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BACKWARD AND FORWARD MASKING WITH
REPRODUCIBLE NOISE BURSTS

by

SUSAN B. WALTZMAN

A dissertation submitted to the Graduate Faculty in Speech and Hearing Sciences in partial fulfillment of the requirements for the degree of Doctor of Philosophy, The City University of New York.

1974

This manuscript has been read and accepted for the Graduate Faculty in Speech and Hearing Sciences in satisfaction of the dissertation requirement for the degree of Doctor of Philosophy.

May 2 - 1974

date



Chairman of Examining Committee

May 2, 1974

date



Executive Officer

James M. Pickett



Juergen Tonndorf



Moe Bergman



Supervisory Committee

The City University of New York

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CHAPTER I

INTRODUCTION

Over the past twenty years interest has developed in the phenomenon of both backward and forward masking (temporal masking). Forward masking refers to the condition where the stimulus to be masked follows the masker in time; backward masking refers to the condition where the stimulus to be masked precedes i.e. occurs before the masker. Certain general statements can be made to summarize the present state of temporal masking.

First, all studies have shown that the less the time (Δt) elapsing between the masker and the stimulus the greater the amount of masking. However, to date, disparate results exist regarding the Δt 's over which temporal masking exists. Deatherage and Evans (1968) demonstrated the temporal effects for Δt 's up to ± 250 msec. Elliott (1962) found the presence of the phenomenon up to ± 50 msec.; however, in 1967, she found the backward masking function existed as far back as -100 msec. in agreement with a study done by Raab (1961) using clicks.

On the other hand, Chistovich and Ivanova (1959) using clicks found that the masking effects lasted only up to 28 msec. and Babkoff and Sutton (1968) also utilizing clicks found the masking effect only with a time interval of +10 msec. or less. Differences in experimental conditions and analysis of data could perhaps account for some of the discrepancies; for instance, Guttman (1960) studied temporal masking with binaural fusion of clicks and obtained results similar to those of Babkoff and Sutton. In general, however, most of the masking effects appear to occur at masking intervals up to +100 msec.

The intensity of the masker does have an effect but the effect does not appear to be linear (Elliott, 1962; Babkoff and Sutton, 1968) although this variable has not been researched thoroughly. The effect of the relationship between the frequency of the signal and the masker has been studied. Wright (1964) and Elliott (1967) showed that for backward masking up to -100 msec. the probe stimuli whose frequencies were within the narrow band noise of the masker had thresholds poorer than stimuli that fell outside of the frequency range of the masker noise. In the same study Elliott confirmed via

forward masking that a narrow band noise requires time to develop its narrow band characteristics and initially acts as a wide band stimulus. Consequently, although Elliott (1964) showed that masker duration has no effect upon backward masking it has somewhat of an effect upon forward masking at short time intervals. Signal frequencies outside the narrow band masker showed less forward masking when a 200 msec. masker was employed than when a 25 msec. masker was employed. When the 25 msec. masker was used the results resembled those obtained with a wide-band masker. Henceforth, it appears that there exists a relationship between frequency of the probe signal and masker for both forward and backward masking.

Temporal effects are the greatest when the probe signal and the masker are presented monotonically. With dichotic presentation masking effects are found to a lesser degree with forward masking suffering the greatest loss. Finally, when the probe signal was placed between two maskers, consequently being affected by both forward and backward masking, the effects were greater than would have been expected from simple additivity (Pollack, 1964; Elliott, 1969; Dirks and

Bower, 1970; Wilson & Carhart, 1971).

No complete theory to explain temporal masking has yet been evolved. It appears that the masking effect lasts longer than the time it takes for the traveling wave to complete its path and decay along the basilar membrane and henceforth, higher neural centers might be involved. Researchers who have found little evidence of temporal masking, particularly of backward masking, postulate that a peripheral masking explanation is sufficient to explain the phenomenon. It is the contention of this author that further study needs to be done in the area of temporal masking before a comprehensive theory can be formulated.

CHAPTER II

REVIEW OF THE LITERATURE--TEMPORAL MASKING

Backward and Forward Masking

In 1947 Miller noted the effects of backward masking on pure tones. He varied the phase relations between two trains of gated sinusoids and found that the largest amount of masking occurred when the envelope of the signal preceded the envelope of the masker by 90° (1-2 msec.) for most combinations of signal and masking frequencies. In 1949 Luscher and Zwislocki in an attempt to study forward masking found that adaptation was almost completed 400 msec. following the offset of the stimulus whose duration varied from $\frac{4}{10}$ of a second to 2 seconds. When the experiment was done dichotically they found no forward masking in the test ear until the masking noise in the contralateral ear exceeded 60 dB, which could have been due to contralateral masking.

During the 1950's much of the research was performed in Russia. Samoilo~~v~~va (1956) in an effort

to understand masking phenomena in speech used probe signals of 20-30 msec. in duration and masking tones of 30 msec. in duration to closely approximate the durations of consonants and vowels. Backward masking occurred for masking intervals up to -100 msec. with the greatest effects occurring as the intensity of the masking tone increased from 0-100 dB, as the duration of the signal (probe) tone decreased from 100 msec. to 20 msec., as the masking interval (from onset of tone to onset of masker) decreased from 100 msec. to 1 msec.) and at probe frequencies which were higher than the frequency of the masker. Maximum backward masking occurred with probe signals of 550 Hz and 1400 Hz for 500 Hz and 1000 Hz maskers respectively. In 1959, Samoilova reported on the masking effects of varying frequencies. The masking interval was held constant at 30 msec. In this instance she found at least as much or more masking of a 1000 Hz probe tone by a 4000 Hz tone than for a 3000 Hz probe tone by a 1000 Hz masker, which was in contrast to her initial findings in 1956. In a second experiment in 1959 pairing a masking tone of 250 Hz with a probe signal of 300 Hz and a masking tone of 500 Hz with a probe signal of 6000 Hz, Samoilova found greater backward than

forward masking at all masking intervals. During the same experiment, when a 1000 Hz masker at 90 dB was paired with a 1200 Hz probe signal about 5 dB of masking was noted with a masking interval of -1,020 msec. For all combinations of probe signal and masking tone greater backward than forward masking was seen for brief masking intervals.

Also in 1959, Chistovich and Ivanova reported on backward and forward masking effects of pulses separated by masking intervals ranging from 1 msec. to 200 msec. They found relatively no evidence of backward masking and the existence of forward masking only for masking intervals up to 28 msec. They defined three phases in temporal masking. In the first phase where the judgments were based on click loudness considerable masking occurred from 0 msec. to ± 1.5 msec. The masking effect was essentially equal for both the forward and backward conditions. In phase two, backward masking was non-existent from -1.5 msec. to 50 msec. and 100 msec. whereas forward masking diminished from +1.5 msec. until its disappearance at 30 msec. In this case probe stimulus identification appeared to be made on the basis of a distortion in the sound of the click; that is,

"crackling". Phase three showed a slight reversal in tendency based on the fact that the probe stimulus was heard as a separate click. Both backward and forward masking showed a slight increase from ± 50 msec. and ± 100 msec. to ± 300 msec. and ± 500 msec.

Gol'dburt (1961) used probe stimuli of 1000 Hz tone bursts which were varied in duration from 5 msec. to 400 msec. and presented at suprathreshold levels. The masker employed was a 100 dB SPL 1000 Hz burst of 400 msec. in duration. He found backward masking effects at masking intervals of -1000 msec. The great extension of the backward masking function may have been due to the use of suprathreshold probe stimuli.

In the late 1950's interest in temporal masking began in the United States. In 1959, Zwislocki, Pirodda and Rubin measured forward masking effects using a 1000 Hz probe tone and a 1000 Hz tonal masker presented at 85 dB SPL. They found that forward masking effects were observable for more than 150 msec. By varying the stimulus duration they concluded that one important factor influencing forward masking is the interval between the offset of the masker and the onset of the probe tone.

Also in 1959, Pickett reported on the investiga-

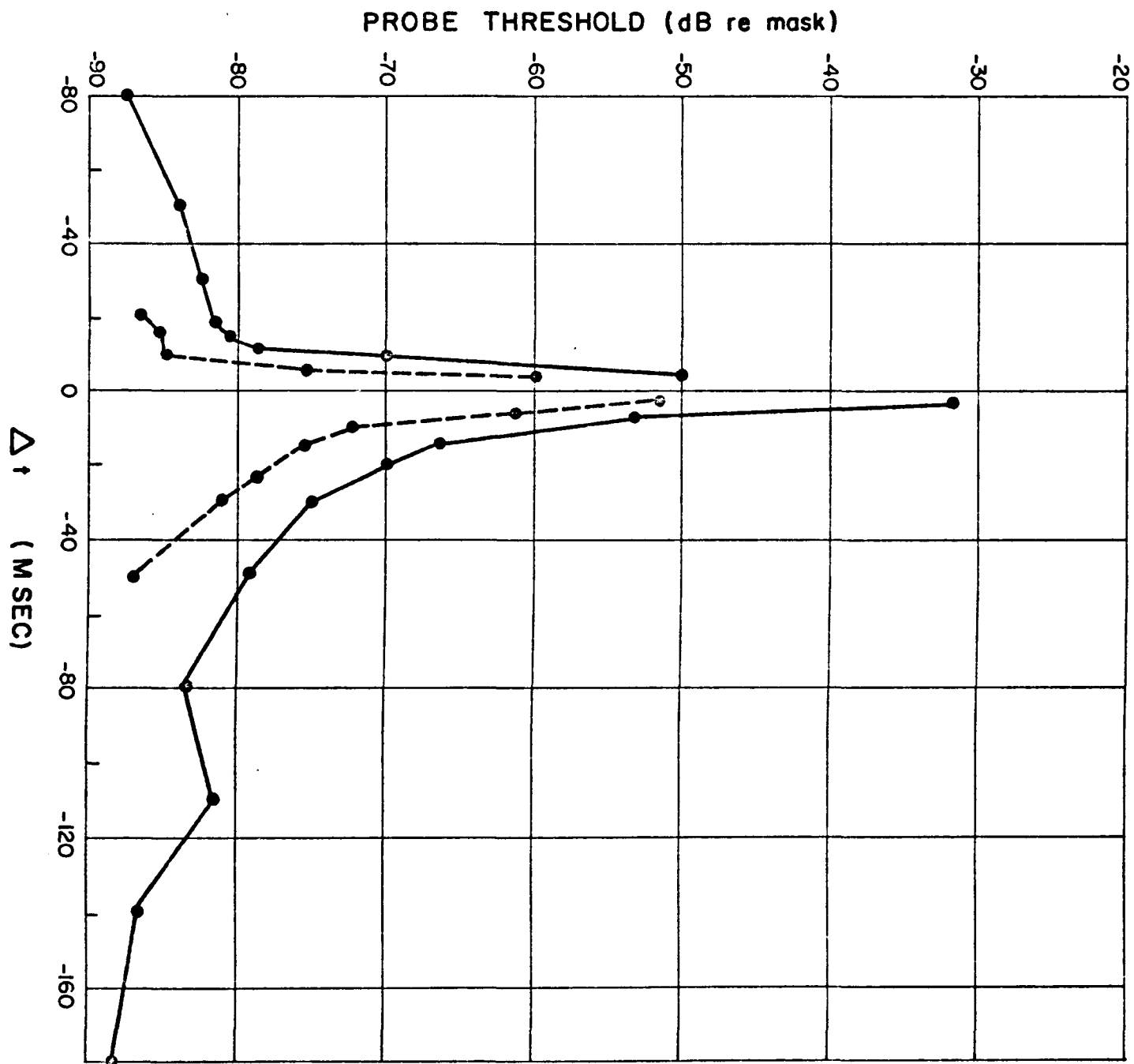
tion of the backward masking effect on a tone followed by a burst of noise. The listener triggered an interval generator which presented two stimuli--a brief 1000 Hz probe tone followed, after a silent interval, by a 50 msec. burst of white noise--over an earphone. He used tone durations of 5, 10, 15, 20, 25, and 50 msec., silent intervals of 0, 2, 5, 10, 25, and 100 msec. and noise burst levels ranging from 50 to 130 dB SPL. Three subjects were carefully trained to perform the threshold adjustments under all experimental conditions. He found that with tone durations of 5 and 10 msec. and silent intervals of less than 25 msec. large threshold increases appeared. Thresholds also increased as noise burst level increased and with shorter silent intervals. Backward masking effects were not appreciable for a 50 msec. tone but were present for the 25 msec. tone. The range of backward masking in time appeared to be independent of the masker intensity levels between 50 and 120 dB SPL although some differences between subjects were noted. It appeared that the masking interval was a more important factor than tone duration. In general, however, this study showed 30 dB to 40 dB less masking

than did the study by Samoilova but these discrepancies may have been due to differences in experimental design; for instance, duration of masking tone, duration of probe stimulus.

In 1961, Raab measured thresholds with the probe click preceding as well as following the masker. Each trial began with a faint 800 Hz warning tone in the non-test ear one second before the trial began. Trials were eight seconds apart and consisted of two presentations of a 0.2 msec. masking pulse presented 0.8 msec. apart at 70 and 80 dB SPL. The probe click accompanied one or the other of the masks. Raab found that both backward and forward masking did occur but the forward masking function was more pronounced and longer lasting. See Figure 1.

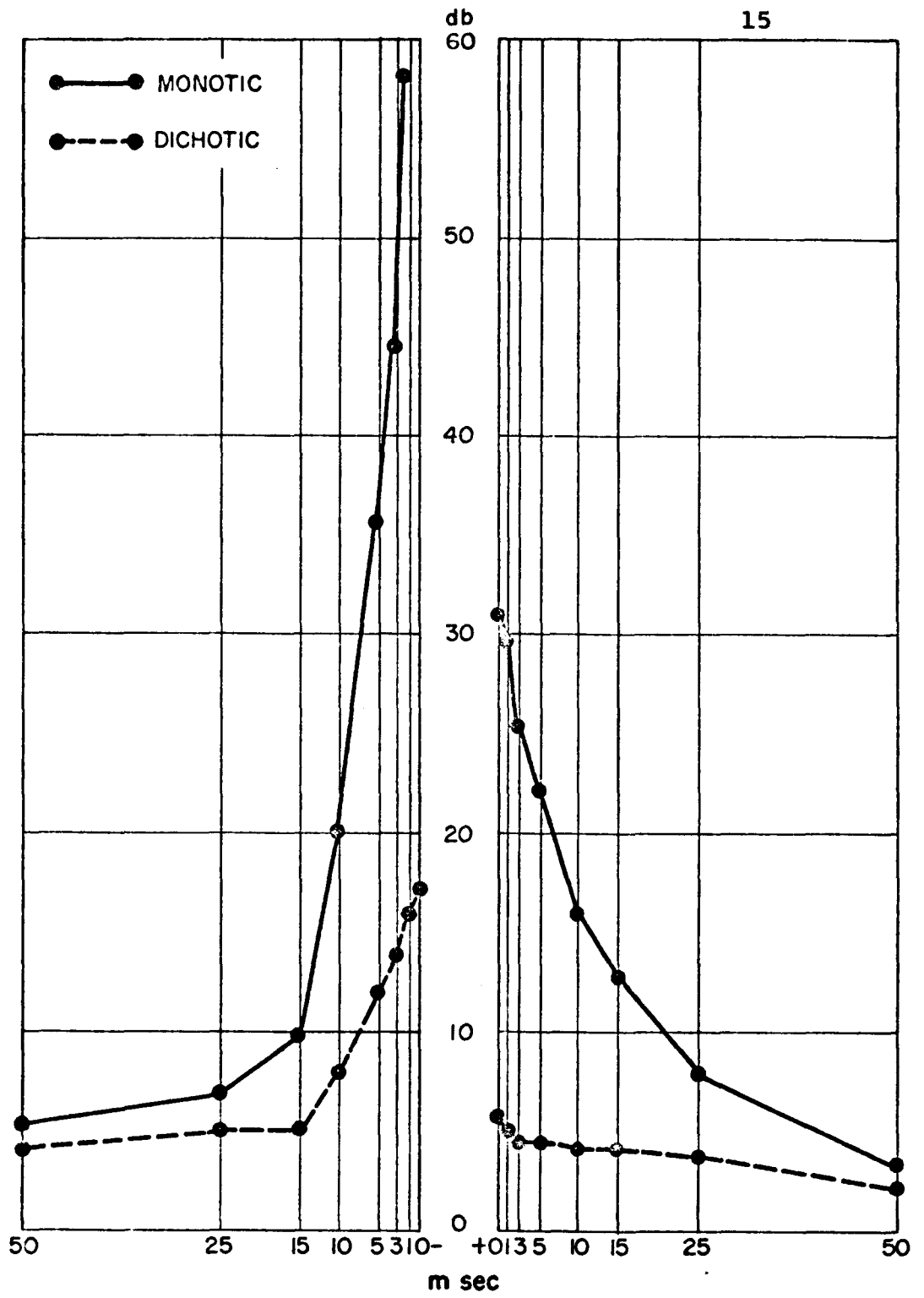
Elliott (1962) studied backward and forward masking for monotic and dichotic conditions. The sequence of presentation for backward masking was as follows: signal light, 0.6 second ready interval, masking stimulus, one second interval, signal (probe) tone, masking interval, and masking stimulus. The same paradigm was used to test forward masking except the probe tone followed the second masking stimulus.

Figure 1. Thresholds for the probe click as a function of the time interval before and after the masking click. For the points connected by solid lines, the mask SL was 85 dB; for the dashed lines, 70 dB. (From Raab, 1961.)



White noise (70 and 90 db SPL) with a duration of 50 msec. and a rise and decay time of about 10 msec. was used as the masking stimulus. The probe tone was a 1000 Hz tone with a duration of 5 and 10 msec. and a rise and decay time of 1 msec. Masking intervals of 0, 1, 3, 5, 10, 15, 25, and 50 msec. were used. Each subject was required to judge only if there was a difference between the standard masking stimulus and the masking stimulus accompanied by the tone pulse; that is, he did not have to discriminate the probe tone as a separate signal. Results showed greater backward than forward masking at short masking intervals (in agreement with Samoilova and in disagreement with Christovich, 1959; and Raab, 1961) for both monotic and dichotic conditions with the monotic condition showing a much stronger effect. See Figure 2. The backward masking curve for the monotic condition appeared to be divided into two sections: a sharp slope from 0 to 15 msec. masking intervals, and great loss of the slope and a flattening of the curve from 15 to 50 msec. For all conditions tested the analysis of variance showed that the differences obtained with the two masking stimulus levels and the two probe durations

Figure 2. Results of backward and forward masking under conditions of 90 dB masking and 5 msec. probe duration. Negative values on the abscissa represent backward masking while positive values represent forward masking. The ordinate represents amount of masking in dB. (From Elliott, 1962.)



were significant; that is, the higher the intensity of the mask and the shorter the probe tone, the greater the masking effect. See Figures 2 and 3. The effects of masking interval were highly significant. A comparison of the Elliott & Pickett data is shown in Figure 4. In a follow-up study, Elliott (1962), using the same experimental design, studied backward and forward masking of probe tones at 500, 1000, and 4000 Hz. The only modifications were the usage of only the 90 dB SPL white noise masker and the probe tone of 7 msec. in duration. For the dichotic conditions more backward than forward masking was seen at all three frequencies. For both backward and forward masking 1000 Hz showed the most masking and 4000 Hz the least masking at 0 msec. masking interval. At the 5 msec. masking interval for backward masking and the 3 msec. masking interval for forward masking the two lower frequencies reversed positions while at longer masking intervals there was no difference between frequencies. See Figure 5. For the monotic condition at 0 msec. masking interval for backward masking, 4000 Hz showed the greatest masking and 500 Hz showed the least. At 3 msec. masking interval, 4000 Hz showed the least

Figure 3. Results of backward and forward masking under conditions of 70 dB masking and 5 msec. probe duration. (From Elliott, 1962.)

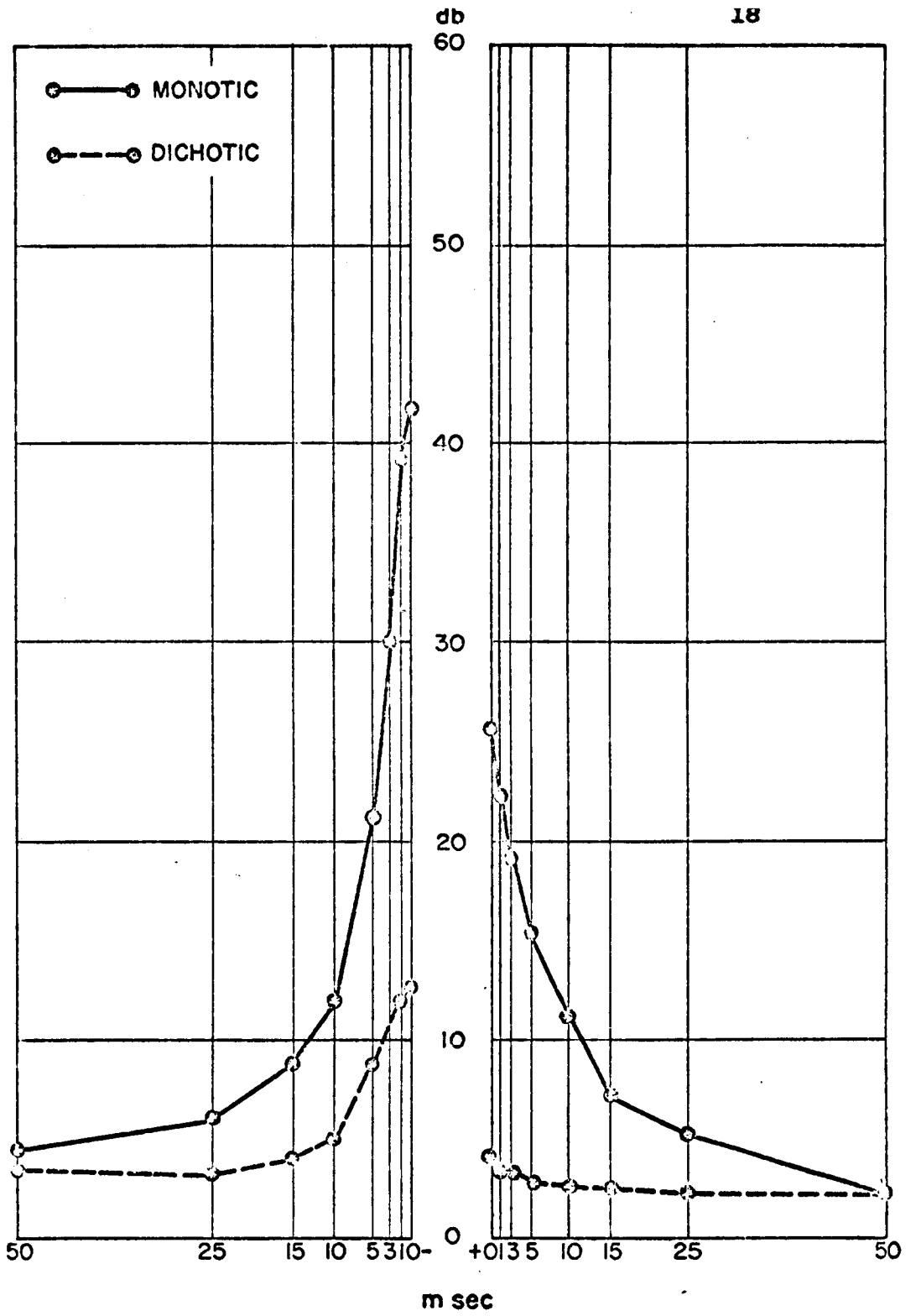


Figure 4. Comparison of Pickett's data with Elliott's data for backward masking with masking intensity of 90 dB and probe duration of 10 msec. (From Elliott, 1971.)

