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Brain and Language 97 (2006) 25–40

Brain and Language

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Effects of nonlinguistic auditory variations on lexical processing in Broca's aphasics

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Accepted 12 July 2005
Available online 22 August 2005

Abstract

In a series of experiments, the effect of white noise distortion and talker variation on lexical access in normal and Broca's aphasic participants was examined using an auditory lexical decision paradigm. Masking the prime stimulus in white noise resulted in reduced semantic priming for both groups, indicating that lexical access is degraded by nonlinguistic white noise distortion. However, talker variation within a prime–target pair had no effect upon the performance of either the normal or aphasic individuals. The absence of a talker variation effect suggests that voice-specific information is not encoded in the lexical representations of words. The normal performance of Broca's aphasics under conditions of both white noise and talker variation supports the view that these patients have a lexical processing impairment rather than a more generalized language deficit characterized by limited computational resources.

Keywords: Lexical access; Aphasia; Speaker variation; White noise; Lexical decision

1. Introduction

Acoustic variability in the speech signal is ubiquitous, ranging from noisy listening conditions to variation within and across the productions of different speakers. Listeners are able to successfully access word forms and meanings in the face of this variability, but are nonetheless affected by it. For example, modifications to phonetic category structure have been shown to affect lexical processing. Reducing or lengthening the voice onset time (VOT) of the initial consonant of a prime stimulus both influences phonetic category goodness, and reduces the magnitude of semantic priming in a lexical decision task (Andruski, Blumstein, & Burton, 1994; Kessinger & Blumstein, 2005; Utman, Blumstein, & Burton, 2000).

White noise, a nonlinguistic source of variability, decreases the intelligibility of speech input and is therefore thought to affect "peripheral" processing of acoustic cues (Aydelott & Bates, 2004). A vast body of literature has shown that similar to modifications of phonetic category structure, presentation of stimuli in noise reduces semantic facilitation in a variety of tasks, both in the visual and auditory modalities (cf. Aydelott & Bates, 2004; Brown & Besner, 2002; Dubno, Ahlstrom, & Horwitz, 2000; Neely, 1991; Singer, Bronstein, & Miles, 1981).

In contrast to white noise, talker variation does not affect the quality of the auditory input. It is an indexical feature which is used by listeners for purposes of speaker identification, as opposed to other properties of the speech signal which convey information about linguistic content (Pisoni, 1997). Thus, it affects "central" linguistic processing, as it increases processing demands without decreasing intelligibility (Aydelott & Bates, 2004; Gordon-Salant & Fitzgibbons, 1995). In fact, talker

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doi:10.1016/j.bandl.2005.07.012

variability within pairs or lists of words decreases accuracy and increases reaction time (RT) in a variety of tasks. These include serial recall, word identification, sex identification, word naming, phoneme classification, phoneme or syllable monitoring, and same/different decisions to the word or voice identity of pairs of stimuli at fairly short inter-stimulus intervals (ISIs) (Bradlow & Pisoni, 1999; Church & Schacter, 1994; Cole, Coltheart, & Allard, 1974; Farnsworth & Mullennix, 1995; Goldinger, 1990; Goldinger, Pisoni, & Logan, 1991; Green, Tomiak, & Kuhl, 1997; Martin, Mullennix, Pisoni, & Summers, 1989; cf. Mullennix, 1997; Mullennix, Pisoni, & Martin, 1989; Mullennix & Howe, 1999; Mullennix & Pisoni, 1988; Nusbaum & Morin, 1989; Nusbaum & Morin, 1992; Nygaard, Sommers, & Pisoni, 1995; Schacter & Church, 1992).

Recent research has explored one of these sources of variability, phonetic/phonological manipulation, and its influence on lexical processing in aphasic patients. In these studies, Broca's aphasics have exhibited lexical processing deficits. In particular, these patients show a loss of semantic priming when prime words are distorted by one phonetic feature (Milberg, Blumstein, & Dworetzky, 1988), and they fail to show semantic priming when a prime stimulus with a reduced VOT has a voiced lexical competitor (Misiurski, Blumstein, Rissman, & Berman, 2005; Utman, Blumstein, & Sullivan, 2001). On the basis of these findings, it has been suggested that Broca's aphasics have a deficit in the dynamics of lexical activation which emerges particularly when phonetic category structure is manipulated. Because of lowered lexical activation levels, bottom-up activation for acoustically manipulated (and hence poor phonetic exemplar) prime stimuli is not sufficient to overcome lexical competition, and consequently semantic priming is lost.

In the above studies, the loss of semantic priming emerged under conditions of both phonetic and phonological manipulations, manipulations which affect the mapping from sound structure to the lexicon for individual segments. What is less clear is whether Broca's aphasics will also show impairments in the context of other types of auditory manipulations. Both white noise and speaker variation are auditory changes that influence the entire word, but these changes do not affect phonetic category structure per se. White noise degrades the quality of the prime stimulus as a whole, whereas speaker variation affects the acoustic structure of the stimulus but not its quality. It would be instructive to determine whether lexical access in Broca's aphasics is affected by any alterations of the auditory input or alternatively is restricted to properties that specifically influence phonetic category structure. Such results may help provide further information on the source of the lexical processing impairment in Broca's aphasics.

Moreover, it is possible that rather than a deficit in the dynamics of lexical activation, as proposed above, Broca's aphasics have a more generalized deficit resulting from limited computational resources (Carpenter, Miyake, & Just, 1994; Just, Carpenter, & Keller, 1996). If this were the case, these patients should be vulnerable to *any* distortion of the input stimulus that increases processing demands, even if the distortion does not affect phonetic category structure per se. That is, lexical access in Broca's aphasics may be influenced by any acoustic variant that 'mismatches' in some perceptible way the acoustic characteristics of an exemplar input stimulus, and hence requires more processing resources to access the lexicon.

If Broca's aphasics are limited in the computational resources needed for accessing the lexicon, then they should show impairments when either white noise or speaker variation is introduced. In contrast, if the source of lexical processing deficits for Broca's aphasics is more focal and emerges when phonetic category structure is manipulated, then the performance of the aphasics should be similar to that of normal subjects in the context of other types of acoustic variation, such as the presence of noise or changes in indexical features.

To explore this issue, the current study investigates the influence of variations in auditory input on the magnitude of semantic priming in a lexical decision task. Experiments 1 and 2 will investigate the influence of white noise on semantic priming in normal subjects and Broca's aphasics, respectively. Experiments 3 and 4 will investigate the influence of speaker variation on semantic priming in normal subjects and Broca's aphasics, respectively.

2. Experiment 1: White noise distortion with normal subjects

Experiment 1 investigated whether normal subjects show changes in the magnitude of semantic priming in a lexical decision task when the prime stimulus is presented in the context of white noise.

2.1. Method

2.1.1. Participants

Forty Brown University students were paid for their participation in the experiment. All of the subjects were native speakers of English between the ages of 18 and 30, with no known hearing impairments.

2.1.2. Stimuli

The stimuli consisted of a subset of those stimuli used in the lexical decision task of Andruski et al. (1994). These stimuli were controlled for frequency and included a set of 22 primes, each of which was a CVC(C) word with a voiceless stop consonant (/p/, /t/, /k/) in the initial position (e.g., 'peace,' 'tub,' 'cold'). Half of these primes had a voiced word competitor, i.e., changing the initial segment from voiceless to voiced resulted in a word (e.g., ‘cold’ > ‘gold’). For the other half, this change resulted in a nonword (e.g., ‘peace’ > /bis/). All of the prime words were paired with 22 semantically related targets (e.g., ‘peace’–‘war’, ‘tub’–‘bath’) to make 22 semantically related pairs. The target words were also paired with 22 unrelated CVC(C) words to make 22 unrelated pairs (e.g., ‘hip’–‘war’, ‘key’–‘bath’) (see Appendix A).

