Backward recognition masking

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(Received 3 March 1975; revised 28 April 1975)

Backward recognition masking refers to the interference of a second sound on recognition of another sound presented earlier in time. Previous experiments have demonstrated backward recognition masking in an absolute judgment task. In those experiments, all of the experimental conditions were varied randomly within a test session. In the first experiment reported here, backward-masking functions generated between blocks of trials were compared to those determined within an experimental session. The results showed backward masking using both experimental procedures. The next two experiments evaluate backward-masking effects in a two-interval forced-choice task and a successive-comparison task. Backward masking was observed in both experiments. The final experiment showed that selectively attending to the ear of the test tone presentation does not attenuate the backward-masking effects of a second tone presented to the opposite ear.

Subject Classification: 65.22, 65.58, 65.75.

INTRODUCTION

Backward recognition masking refers to the interference of a second sound on the perceptual resolution of a sound presented earlier in time. The second sound disrupts recognition of the first sound but does not prevent its detection. When the two sounds are presented at the same loudness, the observer is able to detect whether or not the first sound occurred but is not always capable of recognizing its pitch, loudness, or spatial location. Previous results have shown that recognition of 20-msec test tones improves with increases in the silent intertone interval before a masking tone is presented.

In a typical experiment by Massaro (1970), two short tones were chosen that differed in frequency by an amount that made them relatively confusable. In one experiment, the frequencies of the 20-msec test tones were 870 and 770 Hz. The observers were given a series of identification trials with feedback and were trained to call the tones high and low, respectively. In the experiment proper, the test-tone presentation was followed by a second masking tone after a variable silent interval. The masking tone was 820 Hz and was presented at the same intensity as the test tone. The results indicated that accurate pitch identification improved with increases in the silent interval asymptoting at 250 msec.

In Massaro's (1970) experiment, the test tone was followed by the masking tone after any of eight silent intervals giving a total of 16 experimental conditions [(2 test tones)×(8 silent intervals)]. All 16 experimental conditions could occur with equal probability in a given experimental session. Given that the experimental conditions could occur randomly, observers may not have been able to employ optimal strategies under each of the experimental conditions. It is, therefore, necessary to determine if backward recognition masking occurs in the absolute identification task when the experimental conditions are blocked rather than randomized. Blocking the experimental conditions may attenuate the backward masking effect relative to the randomization procedure. The first experiment provides a direct comparison between these two experimental procedures.

I. EXPERIMENT I

A. Procedure

Two males and one female attending the University of California were employed in the present study. They were paid $1.88 an hour for their serivces.

In the present experiment, observers were required to identify the pitch of a test tone. The duration of the test tone was 20 msec. On any trial one of two tones could be presented. The two test tones were programmed to occur randomly and with equal probability. The observer's task was to identify the higher tone (830 Hz) as "high" and the lower tone (810 Hz) as "low." A second tone (820 Hz), referred to as the masking tone, followed the test tone after a silent intertone interval. The masking tone lasted 500 msec, and the silent interval lasted 10, 60, 120, or 240 msec. The loudness of the test and masking tones was 81 dB.

The observers were tested simultaneously in a sound-insulated chamber (Industrial Acoustics). All experimental events were controlled by a PDP-8 computer. A digitally controlled oscillator (Wavetek model 155) was used to produce the pure tones. The stimuli were presented binaurally over matched headphones (Grason Stadler model TDH-39). Each observer recorded his "high" or "low" response by pressing one of two push-buttons labeled "high" and "low," respectively. After the response period of 2 sec, feedback was given by illuminating a small light for 500 msec above the correct response button. The intertrial interval was $2\frac{1}{2}$ sec.

