Effects of Competing Speech on Sentence-Word Priming: Semantic, Perceptual, and Attentional Factors

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Abstract

This study examined the effects of a competing signal on sentence-word priming using an auditory lexical decision paradigm. Previous studies have suggested that the facilitatory component of the sentential priming effect is particularly sensitive to acoustic distortions that reduce the perceptibility of the sentence context, whereas the inhibitory component is more sensitive to increased attentional demand. Three competing signal conditions were compared: forward speech presented to a different ear, backward speech presented to a different ear, and forward speech presented to the same ear. The results demonstrate that the competing signal has different effects on priming depending upon the semantic content of the signal and its perceptual isolability from the sentence context.

Introduction

The influence of sentence meaning on lexical processing has been studied extenstively in sentence-word priming studies, which have demonstrated that sentence context has both facilitatory and inhibitory effects on responses to single words (e.g., Stanovich & West, 1983; Meyer & Schvaneveldt, 1976; Simpson, Peterson, Casteel, & Burgess, 1989; Duffy, Morris, & Henderson, 1989). In other words, reaction times for words preceded by a highly congruent sentence context are faster than those preceded by a neutral context, whereas responses to words presented in an incongruent are slowed relative to a neutral context. Further, facilitatory and inhibitory effects tend to emerge under different experimental conditions in both sentence-word and word-word priming studies. Specifically, facilitation effects emerge at brief stimulus onset asynchronies (SOAs), and are generally insensitive to expectancy and processing strategies (Neely, 1991; Utman & Bates, 1998a,b), to the extent that facilitation is observed even when a prime stimulus is presented briefly and then masked, such that subjects are not consciously aware of the identity of the prime (Neely, 1991). In contrast, inhibitory effects 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 (Neely, 1991), and tend to be reduced in populations with limited attentional capacity (e.g., Faust, Balota, Duchek, Gernsbacher, & Smith, 1997). Based on this evidence, researchers have argued that facilitation occurs rapidly and requires little in the way of attentional and/or processing resources, whereas inhibition occurs later in the time course of lexical access, and may reflect more controlled or strategic processing (Faust & Gernsbacher, 1996; Gernsbacher, 1997; Neely, 1991; Utman & Bates, 1998a,b).

Recent studies have revealed that the facilitatory and inhibitory components of the sentence-word priming effect respond differently to acoustic distortion of the semantic context. Specifically, facilitatory effects are particularly sensitive to distortions that reduce the intelligibility of the acoustic signal, whereas inhibitory effects are more sensitive to distortions that reduce processing time and/or increase attentional demand (Utman & Bates, 1998 a,b; Utman, Dick, Prat, & Mills, 1999). For example, low-pass filtering of the sentence context significantly reduces facilitation of congruent targets (Utman & Bates, 1998a,b). In contrast, temporal compression of the context significantly reduces inhibition of incongruent targets, but has no effect on facilitation (Utman & Bates, 1998a,b). These findings suggest that facilitation effects are more dependent on bottom-up information from the acoustic signal, whereas inhibition effects are more dependent on attentional resources.

In the present study, we sought to investigate how competing speech influences the facilitatory and inhibitory components of the sentence-word priming effect. The separate influences of perceptual and attentional factors on facilitation and inhibition have particular implications for competing speech. It is generally recognised that competing speech places an increased demand on processing resources, as the listener must selectively attend to one signal while suppressing another. For example, Downs & Crum (1978) found that competing speech significantly increased effort required for auditory learning, although actual performance was not affected. They concluded that competing speech increased attentional load, thereby decreasing resources for speech processing. More recently, Connolly, Phillips, Stewart, & Brake, (1992) found that hearing competing speakers resulted in a decreased ability to process semantic features of the target speech, indicating that the increased attentional demand of competing speech directly affects semantic processing.

Competing speech may also be relatively more demanding than a competing signal with no semantic content, because the speech signal will activate linguistic representations that are in conflict with the attended signal. Unattended speech has been found to be processed at a semantic level by Moray (1959) as well as Bentin, Kutas, & Hillyard (1995). Further, Garstecki & Mulac (1974) found that subjects had more difficulty on an auditory discrimination task when competing speech was played forwards than when it was played backwards, although subjects described the backwards speech as sounding like language. The interference effect was attributed to the semantic content of the forward speech. In addition, Harris, Benedict, & Leek (1990) observed that performance on a language-based task was more severely disrupted by more intelligible competing speech, and that performance was worst with only one competing speaker, as it is easier to extract semantic information from the competing signal of a single voice than several.