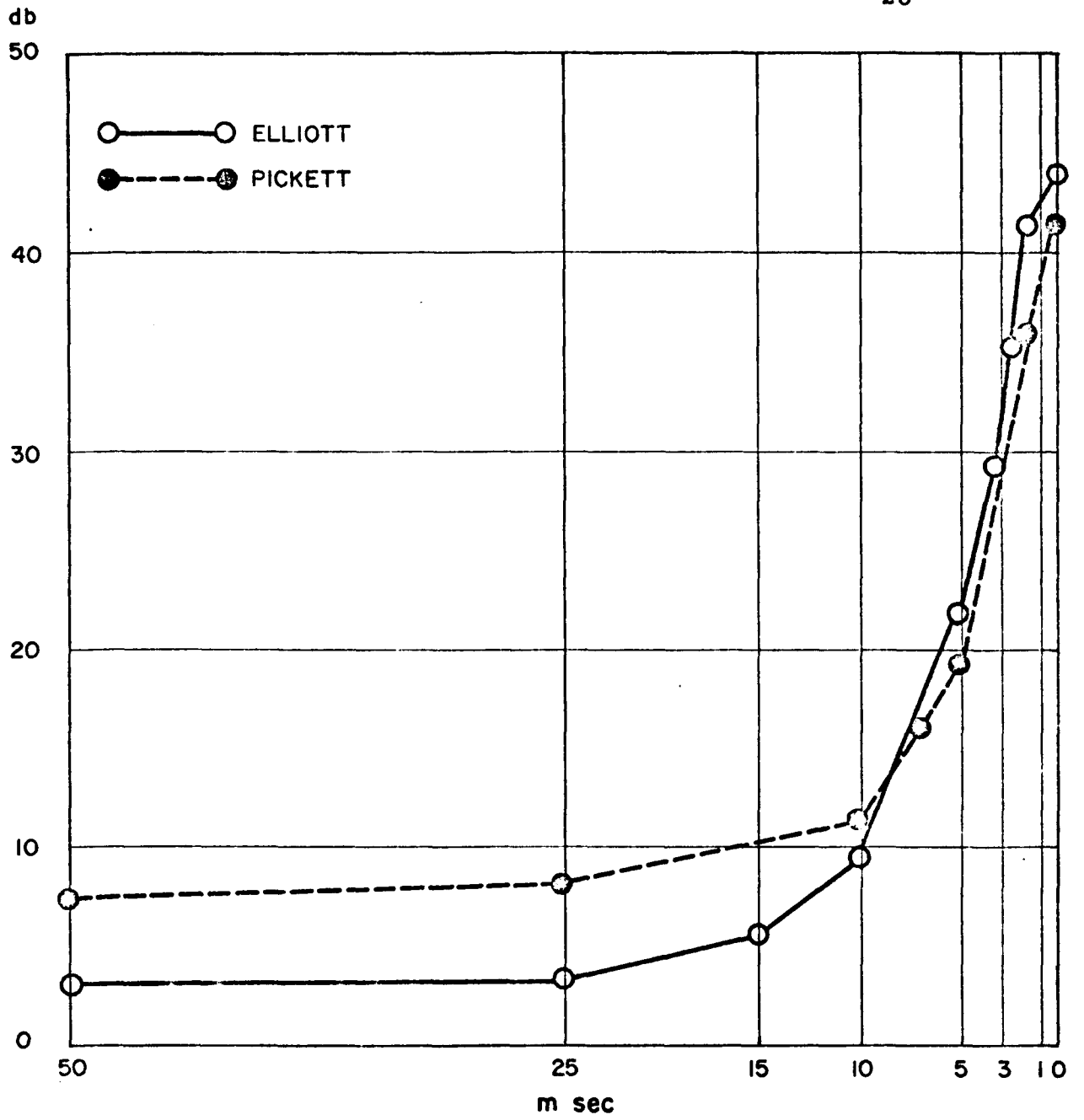
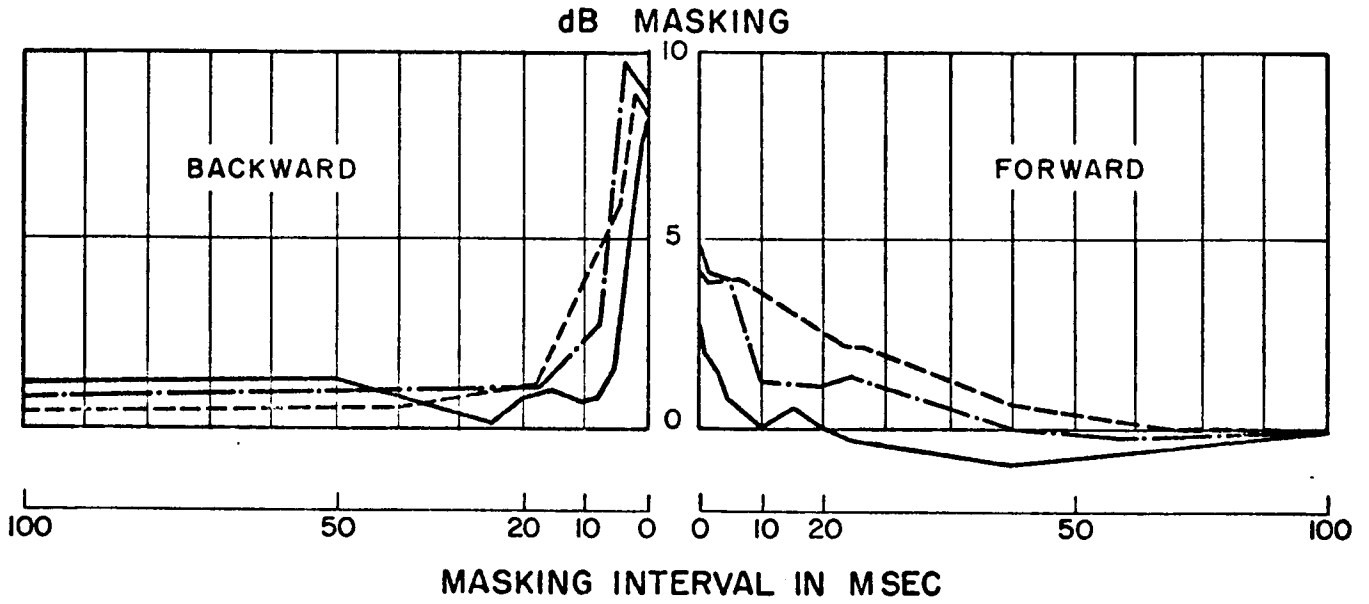


Figure 5. Results of dichotic backward and forward masking. (From Elliott, 1962.)

----- 500 CPS
- . - . - . 1000 CPS
————— 4000CPS



masking effect and this pattern continued to the 100 msec. masking interval. For the forward masking monotic condition, there was less masking at 4000 Hz and 1000 Hz than in the backward masking condition. From 0 to 10 msec., 500 Hz had the greatest masking effect while 4000 Hz had the least effect. At longer masking intervals the pattern reversed itself and 4000 Hz had the largest masking effect. See Figure 6.

Osman and Raab (1963) studied the backward and forward masking effects of clicks by bursts of white noise. The probe click was 0.1 msec. in duration and the noise bursts were 10 and 100 msec. in duration and presented at levels of 60, 75, 85, and 95 dB SPL. Temporal positions ranged from 50 msec. before the mask onset to 10 msec. following the mask offset. They found that the backward masking effects were greatest for masking intervals between 0 and -10 msec. and diminished at masking intervals above -10 msec. See Figure 7.

Babkoff and Sutton (1968) also studied the masking of auditory transients with a systematic regulation of masking levels and signal intensities. The masking signal and the probe signal were kept at fixed supra-threshold levels with only the time interval manipulated;

Figure 6. Results of monotic backward and forward masking. (From Elliott, 1962.)

----- 500 CPS
- . - . - . 1000 CPS
————— 4000CPS

dB MASKING

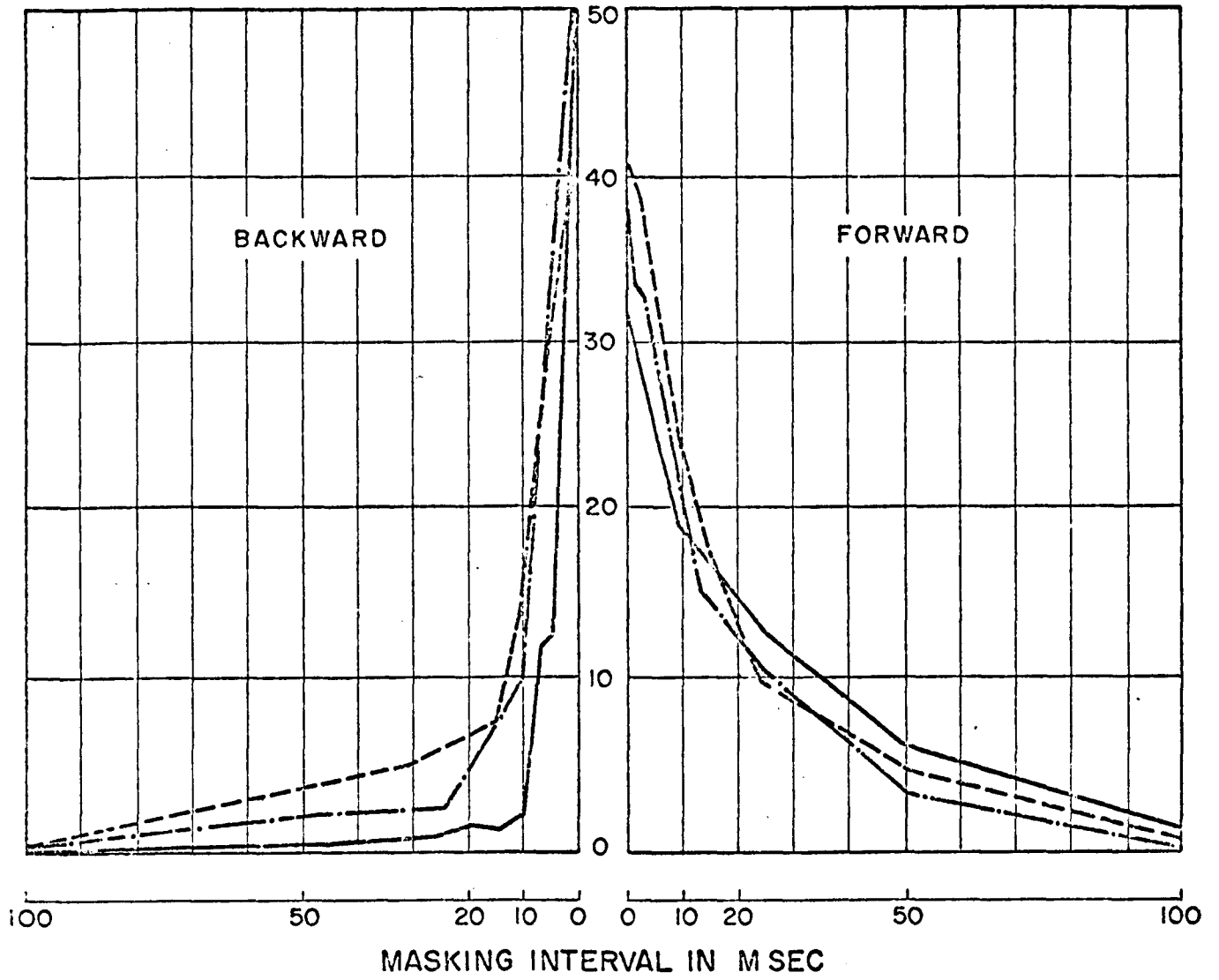
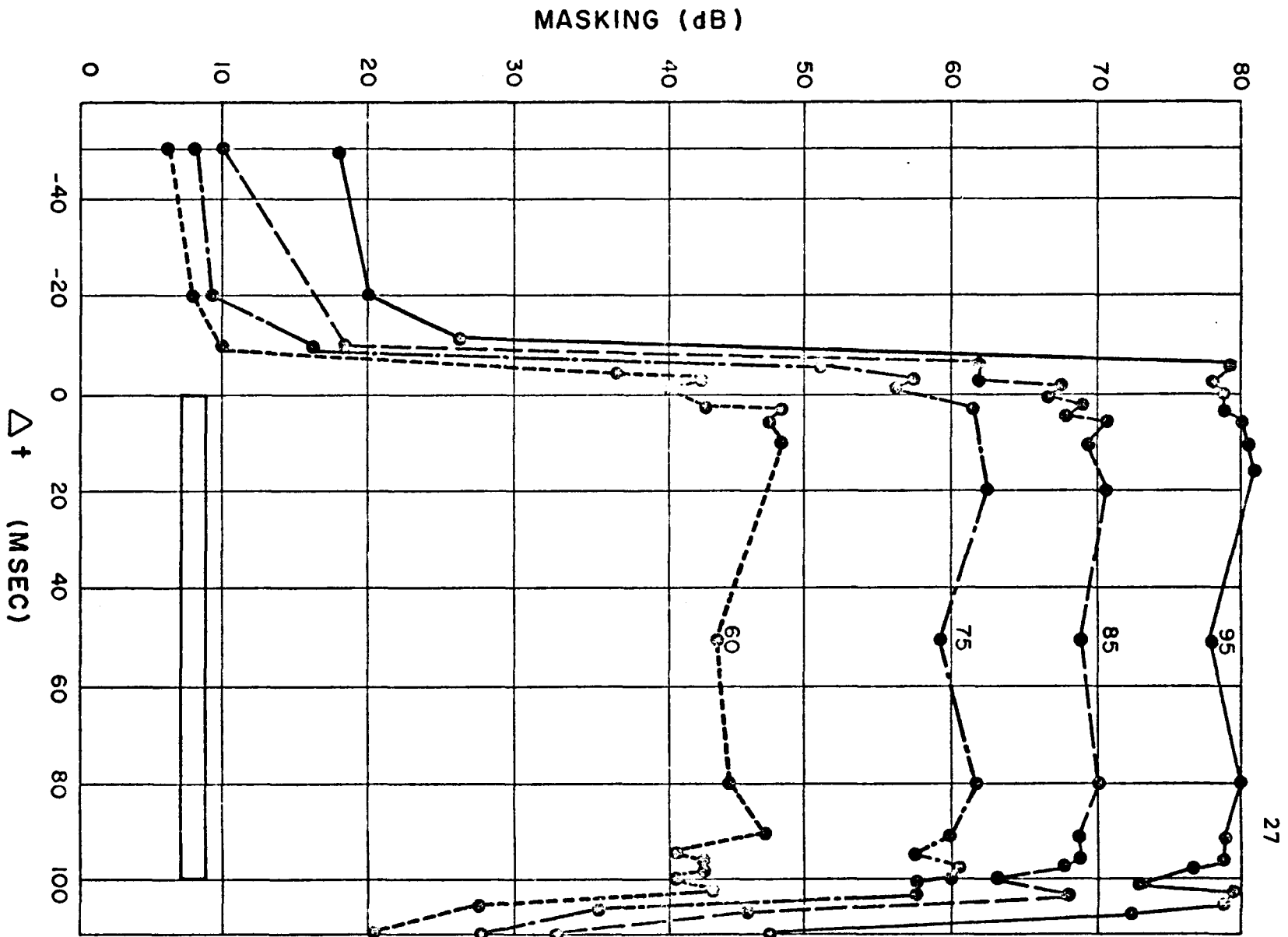


Figure 7. Masking of a click by a noise burst. The parameter is the over-all SPL of the mask. The horizontal bar indicates the duration of the mask. (From Osman and Raab, 1963.)



thus the experiment became a special case of resolution between two unequal auditory stimuli. Nine levels of masking clicks from 35 dB to 70 dB and three levels of the signal click (15 dB, 30 dB, 45 dB) were used. Thirteen forward and thirteen backward masking conditions were tested monaurally. The results found were in agreement with those of Chistovich and Ivanova (1959) and Raab (1961) who found greater forward than backward masking at short time intervals; however, Babkoff and Sutton found that the backward masking function only reached as far back as -2.5 msec. when the masker was at its highest intensity and the probe signal at its lowest level. In all other studies the backward masking function was shown to be considerably longer.

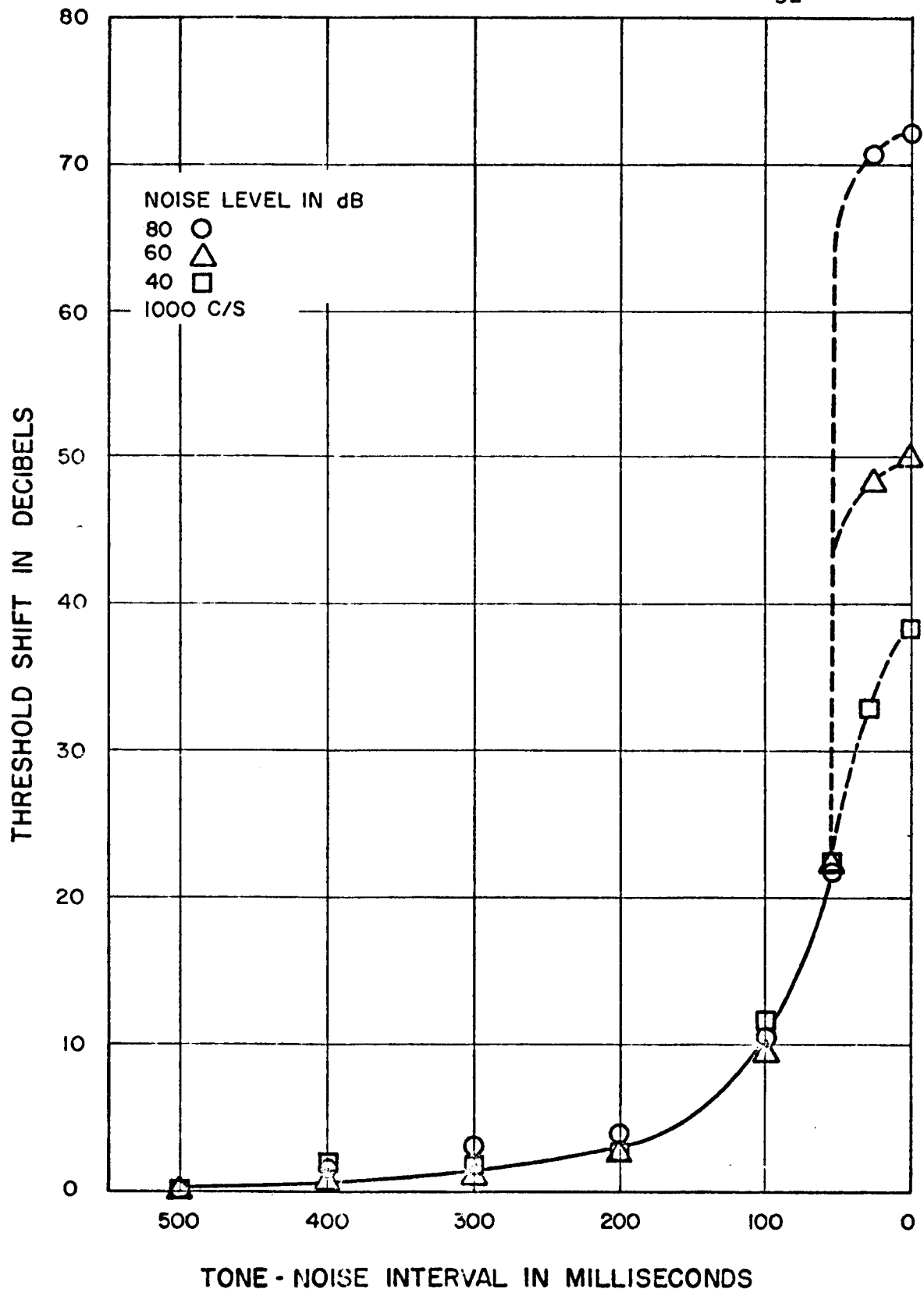
Guttman, van Bergeijk, and David (1960) also employed the resolution paradigm to study monaural backward and forward masking; however, they utilized binaural interaction to study the monaural phenomena. Two clicks were presented to one ear while a third click was presented to the opposite ear. The subjects were instructed to control the relationship of the single click to each of the clicks in the opposite ear so as to obtain a centered image with each click. Threshold was considered

the minimum time separation between the clicks where the subjects could achieve centering with both clicks in the pair. These authors also found greater forward than backward masking, in agreement with Babkoff and Sutton; that is, masking effects at intervals of less than -10 msec. Methodological differences could perhaps account for the small backward masking functions found in these studies.

