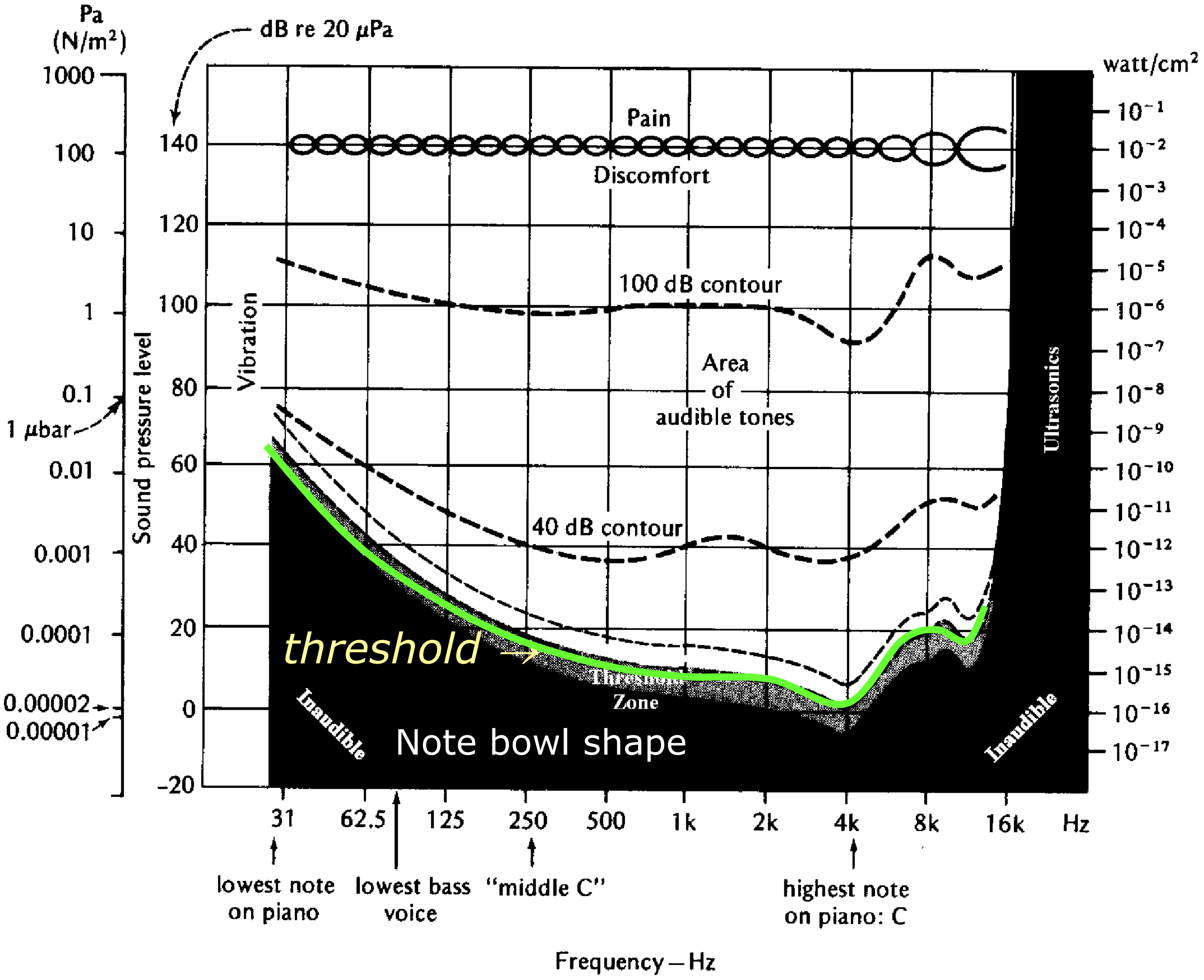
Loudness and the perception of intensity

