sets (Francis & Kucera, 1982). A one-way ANOVA revealed no statistically reliable differences for word frequencies across prime type (Related, Modified Competitor, or Neutral) $F(3,81) = .518$, $p > .671$. In total, the experimental stimuli consisted of 126 stimuli, 63 test pairs in which the targets were real words and 63 test pairs in which the targets were nonwords. The stimuli were presented in three randomized blocks of trials such that a different version of each prime word (*Related*, *Modified Competitor*, or *Neutral*) was assigned to one of the blocks. The presentation of the three prime words was counterbalanced across blocks and each block contained an equal number of related, modified competitor, and neutral trials. The proportion of semantically related trials in the experiment was one-third of the test trials. In Experiment 1a the interval (ISI) between prime and target words was set at 50 ms and in Experiment 1b the ISI was set at 250 ms. In both cases, the inter-trial interval (ITI) was fixed at 3000 ms.

All stimuli were recorded by a male speaker onto a DAT tape in a sound-treated room using a Sony TCD-D7 DAT recorder and a Sony ECM-909A stereo microphone. The stimuli were then digitized onto a Gateway 2000 computer with a ZA2 DAT card at a 20 kHz sampling rate and a 14-bit quantization. All waveform editing and stimulus preparation were performed on this computer.

The modified competitor stimuli were created in a manner similar to Andruski et al. (1994). The VOT of each unaltered word was measured from the beginning of the burst to vowel onset. The midpoint between the two measurement cursors was determined, and one-third of the total VOT was excised from either side of the VOT midpoint, producing tokens in which the original VOT was reduced by two-thirds. In this way, both the onset and offset characteristics of the initial stop consonant were preserved. All modified competitor stimuli were checked to assure that there were no transients or distortion introduced by the alteration process.

A discrimination post-test was created in order to ensure that the acoustically modified competitor prime stimuli were still being perceived as the voiceless words from which they were created and not their voiced counterparts and that subjects were sensitive to the voice-onset time manipulations. Stimuli for this task consisted of each of the 21 unmodified voiceless exemplars of the prime stimuli paired with itself (e.g., *time–time*), with its VOT-shortened exemplar (e.g., *t*ime–time*), or with its voiced lexical competitor (e.g., *dime–time*). Because "same" was the expected response in the first two conditions, each of the "different" pairs in the third condition occurred twice in the set. This resulted in a total of 84 experimental trials, the order of which was randomized. Analogous to the lexical decision task, there was an ISI of 50 ms in Experiment 1a and 250 ms in Experiment 1b. The ITI was fixed at 3000 ms.

2.1.3. Apparatus

The apparatus for the experiment consisted of a Dell Dimension XPS M200s computer, Koss R/80 stereo headphones, and a response box. Stimuli were presented to subjects at a comfortable listening level over the stereo headphones in a sound-treated room. The response box consisted of two buttons, labeled "WORD" and "NONWORD" for the lexical decision task, and "SAME" and "DIFFERENT" for the discrimination post-test. The computer began timing at the onset of each target stimulus. The timer was stopped when the participants pressed either button on the response box.

2.1.4. Procedure

For the lexical decision task, subjects were told they would hear pairs of stimuli, some of which would be real words in English and some of which would be nonwords. The subjects' task was to make a decision as to whether or not the second item in each pair was a real word. Subjects were instructed to indicate their decision by pressing the appropriate button on the response box as quickly as possible without compromising accuracy. Responses were made with the subjects' preferred hand, which subjects were instructed to position between the two buttons. For half of the subjects, the button on the right was labeled "WORD" and the button on the left was labeled "NONWORD". For the other half, this order was reversed. The experiment proper was preceded by a short practice period to familiarize subjects with the procedure. The practice test consisted of 8 stimulus pairs (4 with real-word targets and 4 with nonword targets). None of the stimuli presented in the practice test were included in the experiment proper. The total test time was approximately 15 min.

For the post-test discrimination task, participants were told they would hear pairs of real words. For each pair, they were instructed to indicate whether the two words in the pair were the same word or different words by pressing the appropriate button on the response box. Participants were encouraged to respond as quickly and as accurately as possible. The labels "SAME" and "DIFFERENT" were alternated on the panel for half of the participants. The discrimination task lasted for approximately 5 min.

2.2. Results

2.2.1. Experiment 1a: 50 ms ISI

2.2.1.1. Lexical decision task. The results of the lexical decision task were scored for both accuracy and response times. Both subject and item analyses were conducted. For each subject, any responses that were greater than two standard deviations from that subject's mean RT were considered to be outliers and excluded from the analyses.

Mean RTs for correct responses to real-word targets across conditions are shown in Fig. 1. A one-way repeated-measures ANOVA was performed on the reaction time data as a function of prime type (*Related* vs. *Modified competitor* vs. *Neutral*). A significant main effect of prime type was found by both by subject $F(2,30) = 20.845$, $p < .0001$, and by item $F(2,40) = 12.114$, $p < .001$. Newman–Keuls tests showed that the mean RTs for all three conditions were significantly different from each other by subject and by item. Thus, significant priming occurred

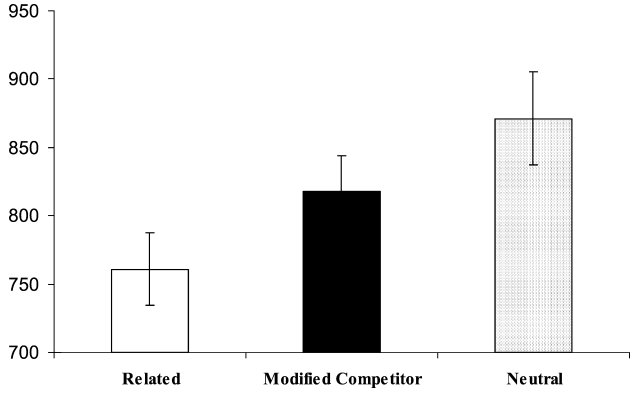

Fig. 1. Mean reaction time latencies and standard errors (in ms) for correct responses for normal subjects in the lexical decision task at the 50 ms ISI.

in both the *related* and *modified competitor* conditions; however, the magnitude of priming for the acoustically modified competitor stimuli (*t*ime–penny*) was significantly less than that for the unmodified semantically related stimuli (*dime–penny*).