In addition to placing increased demands on attentional resources, competing speech may also affect the perceptibility of the attended signal by masking the spectral frequencies of the signal, thereby interfering with the bottom-up encoding of phonetic contrasts. This effect may be particularly pronounced when the two competing signals come from a similar spatial location, making the target signal more difficult to isolate.

These possibilities were explored in a sentence-word priming study, in which the sentence context was presented in isolation or in the presence of a competing signal. Lexical decision responses to target words were compared when the targets were presented in congruent, neutral, and incongruent sentence contexts. Given the framework described above, it was possible to predict the effect of different forms of auditory competition on lexical decision following biasing sentence contexts.

When the context was easily isolable from the competing signal, we expected that the primary effect of competing speech would be to increase attentional demand, leaving the perceptibility of the context relatively unaffected. As a result, we predicted that strategic or attentional inhibitory processes would be severely compromised, while facilitation would remain intact. This hypothesis was tested by presenting the semantic context and the competing speech signal to different ears. In this case, we predicted no significant change in reaction times to contextually congruent targets, but a significant decrease in inhibition for contextually incongruent words.

We expected this release from inhibition to be more pronounced for a competing signal with semantic content, as a meaningful signal should place relatively greater demands on available resources for semantic processing. To confirm this prediction, we compared the effect of competing speech with that of a similar competing signal with no semantic content, i.e. backward speech. Since backward speech does not appear to greatly tax attentional resources despite its speech-like properties, we predicted no significant difference in reaction times between targets preceded by sentence contexts presented in isolation and targets preceded by sentence contexts accompanied by competing backward speech in a different ear.

We also considered the effect of competing speech when presented in the *same* auditory channel as the sentence contexts, by presenting forward speech in the same ear as the semantic context. In this case, we expected that the competing signal would have a masking effect, disrupting the peripheral encoding of the speech input, as well as making it more difficult to attend only to the appropriate sentence. Consequently, we predicted that both facilitatory and inhibitory effects of sentence context would be affected.

Method

Participants

Thirty-six undergraduates (15 male and 21 female) at Oxford University participated in the experiment. All participants were right-handed, native British English speakers. None reported any hearing impairments.

Stimuli

The stimuli consisted of 30 target words, 30 nonwords, a neutral sentence, and 60 highly constraining sentence contexts (30 to be paired with targets and 30 with nonwords).

The targets were one-syllable words containing 3-5 phonemes (mean = 3.27, SD = 0.64) with a mean Kucera-Francis print frequency of 139 (SD = 99) (Kucera and Francis, 1967), a mean London-Lund spoken frequency of 14 (SD = 81) (Brown, 1984), and a mean concreteness rating of 546 (SD = 81) as specified in the MRC Psycholinguistic Database (Coltheart, 1981). To avoid possible morphological and morpho-phonological constraints of determiners (*a/an*, *the*), mass nouns (e.g., *blood*, *dust*) were excluded, and all targets were consonant-initial. The nonword distracter targets consisted of phonologically permissible one-syllable nonsense items, which did not differ significantly from the targets in terms of number of phonemes (mean = 3.33, SD = 0.61).

The sentence contexts matched with the word targets were approximately ten syllables in duration (mean = 9.47, SD = 2.66), containing a maximum of six content words (mean = 3.37, SD = 1.07), and a maximum of three words related to the congruent target (mean = 1.13, SD = 0.51). There was no significant difference in length or number of content words between sentences paired with word targets and sentences paired with nonword distractors.

In the congruent condition, word targets were matched with the appropriate sentence context (e.g., *He wanted to come in, but she refused to open the...* - DOOR). In the incongruent condition, word targets were matched with a sentence context appropriate to another target in the stimulus set (e.g., *He wanted to come in, but she refused to open the...* - HORSE). Pilot analyses revealed that word targets had a mean cloze probability of 100% (SD = 0%) when presented in the correct context. Therefore, if a target was presented in an incongruent context its cloze probability was 0%. A neutral sentence context, providing no semantic cues with regard to the target (*The next item is...*), was created to serve as a neutral baseline.