Twenty-two nonword targets were also chosen from the Andruski et al. (1994) stimuli, which were phonologically permissible strings that did not form a word in English, e.g., ‘dend.’ The list of 22 nonword primes paralleled the test pairs in structure: they consisted of CVC(C) words, half of which contained the initial stop consonant /p/, /t/, or /k/, and half of which did not (see Appendix B). In all, the stimuli for the lexical decision experiment consisted of 22 test (word target) pairs (11 related, 11 unrelated), and 22 distractor (nonword target) pairs.

In the noise condition, each of the prime stimuli was presented in white noise superimposed over the speech signal at a signal-to-noise (S/N) ratio of 14 dB. The selection of a S/N ratio of 14 dB was based on a pilot experiment in which stimulus words were presented to subjects at 8, 14, and 20 dB S/N ratios. The medium signal-to-noise ratio of 14 dB was selected, as presentation at this noise level resulted in performance that was significantly different from the no-noise condition, but also resulted in relatively good performance at 80% accuracy.

The experiment was designed so that there was no repetition of stimuli for any subject. To this end, the prime stimuli were separated into two series, divided evenly for the parameters: related/unrelated and word/nonword voiced competitor. The distribution of /p/, /t/, and /k/ initial prime stimuli for the related primes was such that Series 1 contained one word beginning with /p/, five words beginning with /t/, and five words beginning with /k/, while Series 2 contained one word beginning with /p/, six words beginning with /t/, and four words beginning with /k/. The target stimuli were the same for each series, but were arranged so that for a given target, the related prime–target pair appeared in one series and the corresponding unrelated prime–target pair appeared in the other series. There was also no repetition of distractor stimuli for any subject.

2.1.3. Procedure

Participants were tested in groups of one to three wearing Sony MDR-2V headphones. Subjects were assigned to either the noise condition or the no-noise condition, and, within each condition, were assigned Series 1 or Series 2. Thus, there were 20 subjects in each condition, within which ten subjects heard each series. Responses were made on a button box with two buttons labeled “Yes” and “No.” Participants were told that they would hear pairs of stimuli. For each pair, they were instructed to push the button labeled “Yes” if the second stimulus was a real English word and to push the button labeled “No” if the stimulus was not a real English word. The position (left vs. right) of the “Yes” and “No” buttons was counterbalanced across subjects. Participants were asked to respond with their right hand as quickly as possible without sacrificing accuracy, and to leave their hand midway between the buttons on the response board when they were waiting for the next trial. A practice list of 12 trials similar to the test trials was presented to each subject. The 44 test stimuli in each list were randomized and presented with an ISI of 50 ms and an inter-trial interval (ITI) of 4000 ms.

Each subject also participated in a post-test designed to test for accurate perception of the prime word stimuli. The prime stimuli that the particular subject heard during the lexical decision experiment were presented over headphones one at a time. Subjects were instructed to write down what they heard on an answer sheet, and then press any button on the control box when they were ready for the presentation of the next word. They were told that this was a test to determine how well they perceived the stimuli, that all the words were real words, and that the test was not timed.

2.2. Results

The results of the lexical decision task were scored for both accuracy and reaction time (RT), for both “Word” and “Nonword” responses. Both subject and item analyses were conducted. For each subject, any responses that were more than two standard deviations away from that subject’s mean for that condition were considered to be outliers and excluded from the analysis.

The mean reaction times are shown in Fig. 1A. A two-way, repeated measures ANOVA with Distortion (noise vs. no-noise) as a between subjects factor and Condition (related vs. unrelated) as a within subjects factor was conducted on the reaction time data. The main effect of Condition was significant both by subject $F(1,38) = 113.506$, $p = .0001$, and by item, $F(1,21) = 56.795$, $p = .\ 0001$. The main effect of Distortion was not significant by subject $F(1,38) = 2.058$, $p = .1596$, but was significant by item, $F(1,21) = 11.274$, $p = .0030$. There was also a significant interaction between Distortion and Condition by subject $F(1,38) = 5.180$, $p = .0286$, and by item $F(1,21) = 5.102$, $p = .0347$. Post hoc analysis showed that the interaction was due to a significant reduction in the magnitude of semantic priming due to slowed reaction time latencies for related prime–target pairs in the noise condition.

Table 1 shows a summary of mean subject performance, for both word and nonword targets in all conditions. Overall accuracy was high. A two-way, repeated measures ANOVA was performed on the performance data for each subject, with Distortion as a between subjects factor and

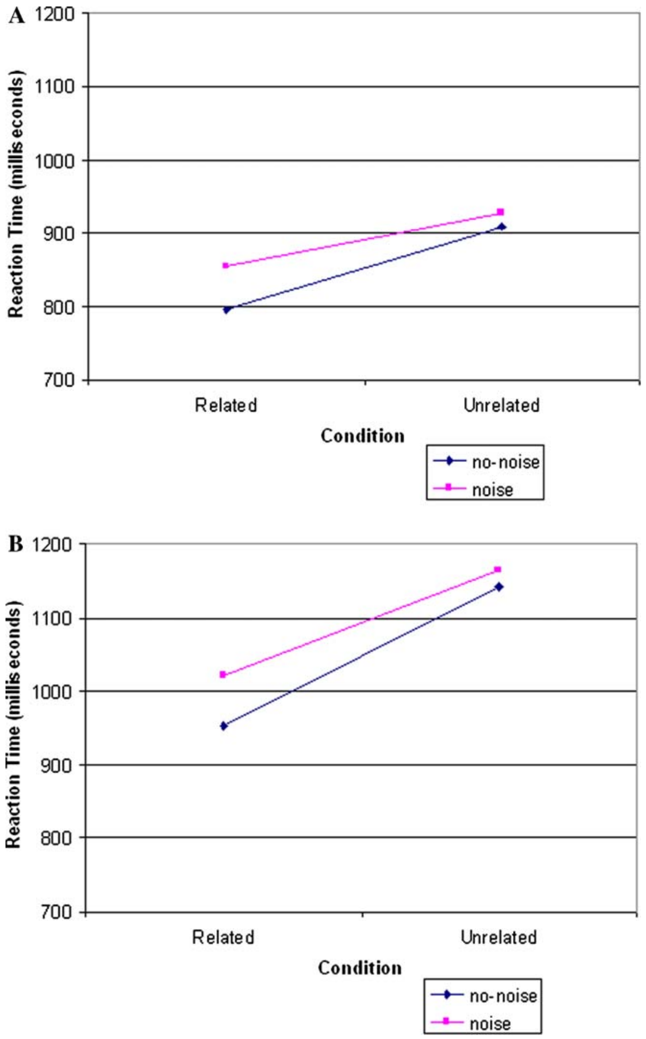

Fig. 1. (A) Reaction times to correct responses by normal subjects to word targets across prime conditions in Experiment 1 as a function of Condition (related vs unrelated) and Distortion (noise vs no-noise). (B) Reaction times to correct responses by Broca's aphasics to word targets across prime conditions in Experiment 2 as a function of Condition (related vs unrelated) and Distortion (noise vs no-noise).

