Auditory forward and backward masking interaction

RICHARD E. PASTORE, LAURA B. HARRIS, and LYNN GOLDSTEIN
State University of New York, Binghamton, New York 13901

Recent research on forward masking and backward masking has led us to the hypothesis that combined forward and backward masking may involve at least two different types of interaction patterns. The previously documented interaction results in masking are greater than predicted by the simple summation of masking effects obtained with each masker alone (Lynn & Small, 1977; Patterson, 1971; Wilson & Carhart, 1971). Another possible type of interaction is based upon the finding that backward masking, but not forward masking, can be reduced by cues providing timing information (Puleo & Pastore, 1980). A forward masker appears to involve minimum temporal uncertainty (Pastore & Freda, 1980) and, therefore, should be able to act as such a source of timing information to reduce the contribution of a later occurring backward masker. Both types of interaction patterns were found, with the specific forward and backward masker parameters determining which pattern is observed.

Backward and forward masking both involve a decrement in signal detectability due to the presence of a masking stimulus in close temporal proximity. Recent data seem to suggest the involvement of at least some processes that may be unique to each type of masking. Given analogous conditions, including dichotic presentation, greater backward than forward masking generally has been found (Elliott, 1971; Lynn & Small, 1977). Also, backward masking does not require as close a frequency relationship between the signal and the masker (Weber, 1978). These and similar results have led to the hypothesis that, while forward masking may largely involve a temporal persistence of the masker effects which results in the interference of the processing of the subsequent signal (Zwislowski, 1960), backward masking may involve some interactions between the signal and masker at higher processing levels.

The proposal of different processes operating for forward masking and backward also has received support from work examining the combined effects of a forward and a backward masking stimulus. Using clicks as either masker or signal, more masking typically is found with combined maskers than would be predicted if the interaction between the two types of masking were strictly additive (Elliott, 1971; Lynn & Small, 1977; Patterson, 1971; Wilson & Carhart, 1971).

This research was supported by NINCDS Grant 10995 to the first author. These results, in part, were presented to the 95th meeting of the Acoustical Society of America, Providence, Rhode Island, May 1978. Reprint requests should be sent to: Psychoacoustics Laboratory, Department of Psychology, State University of New York at Binghamton, Binghamton, New York 13901

Stimulus uncertainty is a concept that has been linked to backward masking (Pastore & MacLachy, 1975). Such uncertainty might involve the exact nature of the signal or imprecise information about when the signal might occur. Puleo and Pastore (1980) investigated uncertainty in backward masking with a monaural detection with contralateral cuing (MDCC) paradigm. The assumption underlying this research is that an effective contralateral cue provides specific information which reduces a type of uncertainty characteristic to the given situation. Phase-locked sinusoidal segments, uncorrelated band-limited noise, and silent gaps in an uncorrelated broad-band noise all proved effective, but not differentially effective, as cues in reducing backward masking. Therefore, both the phase and frequency relationships between cue and signal are relatively unimportant aspects of cues in backward masking. Only the precision of timing information seemed to be a critical factor in reducing backward masking. Since uncertainty is probably largely central in nature, the idea that the backward masking stimulus introduces stimulus uncertainty is compatible with the current conception that backward masking is more than a peripheral phenomenon.

In subsequent research with a forward masking paradigm, Pastore and Freda (1980) utilized MDCC techniques to assess uncertainty in forward masking. This extensive study failed to identify any contralateral cues (including timing cues) that were effective in reducing forward masking. Since timing cues effective in backward masking are ineffective in forward masking, it appears either that the observers are unable to utilize cues in this situation or that timing uncertainty is not a critical factor in forward

masking. The latter would be the case if the forward masking stimulus acts as a source of timing information; any contralateral timing cues then would be redundant and therefore ineffective.

In situations with both a forward and a backward masking stimulus, temporal cuing properties of a forward masker could be an important source of interaction, since timing information appears to be a relevant factor for the backward masker. The absence of such forward masker cuing effects in the masking interaction literature may be the result of employing forward maskers in which the masking properties would predominate. The use of less intense forward maskers would minimize masking effects and might be expected to produce a very different type of interaction in a combined masking paradigm. Therefore, we predicted that a weak forward masker in combination with a backward masking stimulus would reduce masking to below that obtained for backward masking alone.

METHOD

Subjects

Three undergraduate female observers with no known hearing deficits were employed as subjects in this experiment. Two had extensive prior experience as subjects in psychoacoustics studies.

Stimuli

On every trial, the subjects were asked to detect the presence of a 10-msec segment of a 2,000-Hz sinusoid gated-on with a 1-msec rise-fall time. This filtered (1,600-2,500 Hz) signal was presented during a visually delimited observation interval. During the masker intervals, a burst of noise (1,600-2,500 Hz) was presented. The backward masker had a fixed 500-msec duration, while the forward masker duration varied (200, 50, and 10 msec). Each masker was varied in intensity from 40 to 60 dB in 10-dB steps. All stimuli were gated through Grason-Stadler electronic switches and presented monaurally through TDH-39 (300) headphones. Both maskers had rise-fall times of approximately .04 msec. The ISI between the forward masker and the signal was either 3 or 10 msec, while the ISI between the signal and backward masker was fixed at 3 msec.