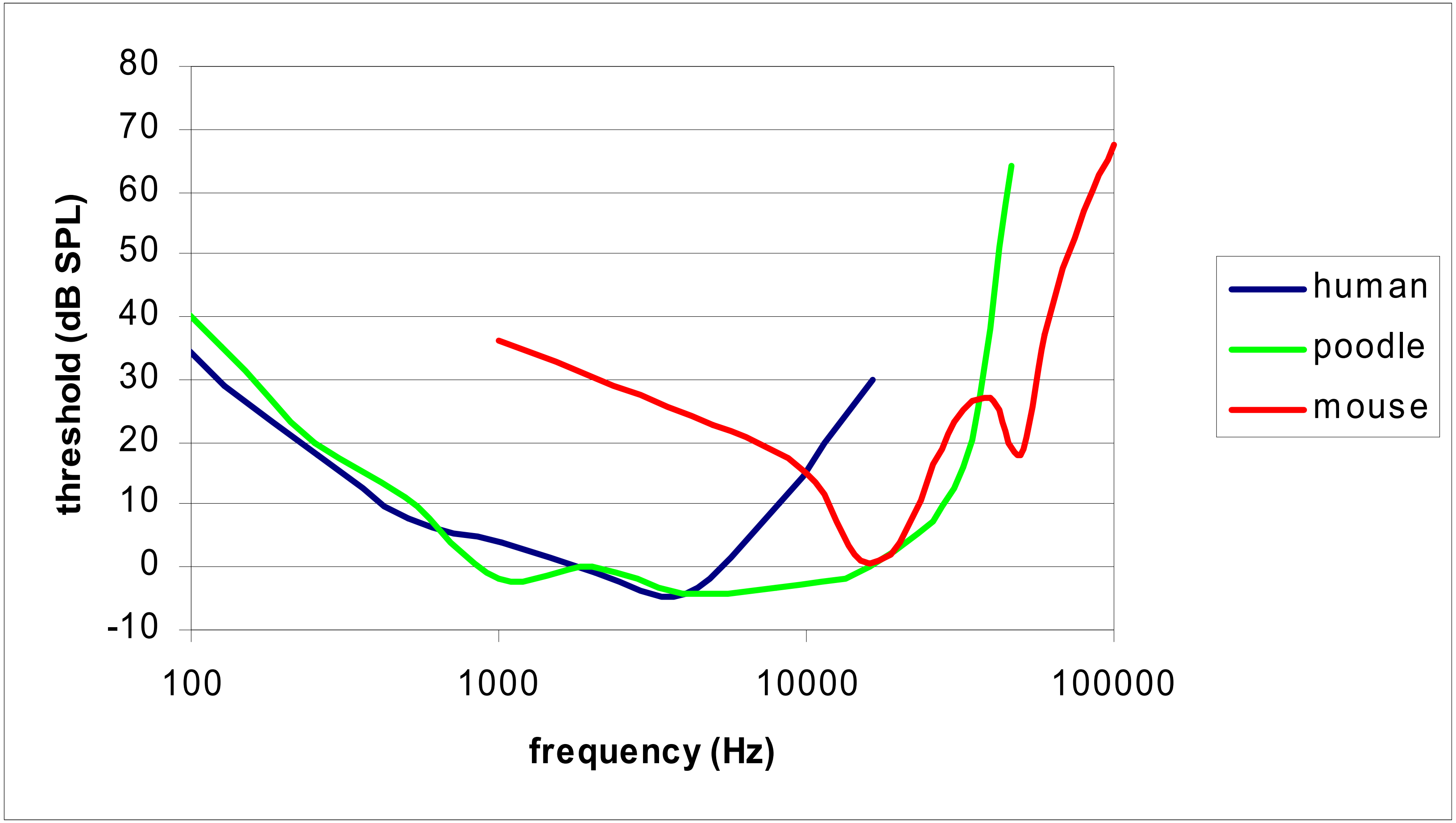
Loudness



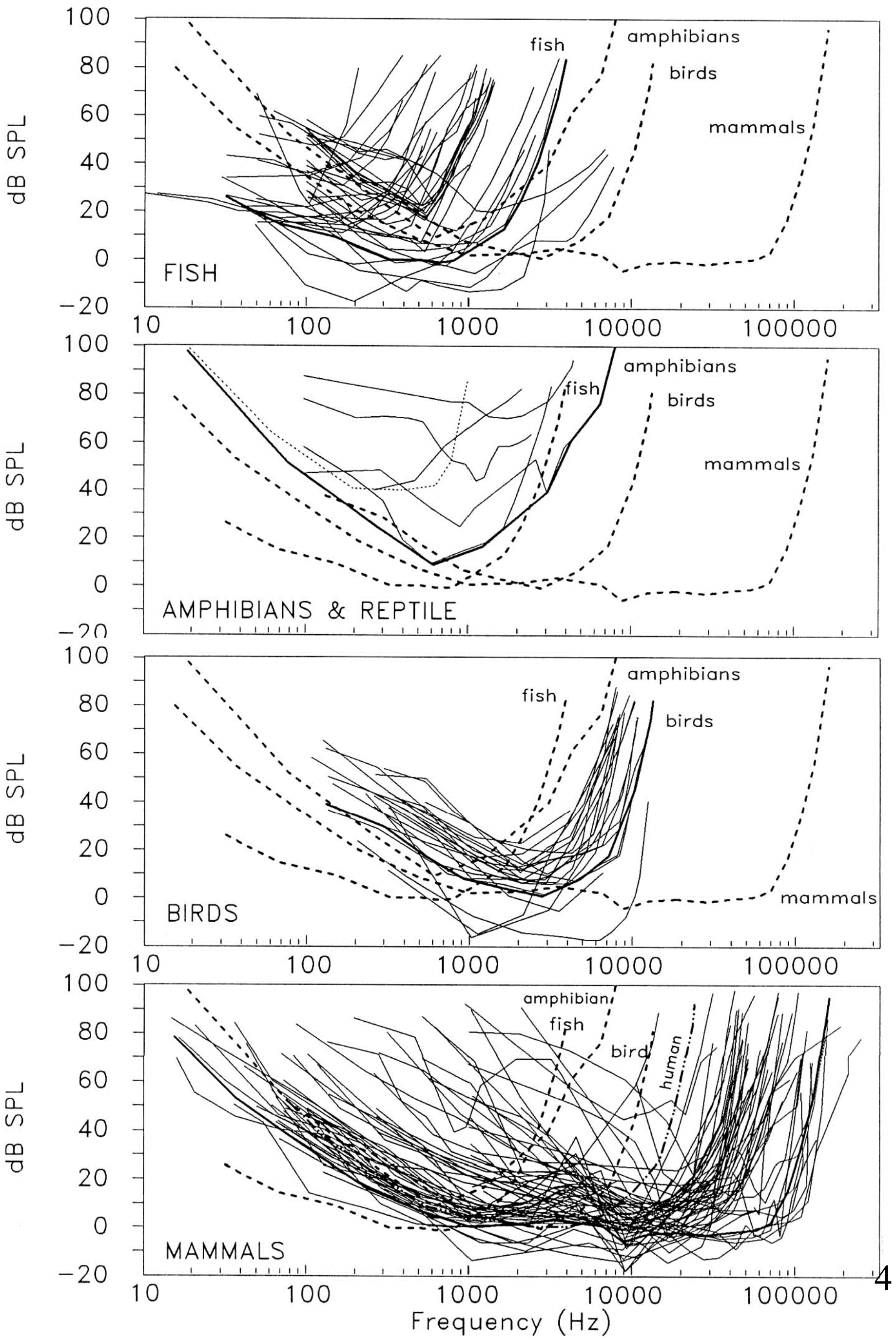
threshold →

Note bowl shape

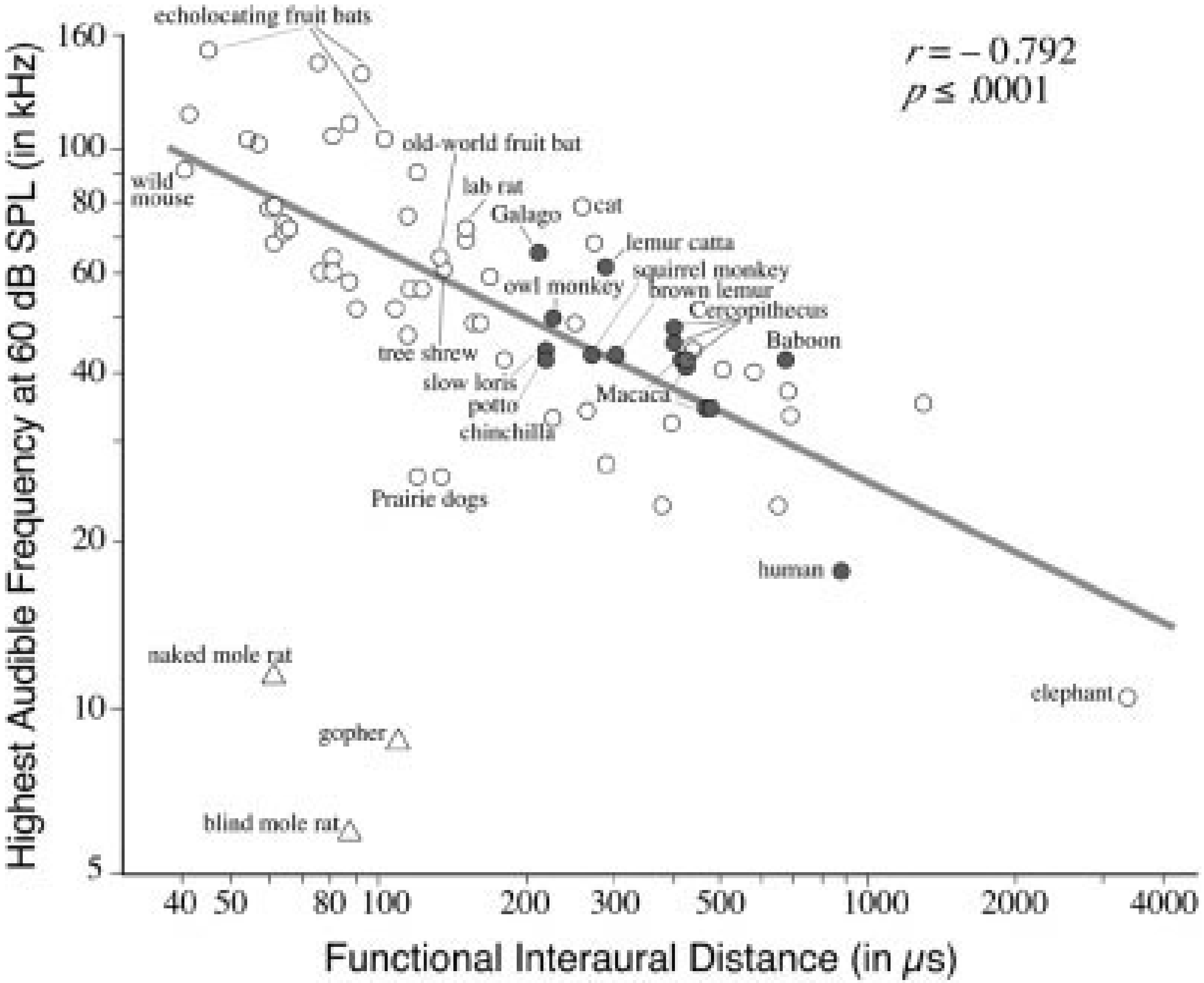
Thresholds for different mammals



Mammals excel in hearing high frequencies



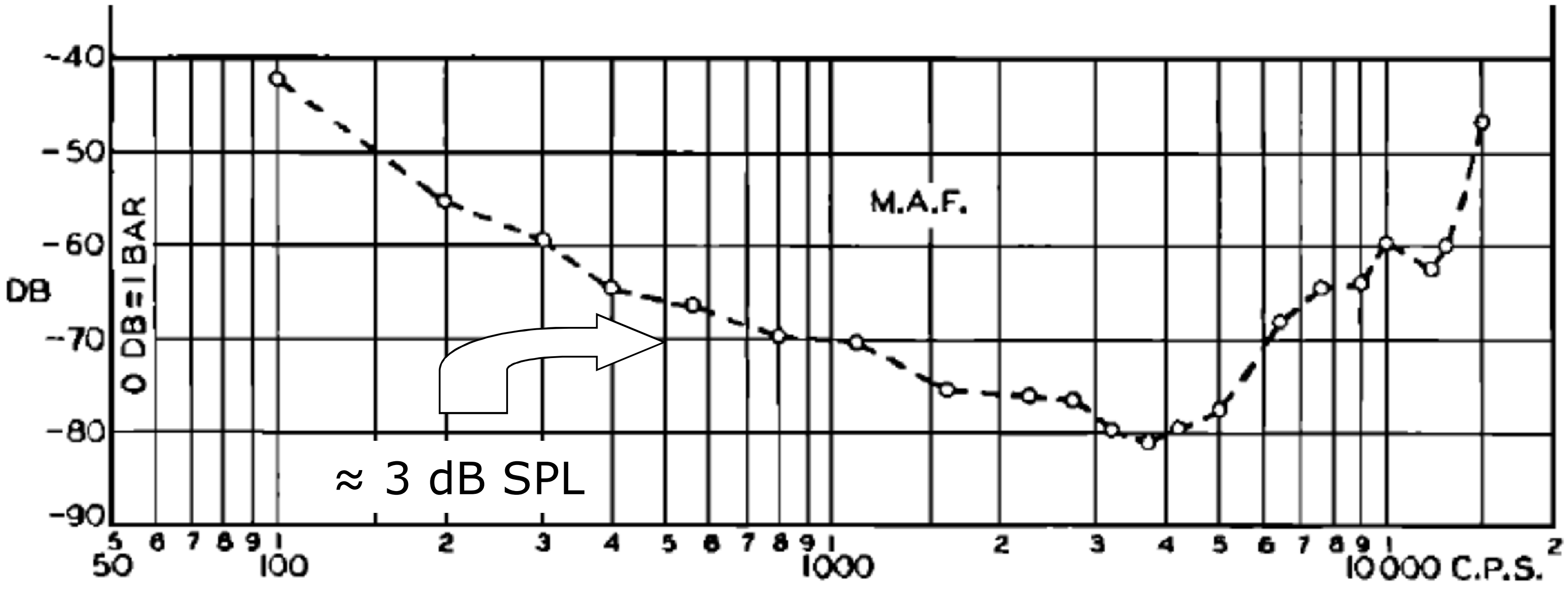
Highest audible frequency correlates with head size in mammals



Heffner, 2004

Sivian & White (1933) JASA

Sivian & White 1933



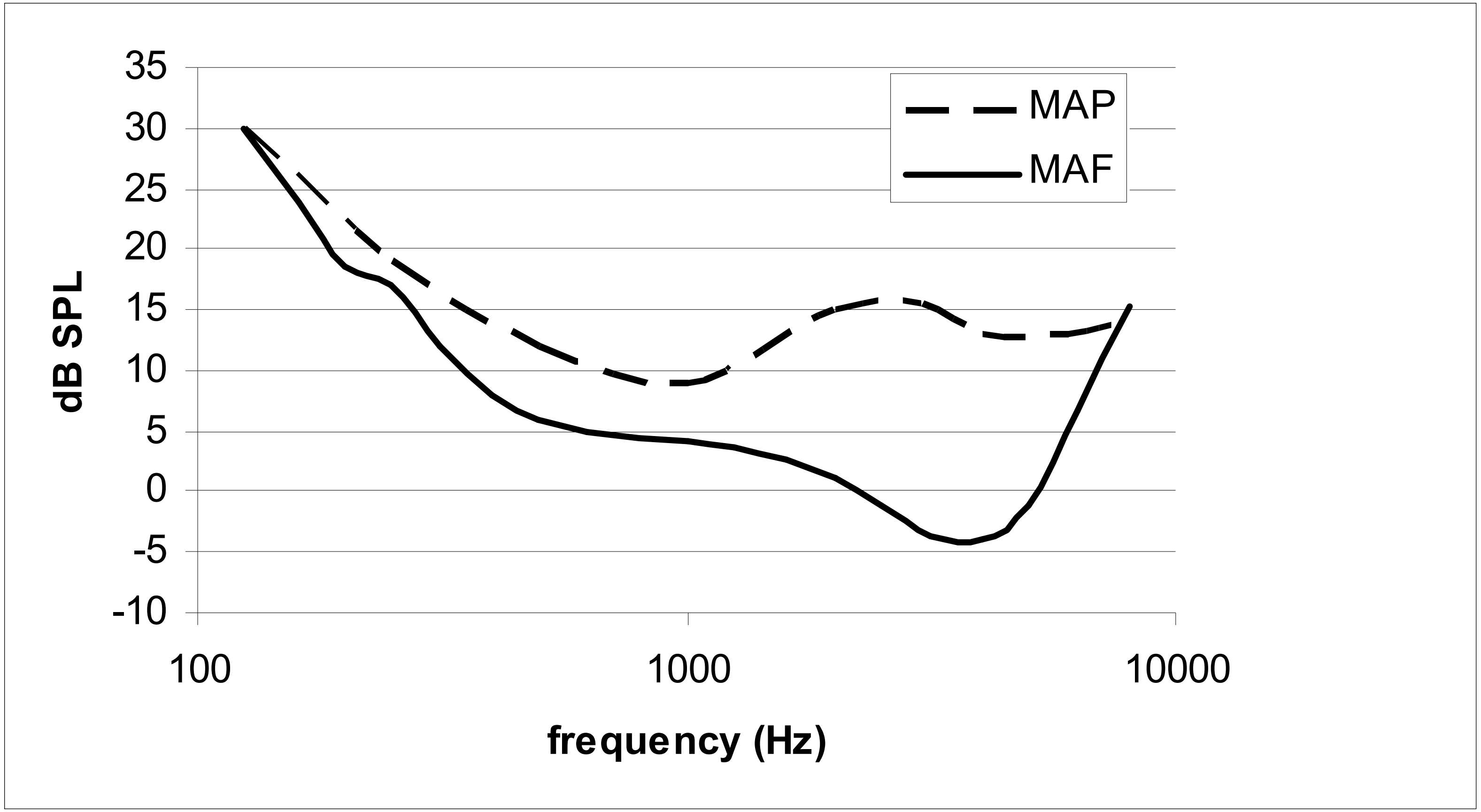
≈ 3 dB SPL

FIG. 3. *Monaural M.A.F., group A.*

Two ways to define a threshold

- minimum audible field (MAF)
  - in terms of the intensity of the sound field in which the observer's head is placed
- minimum audible pressure (MAP)
  - in terms of the pressure amplitude at the observer's ear drum
- MAF includes effect of head, pinna & ear canal

MAP vs. MAF
Accounting for the difference

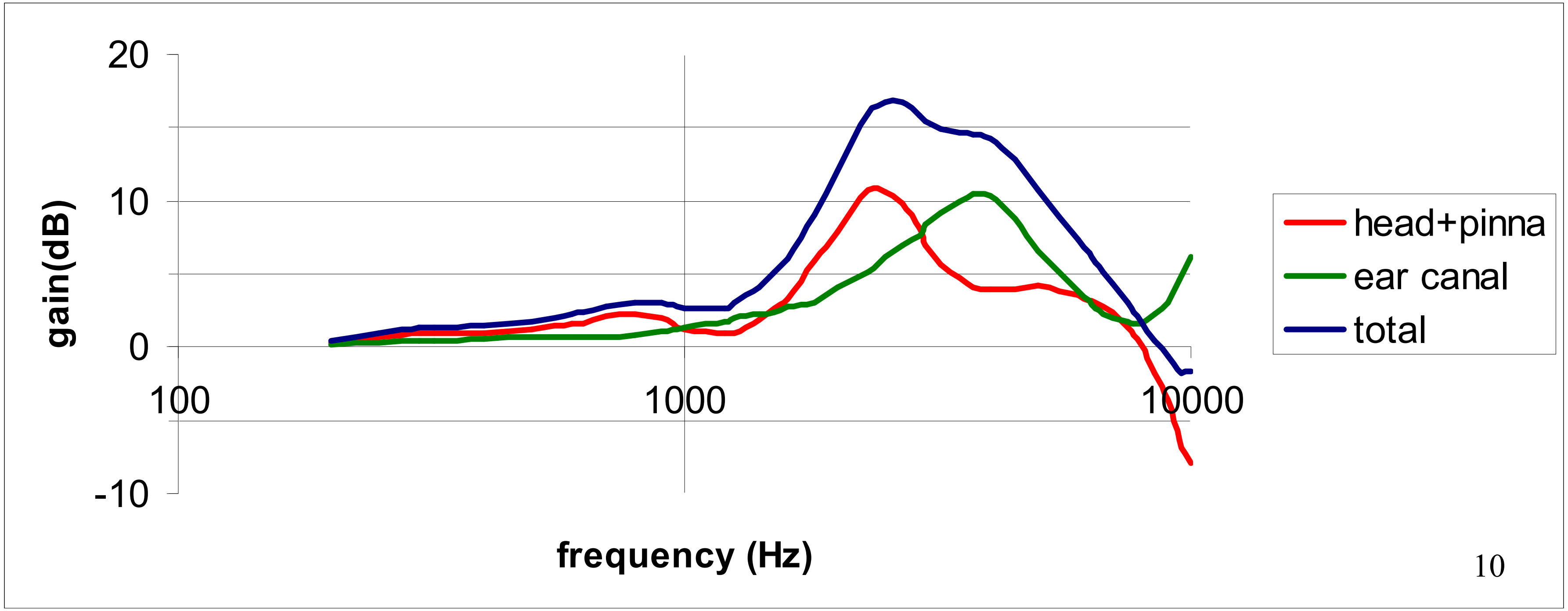


Frequency responses for:

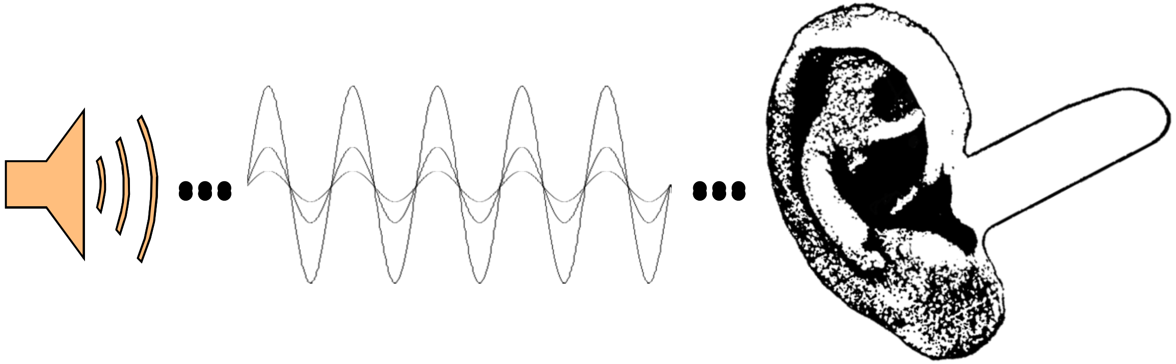
$$\frac{\text{ear-canal entrance}}{\text{free-field pressure}} \qquad \frac{\text{near the ear drum}}{\text{ear-canal entrance}}$$

Total Effect:

$$\frac{\text{near the ear drum}}{\text{free-field pressure}}$$

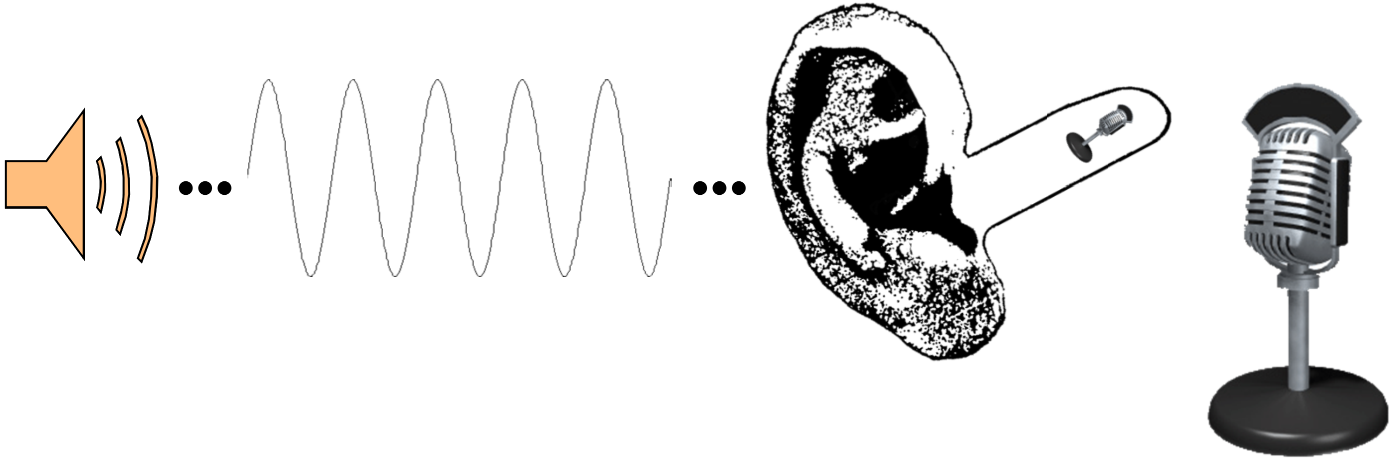


Determine a threshold for a 2-kHz sinusoid using a loudspeaker



Now measure the sound level

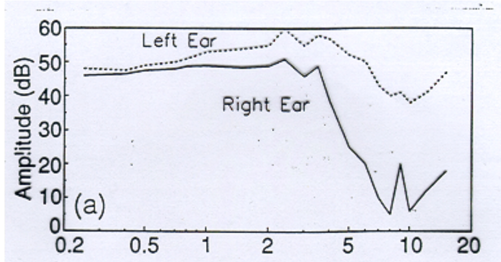
at ear canal (MAP):
15 dB SPL

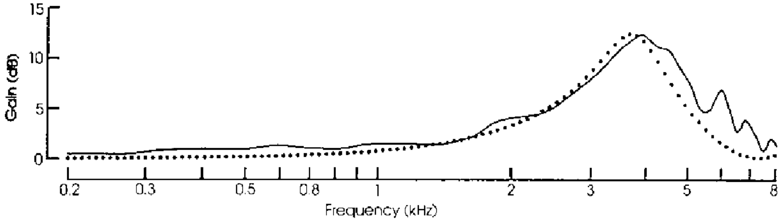


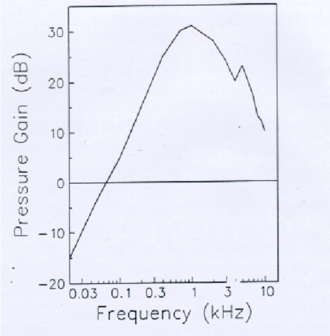
at head position without head (MAF): 0 dB SPL