Table 1
Mean percent correct in word and nonword conditions for normal subjects (Experiment 1)

Condition	Mean percent correct
No-noise related	100
No-noise unrelated	92
Noise related	99
Noise unrelated	98
No-noise nonword	97
Noise nonword	98

Condition as a within subjects factor. A significant effect of Condition was found by subject $F(1,38)=7.158$, $p=.0109$, but not by item $F(1,21)=4.002$, $p=.0585$, with subjects performing worse when the pair was unrelated. There was neither a main effect of Distortion by subject $F(1,38)=.095$, $p=.7590$, or by item $F(1,21)=.137$, $p=.7147$, nor an interaction between Distortion and Condition by subject $F(1,38)=.795$, $p=.3781$, or by item $F(1,21)=.811$, $p=.3780$.

Among nonwords, a one-way, repeated-measures ANOVA was performed to test for a difference between the no-noise and noise groups. The average reaction time for subjects was 982 ms in the no-noise condition and 973 ms in the noise condition. This difference was not significant by subject $F(1,38)=.097$, $p=.7567$, or by item $F(1,21)=1.874$, $p=.1874$. A one-way, repeated measures ANOVA was also performed on the nonword error data. There was no main effect of Distortion by subject $F(1,38)=.138$, $p=.7122$, or by item $F(1,21)=.083$, $p=.7757$.

Results of the post-test were analyzed for accuracy. Subjects performed at an accuracy of 98% in the no-noise condition and 78% in the noise condition. This difference was significant, $F(1,38)=74.475$, $p=.0001$.

To determine whether the reduction in the magnitude of priming in the noise condition was because subjects were unable to perceive certain prime words in noise, a one-way ANCOVA was performed with the post-test score for each item as the covariate, and the reaction time as the dependant variable. The effect of Category (related no-noise, related noise, unrelated no-noise, unrelated noise) was found to be significant $F(3,83)=10.533$, $p=.0001$, but the effect of the post-test scores was not found to be a significant factor in determining reaction times $F(1,83)=.208$, $p=.6493$. Thus, longer reaction time latencies were not correlated with post-test scores.

2.3. Discussion

Experiment 1 showed a reduction in the magnitude of semantic priming when the prime stimulus is presented in noise. This reduction in priming emerged due to slowed reaction time latencies for semantically related pairs in the noise condition. Thus, the presence of noise reduced the magnitude of priming presumably because the auditorily degraded prime stimulus no longer activated its semantically related target to the same extent as in the no-noise condition. Nonetheless, of interest, the performance data indicated that the presence of white noise on the prime stimuli had minimal effect on the accuracy of responses to the targets which were presented without noise.

The ANCOVA on the post-test scores shows that the semantic priming effect is not correlated with the perceptibility of the prime stimuli in noise. If this were the case, the magnitude of semantic priming would be reduced because some stimuli showed priming and others did not. Instead, the results of Experiment 1 support the hypothesis that nonlinguistic white noise distortion reduces the level of activation of the prime and hence the strength of spreading lexical activation to the target, which in turn reduces the magnitude of semantic priming.

3. Experiment 2: White noise distortion with Broca's aphasics

Experiment 2 was conducted to investigate whether Broca's aphasics, who have demonstrated lexical processing impairments, would show deficits in semantic priming under conditions of white noise distortion.

3.1. Methods

3.1.1. Participants

Six Broca's aphasic patients between the ages of 54 and 81 (mean age = 64 years) were paid for their participation in the experiment. Patients were recruited from the Aphasia Research Center of the Boston Veterans Administration Medical Center, Roger Williams Hospital, and the Rhode Island Hospital. All patients were classified as Broca's aphasics based on the constellation of results of either the Boston Diagnostic Aphasia Exam (BDAE) (Goodglass & Kaplan, 1983) or the Western Aphasia Battery (Kertesz, 1982). Patient age, years post-onset, fluency rating, auditory comprehension *z* scores from the BDAE, and lesion information are summarized in Table 2.

3.1.2. Stimuli

The stimuli for Experiment 2 were identical to those used in Experiment 1. However, the ITI was changed from 4000 to 6000 ms to allow for the slower reaction times of the aphasic patients.

3.1.3. Procedure

The procedure for Experiment 2 differed only slightly from that of Experiment 1. The testing was done at the patients' homes with a portable IBM Thinkpad and Sony MDR-2V headphones. Due to the small number of patients and the impossibility of matching for lesion site across patients, each subject participated in both the noise and no-noise conditions of both series. This allowed evaluation of the performance for each patient using the no-noise condition as a baseline and comparing the effects of noise relative to that baseline. Subjects were tested in two 40 min sessions that were 1 week apart, with the exception of one subject who was tested 2 weeks apart (the second session was rescheduled due to a snowstorm). Order of presentation was counterbalanced with respect to Series and Distortion such that half of the patients were tested on the noise version of Series 1 and the no-noise version of Series 2 during the first session, and were given Series 1, no-noise and Series 2, noise during the second session. The other half of the patients received the reversed order (2-noise, 1-no-noise; 2-no-noise, 1-noise).

3.2. Results

The performance of the subjects was analyzed for both accuracy and RT, for both "Word" and "Nonword" responses. 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 for that condition were considered to be outliers and excluded from the analyses.

The mean reaction times of the patients are shown in Fig. 1B, and individual reaction times in milliseconds for both word and nonword targets in all conditions are shown in Table 3. Owing to the large variability both within and between subjects, all reaction times were log normalized for the analysis. A two-way, repeated measures ANOVA with Condition and Distortion as within-subject factors was conducted. The main effect of Condition was significant by subject, $F(1,11) = 24.437$, $p = .0004$, and by item, $F(1,21) = 43.805$, $p = .0001$. The main effect of Distortion was not significant by subject, $F(1,11) = .707$, $p = .4184$, but was significant by item, $F(1,21) = 8.810$, $p = .0073$. There was a significant interaction between Distortion and Condition by subject, $F(1,11) = 5.189$, $p = .0437$, but not by item $F(1,21) = 2.507$, $p = .1283$. Post hoc analysis showed that, as in

Table 2
Summary profile of Broca's aphasics (Experiment 2)

ID	Gender	Age at testing	Years post-onset	Auditory Comp. *z* score	Fluency	Etiology	Lesion
B1	F	55	10	0.94	Nonfluent	CVA	Large insular lesion extending to temporal lobe, sparing Wernicke's area and part of Broca's area
B2	M	70	24	0.88	Nonfluent	Hemorrhage	Left inferior lesion, frontal to sylvian fissure, deep to ventricles
B3	M	65	24	0.78	Nonfluent	CVA	Left hemisphere lesion in 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 these areas
B4	M	81	21	0.75	Nonfluent	CVA	Left frontal lesion involving Broca's area with deep extension across to left frontal horn-lower motor cortex (face and lips). Includes part of left temporal lobe
B5	M	54	12	0.63	Nonfluent	CVA	Left caudate and global pallidus, anterior internal capsule to medial temporal cortex and insula, anterior PVWM
B6	M	60	2	0.91	Nonfluent	CVA	Large lateral frontal lesion, a large lesion in the frontal operculum, and two small lesions, one in the motor cortex and the other in the caudate, putamen, ALIC

Table 3
Individual mean reaction time in milliseconds for Broca's aphasics (Experiment 2)

ID	Noise			No-noise		
	Related	Unrelated	Nonword	Related	Unrelated	Nonword
B1	1113	1207	1174	1104	1259	1101
B2	786	938	906	799	858	880
B3	930	973	990	812	907	913
B4	1080	1130	1230	908	1085	1260
B5	956	1010	1082	919	1040	1036
B6	1260	1724	1610	1178	1704	1487
Mean	1021	1164	1165	953	1142	1113

Experiment 1 with normal subjects, the interaction was due to slowed reaction time latencies for related prime–target pairs in the noise condition. Even though the interaction of the effects was not present by item, analysis of simple effects by item showed the same pattern of results as by subject.

