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Masking by Tones *vs* Noise Bands*

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In a previous study it was proposed that tonal masking arose mainly from the cochlear activity pattern of the masking tone, modified by the formation of beats between the signal and masking tones. The present study casts further light on these proposed mechanisms by comparing the masking effects of pure tones of 500, 1000, 2000, and 4000 cps at 60 and 80 db SL with $\frac{1}{3}$ octave bands of noise of equal intensities and centered at the same frequencies. The results show that the noise bands produce about the same amount of extended masking despite the absence of any possible aural harmonic distortion, but greater direct masking due to the elimination of beats. Furthermore, the noise-masking curves join the tone-masking curves at the second peak in the latter, providing strong additional support for the proposed mechanisms of auditory masking.

IN a recent study[1] of masking by tones it was found (1) that above the masking frequency the masking pattern became irregular and unsymmetrical with respect to the low-frequency side before any appreciable masking occurred at the second harmonic of the masking tone and (2) that even at higher masking levels where appreciable masking occurred at the second harmonic a secondary peak in the masking curve fell between the masking frequency and its second harmonic.

These general findings together with others in the same study and in the work of others seemed to require a revision of the theory of masking. Therefore, it was hypothesized that the masking pattern of a tone was determined primarily by two mechanisms, the activity pattern set up by the masking tone in the cochlea and auditory beats resulting from the superposition of the test tone upon the masking tone in the cochlea. It was thought that the activity pattern was the primary determinant of the extent (in frequency) and amount (in intensity) of masking, and that beats, where they occurred, served to lower the amount of masking. The hypotheses minimized the role of aural distortion (harmonics and difference tones), for the most part relying on the extension of the activity pattern of the masking tone toward the base of the cochlea as shown in physiological experiments[2–4] for an explanation of the rapid advance of masking upon high frequencies, and relying on the widespread occurrence of beats to explain some of the details of the obtained masking patterns.

Since direct tests of these hypotheses are not feasible, further evidence bearing upon them must come from indirect tests. Such indirect tests can be made by using a nonperiodic masking stimulus such as a band of noise and comparing its masking patterns with those produced by tones. With a noise band of the same intensity as a tone, the energy at each frequency within the band will be much lower than that of the tone, thereby producing much less, if any, harmonic distortion.[5] Under these conditions, the classical view would expect no extended masking, and the masking pattern of the noise should be symmetrical. Of course, the situation is not that simple, being complicated by the fact that the cochlea is not a perfect frequency analyzer, but if the noise band is broad enough to include a few critical band widths its energy should be sufficiently spread out in the cochlea to minimize the production of aural harmonics due to overload.

On the other hand, the hypotheses proposed here, attributing extended masking to spread of cochlear activity, would still predict extended masking to occur as a result of a noise band, and to about the same extent as for a tone at the same over-all SPL. In addition, these hypotheses predict that there would be more masking at the frequencies in the noise band than with the single tone, but that the noise-masking curve would join the tone-masking curve at the latter's secondary peak due to the elimination of beats between the tonal signal and the masking stimulus. Of course, it is expected that the noise-masking curve would extend somewhat farther to low frequencies simply because the noise band extends to frequencies lower than the masking tone.

Certain evidence already available encourages the expectations embodied in the preceding paragraph. Egan and Hake,[6] in determining the masking pattern of a simple auditory stimulus, compared the masking patterns of a 400-cps tone and a band of noise 90 cps in width centered at 410 cps, both at 80 db over-all SPL. Their Fig. 7 portrays almost exactly what the present hypotheses predict. It was thought, however, that a broad sampling of frequencies and levels should be studied to subject these hypotheses to a more rigorous test.

PROCEDURE

The equipment and procedure were the same as used in the previous study[1] except for the noise bands which were produced by passing the output of a gas-tube noise

* These results were presented to the American Psychological Association, September 3, 1957.
[1] R. H. Ehmer (to be published).
[2] G. v. Békésy, J. Acoust. Soc. Am. 21, 245–254 (1949).
[3] Davis, Tasaki, and Legouix, J. Acoust. Soc. Am. 24, 502–519 (1952).
[4] I. Tasaki, J. Neurophysiol. 17, 97–122 (1954).
[5] J. L. Hunter, *Acoustics* (Prentice-Hall, Inc., Englewood Cliffs, New Jersey, 1957), p. 260.
[6] J. P. Egan and H. W. Hake, J. Acoust. Soc. Am. 22, 622–630 (1950).