Following the early 1960's with temporal masking clearly established as a repeatable phenomenon, researchers attempted to broaden their investigation to include other auditory phenomena. Wright (1964) related temporal summation and backward masking. In contrast to previous studies (with the exception of Samoilova, 1959); and Gol'burt, 1961) Wright utilized a narrow band of noise centered around 1000 Hz as the masker. The noise had a duration of 600 msec. and was presented at levels of 40 dB, 60 dB, and 80 dB. A 1000 Hz probe tone whose duration varied from 1 second to 500 msec. was utilized. Both tone and noise had a rise-fall time of 10 msec. The tone always terminated 100 msec. prior to noise offset which meant that the tone and noise overlapped under most experimental conditions. Time intervals between

tone and noise onset were: 500, 400, 300, 200, 100, 50, 25, 10, and 0 msec. Monaural thresholds were obtained by having the experimenter adjust the attenuator in 2 dB steps to a level at which the subject responded 50% of the time. Tone and noise were alternated with noise alone. Wright utilized calculations from the theory of temporal summation (Zwislocki, 1960) to separate backward masking effects from shortened-tone effects and to predict backward masking. He established three phases in backward masking: a) a short phase (25 msec.) where the amount of masking is dependent upon the level of the masker, b) a transitional phase at 25 to 50 msec. which was variable but where the masking steadily increased with each noise level, and c) a long phase where the threshold was independent of the masker. See Figure 8. In comparing experimental results to the predicted results, Wright found that the theory of temporal summation adequately predicted the threshold shifts for the long phase of backward masking while some discrepancies in amount of threshold shift existed for the short phase. It was impossible to predict shifts for the transitional phase since tone duration did not affect threshold during that condition. In a followup study in

Figure 8. Threshold shift during backward masking. (From Wright, 1964.)



1964, Wright used a 1000 Hz masker, 162 Hz wide, presented at 80 dB to determine the backward masking effects on tones outside of the narrow-band of noise. Probe tones of 800 Hz, 1000 Hz, 1200 Hz, and 1750 Hz were used. The experimental paradigm was the same as described above, and again, calculations based on the theory of temporal summation were used. Results showed that masking at 800 Hz, 1200 Hz, and 1750 Hz was similar to that at 1000 Hz but did not extend as far back in time. See Figures 9 and 10. These results were interpreted to mean that masking first affects those tones within a noise band and then spreads to frequencies outside the noise band with a reduced effect.

In a further effort to study the effects of narrow band noise, Elliott (1967) studied temporal masking using narrow band maskers. The two narrow bands of noise used were a 200 Hz band at 1270 Hz and a 400 Hz band at 2550 Hz presented at 70 dB SPL. Since Elliott (1964) had shown that backward masking is not affected by mask duration, a duration of 100 msec. was chosen for the masker in this experiment. Probe duration was 10 msec. and the masking intervals measured from onset of probe to onset of masker were -100, -50, -35, -20, -15 and

Figure 9. Threshold shift during backward masking with frequency as the parameter. (From Wright, 1964.)

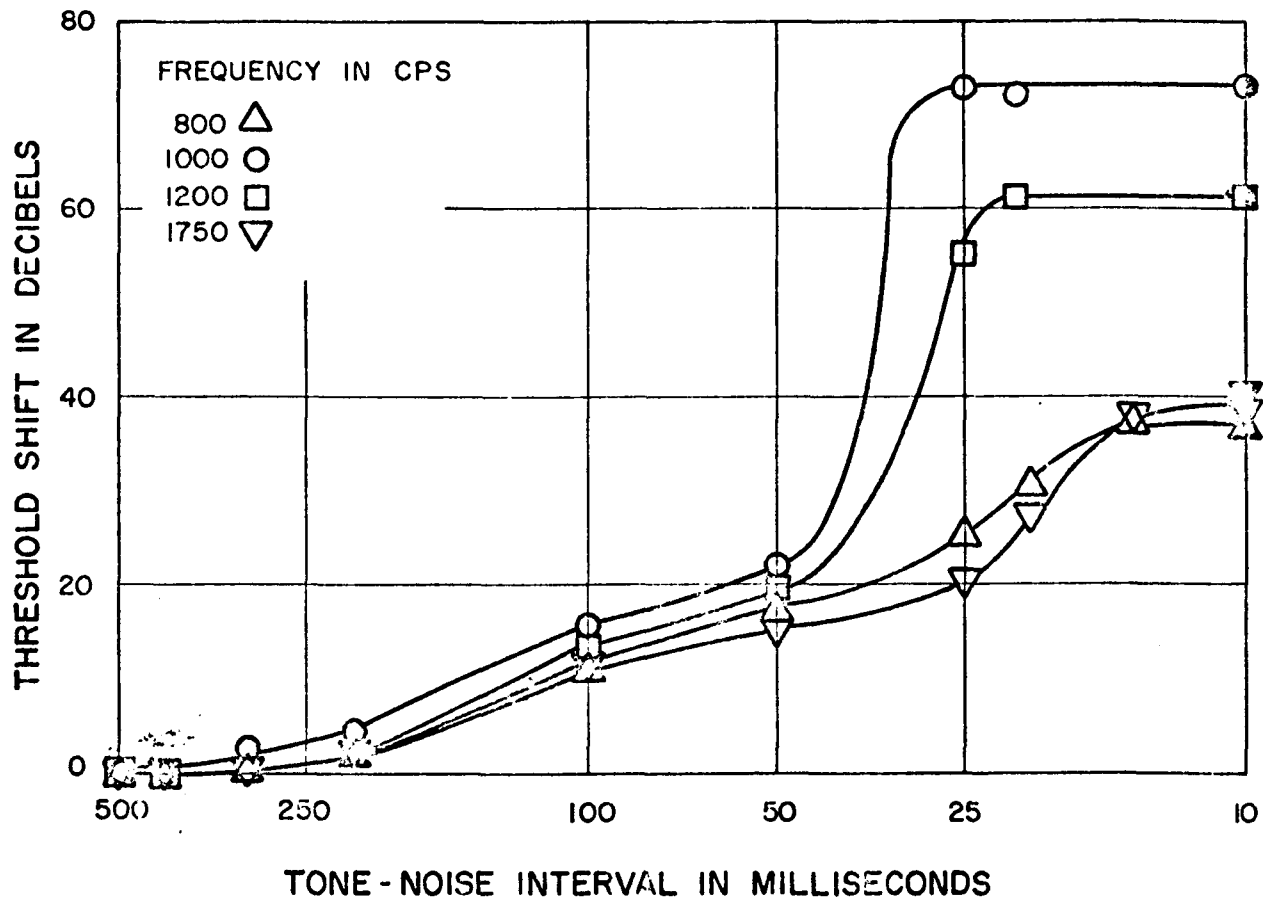
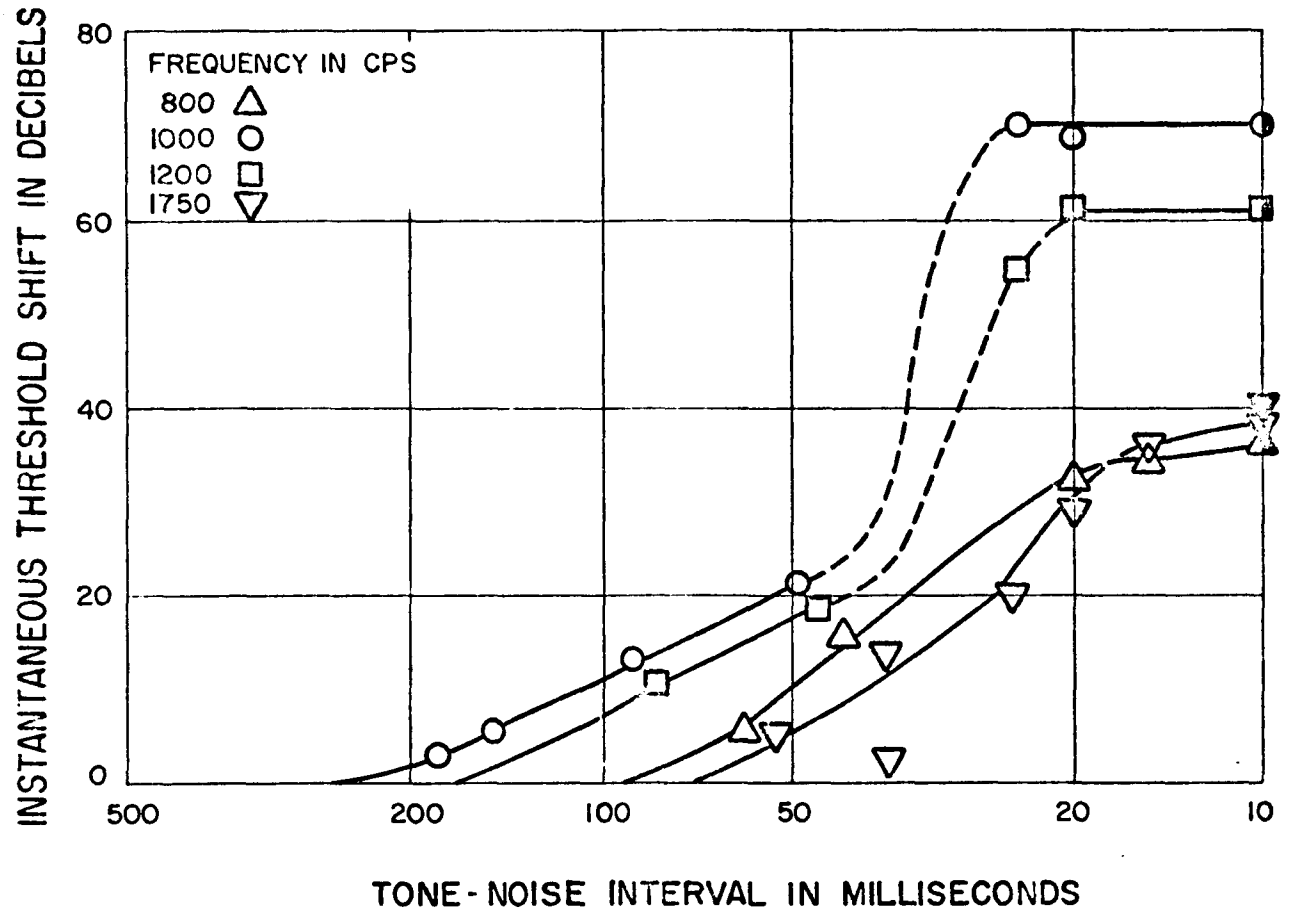


Figure 10. Instantaneous threshold shift with frequency as the parameter. (Wright, 1964.)



-10 msec. for probe frequencies of 250, 400, 800, 950, 1100, 1300, 1450, 1600, 2000, 3000, and 4000 Hz. For the backward masking experiment the maskers were wide-band noise and the narrow-band noise centered at 1270 Hz. Results are shown in Figures 11 and 12. In general, for the wide-band masker a small amount of backward masking occurred for intervals as long as -100 msec. For the narrow-band masker at the same masking interval there was a small amount of selective masking at frequencies within the narrow band of noise. At shorter time intervals, there was increased masking for probe frequencies within the narrow band of noise but there was also much masking for probe frequencies lying outside of the narrow-band. These results were in agreement with those of Wright (1964). In studying forward masking, masker durations of 25 msec. and 200 msec. were used for the two narrow-band maskers and the broad-band noise. Probe frequencies of 800, 1300, and 2000 Hz were paired with the lower frequency narrow-band noise and the probe frequencies 1900, 2600, and 4000 Hz were combined with the higher frequency narrow-band noise. All probe tones were paired with the broad band noise. The signal duration remained at 10 msec. and the masking intervals of 0,

Figure 11. Backward masking of a 10 msec. tonal signal by wide-band noise. (From Elliott, 1967.)

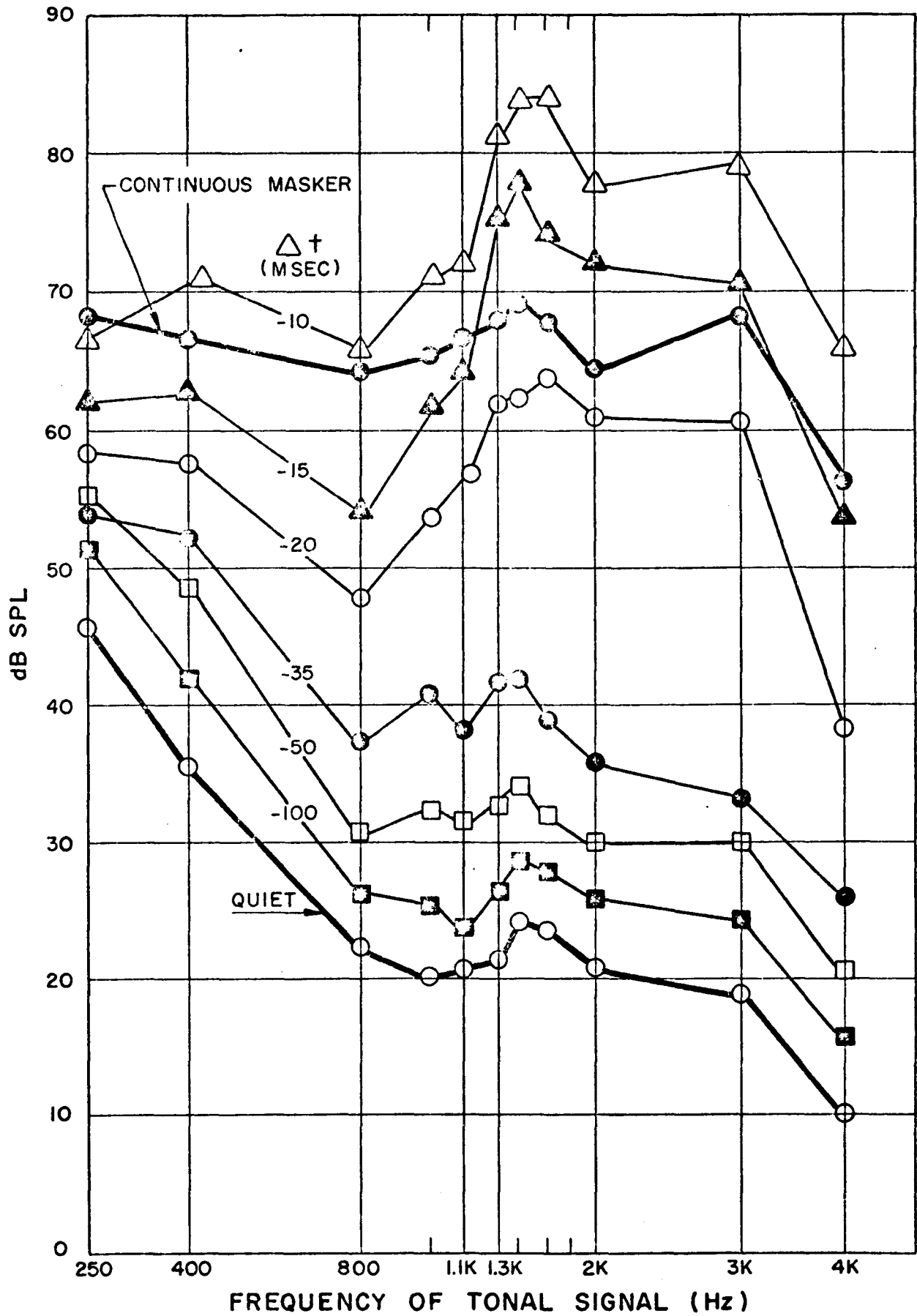
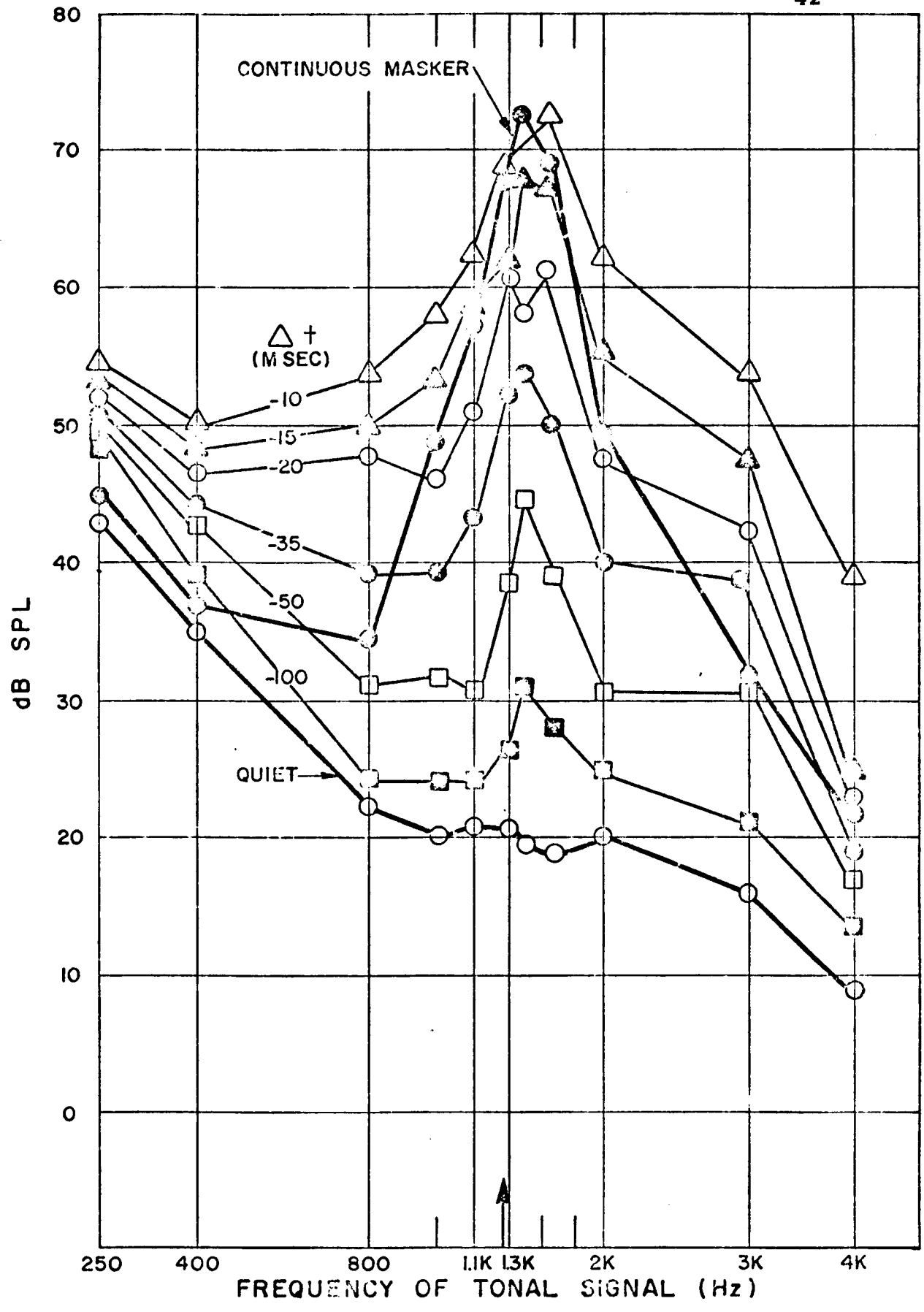


Figure 12. Backward masking of a 10 msec. tonal signal by a 200 Hz band of noise centered at 1270 Hz. (From Elliott, 1967.)



2, 5, 10, 20, 50, and 100 msec. were measured from masker offset to signal onset. Results are shown in Figures 13a, 13b and 14a, 14b. For both the wide-band noise and the probe frequencies within the narrow-band maskers, the longer masker produced the greatest amount of masking. For the probe frequencies just outside of the narrow-band maskers, at brief time intervals the 25 msec. masker produced poorer thresholds than did the 200 msec. masker. It appears that a 25 msec. masker does not have time to organize its narrow-band qualities and therefore acts as a wide-band noise. The longer masker, having had the time to organize the narrow-band characteristics has less of an effect upon frequencies outside of the narrow-band.

Glattke and Small (1968) tested the critical band hypothesis in forward masking. Paired sinusoids in the region of 800 Hz and 3200 Hz at 80 dB SPL with a duration of 400 msec. were used as maskers. A 20 msec. silent period followed the masker after which there was a 40 msec. sinusoid signal. A two alternative forced choice procedure was used. Results showed that a probe frequency closer to the masker showed greater shifts in threshold than a probe signal further

Figure 13a. Forward masking of a 10 msec. tonal signal by a 200 Hz noise band at 1270 Hz. (From Elliott, 1967.)

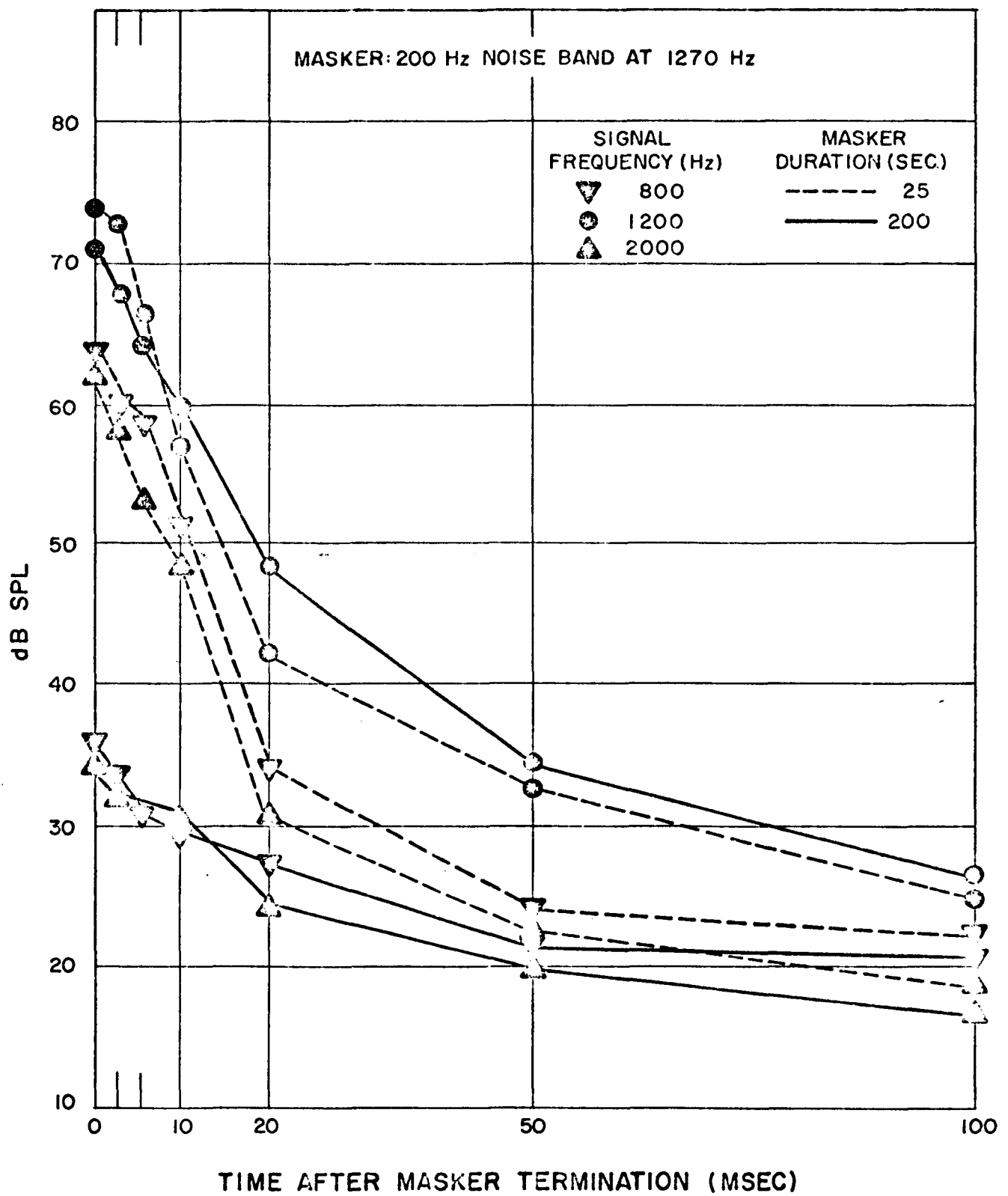


Figure 13b. Forward masking of a 10 msec. tonal signal by wide-band noise. (From Elliott, 1967.)

