Dual tuning in the mammalian cochlea: dissociation of neural and basilar membrane responses at supra-threshold sound levels – a meta-analysis

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Abstract

In the basal turn of the cochlea, tuning of auditory nerve fiber (ANF) and basilar membrane (BM) responses are closely correlated at threshold levels. Their correlation also at supra-threshold levels has always been an implicit postulate of BM transmission line theory. A test of this postulate by empirical data, however, has never been published. In order to elucidate this discrepancy, a large number of ANF recordings was analyzed and compared to equivalent BM recordings. The results show that, at least in the basal turn of the cochlea, the best frequency (BF) of BM responses drops by about half an octave between 30 and 100 dB SPL. The comparable neural data never reflect anything similar. 1) In the majority of cases (52%) BF is totally unaffected by sound level. 2) In a minority of cases (36%) BF drops slightly at the highest sound levels, but only by about half as much as for the BM. 3) In a relevant number of cases BF is bimodal at the highest sound levels, such that the antagonistic majority and minority versions appear concurrently. These results indicate a dual tuning, such that BM and organ of Corti (OC) are tuned separately, and they are consistent with the concept of overload protection of OC sensitivity as the genuine function of BM tuning.

Fig. 1

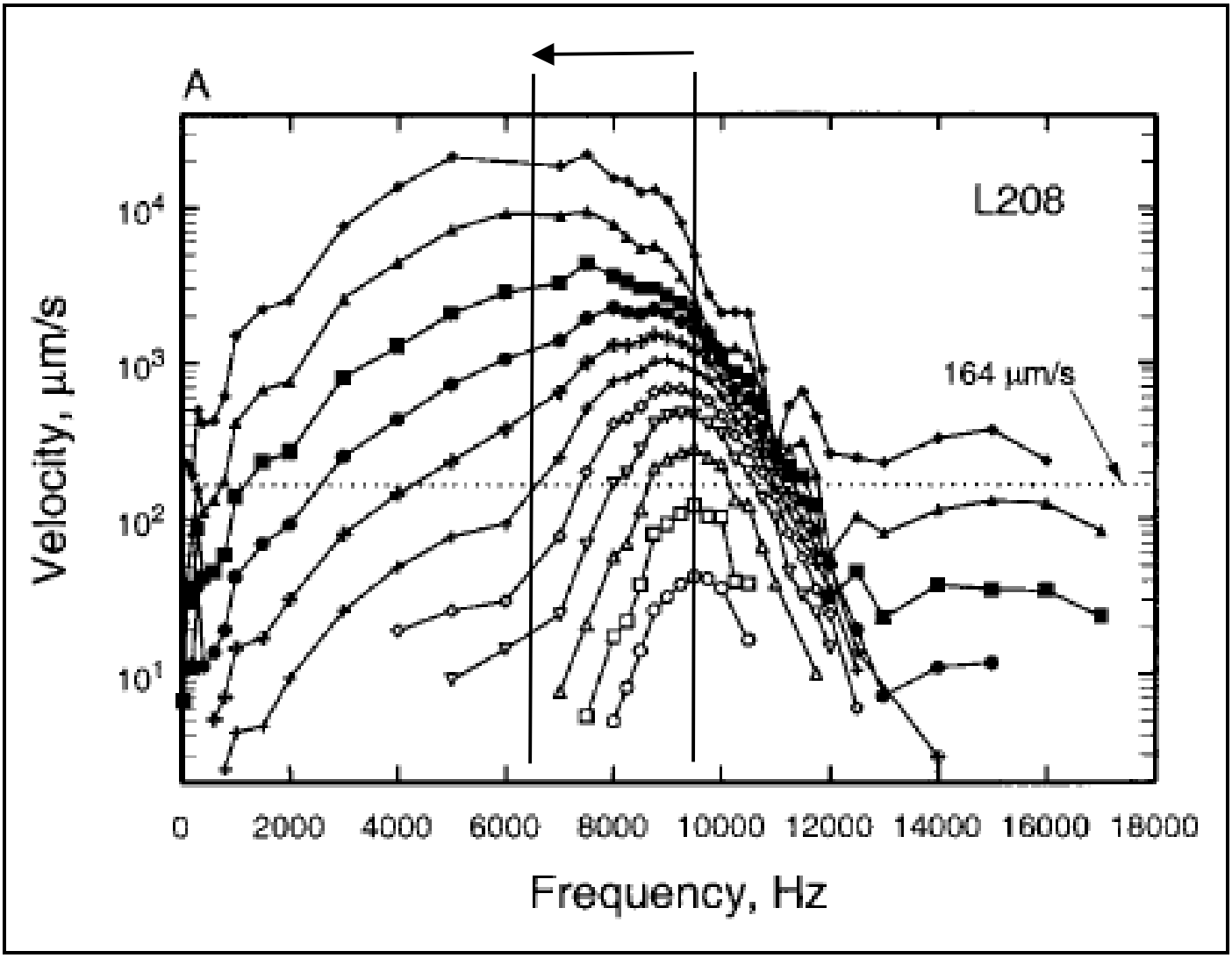

Fig. 1. BF shift of BM responses at supra-threshold sound levels in the chinchilla. Iso-intensity curves: bottom 0 dB SPL; top 100 dB SPL; inter-curve distance 10 dB SPL. Adapted from Fig. 1A of Ruggero et al. (2000).

Fig. 2

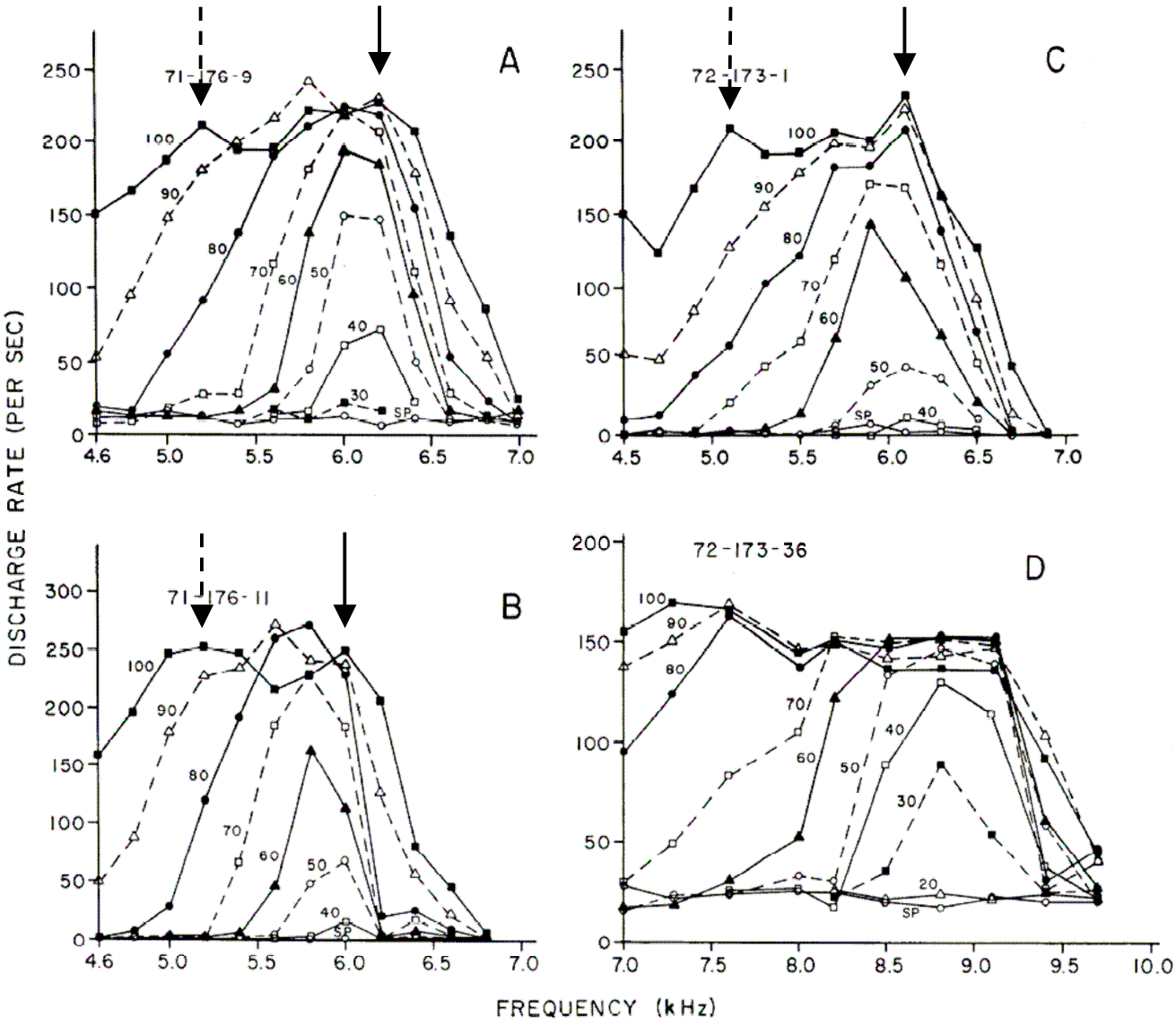

FIG. 7. Response areas of two pairs of nerve fibers. *A* and *B:* from monkey *71-176*. *C* and *D:* from monkey *72-173*.

