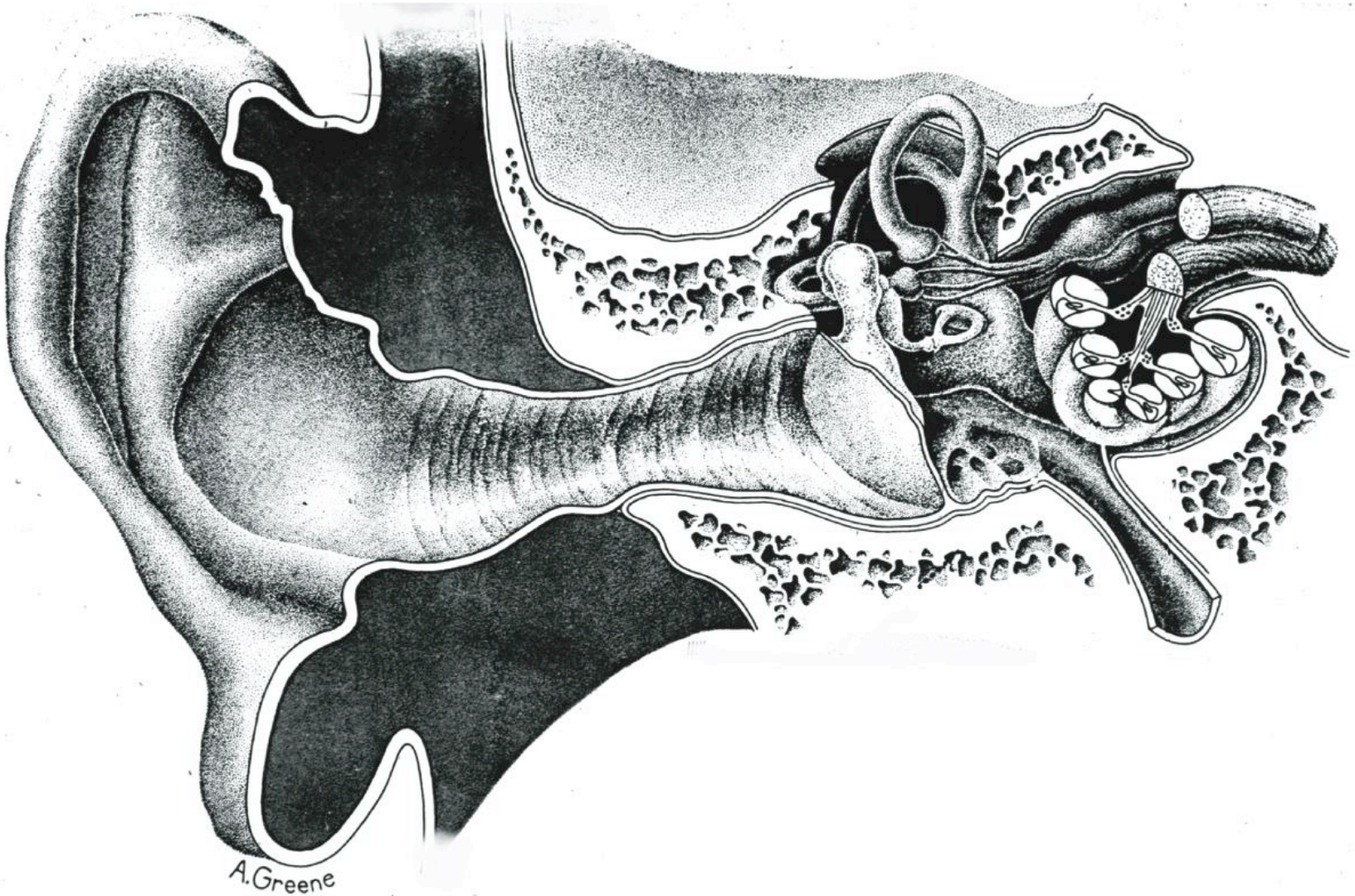
Maryanne Amacher
(1938-2009)

Christopher Bergevin
Columbia University

MIT 10.22.11


A. Greene

When played at the right sound level, which is quite high and exciting, the tones in this music will cause your ears to act as neurophonic instruments that emit sounds that will seem to be issuing directly from your head ... (my audiences) discover they are producing a tonal dimension of the music which interacts melodically, rhythmically, and spatially with the tones in the room. Tones 'dance' in the immediate space of their body, around them like a sonic wrap, cascade inside ears, and out to space in front of their eyes ... Do not be alarmed! Your ears are not behaving strange or being damaged! ... these virtual tones are a natural and very real physical aspect of auditory perception, similar to the fusing of two images resulting in a third three dimensional image in binocular perception ... I want to release this music which is produced by the listener ...