Accounting for the ‘bowl’

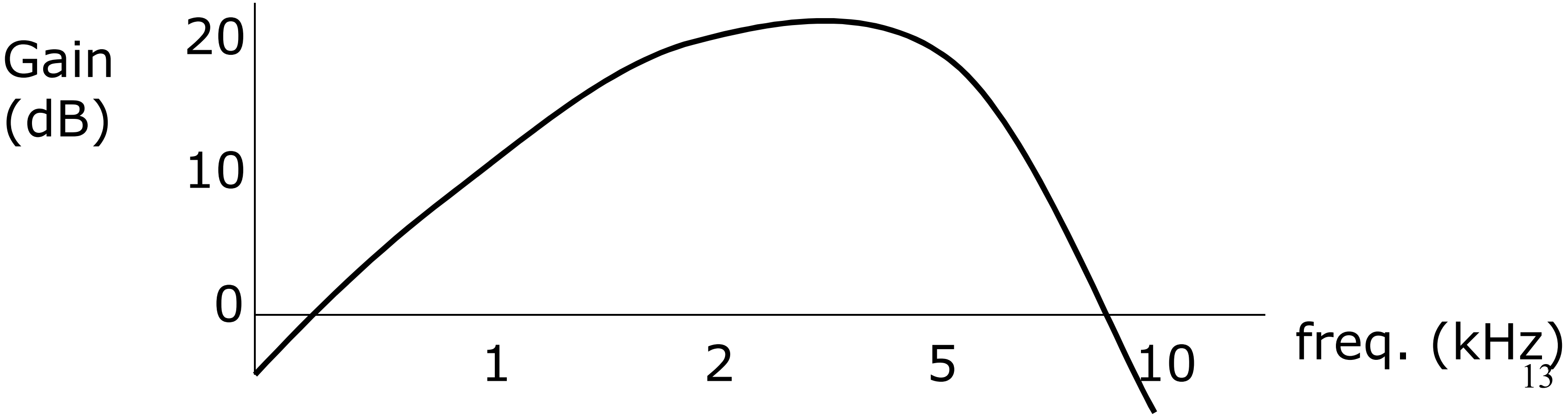
Combine head+pinna+canal+middle ear



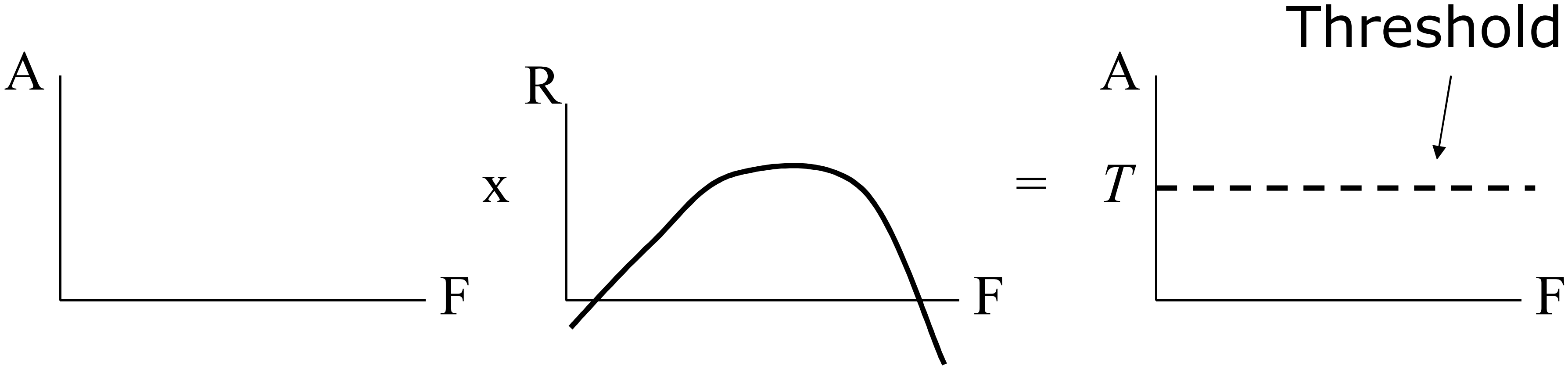




Overall

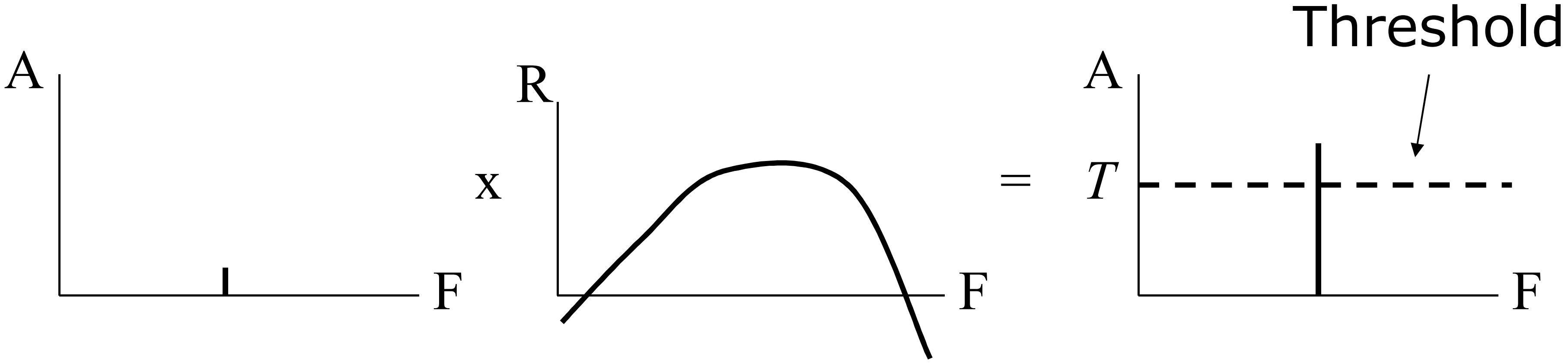


Detection of sinusoids in cochlea



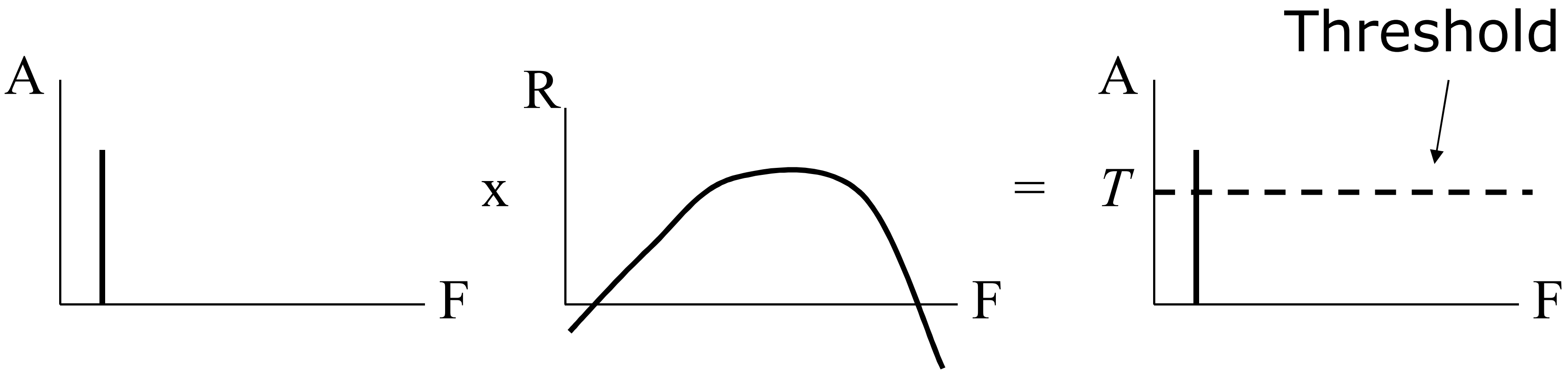
- How big a sinusoid do we have to put into our system for it to be detectable above some threshold?
- Main assumption: once cochlear pressure reaches a particular value, the basilar membrane moves sufficiently to make the nerves fire.

Detection of sinusoids in cochlea



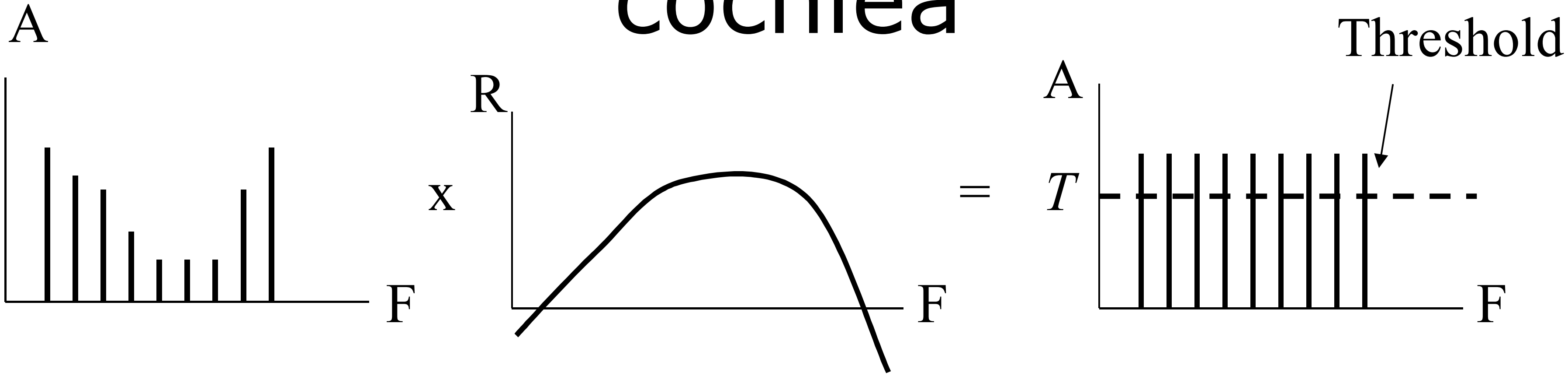
- A mid frequency sinusoid can be quite small because the outer and middle ears amplify the sound

Detection of sinusoids in cochlea



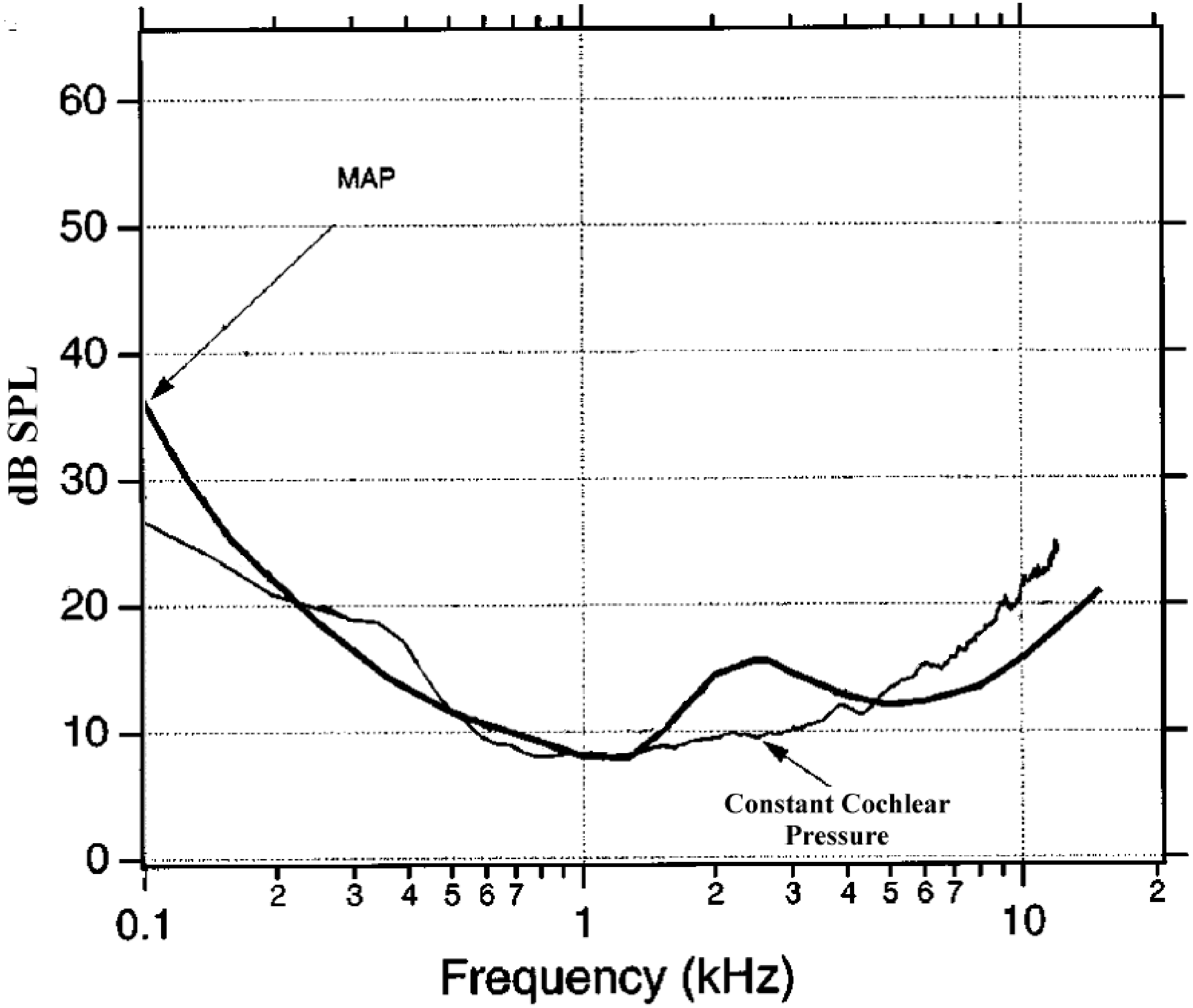
- A low frequency (or high frequency) sinusoid needs to be larger because the outer and middle ears do not amplify those frequencies so much

Detection of sinusoids in cochlea



- So, if the shape of the threshold curve is strongly affected by the efficiency of energy transfer into the cochlea …
- The threshold curve should look like this response turned upside-down: like a bowl.