Each participant received one of six randomised lists, each containing 60 trials. Across lists, each target appeared in each condition (congruent alone, congruent + competing signal, neutral alone, neutral + competing signal, incongruent alone, and incongruent + competing signal), with no target or biasing context appearing more than once per list. In each of the three semantic context conditions, half of the sentences were presented without a competing signal (presented alone in only one ear), or with a competing signal (presented in one ear with the competing signal presented in the same ear or the other ear). Thus, semantic bias (congruent, neutral, or incongruent) and competing signal (present or absent) served as within-subjects variables (each participant received all six conditions). This pattern also applied to the thirty nonwords and their sentence contexts in each list.

The stimuli were produced by native speakers of British English. 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. The stimuli were recorded onto digital audio tape in an Industrial Acoustics 403-A audiometric chamber with a Tascam DA-P1 Digital Audio Tape recorder and a Sennheiser ME65/K6 supercardioid microphone and pre-amp at gain levels between -6 and -12 db. The recorded stimuli were then digitised via digital-to-digital sampling onto a Macintosh G4 computer via a Digidesign audio card using ProTools LE software at a sampling rate of 44.1 kHz with a 16-bit quantization. The waveform of each sentence, target, and nonword was then edited and saved in its own mono-audio file. All the stimulus files were converted into 16-bit 22.05 kHz stereo files in SoundEdit16 and saved in System 7 format.

Competing Speech Conditions

A passage from the book *Profit Patterns* (Slywotzky, 1999) was also recorded and edited on the same equipment and under the same conditions (including gain levels) but using a different female speaker. This recording was then used for both the forward and backward competing speech conditions.

In the forward competing speech condition (different ear), copies of all the stereo sentence files were made and segments of competing speech of the same duration as the sentence context were excised at random and inserted on the blank track in the stereo sound file.

In the backward competing speech condition (different ear), the same competing speech was used as in the forward speech condition, played backward. This was achieved using the backwards function in SoundEdit16. This condition was intended to produce auditory interference with the same frequency spectrum as speech but without semantic content.

In the forward competing speech condition (same ear), the sentence contexts were mixed with the forward speech and presented through a single channel. All the original stereo files containing forward competing speech were converted into new stereo files in which the two tracks had been mixed together using the mix function in SoundEdit16.

Type of competing signal (forward/different ear, backward/different ear, and forward/same ear) served as a between-subjects variable (each participant was assigned to one of the three conditions).

Procedure

The test trials were presented auditorily with an inter-stimulus interval of 1500 ms on a Macintosh G4 computer using SuperLab software. The stimuli were presented through Sennheiser HD 25-1 headphones via a Sirocco VideoLogics amplifier in a sound-protected testing room. Reaction times (RTs) and accuracy were recorded in SuperLab from a Cedrus RB-610 response box. Subjects were instructed to respond as quickly and accurately as possible after hearing the target word, and to press a green button if they heard a real English word or a red button if they heard a nonword. Whether the participant heard the context sentence in the left or right ear was counterbalanced across both lists and male and female subjects.

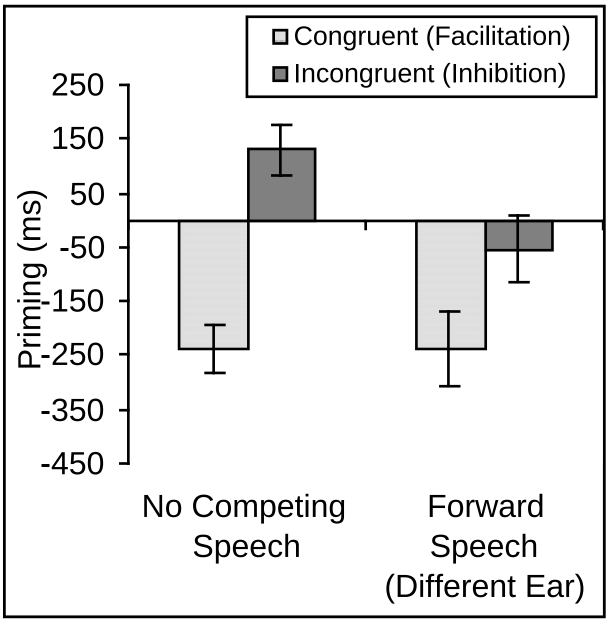

Figure 1. Effect of forward competing speech (different ear). Error bars indicate standard error.