The percent of correct responses for individual patients (for both word and nonword targets in all conditions) is presented in Table 4. A two-way, repeated measures ANOVA was performed on the error data for each subject, with Distortion (noise vs. no-noise) and Condition (related pair vs. unrelated pair) as within subjects factors. There was no significant main effect of Condition by subject, $F(1,11) = .508$, $p = .4910$, or by item, $F(1,21) = 1.212$, $p = .2835$, nor was there a significant main effect of Distortion by subject, $F(1,11) = -2.000 \times 10^{-18}$, $p = 1.000$, or by item $F(1,21) = 2.680 \times 10^{-19}$, $p = 1.000$. There was also no significant interaction of Condition and Distortion by subject, $F(1,11) = 3.980 \times 10^{-19}$, $p = 1.000$, or by item $F(1,21) = 9.110 \times 10^{-19}$, $p = 1.000$.

Among nonwords, a one-way, repeated measures ANOVA was performed to test for a difference in log-normalized reaction times between the no-noise and noise groups (see Table 3 for the reaction times in milliseconds). There was no main effect of Distortion by subject, $F(1,22) = .123$, $p = .7288$, or by item, $F(1,21) = .240$, $p = .6292$. A one-way, repeated measures ANOVA was also performed on the nonword error data (see Table 4 for individual patients' percent correct data); there was no main effect of Distortion by subject, $F(1,22) = .111$, $p = .7420$, or by item, $F(1,21) = .462$, $p = .5041$.

Table 4
Individual mean percent correct in each condition for Broca's aphasics (Experiment 2)

ID	Noise			No-noise		
	Related	Unrelated	Nonword	Related	Unrelated	Nonword
B1	91	91	77	86	91	89
B2	91	77	86	95	86	77
B3	95	91	86	95	100	82
B4	95	95	73	100	95	75
B5	100	100	91	86	91	91
B6	91	95	70	100	86	77
Mean	94	92	81	94	92	82

To determine whether the pattern of results that emerged in the aphasic patients was influenced by the presence of a voiced competitor, as was shown by Utman et al. (2001), the magnitude of priming was compared in the noise and no-noise conditions as a function of the presence or absence of a voiced lexical competitor. Results showed no significant effects of lexical competition: there was no significant interaction of Distortion, Condition and Competitor, $F(1,20) = 1.696$, $p = .2076$. That is, the amount of semantic priming was reduced in the noise condition, but was not affected by the presence of a voiced competitor for the prime.

3.3. Discussion

The results of Experiment 2 paralleled those of Experiment 1. Although the mean response times of the aphasic patients were more variable within and across subjects, the pattern of reaction times and errors was similar to that found for normal subjects. Like the normal subjects, aphasic patients showed semantic priming in both the no-noise and noise conditions, with a significant reduction in the magnitude of priming for the noise condition. This decrease in the magnitude of priming was due to increased RTs in the noise condition for semantically related pairs. Importantly, white noise distortion did not result in either increased reaction time latencies or a loss of semantic priming for those primes having voiced lexical competitors.

4. Experiment 3: Talker variation with normal subjects

Experiments 1 and 2 showed that white noise reduces the magnitude of semantic priming in a lexical decision task. Experiment 3 investigated whether another auditory source of variability, speaker, would also influence the magnitude of semantic priming.

4.1. Method

4.1.1. Participants

Sixteen Brown University students were paid for their participation in the experiment. All of the subjects were right-handed, native English speakers between the ages of 18 and 27, with no known hearing impairments.

4.1.2. Stimuli

Two speakers of American English recorded the stimuli, since it has been shown in the literature that increasing the number of talkers in multiple-talker lists from 2 to 20 has little impact upon subjects' reaction times or accuracy (Goldinger, 1997; Palmeri, Goldinger, & Pisoni, 1993). However, because the similarity of voices affects performance, as measured by word identification and recognition memory accuracy scores (Goldinger, 1992, 1996, 1997), the speakers used were very distinct: a female (F) from New England and a male (M) from the Middle Atlantic States.

All stimuli were recorded using a Sony TCD-D8 DAT tape recorder with a Sony ECM-909A stereo microphone in a sound treated room. The digital data were then transferred and downloaded to a computer with a Sound Blaster Live audio card at a 22 kHz sampling rate with 14 bit quantization. Three to five tokens of each word were recorded and the clearest token was chosen for the test stimulus. The stimuli were controlled for spoken duration as a function of speaker on a pair-wise basis: there was no significant difference between the male stimuli (mean length = 587.29 ms) and the female stimuli (mean length = 586.85 ms) ($t = -.268, p = .79$).

One hundred and sixty target words were used. The target words were paired with 160 related prime words to make 160 semantically related pairs. The same targets were also paired with 160 semantically unrelated primes to make 160 semantically unrelated pairs (see Appendix C). There was no difference in the frequencies of the related and unrelated primes ($t = -.700, p = .48$) (Kucera & Francis, 1967), and there were an equal number of one and two syllable stimuli in each of the targets, related primes, and unrelated primes.

One hundred and sixty phonotactically possible English nonwords were created, and each nonword target was paired with a real word prime for a total of 160 distractor pairs (see Appendix D). There was no difference in the frequencies of the distractor primes compared to either the primes in the related ($t = -1.020$, $p = .31$) or the unrelated conditions ($t = -.515, p = .61$) (Kucera & Francis, 1967). There were an equal number of one and two syllable nonword targets, and there were 81 one-syllable and 79 two-syllable distractor primes.

There was a total of four conditions for the test pairs: Same-Speaker Related (e.g., *king-queen*, M–M or F–F), Same-Speaker Unrelated (e.g., *carbon-queen*, M–M or F–F), Different-Speaker Related (e.g., *king–queen*, M–F or F–M), and Different-Speaker Unrelated (e.g., *carbon-queen*, M–F or F–M). To avoid within-subject repetition of the real word targets, the experimental stimuli were divided into four separate lists. Across lists, any given related or unrelated prime–target pair appeared in both the Same-Speaker and Different-Speaker condition. Each distractor pair appeared in each of the four possible voice combinations across lists: Same-Speaker (M–M or F–F) or Different-Speaker (M–F or F–M). Each condition was counterbalanced for the number of one and two syllable primes and targets.

4.1.3. Procedure

The experiment was run on a Dell Optiplex GX240 (DHM model) computer using software designed for the Brown University Speech Lab (Mertus, 2002; http://www.cog.brown.edu/localSites/mertus/BlissHome.htm). Participants were tested individually in a sound-treated testing booth wearing Koss PRO/4XTC stereo headphones. Responses were made on a button box with two buttons labeled “Yes” and “No.” Participants were told that they would hear pairs of stimuli. For each pair, they were instructed to push the button labeled “Yes” if the second stimulus was a real English word and to push the button labeled “No” if the stimulus was not a real English word. The position (left vs. right) of the “Yes” and “No” buttons was counterbalanced across subjects. Participants were asked to respond with their right hand as quickly as possible without sacrificing accuracy, and to leave their hand midway between the buttons on the response board when they were waiting for the next trial.