Procedure

Subjects were run singly, or in pairs, in commercial sound-attenuated chambers. The presentation of the stimuli and the recording of observer responses were under computer control. Levitt's transformed up-down single-interval procedure was employed using the 2:1 rule with a 2-dB step size. Observers first ran a series of control conditions in which baseline performance was established for signal alone, signal plus forward masker (for the three durations at the three intensities with the two ISIs), and signal plus backward masker (for all three intensities). All control conditions were replicated at the end of the study. Combined forward and backward masking conditions then were run for all combinations of masker intensities and forward masker durations at both ISIs. Completion of each condition required two consecutive blocks of 100 trials that met a priori criteria: the range of means and the standard deviations both within and across blocks of trials had to be less than twice the step size (Levitt, 1971).

RESULTS AND DISCUSSION

Presented in Figure 1 are the data for the two

Figure 1. The amount of masking in decibels for all observers as a function of backward masker intensity for all durations (columns of panels) and intensities (various symbols) of the forward masker for two previously experienced (first two rows of panels) and one previously naive (third row) subjects.

practiced (top two rows of panels) and one previously naive subject. In this figure, the three columns of panels represent forward masker durations of 10, 50, and 200 msec with the 3-msec interval between the forward masker offset and the signal onset. Excluded from the figure are the data for the 10-msec interval between the forward masker and the signal, since it was nearly identical in nature to the 3-msec interval data.¹ The abscissa of each panel indicates the intensity of its backward masker, while the ordinates indicate masking in decibels. The data for the forward masker in the absence of the backward masker are plotted at $-\infty$ on the abscissa and represent baselines of forward masking effects. Within each panel, the filled circles represent backward masking in the absence of a forward masker, and therefore analogously represent baselines for evaluating the effects of the addition of the forward masker.

We first can compare the effects of the isolated masker ($-\infty$ level of other masker). When the maskers were equal in duration (200 msec; right column of panels) and equal in intensity, there was consistently more backward masking than forward mask-

ing, a finding consistent with that previously reported (Elliott, 1971; Lynn & Small, 1977). When the forward masker was shortened, thus decreasing masker energy, two of the subjects (rows 1 and 3) exhibited a consistent increase in the amount of masking, while the third subject (row 2) did not exhibit a consistent change in masking. Both Feth and O'Malley (1975) and Penner (1979) have reported the opposite results; less masking was produced by shorter equal energy maskers for ISIs of 3 msec or greater. To explain these previous results, Penner (1979) proposed a modified running average model involving a compression by the auditory system prior to integration. The results for two of our subjects (rows 1 and 3) are more consistent with the notion that one aspect of nonsimultaneous masking involves special characteristics of the masker associated with its onset (and possibly its offset). Both Elliott (1971) and Pastore and MacLachy (1975) have reported such onset/offset masking effects. It is probable that both onset/offset effects and integration effects are present in nonsimultaneous masking to varying degrees for different subjects, with the onset/offset effects being stronger for two of our subjects (rows 1 and 3) and the two effects being approximately equivalent for the third (row 2).

We next can examine the effects of adding the various forward maskers to the backward masking conditions. The 40-dB 200-msec forward maskers consistently reduced the amount of masking relative to the same backward masking stimulus acting alone (right column 4 panels; open circles relative to the filled circles). Increasing the intensity of the forward masker reduced the effectiveness of the forward masker as a cue and increased its masking effects (right column; open symbols). Decreasing the duration of the forward maskers similarly increased their masking effectiveness and reduced their cuing effectiveness (right, center, and left columns). With the briefest, most intense forward masker (left column; triangles), the total amount of masking is greater than would be predicted on the basis of a linear summation of the simple masking effects of the isolated forward and backward masking stimuli. This result is consistent with the greater than simple summation of masking effects previously reported (Elliott, 1971; Lynn & Small, 1977; Patterson, 1971; Wilson & Carhart, 1971). Thus, it would appear that there is a continuum of forward masker effects on backward masking which runs from additional masking to temporal cuing.

The finding of greater than additive masking effects for combined backward and forward masking

supports the notion that backward and forward masking involve, at least in part, different mechanisms. Our results lead us to conjecture that backward masking involves a high degree of temporal uncertainty, with the subject normally not knowing exactly when to listen for the signal until after the onset of the backward masker. Forward masking involves minimal temporal uncertainty, with temporal properties of the masker providing temporal information about the signal. Forward masking would appear to involve both some form of integration of masker energy (such as proposed by Penner, 1979) and some special characteristics of masker onset and probably offset.

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NOTE

1. The data for the 10-msec ISI conditions may be obtained from the first author.

(Received for publication February 25, 1980;
revision accepted August 25, 1980.)