A summary of the error data is shown in Table 1. Overall accuracy was high across conditions. A one-way repeated-measures ANOVA was also performed on the error data as a function of prime type. Here too a significant main effect of prime type was found both by subject $F(2,30) = 7.803$, $p < .005$, and by item $F(2,40) = 8.488$, $p < .001$. Post hoc Newman–Keuls tests showed both the related and the modified competitor conditions to differ significantly from the neutral condition. The comparison between the related and the modified competitor conditions did not reach significance.

Analysis of the nonword data showed similar reaction time latencies across conditions (889, 904, 889 ms). A one-way ANOVA revealed no statistically reliable differences for reaction time latencies $F(2,30) = .964$, $p > .10$. These results indicate that the acoustic modifications did not affect reaction time latencies to the nonword targets.

2.2.1.2. Discrimination post-test. The results of the post-test were analyzed for both accuracy and response times. Both subject and item analyses were conducted. Outlier responses, which varied by more than two standard deviations from each subject's mean RT, were excluded from the analyses. Only responses to pairs for which the expected response was "same" were included in the analyses.

The error data revealed that pairs with a modified competitor exemplar were overwhelmingly considered voiceless (1.062 mean errors out of a possible 21 errors). A one-way ANOVA for the error data showed that pairs containing a modified competitor exemplar (*t*ime–time*) were more likely to elicit an erroneous response (1.062 errors) than identical word pairs (.25 errors). This effect was significant by subject $F(1,15) = 7.061$, $p < .05$, but only marginally significant by item $F(1,20) = 3.747$, $p < .067$.

A one-way ANOVA for the reaction time data showed that word pairs containing an acoustically modified competitor exemplar took longer to respond "same" to (609 ms) than pairs containing intact stimuli (575 ms). This effect was significant by subject $F(1,15) = 8.658$, $p < .01$, and by item $F(1,20) = 6.696$, $p < .05$. Thus, although subjects considered the modified competitor stimuli to be voiceless, they were sensitive to the acoustic manipulations.

Table 1
Mean errors (out of 21) for lexical decision task in normals at 50 and 250 ms ISI

Condition	50 ms	250 ms
Related (*dime–penny*)	.125	.188
Modified competitor (*t*ime–penny*)	.562	.438
Neutral (*nose-penny*)	1.188	.375

2.2.2. Experiment 1b: 250 ms ISI

Procedures used for the data analysis were the same as those described above for the 50 ms ISI.

2.2.2.1. Lexical decision task. Fig. 2 shows the reaction time data for correct lexical decisions. The pattern of results for the 250 ms ISI condition was identical to those at 50 ms. Analysis of the reaction time data showed a main effect of prime type, which was significant both by subject $F(2,30) = 40.521$, $p < .0001$, and by item $F(2,40) = 13.308$, $p < .0001$. Newman–Keuls post hoc tests confirmed that the RT means for all three conditions were significantly different from each other by subject. A summary of the error data is shown in Table 1. Overall accuracy was high across conditions. A one-way repeated-measures ANOVA was also performed on the error data as a function of prime type. No significant effect of prime type was found in the analysis of the error data by subject $F(2,30) = 1.089$, $p > .10$, or by item $F(2,40) = .206$, $p > .10$.

Reaction time analysis of the nonword data showed similar reaction time latencies across the three conditions (1027, 1039, 1018 ms). A one-way ANOVA revealed no statistically reliable differences for reaction time latencies $F(2,30) = .979$, $p > .10$. These results indicate that the acoustic modifications did not affect reaction time latencies to the nonword targets.

2.2.2.2. Discrimination post-test. Error data showed that listeners perceived pairs with a modified competitor exemplar as voiceless (.812 errors out of a possible 21). A one-way ANOVA showed that pairs of words containing a modified competitor exemplar were more likely to elicit an erroneous response (.812 errors) than identical word pairs (.25 errors). This effect was significant by subject $F(1,15) = 6.361$, $p < .05$, and marginally significant by item $F(1,20) = 3.333$, $p < .083$.

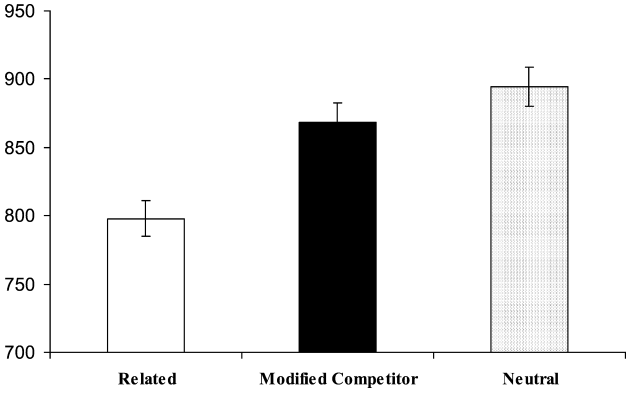

Fig. 2. Mean reaction time latencies and standard errors (in ms) for correct responses for normal subjects in the lexical decision task at the 250 ms ISI.

Reaction time analysis revealed that although word pairs containing an acoustically modified competitor exemplar took longer to respond "same" to (635 ms) than pairs of intact stimuli (616 ms), this effect was not significant by subject $F(1,15) = 2.030$, $p > .10$, or by item $F(1,20) = 1.439$, $p > .10$.