- Maryanne Amacher

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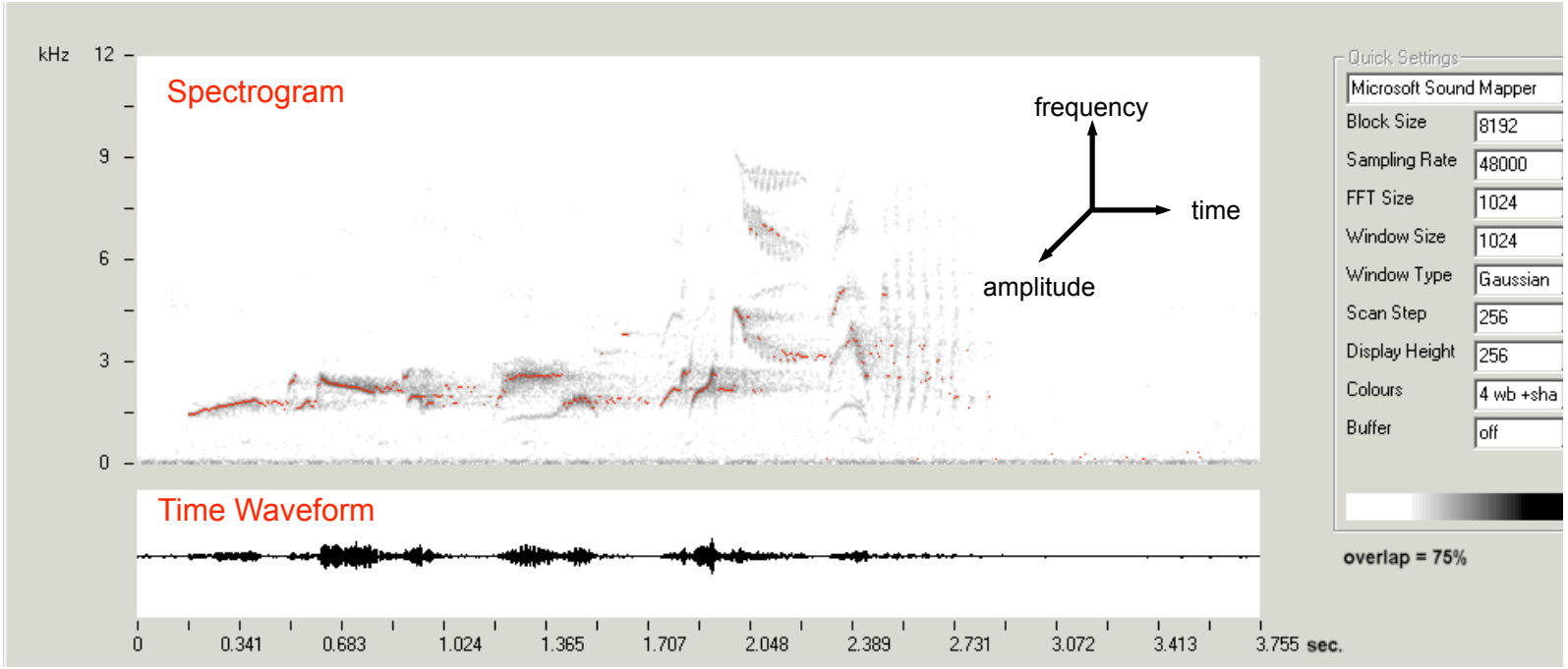
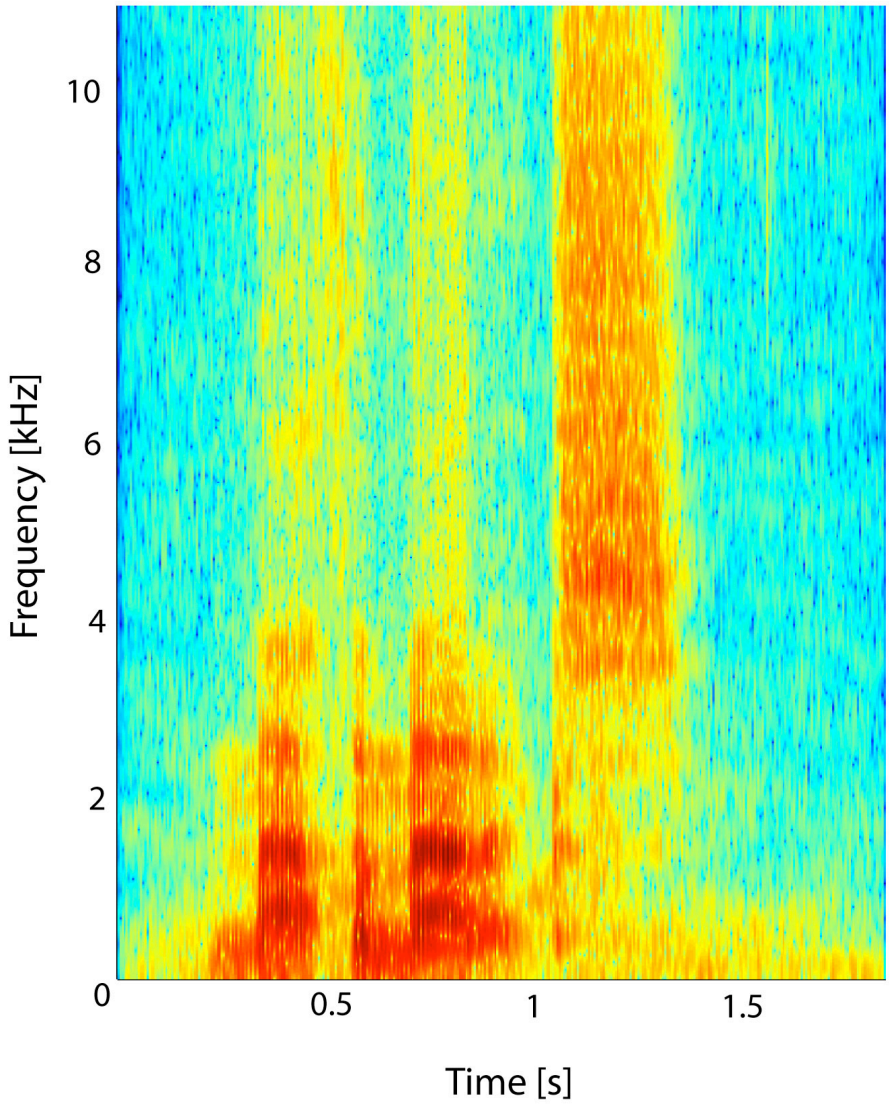
Blackbird (*Turdus merula*)