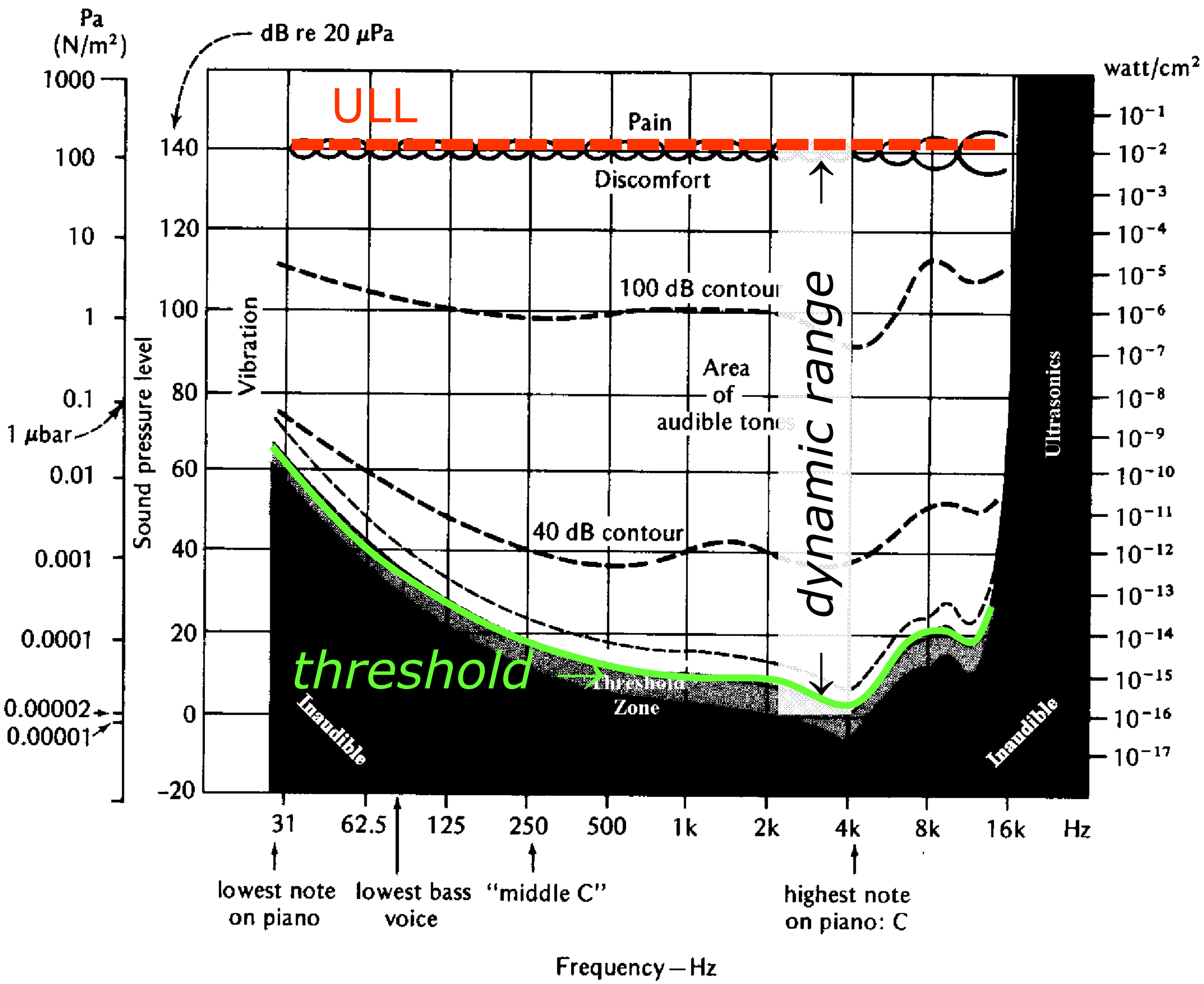
Use MAP, and ignore contribution of head and ear canal



Much of the shape of the threshold curve can be accounted for by the efficiency of energy transfer into the cochlea

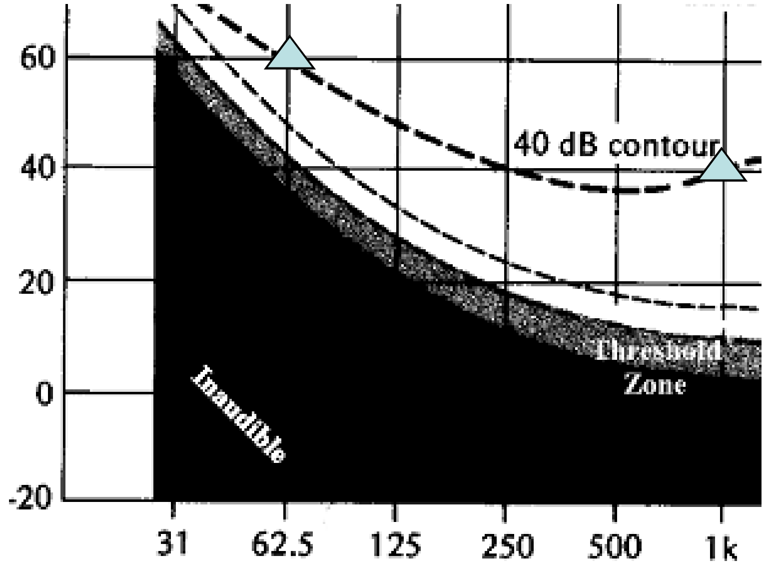
(from Puria, Peake & Rosowski, 1997)

Loudness of supra-threshold sinusoids



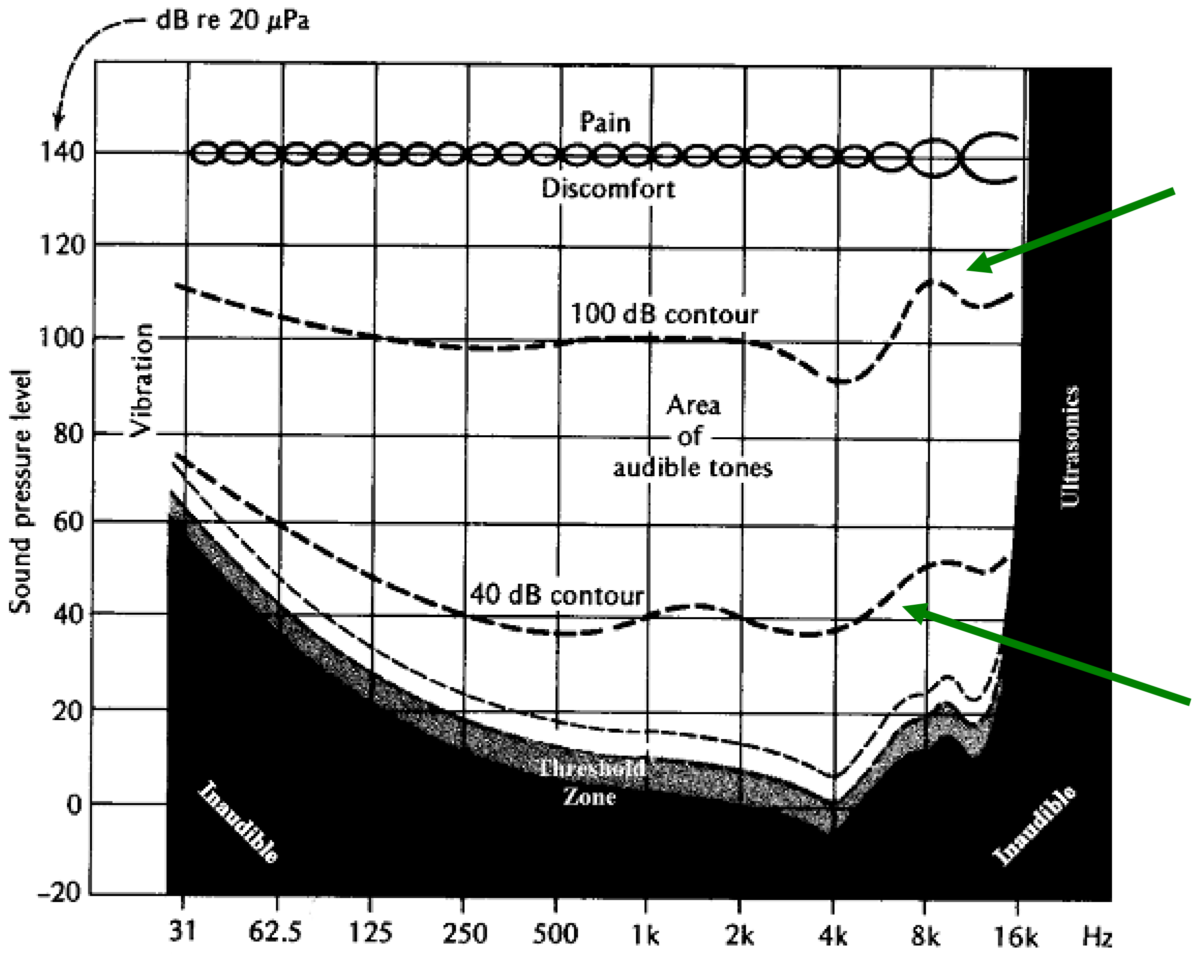
The Phon scale of loudness

- "A sound has a loudness of *X* phons if it is equally as loud as a sinewave of *X* dB SPL at 1kHz"



e.g. A 62.5Hz sinusoid at 60dB SPL has a loudness of 40 phons, because it is equally as loud as a 40dB SPL sinusoid at 1kHz