On every trial, the observers heard a test tone followed by a silent interval followed by the masking tone. They identified the test tone as "high" or "low" and were then informed of the correct answer for that trial. The observers were practiced in this task for four days (about 3200 trials) before the present study. The main variable of interest was whether the silent intertone intervals were varied between sessions or within an experimental session. There were four possible intervals and a given session either employed only one of the four intervals or all four intervals. On each day for five days, the five possible sessions were presented according to a 5×5 Latin square. Sessions with 1 and 4 intervals lasted 100 and 400 trials, respectively. Therefore there was a total of 800 trials per day. The observers did not respond to the first five trials of each session. The results of one observer are not shown since he did not complete the experiment. However, his results showed the same trends as the other two observers.

B. Results

Figure 1 presents the percentage of correct identifications of the test tone for each observer as a function of the duration of the silent interval before the onset of the masking tone for the between versus within experimental sessions. The percentages are determined from both the high- and low-tone trials from the five days of the experiment. Accordingly, about 500 observations contribute to each data point. The results indicate that identification performance improved as the intertone interval increased regardless of whether the intertone intervals were varied between experimental sessions or within a session.

The small difference between the between and within conditions is the steepness of the masking function. For both observers, the improvement in performance with increases in the silent intertone interval is greater for the between than the within conditions. Performance in this task is critically dependent on the memory for the test tones. To the extent the masking tone interferes with recognition of the test tones, it also interferes with their memory. Therefore, differences in performance as a function of intertone interval reflects both perceptual and memory effects when the intertone interval conditions are varied between experimental sessions. Randomizing the intertone interval within a

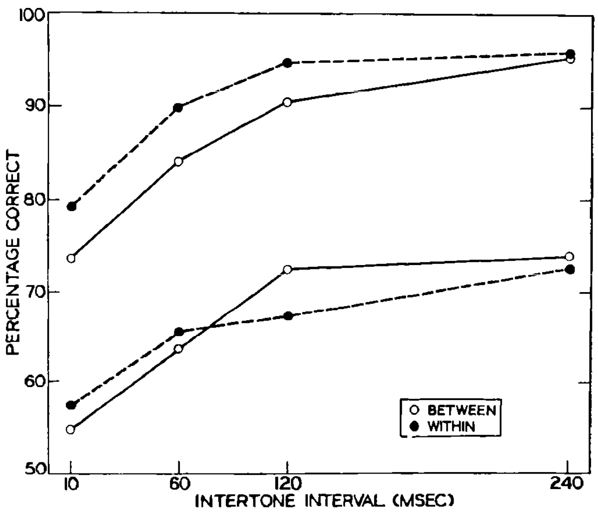

FIG. 1. Percentage of correct identifications of the test tone as a function of the silent intertone interval between the test and masking tones. The two functions for each observer measure performance when the experimental conditions were blocked between sessions or randomized within a session.

session eliminates any differences in memory. When the silent interval is varied from trial to trial, the average memory for the test tones will be constant under all intertone interval conditions. Varying the intertone interval within sessions gives a purer form of the masking function of identification since memory does not differ as a function of the masking interval.

The next two experiments ask whether backward masking is limited to the absolute identification task or can be found using other psychophysical procedures. The second experiment uses a two-interval forced-choice procedure and the third employs a same-different successive comparison task.

II. EXPERIMENT II

A. Procedure

Four subjects participated for an hour a day for five consecutive days. The students volunteered in order to fulfill an introductory psychology course requirement.

A two-interval forced-choice task was employed. Two 20-msec tones differing in frequency were presented on each trial. The interval between the onset of the tones was 750 msec. The observer's task was to indicate whether the higher frequency tone was the first or second test tone presented on that trial. The higher tone was equally likely to be the first or second test tone on a trial. The observer made his response by pushing one of the pushbuttons labeled 1 and 2, respectively. After the 2-sec response interval, feedback was given by visually presenting the numbers 1 or 2 for 0.5 sec. The intertrial interval was 1.5 sec. Subjects were given two sessions of 300 trials each per day for five consecutive days. The experiment proper was carried out on the last three days.