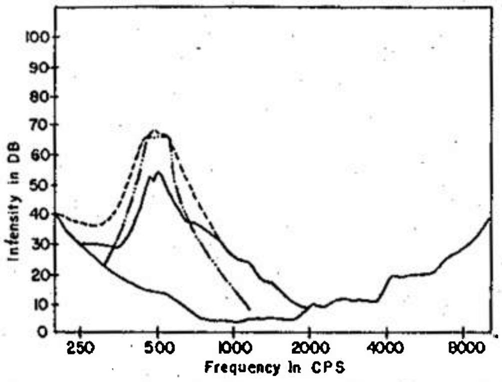

FIG. 1. Masked thresholds for 500 cps, 60 db SL. The over-all SPL of tone and noise band are 71 db. The frequency limits of the noise band are 450 and 580 cps and the SPL per cycle is 50 db.

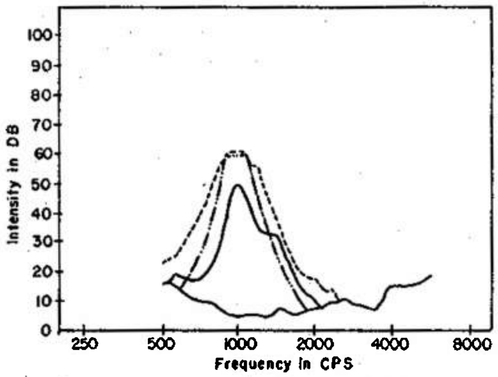

FIG. 2. Masked thresholds for 1000 cps, 60 db SL. The over-all SPL of the tone and noise band are 67 db. The frequency limits of the noise band are 880 and 1150 cps and the SPL per cycle is 43 db.

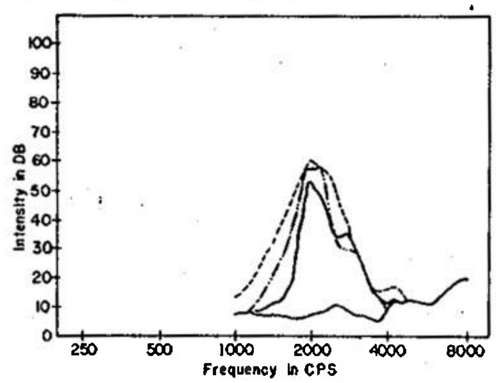

FIG. 3. Masked thresholds for 2000 cps, 60 db SL. The over-all SPL of the tone and noise band are 66 db. The frequency limits of the noise band are 1800 and 2300 cps and the SPL per cycle is 39 db.

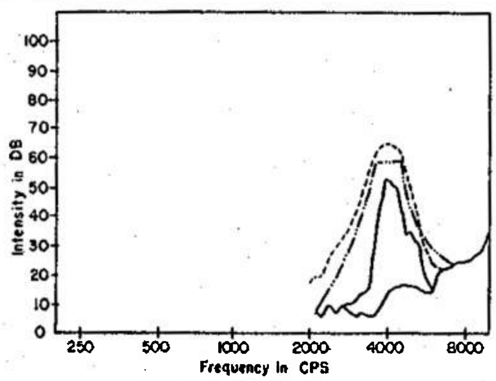

FIG. 4. Masked thresholds for 4000 cps, 60 db SL. The over-all SPL of the tone and noise band are 75 db. The frequency limits of the noise band are 3400 and 4600 cps and the SPL per cycle is 44 db.

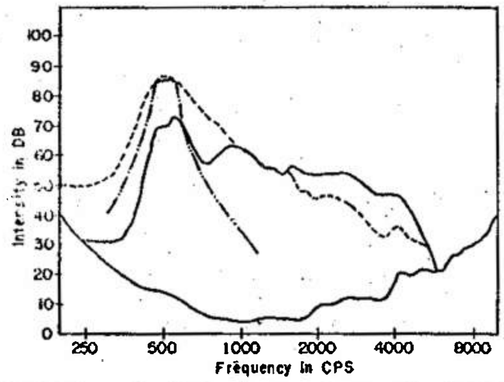

FIG. 5. Masked thresholds for 500 cps, 80 db SL. The over-all SPL of the tone and noise band are 91 db. The frequency limits of the noise band are 450 and 580 cps and the SPL per cycle is 70 db.

