Perception: Psychophysics and Modeling

17 | Auditory System II

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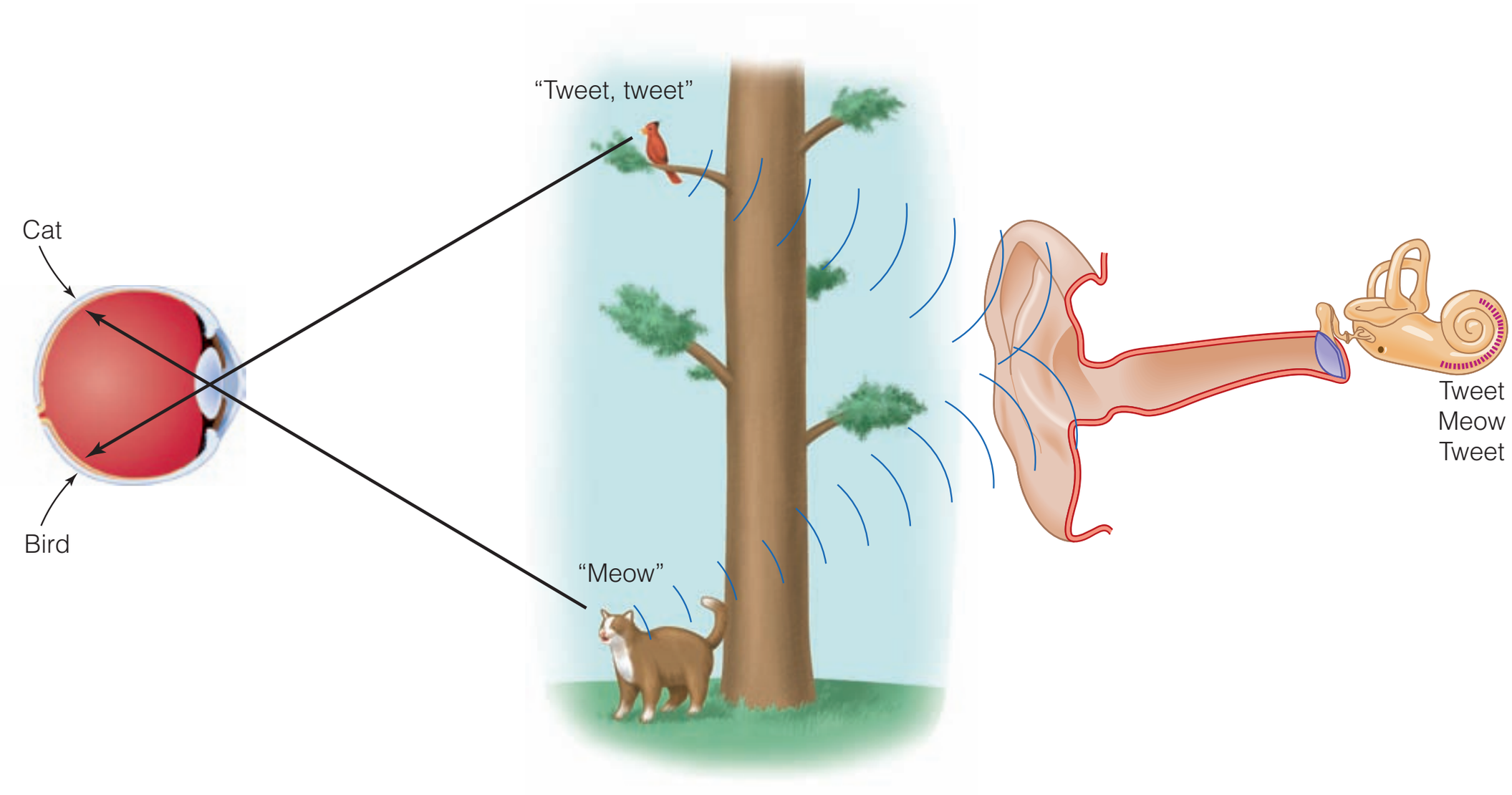
Overview

Sound Localization

Hearing Impairment

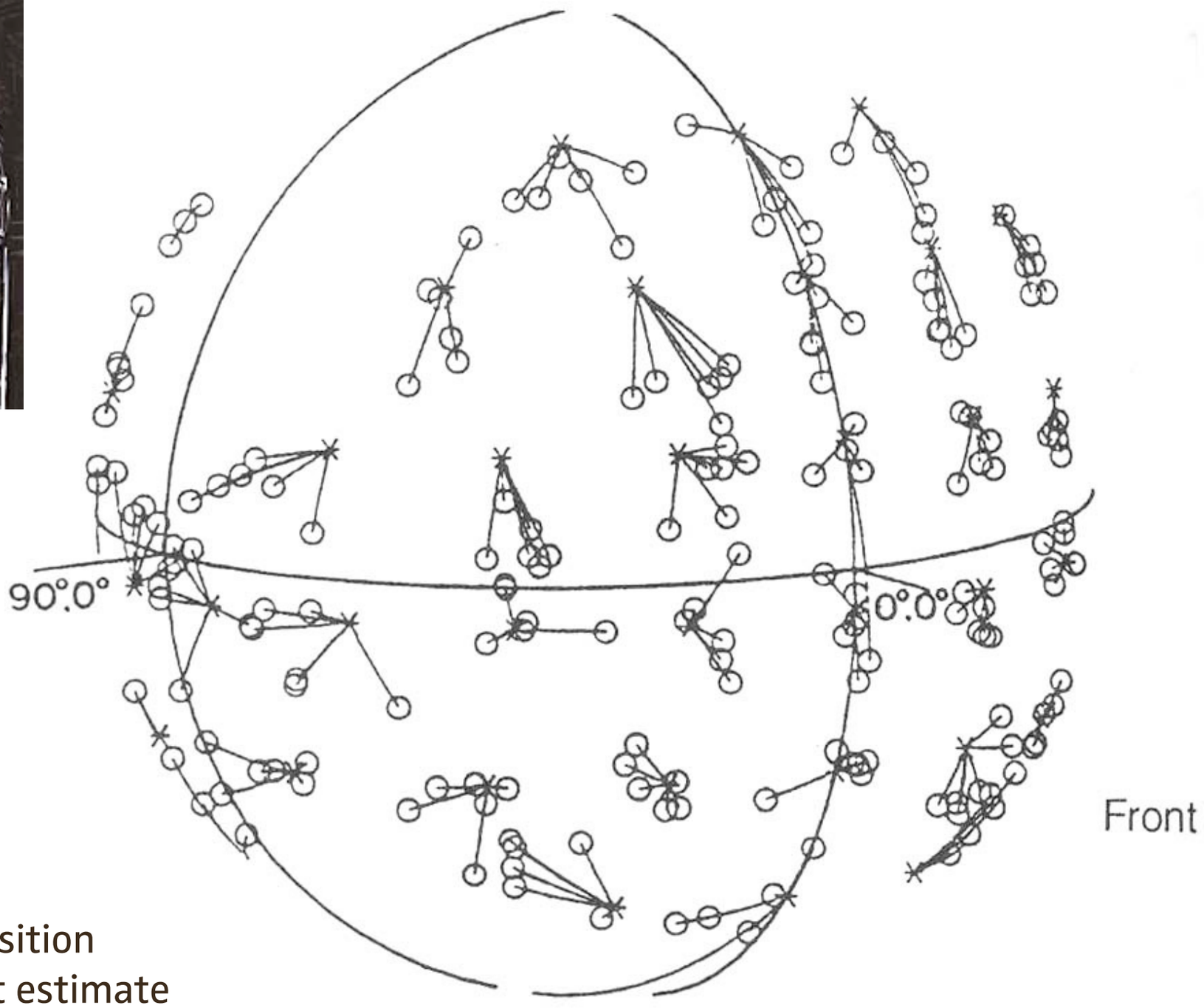
A Spectral Analyser / The Critical Band

Intensity, Loudness and Sensation



from: Goldstein (2007)

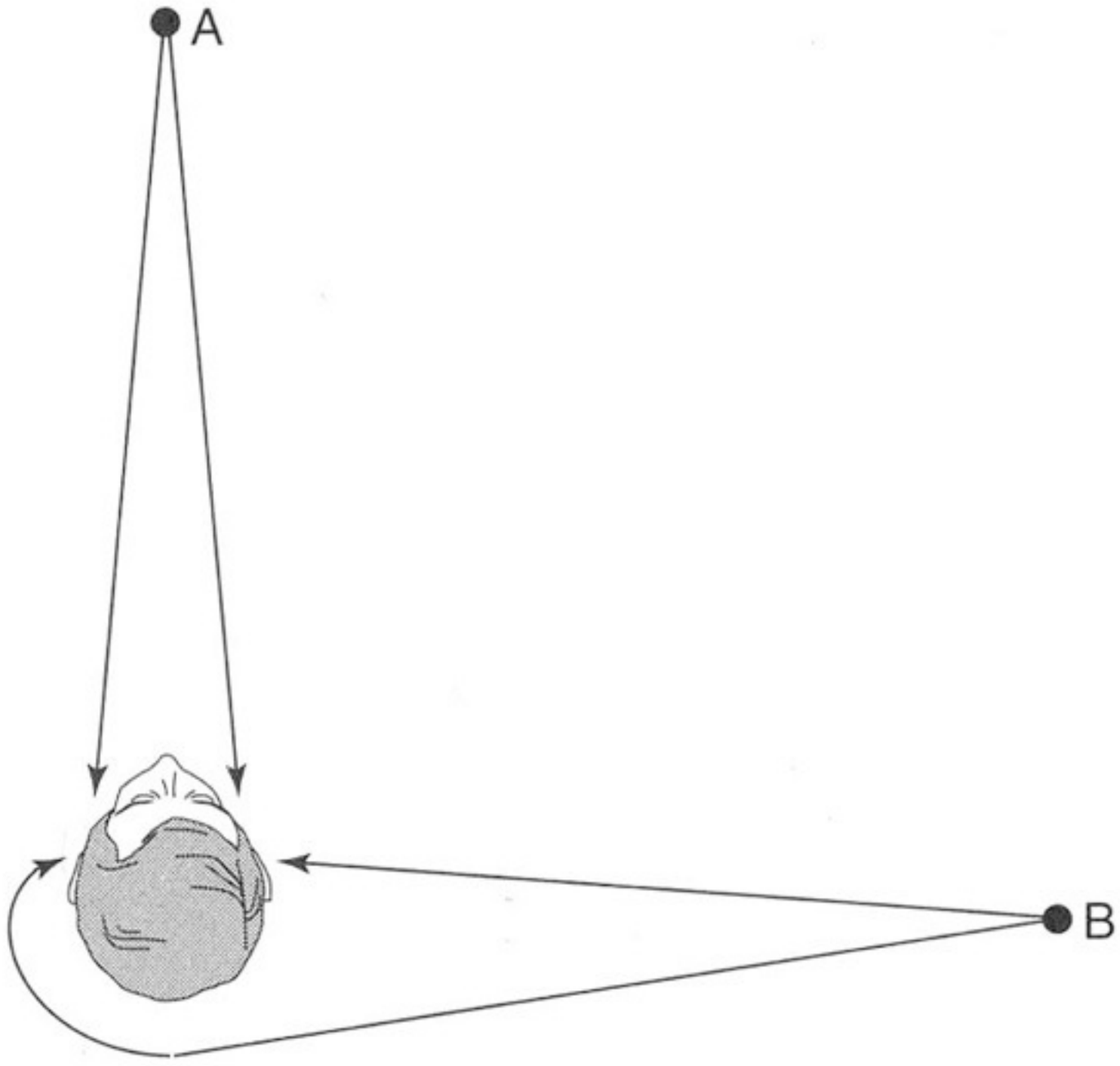
Sound Localization



x - real position
o - subject estimate

Goldstein, 2002

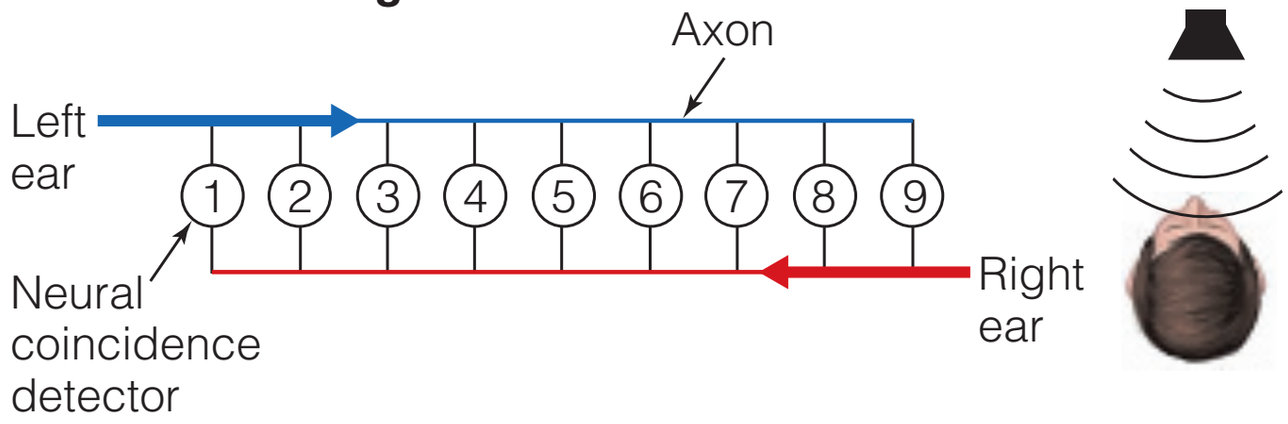
Interaural Time-Difference (ITD)



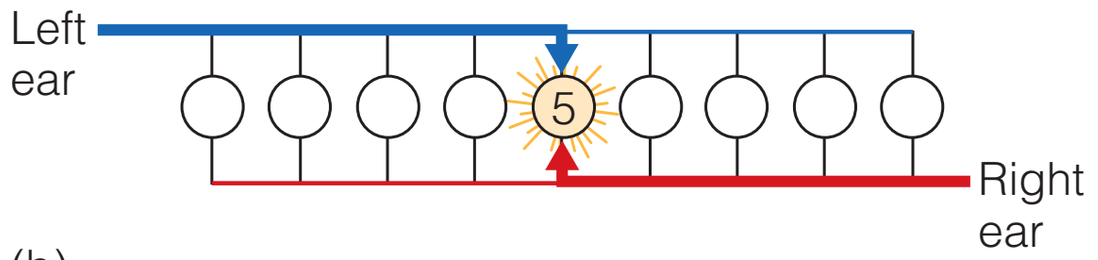
Goldstein, 2002

Jeffress' Model

Sound from straight ahead:

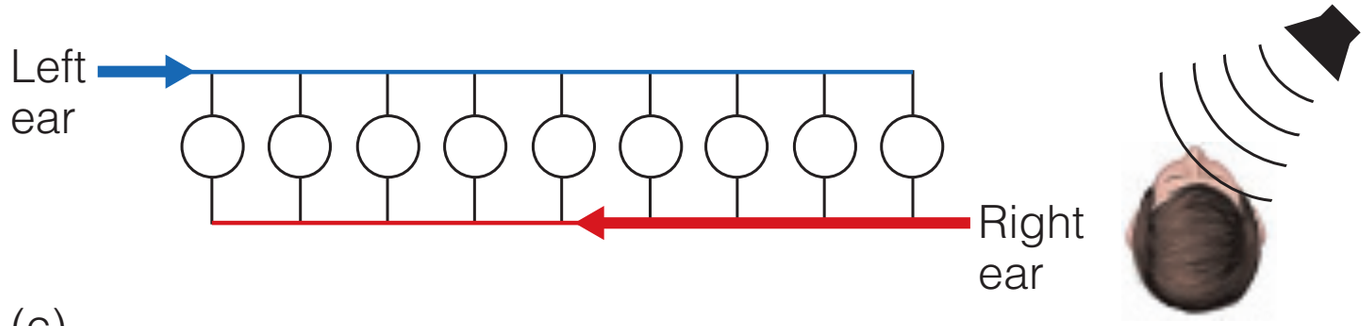


(a)

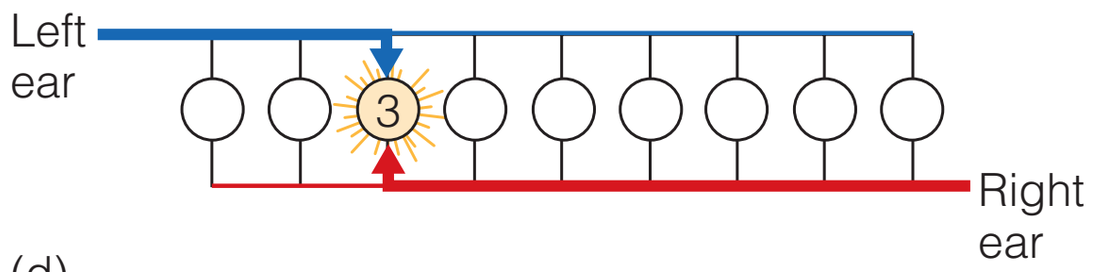


(b)

