Frequency discrimination near masked threshold¹

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Frequency DLs (Δf) at 1000 Hz were obtained in quiet and under masking conditions similar to those used in pitch-shift experiments, narrow-band noise at levels of 60, 80, and 100 dB SPL and tones at 15 dB SL or less. The Δf s were obtained by means of a tracking task in which the S controlled the input voltage to a frequency modulator. Characteristic improvement was seen when Δf was plotted as a function of sensation level. However, noise level itself was a significant factor, with more intense noise resulting in larger Δf s for tones of equal sensation level re masked threshold. This departure from previous findings is attributed to the signal and noise levels used, although the possibility exists that it is due to the use of modulated tones.

The phenomenon of pitch shift for pure tones in noise has been demonstrated by several investigators (Schubert, 1950; Watson & Frazier, 1950; Egan & Myer, 1950; Webster, Miller, Thompson, & Davenport, 1952; Webster & Schubert, 1954). The degree of pitch shift increases when the tone is located near an abrupt change in the spectrum of a filtered noise (Webster, Miller, Thompson, & Davenport, 1952). Although it is not entirely clear whether the shift in pitch is always up or whether it is a shift away from the band of noise or region of hearing loss, it is widely agreed that it occurs only for tones less than 20 dB SL re masked threshold. It has also been suggested (Webster & Schubert, 1954; Watson & Frazier, 1950) that there is a positive correlation between hearing loss or masking and the degree of shift, and most studies have maximized pitch shift by using narrow-band noise of high spectrum level. Since the shifts have always been measured by pitch matching, no data exist concerning the frequency difference limen in situations in which pitch shift occurs.

The data for frequency discrimination in noise, with which DLs during pitch shift would have to be compared, are not complete; and their usefulness is limited by the bewildering variety of ways in which parameters in masking studies have been controlled and specified. The studies to date (Harris, 1948, 1966; Brandt & Small, 1963; Henning, 1967) have all used some form of the method of constant stimuli as the psychophysical procedure and have used wide-band noise of moderate spectrum level in combination with signal levels well above masked threshold. They have found that varying noise level, for the signal levels and noise levels used, has no effect as long as signal level is held constant relative to masked threshold. Equivalent results have been found in studies of the difference limen for intensity (Tonndorf, Brogan, & Washburn, 1955; Sherrick, 1959; Small & Minifie, 1963).

The masking conditions in which pitch shifts occur have not been used in studies of frequency or intensity DLs. Although amplitude modulation has been used by Tonndorf, Brogan, and Washburn (1955) and Sherrick (1959), a frequency-modulation procedure of the type used by Shower and Biddulph (1931) has not been used to measure frequency discrimination in noise. Feth, Wolf, and Bilger (1969) have recently developed a procedure that makes it possible to obtain frequency DLs, or Δf s, comparable to those obtained by Shower and Biddulph using a frequency-modulation tracking procedure analogous to the amplitude-modulation tracking procedure used by Sherrick. The present experiments represent an attempt to use this procedure to obtain frequency DLs for masking conditions comparable to

those for pitch shift, but with the tone in the center of the band of noise rather than in the upper or lower tail.

Apparatus

A schematic diagram of the apparatus used in this experiment is presented in Fig. 1. The beat-frequency oscillator (Brüel & Kjaer, Type 1022) contains a reactance-tube modulator. This frequency modulator was driven by a 2-Hz triangular waveform from the function generator (Hewlett-Packard, Model 202A). As a result, the center frequency of the BFO is modulated at a rate of 2 Hz through a range (Δf) proportional to the voltage amplitude of the triangular wave. The S controlled the extent of modulation (Δf) by varying the attenuation in a recording attenuator (Grason-Stadler, Model E3262A). The attenuator was operated in its stepped mode, through 1-dB steps, under control of the S's "increase-decrease" (center-off) switch. A complete description of the calibration and operation of this system is given by Feth, Wolf, and Bilger (1969).

The recording attenuator that follows the electronic switch was introduced to facilitate determination of absolute threshold, in quiet and in noise. The noise was filtered through two cascaded filters (Krohn-Hite, Model 310-ABR) that were set to pass the band of frequencies between 700 and 1400 Hz. The rejection rate of the cascaded filters beyond their cutoffs was 48 dB per octave.