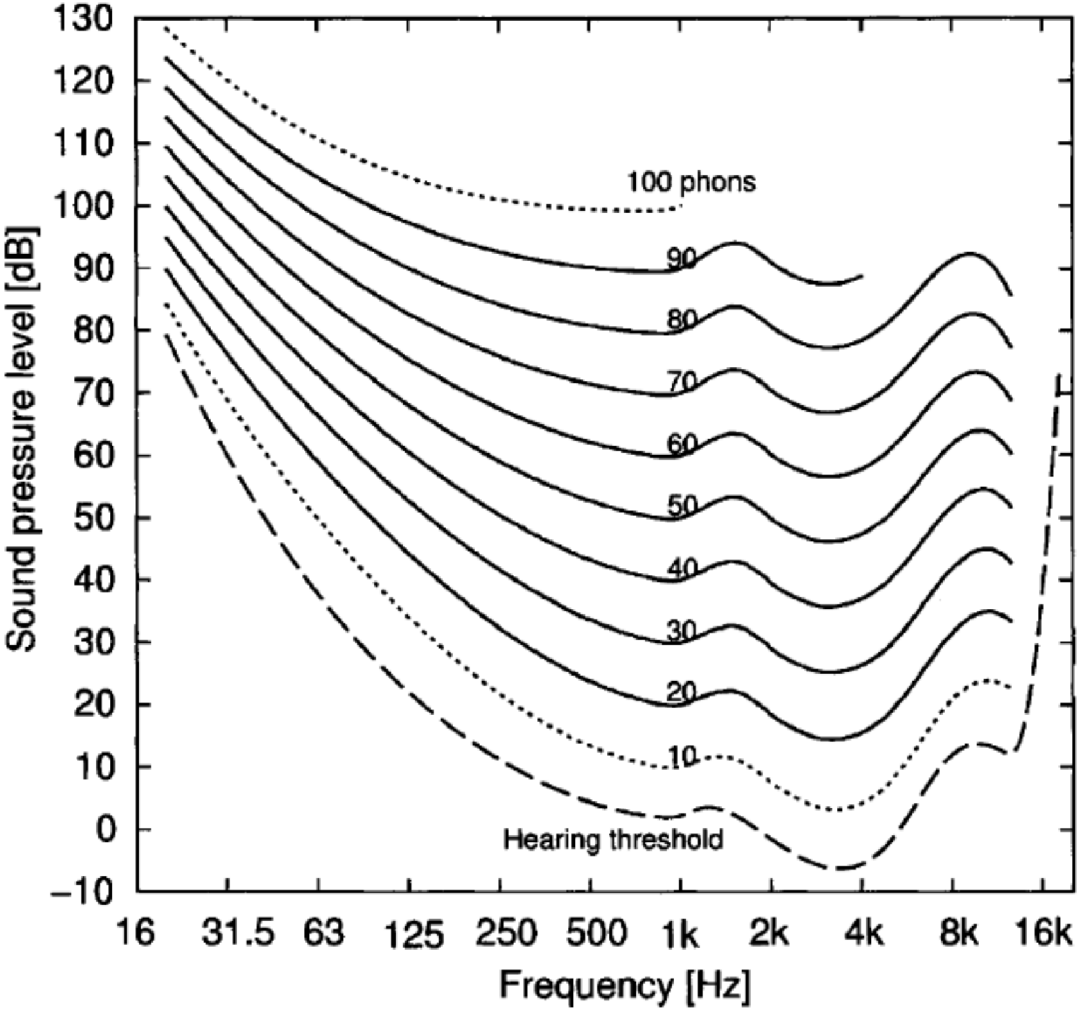
Equal loudness contours



Contour of tones equal in loudness to 100 dB SPL sinusoid @ 1kHz

Contour of tones equal in loudness to 40 dB SPL sinusoid @ 1kHz

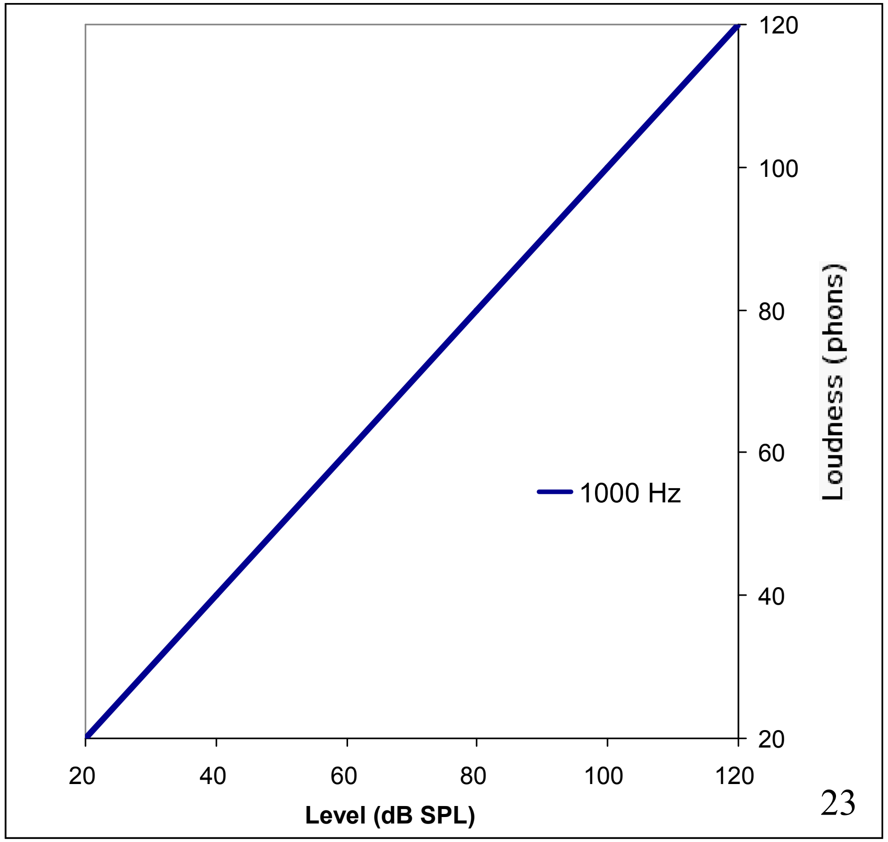
Contemporary equal loudness contours



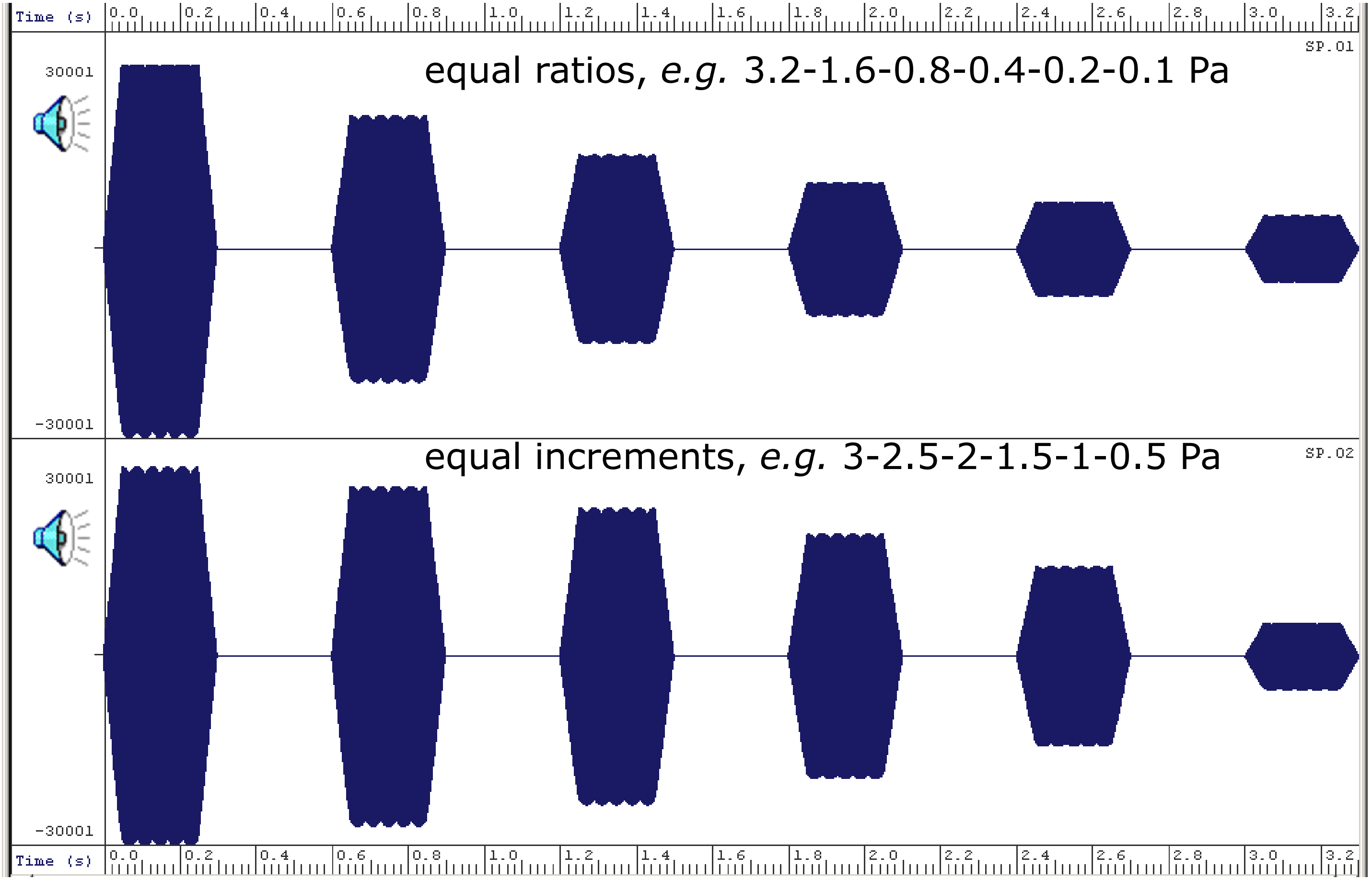
From Suzuki & Takeshima (2004) JASA

So now we can specify the loudness of sounds in terms of the level of a 1 kHz tone …

but how loud
is a 1kHz tone
at, say,
40 dB SPL?



Perceived loudness is (roughly) logarithmically related to pressure



equal ratios, *e.g.* 3.2-1.6-0.8-0.4-0.2-0.1 Pa

equal increments, *e.g.* 3-2.5-2-1.5-1-0.5 Pa

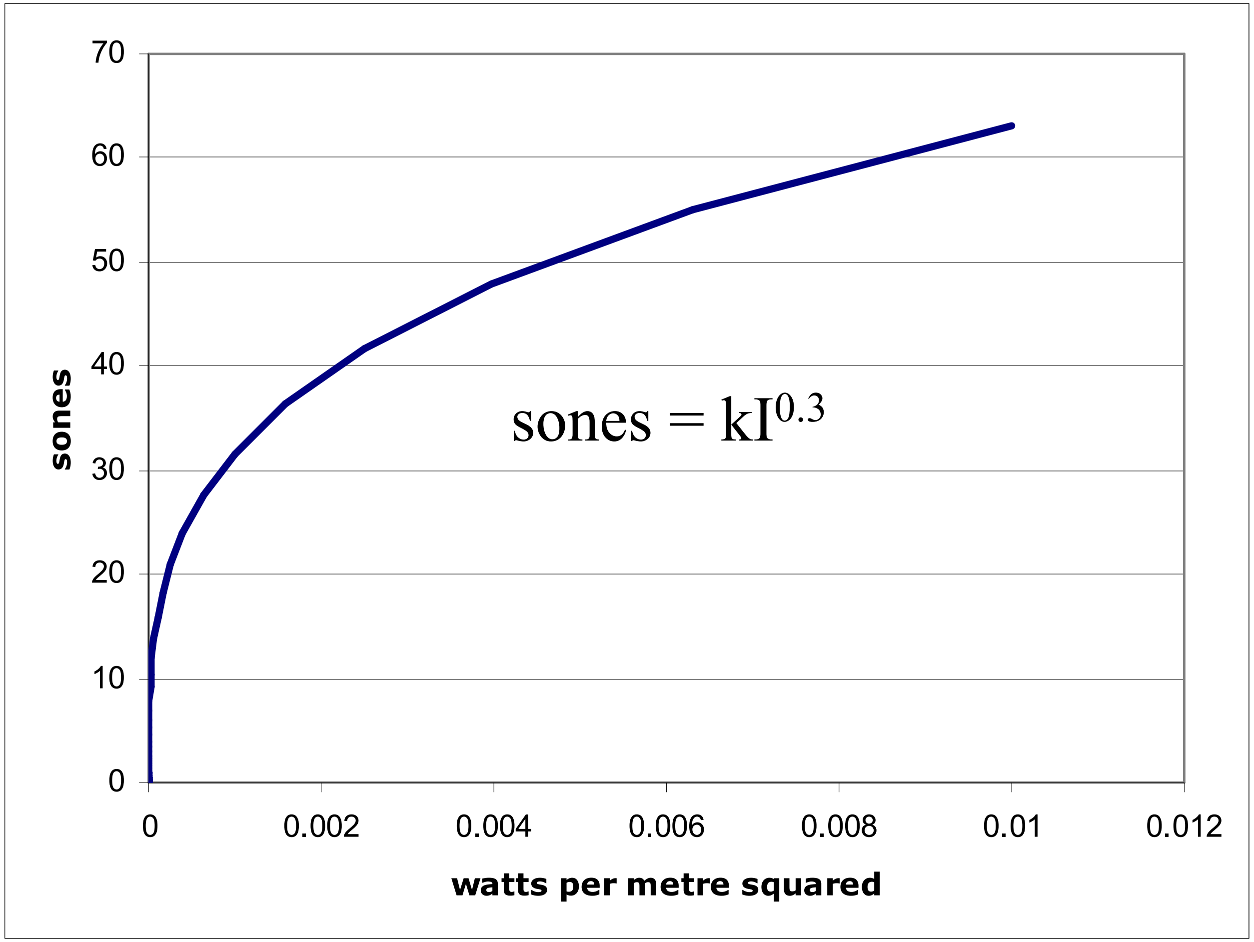
Direct scaling procedures: Magnitude Estimation

- Here’s a standard sound whose loudness is ‘100’
- Here’s another sound
  - If it sounds twice as loud, call it 200
  - If it sounds half as loud call it 50
- In short - assign numbers according to a ***ratio*** scale

Alternatives to magnitude estimation

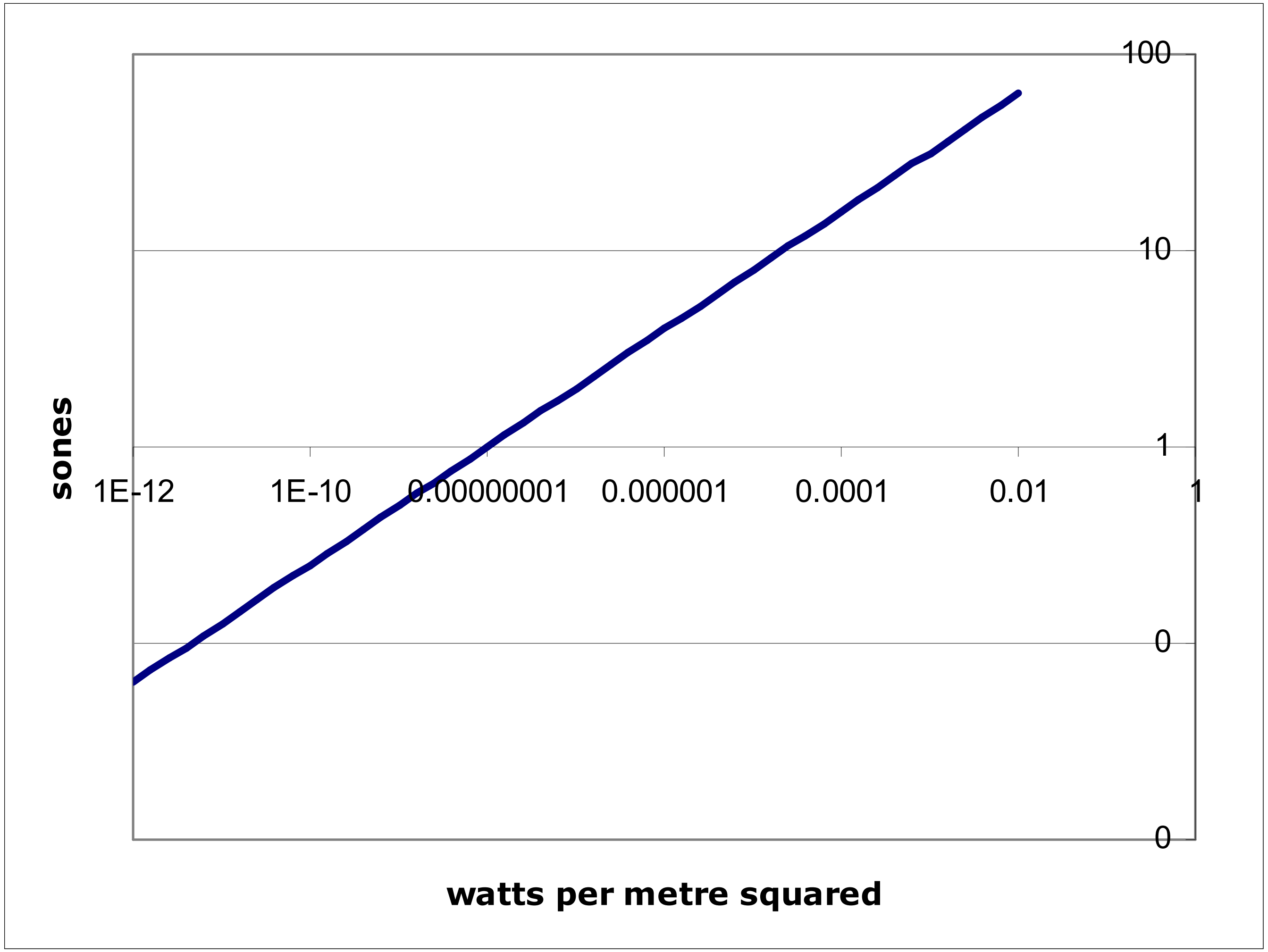
- Magnitude production
  - Here’s a sound whose loudness we’ll call 100
  - Adjust the sound until its loudness is 400
- Cross-modality matching
  - Adjust this light until it as bright as the sound is loud

Magnitude estimates are well fit by power functions



a strongly *compressive* function

… which are linear on log-log scales



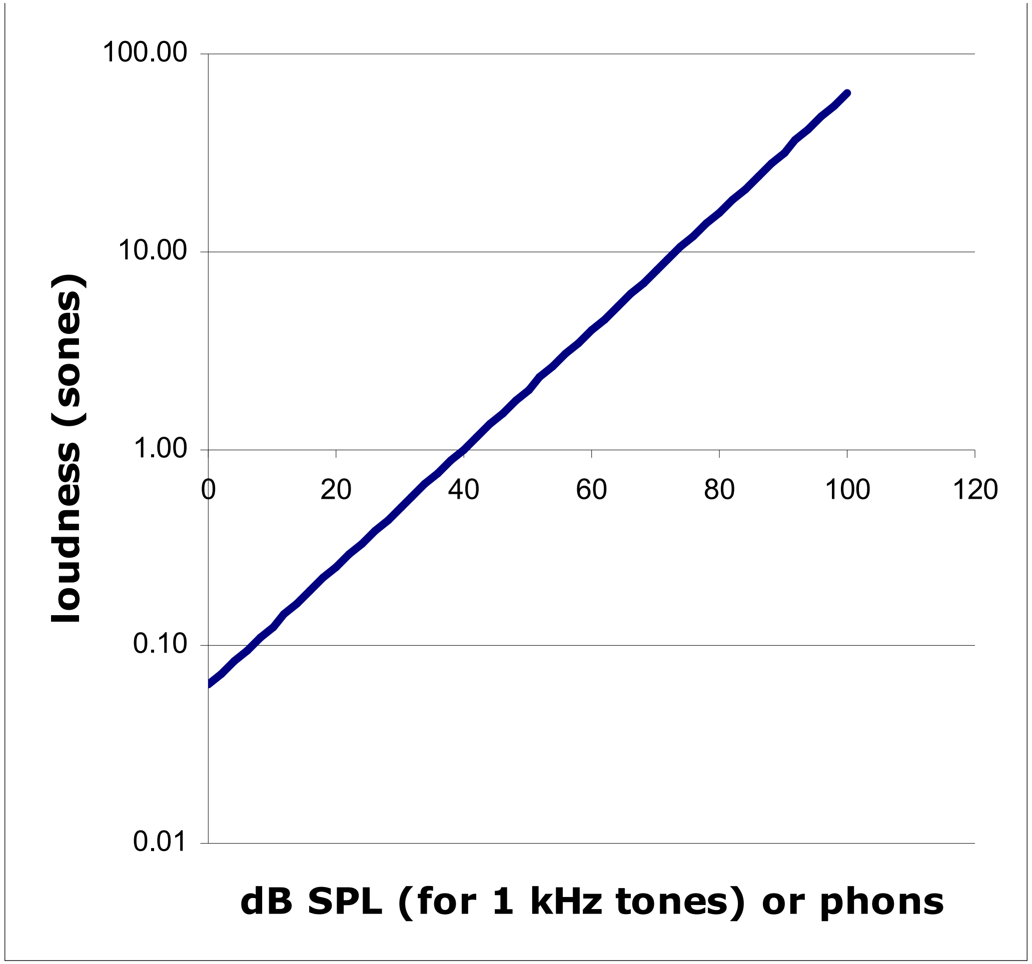
… so also on log-dB scales

1 sone = 40 phon (by definition)