Results

To minimise the effect of outliers in the RT data, the median RT for correct responses was calculated for each subject in each condition for use in the statistical analyses (Wilcox, 1992; Ulrich & Miller, 1994). The magnitude of the priming effect was obtained for both RTs and accuracy by subtracting average median values in the biasing conditions from average median values in the neutral baseline condition for each subject. Four-way subject and item analyses of variance (ANOVAs) comparing the magnitude of the priming effect across conditions were conducted for accuracy (percent correct) and RTs (milliseconds), with competing signal (present vs. absent) and semantic bias (congruent vs. incongruent) as within-subjects variables and type of signal (forward/different ear vs. backward/different ear vs. backward/same ear) and context ear (left vs. right) as between-subjects variables. There was no main effect of context ear in either the accuracy or RT analyses. Further, there was no significant interaction of context ear with competing signal, type of signal, or semantic bias, and no four-way interaction, in either the accuracy or RT analyses. Thus, there was no significant right ear advantage for semantic context, and no significant difference between the pattern of performance obtained across conditions when the semantic context was presented to the right ear and the pattern when the semantic context was presented to the left ear.

A significant interaction of competing signal x semantic bias x type of signal emerged (Subject $F(2,30) = 4.69$, $p < .05$) emerged, although this effect failed to generalise across items. The accuracy analyses revealed no significant three-way interaction, nor was the pattern of results indicative of speed-accuracy trade-offs when compared with the RT data.

To provide a clearer picture of the patterns of performance produced by the three types of competing signal, separate ANOVAs were conducted on the RT data for each competing signal condition.

Forward Speech (Different Ear)

Figure 1 shows the average priming effect produced by biasing contexts presented in the presence or absence of a competing signal in the forward speech condition (different ear). The magnitude of the priming effect was analysed in two-way subject and item ANOVAs with semantic bias and competing signal as within-subjects variables. There was a significant main effect of semantic bias (Subject $F(1,11) = 45.17$, $p < .001$; Item $F(1,29) = 11.28$, $p < .01$), but no significant main effect of competing signal. A significant semantic bias x competing signal interaction emerged for RTs (Subject $F(1,11) = 10.31$, $p < .01$; Item $F(1,29) = 4.54$, $p < .05$). Planned contrasts conducted within a general linear model revealed that inhibition was significantly reduced when the context was presented along with competing forward speech in a different ear, relative to when the context was presented in isolation (Subject $F(1,11) = 20.35$, $p < .001$; Item $F(1,29) = 5.41$, $p < .05$). However, this manipulation did not significantly affect facilitation.

Backward Speech (Different Ear)

Figure 2 shows the average priming effect produced by biasing contexts presented in the presence or absence of a competing signal in the backward speech condition (different ear). The magnitude of the priming effect was analysed in two-way subject and item ANOVAs for RT and accuracy with semantic bias and competing signal as within-subjects variables. There was a significant main effect of semantic bias (Subject $F(1,11) = 48.77$, $p < .001$; Item $F(1,29) = 63.62$, $p < .001$), but no significant main effect of competing signal. The interaction of semantic bias and competing signal did not approach significance in either the subject or item analysis. Further, planned contrasts revealed no significant effect of this competing signal on facilitation or inhibition.

Forward Speech (Same Ear)

Figure 3 shows the average priming effect produced by biasing contexts presented in the presence or absence of a competing signal in the forward speech condition (same ear). The magnitude of the priming effect was analysed in two-way subject and item ANOVAs with semantic bias and competing signal as within-subjects variables. There was a significant main effect of semantic bias (Subject $F(1,11) = 21.92$, $p < .001$; Item $F(1,29) = 16.02$, $p < .001$), but no significant main effect of competing signal. A significant semantic bias x competing signal interaction emerged (Subject $F(1,11) = 14.24$, $p < .01$; Item $F(1,29) = 4.76$, $p < .05$). Planned contrasts revealed that facilitation was significantly reduced when the context was presented along with competing forward speech in the same ear (Subject $F(1,11) = 22.40$, $p < .001$; Item $F(1,29) = 13.58$, $p<.001$). However, this manipulation did not significantly affect inhibition.