The independent variables were varied randomly within a given session. The frequencies of the two tones presented on each trial could differ by 20, 40, 60, or 80 Hz (Δf = 20, 40, 60, or 80 Hz). The tone frequencies were always balanced around 720 Hz. For example, the high and low tones would be 700 and 740 Hz in the Δf = 40 Hz condition. Each of these four conditions could occur with equal probability on every trial. There were seven possible silent intervals between the test and masking tones. The intervals were 0, 20, 40, 80, 120, 180, and 240 msec. The masking tone was a 20-msec presentation of a 900-Hz tone at the same loudness as the test tones. On one-eighth of the trials, no masking tones were presented. These eight conditions were also programmed to occur with equal probability on each trial. The amplitude of the test and masking tones was 86 dB SPL.

On the first day of the experiment subjects were given one session of trials without a masking tone at Δf = 60 Hz. Sessions 1 and 2 of day 2 had Δf = 60 and 40 Hz, respectively. The experiment proper was carried out on days 3, 4, and 5, and the data are taken from these three days giving 1800 trials per subject. Given that the experiment conditions were completely random, there are roughly 1800/32 ≈ 56 observations at each of the 32 experimental conditions for each subject.

The four observers were tested simultaneously in separate sound-insulated rooms. The experimental events were controlled by a PDP-8L computer. A digitally controlled oscillator (Wavetek model 155) produced the pure tones. The tones were presented binaurally over matched headphones (Grason–Stadler TDH-49). The visual feedback was presented on a display of light-emitting diodes (Monsanto model MDA III).

B. Results

The results, taken from the last three days of the study, are presented in Fig. 2. The figure plots percentage of correct judgments across the eight masking conditions for each of the four Δf values, the frequency differences between the high and low test tones. As expected, overall performance improved, with increases in Δf. Performance also improved, however, with increases in the intertone interval between the test and masking tones at each of the Δf values. This result shows that backward masking does occur in a two-interval forced-choice task in the same way that it does in an absolute identification task (cf. Figs. 1 and 2).

The results of $\Delta f = 20$ and 40 Hz make apparent two important processes in the two-interval forced-choice task. These processes are perceptual and mnemonic, respectively. The observer must perceive the first tone and remember its sound quality in order to compare it to his perception of the second tone. The masking tone can disrupt the perception of both of the test tones and can also interfere with the memory of the first tone. If the masking tone is presented before the pitch of a tone is resolved, it serves to terminate further resolution of the pitch. Therefore, performance improves with increases in the silent intertone interval between the test and masking tones. The masking tone in the two-interval forced-choice task also interferes with memory for the sound quality of the first tone. Performance asymptoted somewhere between the 120- and 240-msec intertone interval. This means that the masking tone no longer interfered with the resolution of the pitch of the test tone after this period. However, the poorer performance relative to the no-mask condition shows that the masking tone also interfered with memory for the first test-tone presentation. This difference is not noticeable at the $\Delta f = 60$- and 80-Hz conditions, because of the ceiling in asymptotic performance in these conditions.

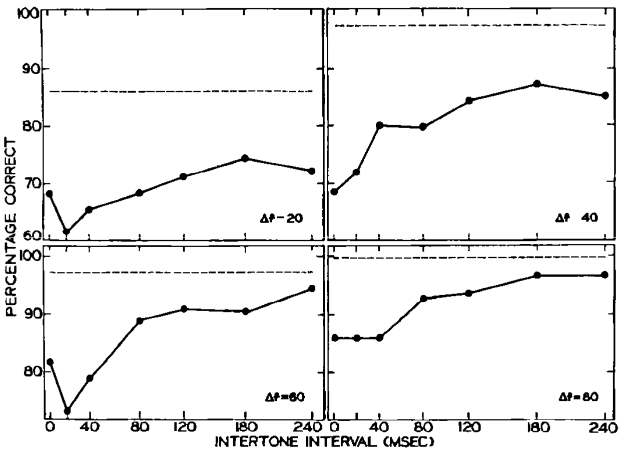

FIG. 2. Percentage of correct judgments in the two-interval forced-choice task as a function of the silent intertone interval between the test and masking tones. The dotted lines give performance when no masking tones were presented.

