Binaural interaction in backward masking*

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The binaural auditory system exhibits certain advantages over the monaural system when detecting a tonal signal in a background of masking noise. These advantages have been described in detail and are referred to as masking-level differences, or MLDs. It has been demonstrated, for example, that performance in detecting a tonal signal that has been reversed in phase at one ear relative to the other ear is about 15-17 dB better than detection of the same signal in-phase at the two ears when masked by moderately intense masking noise that is in-phase at the two ears. The explanations for this phenomenon fall into two general categories, and both types of explanations are based upon the *interaction* of the tonal signal and masker when they are added together. In the present paper, data are presented which indicate that an MLD of at least 4-5 dB can be obtained in a binaural masking experiment in which the offset of the tonal signal precedes the onset of the noise masker.

During the past several years, a great many investigations have been concerned with describing and explaining the general phenomena of masking-level differences (MLDs). An MLD is the advantage exhibited by the binaural auditory system relative to the monaural auditory system when detecting a tonal signal in a background of masking noise. These advantages are well documented, and in general, they are a function of interaural disparities of either the tonal signal or the masking noise.

In general, for the conditions which are about to be considered, the explanations for these phenomena have taken one of two forms. They have either considered the time shift caused by the addition of the signal to the masker, i.e., the Webster-Jeffress hypothesis (Webster, 1951; Jeffress, Blodgett, Sandel, & Wood, 1956; Jeffress, in press), or they have suggested that the power of the difference of the two waveforms arriving at the two ears represents the salient cue, i.e., the Durlach equalization-cancellation model (Durlach, 1960, 1963, in press) for detection.

It should be noted that both models are fairly successful at accounting for the size of the MLD as a function of several signal and noise parameters. The models, for example, predict the

relative changes in the size of the MLD as a function of such signal parameters as intensity, frequency, and interaural phase and such masker parameters as interaural correlation and interaural phase. It should also be noted that both models assume that the *signal and masker occur simultaneously* or that the presentation of the signal occurs some time *during* the occurrence of the masker. For both models, it is the *interaction* of the signal and masker that leads to binaural improvement.

The present paper is concerned with

the demonstration of a binaural improvement or an MLD in a masking situation in which the signal and masker do not occur simultaneously or temporally overlap. One such condition is the traditional backward masking paradigm in which the signal occurs previous to the onset of the masker (Elliott, 1962). Since the signal and masker are temporally separated, the two types of models discussed above would not predict binaural improvement relative to monaural performance.

PROCEDURE

The temporal relations between the tonal signal and noise masker considered in the present investigation are illustrated diagrammatically in Fig. 1. In the simultaneous condition, the signal and masker were gated simultaneously, i.e., the points of onset were equivalent. The signal had a duration of 8 msec and a 2.5-msec rise-fall time. The masker duration was 75 msec, with instantaneous rise-fall time. In order to vary the temporal relation between the signal and masker, the onset of the masker was delayed and the amount of onset-delay was described as Δt . For a Δt of 8 msec, for example, the onset of the noise masker occurred at 8 msec after the onset of the signal. Other Δt s investigated were 10, 12, 14, 16, and 20, although each Δt was not run in each Δt condition. Since signal duration was 8 msec and had approximately a 2.5-msec rise-fall time, any Δt greater than 10.5 msec

Fig. 1. A schematic representation of the signal-noise temporal relations used in the present experiment. All Δt s beyond approximately 10 msec represented conditions in which the signal and noise did not temporally overlap.

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Fig. 2. These curves show a portion of the results of the experiment for O1. Each function represents the percent correct in a 2ATFC paradigm as a function of the S/N ratio expressed in decibels. The parameter for each curve is the interaural phase relation of the signal and masker (either NOSO or NOS π). Results shown in the upper segment were obtained at a $\Delta t = 0$ msec. The middle segment indicates results obtained at a $\Delta t = 12$ msec, and the lower segment results at a $\Delta t = 20$ msec.

represented a masking condition in which the signal and masker did not overlap in time.

The two binaural masking conditions considered at each temporal relation were the homophasic condition (NOSO) and the antiphasic condition (NOS π). The homophasic condition is one in which the masker and signal are presented in-phase at the two ears. The antiphasic condition is one in which the masker is in-phase at the two ears, but the signal has been phase-shifted at one ear by 180 deg relative to the other.

In order to measure performance in each of the masking conditions and to determine the magnitude of improvement in the antiphasic condition relative to the homophasic condition, a two-alternative temporal forced-choice (2ATFC) technique was

used. Each trial consisted of the following temporal sequence: warning interval (0.5 sec), pause (0.5 sec), first observation interval (0.008 sec), pause (0.5 sec), second observation interval (0.008 sec), response interval (1.5 sec), and "feedback" interval (0.5 sec). Lights were used to designate the intervals and were spatially and temporally discrete. The signal occurred once and only once on every trial. The probabilities that it fell in the first or second interval were equal. The "feedback lights" informed the listener, after each trial, which of the two observation intervals contained the signal.

