Effect of "backward" masker fringe on the detectability of pulsed diotic and dichotic tonal signals

CONSTANTINE TRAHOTIS

University of Illinois, Champaign, Illinois 61820

and

TERRENCE R. DOLAN and THEODORE H. MILLER

Parmlay Hearing Institute and Loyola University, Chicago, Illinois 60626

The effects of backward masker "fringe" on performance in homophasic and antiphasic masking conditions were investigated. The results of the study indicate that (1) the presence of a backward masker fringe has only a small effect on performance in homophasic masking conditions; (2) under antiphasic masking conditions, the presence of a backward masker fringe improves performance; (3) similar to the results of studies investigating the effects of forward masker fringe, the magnitude of the improvement in performance increases as the duration of the fringe increases; and (4) the magnitude of the improvement caused by the presence of backward masker fringe is considerably smaller than the magnitude of the improvement caused by the forward masker fringe. It appears, then, that the presence of backward masker fringe may provide a baseline or reference phase similar to that which the forward fringe is presumed to provide. The presence of this reference phase after the offset of the signal apparently makes the phase shift associated with the signal-plus-noise waveform more discernible, thus leading to higher detectability. However, for reasons not yet clear, the presence of a baseline or reference phase after the offset of the signal (backward fringe conditions) does not make the signal-plus-noise phase shift as discernible as do either the presence of that same reference phase before the onset of the signal (forward fringe condition) or the presence of that same reference phase both before signal onset and after signal offset (continuous masker condition).

Most of the investigations of binaural masking have employed continuous noise as the masker and a gated tone as the signal (i.e., Hirsh, 1948; Hirsh & Webster, 1949; Webster, 1951; Jeffress et al, 1956). McFadden (1966), however, studied the effects of continuous vs pulsed noise maskers in homophasic and antiphasic conditions (see also Watson, 1962). McFadden used a 400-Hz tone of 125 msec duration as the signal and a wide-band thermal noise as the masker. In the pulsed condition, the noise and the signal onsets and offsets were simultaneous. He found that, in the homophasic condition, N_0S_0 , signal detectability when the noise was pulsed was the same as it was when the noise was continuous. However, signal detectability in the antiphasic conditions (N_0S_π and $N_\pi S_0$) was degraded when the masker was pulsed relative to the conditions in which the masker was continuous, resulting in a smaller MLD (an MLD, or masking level difference, is the advantage exhibited by the binaural system when detecting a tonal signal in a background of masking noise in antiphasic relative to homophasic stimulus conditions).

In the second part of this study, McFadden investigated the effect of extending the duration of the masker forward in time (prior to the onset of

the signal) from the pulsed condition just described. The masker and signal offsets occurred simultaneously, but the onset of the masker preceded the onset of the signal. The results indicated that the MLDs increased from about 12 dB at 0 msec of forward "fringe" to about 16 dB at 600 msec of "fringe," the value of the MLD that was obtained in continuous noise.

McFadden explained the results of this study in relation to the Webster-Jeffress hypothesis (Webster, 1951; Jeffress, Blodgett, Sandel, & Wood, 1956; Jeffress, 1972). He suggested that the continuous noise condition provided the binaural auditory system with a baseline or reference phase prior to the onset of the signal. At the onset of the signal, then, the resultant phase shift (θ) was from a known interaural phase to an interaural phase relation that was dependent upon the characteristics of the signal. In the pulsed masker condition, however, there was no interaural phase relation prior to the onset of the signal since there was no "noise alone." The noise and the signal were added prior to presentation so that the phase shift caused by the simultaneous presentation of the two waveforms was not away from a reference phase and was therefore less discernible.

In a recent study investigating backward masking, Dolan and Trahiotis (1972) used a masking noise of fixed duration (75 msec) to mask an 8-msec tone in order to determine the effect of various temporal relations between signal and masker on the MLD (N_0S_0 relative to N_0S_π). They varied the temporal relations between the tonal signal and the noise masker by delaying the onset of the noise relative to the onset of the signal. One of their conditions, $\Delta t = 0$, is comparable to the pulsed masker condition studied by McFadden except for the 67 msec of masker occurring after the offset of the signal. It is interesting to note, however, that the size of the MLD obtained by Dolan and Trahiotis in this condition was 20 dB, whereas McFadden's pulsed masker condition yielded an MLD of only 12 dB. Even though it has been shown that, as the duration of a tonal signal decreases, the magnitude of the MLD increases (Blodgett, Jeffress, & Taylor, 1958), an MLD of the magnitude obtained by Dolan and Trahiotis would not be expected. This is so because the maskers used in their conditions were gated and, unlike those used by McFadden, had no forward fringe. Evidently, then, the occurrence of part of the masking noise after the offset of the signal in the Dolan and Trahiotis study may have acted much like the forward fringe in the McFadden study.

These data may be interpreted as evidence that the binaural system uses the occurrence of the masking noise after the offset of the signal to provide a baseline or reference phase similar to that discussed by McFadden (1966). Thus, the phase shift of the signal-plus-noise waveform might become more apparent and result in higher detectability and a larger MLD. The present study was an attempt to determine the extent to which occurrence of masking noise after the offset of the signal improves performance in a binaural detection task.