Sound from the right:



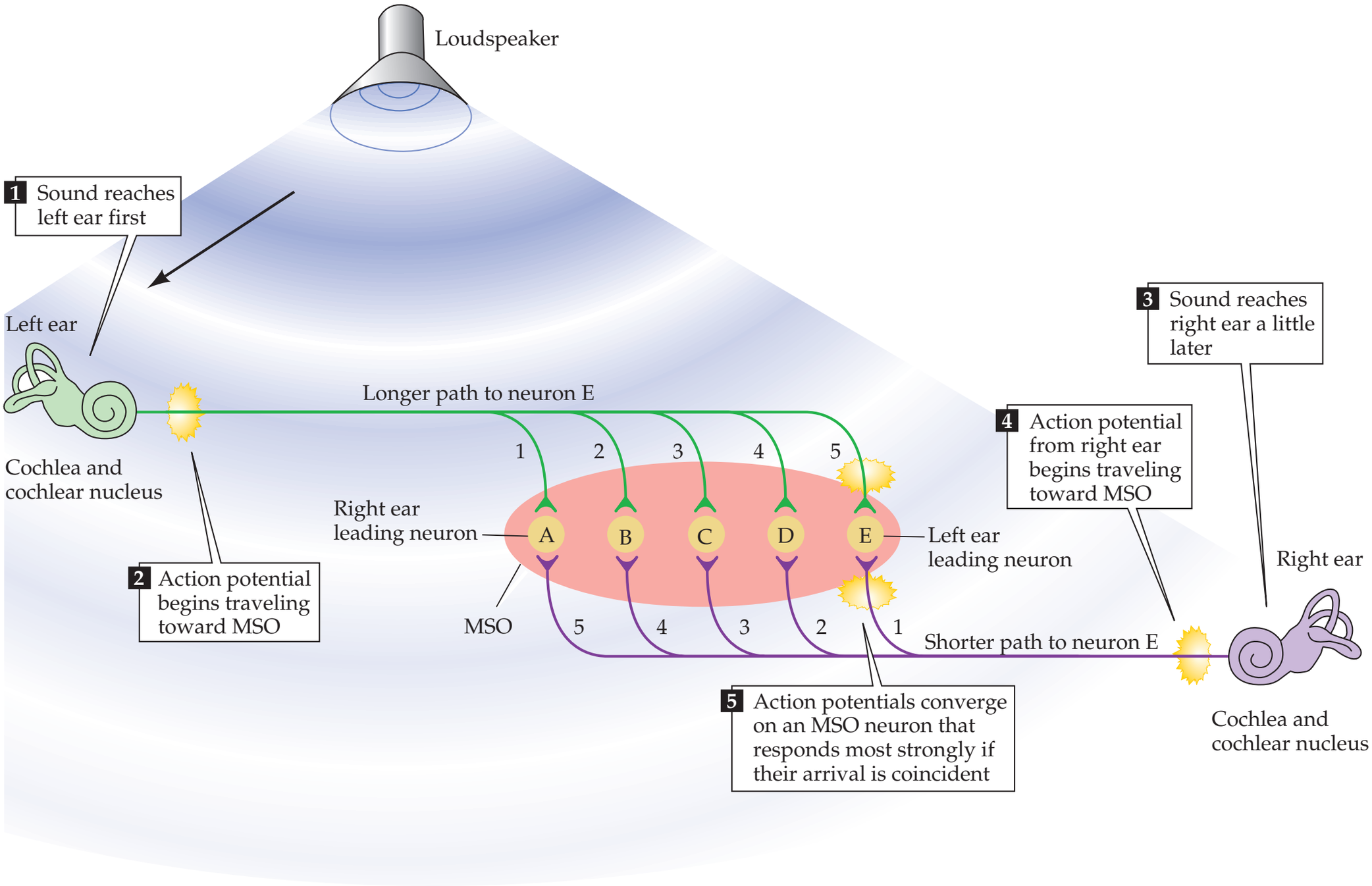
(c)



(d)

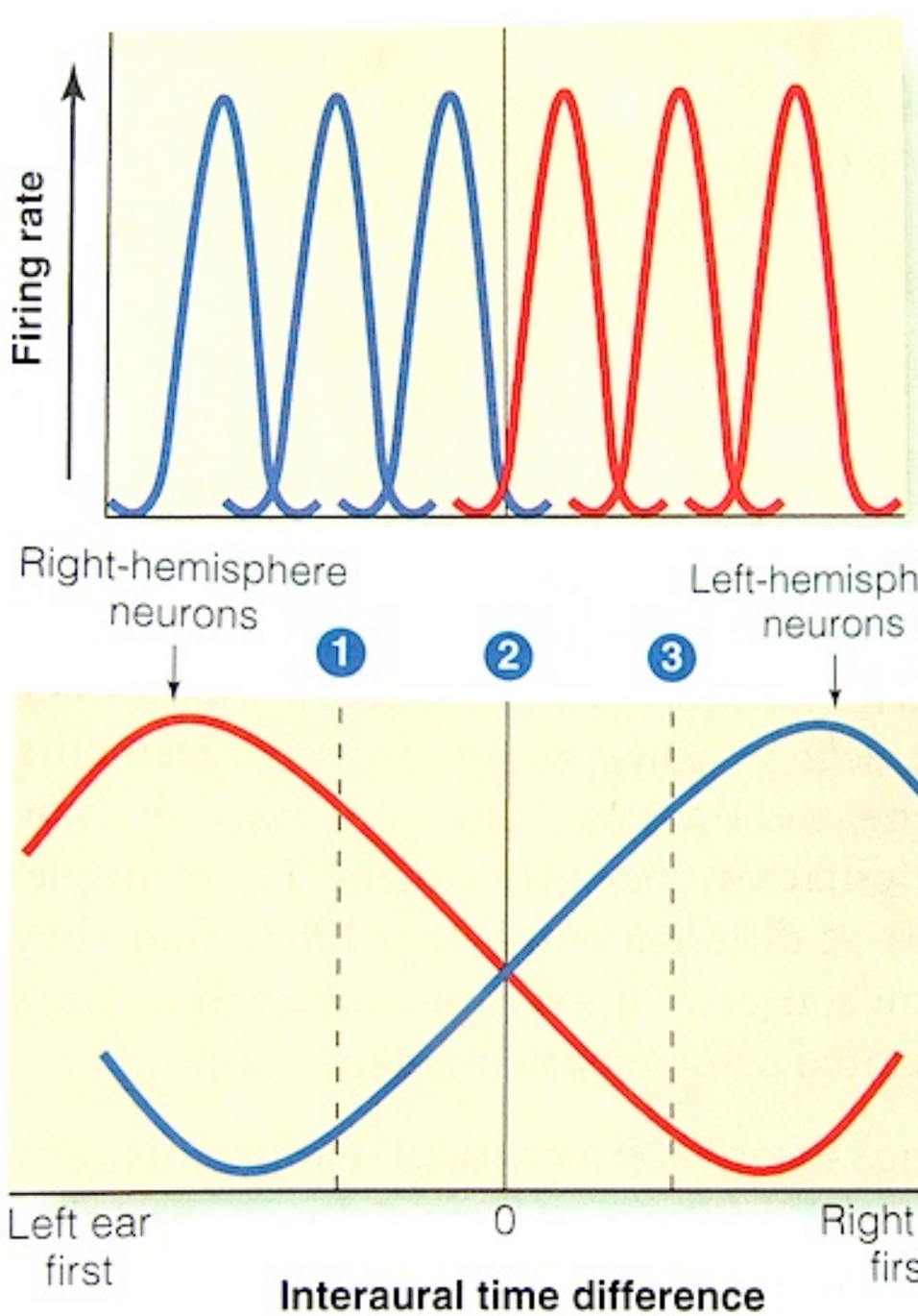
from: Goldstein (2007)

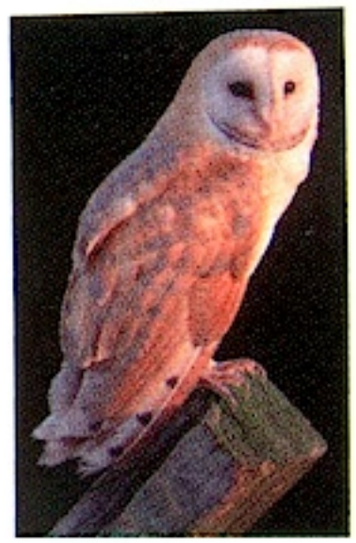
Jeffress' Model (physiology)



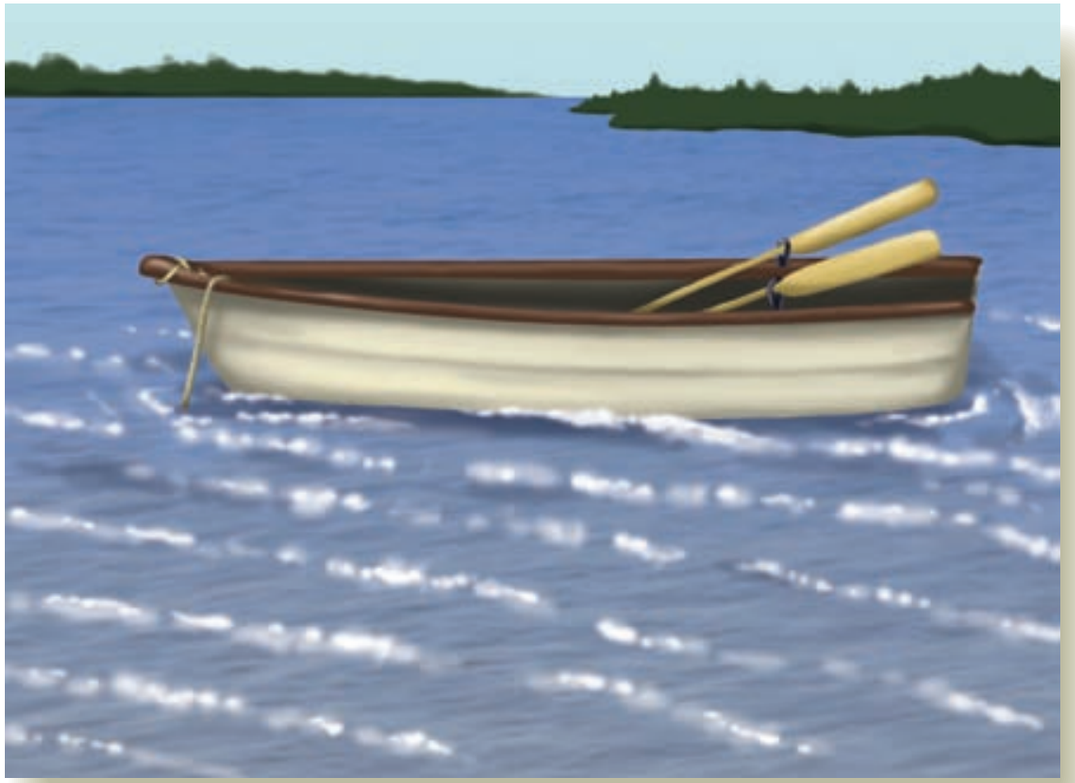
Purves, Neuroscience, 2004

ITD Tuning in Different Species



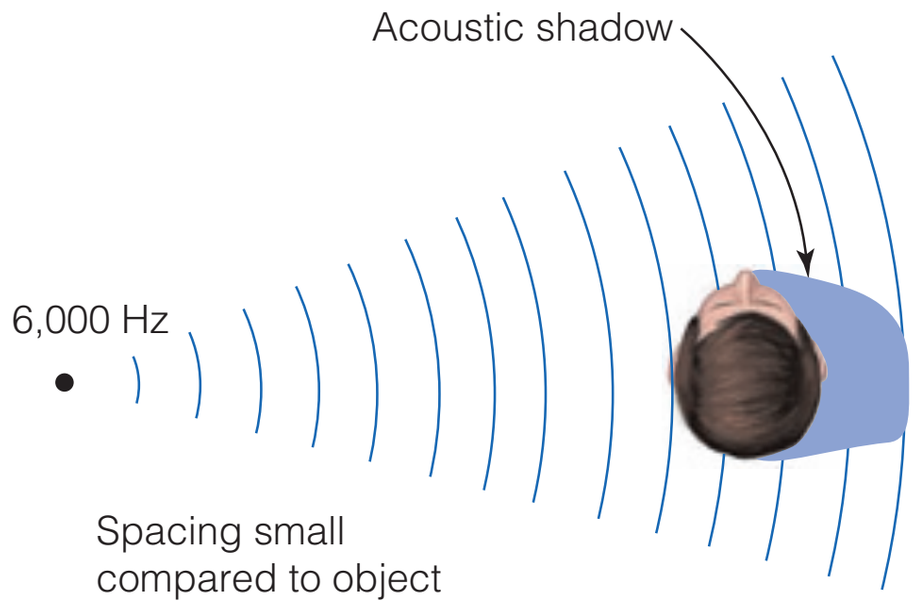


Goldstein, 2007 / McAlpine 2005

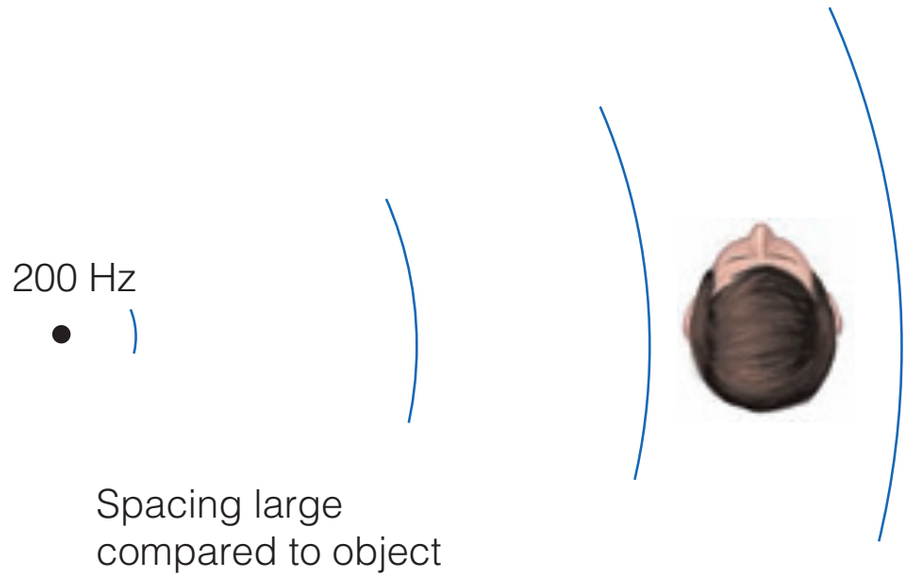


(a)

(b)