There was a slight upturn in performance with a zero intertone interval at the $\Delta f = 20$- and 60-Hz conditions and a trend of a smaller improvement in performance from a 0- to a 20-msec interval than the 20–40 msec interval. This result can be interpreted in terms of an integration mechanism (Massaro, 1973, 1975). The masking tone can be integrated with the test tone at the zero interval producing a percept of a single gestalt unit (Massaro, 1972). In this case, the subject can be slightly more accurate in comparing the difference between the gestalt units present in the first and second intervals in the forced-choice task. This slight upturn in performance was also observed in Massaro's (1970) study.

C. Discussion

Leshowitz and Cudahy (1973) determined frequency thresholds under backward masking. They used a two-interval forced-choice procedure. Test and masking tones were presented in each of the two observation intervals. The practiced observers had to state which interval contained the test tone lower in frequency. Each experimental condition was tested within a separate block of trials, using the psychophysical Method of Limits. On the first trial, the difference in frequency between the high and low test tones was large enough for a correct response. Then the difference was decreased by a constant on each of the next seven trials followed by seven trials which increased the frequency difference by the same constant. The authors state that a smooth psychometric function was fit by eye to the individual data, and the frequency difference corresponding to 75% correct discrimination was determined using visual interpolation.

In the first experiment using 20-msec tones, very little backward masking was found and there was no indication of an improvement in performance with increases in the silent interval between the test and masking tones. In the second experiment with 10-msec tones, significant backward masking was found and there was a large improvement in performance with increases in the interstimulus interval out to at least 200 msec. The significant backward masking results were then replicated with additional observers in another experiment (Leshowitz and Cudahy, 1973, Fig. 3). The last two experiments replicated the first two except that the test tone was always presented to one particular ear and the masking tone to the other ear. Although the less masking was observed, significantly more backward masking was found with 10-msec than 20-msec test tones. The investigators were not able to give an explanation of the conflicting results across the five experiments.

It is possible that the inconsistencies in Leshowitz

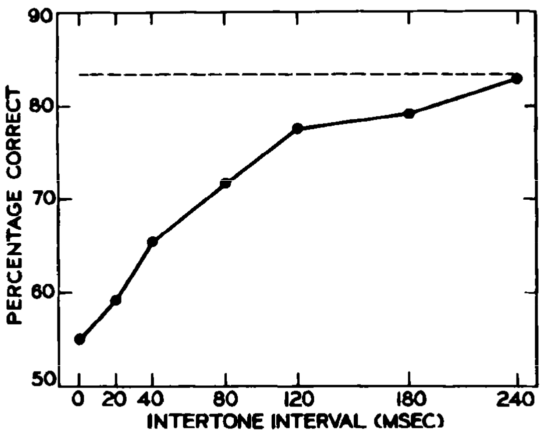

FIG. 3. Percentage of correct judgments in the same-different comparison task as a function of the silent intertone interval between the comparison and masking tones. The dotted line gives performance under the no-mask condition.

and Cudahy's results are due to the insensitivity and unreliability of the psychometric functions in those experiments. First, the frequency differences that were used to determine the psychometric functions may have been too large and too small to measure performance in a range where it would be sensitive to independent variables. Second, the psychometric functions may not have been reliable because of the small number of observations at each point. The only individual psychometric functions that are presented by Leshowitz and Cudahy are those from a study based on twice as many observations as the results of the other experiments. The results showed significant backward masking for each subject. These psychometric functions were drawn through the observed points although the authors claimed to have drawn smooth functions fit by eye for the estimates of the just noticeable differences. The psychometric functions that were presented are too variable to justify fitting smooth functions by eye. Given that the psychometric functions were highly variable, the smooth functions may not give a sensitive and reliable measure of performance under each of the experimental conditions. In summary, it must be argued that the Leshowitz and Cudahy results are insensitive and unreliable and cannot be taken as evidence for or against a given theory. The second experiment presented here showed that backward recognition masking can be obtained in a two-interval forced-choice task. The next experiment determines a backward masking function in a same-different comparison task.