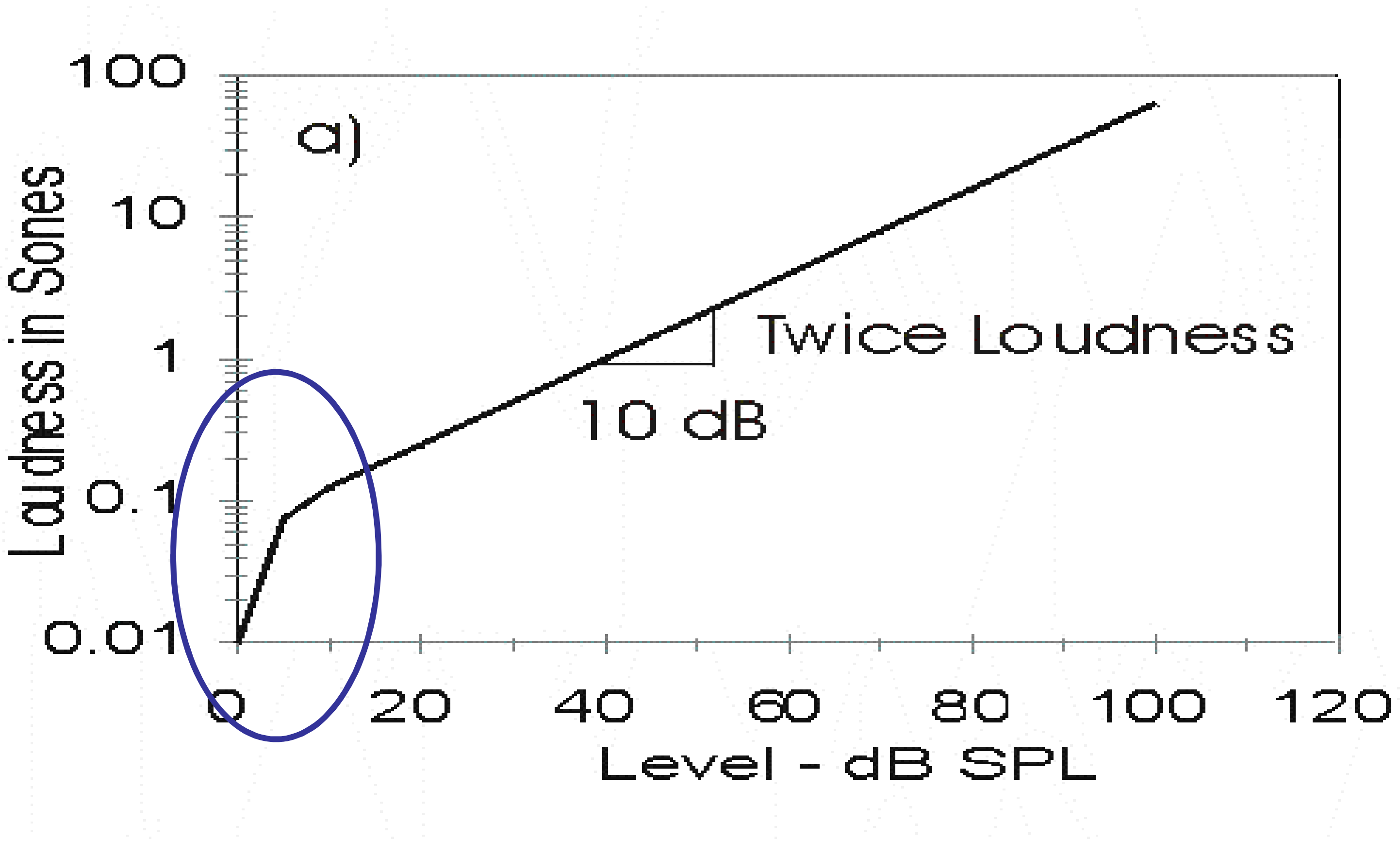
a 10 dB increase in level gives a doubling in loudness

What's the slope in dB terms?

Reminiscent of ?



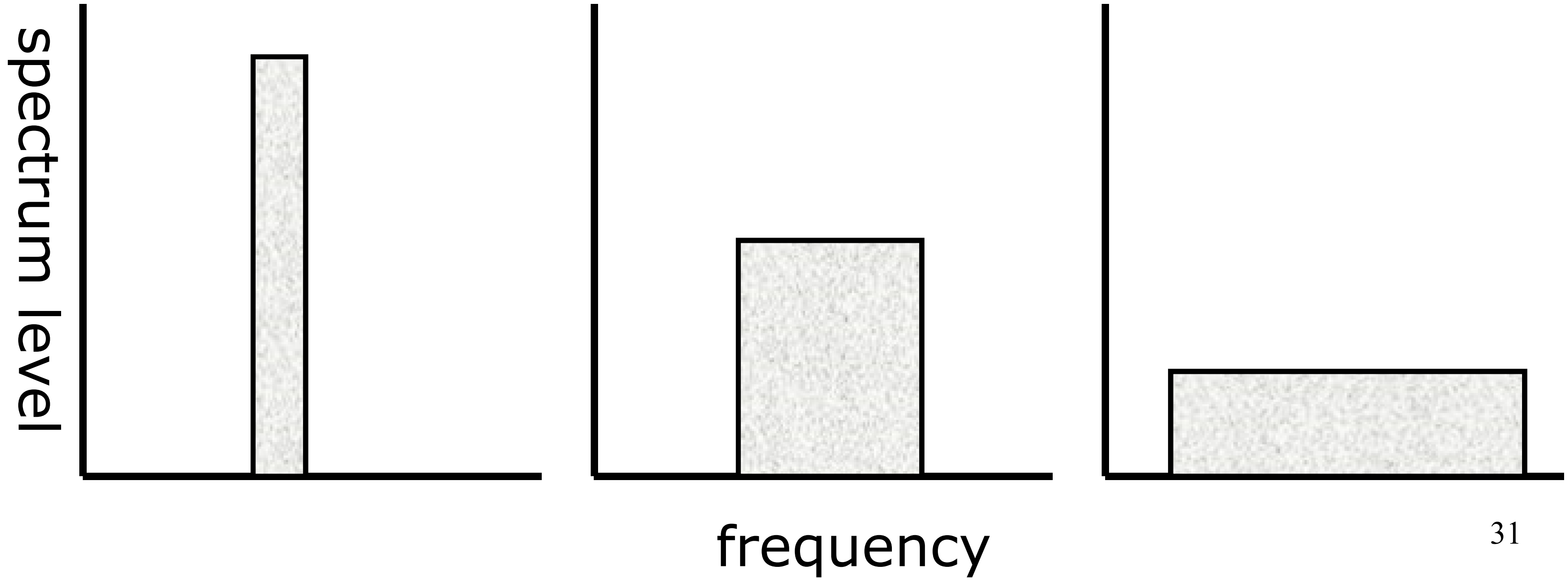
Strict power law not quite right



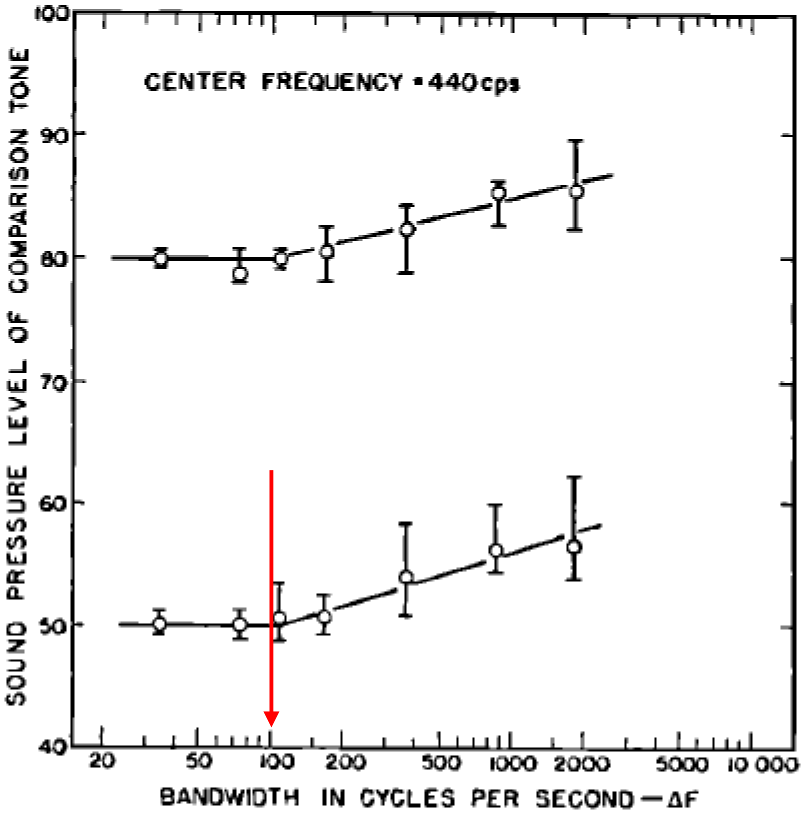
from Yost (2007)

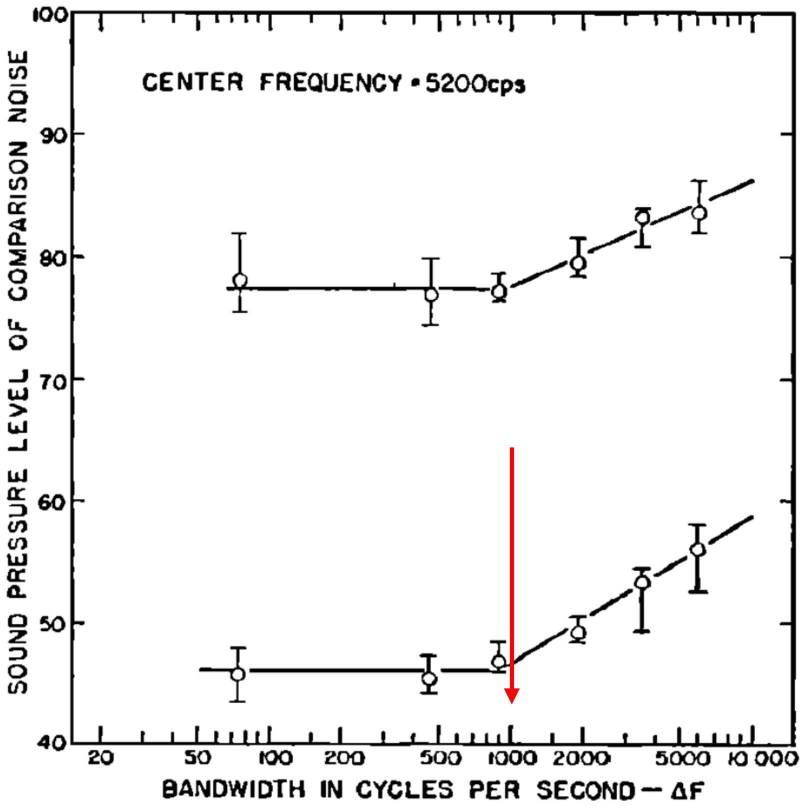
How does loudness for noises depend on bandwidth?

Vary bandwidth of noise keeping total rms level constant



Loudness for noise depends on bandwidth



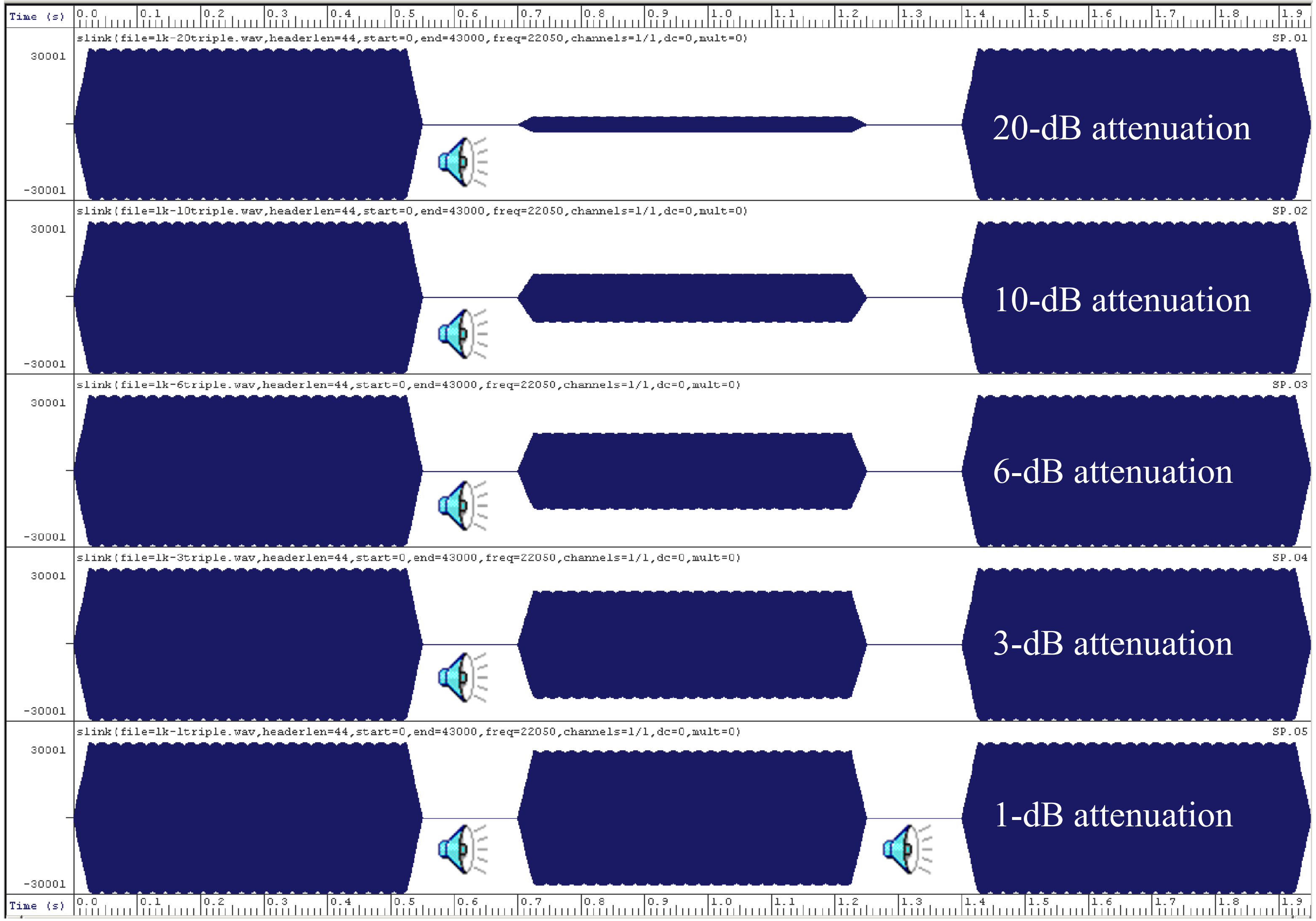


from Zwicker, Flottorp & Stevens (1957) JASA

Discrimination of changes in intensity

- Typically done as adaptive forced-choice task
- Two steady-state tones or noises, differing only in intensity
- Which tone is louder?
- People can, in ideal circumstances, distinguish sounds different by ≈ 1-2 dB.