A practice list of eight trials similar to the test stimuli was presented to the subjects. Each participant was presented with one of the experimental lists (four participants were tested on each list). Each list contained one presentation of a given target item along with either its related or unrelated prime, in one of the four conditions (due to an error, one of the experimental lists contained two homophones: the female prime “deer” paired with the unrelated target “beg”, and the male prime “dear” paired with the unrelated target “ocean”). Each list also contained one presentation of a given nonword target with its prime in one of the four voice combinations, for a total of 320 items in each list (160 word responses and 160 nonword responses). Within each list, an equal number of prime–target items appeared in each condition (e.g. Same-Speaker Related) and in each possible voice combination (M–M, M–F, F–F, and F–M). In each list, there was also an equal number of distractor pairs in each possible condition (Same-Speaker or Different-Speaker) and voice combination. The lists were counterbalanced for one and two syllable related primes, unrelated primes, nonword targets, and distractor primes. The 320 trials in each list were randomized and presented with an ISI of 50 ms and an ITI of 3000 ms.

4.2. Results

The results of the lexical decision task were scored for both accuracy and RT, for both “Word” and “Nonword” responses. 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 for that condition were considered to be outliers and excluded from the analyses.

The mean subject reaction times for the four conditions appear in Fig. 2A. A two-way, repeated-measures ANOVA with Condition (Related vs. Unrelated) and

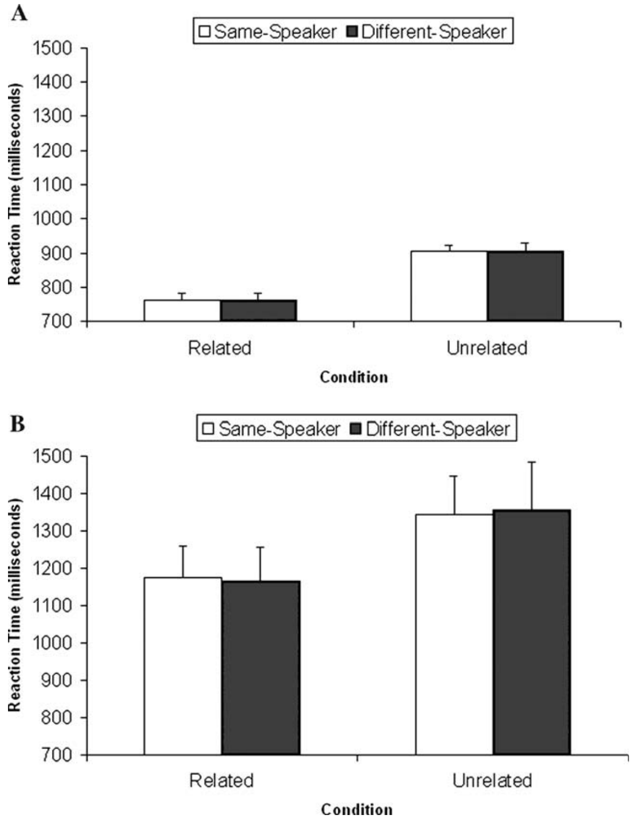

Fig. 2. (A) Reaction times to correct responses by normal subjects to word targets across prime conditions in Experiment 3 as a function of Condition (related vs unrelated) and Speaker (same vs different). Error bars represent standard error of the mean. (B) Reaction times to correct responses by Broca's aphasics to word targets across prime conditions in Experiment 4 as a function of Condition (related vs unrelated) and Speaker (same vs different). Error bars represent standard error of the mean.

Speaker (Same vs. Different) as within-subject factors was conducted on the RT data. A significant main effect of Condition was found both by subject, $F(1,15) = 180.718$, $p = .000$, and by item, $F(1,159) = 231.913$, $p = .000$. No significant effect of Speaker was found by subject, $F(1,15) = .029$, $p = .868$, or by item, $F(1,159) = .073$, $p = .787$. There was no significant interaction by subject, $F(1,15) = .016$, $p = .902$, or by item, $F(1,159) = .024$, $p = .877$.

The mean subject error rates for all conditions (both word and nonword targets) are presented in Table 5.

Table 5
Mean percent correct in word and nonword conditions for normal subjects (Experiment 3)

Condition	Mean percent correct
Same-Speaker Related	99
Same-Speaker Unrelated	94
Different-Speaker Related	99
Different-Speaker Unrelated	94
Same-Speaker Nonword	98
Different-Speaker Nonword	98

Overall accuracy was high across conditions. A two-way, repeated-measures ANOVA with Condition and Speaker as within-subject factors was performed on the error data. Just as in the RT data, a significant main effect of Condition was found by subject, $F(1,15) = 32.947$, $p = .000$, and by item, $F(1,159) = 25.916$, $p = .000$. There was no significant main effect of Speaker found by subject, $F(1,15) = .009$, $p = .926$, or by item, $F(1,159) = .016$, $p = .899$. There was also no significant interaction by subject, $F(1,15) = .394$, $p = .539$, or by item, $F(1,159) = .408$, $p = .524$.

The mean subject reaction time latencies for the nonword responses were 941 ms in the Same-Speaker condition and 934 ms in the Different-Speaker condition. A one-way, repeated-measures ANOVA performed on the nonword data found no significant main effect of Speaker by subject, $F(1,15) = 2.160$, $p = .162$, or by item, $F(1,159) = .073$, $p = .787$. A one-way, repeated-measures ANOVA performed on the nonword error data also found no significant main effect of Speaker by subject, $F(1,15) = .050$, $p = .827$, or by item, $F(1,159) = .043$, $p = .836$.

4.3. Discussion

The results show semantic priming in a lexical decision task, but no differences in the magnitude of semantic priming as a function of speaker variation. Moreover, there was no effect of speaker variation on performance in the nonword condition. These findings suggest that although distortions of auditory input affect the magnitude of semantic priming, changes which do not degrade the quality of the prime stimulus fail to affect the magnitude of semantic priming.

5. Experiment 4: Talker variation with Broca's aphasics

Although the results of Experiment 3 failed to show effects of talker variation on semantic priming, it is possible that Broca's aphasics might show such an effect. It may be the case that a lexical decision task is not sensitive enough to detect the processing cost associated with speaker variation in normal subjects, but that the impairment of Broca's aphasics may exaggerate any effect of speaker variation on lexical processing. To test this possibility, Experiment 4 was conducted.