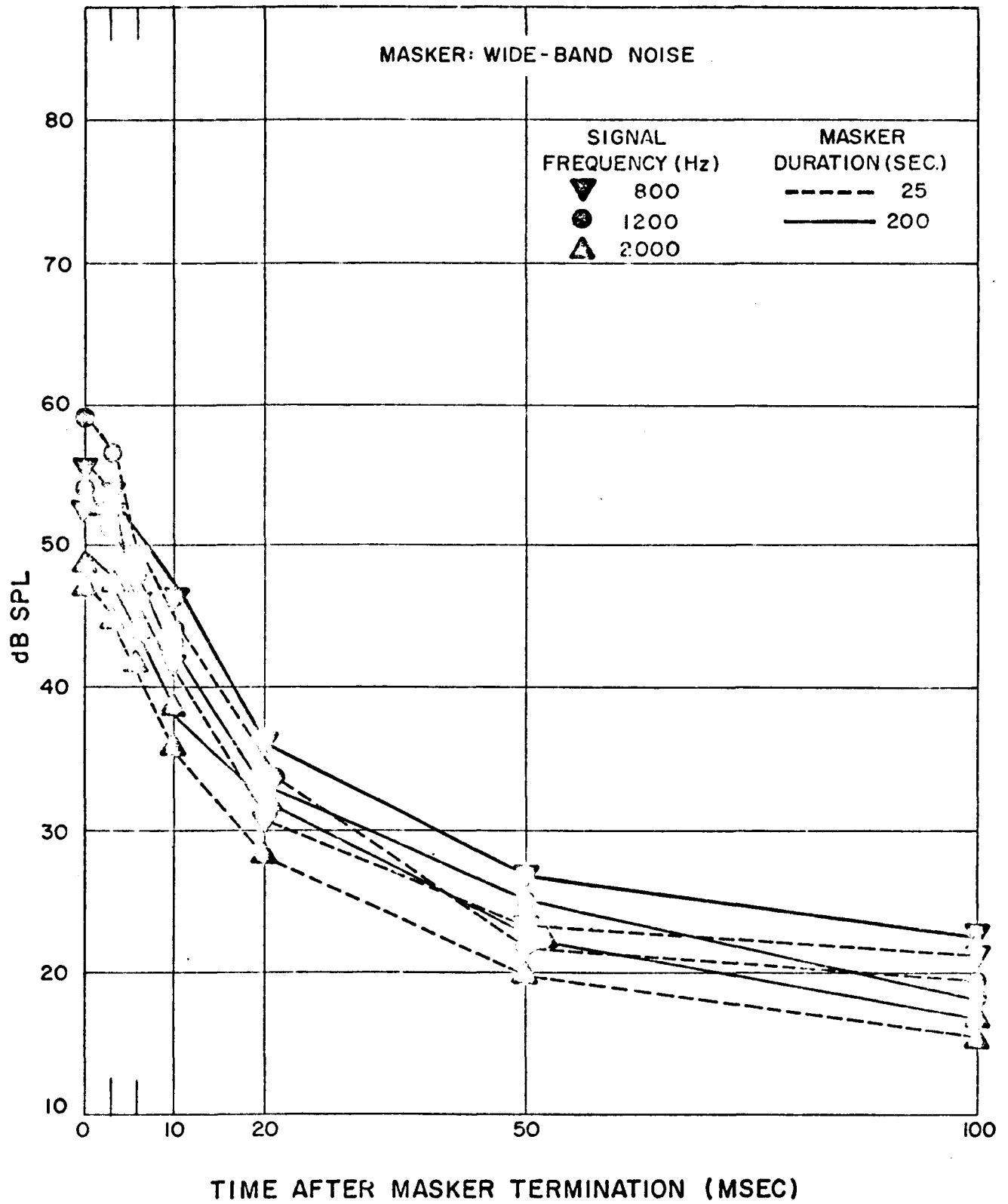


Figure 14a. Same as Fig. 13a except that signal frequencies and noise masker are varied. (From Elliott, 1967.)

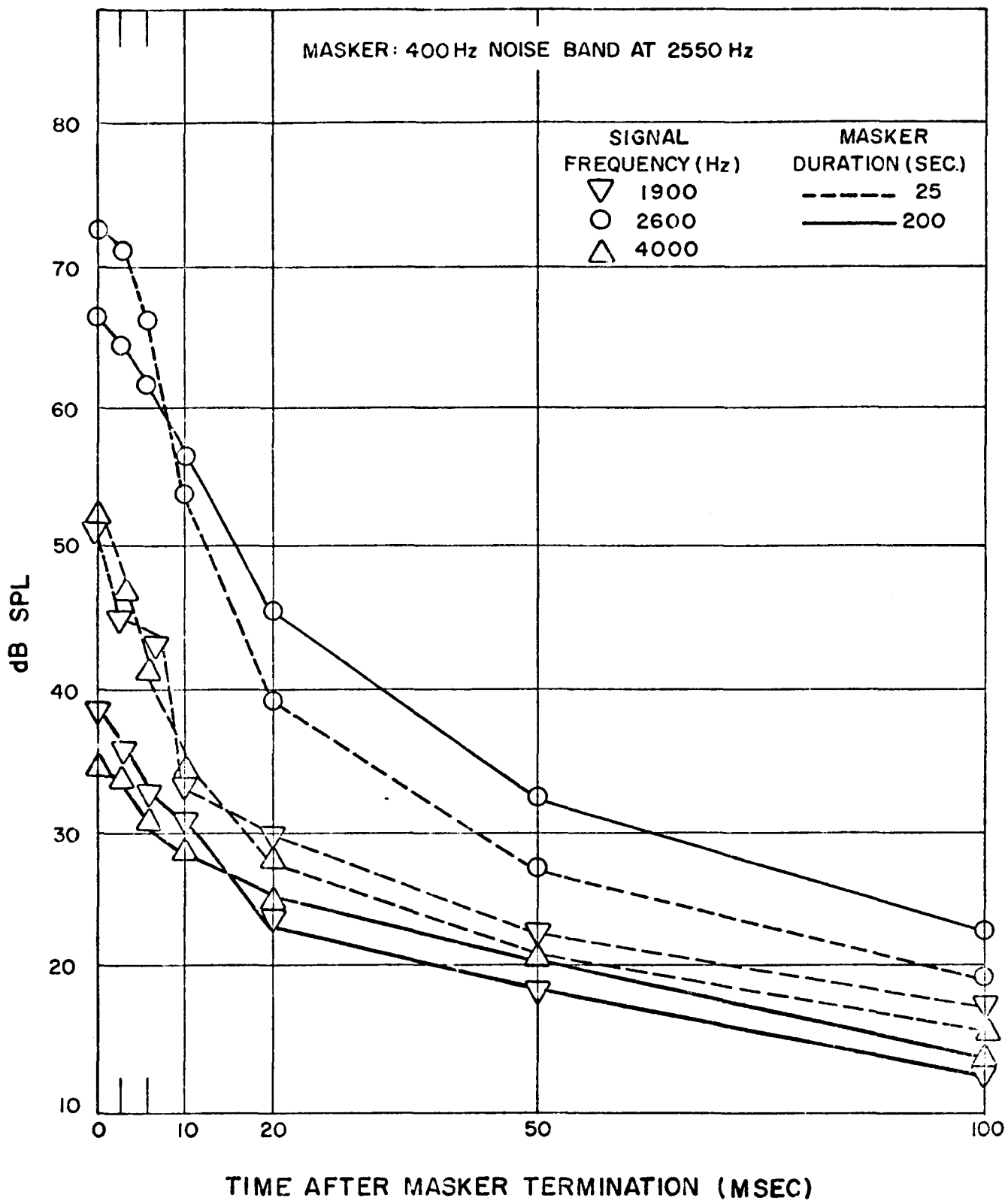
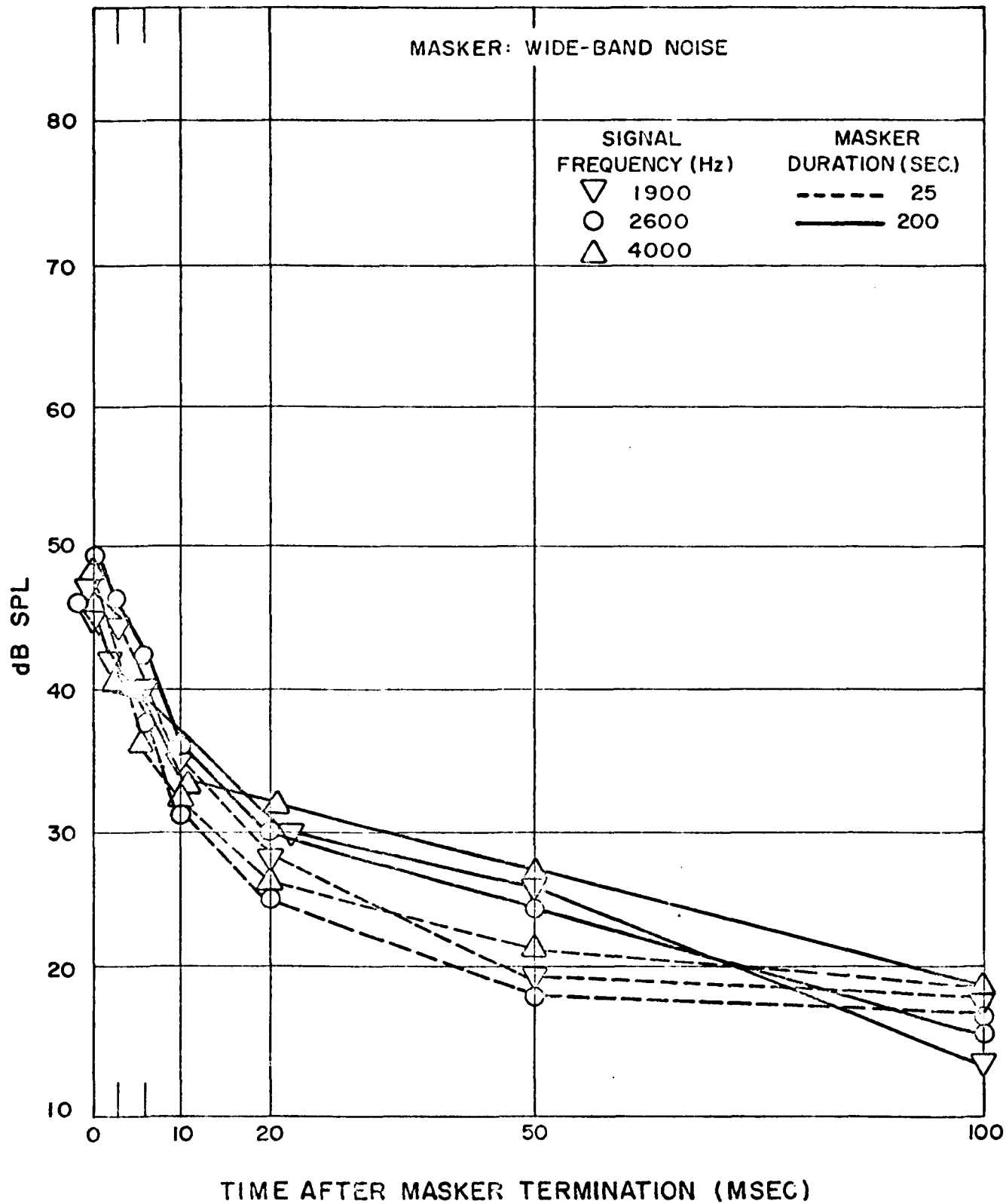


Figure 14b. Same as Fig. 13b except that signal frequencies are varied. (From Elliott, 1967.)



removed from the masker. It appeared that the critical band hypothesis only held true when the masker was in constantly, as in simultaneous masking, and not when the stimuli were sequential.

Homick, Elfner, and Bothe (1969) attempted to relate temporal masking and the perception of order. Three probe signals--1500 Hz, 850 Hz, and 2600 Hz were presented at 6, 12, 18, 24, 30, and 36 dB SPL. The duration of the probe was 12 msec. with a 1 msec. rise and decay time for both the tone and the noise. The masker was a narrow band of noise centered at 1500 Hz at 70, 80, and 90 dB SPL with a duration of 250 msec. Results for the 90 dB SPL masker are shown in Figures 15a and 15b. In general, the results agreed with prior studies (Samoilova, 1959; Elliott, 1962) which showed greater backward than forward masking for short masking intervals. For backward masking, the masking was greatest for the signal centered within the band and least for the signals below the noise band. Probe signals above the noise band showed greater masking than signals falling below the narrow-band of noise. For forward masking, the greatest amount of masking occurred for the signal within the band only when the signal was

Figure 15a. Plot of forward masking. (From Homick, Elfner, and Bothe, 1969.)

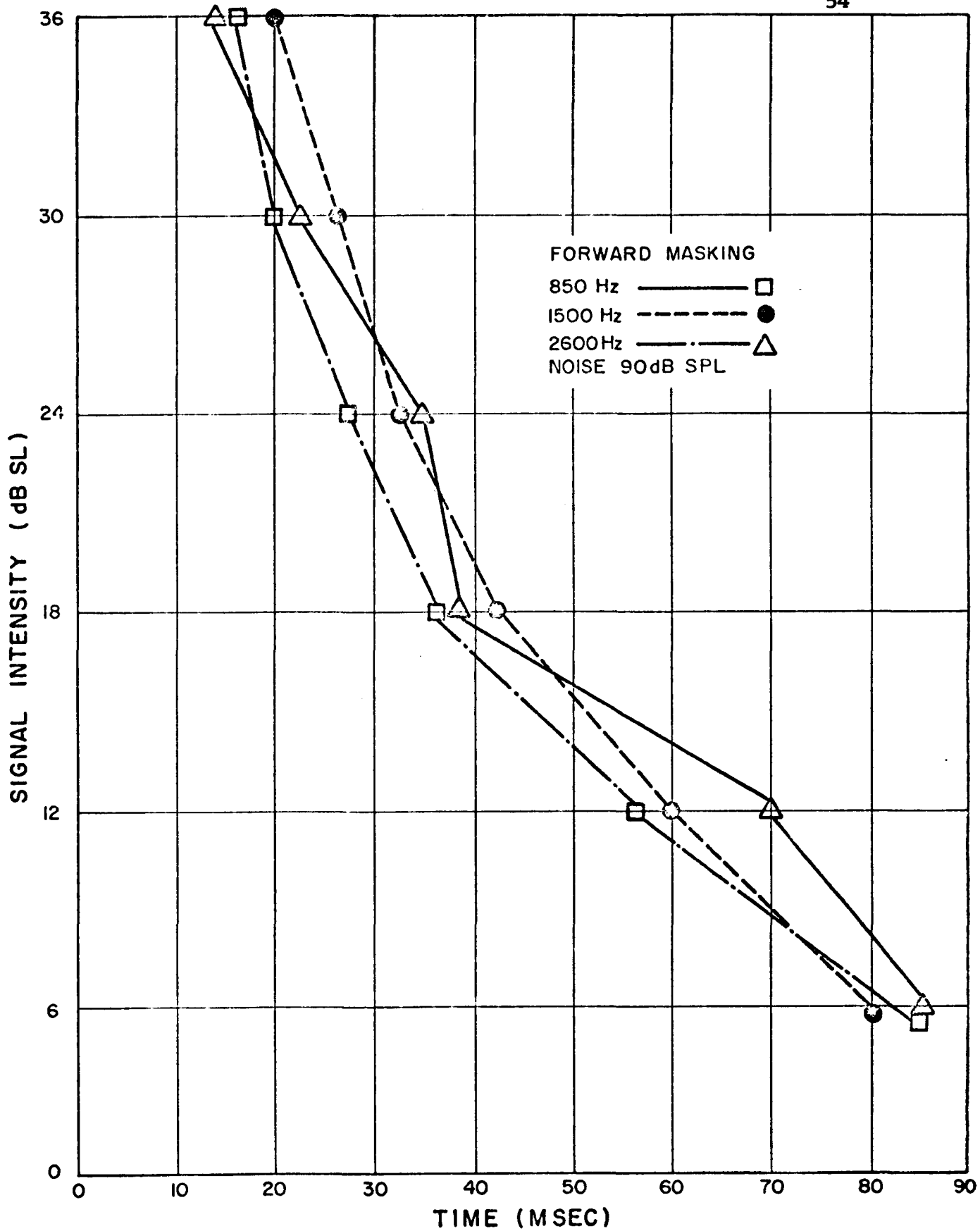
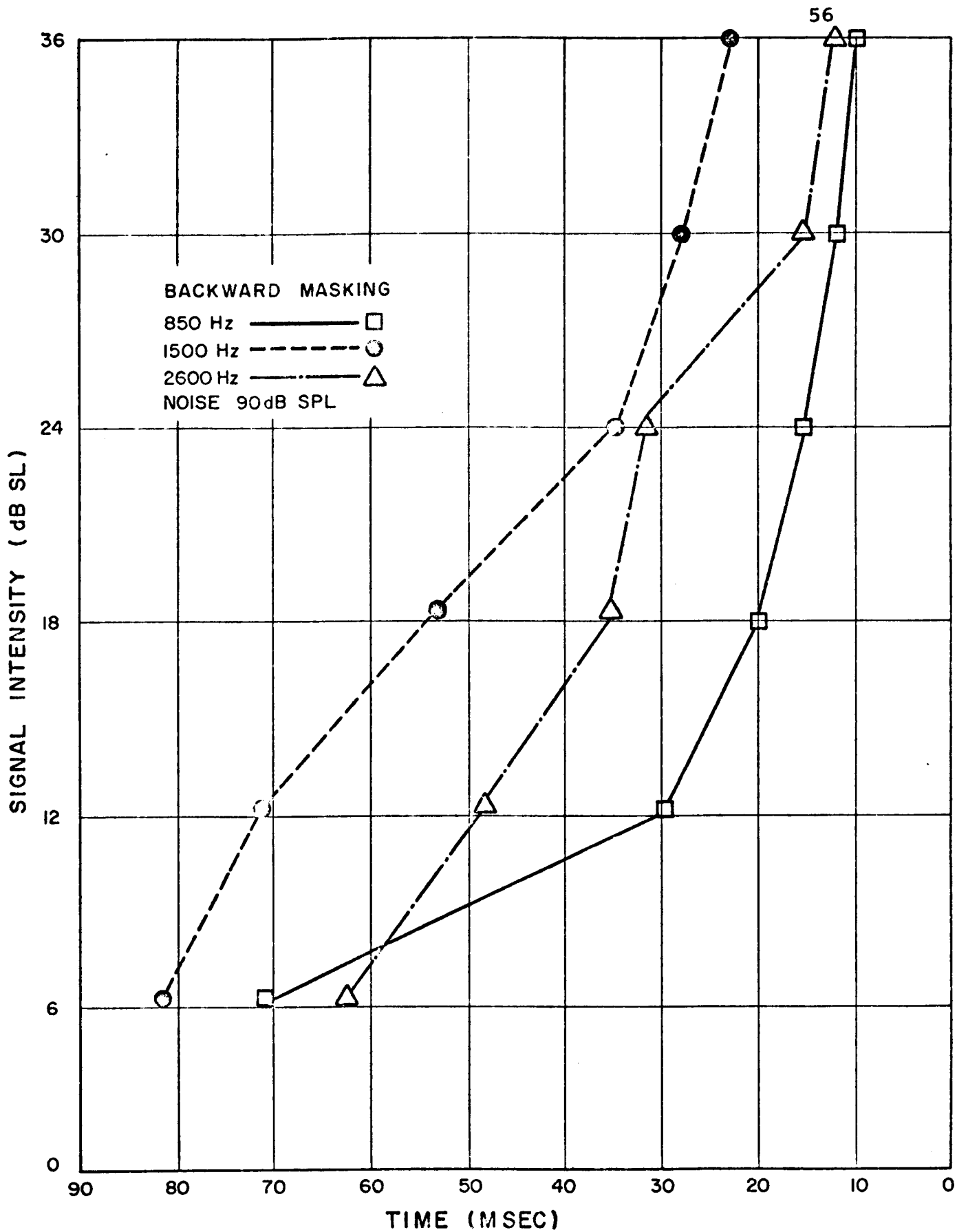


Figure 15b. Plot of backward masking. (From Homick, Elfner, and Bothe, 1969.)



at the highest sensation level. With a less intense probe the greatest amount of masking occurred for the frequency above the narrow-band of noise. The authors found that the same relationship that exists between frequency and intensity for temporal order exists also for backward masking.

Binaural Forward and Backward Masking

The majority of the studies dealing with temporal masking have been monaural. Elliott (1962) studied backward and forward masking under dichotic conditions. The experimental paradigm was identical to that described previously for the monaural condition with the exception being that the masking was presented to the left ear and the probe tone to the right ear. Results are shown in Figures 2 and 3. In general, Elliott found that temporal masking could be demonstrated under dichotic conditions although the masking effect is considerably greater for monotically presented stimuli.