Fig. 2. Bimodal BF at high sound levels in ANF iso-intensity curves from the squirrel monkey. Adapted from Fig. 7 of Geisler et al. (1974).

Fig. 3

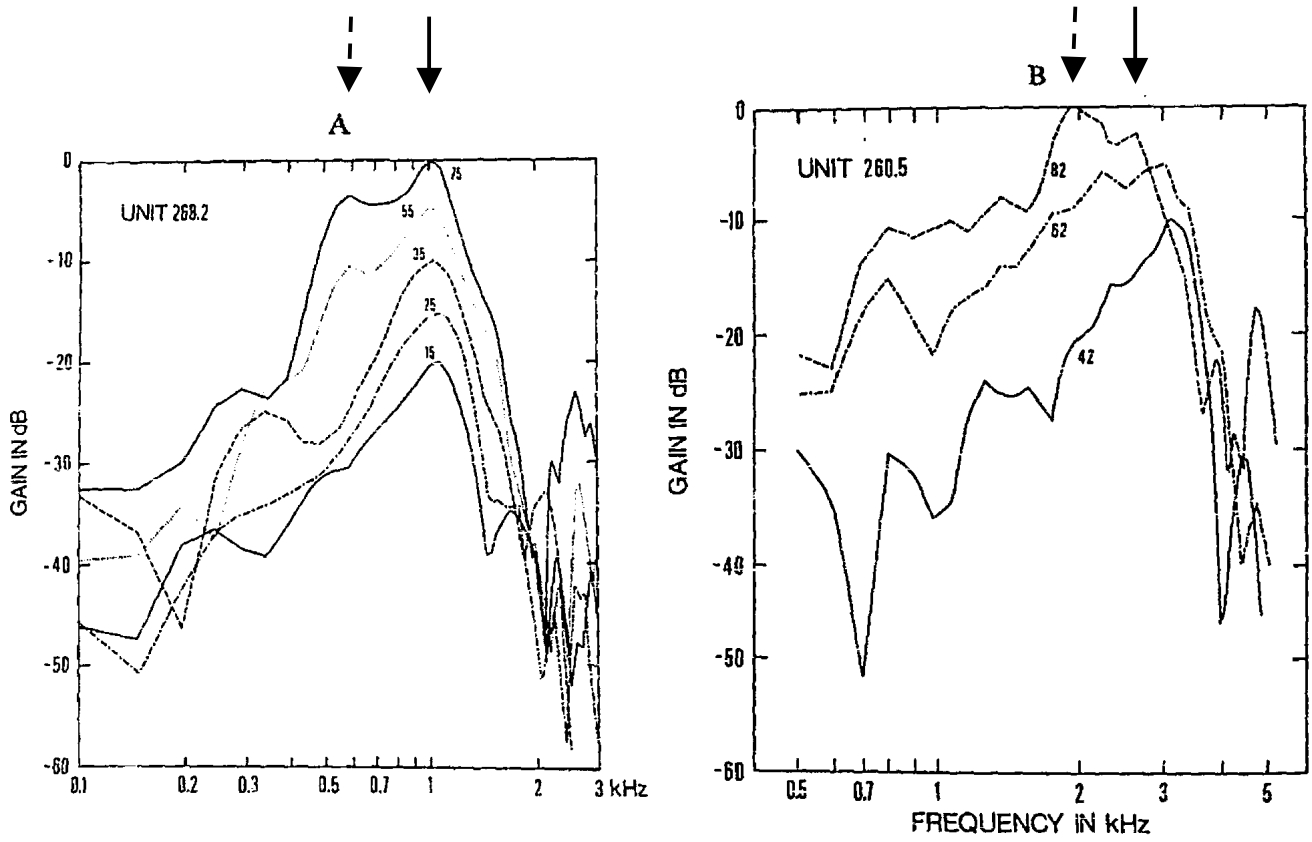

Fig. 3. Frequency transfer functions obtained in two different fibers. The individual curves were obtained at different sound levels, indicated by legend numbers, in dB SPL measured in a $\frac{1}{3}$ octave band. The curves are shifted vertically in such a way that there is a 5 dB difference between the maximal values of the individual curves. This was done in order to facilitate comparison of the width and center frequency of the individual curves.