EXPERIMENT 1

The Ss in the first experiment were five paid undergraduates

Fig. 1. Block diagram of the equipment used for determination of Δf s and absolute thresholds.

with normal hearing who had very limited experience in tracking masked thresholds and no previous experience with the frequency-modulation tracking task. They were instructed to track the boundary between the region in which they heard a steady tone and the region in which they detected some frequency modulation or warble in the tone. Because the S controlled the recording attenuator with a center-off switch, it was possible for him to listen under fixed conditions until he had enough information to make a decision.

After several practice trials, Δf s at 1000 Hz were obtained in quiet and at three noise levels, 60, 80, and 100 dB SPL overall. Δf s were obtained at sensation levels of 4, 6, 10, and 15 dB relative to masked threshold for each noise level. In a trial, the Ss tracked Δf for approximately 2 min at each sensation level for a given level of noise. The sensation levels were based on thresholds obtained by tracking the appropriate masked or quiet threshold for a 1000-Hz interrupted tone immediately before each trial. A control condition was run in which the Ss tracked Δf in quiet at the signal intensity used for 6 dB SL re masked threshold for each noise. Each S was tested four times under each condition.

Results

Figure 2 shows average Δf s for the five Ss. These data show an improvement in Δf with increasing sensation level that is characteristic of the other results for differential threshold, whether it be intensive or frequency discrimination. In addition, there is a definite effect that can be attributed to noise level, with more intense noise resulting in increased Δf s for tones of equal sensation level re masked threshold. Unlike previous masking data, sensation level or signal-to-noise ratio is not the only variable operating. If it were, the lines in Fig. 2 would fall on top of one another. The noise effect is not due to the increasing intensity of the tones. Results from the intensity control condition show that even at high intensities, in quiet Δf becomes smaller, nor larger, with increasing intensity. At 56, 76, and 96 dB SPL (which levels approximate the 6-dB-SL condition for each noise), the mean values of Δf were 7.0, 5.6, and 3.8 Hz, respectively.

Fig. 2. Mean Δf as a function of sensation level for quiet and three noise levels. Each point represents four trials for each of five Ss.

Fig. 3. Mean Δf as a function of sensation level for quiet and three noise levels. Each point represents two trials for each of three Ss.

Although the noise effect was statistically significant, there were several aspects of the data that led us to question these results. The Δf s in quiet for these Ss were higher than those reported by Shower and Biddulph (1931) and higher than those obtained previously with the same apparatus in our laboratory. In addition, the absolute thresholds in noise were higher and more variable than they should have been, which no doubt contributed to the high variability among Δf s. The noise-by-sensation-level interaction, which appeared to exist in the average Δf s and which seemed necessary in any reasonable explanation of a noise-level effect, was not significant. The nature of the noise-level effect, therefore, was not very clear and it could possibly have been attributed to the Ss' lack of experience in masking experiments. These misgivings led us to repeat the experiment.

EXPERIMENT 2

The second experiment used as Ss three members of the laboratory staff, who had extensive experience in tracking absolute threshold in noise and in tracking Δf in quiet. The procedure and conditions were identical to the first experiment except that sensation levels of 5, 10, and 15 dB re masked threshold were used. These trained Ss were tested twice under each condition. The intensity-control condition used originally, in which Ss tracked Δf in quiet at a representative signal intensity for each noise level, was eliminated in the second experiment, since the data from Experiment 1 were clear concerning this issue.

Results

Figure 3 shows the average Δf s for the three trained Ss. A very definite noise-level effect and noise-by-sensation-level interaction is apparent. The noise effect separates the Δf s into to groups, with 80- and 100-dB noises having very similar effects, and 60-dB noise being close to quiet. This is true in the data for each individual S, since variability among the three Ss was very low. As

was true in the first experiment, noise-level effects for tones at 15 dB SL were negligible.

DISCUSSION

Taken together, the experiments indicate that there are situations involving masking in which signal-to-noise ratio is not the only determinant of differential threshold. Using Ss who were less likely to be distracted by the noise resulted in an increase, rather than a decrease, in the effect of noise level upon Δf . This departure from the conclusions of previous studies of frequency discrimination in noise can be associated with differences both in the signal and noise levels used and in the psychophysical procedure.