Deatherage and Evans (1969) did a systematic study of binaural effects in temporal masking. The probe signal was a 1000 Hz tone of either 25 msec. or

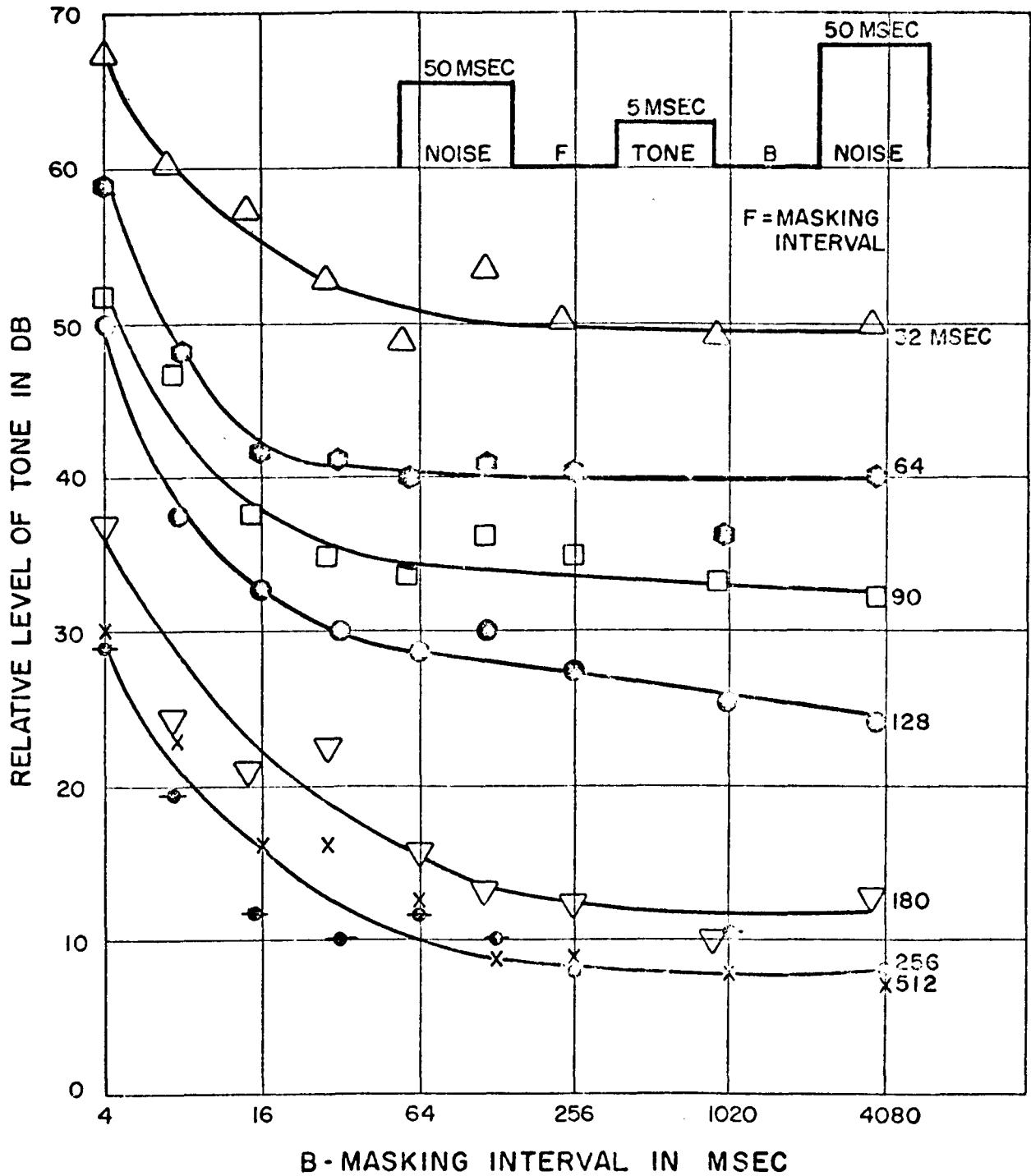
100 msec. in duration with a rise and decay time of 5 msec. The masker was a 1000 Hz tone of 500 msec. in duration with a rise-fall time of 5 msec. A wide-band noise was on continuously at 74 dB SPL. Five experimental conditions were tested: probe tone and masker in same ear, probe tone and masker in opposite ears, probe tone and masker in one ear and masker only in opposite ear, probe tone and masker in one ear and probe tone alone in the opposite ear, and probe tone and masker in both ears. Time intervals ranged from 250 msec. from probe tone onset to mask onset to 250 msec. from masker offset to probe tone onset. In general, results agreed with prior experiments in that masking decreased as signal duration increased and the greatest masking effects occurred with the probe tone and masker in the same ear. Overall effects showed binaural presentation resulted in less masking effects than monaural presentation. One very interesting result was that backward and forward masking was evidenced for masking intervals as long as ± 250 msec.; however, results were reported in terms of a computed d' as opposed to decibel shifts and how the d' was computed was not entirely clear.

Interaction of Forward and Backward Masking

Several researchers, utilizing a different design where the probe signal was presented between two bursts of masker, attempted to study how backward and forward masking interact with and affect one another. Pollack (1964) used a white noise burst of 50 msec. in duration at 120 dB and a 1000 Hz probe tone burst of 5 msec. in duration. The time between the initial noise burst and the tone burst was varied as was the time between the tone burst and the second mask. Results are shown in Figure 16. Pollack found that forward and backward masking effects are relatively independent of one another.

Wilson and Carhart (1971) studied backward and forward masking interactions, as well as each one individually. They found greater forward than backward masking, in agreement with Chistovich and Ivanova (1959) and Raab (1961). When the probe click was presented between the two noise bursts, greater masking was found when the click was closer to either of the bursts. More masking was found than could be attributed to either forward or backward masking effects. Additivity of the bursts could not be used as an ex-

Figure 16. Interaction of forward masking and backward masking. The parameter is the forward masking interval. (From Pollack, 1964.)



planation since no maskers were present during the time intervals nor could additivity of the residual effective powers explain the results since the masking effect was greater than would have been predicted. It was concluded that temporal masking does not necessarily follow the same pattern as simultaneous masking where additivity of power was first established. In addition, it has been shown (Bilger, 1959; Green, 1967) that even during simultaneous masking combined effects can exceed simple addition of noise powers.

Simultaneous Masking

Results of earlier studies in simultaneous masking were often inconsistent. Elliott (1964) and Zwicker (1965) used a tone as a probe signal and white noise as a masker and found overshoot. (Overshoot refers to an elevation in the threshold of the signal when the signal and masker are begun simultaneously or at short time intervals from one another.) Osman and Raab (1963) and Wilson and Carhart (1971) used a click as the signal and white noise as the masker and found little or no overshoot. Wilson and Carhart felt that the 3 to 4 dB less masking which occurred at the onset and the offset of

the noise may have been due to different detection criteria used by subjects. Similarly, Wright (1964) with a tone as the signal and narrow-band noise as the masker and Zwicker (1965) with white noise as both signal and masker found no overshoot. In addition, Zwicker and Wright (1963) found no overshoot when both the signal and the masker had narrow spectra. Zwicker (1965) after varying the bandwidth of the signal while keeping the noise wide-band, found that overshoot will occur when the width of the spectral distribution is dissimilar for the signal and the masker.

Elliott (1965) studied simultaneous masking in relation to the delay time between masker and signal onset. Her results appeared to confirm those of earlier studies. She found that with a 1000 Hz brief signal and a wide-band masker of 30 msec. duration or more, threshold was dependent upon and elevated for short time intervals. In agreement with Osman and Raab (1963) Elliott found that the masking of a click by wide-band noise was, for the most part, not dependent upon the onset. For narrow-band signals masked by narrow-band noise, Elliott found that for higher frequencies (1270 Hz narrow-band noise and 2250 Hz narrow-band noise) little overshoot occurred

for those frequencies within the narrow-band noise while overshoot increased greatly for tones bordering on the band of noise. The same pattern was not observed when the noise band was centered at 250 Hz. These results were in agreement with those of Zwicker and Wright (1963) who found relatively little overshoot when both the signal and the masker had similar narrow-band characteristics. It appears that Zwicker's conclusion was correct in that overshoot occurs when there are differences in the band spectral characteristics of the signal and the masker.

Elliott (1965) found that for dichotic presentations of masker and signal the same effects to a lesser degree were noted as for monotic presentation. Deatherage and Evans (1969) found that binaural presentation resulted in less masking than monaural presentation with Masking Level Differences playing a large role.

Several investigators considered the effect of phase on monaural detection. Pfafflin and Mathews (1962) found that when a background sinusoid of the same frequency and phase as the signal (a pedestal) was added 90° out of phase with the signal, detection was not improved; however, very intense pedestals did reduce detectability regardless of the phase. Raab, Osman, and Rich (1963) found

that detection of a 500 msec. noise burst signal was increased by as much as 16 dB if the signal burst and masker were added in phase. The out-of-phase condition did also improve threshold but not to the same degree as did the in-phase condition.

The Proposed Study

The data reported in the literature and cited in this review suggest that the type of stimuli used affect the results obtained for temporal masking. To confirm the extent of the influence which the masking noise has upon signal detection, the characteristics of the noise waveform during each test condition must be specified. Recently, advances have been made in the area of digitally produced waveforms which offer the researcher greater control over the masking stimulus than was obtainable with conventional noise sources. Pfafflin and Mathews (1966) and Mathews (1968) used a computer to digitally generate white noise which was passed through a low pass filter and utilized as the masker in a detection experiment. The use of a digital noise generator insures the exact reproduction of the waveform for each trial while being immune to the distortions of tape recorded stimuli.

The purpose of this study is to investigate the effects of various narrow-band waveforms, digitally produced and centered at the same frequency, on temporal masking at short masking intervals and, further, to assess the effects of phase shifts on backward and forward masking.

CHAPTER III

EXPERIMENTAL PROCEDURE

Subjects

Four sophisticated listeners (three men and one female ranging in age from 25 to 45 years) were subjects for this study. Prior to the experiment, each individual's pure tone threshold at 250, 500 and 1000 Hz was determined and found to be within normal limits. The test tone used was of the same duration and rise-decay time as that used in the main experiment.

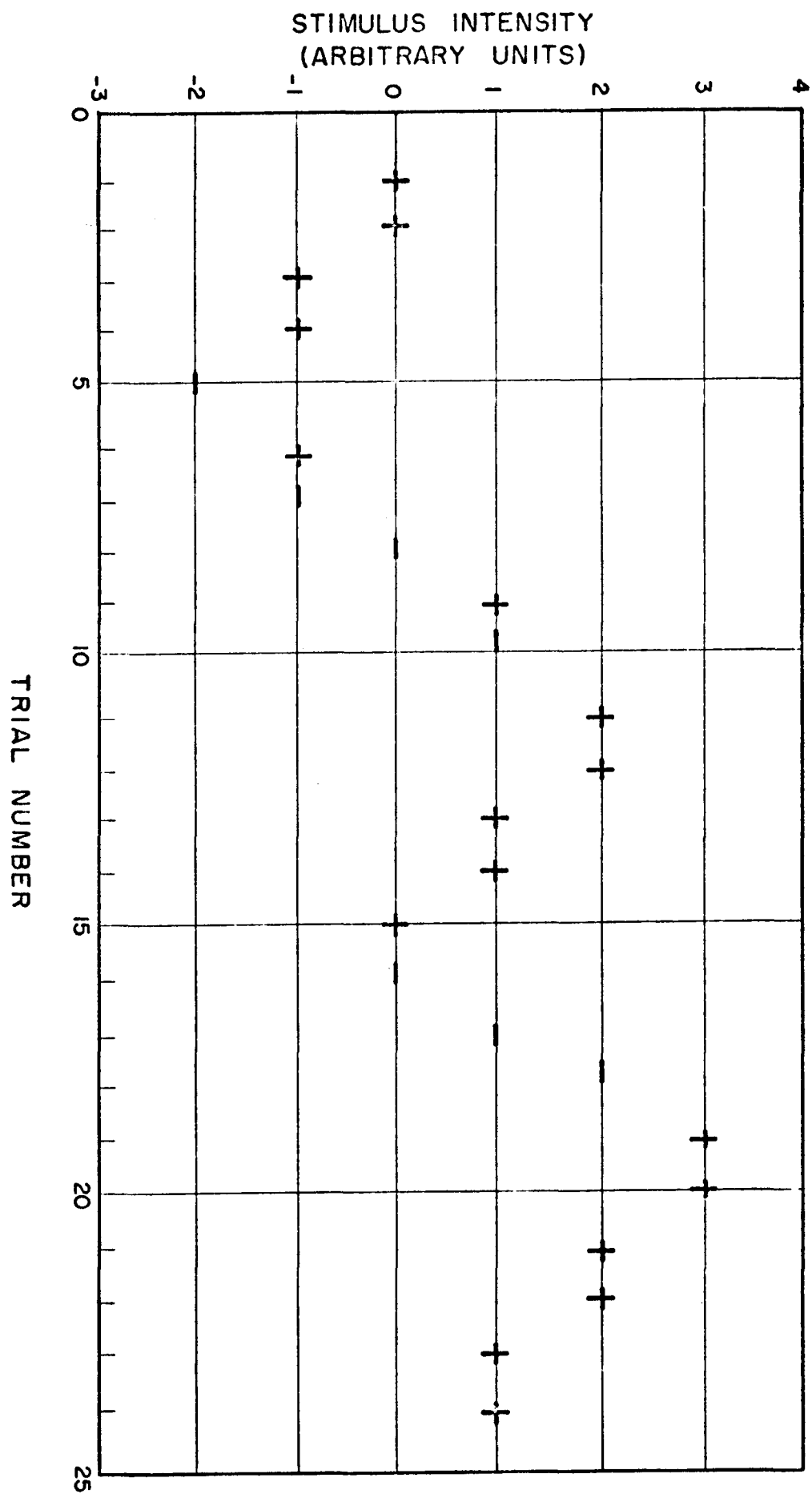
Psychometric Procedure

The subject's task was to detect a monaurally presented tone burst that either preceded, occurred simultaneously with, or followed a 40 msec. burst of narrow-band noise. The procedure used was the two interval forced choice (2IFC) technique where the subject was presented with two intervals of the noise masker only one of which contained the tone burst signal. The subject was instructed to decide on the interval in which

the tone was delivered and to respond appropriately by pressing a button.

The adaptive technique used for threshold estimates was a transformed up-down procedure (Levitt, 1971). With this procedure it was possible to converge rapidly on that stimulus level at which 70% of the responses are correct. Threshold, as defined in this study, was taken to be this 70% point. In general, in an adaptive technique, the subject's responses determine stimulus levels. In this method, for each two consecutive correct (+) responses the signal was attenuated by one decibel. A single incorrect (-) response automatically increased the signal level by one decibel, i.e. in order to increase signal level either of the response sequences, - or + are needed. If the response sequence ++ is obtained, the signal is attenuated by 1 dB. A series of changes in one direction (i.e. either a sequence of 1 dB steps of attenuation or 1 dB steps of gain in signal level) followed by a reversal in direction was defined as a run. Figure 17 shows a typical subject response pattern. Fifteen runs completed one test. The estimation of the threshold is the average mid-value of the last 12 runs. The first 3 runs were not used to obtain threshold measurements.

Figure 17. A typical subject response pattern.
(From Levitt, 1971.)



This was done to allow the subjects time to settle down.

Test Tone Bursts

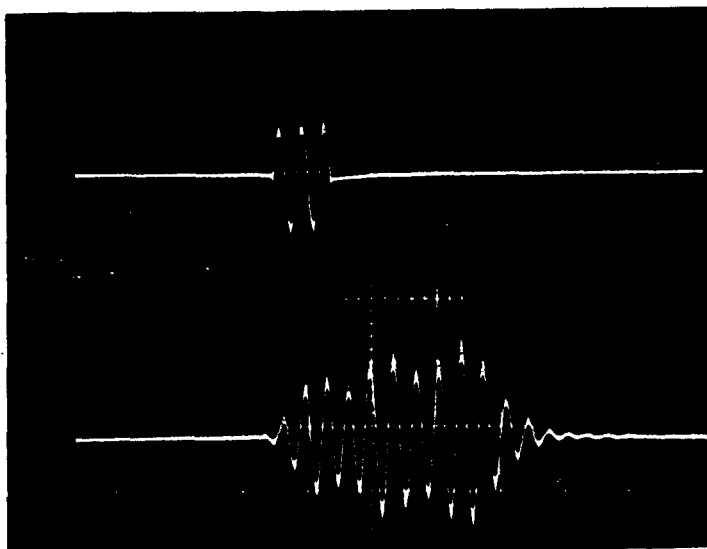
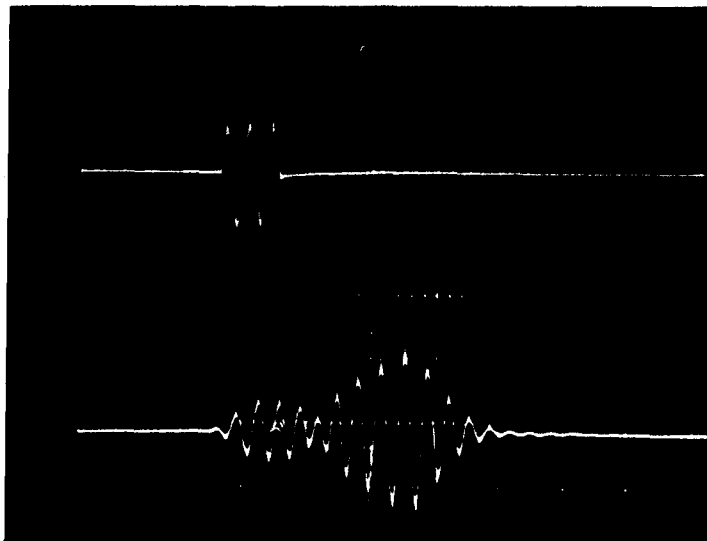
Bursts of a 250 Hz tone were used. The bursts were nominally 12 msec. in duration (i.e. three periods) with a rise-time and a fall-time of 4 msec. A maximum level of 92 dB SPL for the continuous tone was selected. This corresponded to a setting of 30 dB on the recording attenuator. The signal was presented randomly within one of the two noise intervals and was followed by a 3 second listener response period. Prior to each test run the tone pulse was set at its maximum level (i.e. 92 dB SPL for the carrier tone) to familiarize the subject with the signal.

Factors Investigated

Noise Waveform

Two different noise waveforms 50 msec. in duration were employed. See Figure 18. The wide-band output of a digital noise generator programmed to produce repeatable waveforms with each presentation, was passed through a narrow-band filter with a 50 Hz bandwidth and center frequency of 250 Hz. An Allison bandpass filter

Figure 18. The lower trace on the top photograph illustrates Noise Waveform I. The lower trace on the lower photograph illustrates Noise Waveform II.



was used with a cut-off rate of 36 dB and 3 dB cut-off points at 225 Hz and 275 Hz. Two waveforms with differing envelopes were selected in order to examine possible effects of envelope shape upon the detection of the tone pulse at threshold. The intensity of the waveforms was held constant at 90 dB SPL (spectrum level of 73 dB) for the continuous noise.

Relative Timing

Five simultaneous, three backward, and three forward masking conditions were investigated:

Backward conditions: -10 msec., -20 msec.,
-30 msec.

Simultaneous conditions: 0 msec; 10 msec., 20
msec., 30 msec., 40 msec.

Forward conditions: 50 msec., 60 msec., 70 msec.

The nominal delay times above as expressed in milliseconds refer to the intervals between the onset of the acoustic masking stimulus and the onset of the electrical tonal pulse. The delay settings were set by manual adjustment and were checked visually on the oscilloscope. The resolution of these settings was on the order of 0.5 msec.

Phase Conditions

In order to determine if the onset phase of the tonal pulse has an effect upon signal detection, three phasic conditions of the signal were set: in-phase (0°), 90° out of phase, and 180° out of phase.

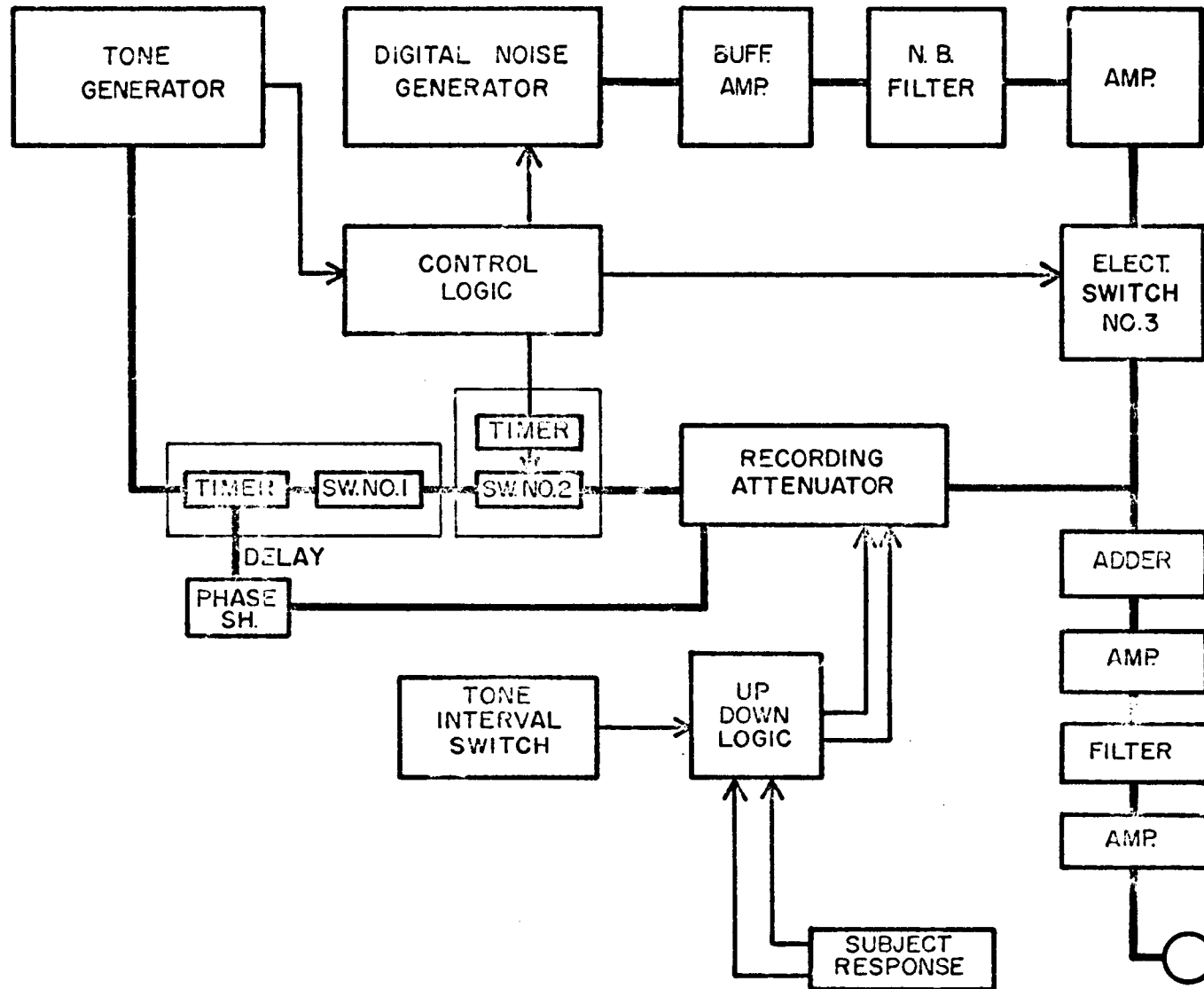
Ordering and Replications

Each combination of all factors investigated was presented to each subject twice in random order. As noted earlier, each of these threshold determinations was derived from the average of 12 runs.