Fig. 3. Bimodal BF at high sound levels in ANF cross correlation (revcorr) spectra from the rat. Sound levels in dB SPL are 15, 25, 35, 55, and 75 in plot A and 42, 62, and 82 in plot B. Adapted from Fig. 3 of Møller (1978).

Fig. 4

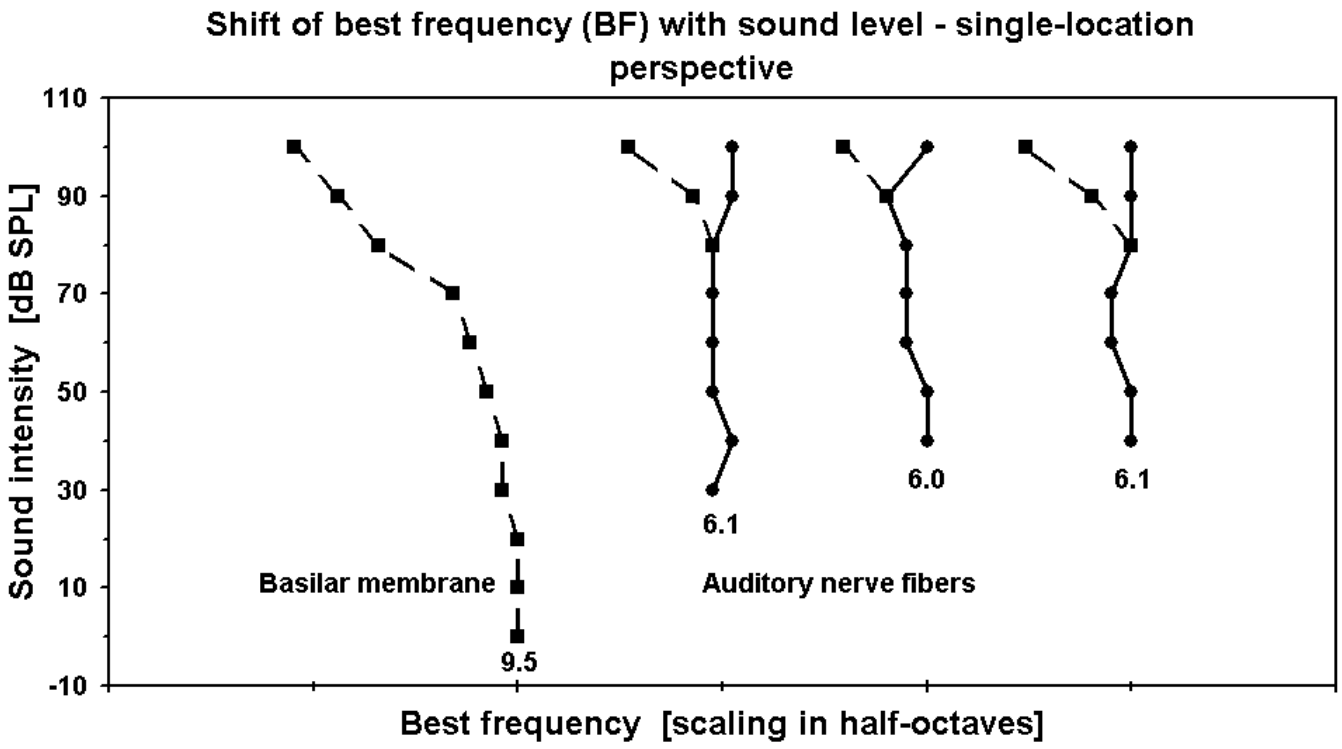

Fig. 4. BF versus sound level. X-axis: BF as defined by the peaks in the iso-intensity curves of BM and ANF responses. Y-axis: sound intensity of the stimulus. The four curves are spaced in half-octaves re threshold BF, which is stated in kHz below each curve. Leftmost curve: plotted from the BM velocity data in Fig. 1. Other three curves: plotted from the ANF firing-rate data (3 fibers of 2 animals) in Figs. 2A-C. Stimuli were 128 to 512 tone bursts of 5 to 100 ms per stimulus condition for the BM recordings and 4 to 8 tones of 500 ms per stimulus condition for the ANF recordings.

