Backward recognition masking as a function of ear of mask presentation

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Two experiments were conducted to determine whether the magnitude of auditory backward recognition masking (ABRM) differed as a function of whether the mask was presented contralaterally or ipsilaterally to the test tone ear; the mask/test tone ear relationship was a blocked variable in the experiments. On a pitch discrimination task, performance was better when a mask was presented contralaterally rather than ipsilaterally. However, in contrast to an earlier study, there was substantial ABRM on contralateral mask trials, although not as much as on ipsilateral trials. The implications of these results for theories of ABRM are discussed.

A listener's ability to categorize a target sound is often impaired if a second sound is presented shortly after presentation of the target. For example, categorization of a target sound's pitch, timbre, lateralization, duration, and loudness is generally impaired if a second sound is presented within approximately 250 msec of target sound onset (Hawkins & Presson, 1977; Idson & Massaro, 1977; Kallman & Massaro, 1979, 1983; Massaro, 1970, 1972, 1975a, 1975b; Massaro, Cohen, & Idson, 1976; Massaro & Idson, 1976, 1977; Moore & Massaro, 1973). The second sound's effect on recognition of the first has been termed *auditory backward recognition masking* (ABRM); the second sound is referred to as the *backward mask*. Within the 250-msec range of stimulus onset asynchronies (SOAs) that result in masking, accuracy of target sound categorization generally improves as the SOA increases.

Although much research has been conducted on ABRM, there is little consensus on what constitutes a satisfactory explanation of the effect. Explanations range from those that assume that the mask interferes with perceptual resolution of an earlier presented target sound (e.g., Massaro, 1975a), with memory of the target (Sparks, 1976), with *both* perception and memory of the target (Kallman & Massaro, 1979), and with the categorization process itself (Treisman & Rostron, 1972).

The present research was designed to clarify an earlier finding by Hawkins and Presson (1977) that seemed to indicate that the effect of a backward mask could be eliminated if a listener was tested under conditions that allowed him/her to direct his/her

attention away from the mask and to the target sound. Earlier research has demonstrated that ABRM occurs regardless of whether the mask is presented contralaterally or ipsilaterally to the target tone ear (Massaro, 1975a; Massaro & Cohen, 1975); in these studies, the ear of mask presentation varied randomly from trial to trial. Hawkins and Presson (1977) replicated this result but found that when the ear to which a fixed-frequency mask was presented remained constant within a block of trials, there was little masking with binaural or contralateral masks, although a typical masking function was found with ipsilateral masks. These blocked masker results can be seen in Figure 1 and were interpreted as showing that masking fails to occur when subjects know in advance that the fixed-frequency mask will be presented to a spatial location that is different from that of the target tone. Hawkins and Presson argued that their subjects "tuned out" the mask under the blocked contralateral and binaural mask conditions but were unable to do so with randomized mask presentations. If this was the case, an adequate theory of ABRM would have to incorporate attentional processes as a major theoretical component. Furthermore, because such a finding highlights attentional processes in masking, it would be problematic to those theories of ABRM that emphasize automatic processes such as replacement of target-tone information by the mask in pre-perceptual storage (e.g., Massaro, 1975a).

There is a good reason, however, to question the interpretation of Hawkins and Presson's findings. On each trial of their critical experiment, the subject's task was to indicate whether the presented test tone was high or low in pitch; the two test tones were 863 and 787 Hz, respectively. Feedback about the correct response was provided after each trial. As Hawkins and Presson pointed out, to categorize the test tone, this procedure requires that subjects maintain, from trial to trial, a memory of the two possible test tones. If the strengths of the memories for the

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Figure 1. Percentages correct as a function of stimulus-onset-asynchrony (SOA) and ear of mask presentation in Hawkins and Presson's experiment. Because the test tone was 20 msec in duration, the SOA was equal to the ISI plus 20 msec. The MF level of SOA refers to a mask-free or no-mask condition (from Hawkins & Presson, 1977).

low and high test tones differ between trial blocks, this would be reflected in different overall levels of performance within the separate blocks. If all experimental conditions are randomly presented within each block of trials, such differences in memory between blocks would affect the experimental conditions equally and thus would not bias the results. However, if the experimental conditions were blocked, differences between blocks in test tone memory could differentially influence the experimental conditions; it would then be impossible to know whether differences between conditions were due to differences in trial-to-trial test tone memory or to differences in backward masking.