Changes in intensity



Across level, the jnd is, roughly speaking,
a constant *proportion,* not a constant *amount*.

Weber’s Law

- Let Δp be the minimal detectable change in pressure, or *just noticeable difference* (jnd)
- Weber’s Law: the jnd is a constant proportion of the stimulus value

  $\Delta p = k \times P$ where k is a constant

  $\Delta p / P = k$
- Like money!
- Also a constant in terms of dB

The near miss to Weber's Law in intensity jnds for pure tones

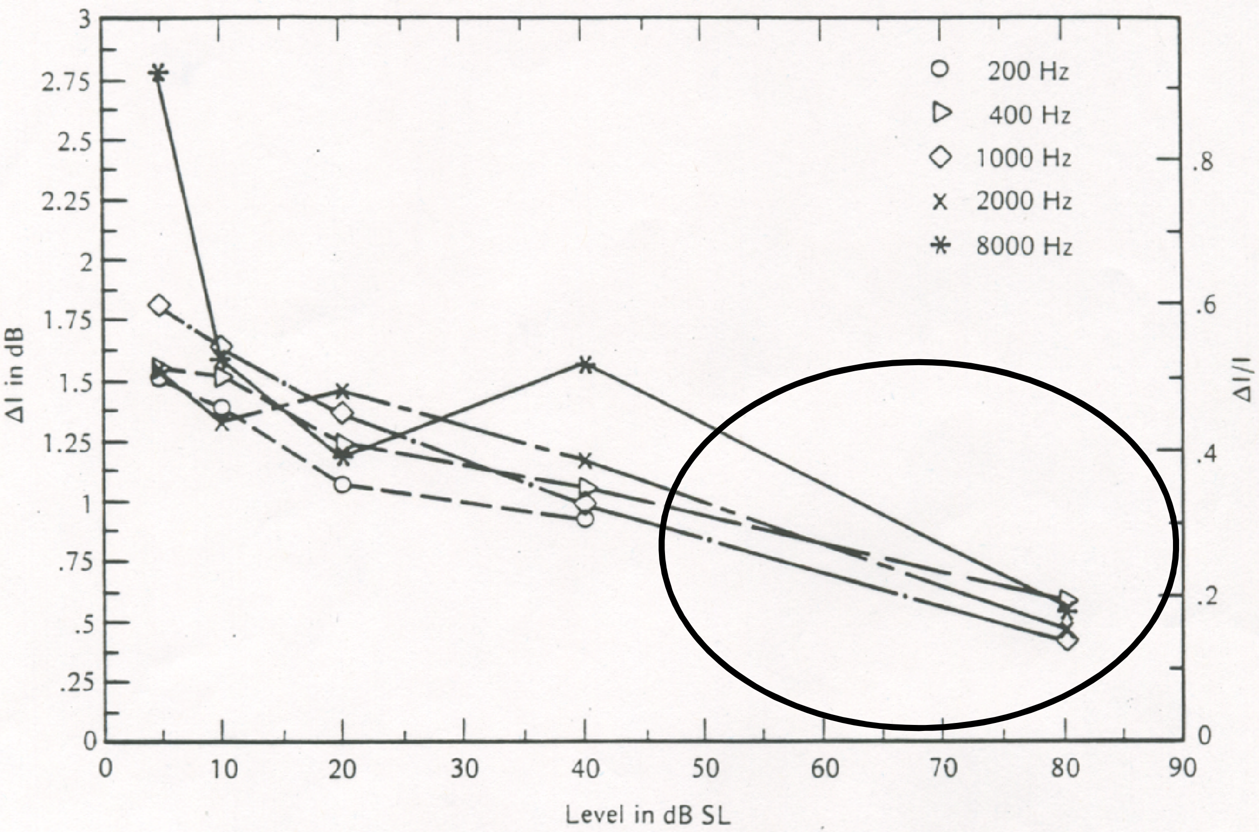
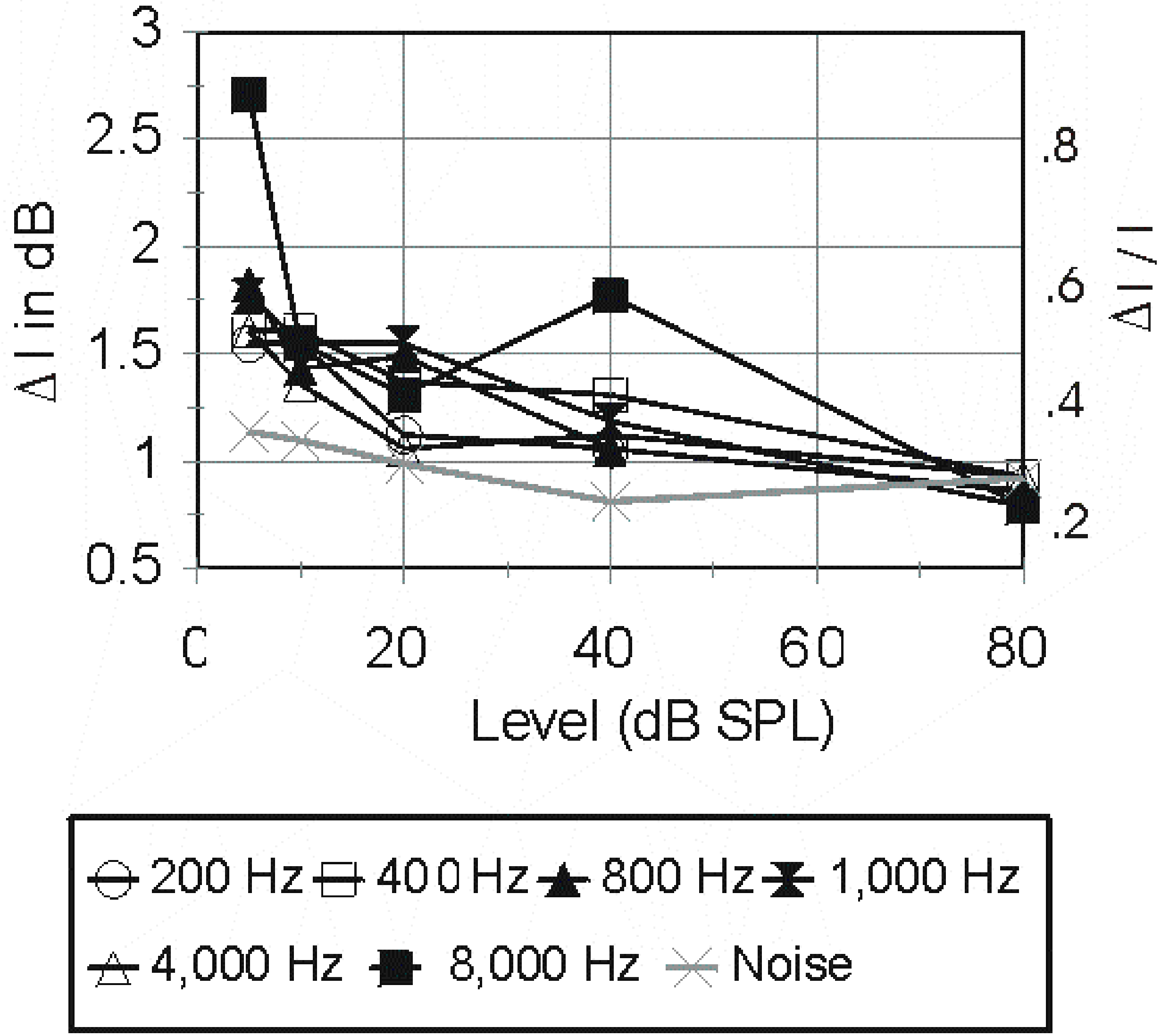


Figure 10.8 The value of ΔI in decibels (the difference in decibels between the more and less intense tones) required for threshold discrimination is shown as a function of overall tonal intensity in dB SL. Data for five frequencies are shown.
Based on data of Jesteadt, Weir, and Green, 1977, with permission

From Yost & Nielsen (1985)



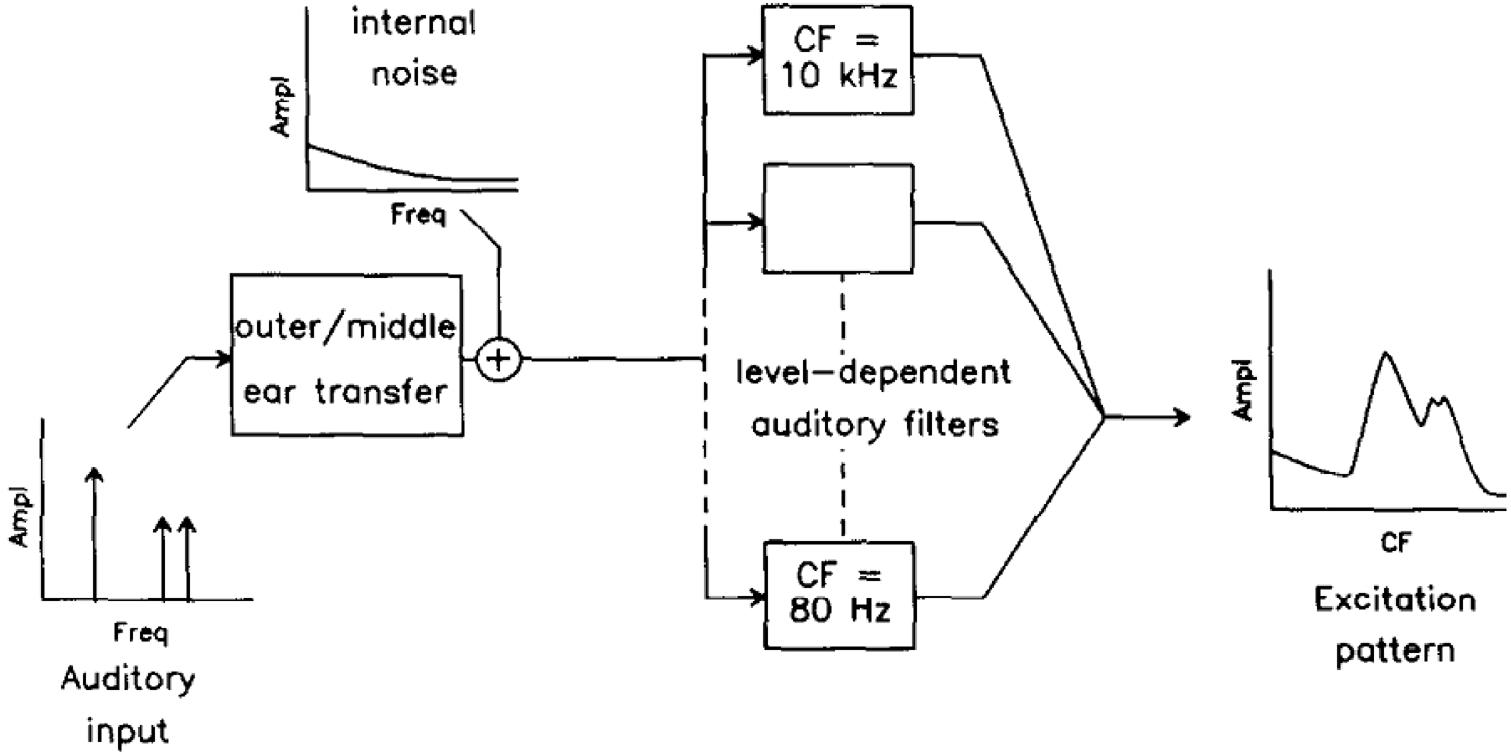
jnds for
noise
don’t
miss

from Yost (2007)

Intensity jnds

- For pure tones, the jnd for intensity decreases with increasing intensity (the near miss to Weber's Law)
- For wide-band noises, Weber's Law (pretty much) holds
- Probably to do with *spread of excitation* –
  - See Plack *The Sense of Hearing Ch 6.3*

A little detour: Excitation Pattern models



van der Heijden, M., and Kohlrausch, A. (**1994**). "Using an excitation-pattern model to predict auditory masking," Hearing Research **80**, 38-52.

Excitation patterns for a 1kHz tone

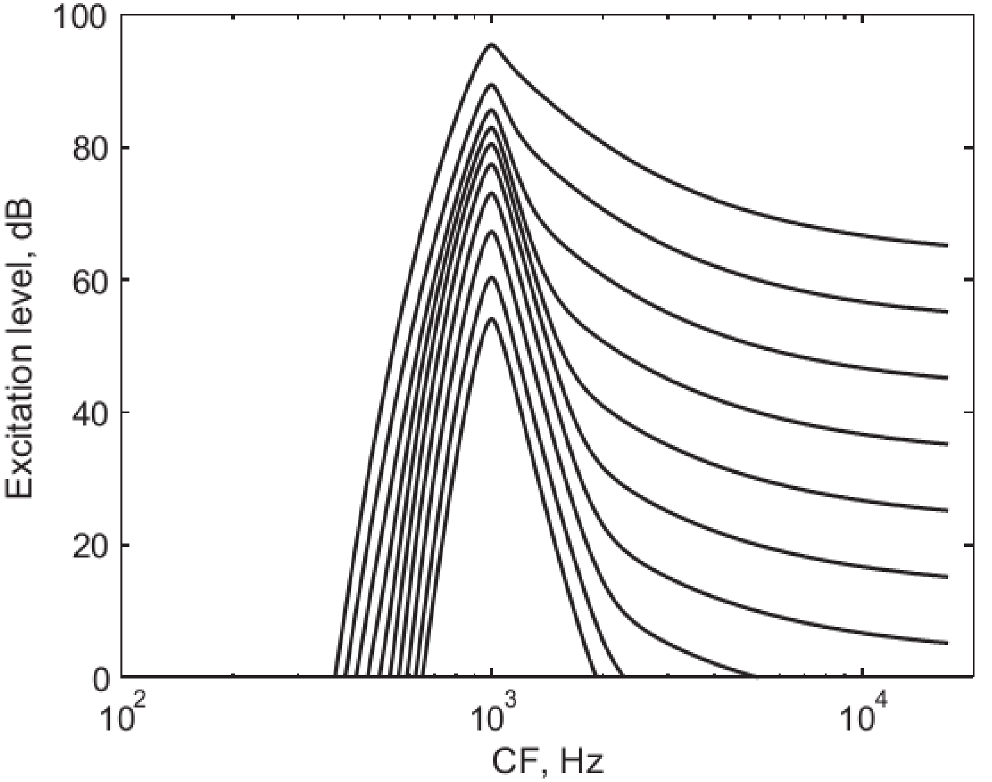


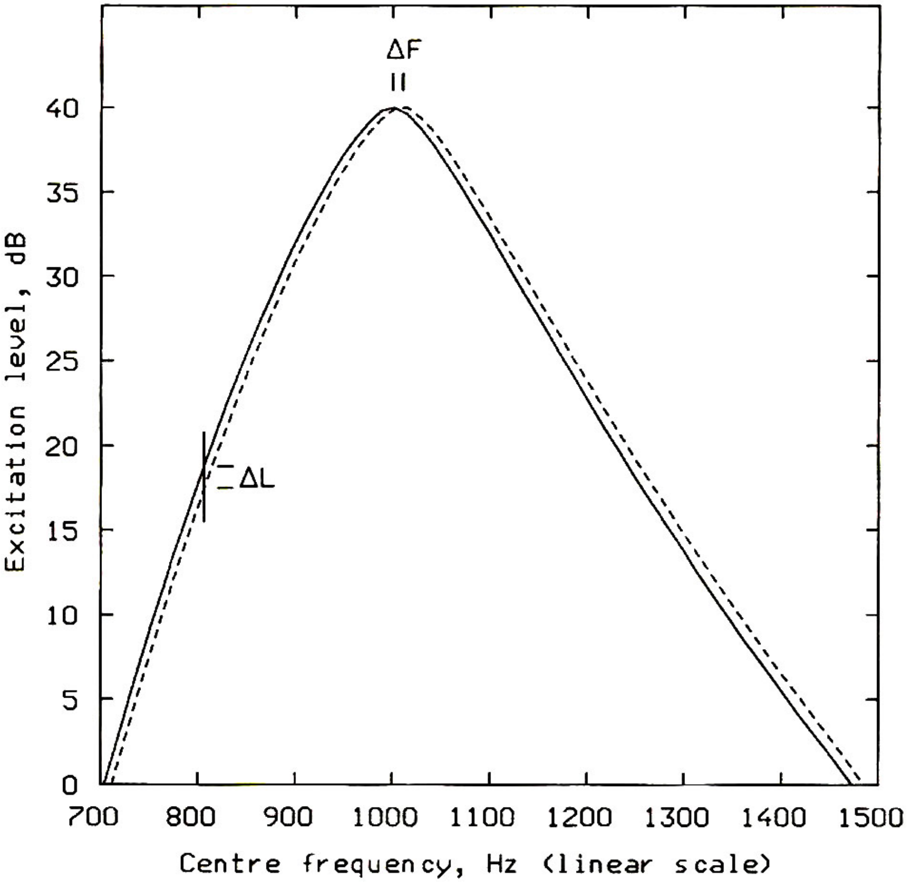
Fig. 7. Calculated excitation patterns for a 1-kHz tone at levels of 2 dB SPL and 10–90 dB SPL in 10-dB steps.