Fig. 5

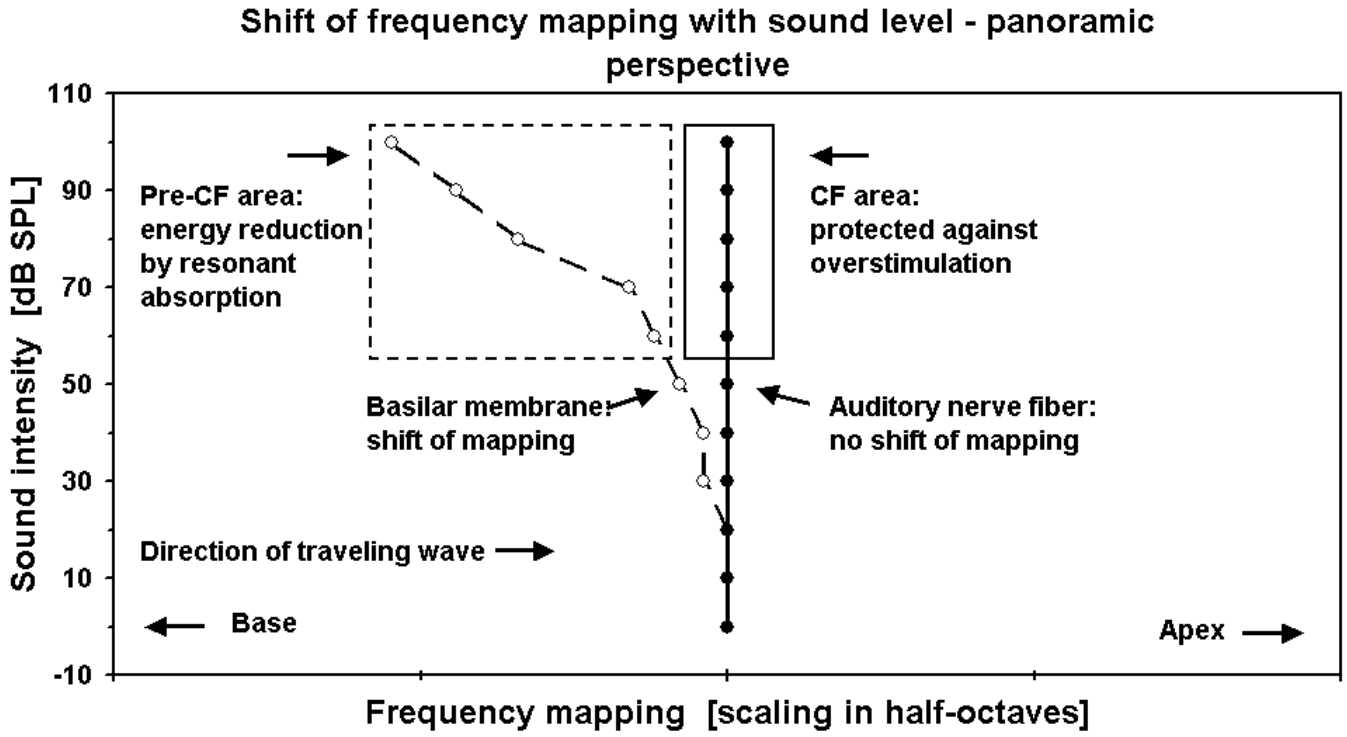

Fig. 5. Cochlear frequency mapping versus sound level. X-axis: BF place position along the length of the cochlea. Y-axis: sound intensity of the stimulus. BM data according to sample in Fig. 4. ANF data according to the summarized results of the present study.