2.3. Discussion

The results for normal subjects showed consistent priming effects across all conditions. Thus, subjects showed priming for word pairs in which the acoustically intact prime stimulus was semantically related to the target (e.g., *dime–penny*), as well as for words pairs in which the prime stimulus was a voiceless lexical competitor of that prime, even though it was semantically unrelated to the target (e.g., *t*ime–penny*). Nonetheless, the magnitude of RT facilitation elicited by the voiceless lexical competitor primes was significantly less than that elicited by the semantically related, acoustically unmodified prime stimuli. That priming emerged for the acoustically modified competitor stimuli was presumably due to the fact that the initial voiceless stop consonant was close in acoustic space to its voiced phonetic contrast. Hence, the acoustically modified competitor prime stimulus *t*ime* activated not only the voiceless phonetic category [t] and the lexical representation for 'time', but also partially activated the voiced phonetic category [d] and the lexical representation for 'dime', which in turn activated its lexical network, i.e., 'penny'.

Consistent with these data are the results for the nonword condition. In particular, shortening the initial voice-onset time of a real word prime that had a voiced lexical competitor (e.g., *c*age*; voiced competitor *gauge*) did not result in slower reaction-time latencies for nonword targets (e.g., *shenny*). Hence, the reduction in the magnitude of semantic priming in the modified competitor condition could not be due to the acoustic manipulations per se, but rather to the partial activation of the lexical semantic network of the voiced lexical competitor.

Of interest, these lexical priming effects emerged across both ISI conditions. These results contrast with those of Andruski et al. (1994) who showed that the reduction in priming for semantically related stimuli which were acoustically modified emerged at 50 ms but disappeared by 250 ms. The implications of these results for the time course of lexical activation will be considered below in the General Discussion.

The results from the post-test revealed that subjects perceived the modified competitor prime stimuli as voiceless over 95% of the time. That is, the initial consonant sound of *t*ime* was heard as the voiceless stop consonant /t/ and not as the voiced stop /d/. Nonetheless, subjects were perceptually sensitive to the acoustic difference between the unmodified and VOT-reduced stimuli, as evidenced by their significantly slower reaction times to stimulus pairs in which the two exemplars of a given word were not acoustically identical. This effect was observed at the shorter ISI, but only weakly observed at the longer ISI. Despite this, subjects still showed significant priming in the lexical decision task at the 250 ms ISI for targets preceded by the acoustically modified competitor primes.

3. Experiment 2

Studies with aphasic patients may be used to not only try to understand the nature of their language processing deficit and the functional role of the neural systems underlying it, but they also provide a window into the architecture of the normal processing system. A series of lexical decision experiments have shown that the patterns of performance of Broca's and Wernicke's aphasics are consistent with the view that these patients have deficits in the dynamics of lexical activation (cf. Blumstein & Milberg, 2000; McNellis & Blumstein, 2001). That Wernicke's aphasics, whose lesions involve temporal-parietal structures, have shown such deficits is not surprising. However, it has generally been assumed that Broca's aphasics with damage to anterior brain structures, particularly including the inferior frontal gyrus, have no deficits in lexical processing. Research results have shown that their language impairment is characterized by speech production (articulatory) as well as syntactic (agrammatic) deficits.

Nonetheless, results from a series of experiments have shown that Broca's aphasics display lexical processing impairments under a number of stimulus conditions. Moreover, the patterns of semantic priming in these patients are influenced by the phonological and phonetic properties of the prime stimulus as well as the presence of a phonologically contrasting lexical competitor. Broca's aphasics lose semantic priming when the prime stimulus is a nonword that is phonologically similar to a semantically related real word prime. Thus, although *cat* primes *dog*, *gat* and *wat* fail to do so (Milberg, Blumstein, & Dworetzky, 1988b). Moreover, as described earlier, they lose semantic priming under conditions of lexical competition when the initial voiceless stop consonant of a prime stimulus is a poorer exemplar of the voiceless phonetic category (Utman et al., 2001). Thus, although acoustically modified *c*at* primes *dog*, acoustically modified *p*ear* (having a voiced competitor *bear*) fails to prime *fruit*.

Despite the 'pathological' patterns of semantic priming in the presence of lexical competition, Broca's aphasics show perceptual sensitivity to both phonological and phonetic manipulations of the prime stimuli. They display perceptual sensitivity to the phonological differences between *cat* and *gat* (Milberg et al., 1988b), and they also show perceptual sensitivity to the acoustic manipulations of the voice-onset time of the initial stop consonants of

the stimulus primes (Utman et al., 2001). Hence, the patterns of performance of these patients have been attributed to deficits stemming from the degree to which sound structure elicits lexical activation rather than to deficits in the perception of the sound properties of speech per se or to the integrity of the lexical network itself. In the case of Broca's aphasics, it has been proposed that they have a deficit in the dynamics of lexical activation characterized by a reduction in the level of lexical activation. As a consequence, phonetically or phonologically manipulated stimuli should be particularly vulnerable under conditions of lexical competition. In this view, Broca's aphasics should show semantic priming in the context of a good exemplar, e.g., *dime* should prime *penny*. However, given the lowered lexical activation level for Broca's aphasics, acoustically modified competitor *t*ime* should fail to prime *penny*.

3.1. Method

3.1.1. Participants

Nine right-handed Broca's aphasics were recruited from the following facilities: The Harold Goodglass Aphasia Research Center at the Boston Veterans Administration Medical Center, the Roger Williams Hospital, and the Department of Veteran Affairs Medical in Providence, RI. All aphasic patients were native English speakers and suffered a single stroke to the left hemisphere. The classification of Broca's aphasia was based on performance on the Boston Diagnostic Aphasia Examination (BDAE) (Goodglass & Kaplan, 1972). Description of the characteristics of each patient is shown in Table 2.