III. EXPERIMENT III

A. Procedure

The eight subjects volunteered to fulfill an introductory psychology course requirement. They participated an hour a day for five consecutive days.

A delayed comparison task was employed. A standard tone of a fixed frequency was presented for 20 msec followed by a 20-msec comparison tone after a 250-msec silent interval. The frequency of the comparison tone was either equal to the frequency of the standard or Δf Hz higher or lower than the standard frequency. The subject's task was to respond whether the pitch of the comparison tone was the same as or different from the pitch of the standard tone. The "same" and "different" trials were programmed to occur with equal probability. On different trials, the comparison tone was equally likely to be higher or lower than the standard tone. The subject had 2 sec after the comparison-tone presentation to make his same or different response. The subject responded by pushing one of two push buttons labeled same and different, respectively. Feedback was given at the end of the response interval by visually presenting the letter S or D signifying a same or different trial. The intertrial interval was 1.5 sec. Two sessions of 300 trials each were given each day for five consecutive days.

The experiment proper was carried out on the last three days. For the first four subjects the different comparison time was 40 Hz lower or higher than the standard tone. The different comparison tone was 30 Hz higher or lower than the standard for the second four subjects. The frequency of the standard tone was 700 Hz. The eight masking conditions were varied randomly within a given session. The masking tone was 900 Hz and had a duration of 20 msec. The test and masking tones were presented at 86 dB SPL. The masking tone could follow the comparison tone after a 0, 20, 40, 80, 120, 180, or 240 msec silent intertone interval. On one-eighth of the trails, no masking tone was presented. These eight conditions (seven masking intervals and one no-mask condition) were programmed to occur equally often. Subjects were instructed to respond whether the pitch of the second comparison tone was the same as or different from the pitch of the first standard tone.

The first two days of the experiment were devoted to practice. The first session required the same-different task without a masking tone present. The Δf values of the different comparison tones were decreased over the first two days of the experiment in order to achieve the appropriate range of performance. This manipulation was only partially successful since four subjects were tested at the same time. Two subjects from the first group and one subject from the second group had to be eliminated from the data analysis since they failed to perform above chance accuracy. The results were averaged across the other five subjects during the last three days of the experiment. This gives a total of 1800 observations per subject. Each subject contributed roughly 225 observations at each of the eight conditions of interest.

B. Results

The percentage of correct same and different judgments as a function of the masking condition is plotted in Fig. 3. Performance improved from 55% correct at the zero intertone interval to 83% correct at an intertone interval of 240 msec. Performance at the 240-mse intertone interval was equal to performance under the no-mask condition.

These results in conjunction with the results of the two-interval forced-choice task illuminate the role of perceptual and mnemonic effects in psychophysical tasks. No masking tone is presented after the standard tone in the same–different task. Therefore, perception and memory of standard tone is the same at all masking conditions. The masking tone serves only to interfere with the resolution of the comparison tone. Therefore, performance improves with increases in the silent intertone interval leveling off at the level of performance found for the no-mask condition. This result contrasts with the results found in the two-interval forced-choice task in which the masking tone follows both tones. In that task, the masking tone produces an additional decrement in performance because of interference with memory for the pitch of the tone presented in the first interval. The results demonstrate that both perceptual and mnemonic processes must be accounted for in different psychophysical tasks.