It is possible that in Hawkins and Presson's experiment the differences between the ipsilateral and other mask conditions were due to differences in tonal memory rather than to differential backward masking effects.¹ In fact, there is reason to suspect that memory of the high and low test tones may have differed among the ipsilateral, contralateral, and binaural mask conditions. Deutsch (1978) showed that tone memory interference effects are greater when the interfering stimulus is presented ipsilaterally, rather than contralaterally, to the to-be-remembered

stimulus. In addition to terminating perceptual processing of the target sound, the tonal mask used by Hawkins and Presson may have interfered with the trial-to-trial memories of the high and low test tones. Deutsch's results suggest that there may have been more tonal memory interference during ipsilateral mask blocks than during contralateral mask blocks, and that this may have accounted for the inferior performance on the ipsilateral mask trials. Although Deutsch did not evaluate the effect of a binaurally presented interfering stimulus, it seems likely that it would be less interfering than an ipsilateral stimulus, because the binaurally presented interfering stimulus would be perceived as originating from a location that was different from that of the to-be-remembered stimulus.

The purpose of the present experiments was to clarify whether differences between contralateral and ipsilateral backward masking would be found under blocked masker conditions when the factor of trial-to-trial tonal memory was minimized. In these experiments, a standard tone preceded the target on every trial and the subject's task was to determine whether the target tone was higher or lower in pitch than the standard. The standard was presented on

every trial in order to eliminate the need for subjects to maintain trial-to-trial memories of the high and low test tones. This procedure minimizes the possibility that any performance differences between mask conditions could be attributable to differences in trial-to-trial tonal memory. In addition to the use of a fixed-frequency standard on every trial, care was taken to adjust the difficulty of the task for each subject so that the degree of masking found with the ipsilateral and contralateral masks could be compared without the complication of ceiling effects in either the individual-subject or group data.

EXPERIMENT 1

Method

Subjects. Twelve students at the State University of New York at Albany participated for 3 consecutive days to earn credit in an introductory psychology course. Each subject had taken at least 2 years of music lessons. The subjects were tested individually in a sound-isolated chamber for 1 h a day.

Stimuli and Procedure. Day 1 of the experiment was a practice day to acquaint the subjects with the task and to obtain appropriate Δf values for each subject. Initially, the subject participated in six blocks of simple pitch discrimination trials; the blocks were separated from one another by approximately 30 sec. During each block of 28 trials, the subject's task was to indicate, by pressing one of two buttons, whether a 20-msec test tone was higher or lower in pitch than a 20-msec 800-Hz standard that preceded the test tone by 500 msec. The standard and test tones were presented to the left ear of half the subjects and the right ear of the others; the ear of standard- and test-tone presentation remained constant throughout the experiment, and further counterbalancing of experimental conditions (described below) was done independently for the two groups of subjects. The response interval began at the offset of the test tone and continued for 2 sec. Following the response interval, feedback indicating the correct response was presented over one of two light-emitting diodes (labeled low and high, respectively) and lasted for 250 msec. The intertrial interval from the offset of feedback to the onset of the following standard-tone presentation was 1.4 sec. Delta f was initially set at 25 Hz (i.e., the high and low test tones were 825 and 775 Hz, respectively), but this was adjusted from block to block to obtain performance of approximately 75% correct on the pitch-categorization task.

