EFFECTS OF ACOUSTIC DISTORTION AND SEMANTIC CONTEXT ON LEXICAL ACCESS

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Abstract

This study explored the role of attentional and perceptual factors in lexical access by examining the effects of acoustic distortion on semantic priming of spoken words by a sentence context. The acoustic manipulations included low-pass filtering, which was intended to interfere with the sensory encoding of the acoustic signal by reducing intelligibility, and time compression, which was intended to disrupt central language processing by reducing processing time. These distortions were applied to the sentence context to explore how the contribution of contextual information to lexical access is affected by acoustic degradation. Low-pass filtering significantly reduced semantic facilitation. In contrast, temporal compression significantly reduced semantic inhibition without affecting facilitation. These qualitative differences between two forms of acoustic distortion are discussed in terms of the activation, selection, and integration of lexical-semantic information in models of lexical access. Filtering may have its primary effect on a relatively early, automatic process (reflected in facilitation effects), while compression has its primary effect on a later, more demanding process (reflected in inhibition effects). Practical and theoretical implications for higher-level language processing in hearing-impaired and elderly populations are discussed.

The difficult task of understanding spoken language in the presence of acoustic distortion is familiar to anyone who has attempted to conduct a conversation in a crowded room or over a noisy telephone line: in contrast to listening to speech in a quiet environment, language comprehension under these adverse conditions is demanding and effortful, and portions of the speaker's intended message may be misunderstood. The process of spoken language comprehension relies on the transmission of linguistic information via the acoustic signal, and when portions of this signal are masked by environmental noise or accelerated by changes in speaking rate, this process is disrupted, and comprehension becomes increasingly difficult. Further, acoustic distortion may impose both perceptual and attentional demands upon the listener, and these demands may have particular consequences for language comprehension. The goal of the present experiments is to examine in detail the consequences of acoustic distortion for the comprehension of words and sentences. In particular, we will demonstrate *qualitative* as well as *quantitative* differences in the effects of different kinds of acoustic distortion on lexical retrieval in context.

The access of word meaning from acoustics is essential to the comprehension of spoken language. Auditory lexical access is generally characterized in terms of a set of distinct processes that serve to isolate the appropriate representation from the other items in the lexicon. These processes include the *activation* of candidate representations in response to the acoustic input, the *selection* of the most appropriate item from among these candidates, and the *integration* of this item into the semantic context. Most models of word recognition and lexical access in both the auditory and visual modalities incorporate a similar distinction among component processes (e.g., the cohort model, Marslen-Wilson, 1993; Marslen-Wilson & Warren, 1994; the enhancement/suppression account, Faust & Gernsbacher, 1996; Gernsbacher, 1996, 1997). Activation is the earliest of these processes, and includes the encoding of sensory information and the initial mapping of this information onto word-level representations. A number of researchers have argued that activation is reflected in the *facilitation* of responses to a target preceded by a semantically related prime word or sentence context, relative to responses to the same target when preceded by a neutral or unrelated context (Andruski, Blumstein, & Burton, 1994; Neely, 1991). Facilitatory effects include speeded response times in lexical decision (Meyer & Schvaneveldt, 1976), picture naming (Carr et al., 1982), and pronunciation (reading or cued shadowing) (Bates & Liu, 1996; Seidenberg et al., 1984; Schreuder et al., 1984) tasks. These effects emerge at brief interstimulus intervals (ISIs) or stimulus onset asynchronies (SOAs) of 50-250 ms, and are observed even when the prime stimulus is presented briefly and then masked, such that subjects are not consciously aware of the identity of the prime (see Neely, 1991, for review). These findings suggest that activation occurs rapidly and requires little in the way of attentional and/or processing resources.

In contrast, the selection and integration of lexical items are relatively costly in terms of processing resources. Selection involves the suppression of active candidates that fail to match the sensory input and/or semantic context (Gernsbacher, 1996, 1997; Marslen-Wilson, 1993), and integration involves the assimilation of the novel semantic information into the ongoing sentence or discourse context (St. George et al., 1994). These processes demand varying amounts of attention depending upon, e.g., the degree of physical similarity between the target and its competitors (Goldinger et al., 1992) and/or the cloze probability of the target given the context (Kutas & Hillyard, 1984; Stanovich & West, 1983), and this increased demand tends to result in increased processing time. Thus, the operation of selection and integration processes is reflected not only in the facilitation of related targets, but also in the *inhibition* of targets preceded by unrelated primes or contexts (Neely, 1991; Stanovich & West, 1983). Inhibitory effects, i.e., increased response times to targets in unrelated contexts, are more pronounced at longer SOAs, and are sensitive to factors that affect expectancy, such as the proportion of related/unrelated test trials in the stimulus set (see Neely, 1991, for review). Based on this evidence, researchers have argued that inhibitory processes occur later in the time course of lexical access (Gernsbacher, 1996; Marslen-Wilson, 1993), and may reflect more controlled or strategic processing than facilitatory processes (Neely, 1991).

In all of the above studies, semantic context influences lexical processing. Further, the evidence suggests that context has two separable effects: a facilitatory effect on congruent targets which occurs rapidly and imposes relatively little attentional demand, and an inhibitory effect on incongruent targets which has a relatively slow time course and is sensitive to attentional factors. The characteristics of these effects suggest that specific aspects of lexical processing may be selectively affected by the different types of acoustic distortion encountered by a listener in the comprehension of spoken language.

Certain types of distortion primarily affect the spectral aspects of the acoustic signal, which are essential for the accurate perception of speech contrasts. These distortions therefore disrupt the encoding of linguistic information and reduce the *intelligibility* of the speech signal (cf. Stuart & Phillips, 1996). Such distortions include low-pass filtering and random high-frequency noise, which eliminate or mask the spectral information in the high-frequency region of the speech signal. Distortions of this information significantly reduce the accuracy with which listeners identify spoken words presented in isolation (Sommers, 1997; Stuart & Phillips, 1996; Stuart et al., 1995). In contrast, researchers have classified other types of acoustic distortions, including rate compression and multitalker babble, as affecting central language processing (Connolly et al., 1990; Gordon-Salant & Fitzgibbons, 1995b). Under these distortions, the spectral information in the signal is perceptible and the temporal relationships between spectral events are preserved, so intelligibility is relatively unaffected (Altmann & Young, 1993). However, the presence of a competing speech stimulus and/or a decrease in processing time appears to impose an additional *processing demand*. Recent functional imaging data have indicated that additional brain regions are recruited in the processing of rate-compressed sentences as compared with sentences spoken at a normal rate (Poldrack et al., 1998). Further, normalization for changes in speaking rate also imposes added central processing demand: when spoken words produced at varying speaking rates are presented in a series, identification accuracy is significantly reduced relative to performance on the same series of words spoken at a consistent rate (Nygaard et al., 1995; Sommers, 1997; Sommers et al., 1994).