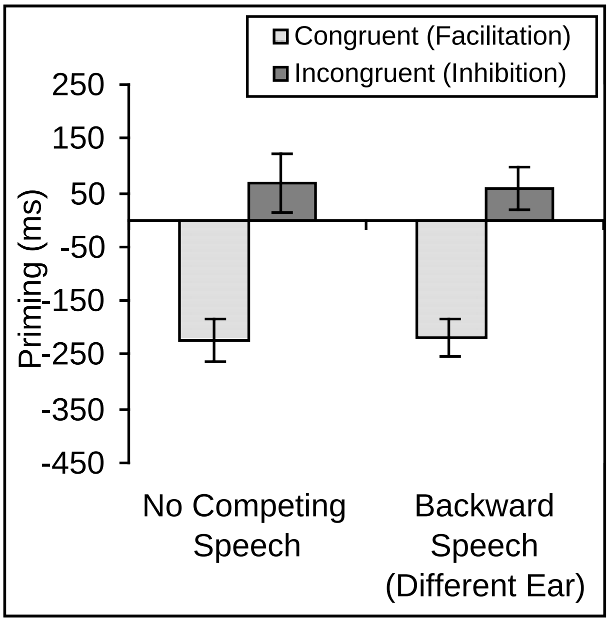

Figure 2. Effect of backward competing speech (different ear). Error bars indicate standard error.

Discussion

These results demonstrate that competing speech modulates the effect of sentence context on the processing of spoken words. Further, the pattern of these effects depends crucially upon the semantic content of the competing signal and the perceptual separability of the competing and target signals. Specifically, competing speech presented in a different ear from the target signal significantly reduced the inhibitory effect of context on incongruent targets, without affecting the facilitatory effect of context on congruent targets. Thus, as predicted, increased attentional demand disrupted only the inhibitory component of the priming effect. However, when backward speech was presented to a different ear, there was no significant effect on facilitatory or inhibitory priming. This finding suggests that it is the semantic content of the competing signal, rather than the signal itself, that increases attentional demand. When forward speech was presented to the same ear, however, the facilitatory effect of context was significantly reduced, whereas the inhibitory effect was unaffected. Thus, when the target signal cannot be isolated from the competing speech, the masking effect of the competing signal disrupts the perceptibility of the target signal, resulting in reduced facilitation.

These results are compatible with previous claims that the facilitatory component of the priming effect reflects the early and automatic processing of lexical-semantic information, whereas the inhibitory component reflects later, more controlled or strategic processes (Faust & Gernsbacher, 1996; Gernsbacher, 1997; Neely, 1991; Utman & Bates, 1998a,b). Future research will examine the implications of these results for language comprehension populations with limited perceptual and attentional capacity, including hearing-impaired and elderly individuals.

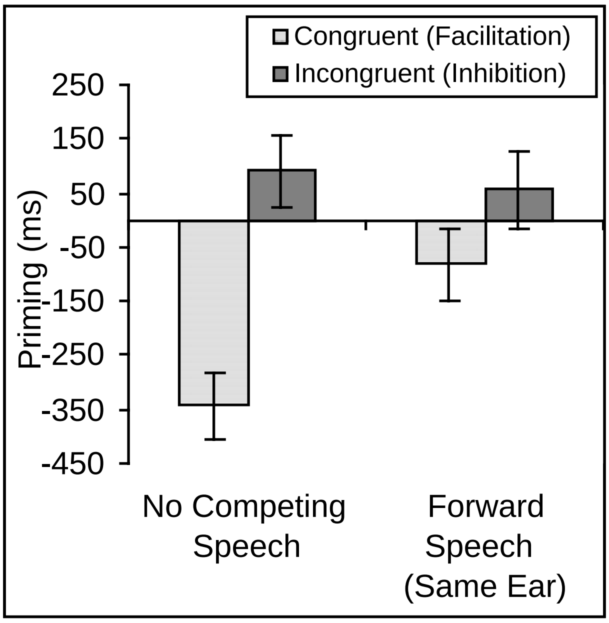

Figure 3. Effect of forward competing speech (same ear). Error bars indicate standard error.

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