5.1. Method

5.1.1. Participants

Six Broca's aphasic patients between the ages of 60 and 87 (mean age = 68 years) were paid for their participation in the experiment. Patients were recruited from the Harold Goodglass Aphasia Research Center of the Boston Veterans Administration Medical Center, Roger

Table 6
Summary profile of Broca's aphasics (Experiment 4)

ID	Gender	Age at testing	Years post-onset	Auditory Comp. *z* score	Fluency	Etiology	Lesion
B1	M	74	18	2.98	Nonfluent	CVA	Left MCA infarct involving Broca's area with deep extension involving subcallosal fasiculus. Patchy posterior lesion across temporal isthmus with superior extension to pre-motor and sensory cortex
B2	M	87	26	0.52	Nonfluent	CVA	Two left frontal lesions involving Broca's area with deep extension across to left frontal horn-lower motor cortex (face and lips). Includes part of left temporal lobe (less than half of Wernicke's area)
B3	M	60	18	0.95	Nonfluent	CVA	Left caudate and global pallidus, anterior internal capsule to medial temporal cortex and insula, anterior PVWM
B4	F	61	16	0.95	Nonfluent	CVA	Large insular lesion extending to temporal lobe, sparing Wernicke's and part of Broca's area
B5	M	67	9	0.77	Nonfluent	CVA	Large lateral frontal lesion, a large lesion in the frontal operculum, and two small lesions, one in the motor cortex and the other in the caudate, putamen, ALIC
B6	F	59	6	0.97	Nonfluent	CVA	Large region of low density in the anterior left MCA centered on sylvian fissure, involving both white and grey matter. Consistent with evolving stroke in anterior left MCA

Williams Hospital and the Rhode Island Hospital. All of the patients were aphasic due to a single stroke and were classified as Broca's aphasics on the basis of results obtained from individual testing on the BDAE (Goodglass & Kaplan, 1983). Patient age, years post onset, auditory comprehension *z* scores and fluency rating from the BDAE, and lesion information are summarized in Table 6.

5.1.2. Stimuli

The stimuli for Experiment 4 were identical to those used in Experiment 3. However, the ITI was changed from 3000 to 5000 ms to allow for the slower reaction times of the aphasic patients.

5.1.3. Procedure

The testing procedure was identical to that of Experiment 3, except that the participants were individually tested using a portable IBM ThinkPad and Koss PRO/4XTC stereo headphones. The testing session took place in a quiet room at the Harold Goodglass Aphasia Research Center or at the patient's residence.

5.2. Results

The results of the lexical decision task were scored for both accuracy and RT, for both "Word" and "Nonword" responses. Subject analyses were conducted, but item analyses were not conducted due to the small number of subjects who received each experimental list (two subjects in Lists 1 and 2, one subject in Lists 3 and 4). For each subject, any responses that were greater than two standard deviations from that subject's mean RT for that condition were considered to be outliers and excluded from the analyses.

The mean patient reaction times for the four conditions appear in Fig. 2B, while individual patient RTs for all conditions (both word and nonword targets) are shown in Table 7. A two-way, repeated-measures ANOVA with Condition (Related vs. Unrelated) and Speaker (Same vs. Different) as within-subject factors was conducted on the RT data, and revealed a significant main effect of Condition by subject, $F(1,5)=41.078$, $p=.001$. No significant effect of Speaker was found by subject, $F(1,5)=.003$, $p=.961$, nor was there a significant interaction by subject, $F(1,5)=.432$, $p=.540$. The same pattern of results emerged when the RTs were log-normalized: a significant main effect of Condition was found by subject, $F(1,5)=437.500$, $p=.000$. There was no significant effect of Speaker by subject, $F(1,5)=.792$, $p=.414$, nor was there a significant interaction by subject, $F(1,5)=.000$, $p=1.000$.

The percent correct responses for individual patients (for both word and nonword targets in all conditions) is presented in Table 8. As the table shows, overall accuracy was fairly high across conditions. A two-way, repeated-measures ANOVA with Condition and

Table 7
Individual mean reaction time in milliseconds for Broca's aphasics (Experiment 4)

ID	Same Speaker			Different Speaker		
	Related	Unrelated	Nonword	Related	Unrelated	Nonword
B1	1600	1838	1344	1614	2000	1246
B2	1116	1306	1226	1053	1237	1266
B3	1138	1293	1140	1115	1293	1091
B4	1061	1259	1030	1048	1178	1055
B5	1069	1190	1271	1106	1216	1298
B6	1057	1180	1096	1054	1206	1079
Mean	1173	1344	1184	1165	1355	1172

Table 8
Individual mean percent correct in each condition for Broca's aphasics (Experiment 4)

ID	Same speaker			Different speaker		
	Related	Unrelated	Nonword	Related	Unrelated	Nonword
B1	80	73	95	83	73	91
B2	90	98	89	98	90	85
B3	90	83	94	98	88	91
B4	95	80	98	93	90	96
B5	98	95	89	98	100	93
B6	93	98	99	98	88	95
Mean	91	88	94	94	88	92

Speaker as within-subject factors was performed on the error data. Just as in the RT data, a significant main effect of Condition was found, $F(1,5) = 7.016$, $p = .045$. There was no significant main effect of Speaker, $F(1,5) = 2.288$, $p = .191$, nor was there a significant interaction $F(1,5) = .431$, $p = .541$.

A one-way, repeated-measures ANOVA was performed on the nonword data as a function of Speaker (Same vs. Different). There was no significant main effect of Speaker using either the original RT data, $F(1,5) = .303$, $p = .606$ or when the results were log-normalized, $F(1,5) = .077$, $p = .793$. A one-way, repeated measures ANOVA performed on the nonword error data also found no significant main effect of Speaker (Same vs. Different), $F(1,5) = 2.455$, $p = .178$.

5.3. Discussion

The results of Experiment 4 parallel those of Experiment 3 in that there is no effect of speaker variation on the magnitude of semantic priming. Thus, although Broca's aphasic patients have shown lexical processing impairments as a result of manipulations of phonetic category structure in a lexical decision task (Milberg et al., 1988; Utman et al., 2001), their reaction times and errors in the present experiment are not differentially affected by a change in speaker within a word pair.

6. General discussion

The purpose of this series of experiments was to investigate the impact of nonlinguistic auditory changes on lexical access by determining the effects of white noise distortion and talker variation on the magnitude of semantic priming in a lexical decision task. Results with normal subjects showed that while masking prime stimuli in white noise resulted in a reduction in the magnitude of semantic priming, talker variation did not have a similar effect. That is, there was no significant difference in the magnitude of priming to same and different-talker pairs.

These results demonstrate that not all variations of auditory input have the same effect upon lexical access. The outcome of Experiment 1 investigating the effects of white noise on semantic priming is consistent with earlier findings: auditory white noise masking has been shown to decrease the magnitude of semantic priming in a visual lexical decision task (Singer et al., 1981). Also, both white noise and low-pass filtering reduce facilitation to word identification and lexical decision on terminal words of semantically congruent sentences (Aydelott & Bates, 2004; Dubno et al., 2000). Our findings provide converging evidence that peripheral sources of noise can influence higher-order semantic processing, in a way that is similar to that of linguistic distortion (Andruski et al., 1994; Milberg et al., 1988).

Nonlinguistic white noise distortion puts a large load on acoustic–phonetic encoding. As a result, the speech input passes less activation to the lexical level and to its lexical-semantic network, which results in a reduced magnitude of semantic priming (cf. McNellis & Blumstein, 2001). Although white noise has a greater effect on the perception of aspiration in stop consonants and fricatives over other sound segments (Ainsworth, 1968; Heinz & Stevens, 1961), its distortion is not specific to a single segment or phonetic parameter in each word and hence there is no bias towards a particular lexical competitor. Thus, while both linguistic distortion (such as VOT reduction) and nonlinguistic white noise distortion reduce semantic priming in a lexical decision task, only the former can further reduce priming under conditions of lexical competition.