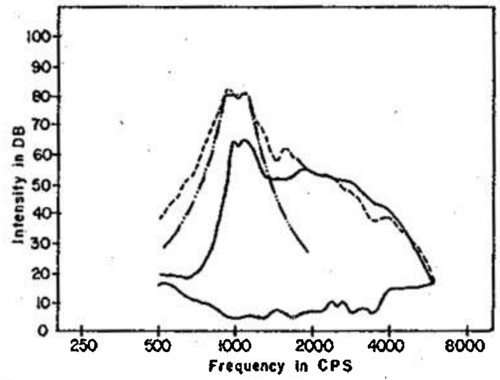

FIG. 6. Masked thresholds for 1000 cps, 80 db SL. The over-all SPL of the tone and noise band are 87 db. The frequency limits of the noise band are 880 and 1150 cps and the SPL per cycle is 63 db.

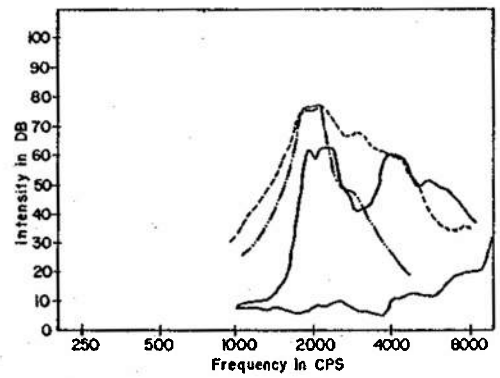

FIG. 7. Masked thresholds for 2000 cps, 80 db SL. The over-all SPL of the tone and noise band are 86 db. The frequency limits of the noise band are 1800 and 2300 cps and the SPL per cycle is 59 db.

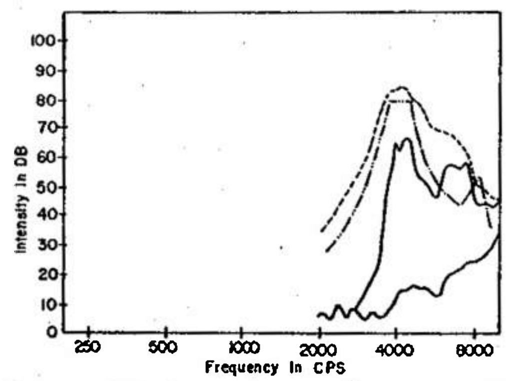

FIG. 8. Masked thresholds for 4000 cps, 80 db SL. The over-all SPL of the tone and noise band are 95 db. The frequency limits of the noise band are 3400 and 4600 cps and the SPL per cycle is 64 db.

generator through the one-third-octave filters of a Brüel and Kjaer Type 2109 Audio Frequency Spectrometer. Thresholds and masked thresholds were obtained by a Békésy audiometer for two listeners with normal hearing; masking stimuli were tones at 500, 1000, 2000, and 4000 cps at 60 and 80 db sensation level (SL) and ⅓ octave bands of noise centered at the same frequencies and set to the same over-all SPLs.

RESULTS AND DISCUSSION

Typical results for one of the subjects are portrayed in Figs. 1–8. In Figs. 1–4, which give the results at 60 db SL, the tone-masking curves are unsymmetrical, but the noise-masking curves are all symmetrical and in addition coincide with or approximate the tone-masking curves at the latters' shoulder or second peak. This agreement between hypotheses and results, while gratifying, may be due more to the width of the noise band than to the correctness of the hypothesis because, the noise-masking curve is about equally far from the filter characteristic curve both above and below the noise band. And since the band of masked frequencies is so much wider than the width of the masking stimulus (even the one-cycle-wide masking tone produces a broad peak in the masking curve), the upper frequencies in the noise band could have pushed the masked threshold beyond the limits of the second descending portion of the tone masking curve in Figs. 2 and 4.