The separation of intelligibility and processing demand has particular implications for psycholinguistic models of lexical access that distinguish between early processes of encoding and activation and higher-level processes of selection and integration. *Specifically, acoustic distortions such as low-pass filtering and high-frequency noise would be expected to interfere with the encoding and activation of lexical-semantic information, whereas distortions such as rate compression and babble noise would be expected to interfere with selection and* *integration.* A number of recent studies have suggested that the influence of semantic context on word recognition is reduced when perceptual degradation is applied to the context. Auditory priming experiments in which the context is a single word have demonstrated that the acoustic distortion of a phonetic segment in a prime word results in a significant reduction in facilitation to a related target (Andruski et al., 1994; Aydelott Utman, 1997; Aydelott Utman, Blumstein, & Burton, 2000; Aydelott Utman, Blumstein, & Sullivan, 2001). In addition, listeners demonstrate significantly more accurate identification of words in congruent sentence contexts than in neutral (Craig, 1988) or incongruent (Bilger et al., 1984; Kalikow et al., 1977) contexts. Further, when the sentence and target stimuli are presented with a competing multitalker babble noise, this difference in performance as a function of context increases with decreasing signal-to-babble ratio, such that listeners show a larger decrement in recognition accuracy in noise as well as greater benefit from context (Bilger et al., 1984; Craig, 1988; Kalikow et al., 1977). Interestingly, similar effects are observed for hearing-impaired and elderly individuals (Dirks et al., 1982; Gordon-Salant & Fitzgibbons, 1993, 1995a,b; Pichora-Fuller et al., 1995), suggesting that both disruption of the sensory perception of the acoustic signal and more general cognitive deficits influence the processing of words in context. This interpretation of the results is further supported by evidence that other factors related to central language processing have similar effects on word identification in context, including concurrent memory load (Pichora-Fuller et al., 1995) and level of proficiency in English (Mayo et al., 1997).

In summary, the literature on acoustic distortion and single-word comprehension indicates that listeners use both acoustic and contextual information in lexical access. Further, degradation of the sensory input affects lexical processing when applied to the word itself or to the context in which the word occurs. In addition, different types of acoustic distortion can separately affect intelligibility and processing demand, with particular consequences for different levels of lexical access.

In spite of the current evidence, however, a number of issues remain to be addressed. In particular, studies of the effects of acoustic distortion on auditory word comprehension have relied almost exclusively on off-line identification accuracy as a behavioral measure (e.g., Bilger et al., 1984; Craig, 1988; Kalikow et al., 1977). Although the results of these studies have been informative, on-line measures of reaction time (RT) can provide a more sensitive measure of the various component processes of lexical access, as well as the time course of these processes and how they are influenced by attentional and perceptual factors. Further, almost all on-line measures of the effects of perceptual degradation on semantic priming have been conducted in the visual modality, and have focused on degradations of the target word as opposed to the context (e.g., Durgonoglu, 1988; Stanovich & West, 1983; Stolz & Neely, 1995)

The present experiment used on-line measures of lexical access in the auditory modality to systematically examine the influence of disruptions of intelligibility and processing demand on various component processes involved in lexical access in context. Of particular interest was the extent to which different types of acoustic degradation modulate semantic priming effects when applied to the semantic context. Target words were presented in congruent, neutral, or incongruent sentence contexts, and an acoustic degradation was applied to the context while the target word remained intact. Two types of acoustic degradation were imposed: low-pass filtering (cf. Stuart & Phillips, 1996) and time compression (cf. Poldrack et al., 1998). These degradations were intended to reduce intelligibility and processing time, respectively. RTs were measured in a lexical decision task to the target words.

Previous studies have demonstrated that lexical decision performance is facilitated by a congruent semantic context, and inhibited by an incongruent semantic context, relative to a non-biasing context (Stanovich & West, 1983). Thus, listeners' response times were expected to be faster to targets in a congruent context, and slower to targets in an incongruent context, relative to the neutral baseline. These contextual priming effects were expected to be separably affected by different types of acoustic distortion. A summary of the predicted effects is shown in Table 1. It was expected that both low-pass filtering and temporal compression of the sentence context would reduce priming. Further, because filtering was expected to interfere with the early encoding of the acoustic signal, it was expected that this manipulation would have its primary effect on *facilitation*. Thus, RTs were expected to be slower for congruent targets in filtered contexts than in unaltered contexts, and the RT difference between targets in congruent and neutral contexts was expected to be reduced. In contrast, because compression was expected to interfere with later, more demanding processes of lexical selection and integration, it was predicted that this manipulation would affect *inhibition*. Thus, RTs were expected to be faster for incongruent targets in compressed contexts than in unaltered contexts, and the RT difference between targets in incongruent and neutral contexts was expected to be reduced. It is important to note that low-pass filtering was also expected to reduce inhibition, as the early disruption produced by the perceptual interference was expected to be carried through to later stages of processing, and possibly to introduce an additional processing demand. However, as time compression was not expected to interfere with early processing, this manipulation was not expected to affect facilitation.

Method

Stimuli

A complete list of test stimuli is shown in Appendix 1. The stimuli consisted of 24 sentence contexts and 24 target words that were highly congruent with these contexts (all targets had cloze probabilities of 100% in context as determined by pilot analyses). The target words appeared in these congruent contexts, as well as in highly incongruent contexts that were appropriate to other targets in the stimulus set. The targets had cloze probabilities of 0% in these contexts, and bore no obvious semantic relationship to the preceding contextual information or to the expected target. An additional sentence context, “Its name is…” was included as a neutral baseline condition. This sentence context provided a syntactic and prosodic context for the target items, without introducing a semantic bias in favor of a particular target. The neutral baseline context was recorded and digitized in the same manner as the biasing contexts, and the same acoustic distortion conditions that were applied to the biasing contexts were also applied to the neutral context. Sample test conditions are shown in Table 2. Each target served as its own control, appearing in all semantic congruency and acoustic distortion conditions. Thus by definition test targets across all conditions were balanced for frequency and acoustic-phonetic parameters.