The measure of performance for each masking condition was the average percent correct, $P(C)$. $P(C)$ was computed after approximately 400 trials were run at each of two signal energies. From these data, two-point psychometric functions [function relating $P(C)$ to signal energy] were generated by each O at several temporal relations for NOSO and NOS π . The psychometric functions were fitted by the equation $d' = m(E/No)^k$, where E is the energy of the signal, No is the noise power per unit bandwidth, and m and k are constants. d' was transformed to $P(C)$, (E/No) was transformed to $10 \log (E/No)$, 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).

In addition to the psychometric functions generated at each masking condition, a two-point psychometric function was also generated on each O in the quiet. The difference between performance in the quiet and performance in any particular masking condition was used to indicate the amount of masking.¹ The difference between the amount of masking in the homophasic condition and the antiphasic condition at each temporal relation was used to indicate the magnitude of the MLD.

The masker in the present study was pulsed band-pass noise, 100-3,000 Hz, with a duration of 75 msec and a spectral level of 50 dB SPL. The signal was a 500-Hz tone burst with a duration of 8 msec. The tone was gated without respect to phase. All stimuli were delivered through Permoflux PDR-10 earphones, wired dichotically, and encased in cushions.

The Os used in the experiment were either members of the staff or students at Indiana University and were paid for their services.

RESULTS

The psychometric functions generated by one O for NOSO and NOS π at three temporal relations are shown in Fig. 2. Each section of the

Fig. 3. Shows the amount of masking in decibels obtained at NOSO (filled-in circles) and NOS π (filled-in triangles) as a function of the time delay on the onset of the masker relative to the onset of the signal (Δt). The data obtained on each O are indicated separately. The amount of masking was obtained by measuring the lateral displacement of the appropriate psychometric functions such as those shown in Fig. 2. The signal for all conditions was a 500-Hz tone with a duration of 8 msec and a rise-fall time of 2.5 msec. The masker was a pulsed band-pass noise, 100-3,000 Hz, with a duration of 75 msec and a spectral level of 50 dB SPL.

graph indicates the relationship between $P(C)$ and signal energy, and the parameter for the curves is the phase relation of the signal and the masker (either NOSO or NOS π). The upper section of Fig. 2 summarizes the data obtained when the signal and the masker were gated simultaneously ($\Delta t = 0$ msec), the middle section indicates the data obtained for $\Delta t = 12$ msec, and the lower section similarly indicates obtained data for 20 msec. The value of k , the slope, which best fitted the data was 1.25. Similar functions were generated by each of the remaining three Os. Note that since the functions are parallel,

the MLD at each temporal relation is simply the lateral displacement of the NOS_{π} function from the $NOSO$ function.

The amount of masking in the homophasic and antiphase conditions at each temporal relation for each O is shown in Fig. 3. The results obtained in the homophasic condition are represented by the filled-in circles and in the antiphase condition by the filled-in triangles. For each of the four Os tested, nearly 60 dB of masking was obtained in the homophasic condition when the onset of the signal and masker occurred simultaneously. The amount of masking decreased, however, as the onset of the masker was delayed relative to the onset of the signal. Each of the four Os also showed less masking in the antiphase condition at $\Delta t = 0$, usually of the magnitude of 20 dB. Three of the Os also showed less masking in the antiphase condition at every Δt investigated.

The difference between the homophasic condition and the antiphase condition, the MLD, is plotted for each O in Fig. 4 at each Δt . As indicated in Fig. 4, three of the four Os yielded MLDs larger than the MLD obtained in the quiet at each temporal relation studied.

DISCUSSION AND SUMMARY

As both models of binaural masking have been quite successful in relating various acoustic parameters to amount of binaural advantage, our first inclination was to suspect an acoustic interaction of signal and masker due to resonance of the headphones. When the pressure-wave output of the PDR-10 headphones was monitored, however, we found no evidence to support this notion.

Our evidence certainly indicates that the Webster-Jeffress hypothesis and the Durlach model are to be understood as describing sufficient, but not necessary, conditions for binaural interaction leading to improved detection. At this time we are not prepared to offer alternative explanations. It should also be noted that explanations of monaural auditory phenomena have similar

Fig. 4. Shows the magnitude of the MLD in decibels at NOS_{π} relative to $NOSO$ as a function of Δt . The data for each O are plotted separately. The size of the MLD was obtained by measuring the displacement of the NOS_{π} psychometric function from the $NOSO$ psychometric function, as shown in Fig. 2.

difficulty when trying to account for monaural forward and backward masking. That is, why does a masker that does not overlap in time with a to-be-detected signal cause such an extensive amount of masking. The data reported here present a further aspect of the problem. It is obvious that detailed aspects of the waveforms such as phase are retained until interaction between the signal and the masker occur. We are beginning

experiments to investigate further the binaural advantages occurring in backward and forward masking. Perhaps, when more data are gathered, an explanation will be evident. It should be mentioned that our data have been essentially replicated in another laboratory,² and the binaural advantage in backward masking appears to be a reliable phenomenon.

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NOTES

1. The amount of masking for the homophasic and antiphase conditions is defined as the difference in signal energy necessary for 80% correct in 2ATFC between these conditions and one in which no external noise was added (i.e., a "quiet" condition). We present the data in this manner so that they may easily be compared to other backward masking studies in the literature.

2. A. Small. Personal communication, 1970.

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