PROCEDURE

The binaural masking conditions investigated in this study were the homophasic condition, N_0S_0 , and the antiphasic condition, N_0S_π . The signal was a 20-msec sample of a 500-Hz sinusoid gated with 2.5-msec rise-fall times. The masker was a band-pass noise, 100-3,000 Hz, with a spectral level of 50 dB SPL. Masker durations were 30, 50, 250, 500, and 1,000 msec. All pulsed maskers were gated with 1-msec rise-decay time. In addition, a continuous masking condition was employed. Three of the six temporal relations between signal

Fig. 1. Three of the six temporal relations of the signal and the noise investigated in the present experiment. In all conditions, the signal was a 20-msec 500-Hz tone. In addition to the masker durations of 30, 50, and 1,000 msec shown here, 250 msec, 500 msec, and continuous maskers were also employed. Rise-fall times were 2.5 msec for the signal and 1 msec for the noise masker.

and masker considered in this study are shown in Fig. 1.

To measure performance in each masking condition and to determine the magnitude of improvement in the antiphase condition relative to the homophase condition, a two-alternative temporal forced-choice (2ATFC) technique was used. The O's task was to state in which of two observation intervals the signal had occurred. Each trial consisted of the following temporal sequence: warning light (0.4 sec), pause (0.4 sec), light indicating first observation interval (0.02 sec), pause (0.4 sec), light indicating second observation interval (0.02 sec), response interval (1.5 sec), and "feedback" interval (0.2 sec). The lights used to designate the intervals were spatially and temporally discrete. The signal occurred on every trial with equal probability of occurrence in each interval. The feedback light informed the O after each trial which of the two intervals had contained the signal.

The measure of performance for each masking condition was the average percent correct, $P(c)$, for Intervals 1 and 2 computed for 400 trials at each of two signal-to-noise ratios. From these data, 2-point psychometric functions (functions relating percent correct to signal energy) were generated for each O at

each temporal relation for the homophase and the antiphase conditions. These psychometric functions were fitted by the equation,

$d' = m(E/N_0)^k$, where E is the energy of the signal, N_0 is the noise power per unit bandwidth, and m and k are constants. d' was transformed to $P(c)$, (E/N_0) was transformed to $10 \log (E/N_0)$, and the best-fitting values of m and k were selected by eye. A more detailed description of this procedure has been reported by Egan (1965).

The four Os used in this experiment were either members of the staff of the Parmlly Hearing Institute or students at Loyola University having clinically normal hearing; they were paid for their services.

RESULTS

Twelve psychometric functions were determined for each O. These functions correspond to the 12 combinations of the two interaural phase relations and the six masker durations. As has been shown by Egan (1965), the slope of the psychometric function may be considered a constant for a single O across all conditions. The values of k , the slope of the function, which best fit the data were 1.25 for one of the Os and 1.00 for the other three.

The size of the MLD in decibels for each masker duration was computed by measuring the lateral displacement of an $N_0 S_\pi$ function from its corresponding $N_0 S_0$ function. Since the inter-O variability was small, only the mean MLDs for the four Os are reported in Fig. 2 as a function of masker duration.

As indicated in Fig. 2, as the

Fig. 2. The magnitude of the mean MLD ($N_0 S_\pi$ relative to $N_0 S_0$) for the four Os as a function of masker duration. Each point represents the magnitude of the mean MLD based on the data for the four Os at one of the six temporal relations investigated.

duration of the masking noise increases from 30 msec to continuous, the mean MLD increases from 7.50 to 15.50 dB. Of this total increase of 8 dB, roughly half (4.25 dB) occurs between the 30- and 250-msec masker conditions. As the masker duration increases from 250 to 1,000 msec, no noteworthy change in the mean MLD takes place. However, in the change from the 1,000-msec duration to continuous masking noise, the mean MLD increases 3.50 dB. Therefore, increase in the mean MLD takes place in the transition between masker durations of 30 and 250 msec and also in the shift from the 1,000-msec masker condition to the continuous masker condition. However, the increases in masker duration from 250 to 1,000 msec had little effect on the mean MLD.

Since the size of the MLD is determined by measuring the lateral displacement of the homophasic and antiphase psychometric functions, it is apparent that the size of the MLD can be altered by changes in the position of either the N_0S_0 function or the N_0S_π function, or both. In order to examine the basis for the change in the MLD obtained as masker duration was manipulated, the mean signal-to-noise ratio necessary for 80% correct detection for the four Os was calculated for each combination of interaural phase relations and masker duration. These data are presented in Fig. 3. Since a theoretical function of the same slope can be fitted rather well to all the psychometric functions for a given O, the MLD is independent of the level of performance. Therefore, the vertical displacement of the N_0S_0 function from the N_0S_π function is the MLD.

It should be noted that as masker duration increases from 30 to 250 msec, there is both a small improvement in performance under the antiphase condition and a small decrement in performance under the homophase condition. The net effect of changes in performance in both the homophase and antiphase conditions is a 4.75-dB increase in the magnitude of the MLD. The increase in the mean MLD between the 1,000-msec and the continuous masker condition is, however, almost solely the result of an improvement in performance under the N_0S_π condition.