Nonword distractor targets consisted of phonologically permissible sequences of segments that generally resembled the real word targets in length, number of syllables, and phonetic content. Nonwords appeared in the same semantic contexts as test targets (both altered and unaltered versions) to minimize guessing strategies on the part of the listeners. To distinguish each target clearly from the preceding context, the words and nonwords were produced by a male speaker, and the sentences were produced by a female speaker (cf. Bates & Liu, 1996). All stimuli were recorded onto digital audio tape using a Sony Digital Audio Tape recorder and high-quality condenser microphone in a soundproof booth. The stimuli were then digitized via digital-to-digital sampling onto a Macintosh computer with a Digidesign audio card and SoundDesigner II software at a sampling rate of 22.05 kHz with a 16-bit quantization. These tokens served as the unaltered versions of the test stimuli in all conditions of the experiment. In addition, two acoustic degradations were imposed on these stimuli to explore the effects of reduced intelligibility and increased processing demand on lexical processing. The acoustic degradations were applied to the sentence contexts. The acoustic degradations included low-pass filtering at 1 kHz, which reduces the intelligibility of the acoustic signal (cf. Dick et al., 2001; Stuart & Phillips, 1996), and 50% time compression, which interferes with the central processing of the acoustic signal by reducing processing time (cf. Altmann & Young, 1993; Dick et al., 2001; Poldrack et al., 1998). These distortions were implemented using the equalizer and tempo functions in the SoundEdit 16 software package. Spectrograms of unaltered, low-pass filtered, and time-compressed speech samples are shown in Figure 1.

All stimuli were presented auditorily. Each target was presented in six conditions for each acoustic distortion manipulation (see Table 2): Congruent-Unaltered (highly congruent with the sentence context, no degradation); Neutral-Unaltered (neutral context, no degradation); Incongruent-Unaltered (highly incongruent with the sentence context, no degradation); Congruent-Altered (highly congruent with the sentence context, context degraded); Neutral-Altered (neutral context, context degraded); and Incongruent-Altered (highly incongruent with the sentence context, context degraded). However, *each biasing context and target appeared only once for each participant, with no repetitions of any target or biasing context.* This was accomplished by dividing the stimuli into six lists, representing the six experimental conditions. Each target appeared only once in each list, but appeared in all conditions across the six lists (i.e., each target appeared in the Congruent-Unaltered condition in one of the lists, the Congruent-Altered condition in another of the lists, the Neutral-Unaltered condition in another of the lists, and so forth). Each participant received only one of the six lists, but heard all of the test conditions and all of the biasing contexts and targets. The type of degradation (Filtering vs. Compression) served as a between-subjects variable.

Subjects

Sixty undergraduates at the University of California, San Diego served as participants in exchange for academic credit. All were monolingual native speakers of American English. None of the participants reported any hearing impairment, and all were between the ages of 18 and 30.

Procedure

The experiment was presented via a Macintosh PowerPC using the PsyScope experiment software, which controlled the timing of events and recorded the accuracy and RT of listeners' responses. The stimuli were presented at a comfortable listening level through high-quality headphones in a sound-protected room. Order of presentation of test trials was counterbalanced across all within-subjects experimental conditions. Contexts and targets were presented with an interstimulus interval (ISI) of 50 ms, and an intertrial interval (ITI) of 3000 ms. Participants were asked to indicate whether each target (the final word in the sentence, spoken in a male voice) was a real word in English by pressing one of two buttons marked 'YES' and 'NO' on a response box. Participants were instructed to respond as quickly and as accurately as possible, and to respond even if they were unsure of their answer. Order of button labels (YES – NO vs. NO – YES) was counterbalanced across subjects.

Results

Three-way subject and item analyses of variance (ANOVAs) were conducted for RTs to correct responses (milliseconds), with Distortion (Altered vs. Unaltered) and Context (Congruent vs. Neutral vs. Incongruent) as within-subjects variables in both the subject and item analyses, and Type (Filtering vs. Compression) as a between-subjects variable in the subject analyses and a within-items variable in the item analyses. To eliminate outliers in the RT data, the median RT was calculated for each subject or each item in each condition for use in the statistical analyses (Ulrich & Miller, 1994; Wilcox, 1992). Subject and item F-statistics are reported as F1 and F2, respectively. Results revealed a highly significant interaction of Type × Distortion × Context in the RT data (F1(2,116) = 7.10, p<.01; F2(2,46) = 14.41, p<.0001), demonstrating that the pattern of results differed significantly for low-pass filtering and time compression. Subject and item ANOVAs performed on the accuracy data (Appendices 2-5) revealed that these findings were not attributable to speed-accuracy trade-offs. In all instances, slower RTs corresponded to decreased accuracy and faster RTs corresponded to increased accuracy, except in conditions where lexical decision performance was at ceiling and no significant differences emerged.

To compare more directly the effects of the two types of distortion on responses to targets in different semantic contexts, difference scores (altered minus unaltered) were obtained in each semantic context condition for each distortion type. Two-way ANOVAs were performed on these data with Context as a within-subject variable in both the subject and item analyses, and Type as a between-subjects variable in the subject analysis and a within-items variable in the item analysis. Results revealed a highly significant Type x Context interaction (F1(2,116) = 7.10, p<.01; F2(2,46) = 14.41, p<.0001), demonstrating that the two types of distortion produced reliably different patterns of results as a function of semantic context.

To provide a clearer picture of the patterns of performance produced by the two acoustic distortions, separate two-way Context x Distortion ANOVAs were conducted on the RT data for each distortion type.

Low-Pass Filtering

Mean RTs for each priming condition are shown in Table 3. Facilitation and inhibition effects are plotted in Figure 2. A highly significant main effect of Context emerged (F1(2,58) = 56.71, p<.0001; F2(2,46) = 29.80, p<.0001), indicating that semantic bias significantly influenced RTs to targets. The main effect of Distortion (slower RTs to targets in altered contexts than unaltered contexts) was significant in the subject analysis (F1(2,58) = 4.63, p<.05) but did not approach significance in the item analysis (F2 < 1).

The Context × Distortion interaction was highly significant (F1(2,58) = 27.79, p<.0001; F2(2,46) = 19.86, p<.0001). Planned comparisons (linear contrasts for repeated measures) were conducted for congruent, neutral, and incongruent targets within each distortion condition (to establish whether significant facilitation, inhibition, and overall priming effects emerged), and for targets in altered and unaltered contexts within each semantic congruency condition (to evaluate the effects of acoustic distortion as a function of semantic bias).