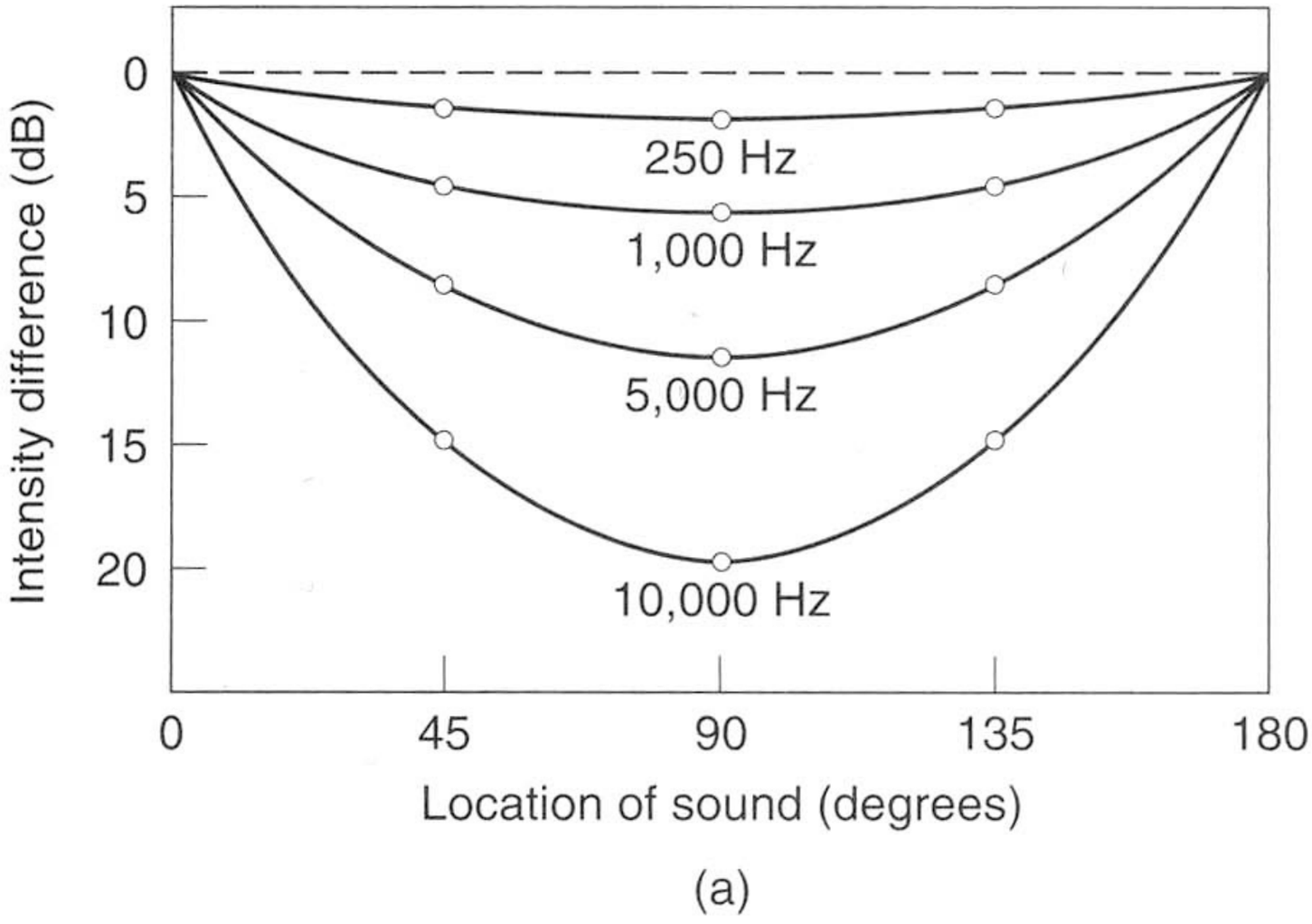
(c)



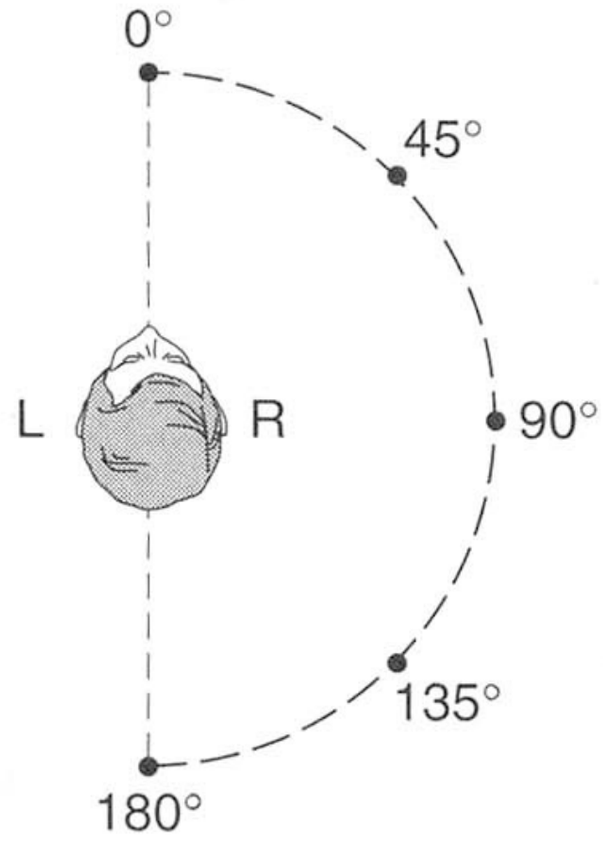
(d)

from: Goldstein (2007)

Interaural Level-Differences (ILD)

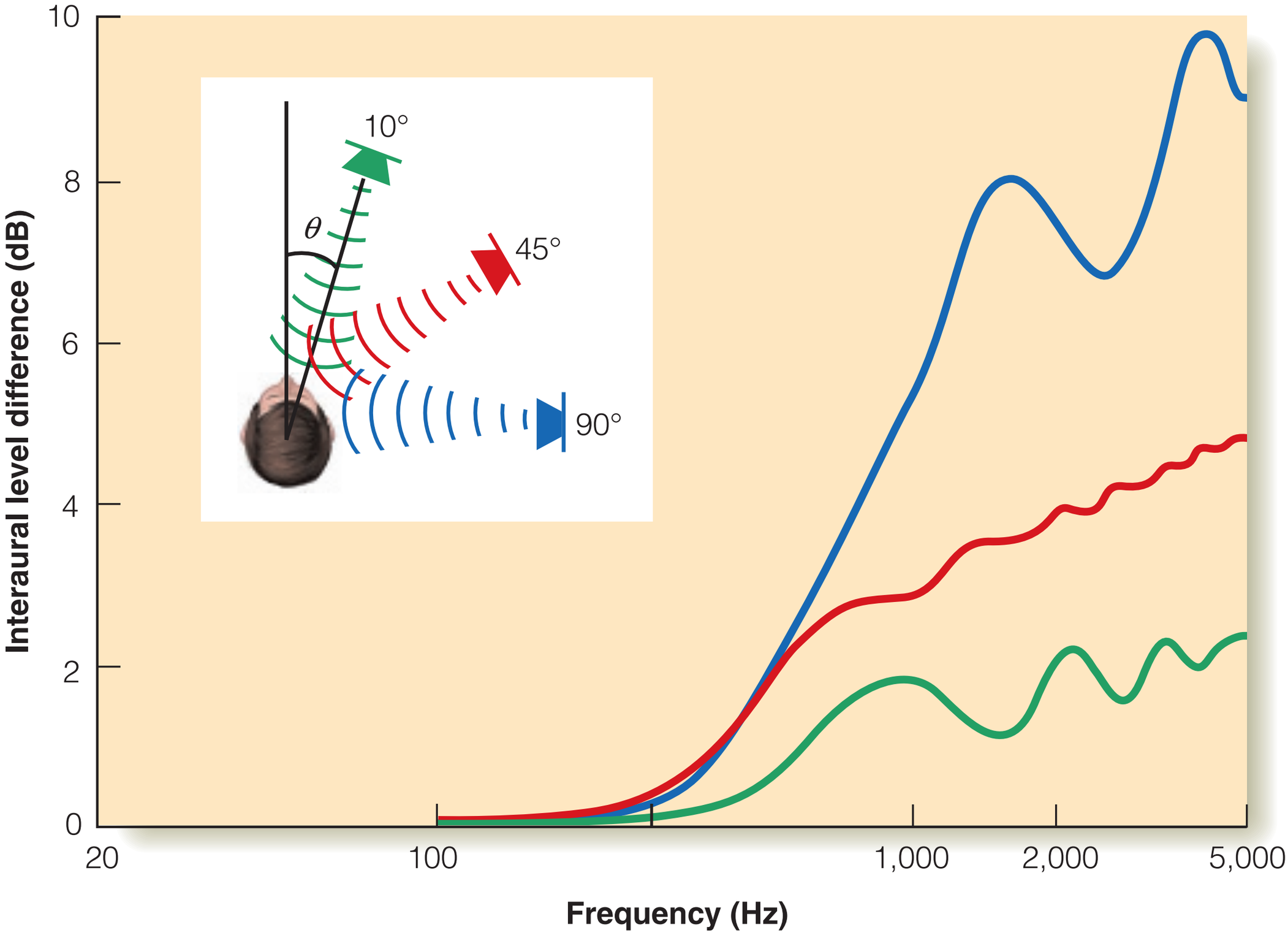


(a)



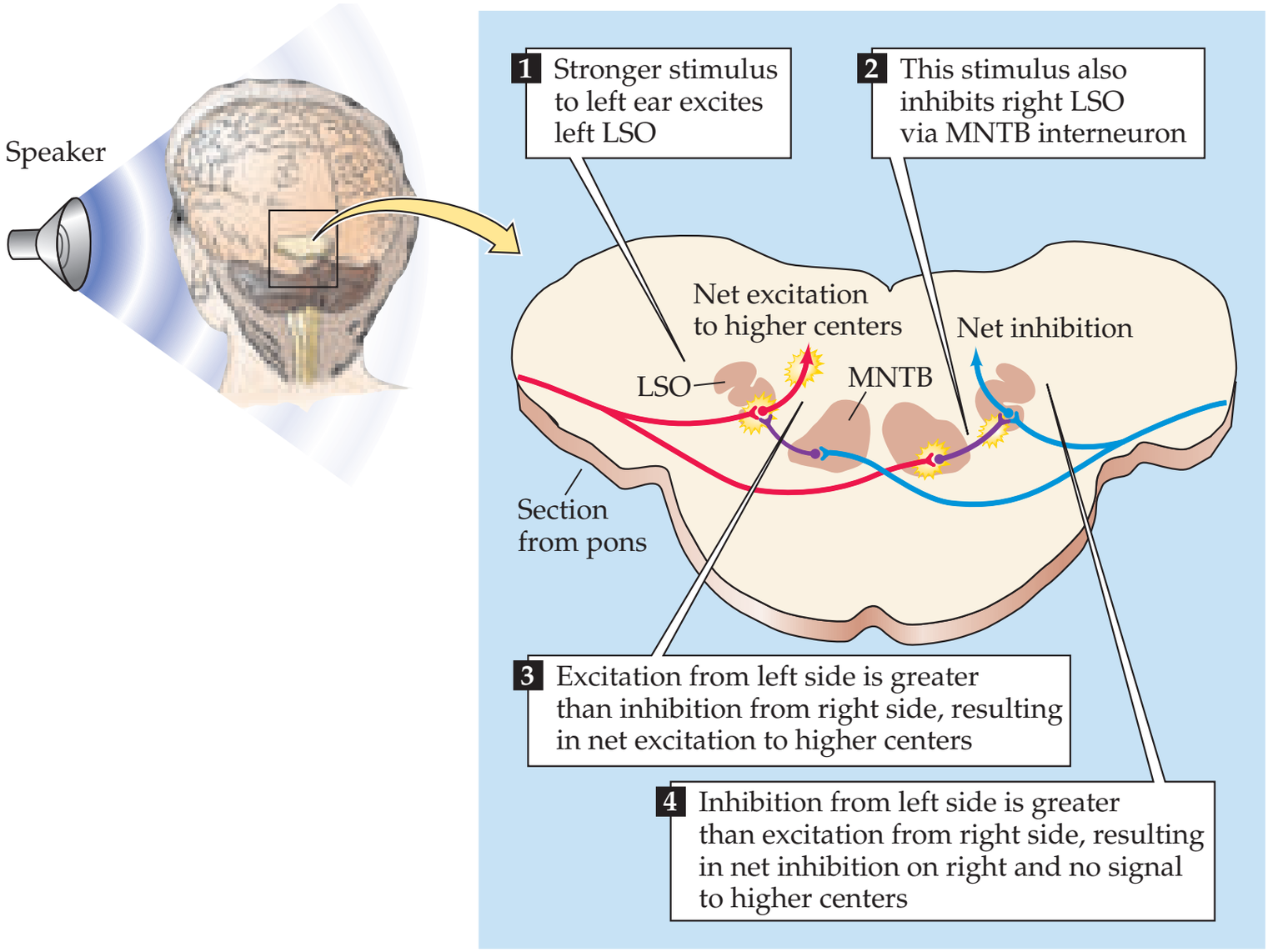
(b)

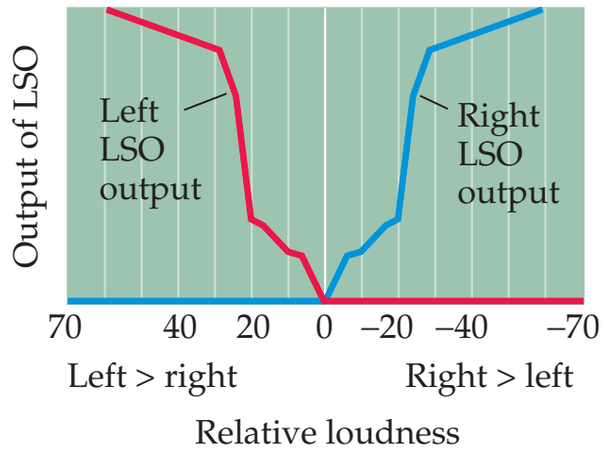
Goldstein, 2002



from: Goldstein (2007)

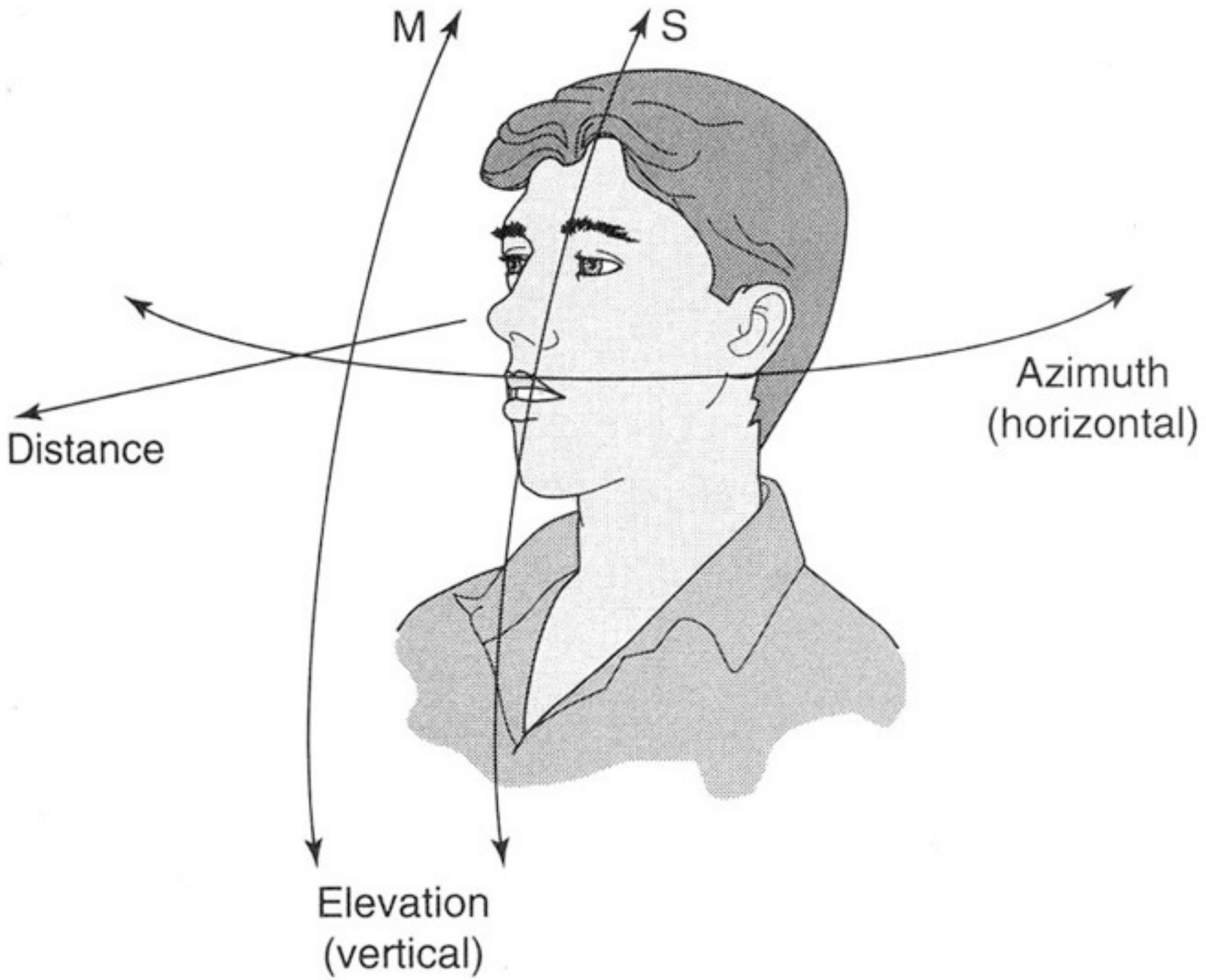
Excitation/Inhibition at the Lateral Superior Olive