Apparatus

Figure 19 displays a block diagram of the experimental equipment used in this research. The heavy lines represent the audio paths which the noise and signal follow, while the thin lines show the stimulus control circuitry. The control logic circuitry initiated the first noise interval during which switch 1 was turned on for the duration of the interval. Switch 2 gated the actual tone pulse presented to the listener only during the interval chosen by the experimenter with the interval selection switch. A timer controlled the temporal relationship between the tonal pulse and the noise. A TDH-39

Figure 19. A block diagram of the experimental equipment.



earphone with MX41/AR cushion was used throughout the study.

Calibration

Before and after each test session, both the masker and the tone burst were photographed and monitored to insure waveform stability from session to session. The 90 dB SPL noise level and the 92 dB SPL tone burst level were measured on a Bruel and Kjaer 2203 sound level meter, 1613 octave filter set, and a type 4152 artificial ear. In addition, photographs were taken from an oscilloscope preceding and following each test session, of the masking noise on one channel and the delayed signal on the second channel so that the stability of the delay times could be monitored throughout the experiment.

CHAPTER IV

RESULTS

Coding and Processing of Data

A subject's threshold for all test conditions was determined by encoding the levels of the peaks and valleys appearing on the recording attenuator on to punched cards. An IBM 370 computer was employed to calculate the subject's threshold from the average of twenty-four such pairs of peaks and valleys. In addition, a five factor analysis of variance for these mean threshold values was performed. The factors were delay (11 nominal delay settings), subjects (4), noise waveforms (2), phase (3), and order (first observation, and second observation). Of the five factors all interactions involving order effect were found to be not statistically significant. For this reason, the ANOVA was collapsed over the order factor i.e. order was treated as a replication. The ANOVA table for the five factors is shown in Table 1. Replication error i.e. the standard deviation was about 2 dB. Estimates of the standard deviation from the 24 runs for each test condition was

Table 1. The five factor analysis of variance
obtained for this experiment.

SOURCE OF VARIATION	SUMS OF SQUARES	DEGREES OF FREEDOM	MEAN SQUARES
C	145765.58750	10	14576.556641
S	10726.91406	3	3576.30469
DS	13266.13672	30	442.20435
N	201.12831	1	201.12831
DN	275.10913	10	27.51090
S	11.42010	3	3.80670
DSN	534.54635	30	17.81921
P	138.67811	2	69.43906
DP	926.41479	20	46.42073
SP	118.36647	6	19.72807
DSP	3712.06812	60	61.86760
RP	20.19830	2	10.09915
DAP	225.35919	20	11.26996
SPP	124.00932	6	20.66823
DSNP	556.65796	60	9.27763
R	1.53414	1	1.53414
DR	21.44473	10	2.14447
SR	10.60328	3	3.53442
DSR	42.02481	30	1.40083
NR	2.13118	1	2.13118
DRR	4.80473	10	0.48047
SRR	6.97905	3	2.32635
DSRR	32.01536	30	1.06718
PR	4.57504	2	2.48752
DRR	23.06534	20	1.15327
SRR	26.29768	6	4.71631
DSRR	132.91264	60	2.21521
NRR	0.40154	2	0.20077
DRRR	37.30237	20	1.86512
SRRR	7.35035	6	1.23176
DSRRR	105.96700	60	1.76612
TOTAL	177092.00000	527	

slightly less than 1 dB. The larger replication value takes into consideration the differences between test conditions e.g. change in location of the headphone, time of day, etc.

From Table 1 it can be seen that each interaction of each factor was found to be statistically significant. By far, the largest effects were found for delay, subjects, and noise waveform and a comparatively smaller effect for phase. Since differences between subjects showed a substantial interaction with delay, the data were plotted for individual subjects. Results are shown in Figures 20 to 23.

Effect of Delay

For all subjects, under each of the experimental conditions, the signal was most detectable for the backward and forward masking conditions and least detectable for the simultaneous masking conditions. The average thresholds over all subjects for each condition showed a steady decline in threshold as the masking interval for backward masking was reduced, a flattening of the curve during the simultaneous conditions, and a steady improvement in threshold as the time delay moved into

Figure 20. Results of this experiment for Subject 1 as a function of delay, noise, waveform, and phase.

SUBJECT I

84

———— PHASE I (0°)
- - - - PHASE II (90°)
- - - - PHASE III (180°)

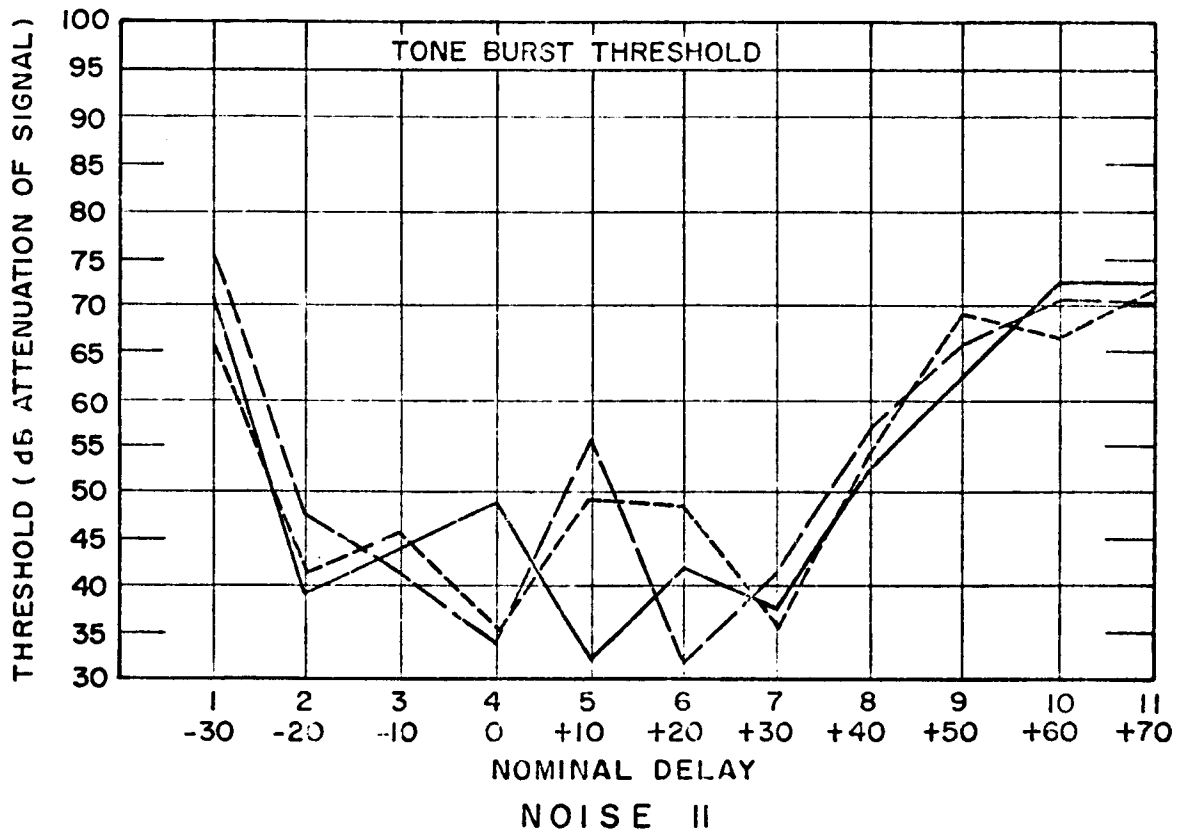
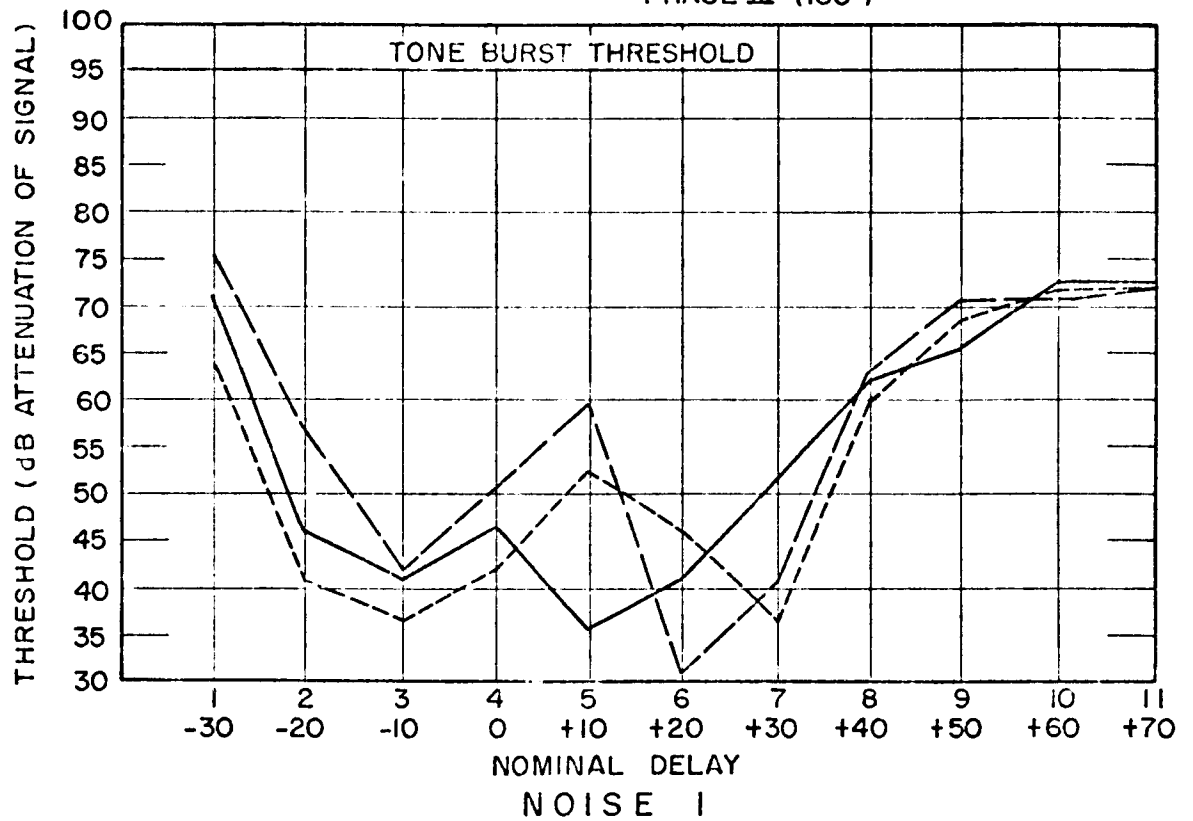


Figure 21. Results for Subject 2.

SUBJECT 2

86

- PHASE I (0°)
- - - - PHASE II (90°)
- · - · PHASE III (180°)

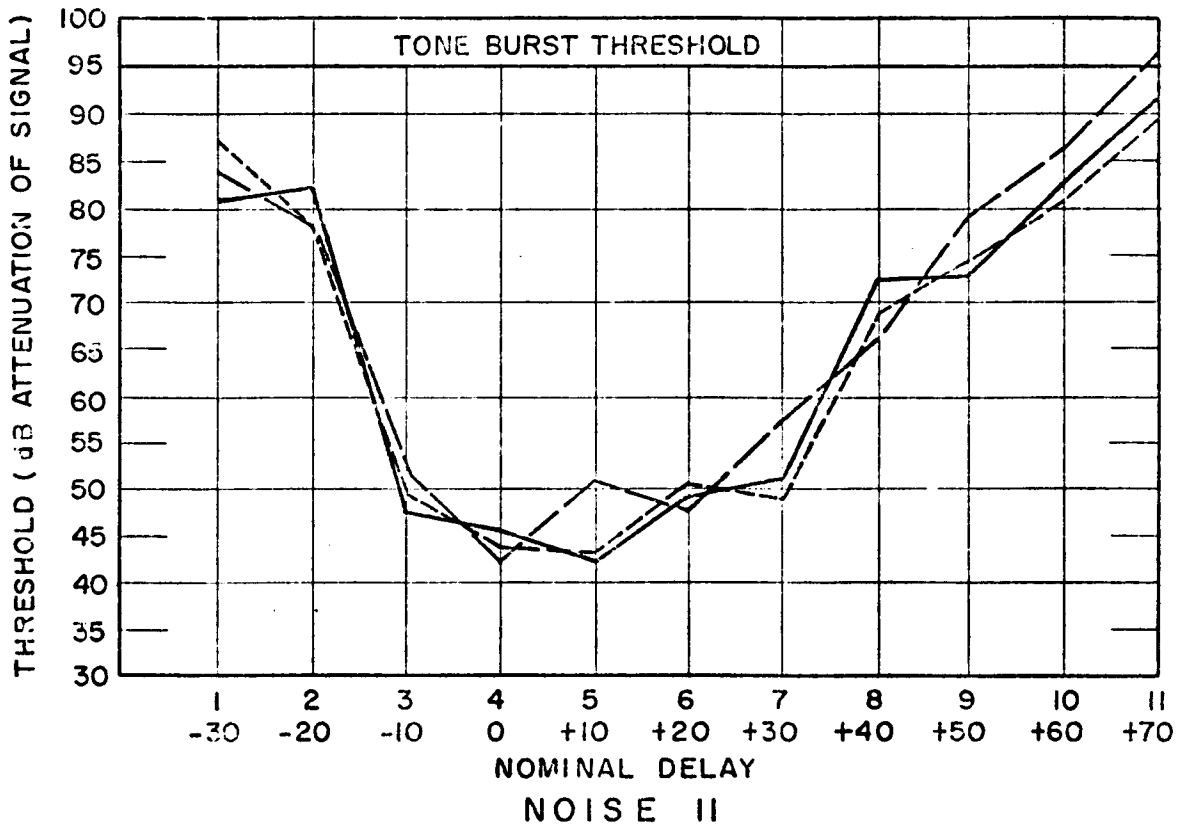
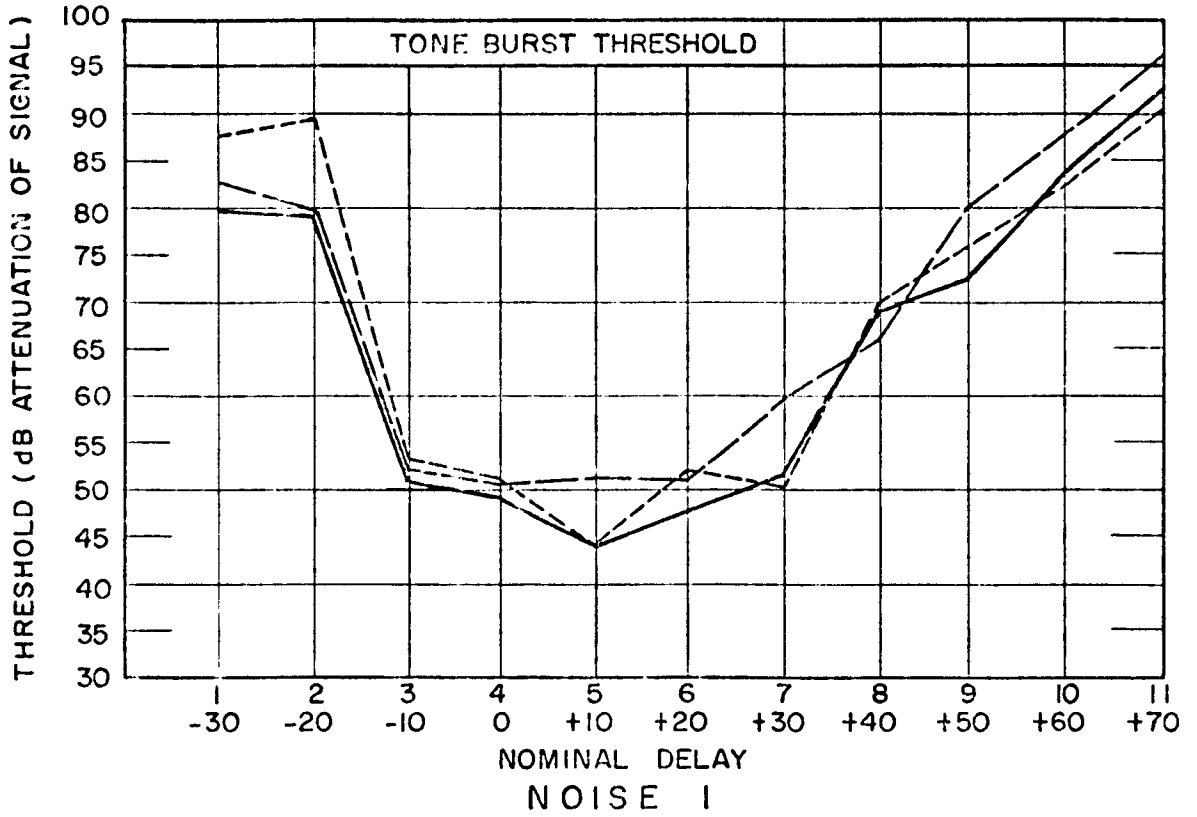


Figure 22. Results for Subject 3.

SUBJECT 3

88

———— PHASE I (0°)
- - - - PHASE II (90°)
- · - · PHASE III (180°)