Significant semantic priming emerged in the RT data irrespective of the presence of acoustic distortion (congruent vs. incongruent conditions: altered contexts F1(1,58) = 9.19, p<.01, F2(1,46) = 8.72, p<.01; unaltered contexts F1(1,58) = 169.32, p<.0001, F2(1,46) = 126.85, p<.0001). Significant facilitation and inhibition effects emerged for unaltered contexts (congruent vs. neutral: F1(1,58) = 85.22, p<.0001, F2(1,46) = 68.34, p<.0001; incongruent vs. neutral: F1(1,58) = 14.29, p<.001; F2(1,46) = 8.98, p<.01). However, when the context was altered, no significant facilitation or inhibition effects were obtained. Specifically, no significant difference between the congruent and neutral conditions emerged, although the difference between the incongruent and neutral conditions was marginally significant (F1(1,58) = 2.99, p<.1; F2(1,46) = 2.67, p<.1).

The comparisons of RTs for altered and unaltered contexts within each congruency condition provided a more detailed picture of the influence of distortion on responses to targets. There was no significant effect of contextual distortion on responses to targets in the neutral condition. This is important, because it means that our neutral condition really is "neutral"; no information is lost or gained when these contexts are distorted. In contrast, distortion of meaningful semantic contexts resulted in significantly slower RTs to congruent targets (F1(1,58) = 52.80, p<.0001, F2(1,46) = 26.73, p<.0001), which we interpret to mean that semantic facilitation is reduced (as predicted in Table 1). Conversely, participants were significantly faster in responding to incongruent targets when the context was distorted (F1(1,58) = 7.32, p<.01; F2(1,46) = 9.85, p<.01). Thus, low-pass filtering of the context may have produced a release from inhibition as well as a reduction in facilitation.

To confirm these interpretations of the results, the magnitude of the priming effect was compared statistically across distortion conditions using difference scores (bias minus neutral). Facilitation and inhibition effects are plotted in Figure 2. Two-way subject and item repeated-measures ANOVAs were conducted on the RT data, with Distortion (Altered vs. Unaltered) and Priming (Facilitation vs. Inhibition) as within variables. A highly significant Distortion

× Priming interaction emerged (F1(1,29) = 40.48, p<.0001, F2(1,23) = 20.70, p<.0001). Planned linear contrasts revealed that, as predicted in Table 1, facilitation was significantly reduced (by 85%) when the context was altered relative to when the context was unaltered (F1(1,29) = 51.12, p<.0001, F2(1,23) = 40.63, p<.0001). Inhibition was also reduced (by 45%) when the context was altered relative to when the context was unaltered, although this effect was only marginally significant in the subject analysis (F1(1,29) = 3.42, p<.1) and did not approach significance in the item analysis, suggesting that low-pass filtering had a weak effect on inhibitory priming. However, it is worth noting that low-pass filtering significantly increased accuracy of responses to incongruent targets in the accuracy analyses (see Appendix 4), indicating that this manipulation did produce a reliable release from inhibition.

Time Compression

Mean RTs for each priming condition are shown in Table 4. Facilitation and inhibition effects are plotted in Figure 3. A highly significant main effect of Context emerged (F1(2,58) = 60.80, p<.0001; F2(2,46) = 52.09, p<.0001), indicating that semantic bias significantly influenced RTs to targets. No significant main effect of Distortion was obtained.

The Context × Distortion interaction was significant (F1(2,58) = 4.80, p<.05; F2(2,46) = 3.08, p<.05). Facilitation and inhibition effects are plotted in Figure 3. Planned comparisons (linear contrasts for repeated measures) were conducted for congruent, neutral, and incongruent targets within each distortion condition, and for targets in altered and unaltered contexts within each semantic congruency condition.

Significant semantic priming was obtained with or without acoustic distortion (congruent vs. incongruent conditions: altered F1(1,58) = 45.37, p<.0001, F2(1,46) = 43.40, p<.0001; unaltered F1(1,58) = 119.20, p<.0001, F2(1,46) = 119.20, p<.0001). Significant facilitation effects emerged for both unaltered contexts (congruent vs. neutral: F1(1,58) = 44.13, p<.0001, F2(1,46) = 19.61, p<.0001) and altered contexts (congruent vs. neutral: F1(1,58) = 32.28, p<.0001, F2(1,46) = 28.77, p<.0001). However, significant inhibition emerged only in the unaltered condition (incongruent vs. neutral: F1(1,58) = 18.28, p<.0001, F2(1,46) = 21.34, p<.0001). No significant difference emerged between the incongruent and neutral conditions when the context was altered, suggesting (as predicted) that compression of the context eliminated its inhibitory effect on incongruent targets. Responses were significantly faster in the incongruent condition when the context was distorted than when it was unaltered ($F1(1,58) = 3.79$, $p<.05$, $F2(1,46) = 5.17$, $p<.05$). There was no significant effect of distortion on responses to targets in the neutral condition, establishing once again that the neutral context really is neutral.

The magnitude of the priming effect was compared statistically across distortion conditions, using difference scores. Facilitation and inhibition effects are plotted in Figure 3. Two-way subject and item repeated-measures ANOVAs were conducted on the RT data, with Distortion (Altered vs. Unaltered) and Priming (Facilitation vs. Inhibition) as within variables. A significant Distortion × Priming interaction emerged ($F1(1,29) = 7.81$, $p<.01$), although this effect was only marginally significant in the item analysis ($F2(1,23) = 3.66$, $p<.1$). Planned linear contrasts revealed a highly significant reduction in inhibition (76%) when the context was altered relative to when the context was unaltered ($F1(1,29) = 9.27$, $p<.01$; $F2(1,23) = 13.94$, $p<.01$). However, as predicted in Table 1, compression of the context produced no significant effect on facilitation ($F1 < 1$; $F2 < 1.10$).

Summary

As predicted, low-pass filtering of the context decreased facilitation. Further, this manipulation also produced a small but significant release from inhibition, which may be attributable to an increased attentional demand imposed by the reduced intelligibility of the sentence stimuli. In contrast, the compression manipulation had no significant effect on facilitation, but significantly reduced inhibition. The theoretical implications of these results are discussed below.

Discussion

The purpose of this study was to examine the effects of acoustic distortion on lexical access, and to determine how distortion interacts with the influence of semantic context in the activation, selection, and integration of lexical-semantic representations. Different types of acoustic distortion were expected to influence different aspects of language processing, and were therefore predicted to interfere with particular levels of lexical access. Specifically, acoustic distortions that affected intelligibility were expected to interfere with the encoding of the acoustic signal and the activation of lexical entries. Thus, these distortions were expected primarily to affect the facilitation of targets by the semantic context. In contrast, distortions that affected central language processing were expected to interfere with the selection of the appropriate lexical candidate and the integration of this candidate into the semantic context. Thus, these distortions were expected to influence only the inhibitory effects of semantic context.