3.1.2. Stimuli

The stimuli used in both the lexical decision task and the discrimination task were the same as the stimuli used with normal subjects in Experiment 1. The only difference was that the ITI was lengthened from 3000 to 5000 ms to allow for the longer reaction time latencies of aphasic patients and to provide the patients a slightly longer interval of rest between trials.

3.1.3. Apparatus

The apparatus in this experiment was the same as in Experiment 1 with the exception that an IBM Thinkpad

Table 2
Clinical and neuroanatomical description of Broca's aphasics

ID	Gender	Age at testing	Years post onset	Auditory comp. *z*-score	Fluency	Etiology	Lesion
B1	F	55	10	+0.95	Nonfluent	CVA	Large left hemisphere insula, extending to temporal lobe, sparing Wernicke's area and part of Broca's area
B2	M	71	24	+0.83	Nonfluent	Hemorrhage	Left hemisphere inferior, frontal to sylvian fissure, deep to ventricles
B3	M	66	24	+0.87	Nonfluent	CVA	Left hemisphere Broca's area and the white matter deep to it; lower 2/3 of the pre-motor, motor, and sensory cortex; white matter and PVWM deep to those areas
B4	M	81	21	+0.52	Nonfluent	CVA	Left frontal involving Broca's area with deep extension to frontal horn-lower motor cortex (face and lips); part of left temporal lobe
B5	M	54	12	+0.95	Nonfluent	CVA	Left hemisphere involving caudate and globus pallidus, anterior internal capsule to medial temporal cortex and insula, and anterior PVWM
B6	M	62	5	+0.77	Nonfluent	CVA	Large left lateral frontal including frontal operculum, and two small lesions, one in the motor cortex and the other in the caudate, putamen, and ALIC
B7	F	53	5	+0.81	Nonfluent	CVA	Large left fronto-parietal involving all of the inferior frontal gyrus including all of Broca's area and white matter deep to it; insular cortex, lateral putamen, with extension across anterior temporal isthmus, lower pre-motor and motor cortex, supramarginal gyrus and PVWM
B8	M	54	3	+0.97	Nonfluent	CVA	Left temperoparietal involving half of Wernicke's area with superior extension into supramarginal gyrus and a small portion of low sensory cortex; also anterior 1/3 of PVWM; sparing of Broca's area and motor cortex
B9	F	60	3	+1.02	Fluent (recovered Broca's)	CVA	Left hemisphere in anterior left MCA distribution centered on the Sylvian fissure and involving both grey and white matter; some extension into the left temporal and parietal lobes

laptop was used rather than a PC. In this way, the test apparatus was portable. The laptop used the same programming software as the PC.

3.1.4. Procedure

Aphasic participants were tested individually either in a quiet room at their residence or in a testing room at the Harold Goodglass Aphasia Research Center. The testing procedure was the same as in Experiment 1, although the patients were given the opportunity to take one or two breaks during the course of the testing. Similar to the normal subjects, all patients received 8 practice trials. None needed any additional training since they performed well above chance.

3.2. Results

3.2.1. Experiment 2a: 50 ms ISI

3.2.1.1. Lexical decision task. As in Experiment 1, the data from the lexical decision task was evaluated for both reaction times and accuracy. Both subject and item analyses were conducted. For each subject, any responses that varied from the mean by more than two standard deviations were discarded.

Mean response times for correct responses to real-word targets across prime conditions are shown in Fig. 3. A one-way repeated-measures ANOVA was performed on the reaction time data as a function of prime type. A significant main effect of prime type was found both by subject $F(2,16) = 20.120$, $p < .0001$, and by item $F(2,40) = 5.570$, $p < .01$. Newman–Keuls tests showed the difference in mean RT between the related and neutral conditions to be significant as well as that between the related and modified competitor conditions both by subject and by item. The difference between the modified competitor and neutral conditions was not significant by subject or by item. Thus, the Broca's aphasics showed semantic priming for *dime–penny*, but failed to show significant priming for *t*ime–penny*.

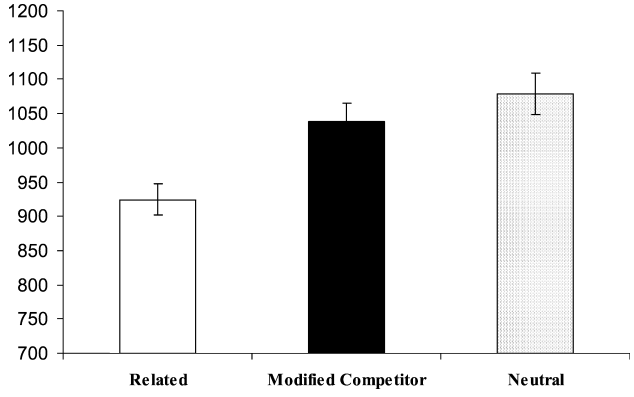

Fig. 3. Mean reaction time latencies and standard errors (in ms) for correct responses for Broca's aphasics in the lexical decision task at the 50 ms ISI.

Looking at the individual performance of the patients, all but one of the nine patients showed semantic priming in the related condition, consistent with previous findings (see Blumstein & Milberg, 2000, for a review). To better assess the patterns of performance of the 8 subjects who showed semantic priming, we compared the magnitude of priming in the modified competitor condition to the magnitude of priming in the semantically related condition for each patient. Two categories were established: one in which the magnitude of priming in the modified condition was greatly reduced (operationally defined as priming that was less than 60% of the magnitude of priming in the semantically related condition), and one in which the magnitude of priming in the modified condition was minimally reduced (operationally defined as greater than 60% of the magnitude of priming in the semantically related condition). The results showed that seven of the eight patients either showed no priming in the modified condition or the magnitude of priming was minimal.

A summary of the error data is shown in Table 3. A one-way repeated-measures ANOVA was also performed on the error data as a function of prime type. A significant main effect of prime type was found both by subject $F(2,16) = 12.412$, $p < .001$, and by item $F(2,40) = 6.014$, $p < .005$. Post hoc Newman–Keuls tests showed that subjects were significantly more accurate in the related condition compared to both the modified competitor condition and the neutral condition. No significant difference in error rates was found between the modified competitor and the neutral conditions.