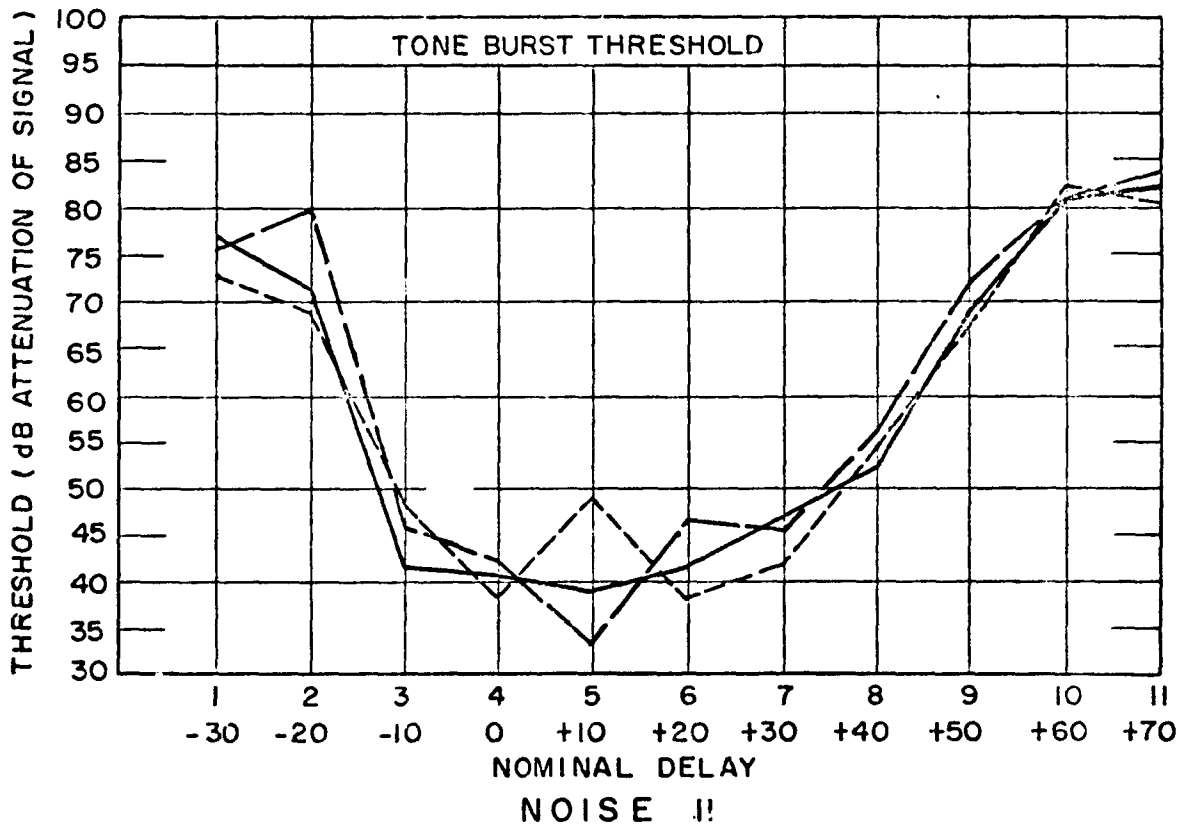
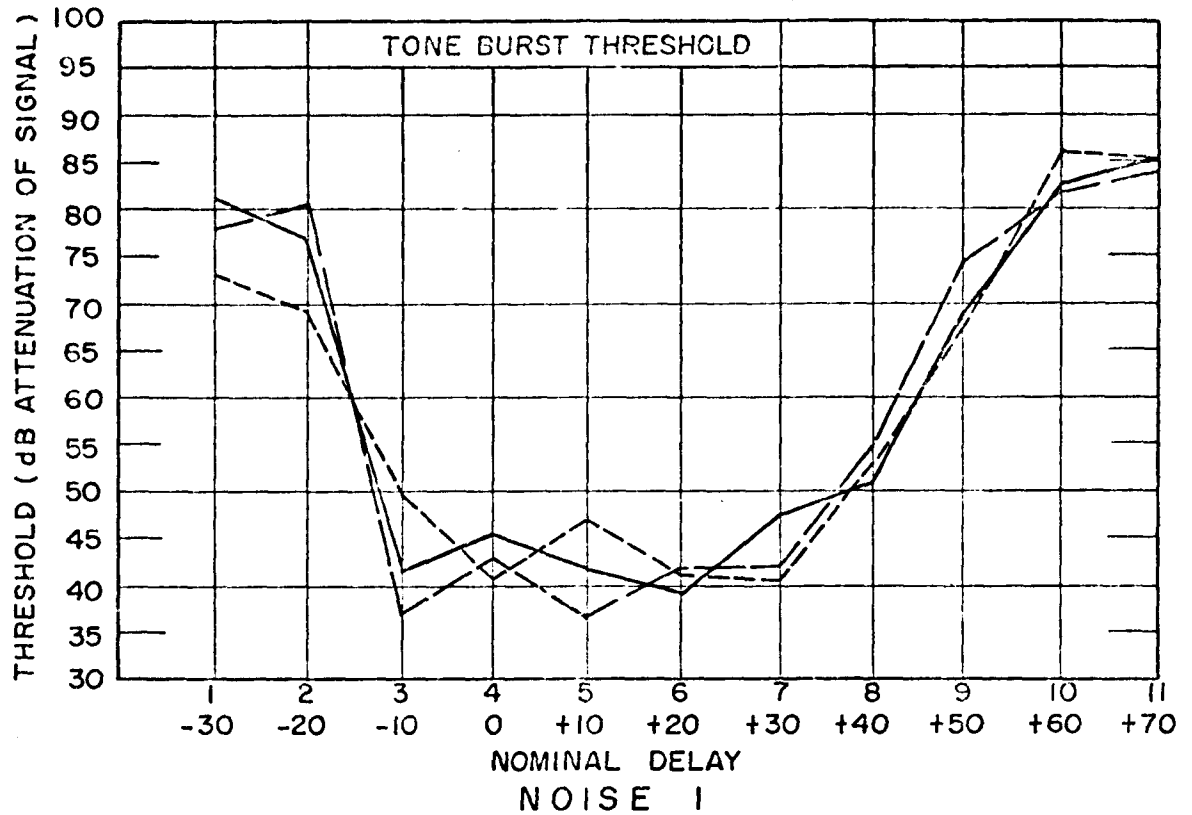
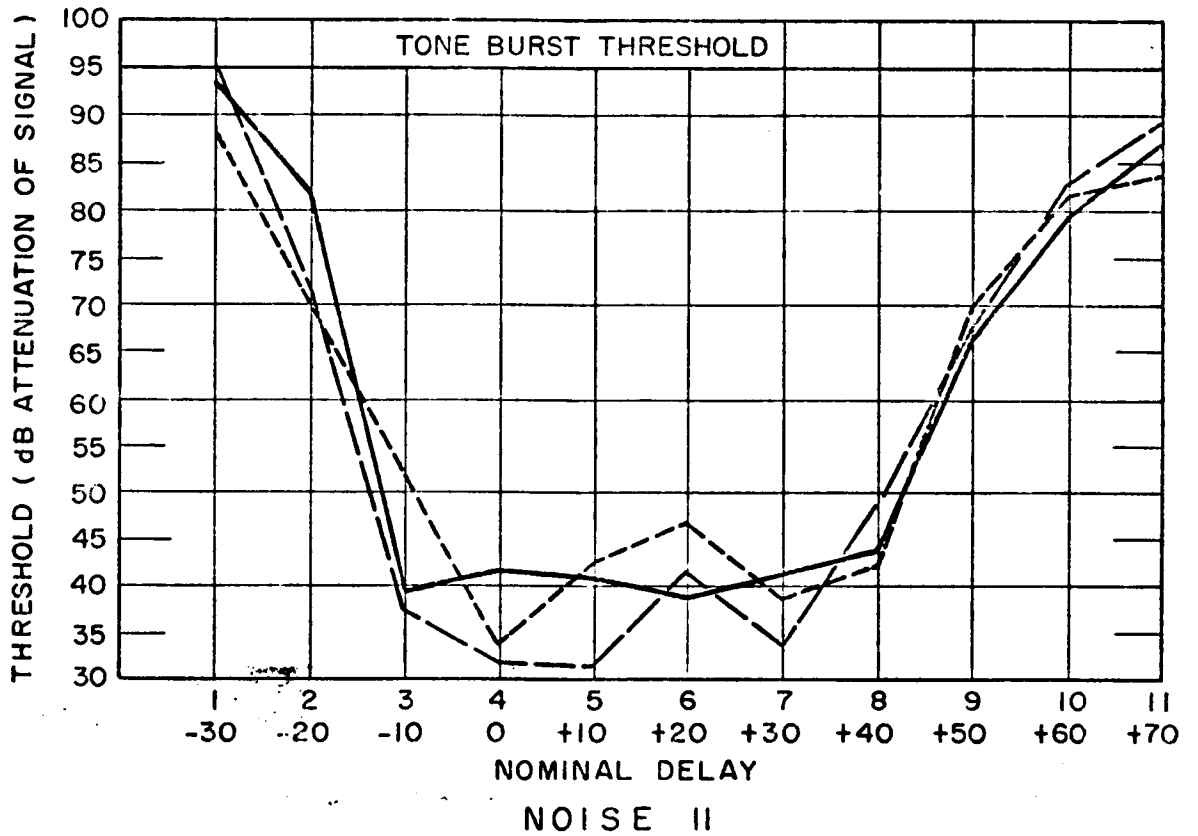
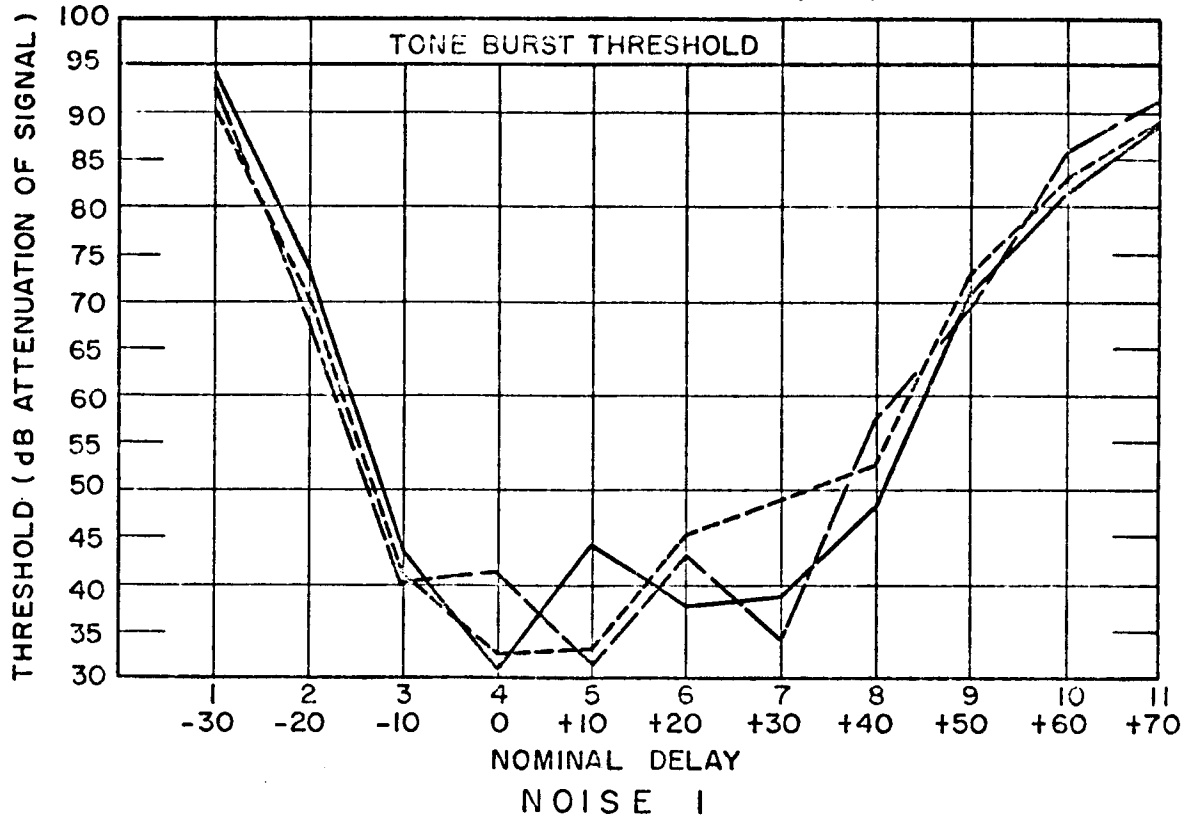


Figure 23. Results for Subject 4.

SUBJECT 4

90

- PHASE I (0°)
- - - - PHASE II (90°)
- · - · PHASE III (180°)



the forward masking conditions. In addition, for all conditions over all subjects, greater backward than forward masking was noted when a short silent interval existed between probe signal and masker i.e. a very steep rise in the curve exists for backward masking while there is a slow rise in the curve for forward masking.

Subject 1 for the most part, showed worse thresholds for the backward and forward conditions than did the other subjects. The same subject also showed greater variability from the mean threshold curves. It is interesting to note that this variability was greatest for the simultaneous masking conditions. In four out of six of the test conditions from nominal delay 0 to nominal delay 10 msec. with decreases again from the 10 msec. nominal delay to the 20 msec. nominal delay.

The differences between subjects proved to be highly significant. All subjects showed a similar trend with greater masking for the simultaneous conditions and less masking for the forward and backward conditions. The differences between the subjects were roughly consistent except for Subject 1 who performed very differ-

ently during the backward masking conditions. For the most part, Subject 1 achieved poorer thresholds than did the other subjects. In addition, his trend during simultaneous masking, particularly from nominal delay 0 msec. to nominal delay 10 msec. differed from that of the other subjects. This accounts in part for the significant subject delay obtained in the analysis of variances. Subject 2 performed consistently better than did the other subjects but showed the same trend as the other subjects. The standard deviation between subjects was on the order of 5 dB.

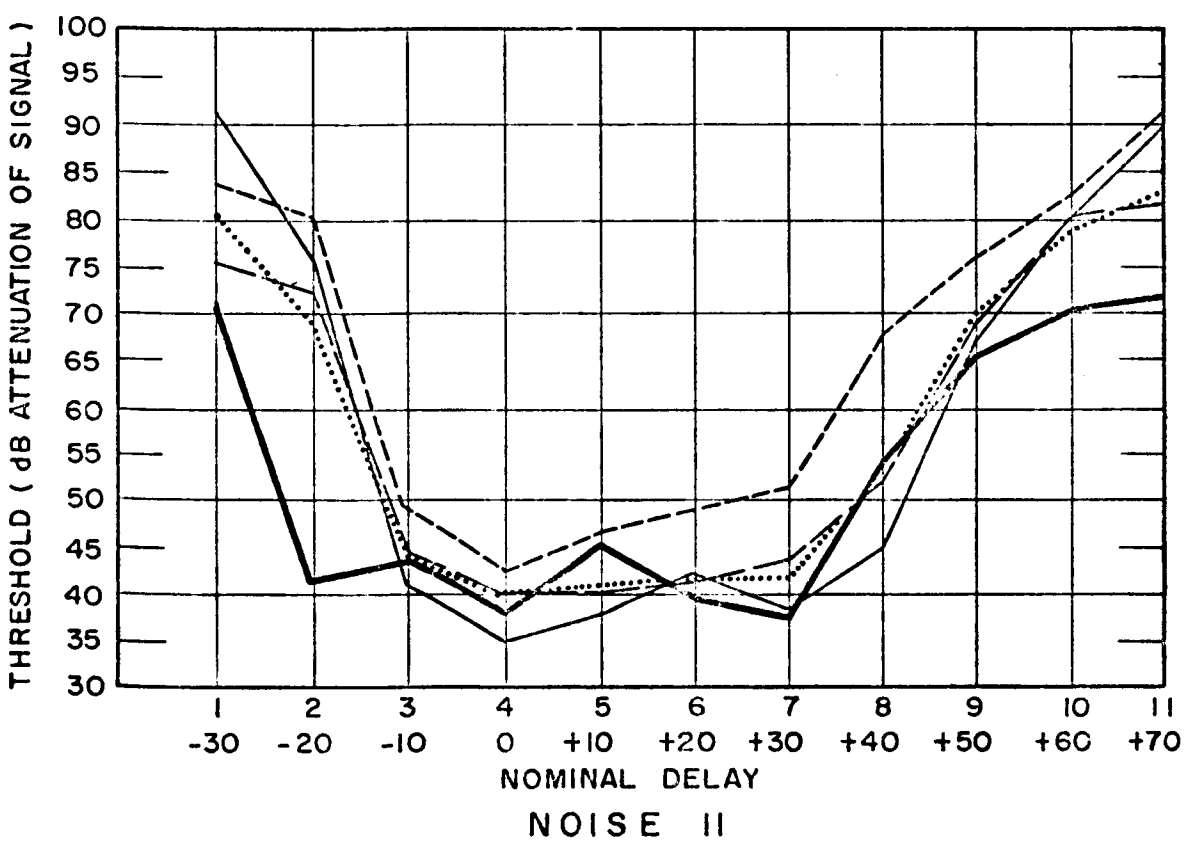
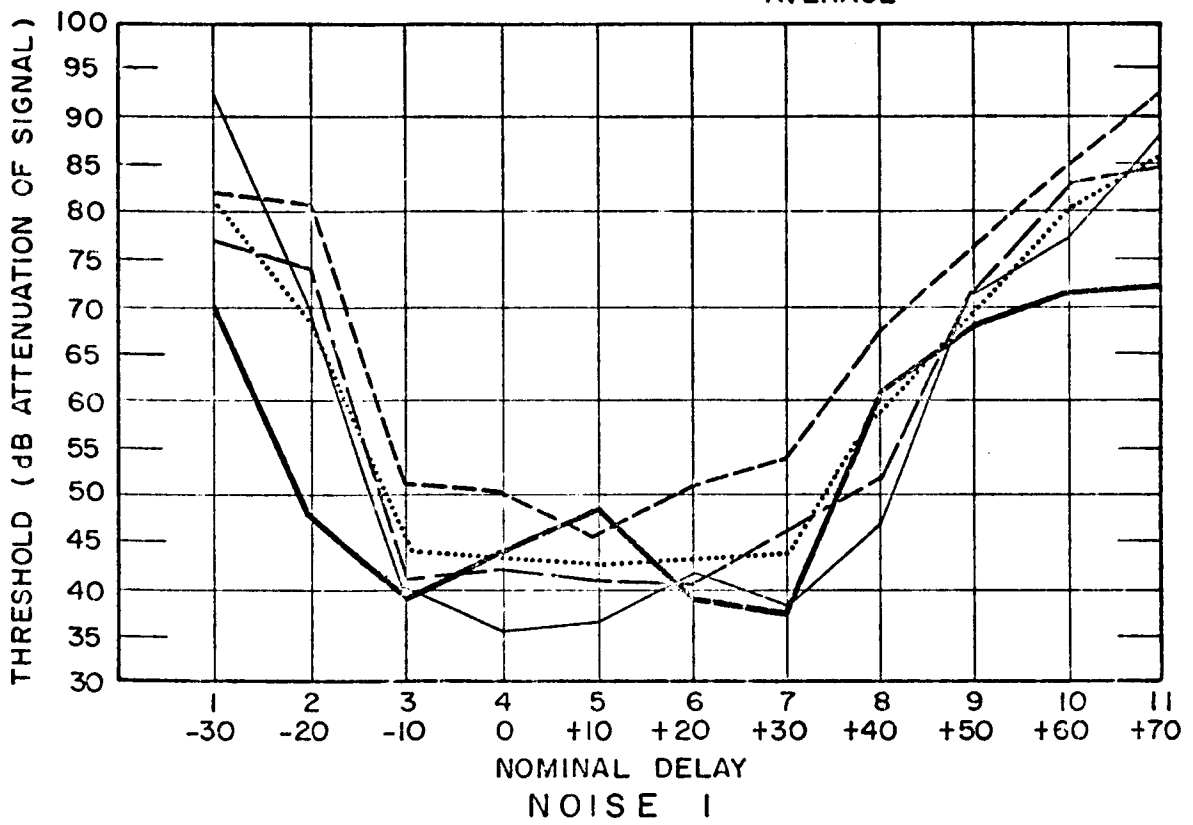
Effect of Noise Waveform

In general, as can be seen in Figures 20 to 24, Noise Waveform I produced lower thresholds than Noise Waveform II. There was no consistent pattern as a function of delay i.e. threshold differences appeared to be interspersed over the backward, forward, and simultaneous conditions. It is interesting to note, however, that major deviations from the norm occurred during the simultaneous masking conditions rather than during either the backward or forward conditions.

Some individual differences are noteworthy. For

Figure 24. The effects of noise waveform.

SUBJECT 1 SUBJECT 3
SUBJECT 2 SUBJECT 4
..... AVERAGE



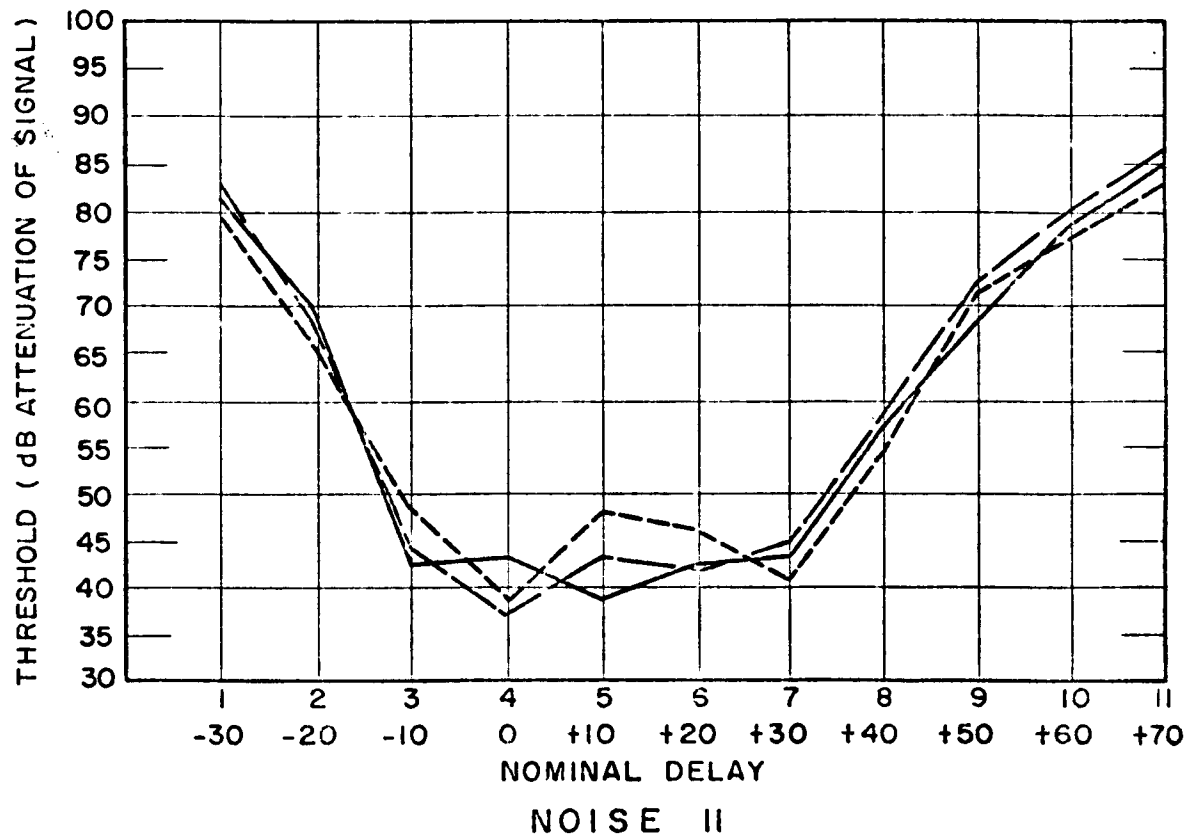
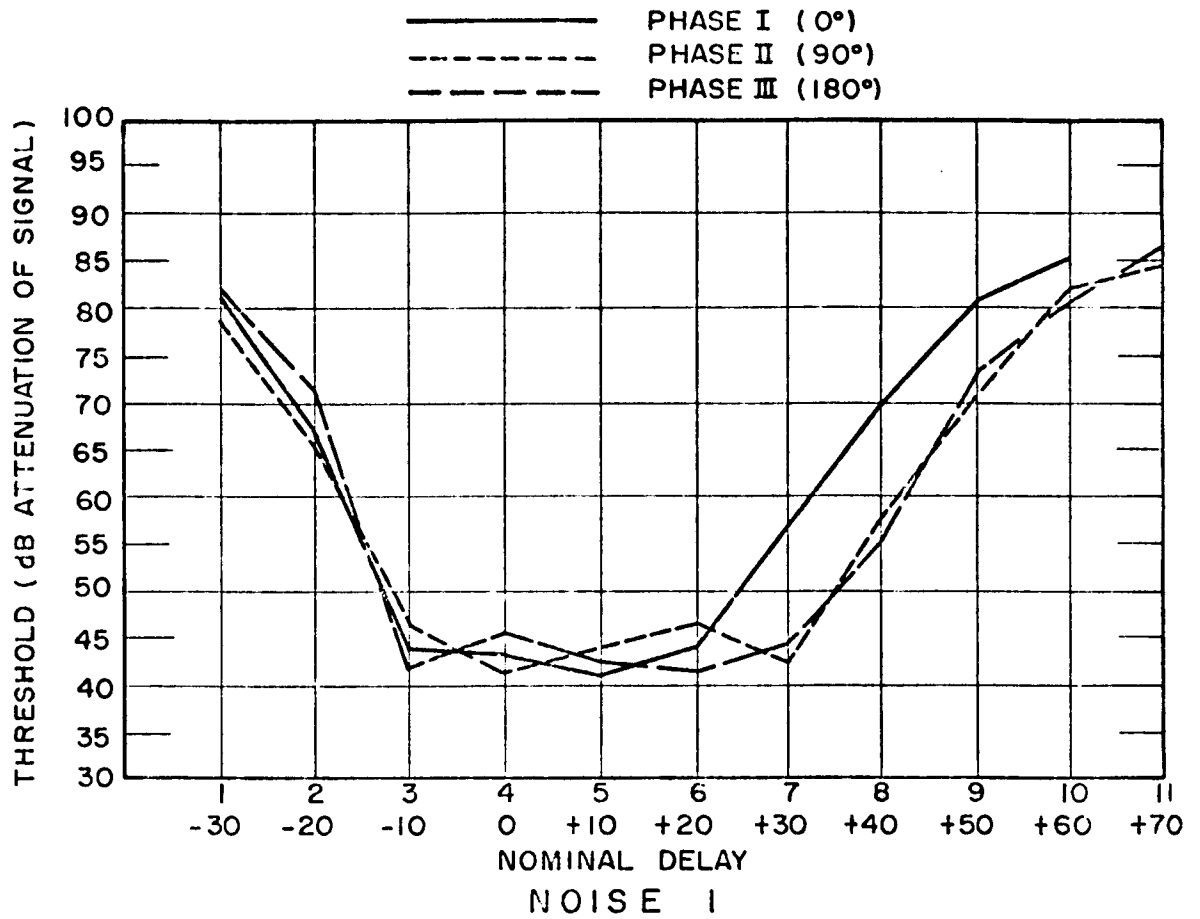
Subject 4, during the in-phase condition, a large reversal in pattern appeared for nominal delay 0 when the noise waveforms were different. During the Noise Waveform I presentation this subject exhibited about a 10 dB increase in (poorer) threshold from nominal delay -10 msec. to nominal delay 0 msec. With Noise Waveform II about a 4 dB decrease in threshold was noted between the same delay conditions. For the 90° out-of-phase condition with Noise Waveform I, the same subject had equal thresholds for nominal delays 0 and +10 msec. With Noise Waveform II, however, about a 6 dB decrease in (better) threshold was noted for the same delay conditions. During the same phase condition for nominal delay setting -10 msec., Subject 1 showed a poorer threshold with Noise Waveform I than with Noise Waveform II.