The findings of the present experiment supported these predictions. Specifically, the application of low-pass filtering to the test stimuli primarily influenced the facilitatory effect of context on RTs to targets in the lexical decision task, whereas the application of time compression affected only the inhibition of incongruent targets. When the semantic context was low-pass filtered, the context produced less activation of intact congruent targets, resulting in a significant reduction in semantic facilitation. This result is compatible with previous findings obtained for single-word contexts (Andruski et al., 1994; Aydelott Utman, 1997; Aydelott Utman et al., 2000, 2001). Low-pass filtered contexts were also less effective in inhibiting incongruent targets, resulting in a marginally significant decrease in inhibition priming. This suggests that reduced intelligibility may also impose an additional attentional demand on the listener, who may make use of other sources of information to disambiguate the degraded signal.

In contrast to low-pass filtering, time compression of the context did not interfere with the activation of congruent targets, yielding no significant difference in the magnitude of semantic facilitation effects for compressed and unaltered contexts. However, compression of the semantic context did affect the inhibition of incongruent targets. Listeners responded faster to incongruent targets preceded by compressed contexts than by unaltered contexts. As in the low-pass filtering condition, this improved performance for incongruent targets may be characterized as a *release from inhibition*, i.e., a reduction in the efficacy of the context in inhibiting incongruent lexical items, when the context was acoustically altered. We may speculate that this rather selective effect is obtained because inhibitory effects of context take time to build up across the course of the sentence, a buildup that is reduced or short-circuited when the context must be processed rapidly.

The results of this study therefore support the separate contributions of both acoustic and contextual information, as well as the dissociation between the effects of facilitation and inhibition, in the processing of lexical-semantic information. The findings are compatible with models of lexical access that incorporate activation, selection, and integration as distinct processes that may be differentially affected by disturbances of particular aspects of language processing (cf. Gernsbacher, 1996, 1997; Marslen-Wilson, 1989, 1993). One possible account of the influence of acoustic distortion on these processes is based on interactive-activation models of lexical access (e.g., Marslen-Wilson, 1989; McClelland & Elman, 1986; Simpson, 1981, 1994), in which multiple sources of information influence the activation levels of lexical entries. According to such models, both semantic context and acoustic information from the target itself contribute to the initial activation of lexical candidates as well as the selection of the most compatible candidate with the input, which must then be integrated into the ongoing discourse. Prior to encountering the target, the semantic context raises the activation level of congruent lexical entries. Targets that are congruent with the context are therefore more easily encoded from the acoustic signal (e.g., Borsky et al., 1998; Connolly & Phillips, 1994) and have stronger initial activation levels (Glucksberg et al., 1986; Schvaneveldt et al., 1976; Simpson, 1981) than targets in neutral or incongruent contexts (but cf. Connine et al., 1994; Onifer & Swinney, 1981; Swinney, 1979; van Alphen & McQueen, 2001; van den Brink, Brown, & Hagoort, 2001). In addition, acoustic information associated with the target directly activates lexical candidates, producing varying degrees of initial activation depending upon how compatible this information is with the target representation (Andruski et al., 1994; Madan et al., 1997; Marslen-Wilson, 1989, 1993; Aydelott Utman, 1997; Aydelott Utman et al., 2000, 2001). These initial activation effects occur early in lexical processing, and are considered by many theorists to be 'automatic' and/or relatively inexpensive in terms of general processing resources (e.g., Gernsbacher, 1996; Posner et al., 1989; cf. Neely, 1991). Further, because these effects are strongly dependent upon the encoding of information from the acoustic signal, they are particularly vulnerable to disturbances of intelligibility. This accounts for the finding that initial activation effects are modulated by low-pass filtering of the semantic context. If the context is low-pass filtered, the associated semantic information is more difficult to encode, and thus is less effective in raising the activation level of congruent targets (cf. Andruski et al., 1994; Aydelott Utman, 1997; Aydelott Utman et al., 2000, 2001).

Once the initial activation of lexical entries has been accomplished, both acoustic and contextual information serve to influence the selection of the most compatible entry from the array of active candidates. Acoustic information associated with the target has an inhibitory effect on less compatible candidates, exaggerating the difference in activation levels between the target and its competitors (Marslen-Wilson, 1993; Marslen-Wilson & Warren, 1994). Contextual information constrains the lexical selection process by favoring semantically compatible candidates (Marslen-Wilson, 1989; Tyler, 1984) and inhibiting incompatible candidates (Gernsbacher, 1996, 1997). Once selected, the candidate that is the best match with the acoustics and the context is integrated into the ongoing discourse. Semantically incongruent targets are more difficult to integrate than congruent targets, resulting in longer RTs and larger N400 brainwave effects than congruent targets (Brown & Hagoort, 1993; Stanovich & West, 1983; St. George et al., 1994). As in the case of facilitatory effects, these inhibitory effects are dependent upon how well the associated contextual and acoustic information is perceived. If the semantic context is poorly encoded, its inhibitory effects will be weakened relative to an intact context. Further, inhibitory effects tend to occur later in processing (Neely, 1991) and are more costly in terms of processing resources (Gernsbacher & Robertson, 1994) than facilitatory effects. Thus, inhibitory effects are especially vulnerable to factors that reduce processing time and/or increase central processing demands. When time compression is applied to the semantic context, the resulting decreased processing time and increased demand produces a release from inhibition, yielding faster RTs for incongruent targets.

The interactive-activation approach therefore provides an account of the present findings in terms of the influence of acoustic and contextual information on lexical activation levels. Nevertheless, it is important to acknowledge that many models of lexical access attribute semantic context effects exclusively to ‘postlexical’ processes of selection and integration, and do not allow for the direct modulation of initial activation levels by the semantic context (e.g., Conrad, 1974; Lucas, 1987; Onifer & Swinney, 1981; Swinney, 1979). According to these models, the activation of lexical entries is accomplished purely on the basis of sensory information, and the role of the semantic context is to select among these active entries. The dissociation between facilitation and inhibition observed here could be accommodated in such a model if the two effects were attributed to the processes of lexical selection and integration, respectively. After lexical representations have been activated by the sensory input (which may occur after only a portion of the word has been perceived; see Zwitserlood, 1989; van Petten et al., 1999), the selection of the appropriate candidate is constrained by the semantic context, leading to the facilitation of targets that are compatible with the context. Selection of targets that are incompatible with the context must be accomplished solely on the basis of the sensory input from the target itself. Reducing the intelligibility of the context limits the influence of contextual constraint on lexical selection, thereby reducing facilitation of congruent targets. Once a lexical candidate has been selected, its meaning must be integrated into the semantic context. According to this interpretation, integration is a relatively late process that requires additional time and processing resources, particularly for targets that are incompatible with the contextual meaning. Thus, incongruent targets are more difficult to integrate, and are therefore responded to more slowly. When processing time is reduced, however, integration processes have not had time to influence responses to targets, resulting in a release from inhibition. Whether the separability of facilitation and inhibition effects are attributable to lexical activation and selection in an interactive processing system, or to post-lexical selection and integration in a serial processing system, cannot be determined by the present results. Nevertheless, these findings may provide a possible means of differentiating between early- and late-stage processes in auditory lexical access.