C. Discussion

Holding, Loeb, and Yoder (1972) presented two experiments that they argue "provide no support for the theory that "preperceptual auditory images" are the storage medium" (p. 253). We agree with their conclusion and present a number of reasons to support Henry Brill's claim that "Failure to get laboratory confirmation is not conclusive disproof; it is only failure to find proof." The design of the Holding *et al.* studies precluded sensitive tests of their independent variables and failed to isolate the processing stage responsible for any effects if they were found. Their goal was to evaluate the effect of variables in a delayed comparison task of pitch memory. Subjects were presented two tones with a 4-sec silent interval between them, and indicated whether the tones were the same or different in pitch. In the first experiment, one of the tones, called the standard, was always 1000 Hz and the other variable tone was either 1000 or 1050 Hz. The eight subjects in this experiment averaged 93.2% correct in this control condition. This result indicates that the basic task was probably too easy for most of the subjects allowing the possibility that ceiling effects would wash out any differences due to the independent variables of interest. This problem is magnified by the large intersubject differences found in this type of task. Evidence for a ceiling effect can be seen in a direct comparison between the first and second experiments. The only difference between the two experiments was that the different variable stimulus differed by 50 Hz in the first experiment and only 25 Hz in the second. Overall performance, however, was equivalent in the two experiments. Therefore, any other differences between the results of the two experiments are meaningless. Holding *et al.* cannot assume, as they do, that the two experiments require course and fine discriminations, respectively.

One problem of interpretation rests on Holding *et al.*'s belief that the subject must compare the standard and variable tone on each trial. A number of investigators (e.g., Harris, 1952) have shown that long-term memory for the standard and variable tones occurs when the same fixed standard is used throughout the experiment. Accordingly, performance may not be sensitive to changes in the time and intervening events between the standard and variable tones (Massaro, 1975). In Holding *et al.*'s experiment, the subject would learn what the standard tone and different variable tone sounded like since these two tones are the only test tones in the experiment. With this information, subjects could make their same–different judgment according to whether the variable tone was the higher or lower test tone without reference to the standard tone presented on that particular trial. Holding *et al.* could have made the standard tone take on a number of different frequencies throughout the experiment. Using this roving-standard procedure forces the subject to process the standard tone on each trial and to make his same–different judgment on the basis of a direct comparison between the standard and variable tones presented on that trial (Massaro, 1975). Many of Holding *et al.*'s conclusions are unjustified since they rest on the assumption that the two test tones were compared on each trial. It is necessary to test their ideas using a roving-standard procedure. In a follow-up study, Loeb and Holding (1972) have discovered and acknowledged many but not all of the deficiencies of their earlier study.

Another methodological problem with the Holding *et al.* and the Loeb and Holding studies makes it impossible to identify the psychological process responsible for any observed effects. The independent variables of the Holding *et al.* experiments involved presenting the test tones for 20 or 300 msec and a white noise or tone interference stimulus. The interference stimulus could be presented either after the first test tone, before the second test tone, or after the second test tone. Also the standard tone could be presented first or second. All of these different conditions were varied between days, between sessions, or between blocks of trials. Therefore the effects of these variables may be due to differences in overall task difficulty rather than the differences in perception of and memory for the tones on any particular trial. Consider a comparison between the control condition and the interference condition in which the interference tone is presented immediately after the first test tone on each trial. The better performance in the control than in the interference condition is open to a number of alternative interpretations. It might be argued that the interference tone interfered with the perception of the first test tone by interfering with a preperceptual auditory representation of the test tone presentation (Massaro, 1970). However, the interference tone may not have interfered with the perception of the test tone at all. The poorer performance may simply be due to the fact that the subject hears three tones throughout the block of trials with the interference tone and only two tones throughout the block of trials in the control condition. Therefore, the subject may learn and remember the two test tones better in the control condition than the interference condition. Each of Holding *et al.*'s findings and Loeb and Holding's findings are open to alternative interpretations of this kind.

IV. EXPERIMENT IV

A. Introduction

Cudahy and Leshowitz (1974) replicated the contralateral masking conditions of Massaro's (1970) study. In this task, the test and masking tones are presented to opposite ears. In one condition, the ear of the test tone presentation was completely predictable whereas in the other it varied randomly from trial to trial. The results were highly variable, but it appears that less backward masking was observed when the ear of the test tone presentation was known in advance. However, given that the predictability of the test tone was varied between blocks of trials, some other psychological process might be responsible for the observed differences. For example, memory for the test tones may have differed in the two conditions. Therefore, it is necessary to manipulate this variable within a given experimental session.