Following the pitch-discrimination trials, the subjects participated in blocks of ABRM trials. The task and procedure were the same as on the pitch-discrimination trials, with the exception that, on 6/7 of the trials, a 100-msec, 800-Hz masking tone followed the test tone after a variable-duration, silent interstimulus interval (ISI); the ISI was 20, 40, 60, 80, 160, or 250 msec. The no-mask condition was considered the seventh level of the ISI variable. The subject was told to categorize the test tone as higher or lower than the standard; to whatever extent possible, the mask was to be ignored. On Day 1, subjects were presented 12 blocks of 14 trials each. Half of the subjects were initially given a block of ipsilateral mask trials and then a block of contralateral mask trials (this sequence will be referred to as an ipsi/contra pair); the other subjects were initially given a block of contralateral mask trials and then a block of ipsilateral trials (a contra/ipsi pair). Contra/ipsi and ipsi/contra pairs of blocks were then alternated until the 12 blocks were completed.

Initially, Δf was set for each subject at three times the value of the Δf used during the last block of simple pitch-discrimination trials. The value of Δf was adjusted after every two blocks of trials in an attempt to arrive at a value that yielded an average percent correct of approximately 75% on the backward masking task.

Within each block of trials, the 14 within-block experimental conditions [test-tone frequencies (2 levels) $\times$ ISIs (7 levels)] were sampled randomly without replacement.

On both Day 2 and Day 3, the subjects participated in four blocks of 154 trials each; the first 14 trials of each block were considered practice and were eliminated from data analysis. Half of the subjects initially received one block of contralateral trials, and the other subjects first received a block of ipsilateral trials. Across Days 2 and 3, the subjects were presented alternating pairs of contra/ipsi and ipsi/contra blocks. Within each block of trials, the experimental conditions were sampled randomly without replacement and sampling began anew with each replication of the 14 experimental conditions. Adjustments in Δf to maintain average performance at 75% correct were made only after a contra/ipsi or ipsi/contra pair of blocks had been completed. This procedure assured that the Δf s for the ipsilateral and contralateral mask trials were equivalent.

All tones in the experiment were sine waves generated by a Wavetek Model 159 digitally controlled oscillator gated through a custom-built Applied Digital Specialties audio switch to a custom-built op-amp mixer. The tones were delivered to the appropriate ear at 78 dB(A) through TDH-50 headphones. The tones began at the zero crossing and reached maximal intensity in one-fourth of a cycle. Experimental events and data collection were controlled by a PDP-12 computer.

Results and Discussion

The mean Δf presented was 19 Hz. The range of Δf values presented to individual subjects was 11 to 37 Hz.

An initial analysis of variance (ANOVA) was performed to evaluate the effect of ISIs. Days (2 levels), mask/target relationship (ipsilateral or contralateral), target tone (high or low), and ISI (7 levels) were within-subjects variables; ear of target presentation was a between-subjects variable. As can be seen in Figure 2, the percentages correct increased substantially with increases in ISI; the effect of ISI was significant [$F(6,60) = 122.52$, $p < .01$].

Because mask/target relationship was a dummy variable under the no-mask level of ISI, a second ANOVA was performed in which the no-mask level of ISI was excluded. Because the main purpose of Experiment 1 was to contrast performance under the ipsilateral mask condition with that under the contralateral condition, all subsequent reports of significance will be based on this second analysis. As is evident from inspection of Figure 2, performance was considerably better with contralateral than with ipsilateral masks [$F(1,10) = 43.63$, $p < .01$]. However, the interaction between mask/target relationship and ISI was not significant ($F < 1$), nor were there any other significant main effects or two-way interactions. Although a couple of the higher order interactions were marginally significant, these will not be reported because they were difficult to interpret and, given the large number of factors, may well have represented Type I errors.