The separable effects of different acoustic degradations on lexical access have particular implications for language comprehension in both hearing-impaired and elderly populations. Both groups suffer from endogenous disturbances in the processing of spoken language that may interfere with the normal access of lexical-semantic representations. Specifically, hearing impairment represents a disturbance in the perception of spoken language, whereas the general cognitive slowing associated with aging interferes with central language processing (cf. Gordon-

Salant & Fitzgibbons, 1995b; Sommers, 1997; Stuart & Phillips, 1996). If these endogenous factors have similar effects on lexical access to exogenous distortions such as low-pass filtering and time compression, then these groups may show similar disruptions of lexical activation and inhibition in the perception of undistorted speech. Further, these populations may be impaired not only in the perception of single words, but also in higher-level language processing. Because lexical representations may include both semantic and syntactic information, a disruption in the access of this information may interfere with the construction of sentence-level representations in hearing-impaired and elderly participants. This proposal is supported by studies of the effects of exogenous acoustic distortions on the processing of complex sentences, which have demonstrated that sentence comprehension is disrupted by low-pass filtering, broad-band noise masking, and time compression (Beasley et al., 1980; Dick et al., 2001; Kilborn, 1991; Wingfield et al., 1984). Further, the effect of multiple acoustic distortions on sentence comprehension is overadditive, such that performance is more severely impaired in response to two or more simultaneous degradations of the acoustic signal than would be predicted based on the effects of each of these degradations in isolation (Dick et al., 2001; Harris, 1960; Lacroix et al., 1979). This overadditivity of multiple distortions may contribute to the particular comprehension difficulties reported by hearing-impaired and elderly listeners in response to rapid speech or speech in competing noise. The effects of hearing impairment and aging on lexical and syntactic processing for both intact and distorted stimuli are thus important topics for future research.

The findings of the present study also indicate that semantic priming effects are highly sensitive to the acoustic quality of the speech stimulus and the rate at which this stimulus is produced. Specifically, the magnitude of contextual priming depends upon both the spectral and temporal characteristics of the input sentence. Further, particular characteristics of the signal can have separable effects on the facilitatory and inhibitory aspects of the semantic priming effect. There is considerable variation in effect size across studies of contextual priming that have used an auditory sentence context, a fact that has led to debate about the interpretation of these studies (e.g., Onifer & Swinney, 1981; Simpson, 1981; see Simpson, 1994, for review). The present study may offer a possible explanation of at least some of this variation in terms of differences in sampling rate, bit size, presentation apparatus and environment, and speech rate characteristics of spoken sentence contexts across experiments, as all of these factors have the potential to influence the magnitude of auditory semantic priming effects. The careful control of these parameters in future investigations may help to resolve some of the inconsistencies that have emerged across experiments and across laboratories.

In summary, the present study demonstrates that the effects of semantic context on lexical access are modulated by acoustic distortion, and that the facilitatory and inhibitory effects of context are separably affected by disturbances of intelligibility and processing demand. We propose that reduced intelligibility interferes with the encoding of the acoustic signal and the early processes involved in the activation of semantic information, whereas increased processing demand affects later stages of selection and integration of lexical items. These results may inform current models of lexical access, and have implications for higher-level language comprehension in populations with endogenous disturbances in the processing of the acoustic signal. Further, the results may offer an explanation for some of the variation in the magnitude of contextual priming effects across experiments in the psycholinguistic literature.

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Appendix 1

Test Stimuli

Context	Target	
	Congruent	Incongruent
Emily poured cereal in a	bowl	star
Elizabeth didn’t know the time because she forgot to wear her	watch	scissors
Before having dessert my friend Sarah must finish all the food on her	plate	boat
The branch broke and I fell out of the	tree	frog
In two more days the astronauts will be landing on the	moon	tree
Tom had trouble eating his salad without a	fork	pumpkin
On Halloween I was a pirate and wore a patch over my	eye	bee
I had a bad cold and always had to blow my	nose	door
Tonight make sure you wish on a	star	table
Since everyone kept walking into my room I decided to lock the	door	cow
The carpenter pounded in the last nail with his	hammer	bread
Mike couldn’t get into his office because he had forgotten his	key	kite
When I’m writing my name I like to use a	pencil	bowl
Your mom doesn’t want you to get stung by the	bee	cake
It is easy to make toast; just find yourself a slice of	bread	pencil
When I make a mess with my supper my mom says I eat like a	pig	watch
Karen cut the long string with a pair of	scissors	pig
On my birthday my grandma always bakes me a	cake	hammer
On a windy day it’s fun to go out and fly a	kite	nose
Sitting on the lily pad there was a big green	frog	eye
For Halloween we always like to carve a	pumpkin	plate
On the farm the farmer gets up early to milk the	cow	fork
Every night before dinner it’s my job to set the	table	moon
Ryan and Meg sailed to the island on their new	boat	key

Appendix 2

Accuracy Data

Distortion Type	Presence of Distortion	Semantic Context	% Correct Responses (Standard Error)
Filtering	Unaltered	Congruent	99.17 (0.08)
		Neutral	95.00 (12.11)
		Incongruent	86.67 (3.74)
	Altered	Congruent	99.17 (0.83)
		Neutral	99.17 (0.83)
		Incongruent	98.33 (6.34)
Compression	Unaltered	Congruent	100.00 (0.00)
		Neutral	100.00 (0.00)
		Incongruent	91.67 (3.02)
	Altered	Congruent	100.00 (0.00)
		Neutral	99.17 (0.83)
		Incongruent	97.50 (1.39)

Appendix 3

Distortion Type x Distortion x Context ANOVAs (Accuracy Data)