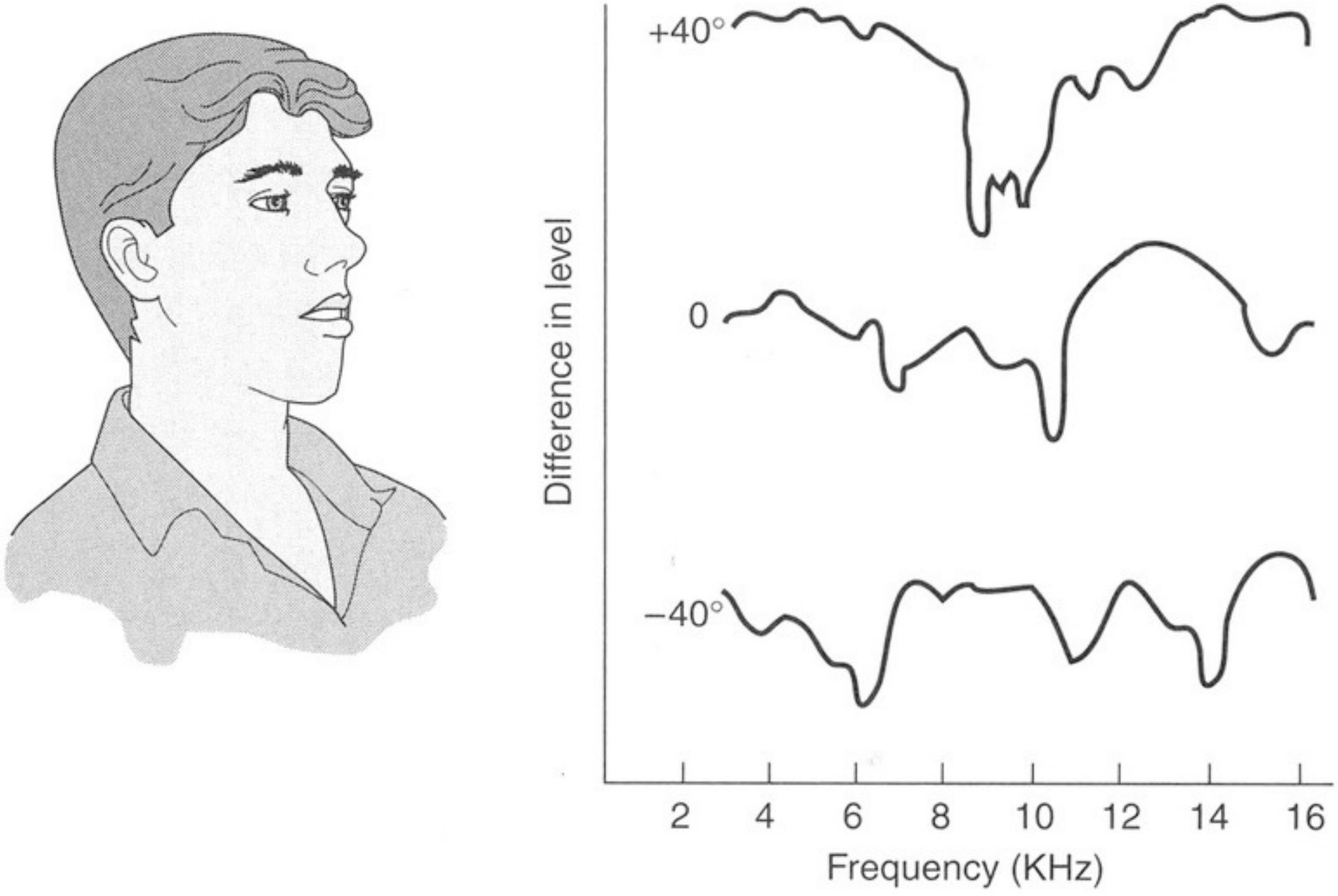
Purves, Neuroscience, 2004

Vertical Sound-Localisation



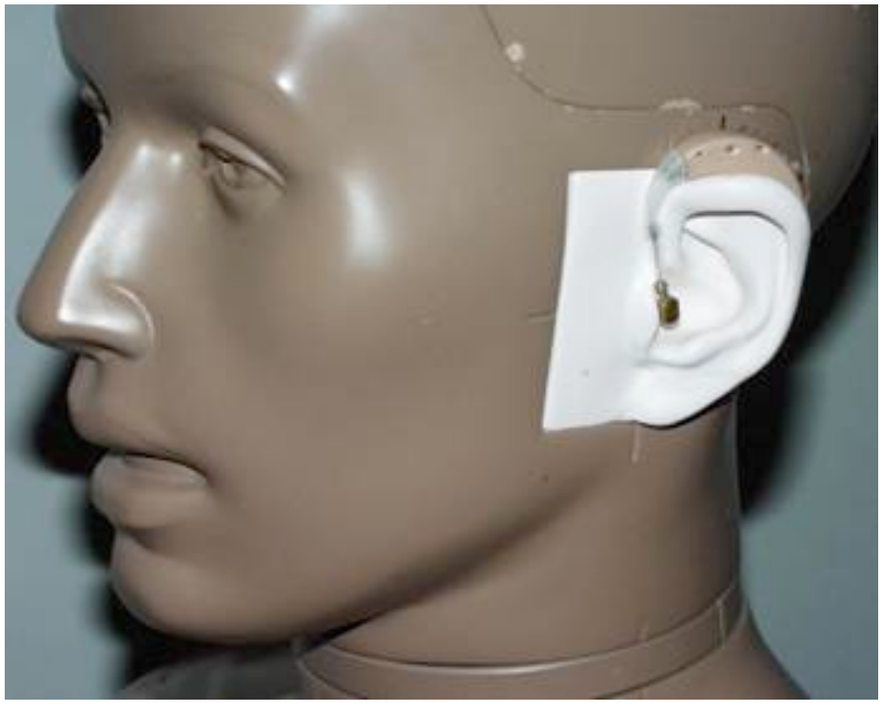
Goldstein, 2002

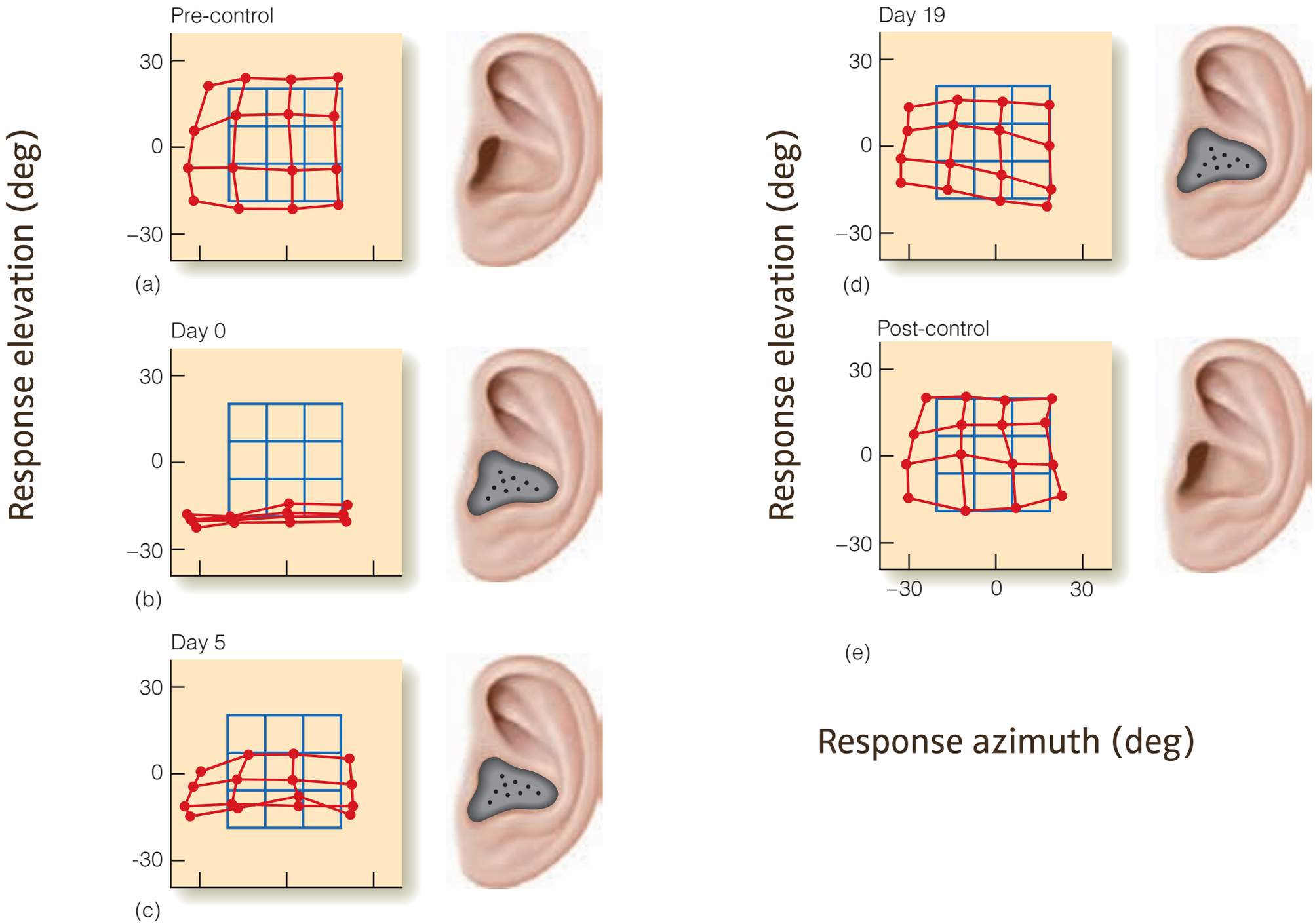
Spectral Signature of Elevation



Goldstein, 2002

Kemar Artificial Head/Torso





adapted from: Goldstein (2007)

Auditory System

The outer and middle ear transduce and amplify sound pressure waves.

In the cochlea these pressure waves are transformed into auditory nerve action potentials.

Highly specialised inner hair cells are the sensory cells for audition, sitting in the organ of Corti.

Outer hair cells are part of an active amplification mechanism, that also sharpens tuning.

The auditory system (initially) follows a strictly tonotopic organization

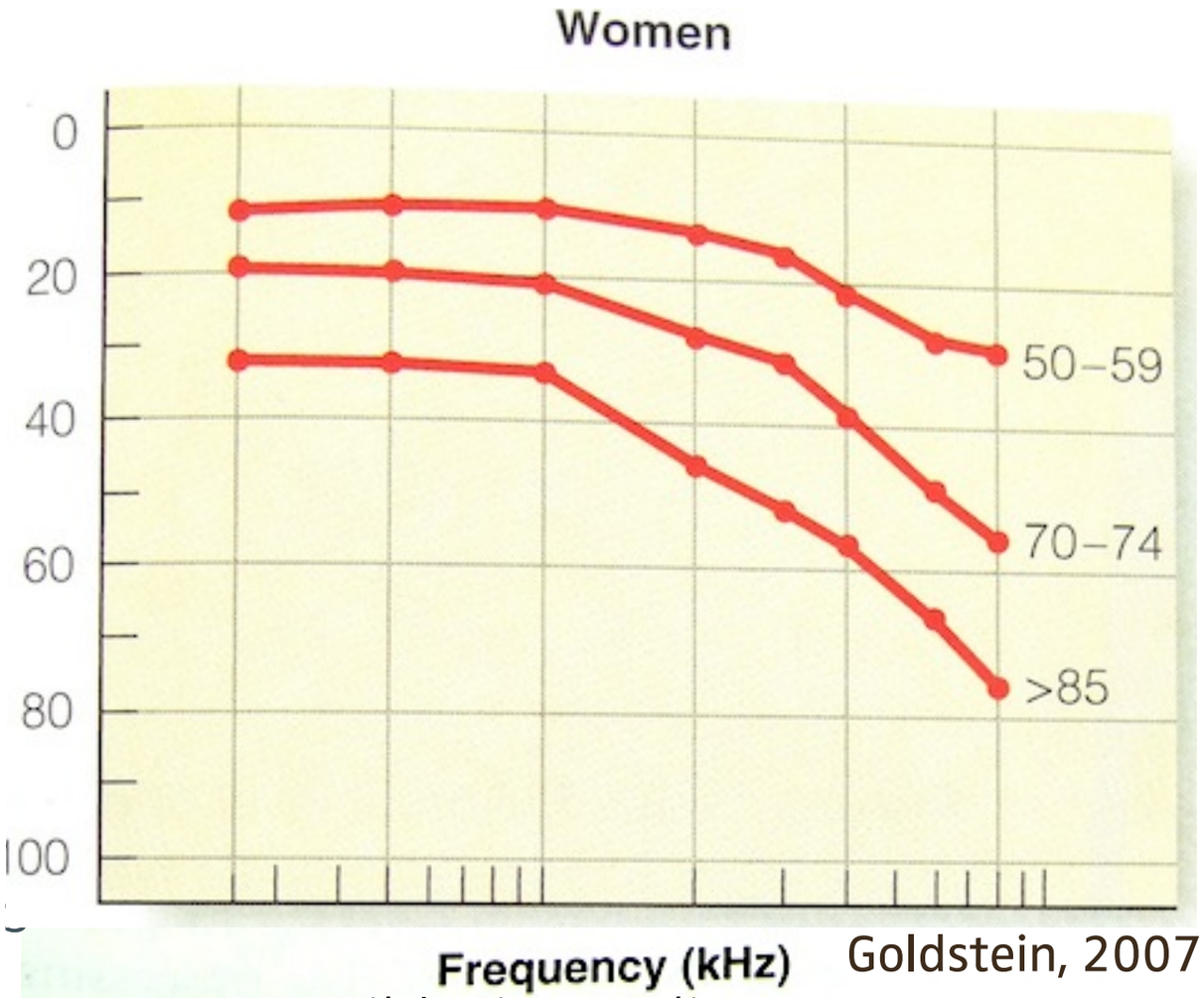
Sound localization much improved using more than one ear. It relies on time and level differences, as well as changes in sound spectrum due to torso/head/pinnae interaction.

Hearing Impairment

natural hearing loss with age

sound/noise induced hearing loss

- sound level, duration of exposure, age, ‘‘suddenness’’, prior exposure
- temporary threshold shift from short exposure at high levels
- permanent threshold shift from long exposure at high levels or impulses



Goldstein, 2007

‘‘conductive’’: outer, middle ear, BM damage - reversible, immediate

‘‘sensory-neural’’: damage to sensory cells - irreversible, long term

other effects: loss of frequency selectivity (focus on sound in noise), tinnitus

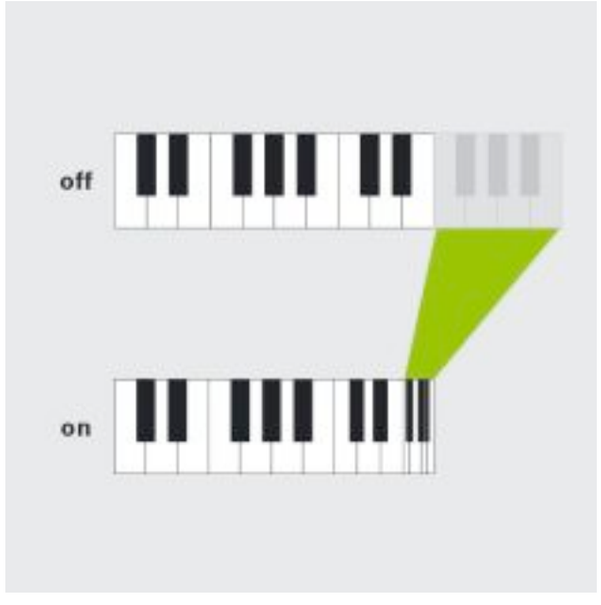

Weber test

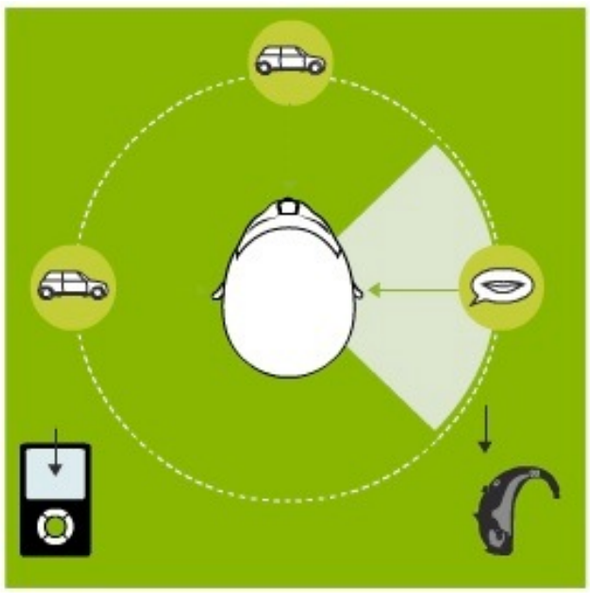
Hearing Aids

Birger Kollmeier - Haus des Hörens (Oldenburg)