Cudahy and Leshowitz (1974) propose that an attention decrement can account for the backward masking observed when the test tone is randomly presented to either ear and the masking tone is presented to the opposite ear. Given that the test tone can be presented to either ear, subjects cannot attend to the appropriate ear in advance. If the subject is listening to the wrong ear when the test tone is presented, he must switch his attention to the appropriate ear. Cudahy and Leshowitz argue that switching time will exceed the duration of the test tone, and therefore it will be too late by the time he switches to the appropriate ear. In this case, the subject is forced to guess the pitch of the test tone and backward masking will be observed. The following experiment provides a direct test of this hypothesis by determining backward-masking functions when the ear of the test-tone presentation is and is not known in advance.

Observers were asked to identify the pitch of a sound as high or low under two attention conditions. In selective attention, observers were cued that the tone would occur at a particular ear. In divided attention, observers were cued that the tone could be presented to either ear. This task was embedded in a backward recognition masking task in which the test tone could be followed by a masking tone after a variable silent interval. The masking tone was always presented to the ear opposite the test-tone presentation. Accordingly, observers could, in selective attention, attend to the cued ear and block out the uncued ear, whereas both ears would have to be monitored in the divided attention condition. The question was, Would attention to the ear of the test presentation prevent backward masking from a tone presented to the opposite ear?

B. Procedure

Three subjects served an hour a day for five days in order to fulfill a course requirement.

Each trial began with the presentation of a visual cue indicating whether the test tone would be presented to the right, left, or either ear. This cue was presented by displaying for 500 msec either "/R/," "/L/," or "/E/" representing right, left, and either, respectively. The /L/ and /R/ cues were each presented on one quarter of the trials; the /E/ cue on the other half of the trials. Immediately following the offset of the cue the test stimulus was presented. The test stimulus was a 20-msec sine wave of 85 dB SPL with a frequency of either 720 or 780 Hz. The task of the observer was to identify the test tone as "high" or "low." There were eight processing conditions. On seven out of eight trials the test tone was followed by a 100-msec masking tone of 85 dB SPL after a silent interval of 10, 20, 40, 80, 120, 180, or 250 msec. On one trial out of eight no masking tone was presented. The masking tone, a 750-Hz square wave, was always presented to the ear contralateral to the test-tone presentation. Each observer recorded his response by pressing one of two buttons labeled "Hi" and "Lo," respectively. Following the response interval, feedback indicating the correct response was presented by visually displaying for 250 msec either "Hi" or "Lo." The intertrial interval was 1 sec.

On each day the observers participated in two sessions of 300 trials each. All 32 experimental conditions [(2 test tones)×(8 processing conditions)×(2 attention conditions)] were selected randomly with replacement in a given session and were programmed to occur with equal probability. On the first day, the observers learned to identify the test tones without a masking tone. The subjects were instructed to utilize the visual cue on every trial and were consistently encouraged throughout the experiment to do so. When given the focused-attention cue, the observers were told to selectively attend to the cued ear and to block out the other ear. When given the divided attention cue subjects were instructed to divide their attention between the two ears since the test tone could be presented to either ear. The results are taken from the last four days of the experiment giving roughly 2400/16 or 150 observations per subject at each of the 16 conditions of interest.

The three observers were tested simultaneously in separate sound insulated rooms. All experimental events were controlled by a PDP-8L computer. The stimuli were produced by a digitally controlled oscillator (Wavetek model 155). The output of the oscillator was then gated by two computer-controlled audio switche (Iconic model No. 0137) to one of two amplifiers (McIntosh model MC-50), one for each ear. The tones were presented over matched headphones (Grason–Stadler type TDH-49).