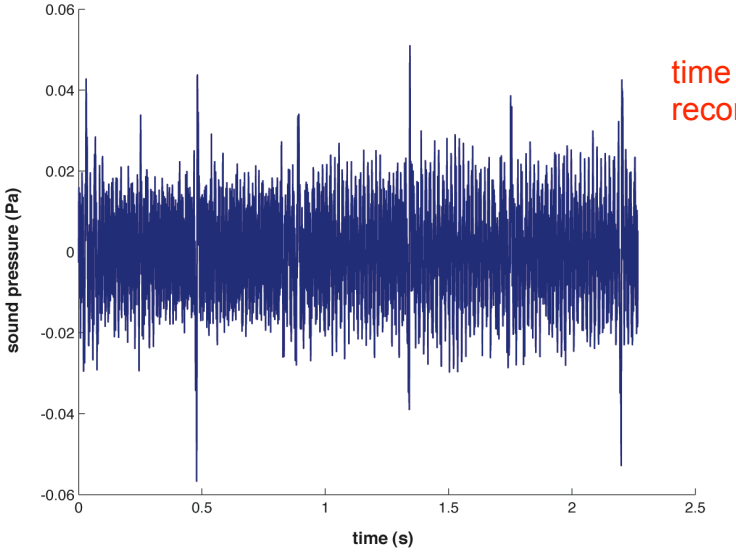
http://www.birdsongs.it/



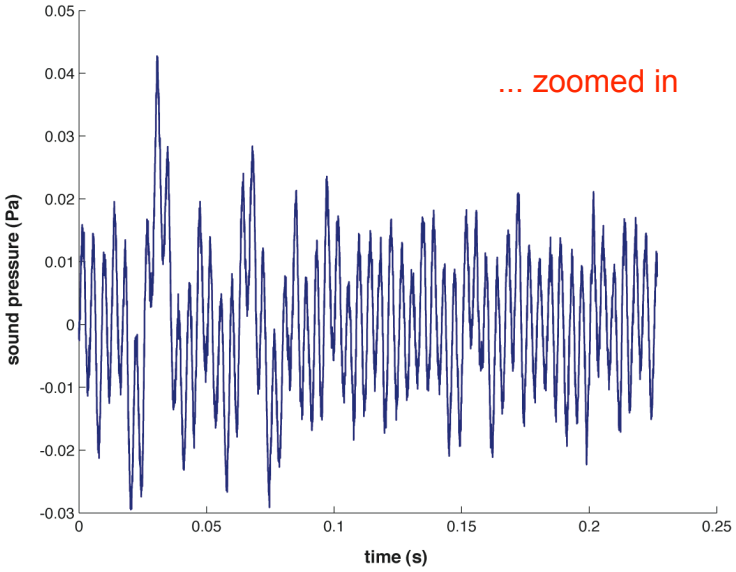
M th mat s
a e ic

Switching Domains….