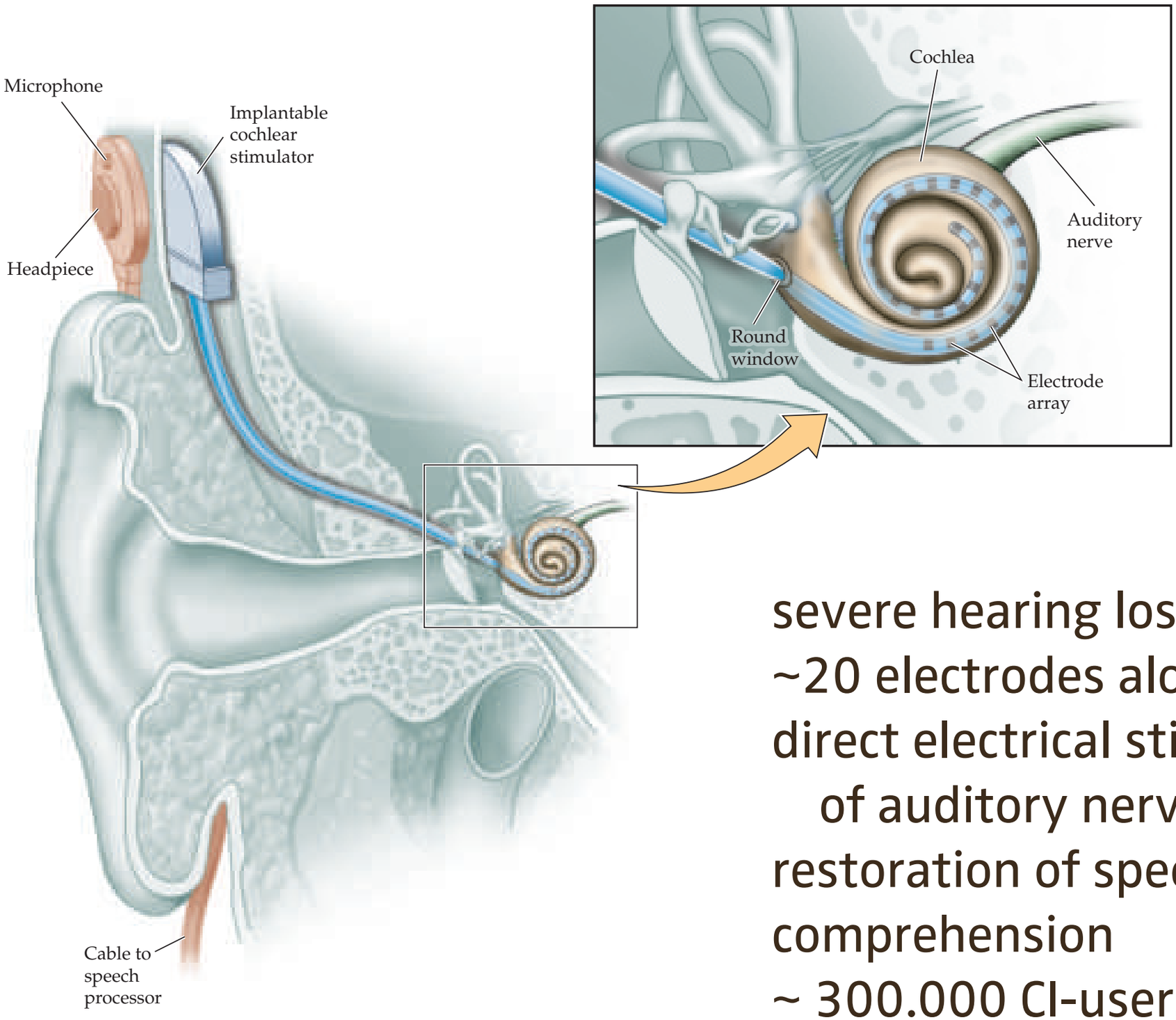
for moderate hearing loss:
sound amplification
noise cancellation
frequency shifts
beam forming

Phonak



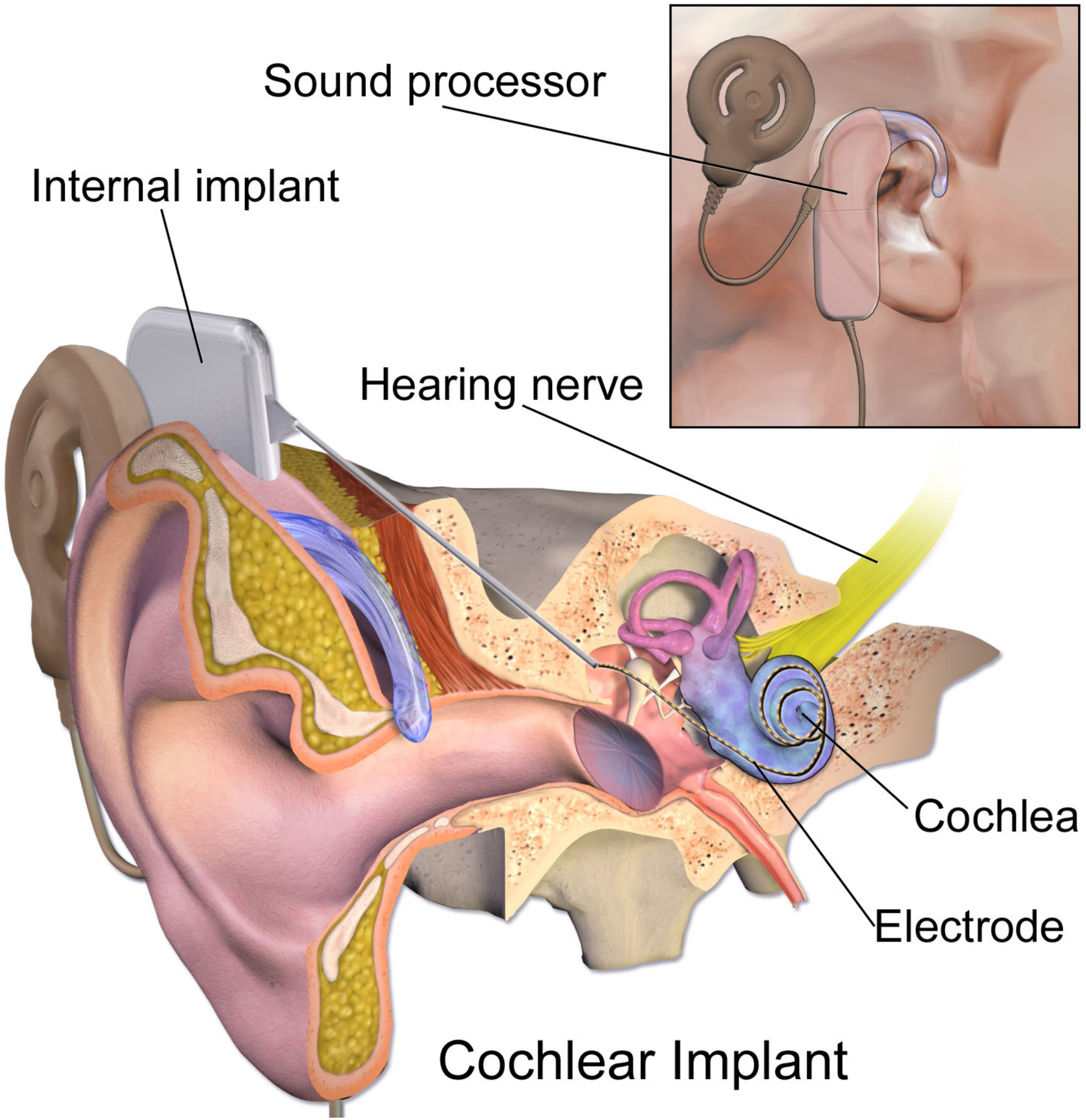


Cochlear Implants



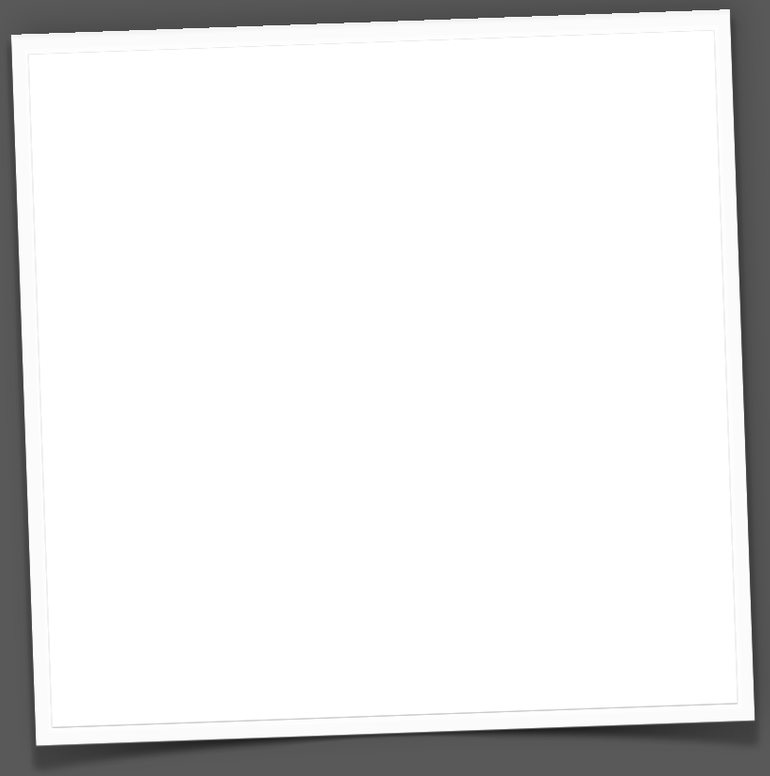
Purves, Neuroscience, 2004

severe hearing loss / deafness
~20 electrodes along cochlea
direct electrical stimulation
of auditory nerve
restoration of speech comprehension
~ 300.000 CI-users worldwide (2012)