Chen, Z. L., Hue, G. S., Glasberg, B. R., and Moore, B. C. J. (**2011**). "A new method of calculating auditory excitation patterns and loudness for steady sounds," Hearing Research **282**, 204-215.

Excitation Pattern models for frequency discrimination

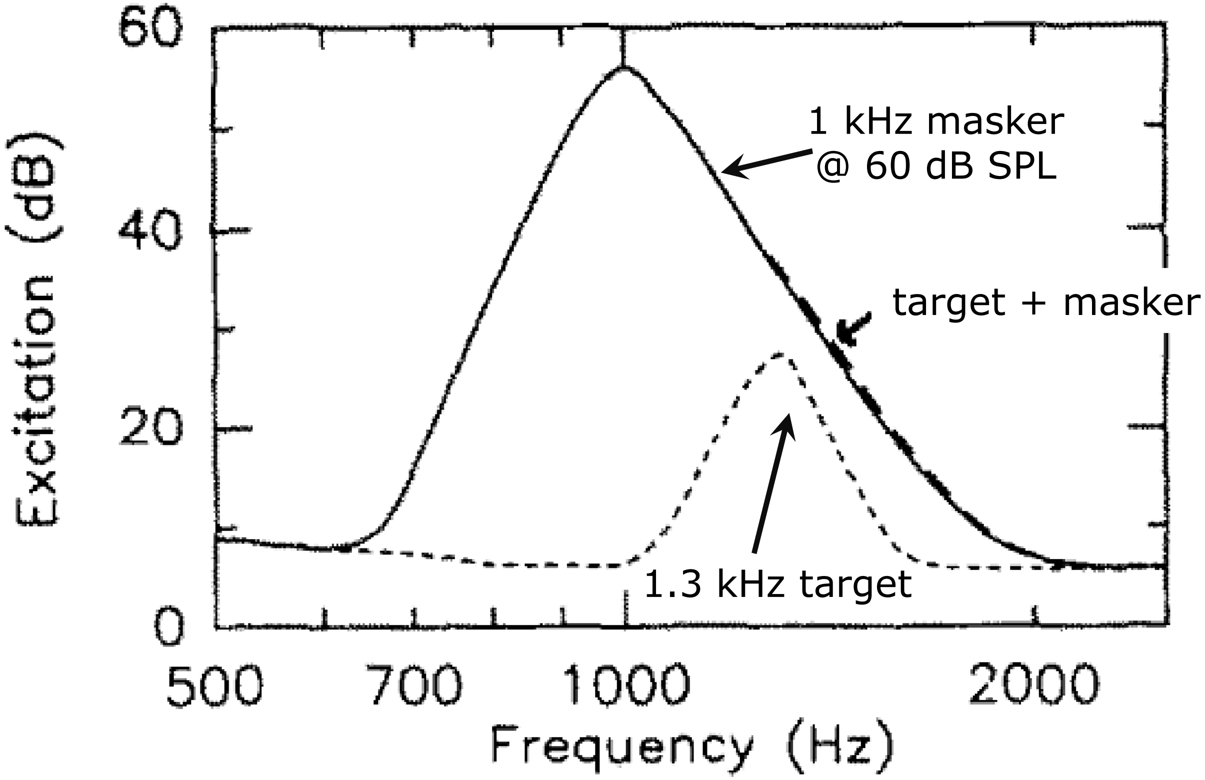
The difference in frequency (ΔF) that a listener can just detect is predicted to depend on the change in level (ΔL) that results.

When any point on the excitation pattern changes in level by 1 dB, the listener is predicted to be able to detect that change.



(Moore, 2007)

Excitation Pattern models for masking



van der Heijden, M., and Kohlrausch, A. (**1994**). "Using an excitation-pattern model to predict auditory masking," Hearing Research **80**, 38-52.

Excitation pattern models for intensity discrimination

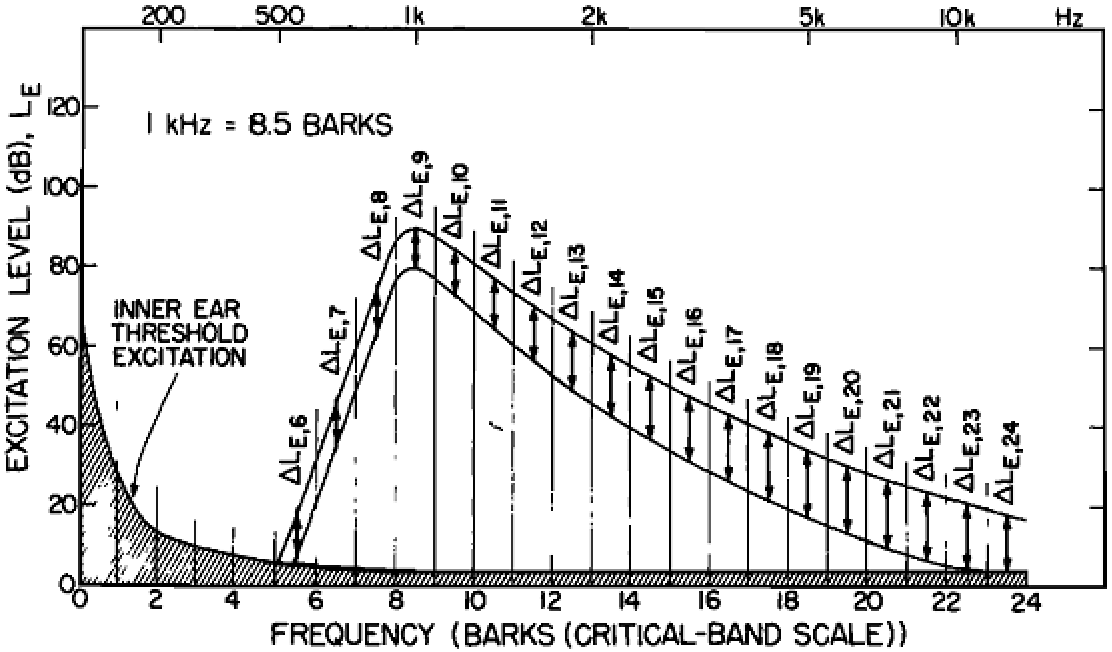


FIG. 1. Excitation level plotted as a function of frequency in barks for two 1-kHz tones differing only in intensity.

- Sounds are perceivably different if excitation pattern is different by 1dB at some place on the basilar membrane (Zwicker)
- Note that no temporal information is represented in these models

Florentine, M., and Buus, S. (**1981**). "An Excitation-Pattern Model for Intensity Discrimination," J. Acoust. Soc. Am. **70**, 1646-1654.

Explaining the near miss to Weber's Law

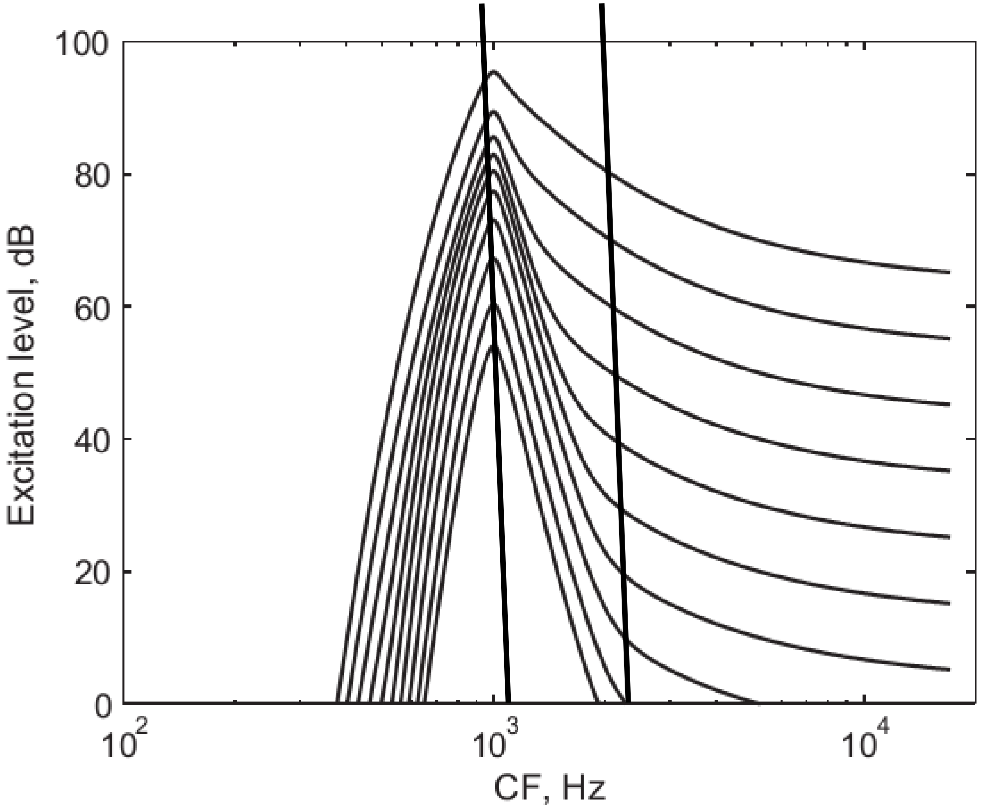
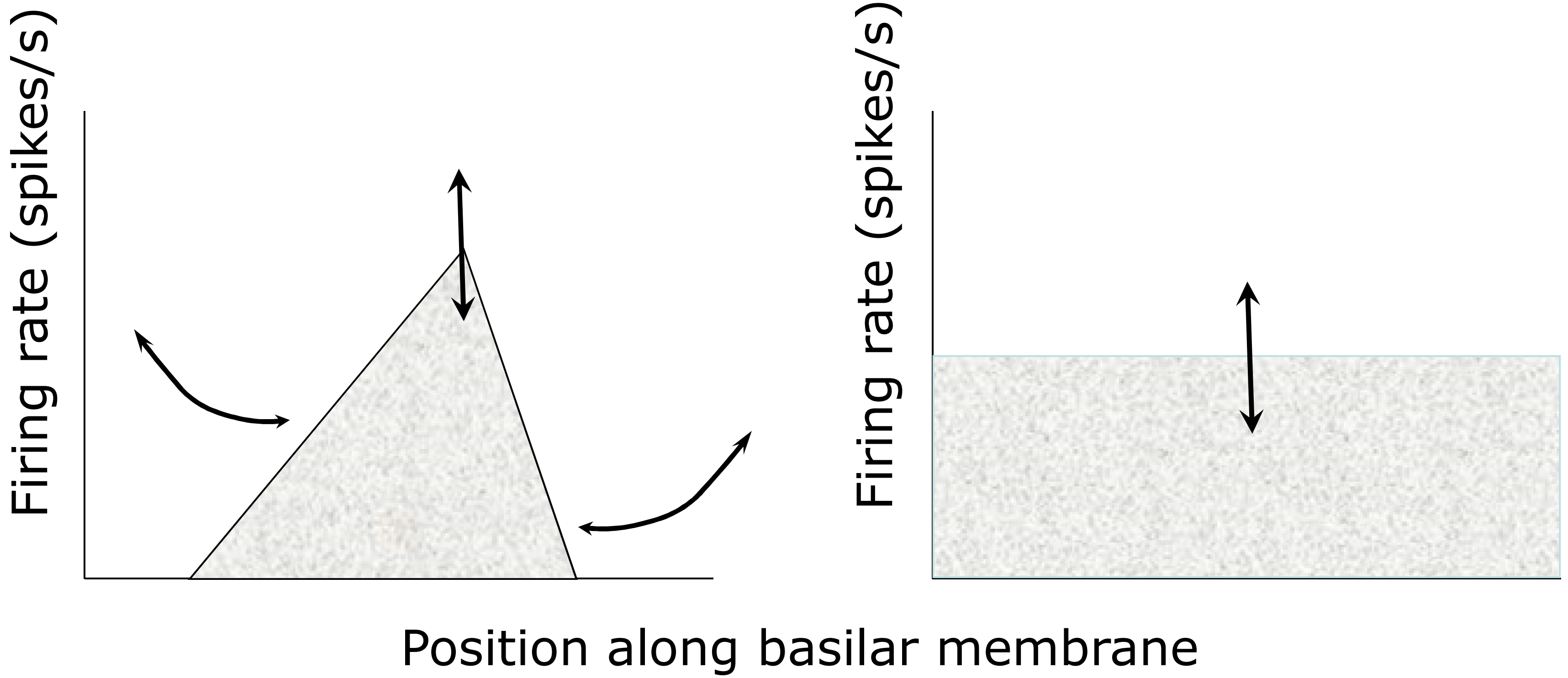


Fig. 7. Calculated excitation patterns for a 1-kHz tone at levels of 2 dB SPL and 10–90 dB SPL in 10-dB steps.

changes
are bigger
here than
near 1 kHz

Chen, Z. L., Hue, G. S., Glasberg, B. R., and Moore, B. C. J. (**2011**). "A new method of calculating auditory excitation patterns and loudness for steady sounds," Hearing Research **282**, 204-215.

Excitation patterns for a tone and broadband noise



bands of noise do not ‘spread’ along the BM as intensity increases