Time Domain



time waveform
recorded from ear canal

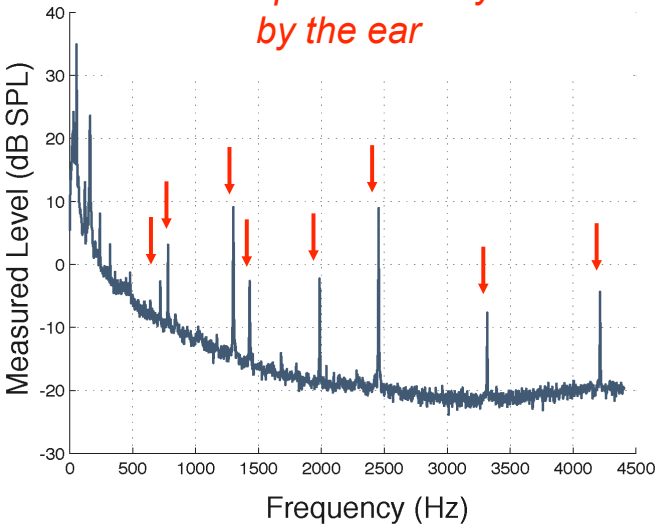


... zoomed in

Fourier transform

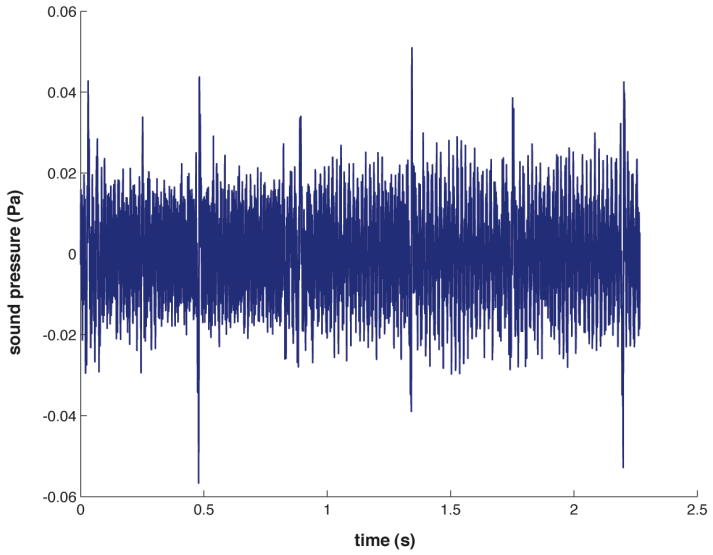
Spectral Domain

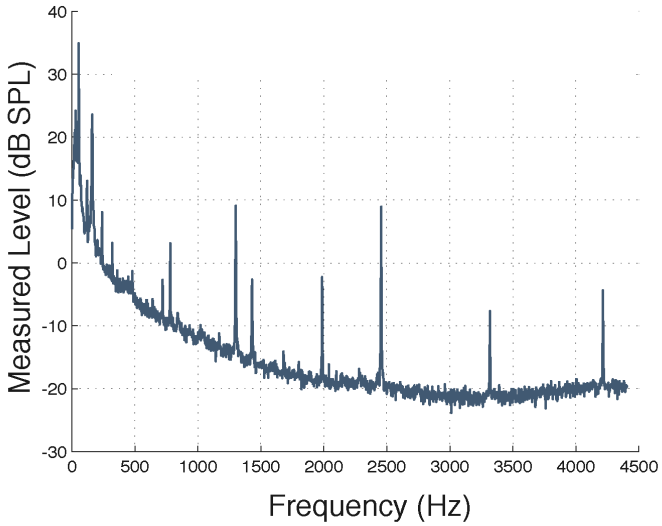
Tone-like sounds spontaneously emitted by the ear



Why might the ear emit sound?

⇒ An Issue of Scale