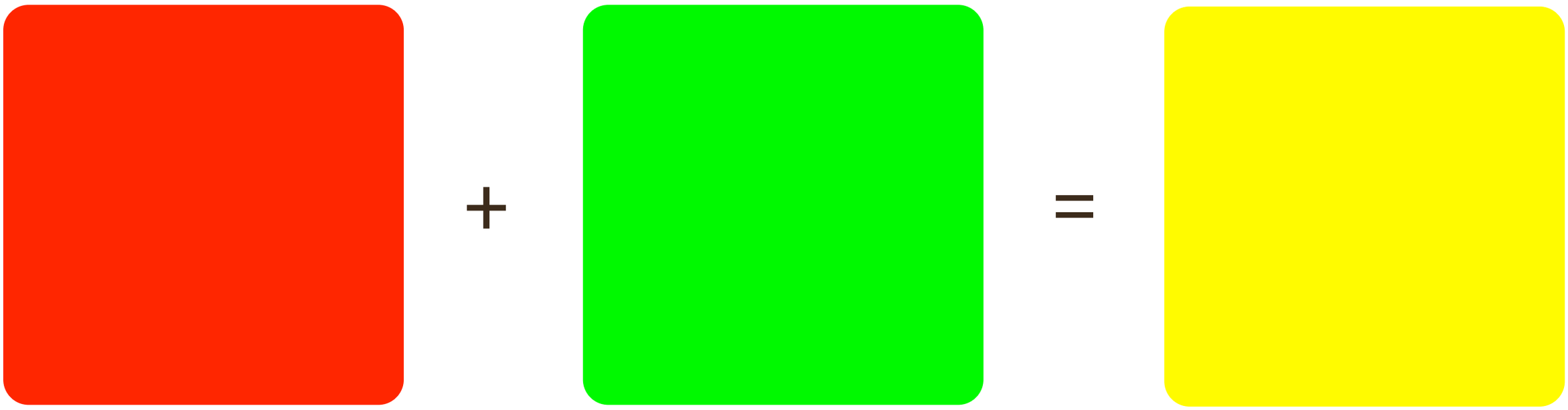


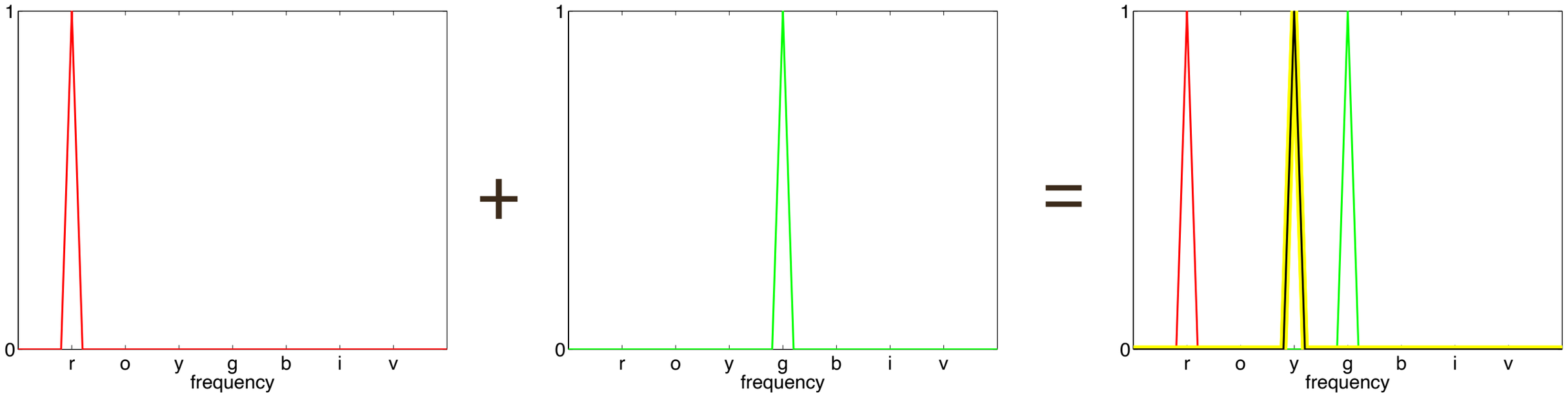
Cochlear Implant

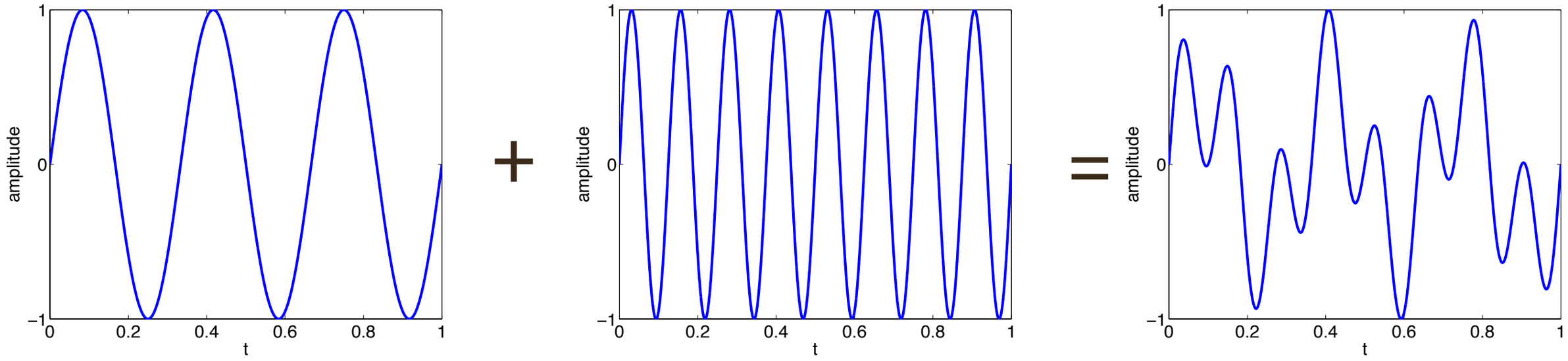
A Spectral Analyser



ceci n’est pas



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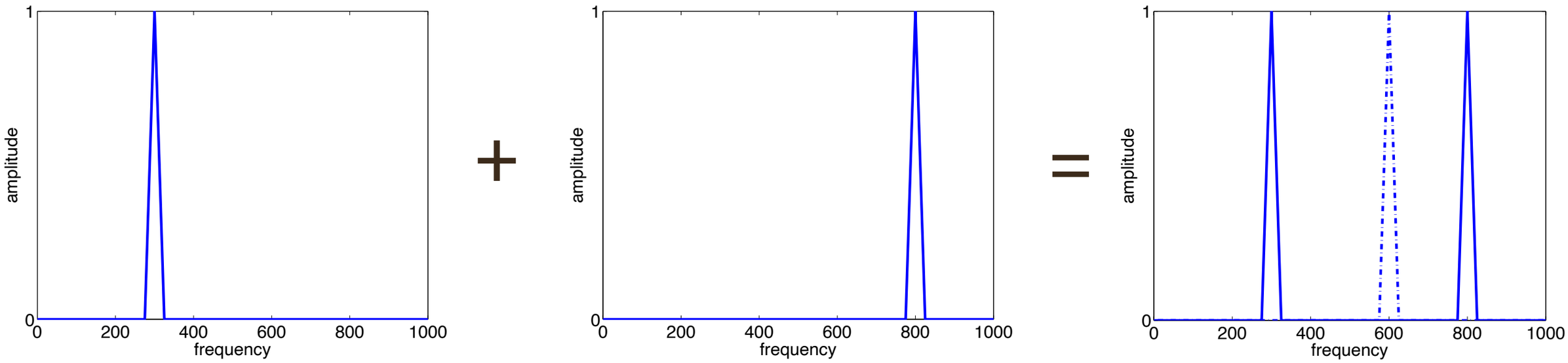
amplitude
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frequency
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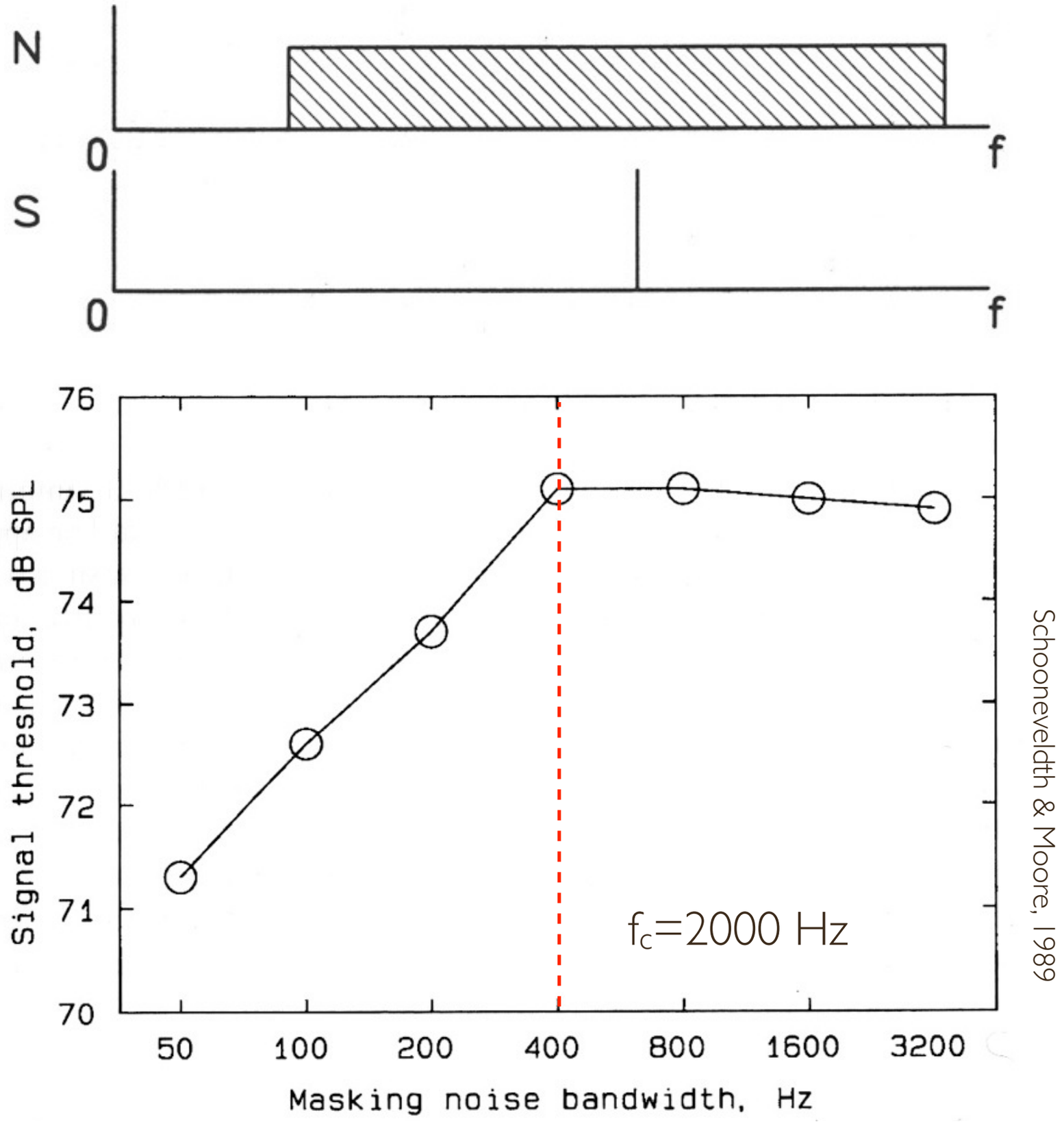
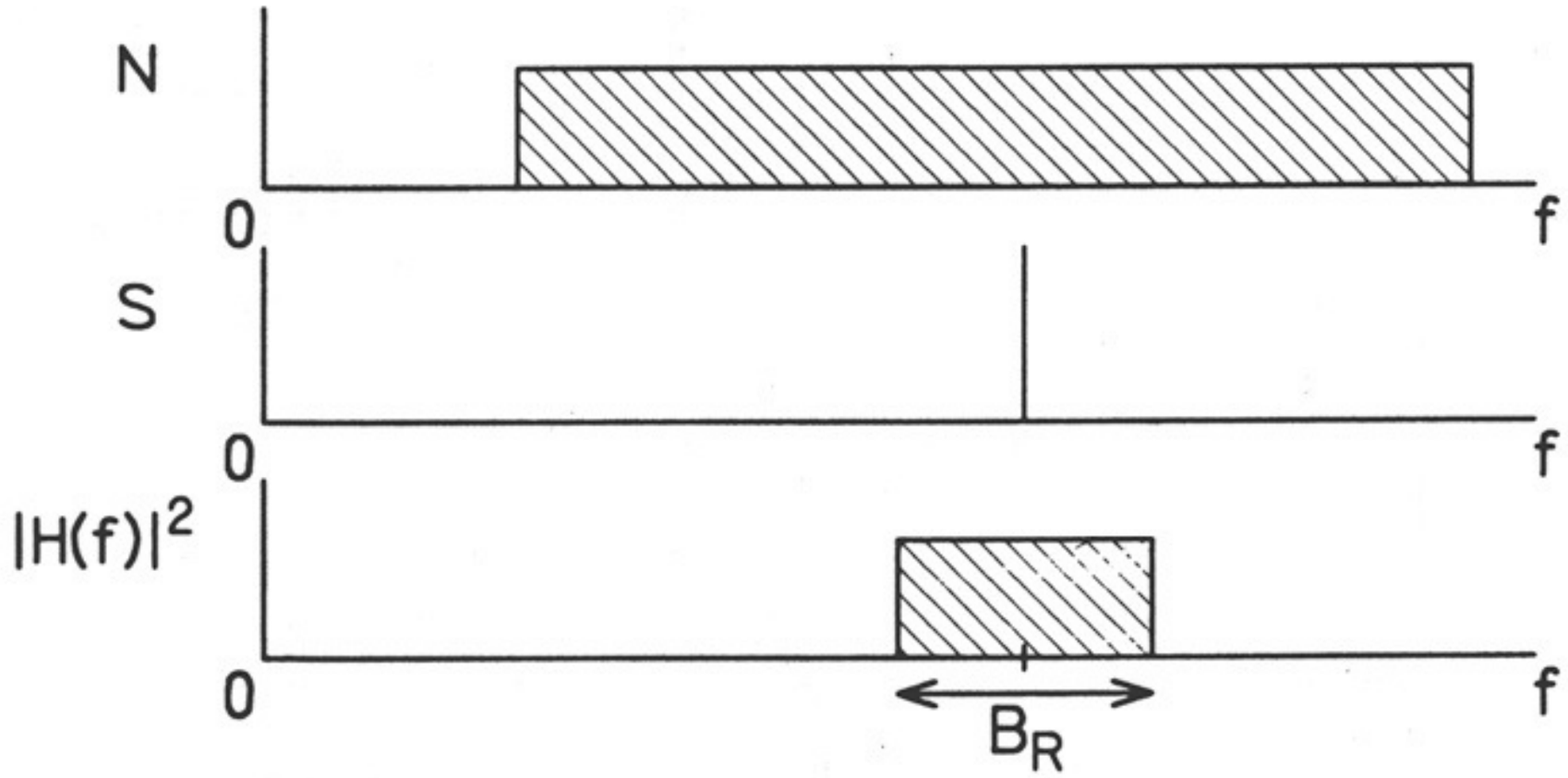
amplitude
frequency



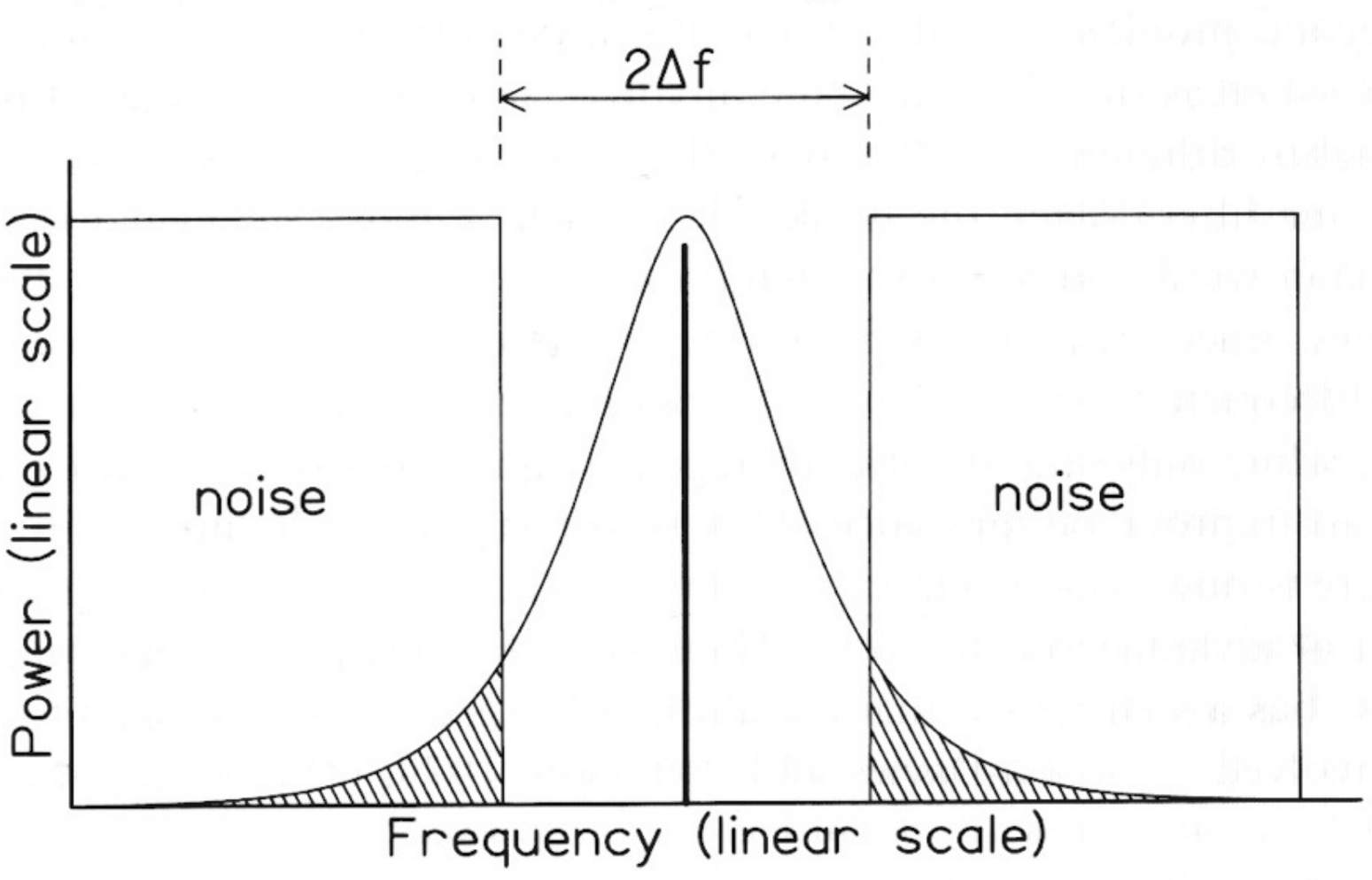
H. Fletcher, JASA (1938)

H. Fletcher, Rev. Mod. Phys. (1940)

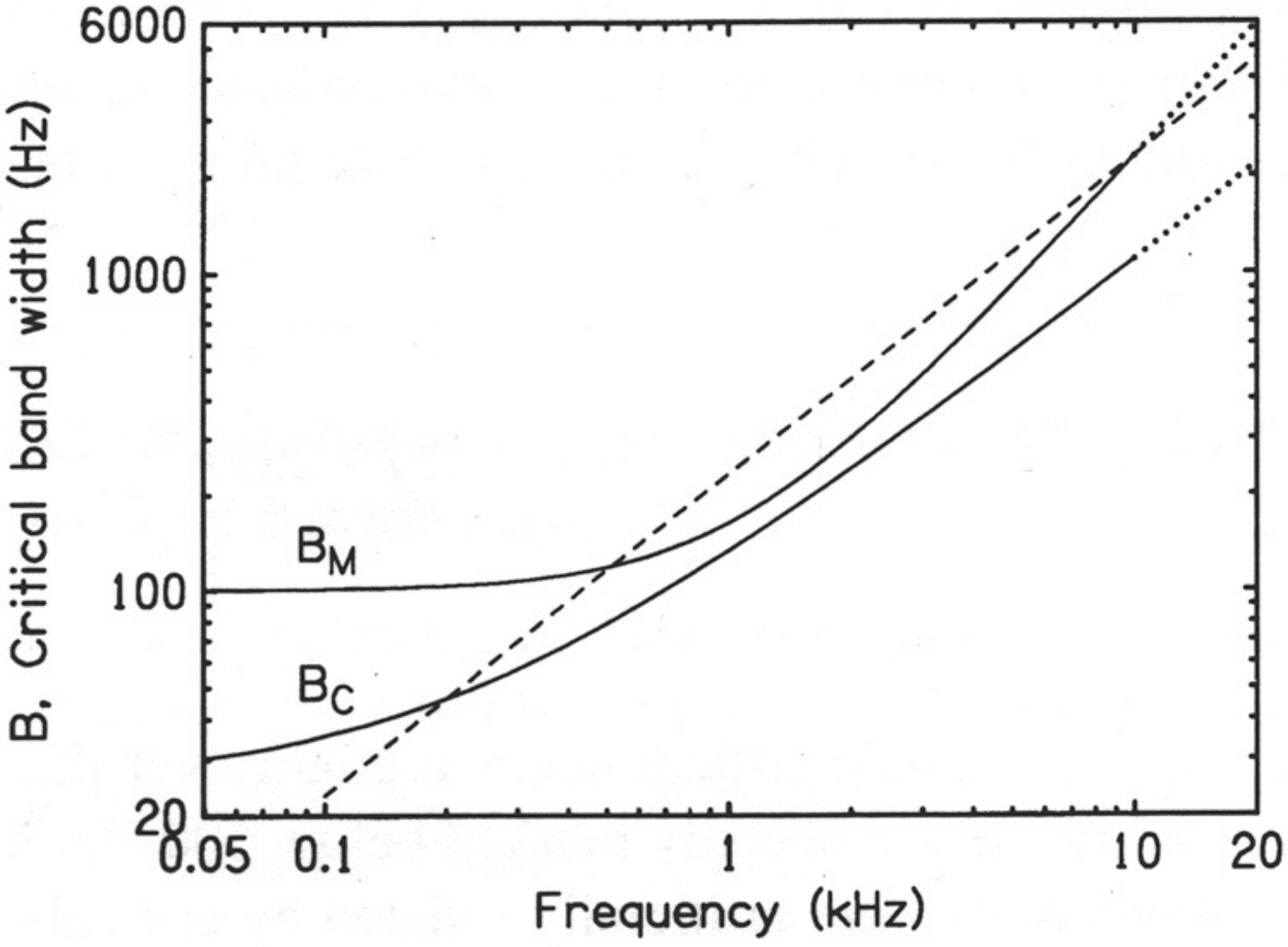
Harvey Fletcher (left) at Bell Telephone Labs in NYC



Fletcher, 1938



Patterson, 1976



BM ... "Munich" Critical Bandwidth (Zwicker, 1961)