Reaction time analysis of the nonword data showed latencies of 1147, 1133, and 1122 ms across the three conditions. A one-way ANOVA for reaction times was nonsignificant, $F(2,16) = .464$, $p > .10$. These results show that, similar to normal subjects, the acoustic modifications of real-word primes did not affect subjects' performance on nonword targets.

3.2.1.2. Discrimination post-test. As in Experiment 1, the results of the post-test were evaluated for both accuracy and reaction time. Outlier responses (those more than two standard deviations from each subject's mean RT) were excluded from the analyses.

All subjects overwhelmingly classified word pairs in which one of the words had been acoustically modified competitor as being the "same" word (1.667 errors out of 21). However, similar to normal subjects, a one-way

Table 3
Mean errors (out of 21) for lexical decision task in Broca's aphasics at 50 and 250 ms ISI

Condition	50 ms	250 ms
Related (*dime–penny*)	1.111	1.000
Modified competitor (*t*ime–penny*)	2.778	2.889
Neutral (*nose-penny*)	3.222	2.556

ANOVA for the error data showed that pairs containing a modified competitor exemplar (*t*ime–time*) were more likely to elicit an erroneous response than identical pairs (1.667 vs. 0.333 errors). This effect was only marginally significant by subject $F(1,8) = 4.000$, $p < .081$, but significant by item $F(1,20) = 11.719$, $p < .005$.

Results for the RT data showed that responses to pairs of acoustically identical stimuli were faster (823 ms) than responses to pairs containing a VOT-modified competitor exemplar paired with its unmodified counterpart (876 ms). A one-way ANOVA showed that the effect was marginally significant by subject $F(1,8) = 4.916$, $p < .057$, and not significant by item $F(1,20) = 1.000$, $p > .10$. These results show that Broca's aphasics perceived the modified competitor stimuli as voiceless, and they showed sensitivity to the acoustic manipulations, although the effects were weak.

3.2.2. Experiment 2b: 250 ms ISI

3.2.2.1. Lexical decision task. Mean RTs for correct responses to real-word targets across the three priming conditions are shown in Fig. 4. Analysis of the reaction time data showed a main effect of prime type, significant by both subject $F(2,16) = 16.129$, $p < .0001$, and by item $F(2,40) = 5.146$, $p < .01$. Post hoc tests once again revealed a significant difference in mean RT between the related and neutral conditions both by subject and by item. A significant difference was also found between the related and modified competitor conditions. However, the comparison between the modified competitor and neutral conditions was not significant. Thus, although Broca's aphasics showed semantic priming, they failed to show priming in the modified competitor condition. Looking at the individual performance of the patients, 8 of the nine patients showed either no priming or the magnitude of priming was minimal.

Analysis of the error data as seen in Table 3 also showed a main effect of prime type, significant by both subject $F(2,16) = 11.832$, $p < .001$, and by item $F(2,40) = 6.676$, $p < .005$. Post hoc tests revealed the same pattern of significant effects as seen in the RT data. Subjects were significantly more accurate in the related condition compared to the modified competitor condition and to the neutral condition. Again, no significant differences were observed between the modified competitor and neutral conditions.

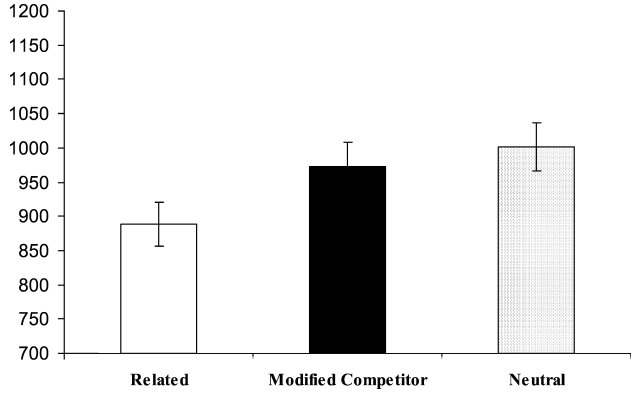

Fig. 4. Mean reaction time latencies and standard errors (in ms) for correct responses for Broca's aphasics in the lexical decision task at the 250 ms ISI.

Analysis of the nonword results showed reaction time latencies of 1003, 968, and 989 ms across the three conditions. A one-way ANOVA on reaction time latencies was nonsignificant $F(2,16) = 1.061$, $p > .10$.

3.2.2.2. Discrimination post-test. Error data showed that listeners perceived pairs with a modified competitor exemplar as voiceless (.889 errors out of a possible 21). Pairs containing a modified competitor exemplar showed more errors than pairs in which the stimuli were acoustically identical (.889 vs. .222). A one-way ANOVA of word errors revealed this effect to be significant by subject $F(1,8) = 5.333$, $p < .05$, but not by item $F(1,20) = 2.400$, $p > .10$. These results are similar to those found for normal subjects.

Reaction time analysis revealed that word pairs containing an acoustically modified competitor exemplar took longer to respond "same" to (802 ms) than pairs of intact stimuli (741 ms). This effect was significant by both subject $F(1,8) = 13.271$, $p < .01$, and by item $F(1,20) = 6.580$, $p < .05$. Thus, Broca's aphasics perceived the acoustically modified competitor stimuli as voiceless, and were also sensitive to the acoustic manipulations.