NOTE: different vertical scales! (one is logarithmic)

$$\text{dB SPL} = 20 \log_{10} \left(\frac{\text{Pa}}{20 \times 10^{-6}} \right)$$

Decibels (dB)

0 dB = x1

10 dB ≈ x3

20 dB = x10

40 dB = x100

60 dB = x1000

80 dB = x10000

100 dB = x100000

...

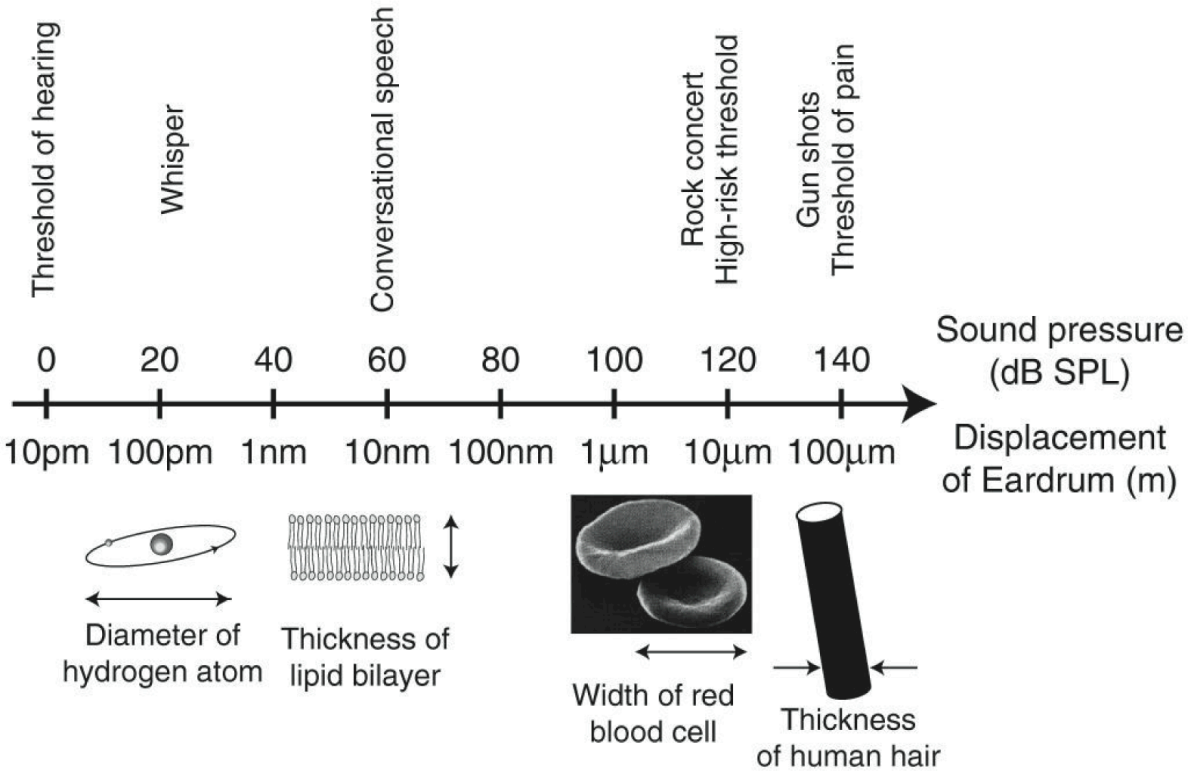
⇒ a dB value is a comparison of two numbers

$$dB = 20 \log(x/y)$$

⇒ Why use a dB scale?