More satisfactory for evaluating the proposed hypotheses of masking are the results obtained at 80 db SL, shown in Figs. 5–8. In these figures, although the masking curve slopes off below the noise band close to the filter characteristic curve, above the band limits the extended masking curves run well above the high-frequency cutoffs. Moreover, in these figures the agreement between data and hypotheses is excellent. Within the frequency limits of the noise band there is much greater direct masking than is produced by the pure tone; above the band limits the noise masking curve falls off rapidly, intersecting with the tonal curve at the second peak and thereafter coinciding with it for perhaps half an octave (in Figs. 5–7) before again diverging. The lone exception occurs in Fig. 8 where the noise curve never does quite reach the tone curve; this departure may be due to the less satisfactory dropoff of the filter high-frequency response.

Although the general agreement is excellent, two minor features require comment. The irregularities in the noise-masking curves and the fact that, where the tone and noise curves of extended masking diverge, the noise curve always runs *below* the tone curve.

The irregularities in the noise-masking curves, seen as the humps at 1600 cps in Fig. 6, 3000 cps in Fig. 7, and 6000 cps in Fig. 8, appear sufficiently often in about the same locations that they may not be regarded as fortuitous. They have also appeared in the data of Egan and Hake[6] (Fig. 2) and Bilger and Hirsh[7] (Figs. 2–8). They do not appear at the right frequencies to be regarded as aural harmonic distortion, and they occur when the level of the energy per cycle of the noise is too low to produce harmonic distortion. Thus, the possibility that the extended masking is a result of harmonic distortion is ruled out. This leaves the possibilities (1) that the hump is indicative of the activity pattern of the noise band in the cochlea and, somewhat overlapping, or (2) that the hump is a product of the interaction of the signal tone and masking noise similar to the processes postulated for the second peaks in the tonal masking curves.

Regarding the first possibility, that the hump is a function of the form of the noise pattern in the cochlea, nothing can be said because of a lack of direct evidence. Regarding the second possibility, the interaction between tone and noise, the change in phenomenological characteristics of the signal tone at threshold when its frequency lies within or close to the band limits of the noise can be mentioned: The signal itself becomes noise-like. Similar observations were reported by Egan and Hake[6] for the masking by a band of noise 90 cps in width and centered at 410 cps. These same investigators also obtained less direct masking within the noise band than for a broad band noise (0–1000 cps) at the same spectrum level. Thus, it appears that a narrow band of noise retains some tone-like properties. Perhaps the noise band maintains a somewhat periodic discharge in the auditory nerve fibers, a discharge modulated by the superposition of a tone of appropriate frequency. Such a possibility was suggested in the case of tonal masking. Again, direct evidence is lacking.

It is not easy to explain why, at frequency regions above their coincidence, the noise-masking curve runs below the tone-masking one. Were it not for the long run of coincidence, it might be thought that, since much of the energy in the noise is *below* the frequency of the tone, there should be less extended masking; but then it would also be expected that the entire extended masking curve of the noise band would run below the tone. The difficulty of explanation is further complicated by the return to coincidence toward the high-frequency end of masking. Nevertheless, these results cannot be satis-

[7] R. C. Bilger and I. J. Hirsh, J. Acoust. Soc. Am. 28, 623–630 (1956).

Figs. 1–8. Masked thresholds for tones *vs* noise bands. The intensity scale is arbitrary but is the same for all figures. In each graph the lowest curve is the absolute threshold. Of the upper curves, the continuous one is the masked threshold for pure tone masker, the dashed one is for the noise band, and the dash double dot gives the frequency characteristics of the filter settings used. The filter characteristics are not plotted at intensities relative to the thresholds but merely to facilitate comparison of the masked threshold with the spectrum of noise producing it. The actual frequency limits and SPL's of the noise are given in the legends to the individual figures.

factorily explained even by reverting to hypothetical aural harmonics.

At this point the discrepancy must be merely acknowledged as a difficulty that requires explanation. The same result also appeared in the findings of Egan and Hake (their Fig. 7) in consequence of an even narrower noise (less than 2 critical bands wide) than used in the present experiment.

It is concluded that the present results add further support to our hypothesis that spread of activity in the cochlea, and not aural harmonic distortion, underlies extended masking.