C. Results

The data are taken from the last four days of the experiment. Figure 4 presents the average percentage of correct identifications of the test tone as a function of the intertone interval under the selective and divided attention conditions. Performance improved roughly 27% with increases in the silent interval between the test and masking tones. In contrast to the large effect of backward masking, Figure 4 shows that the attention manipulation had no significant effect on identification performance. This result held for each of the three observers; the difference in performance of the selective

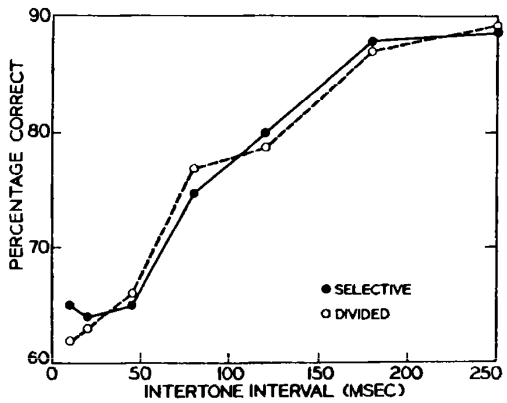

FIG. 4. Percentage of correct identifications of the test tone as a function of the intertone interval and the selective and divided attention conditions.

minus the divided attention conditions was 2.2%, 1.3%, and −2.4% for the three observers, respectively. Performance on trials with no masking tone averaged 93.8% and 90.9% under the selective and divided attention conditions, respectively.

In contrast to the hypothesis of Cudahy and Leshowitz, selective attention to the ear of the test-tone presentation did not attenuate backward masking. The results support the idea that backward recognition differs from detection masking in which very little contralateral masking is observed (Massaro, 1970, 1972, 1975). The masking tone interferes with a central preperceptual representation of the test tone interfering with its recognition. The storage representation exists somewhere higher than where the two ears combine in the auditory system.

V. GENERAL DISCUSSION

Cudahy and Leshowitz (1974) present evidence in their Figure 5 that Massaro's subjects are less sensitive than observers used in other frequency discrimination experiments. Cudahy and Leshowitz make the following errors in their analysis, however. First, they took performance estimates from Massaro's subjects at an intertone interval of 500 msec, making the assumption that this performance was a valid estimate of performance without a masking tone. As noted earlier, testing performance between blocks of trials for the different conditions gives a memory advantage to the no-mask condition. Therefore, the sensitivity of Massaro's observers is underestimated. Second, they assume that "This difference [in sensitivity] does not stem from the particular psychophysical method" (p. 19). This assumption cannot be made since it is well known that the two-interval forced-choice method and the method of adjustment used by the majority of the other studies will produce a much more sensitive measure of performance than the absolute identification task. For example, the forced-choice task gives the observer two observation intervals and allows a direct comparison between the low and high tones. Third, Leshowitz and Cudahy did not include all of Massaro's data in their presentation. Although they cite Massaro's (1971) paper, they do not include the sensitivity estimates from the three subjects used in that study. In fact, the sensitivity of these subjects is in the range of the sensitivity of observers from the Cudahy and Leshowitz (1974) study. Finally, any experience with individual subject differences in pitch judgments would lead one to expect large differences between studies. The four experiments presented in this paper replicate the backward-masking results within a reasonable range of sensitivity values considering the psychological processes involved in the task. Therefore neither the practice of the observers nor their asymptotic sensitivity can account for whether or not backward masking is observed. Backward masking appears to be a reliable and valid phenomenon and can be demonstrated in a number of experimental tasks.

VI. CONCLUSIONS

The results of the present experiments demonstrate backward masking in a two-interval forced-choice task, a same-different task, and an absolute identification task. The backward masking of one sound by a second sound is interpreted in terms of auditory perception continuing after a short sound is complete. A representation of the short sound is held in a preperceptual auditory storage so that resolution of the sound can continue to occur after the stimulus is complete. A second sound interferes with the storage of the earlier sound interfering with its further resolution. The current research contributes to the development of a general information processing model (Massaro, 1972, 1975).

ACKNOWLEDGMENT

This research was supported by U. S. Public Health Service Grant MH-19399. Michael Cohen assisted in the computer programming, data analysis, and commented on an earlier version of the paper.

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