3.3. Discussion

The pattern of performance for the aphasic patients was different from that of normal subjects. Broca's aphasics were significantly slower in the modified competitor condition compared to the semantically related condition, and there was no difference between the modified competitor and neutral conditions. Thus, Broca's aphasics showed semantic priming for word pairs in which the acoustically intact prime stimulus was semantically related to the target (i.e., *dime* primed *penny*). However, they failed to show mediated priming when the prime stimulus was a voiceless competitor of that prime (i.e., *t*ime* failed to prime *penny*). Nonetheless, Broca's aphasics were sensitive to the acoustic manipulations as shown by their performance on the discrimination post-test. They perceived the acoustically modified competitor stimuli as voiceless and they were generally slower in discriminating pairs of stimuli containing the modified competitor exemplar. Moreover, they showed the same pattern of performance for the nonword stimuli, indicating that the failure to show priming in the modified competitor condition was not due to a general slowing introduced by the acoustic manipulations of the prime word stimuli.

3.3.1. Comparison of performance between Broca's aphasics and normal subjects

The results of Experiments 1 and 2 revealed differences in the pattern of performance between the Broca's aphasics and normal subjects. To determine whether these differences were statistically reliable, two 2-way mixed (Condition × Group) ANOVAs were conducted, one for each ISI. In the 50 ms ISI analysis, one patient's data (B8) were excluded from the analysis because this patient did not show semantic priming, i.e., faster reaction time latencies in the related compared to the unrelated condition. Thus, the effects of the acoustic–phonetic manipulations on the magnitude of priming could not be measured for this patient. All normal subjects showed semantic priming in both ISI conditions. Results of the ANOVA showed significant main effects for Condition (related, modified competitor, unrelated), $F(2,44) = 51.463$, $p < .001$, and Group (Broca's, Normals), $F(1,22) = 22.799$, $p < .00$, as well as a significant Condition × Group interaction, $F(2,44) = 3.879$, $p < .028$. In the 250 ms ISI analysis, all subjects including the Broca's aphasics and normal subjects showed semantic priming. Thus, the data from all of these subjects were included in this analysis. Results of the ANOVA showed a significant main effect for Condition (related, modified competitor, unrelated), $F(2,46) = 51.851$, $p < .001$, and Group (Broca's, Normals), $F(1,23) = 12.344$, $p < .002$. Unlike the analysis at the 50 ms ISI condition, the Condition × Group interaction was not significant, $F(2,46) = .354$, $p < .704$.

3.4. General discussion

The results of this series of experiments are consistent with cascade models of language processing allowing for interaction among levels of processing (cf. Dell & O'Seaghdha, 1991; Peterson & Savoy, 1998). Experiment 1 showed that acoustic–phonetic structure does not just affect the mapping of sound structure on to phonetic categories, but it also influences the activation of the lexical–semantic network of a lexical competitor. Importantly, this influence is not restricted to the process by which a particular lexical form elicits the activation of its own lexical semantic network. Rather it is more general in that acoustic–phonetic structure affects the lexical–semantic network(s) of phonetic-phonological competitors as well. As the evidence with normal subjects suggests, *t*ime* not only activates the lexical representation for 'time' and its lexical–semantic network, but also partially activates the lexical representation for 'dime' and its lexical–semantic network. Hence, *t*ime* primes *penny*.

The implications of these results are several. First, they indicate that the details of acoustic–phonetic structure are not 'neutralized' once the phonetic category is activated. Thus, as shown in earlier studies, the magnitude of semantic priming is significantly reduced when a prime stimulus, semantically related to a real word target, contains a poorer exemplar of the phonetic category (Andruski et al., 1994; Kessinger, 1998; Utman et al., 2001). The current study shows that a prime stimulus containing a poor exemplar of a phonetic category partially activates its lexical competitor and its lexical–semantic network. Second, the results of this study are consistent with the view that lexical activation is graded. Thus, the reaction time for the target word *penny* is significantly faster when it is preceded by a semantically related word, such as *dime*, than when it is preceded by a modified competitor of *dime*, such as *t*ime*.

The time course of the influence of acoustic–phonetic structure on lexical competitors occurs quickly, affecting responses to stimuli presented as little as 50 ms after the prime. This influence persists even when the interval is extended to 250 ms. These results are in contrast to Andruski et al. (1994) who showed that the influence of acoustic–phonetic structure on semantic priming was short-lived. With only 50 ms separating the prime and target stimuli, acoustically modified competitor *c*at* produced less reaction time facilitation for *dog* than did an unmodified exemplar of *cat*. By 250 ms, the magnitude of semantic priming for acoustically modified primes was the same as that for unmodified primes. However, Andruski et al. (1994) also showed that the presence of a lexical competitor slowed reaction time latencies in all conditions, and these effects were maintained at both 50 and 250 ms ISIs. Taken together with the Andruski et al. results, the findings of the current study suggest that lexical competitors remain partially activated for at least 250 ms and they affect the time course of lexical activation of those stimuli that have competitors.

The results of the simulations of the computational model of lexical access developed by McNellis and Blumstein (2001) also showed that the presence of acoustic–phonetic distortion and lexical competition can influence the dynamics of activation of the lexical system. As these simulations demonstrated, lexical activations are initially lower for input representations that are acoustically distorted, and over time these activations grow towards their maximum activation levels. The effects of acoustic distortion disappear when these maxima are reached. However, as lexical competition is implemented from the lexical layer to the semantic layer, the effects of distortion persist. This is because the acoustic modification serves at once to reduce the activation level of the intended lexical target, while, at the same time, increasing the activation of a phonetically similar lexical competitor. The competition between these simultaneously activated lexical candidates results in mutually lower activation levels, an effect that resonates throughout their respective lexical networks. In other words, the acoustic phonetic modifications start

a cascading chain of events that affect not only the mapping of the sound structure to lexical form but also affects the activation patterns of potential lexical competitors as well as the activation of their associated lexical–semantic networks.