Fig. 6

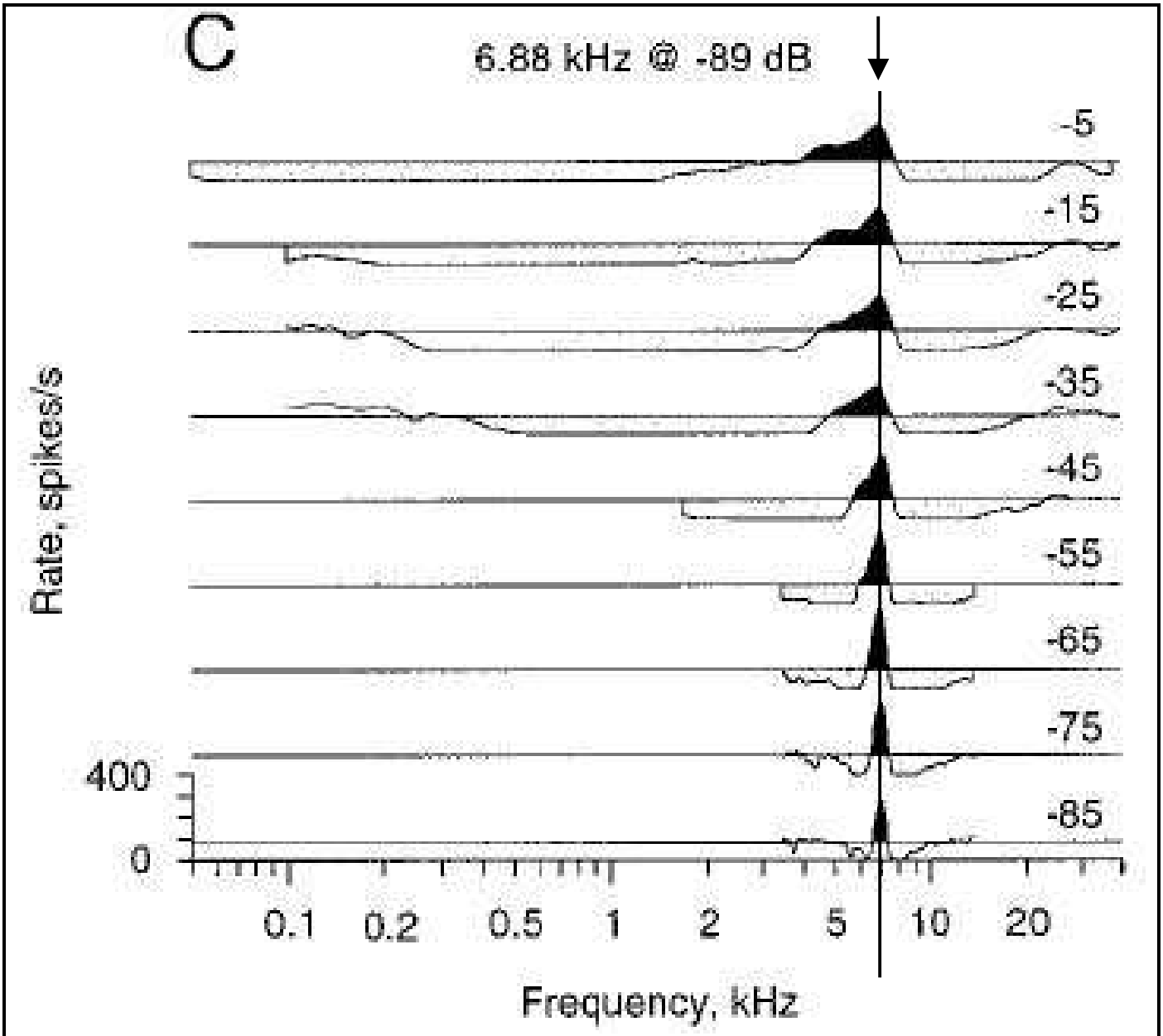

FIG. 3. Representative 2-tone response map recorded from type II unit. Fixed tone was at BF, 3–8 dB above threshold; fixed tone parameters are given in the caption above map. Plot shows rate vs. frequency for a 2nd tone, plotted relative to the rate produced by the fixed tone alone (horizontal lines). Excitatory regions (rate increases above fixed-tone rate) are filled with black; inhibitory regions are shaded. Sound level of the 2nd tone is given as dB attenuation.

Fig. 6. Response area vs. sound level of a unit from the dorsal cochlear nucleus of the cat. Adapted from Fig. 3 of Spirou et al. (1999).

Supporting evidence: Increased tuning sharpness of high-threshold ANFs

Liberman (1978) reported that high-threshold ANFs are more sharply tuned than low- and medium-threshold ANFs (Figs.7-9). Because tuning of BM responses broadens with sound level (Fig.1), the findings of Liberman, which have never been challenged, have been a compelling body of evidence for local tuning in the organ of Corti (OC) for the past 30 years.

References

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