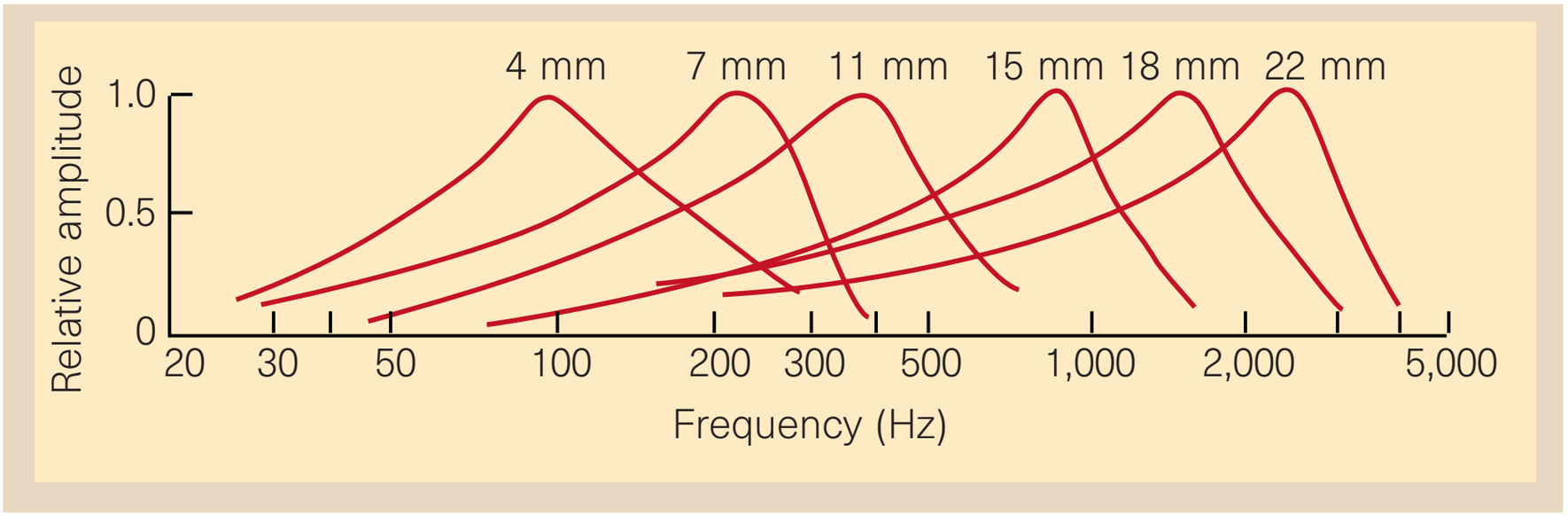
BC ... "Cambridge" Critical Bandwith (1980's, notched)

--- ... 1/3 octave bands

Hartmann, 1998

Psychological Auditory Filters and Physiology

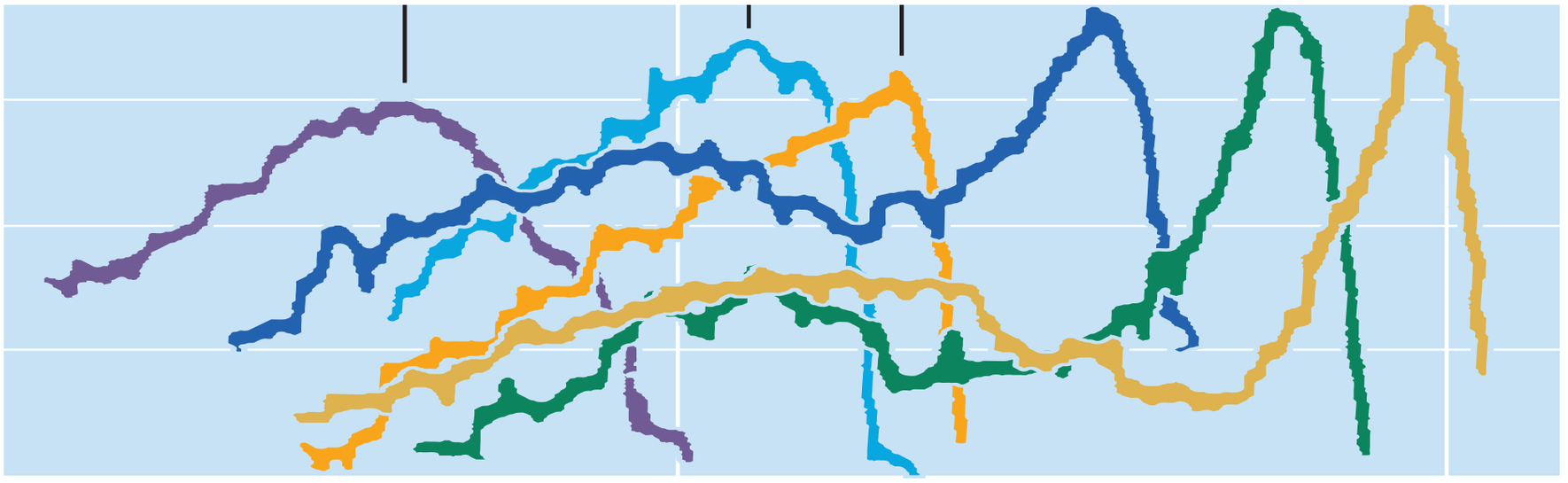
Scaling of critical bandwidth ~ excitation pattern of BM



Moore, Nature, 1999

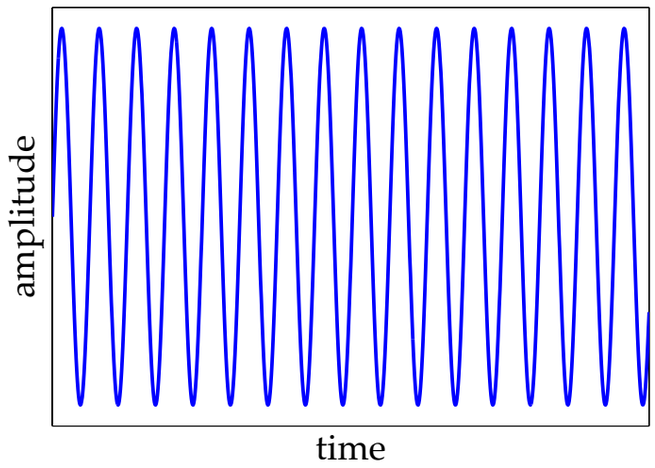
Frequency responses at six different points along the basilar membrane in the inner ear.

~ auditory nerve tuning curves



Purves, Neuroscience

Sound Pressure / Sound Level



- physical unit: pressure (rms force/area in Pascal)
- derived unit: sound level (logarithmic measure in Decibel/dB)

$dB = 20\ Log_{10}\ (P/P_0)$ with P_0 = 20 µPa (average hearing threshold at 1 kHz)

+6 dB ~ 2x P

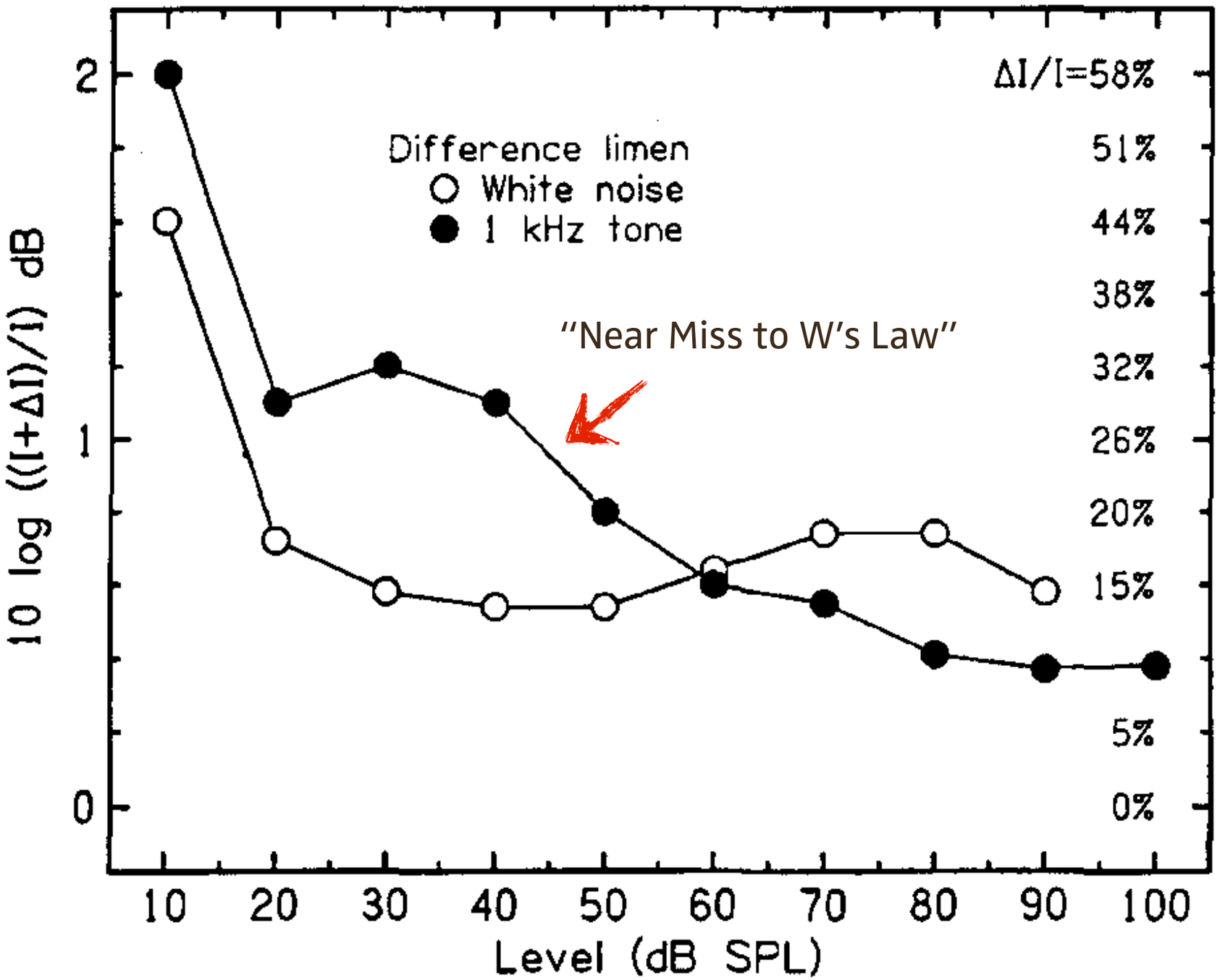
$dB = 10\ Log_{10}\ (P^2/P_0^2) = 10\ Log_{10}\ (I_P/I_{P0})$ with $I_p \sim P^2$

+3dB ~ 2x I_P

precision of measurement ± 1.5 dB (atmos. pressure, temperature, non-plane waves)

– 6 dB per distance doubling with point source in infinite room ($I_p \sim P^2 \sim 1/r^2$)

Just Noticable Differences (JND) / Weber's Law



Weber's Law

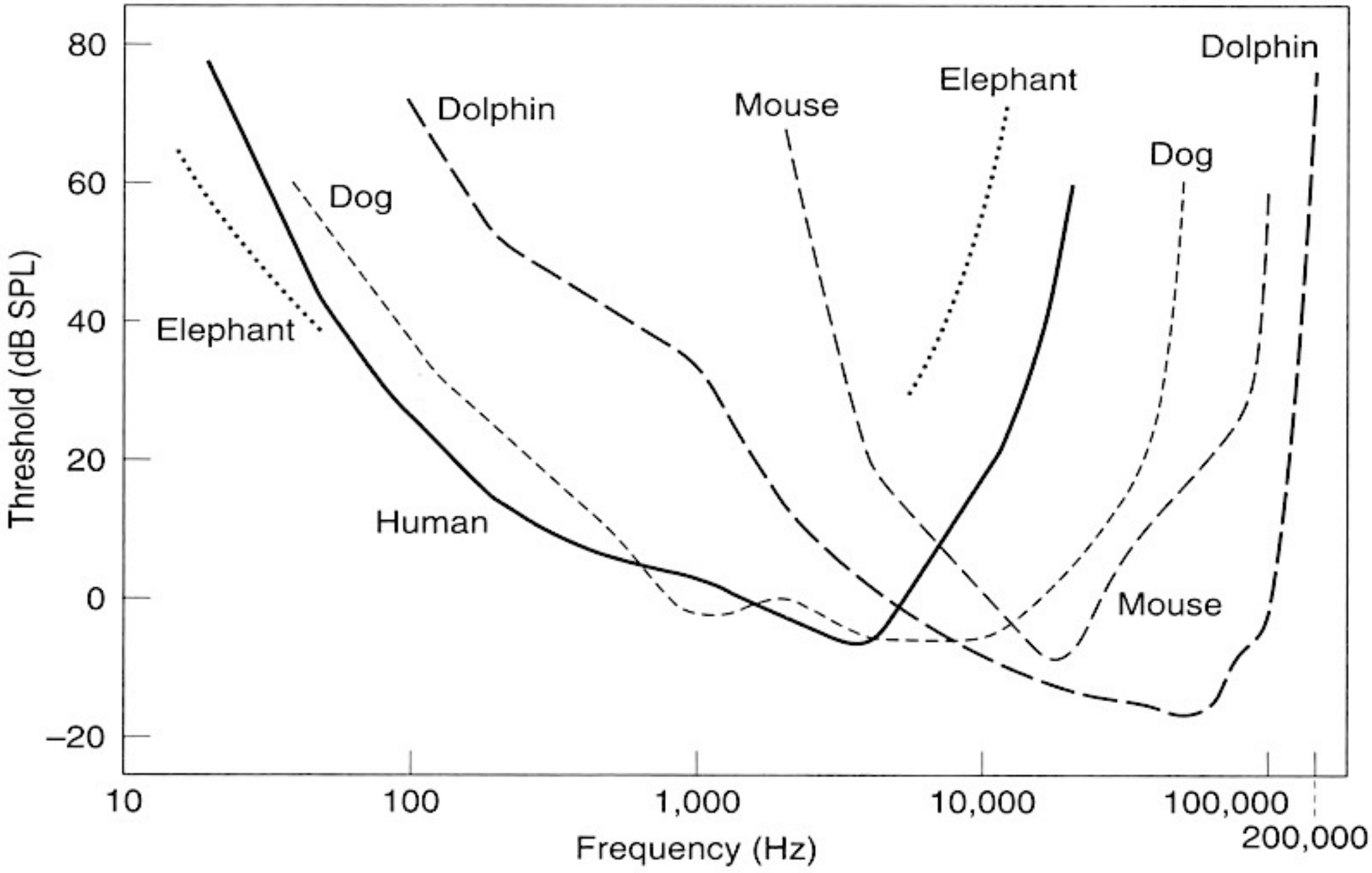
$\Delta L/L$ = const.

or

JND is fixed percentage

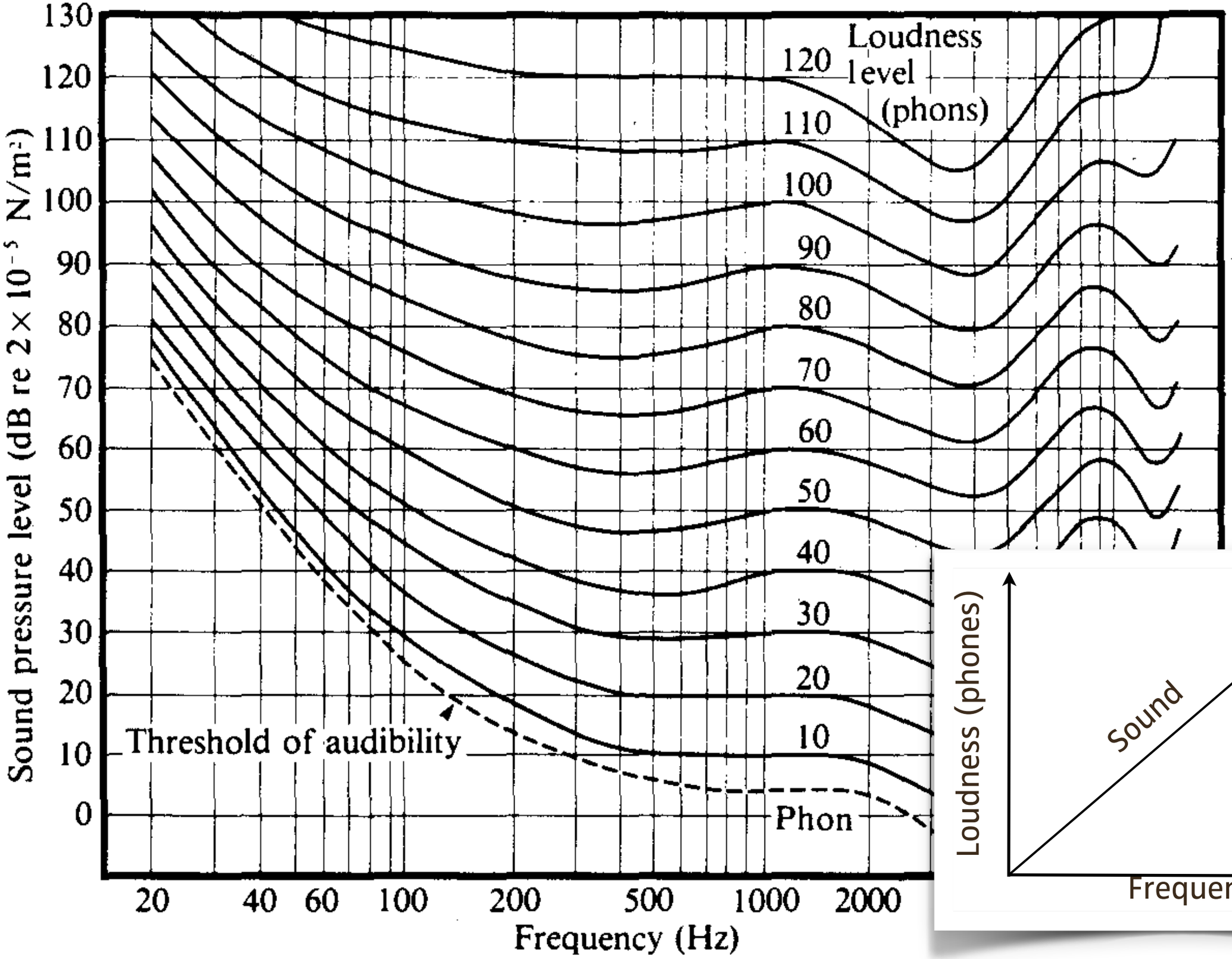
Hartmann, Signals, Sound, and Sensation, 1998