Effect		Main Effect	x Context	x Distortion	x Context x Distortion
Distortion Type	F1 F2	(1,58) 2.47 (1,23) 2.79	(2,116) 0.31 (2,46) 0.29	(1,58) 3.16~ (1,23) 3.52~	(2,116) 0.97 (2,46) 0.62
Distortion	F1 F2	(1,58) **11.67**** (1,23) **8.44****	(2,116) **8.37**** (2,46) **7.38****	•••	•••
Context	F1 F2	(2,116) **16.96**** (2,46) **10.10****	•••	•••	•••

*p<.05 **p<.01 ~p<.1

Appendix 4

Distortion x Context ANOVAs and Means Comparisons

(Accuracy Data, Filtered Contexts)

Effect		Main Effect	x Semantic Context
Acoustic Distortion	F1 F2	(1,29) **9.98**** (1,23) **7.53***	(2,58) **5.41**** (2,46) **3.94***
Semantic Context	F1 F2	(2,58) **8.34**** (2,46) **4.74***	•••

Comparison		Altered vs. Unaltered
Congruent	F1 F2	0.00 0.00
Neutral	F1 F2	2.69~ 1.96
Incongruent	F1 F2	**21.08**** **15.35****

Comparison		Congruent vs. Neutral	Incongruent vs. Neutral	Congruent vs. Incongruent
Unaltered	F1 F2	2.69~ 1.96	**10.75**** **7.83****	**24.20**** **17.62****
Altered	F1 F2	0.00 0.00	0.11 0.08	0.11 0.08

*p<.05 **p<.01 ~p<.1

Appendix 5

Distortion x Context ANOVAs and Means Comparisons

(Accuracy Data, Compressed Contexts)

Effect		Main Effect	x Semantic Context
Acoustic Distortion	F1 F2	(1,29) 2.07 (1,23) 2.76	(2,58) **3.42*** (2,46) 2.65~
Semantic Context	F1 F2	(2,58) **9.05**** (2,46) **10.41****	•••

Comparison		Altered vs. Unaltered
Congruent	F1 F2	0.00 0.00
Neutral	F1 F2	0.18 0.14
Incongruent	F1 F2	**8.83**** **6.83***

Comparison		Congruent vs. Neutral	Incongruent vs. Neutral	Congruent vs. Incongruent
Unaltered	F1 F2	0.00 0.00	**18.01**** **13.94****	**18.01**** **13.94****
Altered	F1 F2	0.18 0.14	0.72 0.56	1.62 1.26

*p<.05 **p<.01 ~p<.1

Table 1

Predictions

Type of Distortion	Predicted Locus of Effect	Predicted Effect of Distortion	Predicted Pattern of Results
Reduced Intelligibility (Low-Pass Filtering)	perceptual encoding/ activation	reduced facilitation	• slower RTs to congruent targets • smaller facilitation priming effect (congruent vs. neutral) • smaller inhibition priming effect (incongruent vs. neutral)
Reduced Processing Time (Temporal Compression)	selection/ integration	reduced inhibition	• faster RTs to incongruent targets • no effect on facilitation priming • smaller inhibition priming effect

Table 2

Sample Test Conditions

Nature of Distortion	**Sentence Context**	**Neutral Context**	**Congruent Target**	**Incongruent Target**	**Distractor Target**
Unaltered	On a windy day, it's fun to go out and fly a	Its name is	KITE	FORK	YERT
Low-Pass Filtering (1 kHz)	**On a windy day, it's fun to go out and fly a*	**Its name is*	KITE	FORK	YERT
Time Compression (50%)	*On a windy day, it's fun to go out and fly a	*Its name is	KITE	FORK	YERT

Table 3

Mean RTs (in milliseconds) to Targets in Filtered Contexts

Acoustic Distortion	Semantic Context	RTs to Correct Responses (Standard Error)
Unaltered	Congruent	612 (21)
	Neutral	818 (27)
	Incongruent	903 (28)
Altered	Congruent	774 (27)
	Neutral	804 (28)
	Incongruent	842 (37)

Table 4

Mean RTs (in milliseconds) to Targets in Compressed Contexts

Acoustic Distortion	Semantic Context	RTs (ms) to Correct Responses (Standard Error)
Unaltered	Congruent	679 (32)
	Neutral	826 (28)
	Incongruent	920 (33)
Altered	Congruent	729 (37)
	Neutral	854 (32)
	Incongruent	877 (28)

Figure Legends

Figure 1. Sample waveform of the sentence context ‘On a windy day, it’s fun to go out and fly a…’, and spectrograms of the unaltered (top panel), low-pass filtered (center panel), and time-compressed (bottom panel) versions of this context.

Figure 2. LOW-PASS FILTERING. Priming effects in unaltered and altered conditions, plotted as the difference in mean reaction times (milliseconds) to targets in biasing and neutral contexts (facilitation = congruent minus neutral; inhibition = incongruent minus neutral). Values above the zero line reflect slower RTs than neutral baseline; values below the zero line reflect faster RTs than neutral baseline.

Figure 3. TIME COMPRESSION. Priming effects in unaltered and altered conditions, plotted as the difference in mean reaction times (milliseconds) to targets in biasing and neutral contexts (facilitation = congruent minus neutral; inhibition = incongruent minus neutral). Values above the zero line reflect slower RTs than neutral baseline; values below the zero line reflect faster RTs than neutral baseline.

Figure 1.