DISCUSSION

The results of this study indicate that the magnitude of the MLD obtained when the signal and masker onsets are simultaneous depends upon the length of time by which the offset of the masker follows the offset of the signal.

Although the effect of this

Fig. 3. Mean signal-to-noise ratio necessary for 80% correct detection (N_0S_0 and N_0S_π) for the four Os as a function of masker duration. Each point represents the mean signal-to-noise ratio for 80% correct detection based on the data for the four Os at one of the six temporal relations investigated. Open symbols represent the N_0S_0 data for a particular temporal relation. Closed symbols represent the N_0S_π data for a particular temporal relation.

"backward fringe" on the MLD is somewhat similar to the effect of the forward fringe as reported by McFadden, there are some important distinctions that should be emphasized. In the present study (see Fig. 3), there was little change in the magnitude of the MLD between the 250- and the 1,000-msec masker conditions. However, as McFadden extended his masker forward in time, the obtained MLD increased steadily until, at 1,000 msec of forward fringe, it closely approximated the MLD obtained in the continuous masker condition. Therefore, McFadden was able to approximate the MLD obtained in the continuous masker condition by adding sufficient forward fringe to his pulsed masker. The results of the present study indicate that no amount of backward fringe leads to an MLD similar in magnitude to that obtained with a continuous masker.

In a recent study, Robinson and Trahiotis (1971) investigated the effect of forward fringe on MLDs by masking tonal signals of various durations with pulsed noise maskers. As in the McFadden study, the offsets of the signal and masker occurred simultaneously, and the onset of the masker was moved forward in time relative to that of the signal. Their results indicated that the effects of forward fringe on the magnitude of the MLD varied as a function of signal duration. At brief signal durations

(i.e., 32 msec), the magnitude of the MLD changed considerably as the duration of forward fringe was varied. At longer signal durations (i.e., 256 msec), however, the duration of forward fringe had little effect on the magnitude of the MLD. In order to compare the magnitude of the forward fringe effect to that of the backward fringe effect, the data from the present experiment are compared to the data obtained by Robinson and Trahiotis when a brief tonal signal was employed.

In Fig. 4, the data from Fig. 3 are replotted as a function of noise fringe rather than masker duration. Thus, a masker duration of 30 msec is represented by a noise fringe of 0 msec (including the rise-fall times of the signal and noise), a masker duration of 50 msec is represented by a noise fringe of 20 msec, and so on. Also plotted in Fig. 4 are the relevant data from the Robinson and Trahiotis study.

It can be seen from the upper set of points that performance in homophase conditions when forward fringed maskers are employed is similar to performance when backward fringed maskers are employed. The only discrepancy between the two sets of data is a 2-dB improvement in performance obtained in the 0-msec fringe condition of the present study. This 2-dB difference represents a small improvement in performance relative

Fig. 4. Data presented in Fig. 3 replotted as a function of noise fringe along with similar data from the Robinson and Trahiotis study. The data from the present study (dotted line) are plotted as a function of backward noise fringe. Therefore, a noise fringe of 0 msec corresponds to a masker duration of 30 msec; a noise fringe of 20 msec corresponds to a masker duration of 50 msec, and so on. The data from the Robinson and Trahiotis study (solid line) are plotted as a function of forward noise fringe. Open symbols represent the data from the $N_0 S_0$ condition, while closed symbols represent the data from the $N_0 S_\pi$ condition. The signal duration for the Robinson and Trahiotis data was 32 msec.

to other homophasic conditions when the signal and noise had simultaneous onsets and offsets. Neither McFadden nor Robinson and Trahiotis found any change in performance under homophasic conditions as a function of temporal relations of the signal and masker. Further investigation of the 30- and 50-msec masker duration conditions in our laboratory, using three other Os, yielded results consistent with those obtained in the present study. Although this difference appears to be reliable, its causes are not clear.

Examination of the lower set of points in Fig. 4 indicates that the performance in the antiphase conditions seems to differ as a function of whether the fringe is in the forward or in the backward fringe direction. Additionally, performance

in the forward fringe conditions approaches that obtained in a continuous masking situation as the duration of fringe increases. When the forward fringe is 500 msec, for example, the magnitude of the MLD is essentially the same as that obtained in the continuous masking situation. These results are not obtained in the backward fringe conditions. Performance in the antiphase masking conditions improves only 3 dB as the backward fringe increases from 0 to 970 msec, and the magnitude of the MLD in the 970-msec backward fringe condition is considerably less than that of the MLD obtained when a continuous masker was used. This difference is indicative of the inability of backward fringe to approximate the effect of a continuous masker on the magnitude of the MLD.

In summary, our data indicate that detectability in forward and backward masker fringe conditions is not equivalent, although both may cause an enhancement in performance. A masker onset 1,000 msec prior to the onset of the signal yields performance comparable to performance obtained when a continuous masker is used. It appears that no amount of backward fringe will produce results equivalent to those found in continuous noise.

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