An examination of the signal and noise levels leads to the more parsimonious explanation of the present results. Since our noise was narrow band, noise comparisons can best be made in terms of spectrum levels of the noises used previously. Although noise parameters have not always been given in masking studies, the critical-ratio data of Hawkins and Stevens (1950) are useful in estimating spectrum levels of the noises used by other investigators.

The noise levels used in our experiments were 60, 80, and 100 dB SPL, with spectrum levels of 31.6, 51.6, and 71.6 dB, respectively. With the exception of the 60-dB noise, for which there was no reliable noise-level effect, these levels are higher than the highest levels used in previous studies. Harris (1948) measured frequency discrimination at 500 and 800 Hz, using noise levels sufficient to mask 45-dB-SL tones for half of the Ss in a group procedure. Assuming that the signal-to-spectrum-level ratio at threshold is 17 dB for these frequencies, the spectrum level of his noise would be 35 dB. In a later study, Harris (1966) used the same procedure to establish noise levels for frequencies from 125 to 2000 Hz. Using the same reasoning, and a critical ratio of 18 dB, the spectrum level of the noise associated with the 1000-Hz tone should have been 34 dB. Brandt and Small (1963) used a wide-band noise sufficient to raise threshold 45 dB at 1000 Hz. Assuming the masked threshold was 52 dB SPL, the spectrum level of the noise was approximately 34 dB. Henning (1967) used spectrum levels of 12 and 32 dB.

The signal levels used were, for the most part, closer to masked threshold than the levels used previously. When occasional low sensation levels have been used, they have been accompanied by enough higher sensation levels to obscure any noise level effect in a statistical analysis. Brandt and Small (1963), for example, used sensation levels relative to masked threshold of 5, 15, 25, and 35 dB. An explanation in terms of the levels of signal and noise used is strengthened by the fact that our data identify a lower limit for noise, the 60-dB-SPL condition, and an upper limit for the signal, 15 dB SL.

It should be noted that in a study of frequency discrimination involving fatigue (Brandt, 1967), fatigue effects were found when the modulated tone was at 10 dB SL, but not at 40 dB SL above the fatigue-shifted threshold. Brandt attributed the negative findings of a previous fatigue study (Elliot, Sheposh, & Frazier, 1964) to the fact that they tested at 60 dB SL.

The correspondence between the conditions required for pitch shift and the conditions apparently required for a noise-level effect is, at first, striking. It should be pointed out, however, that pitch shift appears to increase, with increasing sensation level, up to about 15 dB SL, and then drops quickly for tones above 20 dB SL. Although detailed determinations of pitch shifts and noise-level effects as a function of sensation level have not been made, it is clear that the function for pitch shifts is nonmonotonic. The two functions could not be perfectly correlated. The role of narrow-band noise, aside from making higher spectrum levels tolerable, is not clear for either phenomenon.

The previous masking studies have all used procedures involving discrimination between two steady pure tones. Another possible explanation of the noise-level effect in our data lies in the speculation that discrimination between steady pure tones and detection of frequency modulation are handled differently or involve different neural networks in the auditory system. There is physiological evidence of specialized modulation detectors at several levels of the system. Whitfield and Evans (1965) have reported single units in the auditory cortex of the cat that respond only to specific frequency-modulated signals. More recently, modulation detectors have been found at the level of the inferior colliculus (Nelson, Erulkar, & Bryan, 1966) and of the cochlear nucleus (Erulkar, Butler, & Gerstein, 1968). Although the signal and noise levels we used may be sufficient to account for the noise-level effect, the possibility exists that steady-tone and modulation procedures do not, as generally accepted, represent the same auditory task. If so, then the tasks involved may be differentially susceptible to intense noise.

The data are insufficient to permit more detailed speculation concerning the cause of a noise-level effect, or its generality. They do demonstrate that such an effect exists, a finding that is in conflict with the conclusions generally drawn from previous masking data, but not in conflict with the data themselves. The present data are in agreement with the literature that indicates failures in prediction when extrapolations are made from moderate sensation levels to levels near absolute threshold. Although absolute thresholds are uniquely determined by signal-to-spectrum-level ratio, this information alone is insufficient to predict thresholds for frequency discrimination.

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NOTES

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