Talker variation is likewise a nonlinguistic acoustic change, but it does not degrade the speech signal like white noise; a given talker does not produce consistently worse exemplars of phonemes than another talker. Nonetheless, recent studies in the normal literature have shown that indexical features such as voice information affect both speech perception and word recognition processes (see Mullenix, 1997 for a review). There have been two hypotheses proposed about the processing and representation of voice information. Schacter and Church (1992) and Schacter, Church, and Bolton (1995) propose that a presemantic perceptual representation system (PRS) supports auditory priming, and that voice information and more abstract phonological word form information are stored in separate subsystems. They (Schacter et al., 1995) suggest that voice-specific priming may require the binding together of phonological information and talker information by the episodic memory system, suggesting that talker information is not automatically encoded in lexical entries. This hypothesis is based in part on the finding that unlike normal control subjects, amnesic subjects fail to show priming for same-voice repetitions in a stem completion or filtered word association task, although they show preserved priming effects with various other materials.

In contrast, Pisoni and colleagues (Mullennix et al., 1989; Nygaard et al., 1995; Palmeri et al., 1993; Pisoni, 1997) consider voice information as part of the lexical representation of a word. In fact, Goldinger (1998) proposes an episodic theory of lexical access in which perceptual details such as talker characteristics are encoded as part of the memory traces of words. Because this type of information is retained at higher, lexical levels of representation, talker differences should influence activation of the lexicon and the lexical-semantic network.

Although the previous literature clearly shows that talker variation affects instance-specific memory for spoken words and lower-level acoustic processing, the time course and nature of its influence differs from that of linguistic variation, suggesting distinct linguistic and indexical representations (McLennan & Luce, 2005). This hypothesis is supported by the results of Experiment 3, which failed to show an influence of talker variation on the magnitude of semantic priming. It is possible that lexical entries are "perceptual-cognitive objects" as suggested by Goldinger (1998), and that the absence of a talker effect in Experiment 3 was due to the relatively weak encoding of talker information in a task where subject attention was not focused on surface attributes of the stimuli. However, based on the results of Experiment 3, it is more likely that talker information in the speech signal is instead extracted and analyzed separately from the processes used for accessing the mental lexicon.

Turning to the results of Experiments 2 and 4, the performance of Broca's aphasics was strikingly similar to that of normal subjects and showed that nonlinguistic auditory manipulations do not impair lexical access in these patients.[2] Similar to normal subjects, Broca's aphasics showed a reduction in the magnitude of semantic priming under conditions of white noise, and they failed to show any differences in the magnitude of semantic priming under conditions of talker variation. These findings are in contrast to changes to phonetic category structure, which do result in pathological performance of these patients (Milberg et al., 1988; Utman et al., 2001).

Taken together, the results of the current study do not support the view that the lexical processing disturbance of Broca's aphasics reflects a generalized deficit characterized by limited computational resources. If this were the case, they should have shown abnormally impaired performance in the context of white noise or talker variation, variations that have been shown to increase processing demands in normal subjects. Rather, it appears as though the source of the lexical processing deficit in Broca's aphasics, although residing in lowered activation levels in the lexicon, is revealed by perturbations to phonetic category structure and not by nonlinguistic changes to the auditory input. Data from fMRI and MEG studies also suggest that left hemisphere-damaged Broca's aphasics should not be specifically impaired by white noise: frontal areas of the right hemisphere appear to be recruited to a greater extent when tasks are performed with stimuli masked in noise, whereas activity in the left hemisphere remains at the same level or decreases slightly (Sharp, Scott, & Wise, 2004; Shtyrov, Kujala, Ilmoniemi, & Näätänen, 1999).

As discussed above, talker variation would most likely result in reduced semantic priming if the lexicon encoded talker information. Given their lexical processing impairment, Broca's aphasics should have been even more likely than normal subjects to exhibit effects of competition caused by talker variation at the lexical level. The fact that Broca's aphasics are completely unaffected by talker variation in Experiment 4 is consistent with the hypothesis of Schacter and Church (1992) and Schacter et al. (1995) that voice information is extracted at early stages of perceptual processing independent of phonological and lexical processes.

Moreover, evidence from the neuropsychological literature suggests that different neural systems may underlie the processing of lexical information and voice information (cf. McLennan & Luce, 2005). In particular, Van Lancker, Cummings, Kreiman, and Dobkin (1988) and Van Lancker, Kreiman, and Cummings (1989) demonstrated that damage to the temporal lobe of either hemisphere correlates with voice discrimination deficits, while other studies indicate that both voice discrimination and voice recognition deficits tend to emerge more often after right hemisphere lesions (Assal, Aubert, & Buttet, 1981; cf. Belin, Fecteau, & Bédard, 2004). Of importance, these right-hemisphere patients are able to process the linguistic information embedded in the stimuli normally.

The brain imaging literature implicates temporoparietal areas rather than frontal areas in talker information processing. Using a word recognition task, Wong, Nusbaum, and Small (2004) showed increased bilateral activation in the middle/superior temporal region and the superior parietal lobule for a multiple-talker list compared to a single-talker list. The authors suggest that the activation patterns reflect increased voice processing as well as increased speech processing demands related to resolving acoustic–phonetic ambiguities in the multiple-talker condition. In addition, right temporal areas are preferentially activated when attention is directed to talker information, either during passive listening or when subjects are required

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[2] It is worth noting that the same pattern of performance emerged in both young normal subjects and Broca's aphasics. Had the Broca's aphasics shown pathological performance in these tasks, it would have been necessary to explore the role of nonlinguistic auditory manipulations in age-matched normal controls. However, given that the patients' pattern of performance was not pathological, such a comparison did not appear to be necessary.

to recognize a target voice or discriminate between familiar and unfamiliar voices (Belin & Zatorre, 2003; Nakamura et al., 2001; von Kriegstein, Eger, Kleinschmidt, & Giraud, 2003; von Kriegstein & Giraud, 2004). By contrast, lexical processing is generally held to be left hemisphere dominant, involving temporal, parietal, and frontal structures (Binder et al., 1997). Taken together, this evidence supports the idea that talker information is extracted and analyzed separately from the processes used for accessing the mental lexicon (cf. Belin et al., 2004).

In conclusion, the results of the current experiments indicate that nonlinguistic white noise distortion degrades lexical access in normal subjects and Broca's aphasics, whereas talker variation does not. The absence of a talker variation effect in the current study suggests that voice-specific information is not encoded in the lexical representation of words. Finally, the present findings support the previously proposed hypothesis that Broca's aphasics suffer from a lexical processing impairment, not a general processing impairment that is vulnerable to any degradation of the acoustic input.

Acknowledgments

This research was supported in part by NIH NIDCD Grants 00142 and 00314 to Brown University and NIH Grant NIDCD 0081 to the Boston University School of Medicine.