Experiment 1 was thus successful in demonstrating a reasonable amount of contralateral backward masking under blocked masker conditions. However, it should be noted that although substantial backward masking was demonstrated under both ipsilat-

Figure 2. Percentages of correct test-tone identifications as a function of the interstimulus interval in Experiment 1. The two curves represent performance with masks that were presented either ipsilateral or contralateral to the test-tone ear.

eral and contralateral conditions, performance was nevertheless much better on contralateral trials. Furthermore, asymptotic performance appeared to be achieved at a shorter ISI on contralateral than on ipsilateral trials. However, this finding is difficult to interpret, given the ceiling effects at the longest ISIs.

EXPERIMENT 2

This experiment had two purposes. First, the Δf was lowered for each subject so that ceiling effects would not obscure the contralateral masking functions. Second, subjects were tested for a complete day on the contralateral mask condition only. It was possible that the alternation of contralateral and ipsilateral blocks in Experiment 1 may have contributed to the finding of contralateral masking in Experiment 1; Hawkins and Presson (1977) argued that subjects are able to "tune out" the contralateral mask when it is blocked; however, by alternating contralateral and ipsilateral mask blocks in Experiment 1, we may have disrupted the subjects' abilities to do this.

Method

The subjects who participated in Experiment 1 returned to the laboratory for an additional day to participate in Experiment 2. The standard and test tones were presented to the same ear of each subject, as in Experiment 1, and the experimental procedure was identical to that of Experiment 1 except as noted below. For each subject, the Δf value used was decreased by approximately 30% of the value used on Day 3 of Experiment 1. The subjects were initially given three contralateral mask practice blocks of 28 trials

each. Δf was adjusted after each block of trials if performance on a block deviated much from an average of 75% correct. Following practice, the subjects participated in two blocks of 280 trials each, during which time all backward masks were presented contralaterally to the test-tone ear. If, during the first block of trials, average performance deviated from approximately 75% correct, an adjustment in Δf was made for the second block.

Results

The average Δf presented to the subjects was 13 Hz. The range of values presented was 6 to 28 Hz.

As can be seen in Figure 3, percentage correct increased from approximately 63% at the two shortest ISIs to approximately 90% under the no-mask condition. The ANOVA confirmed that this effect of ISI was highly significant [$F(6,60) = 53.23$, $p < .01$]. The 27% increase in percent correct that occurred with increases in ISIs matches the 27% increase found on contralateral mask trials in Experiment 1. However, it falls short of the 39% increase in percent correct found with the ipsilateral trials of Experiment 1. Finally, the general form of the contralateral masking function was very similar to that of the ipsilateral trials in Experiment 1.

GENERAL DISCUSSION

The present results demonstrate that although a blocked contralateral mask is not as disruptive of performance as a blocked ipsilateral mask, substantial backward recognition masking does result from the presentation of a blocked contralateral mask, at

Figure 3. Percentages of correct test-tone identifications with contralateral mask presentations in Experiment 2.

least under the conditions of the present experiments. This result contrasts with Hawkins and Presson's (1977) failure to find much contralateral masking under similar blocked masker conditions, and suggests that a subject's ability to ignore or "tune-out" a contralateral mask is limited.

We believe that two factors explain why we found contralateral masking under blocked mask conditions, whereas Hawkins and Presson did not. First, as we argued in the introduction, the differences in performance found by Hawkins and Presson on ipsilateral and contralateral mask trials may have reflected the effects of differential trial-to-trial tonal memory in addition to the effects of backward masking. Consequently, the differences between mask conditions was greater in their study than in ours. Secondly, given the large difference between ipsilateral and contralateral trials in Hawkins and Presson's study, it was predictable that, given a fixed Δf , either performance on contralateral trials would be near the ceiling or performance on ipsilateral trials would be near the floor. In either case, one of the masking functions would be obscured. In fact, Hawkins and Presson used a relatively large Δf (76 Hz), which had the effect of pushing performance on contralateral trials to the ceiling. Our experiments demonstrate that contralateral masking can be demonstrated convincingly so long as performance on contralateral trials is not obscured by ceiling effects.²

As noted above, at least part of the ABRM effect appears to be unaffected by the sort of attentional process that Hawkins and Presson suggest may have permitted the mask to be "tuned out" by the listener

under blocked masker conditions. Nevertheless, performance on the ABRM task was better with contralateral than with ipsilateral masks, and this result must be taken into account when evaluating theories of ABRM. Such a result, for example, is inconsistent with a simple replacement explanation of ABRM, such as one that supposes that the mask has its effect solely by replacing target-sound information in a centrally located preperceptual auditory store (cf. Massaro, 1975b). For the simple replacement explanation to be viable, the degree of masking found could not depend on the ear of mask presentation.