Let us consider this chain of events. The poorer exemplar of the lexical candidate affects the mapping of the lexical candidate to its lexical representation. At the same time, lexical competitors are also partially activated based on their phonetic-phonological distance from the lexical candidate. Both the lexical candidate and its lexical competitors then activate their respective lexical–semantic networks. Because of the competing activations at both the lexical and lexical–semantic levels, it takes longer for the lexical candidate and the system to reach threshold (i.e., for there to be a winner among the competing alternatives). It is for this reason that acoustic–phonetic modifications to a lexical candidate coupled with lexical competition increase the time course of activation relative to acoustic–phonetic modifications to a lexical candidate without a lexical competitor.

Even though the results of this research suggest that acoustic–phonetic structure influences the lexical–semantic network, they do not speak to the nature of the representation of lexical form itself. That is, lexical form could be represented in terms of phonetic segments, which themselves are activated by the acoustic–phonetic input in a graded fashion. Hence, a poorer exemplar of a phonetic category would result in lower activation levels for phonetic segments and these in turn would activate in a graded fashion the lexical representation and its lexical–semantic network. Alternatively, it is possible that lexical form is represented episodically, maintaining the fine details of acoustic–phonetic structure in the lexical representation itself (cf. Goldinger, 1998). In either case, phonetic category structure would have an influence on the lexical–semantic network.

As shown in the literature, mediated priming effects with normal subjects have been very difficult to obtain (Chwilla, Kolk, & Mulder, 2000; McNamara & Healy, 1988; O'Seaghdha & Marin, 1997; see also Dell & O'Seaghdha, 1991 for theoretical discussion of this issue). In the current study, however, robust effects emerged for the normal subjects. There are several points of difference between the current study and those conducted in the literature. The first and potentially most important difference is that the current study explored bottom-up processing, i.e., the influence of acoustic–phonetic structure on the lexical–semantic network. Previous studies investigating mediated priming explored top-down effects, i.e., the influence of lexical–semantic structure on phonological form, such that *pen* will prime *inch* through *ink*. In addition, unlike most of the previous studies, the current study was conducted in the auditory modality, and used acoustically manipulated exemplars rather than good exemplars, with shorter ISIs than typically used.

The results of Experiment 2 provide further insights into the neural systems underlying the processes of lexical access. There is a great deal of evidence in the aphasia literature suggesting that posterior brain structures and, in particular, temporal-parietal regions including the superior and inferior temporal gyrus, and the supramarginal and angular gyri, are involved in the processes of lexical access. This evidence comes primarily from the performance of Wernicke's aphasics who typically have neuropathology that extends well beyond Wernicke's area into temporal-parietal regions (Damasio, 1998; Dronkers & Larsen, 2001). Numerous studies have shown patterns of performance consistent with the view that these patients have deficits affecting the dynamics of lexical activation and semantic integration (Milberg et al., 1988b; Milberg et al., 2003; cf. Blumstein, 2001).

The role of anterior brain structures in the processes of lexical access has been less clear. The results of Experiment 2 provide further support for the view that the lexical processing system is more broadly tuned and encompasses anterior brain structures as well as posterior brain structures. As Experiment 2 demonstrated, Broca's aphasics showed semantic priming, *dime* primed *penny*, but they failed to show priming for word pairs in which an acoustically modified competitor prime stimulus was a lexical competitor of a word semantically related to the target, i.e., *t*ime* failed to prime *penny*. Importantly, Broca's aphasics as a group were sensitive to the acoustic manipulations, as shown by their performance on the discrimination post-test. They perceived the acoustically modified stimulus as voiceless as shown by same discrimination judgments for the unmodified stimulus *time* and the acoustically modified stimulus *t*ime*, and they were sensitive to the acoustic manipulations, as shown by slowed reaction time latencies to *t*ime–time* compared to *time–time*. Thus, their failure to show priming in the modified competitor condition (e.g., *t*ime–penny*) was not due to the fact that they perceived the acoustically modified stimuli as containing a good exemplar of the voiceless phonetic category. If this were the case, a failure to show priming for *t*ime–penny* could have been because a good exemplar of [t] does not sufficiently activate [d] and hence *dime*.

One possibility for the failure of Broca's aphasics to show priming in the modified competitor condition is that the acoustic–phonetic manipulations themselves increased the processing load of the patients, resulting in no significant differences between the modified competitor condition and the control condition. Several pieces of evidence argue against this possibility. First, with respect to normal subjects, Andruski et al.

(1994) showed that the slowed reaction time latencies to semantically related word targets preceded by acoustically manipulated semantic primes does not reflect slower processing times for acoustically manipulated prime words. In particular, although reaction time latencies were slowed for *dog* when preceded by acoustically modified *cat*, they were not slowed when *dog* was preceded by an acoustically modified prime that was not semantically related to the target word such as *cake*. Thus, at least for normal subjects, there is no evidence to indicate that acoustic modifications per se affect processing times. With respect to the aphasic patients in the current study, they performed similarly to the normal subjects in the nonword condition. That is, their reaction time latencies to a nonword target were not slowed by an acoustically manipulated real word prime that had a voiced lexical competitor. Since it has been shown that nonwords access the lexicon (Milberg et al., 1988a, 1988b), it is possible that the acoustic modifications to nonword primes could affect reaction time latencies to real word targets. That the aphasic patients showed, similar to normals, no such effects suggests that the acoustic modifications per se are not influencing their reaction time latencies in the modified competitor condition.

Consistent with these findings is additional evidence from two studies exploring lexical processing in aphasic patients. Utman et al. (2001) showed that when a phonetically altered prime stimulus did not have a voiced lexical competitor, Broca's aphasics exhibited patterns of semantic priming similar to those seen with normal subjects. For example, phonetically altered *c*at* showed a significant priming effect for *dog*, but the magnitude of this effect was reduced, as it was in normal subjects. In contrast, these same patients lost semantic priming under conditions of lexical competition. A phonetically altered prime stimulus such as *p*ear* (with a voiced lexical competitor *bear*) failed to prime *fruit*. Thus, the loss of semantic priming was a function of lexical competition, and not the phonetic alterations of the prime stimulus. Moreover, Kessinger (1998) showed that unlike normal subjects, the magnitude of semantic priming was not reduced for Broca's aphasics when the VOT of the prime stimulus was increased by 4/3. The patients showed reduced semantic priming under these conditions only when the prime word had a voiced lexical competitor. The results of the current study, indicating a failure of Broca's aphasics to show mediated semantic priming for a lexical competitor of the prime stimulus, thus suggest that the loss of the priming is not due to the acoustic–phonetic manipulations but rather to an impairment in lexical access.