Range of Hearing across Species



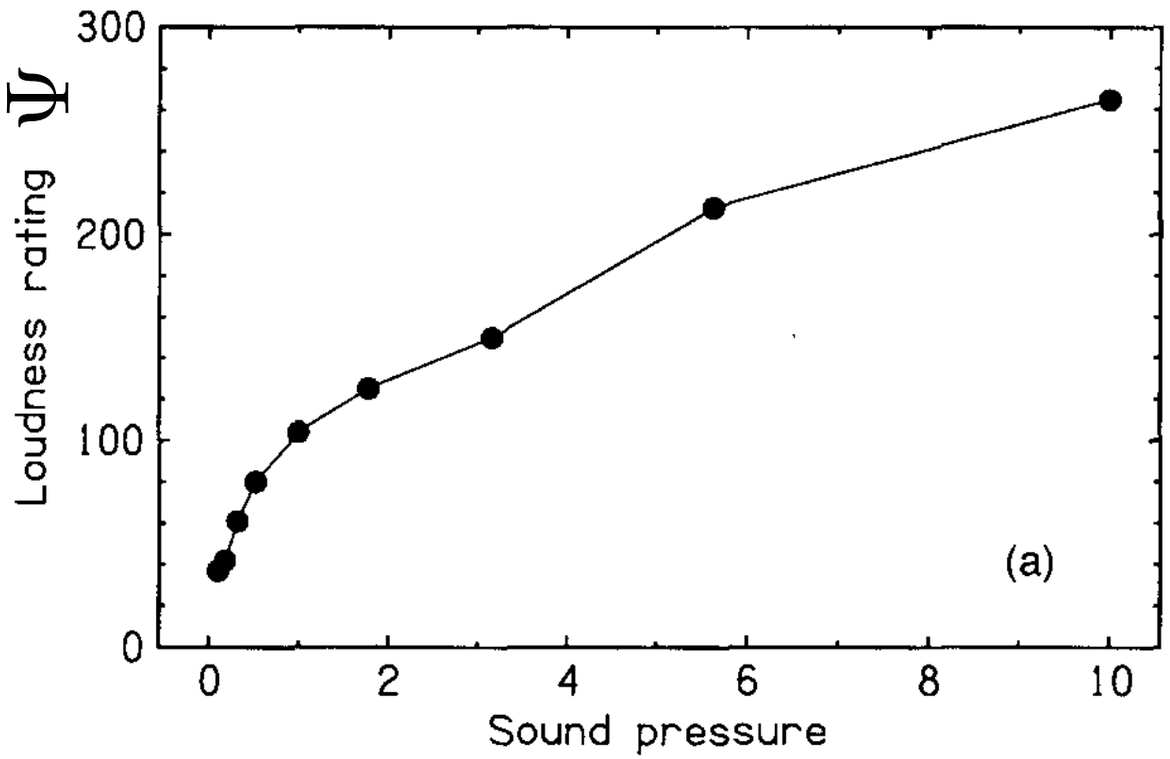
Goldstein, 2002

The Phone-Scale / Equal Loudness Contours



Hartmann, 1998

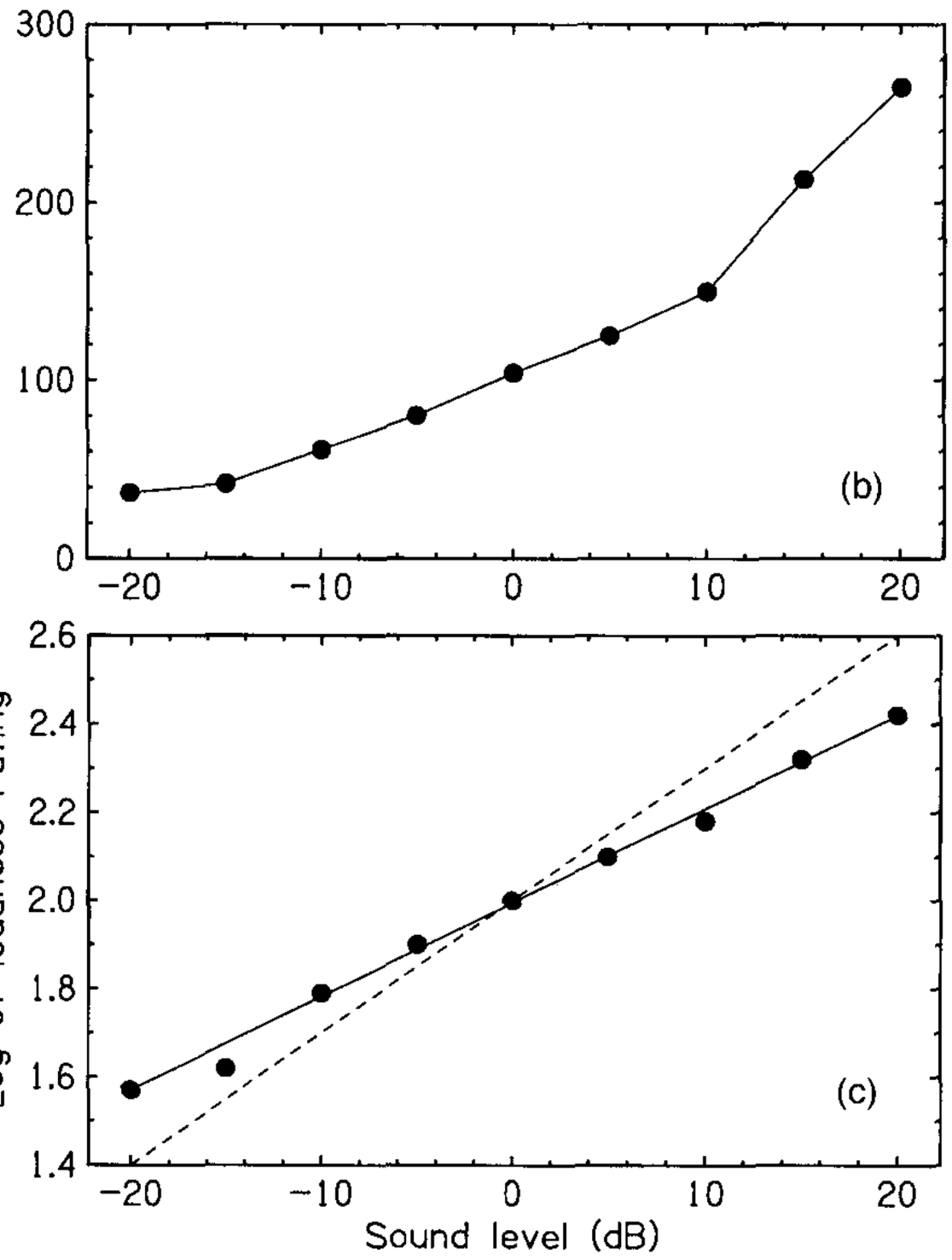
Perceived Loudness



$$\Psi = kI^p$$

$$\log \Psi = \log k + p \log I$$

$$p = 0.2...0.3$$

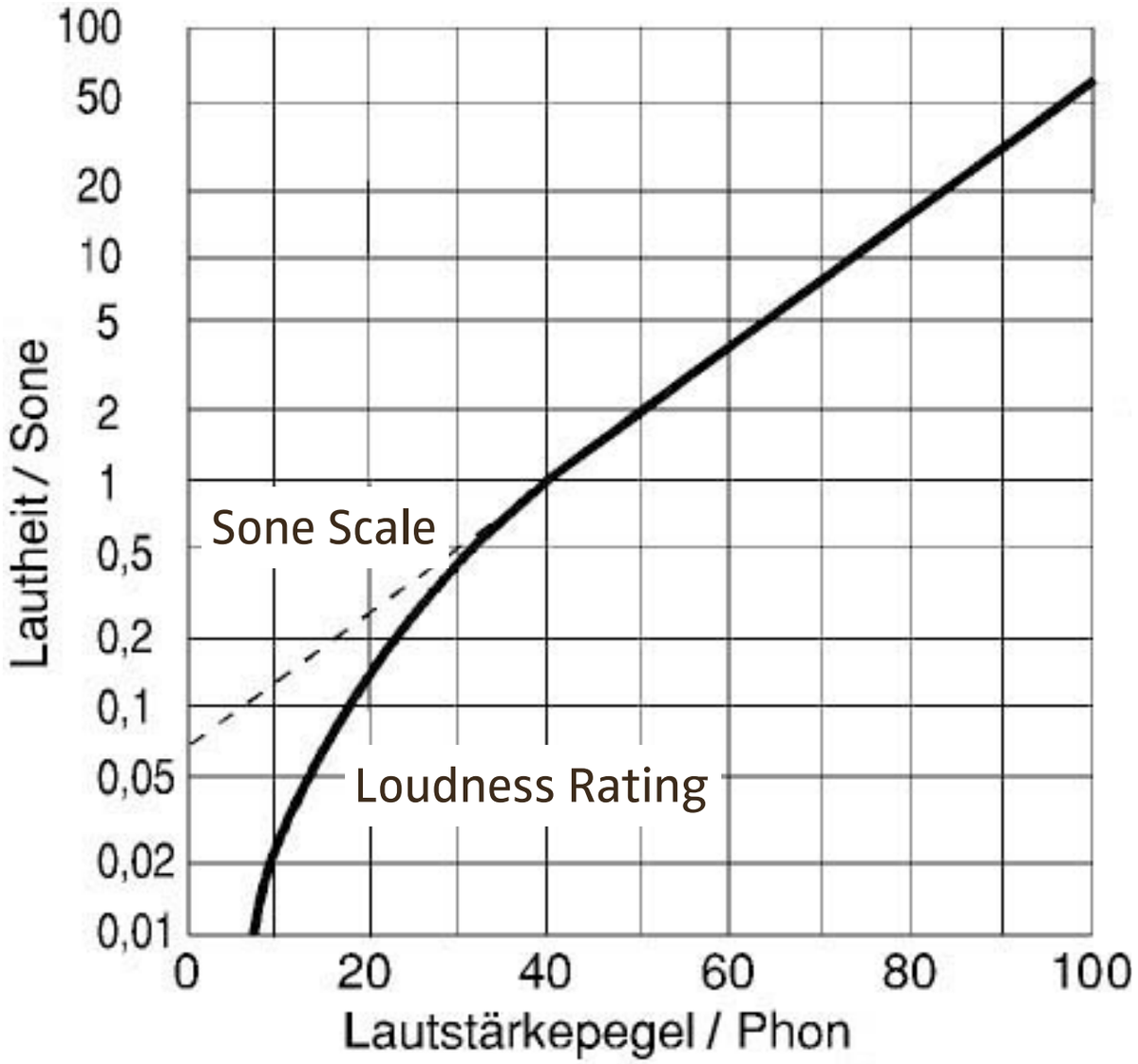


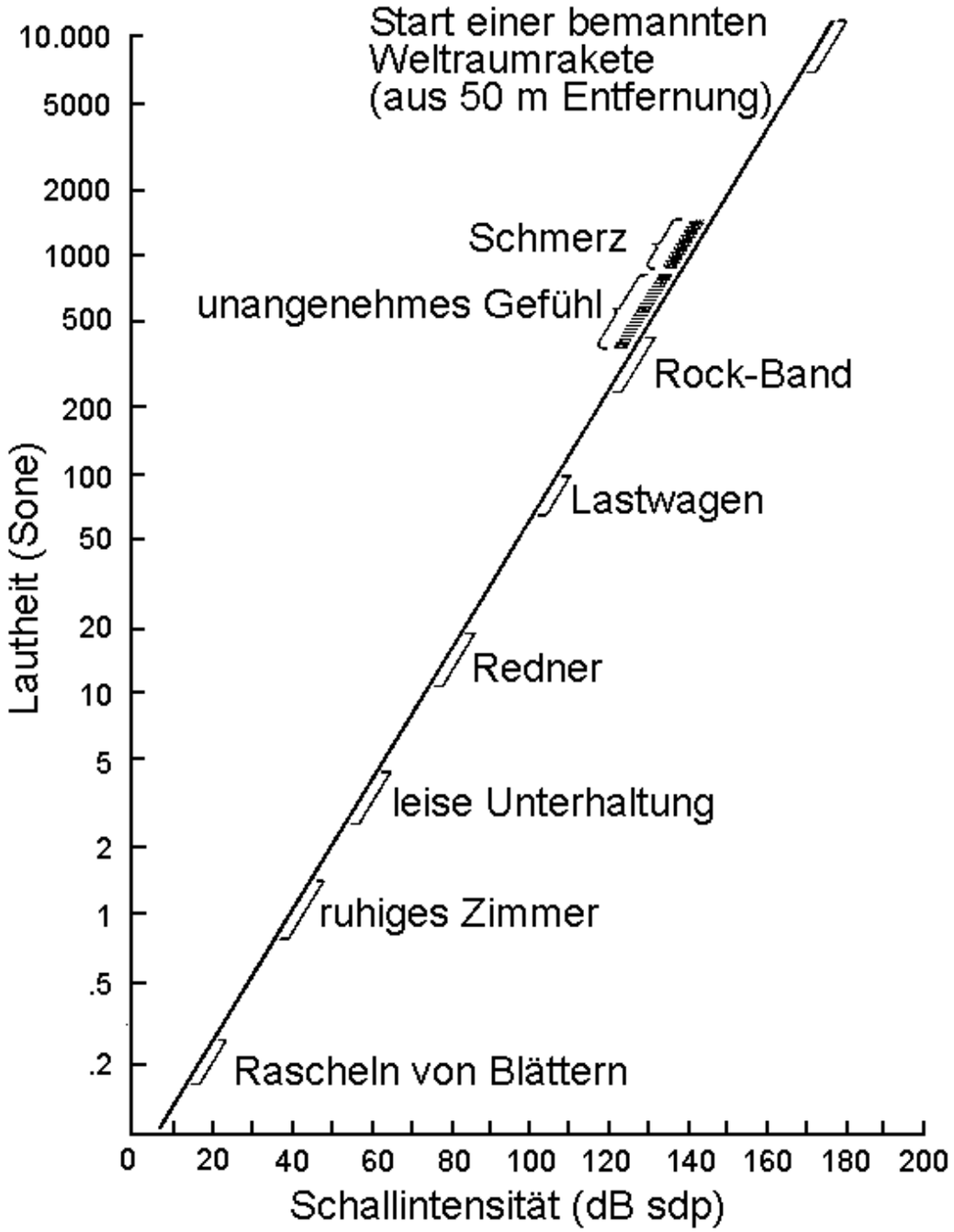
Hartmann, 1998

The Sone-Scale

1 kHz tone at 40 dB ~ 1 sone
any tone at 40 phons ~ 1 sone

$$\Psi(sones) = \frac{1}{15.85}\left(\frac{I}{I_0}\right)^{0.3}$$





The Omni-Present Critical Band (CB)

Noise outside the critical band is irrelevant for tone detection.

Two added tones in different CBs perceived louder than tones in the same CB.

Tones in different CB don’t produce difference tones or beats.

An analysis into harmonics only works for separations larger than CB.

Binaural signal comparison only happens within one CB.

Relative phase of tones in different CBs perceptually irrelevant.

W.M. Hartmann, ‘‘The ubiquitous critical band’’ (chapter 10)
in Signals, Sound, and Sensation (1998)

Congratulations, you have made it to the very end of the course …

Perception: Psychophysics and Modeling

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