Recently, it has been suggested that a number of mechanisms may be responsible for the ABRM effect (e.g., Hawkins & Presson, 1977; Kallman & Massaro, 1979, 1983). It may be that the portion of the ABRM effect that is resistant to attentional manipulations can best be explained in terms of preperceptual replacement or some other sort of perceptual interruption, whereas that part of the effect that disappears when the mask is presented blocked to the contralateral ear can best be explained in terms of some mechanism such as interference with the categorization process. Future research should take into account the high probability that ABRM is the result of a number of different processes, and attempts should be made to try to isolate them.

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- of performance on the no-mask trials from different types of trial blocks (cf. Hawkins & Presson, 1977). However, because performance was at the ceiling (i.e., approximately 95% correct) on the no-mask trials, it is difficult to evaluate whether the trial-to-trial tonal memories varied among the different mask conditions.
- It might be argued that the high level of performance on the no-mask trials suggests that memory for the low and high test tones was excellent during all trial blocks; consequently, one could not explain differences between performance on the different mask trials in terms of differential tonal memory. However, given the large frequency separation of the high and low test tones (i.e., 76 Hz), subjects could have performed very well on the no-mask trials, even if the memories of the high and low test tones were weak. Thus, the lack of any performance differences among the different no-mask conditions cannot be construed as evidence that memory for the test tones was equivalent under the different experimental conditions. Following similar reasoning, one cannot determine whether the mask had any effect on perceptual resolution of the target during the contralateral and binaural mask blocks. Performance was at or close to the ceiling at all SOAs and thus, due to the lack of sensitivity of the test, it would have been difficult to detect any differences between the SOAs, even if different degrees of masking operated at the different SOAs. This problem of ceiling effects also raises difficulties in interpreting the results of Sparks's (1976) experiments, in which performance with contralateral masks was near the ceiling.
2. It should be noted that Hawkins and Presson's experiment and the present experiments differed in a number of ways. It might thus be argued that our use of a fixed standard may not have been the critical feature that differentiated our experiments from theirs. However, we do not believe that the other differences can explain the fact that we found contralateral masking whereas they did not. For example, Hawkins and Presson tested a total of nine ISIs, whereas we tested only seven. It seems unlikely that this slight increase in the number of experimental conditions would affect the results, but if it did, the prediction would be that increasing the number of experimental conditions should result in an increase in masking (Watson & Kelly, 1981). However, the contralateral masking effects found by Hawkins and Presson were smaller than ours, a result opposite to that predicted if the number of tested ISIs were a factor. Similarly, Hawkins and Presson used a 500-msec mask, whereas we used a 100-msec mask, but, if anything, this difference would predict that there would be greater contralateral masking in Hawkins and Presson's experiments, not less. Finally, Hawkins and Presson evaluated the effect of mask frequency by using three mask frequencies—749, 825, and 901 Hz. In their critical experiments, however, mask frequency did not vary within a block of trials, which was also the case in the present experiments. The fact that Hawkins and Presson failed to find much contralateral masking at any of their tested mask frequencies, whereas we found substantial masking at the one mask frequency that we tested only strengthens the contrast between the two sets of results.

NOTES

1. In certain cases, it might be possible to disambiguate the two possibilities by examining performance on no-mask trials. If tonal memory differences were responsible for the differences among the mask conditions, this should be reflected in different levels

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