The pattern of performance for the Broca's aphasics was different from that of the normal participants as revealed by a significant Group by Condition interaction in the 50 ms ISI. That this interaction failed to emerge at the 250 ms ISI could reflect the high degree of variability in the data and the relatively small number of subjects in each group. Thus, the failure to show a difference would have been consistent with a Type II error. A review of the patterns of priming over time for the two groups suggests another possibility. In particular, although the modified competitor condition showed significant priming at both ISIs for normal subjects, there was a reduction in the magnitude of priming at the 250 ms condition. It was 54 ms at the 50 ms ISI and 27 ms at the 250 ms ISI. For the Broca's aphasics, the magnitude of priming in the modified competitor condition was 41 ms at 50 ms and 28 ms at 250 ms. Thus, at 250 ms the magnitude of priming in the modified competitor condition was virtually the same for both the normal subjects and the aphasic patients. Taken together, these results suggest that over time there is a reduction in the magnitude of the competitor effects, so that by 250 ms the difference between the two groups has disappeared. Further research will need to be conducted to determine which interpretation is correct.

The failure of Broca's aphasics to show mediated priming is consistent with the view that they have reduced lexical activation. As a consequence, acoustically modified competitor stimuli will have abnormally lowered activation of their lexical representations, as will their lexical competitors. Thus, although the acoustic modification serves to induce lexical competition, the activation level of the competitor will be insufficient to activate its lexical–semantic network. This is not to say that the acoustic modification failed to activate the lexical semantic network. As shown by Utman et al. (2001), although *t*ime* failed to prime *clock*, a similar modification to *c*at*, a stimulus which does not have a voiced competitor, succeeded in priming *dog*.

The lexical processing deficit of Broca's aphasics has been interpreted in terms of a reduction in lexical activation. There are a number of proposals also suggesting that Broca's aphasics have a deficit in lexical processing. However, in these accounts, the basis of the deficit is *delayed* lexical processing rather than *reduced* lexical processing (cf. for example, Friederici, 1995; Haarman & Kolk, 1994; Swinney, Prather, & Love, 2000; Hagoort, 1990). These theories propose a delay in the activation of lexical entries resulting in a failure to show such effects as semantic priming at shorter ISIs and an emergence of priming effects at longer ISIs. As such, these theories would make similar predictions to the ones made in the current study concerning the performance of Broca's aphasics, although they would also have to make similar assumptions about the architecture of the speech-lexical processing system outlined in the paper.

The classical definition of Broca's aphasia is based not only on a set of clinical features but is also generally assumed to be due to frontal lesions, particularly lesions involving the inferior frontal gyrus (Broca's area) and subcortical structures deep to it (cf. Mohr, 1976). However, as more sophisticated neuroimaging techniques have become available, it has been shown that the lesions of these patients may extend into posterior areas as well. With the exception of patients B2, B3, and B6, all patients in the current study had posterior extension of their lesions, and patient B8 had primarily a posterior lesion. As a result, it makes it difficult to make strong claims about the role of the frontal areas in lexical processing deficits.

However, neuroimaging studies with normal subjects have provided data consistent with the view that anterior brain structures and, in particular, the inferior frontal gyrus, are involved in lexical–semantic processing (Buckner, Koutstaal, Schacter, & Rosen, 2000; Mummery, Shallice, & Price, 1999; Petersen, Fox, Posner, Mintun, & Raichle, 1989; Poldrack et al., 1999; see Gabrieli, Poldrack, & Desmond, 1998, for review). Although a number of studies have proposed that the anterior brain structures are involved in semantic retrieval, a recent study has suggested that the functional role played by these anterior brain structures is the selection of information among competing alternatives from semantic memory (Thompson-Schill, D'Esposito, Aguirre, & Farah, 1997). In this study, greater activation was seen in the inferior frontal gyrus under various task conditions when the stimuli had a large number of appropriate associated responses with no response clearly dominant compared to when the stimuli had only a few associated responses or had only one clearly dominant response. There are a large number of differences between the types of tasks and the stimulus materials used in the Thompson-Schill et al. paper and the current study, not the least of which is a focus on semantically associated competitors in the former study and phonological competitors in the latter study. Nevertheless, Broca's aphasics' failure to show priming under conditions of stimulus competition is consistent with the hypothesis that anterior brain structures involve selection, either implicitly or explicitly, of a lexical target from a set of simultaneously activated lexical competitors.

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Appendix

Test items for lexical decision task

Related prime	Modified competitor prime	Neutral prime	Target
Back	P*ack	Bull	Front
Bear	P*ear	Key	Wolf
Best	P*est	Hair	Worst
Bet	P*et	Nut	Wager
Big	P*ig	Moon	Small
Bun	P*un	Ship	Roll
Bush	P*ush	Sack	Tree
Dame	T*ame	Fork	Lady
Deer	T*ear	Nose	Elk
Den	T*en	Hog	Cave
Dime	T*ime	Fort	Penny
Doe	T*oe	Part	Deer
Down	T*own	Loan	Up
Duck	T*uck	Sheet	Goose
Gab	C*ab	Bell	Talk
Gash	C*ash	Set	Cut
Ghost	C*oast	Chair	Spook
Gold	C*old	Seed	Silver
Good	C*ould	Note	Bad
Gull	C*ull	Cheese	Bird
Gum	C*ome	Sit	Chew

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