In short, the data showed statistically significant complex interactions between subjects, noise, and delay setting.

Effect of Phase

The effects of phase averaged over subjects is shown in Figure 25. The results were statistically sig-

Figure 25. The effects of phase averaged over subjects.



nificant with substantial interactions with delay, subjects, and delay, subjects, and noise. The change in initial phase had a statistically significant effect during the backward, forward, and simultaneous conditions.

Where threshold differences did occur as a result of initial phase shift, Phase III produced more of the lower thresholds and Phase II more of the higher thresholds although the results were scattered among the three phase conditions. It is interesting to note that when the 90° out-of-phase condition (Phase II) produced the lower thresholds they occurred during simultaneous masking conditions. In addition, although Phase III did produce more lower thresholds, the results were obtained primarily for backward and forward test conditions and none of the differences reached the mean of 6.7 dB obtained for the Phase II Noise Waveform II simultaneous masking conditions. Further, although the majority of high thresholds appeared during Phase II, Phase I for a simultaneous condition, exhibited the highest thresholds overall.

Individual subject differences were large; for instance, at the nominal 10 msec. delay two of the four subjects during Phase III had thresholds lower than the average threshold at the best Phase II condition.

Therefore, it is with caution that the mean thresholds over subjects are viewed.

CHAPTER V

DISCUSSION

There are certain problems inherent in experiments on the detection of short duration stimuli. Because of the limited frequency response of the headphones (as well as the ear) the duration of the stimulus is extended. Consider Figure 26, a calibration photograph. The electrical signal, on the upper trace, consists of three periods with a duration of 12 msec. The acoustic signal, on the lower trace, consists of more than three oscillations due to the damped oscillation of the headphone. Hence, for the condition where the tone burst nominally ended at the start of the noise burst (Delay #3), in actuality there was some overlap. In addition, for Delay #8, which had nominally full overlap, the tone burst actually finished following the noise burst. See Figure 27. The calibration photographs always consisted of the electrical tone burst on the upper trace and the acoustic noise burst on the lower trace. This was done since two artificial ears were not available and it was not possible

Figure 26. A photograph of the tone burst used in this experiment. The electrical signal is on the upper trace and the acoustic signal is on the lower trace. The time scale is 5 msec. per division.

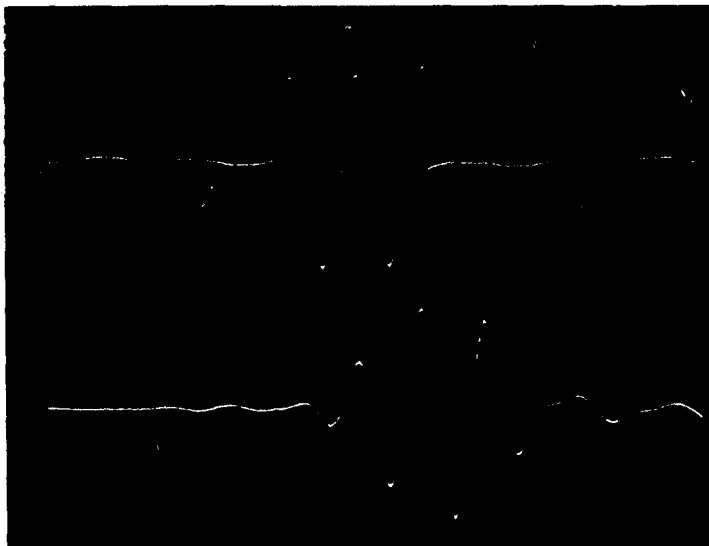
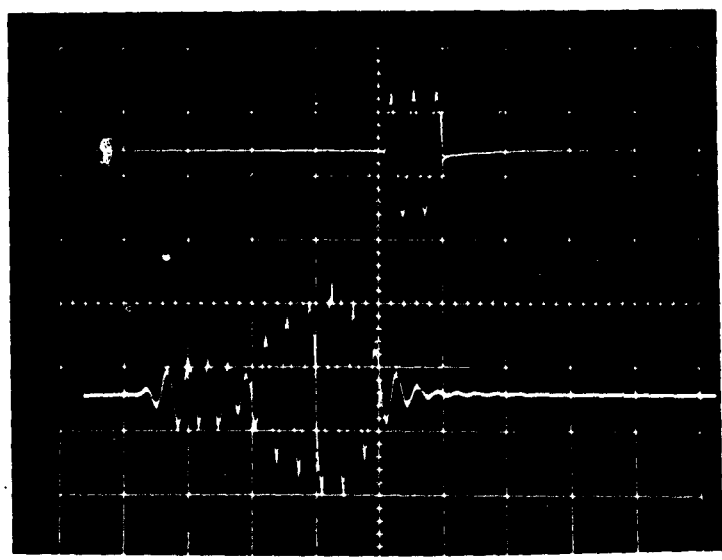


Figure 27. A calibration photograph for Delay #8 with the electrical tone burst on the upper trace and the acoustic noise burst on the lower trace.



to photograph simultaneously the acoustic tone burst and the acoustic noise burst on separate traces. The horizontal axes in Figures 20 to 25 are labelled 'nominal delay' since the actual delay was 2.2 msec. to 3.7 msec. different depending on the criterion for defining the onset of the tone burst. The acoustic tone burst did begin immediately but after 2.2 msec. there was the first noticeable evidence on the oscilloscope trace of the tone burst. The first peak occurred after 3.7 msec. On the electrical (0°) signal, the first peak occurred after 1 msec. ($=\frac{1}{4}$ period).

The term 'ringing' has often been used to refer to the damped oscillations of the headphone diaphragm. These damped oscillations are a property of linear systems including headphones, the middle ear, and, to a first approximation, the basilar membrane.

In summary, there is no instantaneous jump from a no overlap condition to an overlap condition. The large increase in masking that was found for Delay #3 and the decrease in masking that was noted for Delay #8 may be, in part, due to the overlap between signal and noise caused by these damped oscillations. It is not clear from published literature whether this effect

had been taken into account in prior research.

Since ringing occurs in physical systems, it is to be expected that ringing will also occur in the middle ear and at the basilar membrane. Since the bandwidth of a specific point on the basilar membrane is much narrower than the bandwidth of the middle ear, the damped oscillations are likely to be substantially longer at the basilar membrane than due to transmission through the middle ear. From Flanagan's computer model of the middle and inner ears based on Bekesy's data (Flanagan, 1972), significant oscillations continue for at least two periods following cessation of the tone burst; hence, overlap within the ear may be as much as 8 msec. for a 250 Hz tone burst due to the action of the basilar membrane alone.

In experiments such as this a criterion problem also arises. Intersubject differences could possibly be explained on the basis of differences in criteria. For the backward and forward masking conditions the presence of the tone pulse could be perceived as either an increase in loudness, or an increase in the duration of the combined stimulus, or some other change in the quality of the stimulus. Typically, the subjects reported

that the interval containing the signal was longer and "rougher" than the non-signal interval. It should be noted that the phase shift caused a 1 msec. to 2 msec. increase in time delay. Thus, even the phase shift for the forward and backward conditions could perhaps have been perceived on the basis of durational cues.

For the simultaneous conditions, however, the criteria were often less well defined. Depending on the relative phase between tone burst and noise, the interval containing the signal has been either louder, less loud, or equally as loud as the non-signal interval. In an attempt to circumvent this problem, all subjects were advised as to all possible criteria that could be used and were then instructed to utilize any criterion at their disposal in order to detect the signal. Prior to each test condition the tone burst was set at its most detectible level (maximum intensity) so that the subjects could easily identify it. This was done to permit each subject to stabilize the criteria that would be used for that particular test condition. However, subsequent reports by subjects indicated that it was often difficult for them to retain the criterion established at suprathreshold levels for threshold detection.

In addition, memory for the waveform could have had an effect. Since two reproducible noise waveforms were used throughout the experiment, it is possible that the subjects could have learned to recognize the pattern of each of the waveforms respectively.

Fatigue did not appear to be a factor in this experiment. There were no statistically significant differences between the results obtained at the beginning of one test session and those obtained at the end of a second test session for the replication of the same test condition.

In summary, any number of criteria could have been used to detect the signal: loudness, intensity, pattern recognition, duration, or other cues stemming from the interaction between signal and noise. Because of the difficulty reported by the subjects in maintaining a stable criterion in going from suprathreshold to threshold levels, it is not clear to what extent the criterion variations occurred between subjects and between test conditions. Replications, however, showed a high repeatability ($e = 1$ dB) within subjects and test conditions.

Results of this experiment substantiated the

data of other researchers who have shown greater backward than forward masking at short masking intervals. The masking functions obtained in this experiment were similar to those reported by Pickett (1959) and Elliott (1962) although greater masking was found in this experiment when a nominal -10 msec. silent interval existed between tone pulse and masker. The studies by Pickett and Elliott, however, used wide-band maskers. In addition, the nominal -10 msec. silent interval referred to in this experiment was in fact briefer due to the damped oscillations of the tone pulse.

As was expected, greater masking was found for all simultaneous conditions than for any of the backward or forward masking conditions. Significant overshoot was not observed in these data. The lack of overshoot is in agreement with the findings of Zwicker and Wright (1963), Wright (1964) and Zwicker (1965) who observed that little overshoot will occur when the masker and the probe signal have the same or similar spectral characteristics.

There were some unexpected results. Prior to the experiment, it was hypothesized that the differences between the two noise waveforms and the phase shifts would have a

significant effect on the thresholds obtained for the simultaneous masking conditions and little or no effect on the backward and forward masking conditions. The results do not substantiate these hypotheses. Table 2 clearly shows that phase changes had an effect during the backward and forward masking conditions in addition to the simultaneous masking conditions. A significant difference between two phase conditions is approximately 4 dB at the .95 significance level and about 7 dB at the .99 significance level. A single + in Table 2 refers to the 4 dB or greater difference while a ++ refers to the 7 dB or greater difference. The phase shifts which caused a 1 msec. to 2 msec. increase in delay could conceivably have been detected as a durational change (either in overall duration, or, more likely, in the duration of the silent interval) during the backward and forward masking conditions.

The results substantiate the hypothesis that differing sections of a selected narrow-band noise will effect the detection of signals; however, although the differences between the noise waveforms were significant, they were not present to the degree expected. For example, consider Delay #5. One would have expected that

Table 2. The effects of phase shift as a function of delay, subjects, and noise waveform.

		BACKWARD CONDITIONS			SIMULTANEOUS CONDITIONS					FORWARD CONDITIONS		
		DELAY			DELAY					DELAY		
		1	2	3	4	5	6	7	8	9	10	11
SUBJECT 1	NOISE 1	+	+	+	+	+	+	+		+		
	NOISE 2	+	+		+	+	+	+	+	+	+	
SUBJECT 2	NOISE 1	+	+			+	+	+	+	+	+	+
	NOISE 2	+	+			+	+	+	+	+	+	+
SUBJECT 3	NOISE 1	+	+	+	+	+		+		+	+	
	NOISE 2		+	+		+	+					
SUBJECT 4	NOISE 1				+	+	+	+				
	NOISE 2	+	+	+	+	+	+					+

since the initial one-third of Noise Waveform II showed significantly higher levels than the initial one-third of Noise Waveform I, the additivity of the tone pulse and Waveform II would have produced substantially better thresholds. The data show these differences to be negligible. In addition, the effects obtained due to noise waveform differences were interspersed throughout all delay conditions--forward, backward, and simultaneous. However, major deviations from the norm did occur during the overlapping conditions.

As mentioned in Chapter IV, the performance of Subject 1 was noticeably different from the other three subjects. This subject, who had audiometric thresholds within normal limits, was the oldest subject and indeed showed significantly poorer thresholds for many of the experimental conditions. Although he is a highly experienced listener, he expressed difficulty in establishing the criterion for detection, particularly for the backward masking conditions. This was consistent with the data obtained: his performance relative to the other subjects was poorest for the backward masking conditions.

It appears from the data that a theory formulated to explain backward masking would have to include more

variables than temporal effects, intensity effects, and on-effects. Waveform storage becomes a possibility. If the stimulus waveform is processed and stored neurally, (or alternatively short-term spectrum changes stored neurally) then one would expect threshold changes to occur if the shape of the waveform or the phase of the tone pulse is changed. However, since these factors did not produce uniform differences in detection over subjects, it is not possible at this time to explain the data in terms of waveform storage. It is possible that these differences were due to consistent differences in criterion between subjects. Random differences in criterion seem unlikely since the data were highly repeatable within subjects.

Waveform storage implies the involvement of central rather than peripheral mechanisms. However, evidence does exist for backward masking to be explained on the basis of the peripheral mechanism. Guttman, van Bergeijk, and David (1960) proposed that time-intensity reciprocity could explain short term backward masking. The travel time of an intense stimulus is speeded up in the area of neural synapses; a signal presented at a low

intensity level crosses a synapse at a slower rate. Therefore, if one employs an intense masker following a signal presented at a low level, it is possible for the masker to overtake the preceding signal and bring about the condition of backward masking. This time-intensity reciprocity could account for short term backward masking of up to 5 msec. Guttman, van Bergeijk, and David (1960) hypothesized that for longer term backward masking an explanation involving centers above the peripheral neural mechanism should be sought. Waveform storage could be involved in this long term backward masking.

The studies on dichotic backward masking suggest an explanation involving peripheral mechanisms only. All studies found considerably less backward masking when the stimulus and masker were presented to opposite ears than when the presentation was monotic (Elliott, 1962; Deatherage and Evans, 1969). This implies that the interaction between stimulus and masker occurs at a level below that at which binaural interaction first occurs i.e. at least at the level of the cochlear nucleus since physiological evidence of binaural interaction has been observed

at the level of the superior olivary complex. However, since backward masking is reduced but not eliminated under dichotic conditions, this explanation can only account in part for the data. It is more likely that a combination of peripheral and central effects is in operation.

In summary, phase i.e. small time shifts, and noise waveform are important for backward, forward, and simultaneous masking. It is not clear if these effects are due to criterion changes or waveform storage in the auditory system. Clearly, future research must consider criterion problems which affect detection experiments with reproducible noise bursts, even within a forced-choice test paradigm. One possible way to control for and manipulate the criterion is to investigate each criterion individually with each subject. Prior to an experiment, each subject would be presented with the experimental paradigm and instructed to utilize only one criterion, e.g. intensity changes, in order to detect the signal. The subject would then be instructed to perform the same detection task using durational changes as the criterion. This would continue until all likely criteria have been investigated.

An auditory profile could then be established on each subject based upon the differences in threshold obtained with each of the criteria. During the main experiment, the subjects would be instructed to use those criteria which led to the most sensitive thresholds.

REFERENCES

- Babkoff, H., and Sutton, S., "Monaural Temporal Masking of Transients," Journal of the Acoustical Society of America, 44, 1373-1378 (1968).
- Bilger, R. C., "Additivity of Different Types of Masking," Journal of the Acoustical Society of America, 31, 1107-1109 (1959).
- Chistovich, L. A., and Ivanova, V. A., "Mutual Masking of Short Sound Pulses," Biofizika, 4, 170-180 (1959).
- Deatherage, B. H., and Evans, T. R., "Binaural Masking: Backward, Forward and Simultaneous Effects," Journal of the Acoustical Society of America, 46, 362-371 (1969).
- Dirks, D., and Bower, D., "Effect of Forward and Backward Masking on Speech Intelligibility," Journal of the Acoustical Society of America, 47, 1003-1008 (1970).
- Elliott, L. L., "Backward Masking: Monotic and Dichotic Conditions," Journal of the Acoustical Society of America, 1108-1115 (1962).
- Elliott, L. L., "Backward and Forward Masking of Probe Tones of Different Frequencies," Journal of the Acoustical Society of America, 34, 1116-1117 (1962).
- Elliott, L. L., "Temporal Variables in Masking of Short Tones by Noise Bursts," Journal of the Acoustical Society of America, 36, 1028(A) (1964).
- Elliott, L. L., "Backward Masking: Different Durations of the Masking Stimulus," Journal of the Acoustical Society of America, 36, 393 (1964).

- Elliott, L. L., "Changes in the Simultaneous Masked Threshold of Brief Tones," Journal of the Acoustical Society of America, 38, 738-746 (1965).
- Elliott, L. L., "Development of Auditory Narrow-Band Frequency Contours," Journal of the Acoustical Society of America, 42, 143-153 (1967).
- Elliott, L. L., "Masking of Tones Before, During and After Brief Silent Periods in Noise," Journal of the Acoustical Society of America, 45, 1277-1279 (1969).
- Elliott, L. L., "Backward and Forward Masking," Audiology, 10, 65-76 (1971).
- Flanagan, J. L., Speech Analysis Synthesis and Perception, Chapter IV, Springer-Verlag (1972).
- Glatcke, T., and Small, A. Jr., "Frequency Selectivity of the Ear in Forward Masking," Journal of the Acoustical Society of America, 42, 154-157 (1967).
- Gol'dburt, S. N., "Persistence of Auditory Processes within Microintervals of Time (New Data on Retroactive Masking)," Biophysics, 6, 76-81 (1961).
- Green, D., "Additivity of Masking," Journal of the Acoustical Society of America, 41, 1517-1525 (1967).
- Guttman, N., van Bergeik, W. A., and David, E. E., "Monaural Temporal Masking Investigated by Binaural Interaction," Journal of the Acoustical Society of America, 32, 1329-1336 (1960).
- Homick, J. L., Elfner, L. F., and Bothe, G. G., "Auditory Temporal Masking and the Perception of Order," Journal of the Acoustical Society of America, 45, 712-718 (1969).
- Levitt, H., "Transformed Up-Down Methods in Psychoacoustics," Journal of the Acoustical Society of America, 49, 467-477 (1971).

- Ldscher, E., and Zwislock, J., "Adaptation of the Ear to Sound Stimuli," Journal of the Acoustical Society of America, 21, 135-139 (1949).
- Miller, R. L., "Masking Effect of Periodically Pulsed Tones as a Function of Time and Frequency," Journal of the Acoustical Society of America, 19, 798-807 (1947).
- Osman, E., and Raab, D., "Temporal Masking of Clicks by Noise Bursts," Journal of the Acoustical Society of America, 35, 1939-1941 (1963).
- Pfafflin, S. M., "Detection of Restricted Sets of Reproducible Noise," Journal of the Acoustical Society of America, 43, 487-490 (1968).
- Pfafflin, S. M., and Mathews, M. V., "Energy-Detection Model for Monaural Auditory Detection," Journal of the Acoustical Society of America, 34, 1842-1853 (1962).
- Pfafflin, S. M., and Mathews, M. V., "Detection of Auditory Signals in Reproducible Noise," Journal of the Acoustical Society of America, 39, 340-345 (1966).
- Pickett, J. M., "Backward Masking," Journal of the Acoustical Society of America, 31, 1613-1615 (1959).
- Pollack, I., "Interaction of Forward and Backward Masking," Journal of Auditory Research, 4, 63-67 (1964).
- Raab, D. H., "Forward and Backward Masking Between Acoustic Clicks," Journal of the Acoustical Society of America, 33, 137-139 (1961).
- Raab, D. H., "Backward Masking," Psychological Bulletin, 60, 118-129 (1963).

- Raab, D., Osman, E., and Rich, E., "Effects of Waveform Correlation and Signal Duration on Detection of Noise Bursts in Continuous Noise," Journal of the Acoustical Society of America, 35, 1942-1946 (1963).
- Samoilova, I. K., "Masking Effect of a Strong Sound Stimulus on a Previously Applied Weak One," Biofizika, 1, 79-97 (1956).
- Samoilova, I. K., "Masking of Short Tone Signals as a Function of the Time Interval between Masked and Masking Sounds," Biofizika, 4, 550-558 (1959).
- Wilson, R. H., and Carhart, R., "Forward and Backward Masking: Interactions and Additivity," Journal of the Acoustical Society of America, 49, 1254-1263 (1971).
- Wright, H. N., "Temporal Summation and Backward Masking," Journal of the Acoustical Society of America, 36, 927-932 (1964).
- Wright, H. N., "Backward Masking for Tones in Narrow-Band Noise," Journal of the Acoustical Society of America, 36, 2217-2221 (1964).
- Zwicker, E., "Temporal Effects in Simultaneous Masking by White-Noise Bursts," Journal of the Acoustical Society of America, 37, 653-663 (1965).
- Zwicker, E., "Temporal Effects in Simultaneous Masking and Loudness," Journal of the Acoustical Society of America, 38, 132-141 (1965).
- Zwicker, E., and Wright, H. N., "Temporal Summation for Tones in Narrow-Band Noise," Journal of the Acoustical Society of America, 35, 691-699 (1963).
- Zwislock, J. J., "Theory of Temporal Auditory Summation," Journal of the Acoustical Society of America, 32, 1046-1060 (1960).

Zwislocki, J., Pirodda, E., and Rubin, H., "On Some Poststimulatory Effects at the Threshold of Audibility," Journal of the Acoustical Society of America, 31, 9-14 (1959).