Appendix A

Stimuli for Experiments 1 and 2, arranged in alphabetical order by target

Target	Related prime	Unrelated prime
bath	tub	key
bottom	top	nut
bread	toast	size
child	kid	note
city	town	loan
coach	team	rain
dog	cat	fort
exam	test	rag
foot	toe	hill
frog	toad	wish
hot	cold	sack
jacket	coat	zoo
pie	cake	seed
pin	tack	thief
queen	king	bell
shawl	cape	meat
short	tall	choice
spy	code	joke
stick	cane	sheet
swim	pool	lock
war	peace	hip
wild	tame	limb

Appendix B

Distractor target stimuli for Experiments 1 and 2, arranged in alphabetical order by target

Distractor target	Distractor prime
bammer	night
crice	yoke
daucet	tap
dend	turn
damish	cod
folor	tint
foncerned	care
gind	type
glaw	court
laper	park
lodder	robe
loney	coin
rabacco	pipe
shersuade	noon
tedder	map
thridge	wing
tur	joint
unimal	cage
walise	leash
yader	hedge
yarden	rack
yeel	tire

Appendix C

Word target stimuli for Experiments 3 and 4, arranged in alphabetical order by target

Target	Related prime	Unrelated prime
abuse-v.	mistreat	star
against	oppose	choppy
allow	permit-v.	pollen
apple	core	habit
argue	debate	cow
author	writer	stripe
back	front	tape
bad	good	hand
ballet	dancer	drug
ban	forbid	shoe
bar	saloon	shack
bat	ball	record
bath	tub	key
bay	dock	sweater
beak	bird	lock
beep	alarm	nail
beer	keg	outlet
beg	plead	sponge
belt	buckle	vein
bet	wager	glove
better	worse	journey
bill	payment	sewer
birch	poplar	grate
bit	scrap	icon
blanket	quilt	copy
boast	pride	speaker
book	novel	run
bother	annoy	title
bottom	top	nut

Appendix C (*continued*)

Target	Related prime	Unrelated prime
box	package	rain
brass	copper	constant
bray	donkey	dark
bride	groom	total
broad	narrow	label
bump	jolt	ribbon
bush	shrub	trash
butter	toast	hole
cage	confine	day
chain	link	limb
chew	gum	sit
child	kid	note
circle	square	threaten
circus	trapeze	pollute
city	town	loan
comic	cartoon	canoe
cop	police	picture
country	nation	schedule
dagger	cloak	hill
dame	lady	sound
dare	risk	dresser
dart	arrow	slug
daughter	son	roll
dent	scratch	letter
diamond	jewel	active
die	live-v	cable
dill	pickle	work
dip	hollow	mouse
doctor	patient	gather
dog	puppy	pastel
doll	toy	ambush
drain	sink	monkey
drip	leak	fish
drought	famine	knob
dry	wet	light
duck	quack	cloth
early	late	gall
effect	cause	shine
empty	full	leap
exam	test	rag
failure	success	room
fake	pretend	protest-v.
fall	collapse	liquor
finish	start	howl
fix	repair	tourist
flower	blossom	complaint
fortune	fame	hay
frog	toad	wish
funny	clown	array
game	contest-n.	volume
garbage	dump	island
gauge	meter	party
ghost	spirit	zebra
girl	boy	order
glasses	lens	stain
glue	paste	quiet
gold	silver	leader
grab	snatch	arson
gram	ounce	bubble
grape	vine	screen
grave	tomb	imprint
graze	pasture	marker
grime	dirt	coupon

Appendix C (*continued*)

Target	Related prime	Unrelated prime
guilt	shame	wall
guitar	banjo	meat
gut	stomach	teen
hammer	tool	darling
happen	occur	motel
headache	migraine	rule
heavy	ton	react
hot	cold	sack
hotel	inn	finger
hungry	starve	neighbor
ice cream	cone	mountain
jacket	coat	zoo
ketchup	mustard	higher
leave	depart	need
lemon	lime	building
lettuce	salad	dull
lightning	thunder	end
lion	tiger	parent
listen	hear	object-n.
marriage	divorce	place
messy	sloppy	propose
metal	steel	group
middle	center	blood
minor	major	quickly
minus	plus	event
mirror	reflect	night
movie	ticket	tackle
nervous	anxious	switch
number	count	storm
ocean	wave	deer
open	close	penny
orange	citrus	union
painter	artist	lie
pants	zipper	rapid
pen	paper	patrol
pencil	lead	den
pepper	salt	folder
person	human	noise
pin	tack	thief
plane	pilot	seed
present	gift	guard
puzzle	pieces	shawl
queen	king	carbon
question	ask	water
rabbit	bunny	flag
repeat-v.	again	squash
river	stream	hit
rot	decay	locker
sale	bargain	tear-n
shallow	deep	lawyer
shell	turtle	joke
short	tall	choice
shovel	dig	free
skunk	raccoon	applause
small	big	moon
smell	perfume	cancel
stoplight	signal	name
student	teacher	pony
taxi	cab	wolf
tea	coffee	compare
tennis	racket	dinner
time	clock	pillow
try	attempt	cannon

(*continued on next page*)

Appendix C (*continued*)

Target	Related prime	Unrelated prime
uncle	cousin	perform
under	over	ant
war	peace	hip
window	pane	function
winner	loser	burden

Appendix D

Distractor target stimuli for Experiments 3 and 4, arranged in alphabetical order by target

Distractor target	Distractor prime
absire	convict-v.
akend	cotton
aproom	second
asharm	pursuit
ayben	shaky
babor	grass
bainuh	map
bammer	soup
betch	taboo
bilver	prepare
bittle	napkin
bling	lucky
boip	tycoon
booch	rack
boople	cheese
bopdoo	call
bope	first
buzzle	culture
chand	take
chell	kitchen
chiddel	polite
clory	pocket
conforp	retain
consool	castle
crotion	tangle
dacken	sheet
dake	sample
darl	store
dathe	rope
daucet	rug
daugh	respond
depleve	fern
dishow	soccer
dobe	block
dolk	pan
doot	lake
doster	justice
doward	stove
drom	cushion
droof	pecan
dury	next
farlen	construct-v.
feck	ugly
flobber	pail
folor	cod
fook	puppet
foop	cheek
frass	tint
freen	appear

Appendix D (*continued*)

Distractor target	Distractor prime
gaig	career
garm	future
gase	stare
gind	type
gisk	train
glaw	noon
gloocher	door
gortle	rocket
grav	tiny
greeben	cut
gup	locate
gurst	cart
heek	mansion
hegion	compete
heint	engine
imbrect	tire
inbect	sad
jare	stick
jat	award
jeck	code
jeenuv	fat
jettel	content-adj.
jever	nose
jick	pie
kalmo	coast
karken	attach
kear	wing
keetch	table
kibb	weapon
kip	entry
krink	best
krut	leash
kunner	food
kweedle	fan
laper	cocoon
lelk	dime
libe	nickel
litty	fork
lodder	mood
lowney	stone
lummer	coal
mave	yawn
meab	chicken
miloot	temper
mird	pipe
mish	string
mup	intern-n.
nady	ship
nager	gas
naiket	gain
nall	turn
niland	protect
obose	quota
onter	peanut
osten	tree
pame	cave
pappen	income
piquid	bug
pishes	command
plew	park
pluhfer	tent
poonyun	tunnel
poose	soon

Appendix D (*continued*)

Distractor target	Distractor prime
prandle	carpet
preak	picnic
predend	wise
premoor	kitten
quee	gun
rainop	court
reffort	concern
remeeve	pity
rige	echo
rook	gutter
serg	routine
sheck	supper
shersuade	phone
shoil	control
shuhtoll	public
shull	cane
shup	admit
skode	budget
soip	many
sollege	arcade
stoment	money
taffen	hair
targ	single
tedder	care
teeb	exile
telect	said
thoop	cup
thosher	collect
thridge	robe
tosh	expense
tur	joint
vabe	ingest
valk	tap
veekle	couple
volf	size
vook	toe
vunt	bell
vuspy	return
yaider	broom
yarden	eye
yeef	tower
yeep	bread
yoddy	weave
yoll	cat
yut	topic
zod	sentry
zoy	cape
zup	swim

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