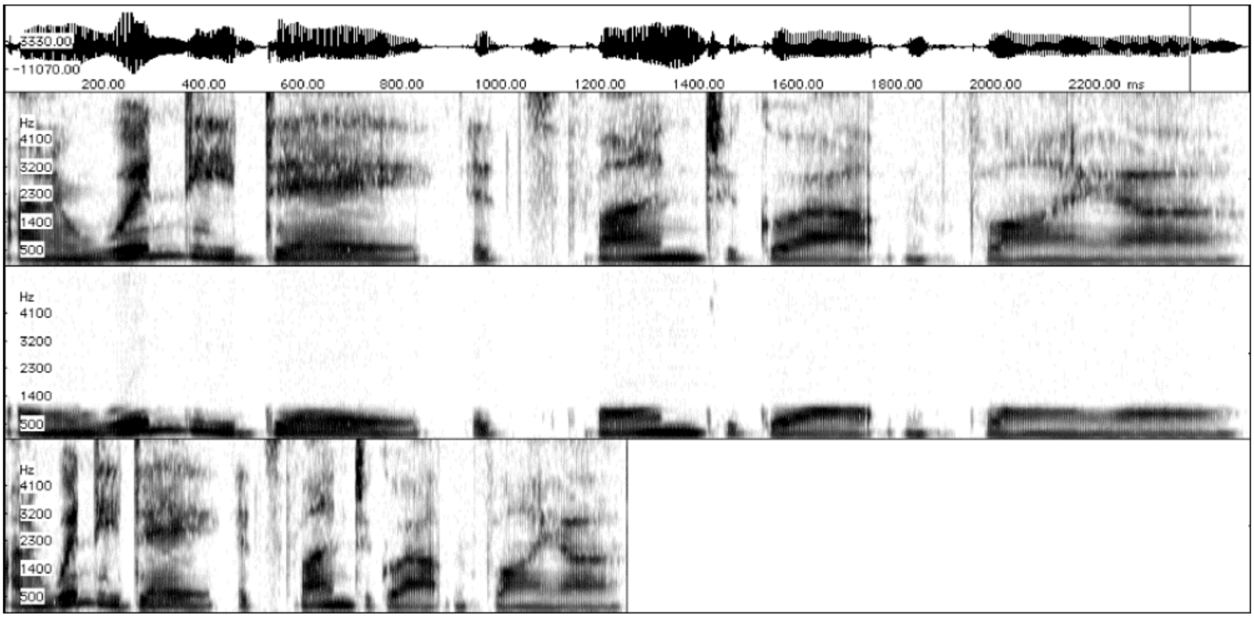

3330.00
-11070.00
200.00
400.00
600.00
800.00
1000.00
1200.00
1400.00
1600.00
1800.00
2000.00
2200.00 ms
Hz
4100
3200
2300
1400
500
Hz
4100
3200
2300
1400
500
Hz
4100
3200
2300
1400
500

Figure 2.

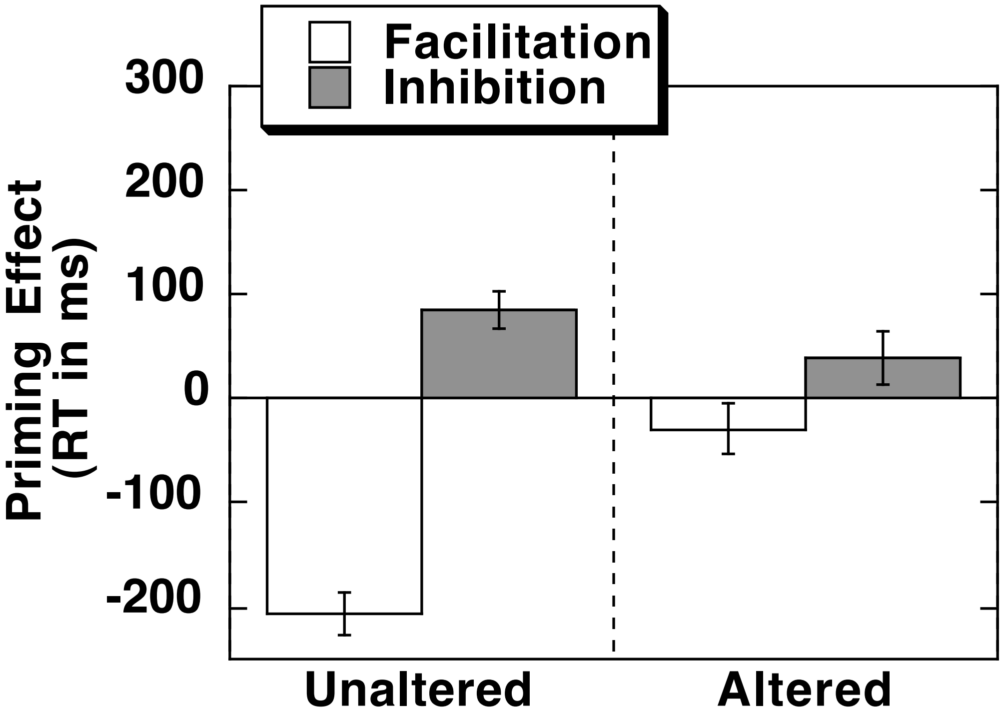
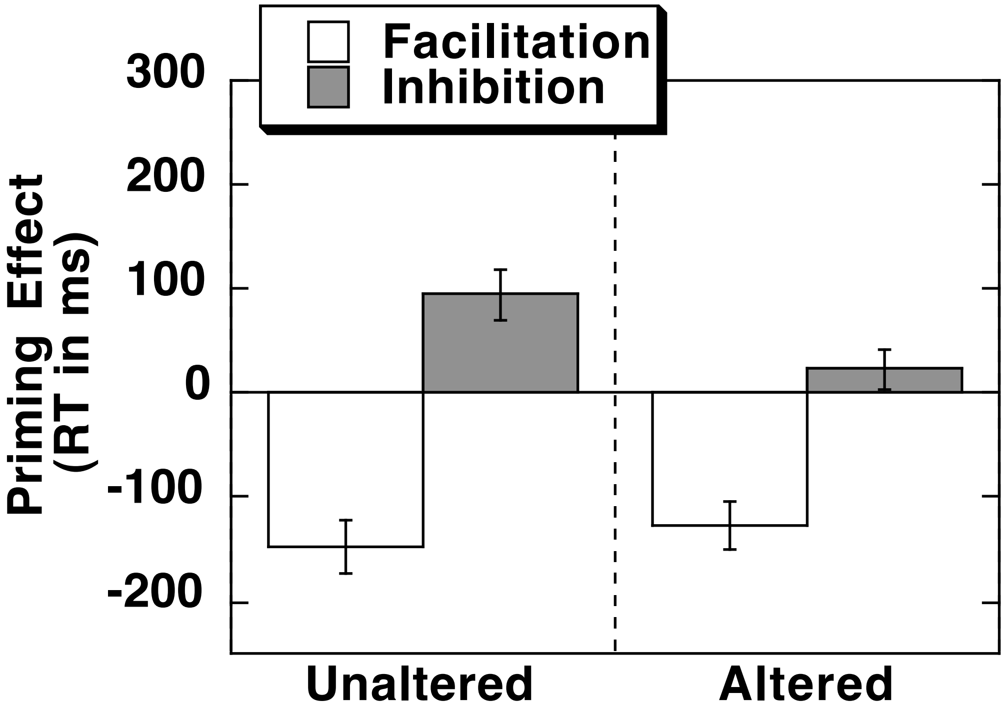

Facilitation
Inhibition
300
200
100
0
-100
-200
Priming Effect
(RT in ms)
Unaltered
Altered

Figure 3.


Facilitation
Inhibition
300
200
100
0
-100
-200
Priming Effect
(RT in ms)
Unaltered
Altered