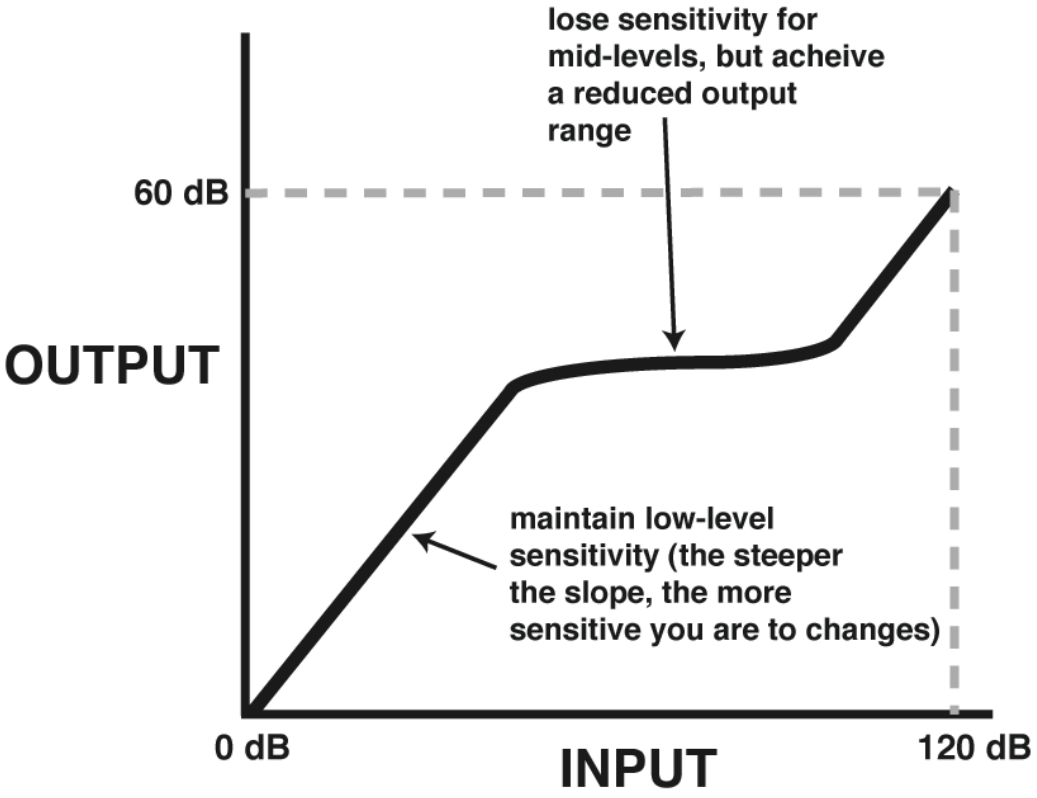
Dynamic Range

Humans hear over a pressure range of 120 dB [that's a factor of a *million*]

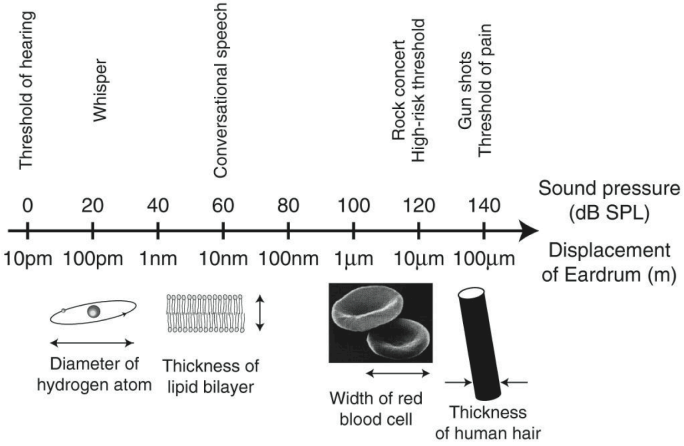


D. Freeman

Compression & Amplification



- Central nervous system can only encode incoming information over a limited range (**COMPRESSION**)
- Ideally want to maintain sensitivity at low levels (**AMPLIFICATION**)



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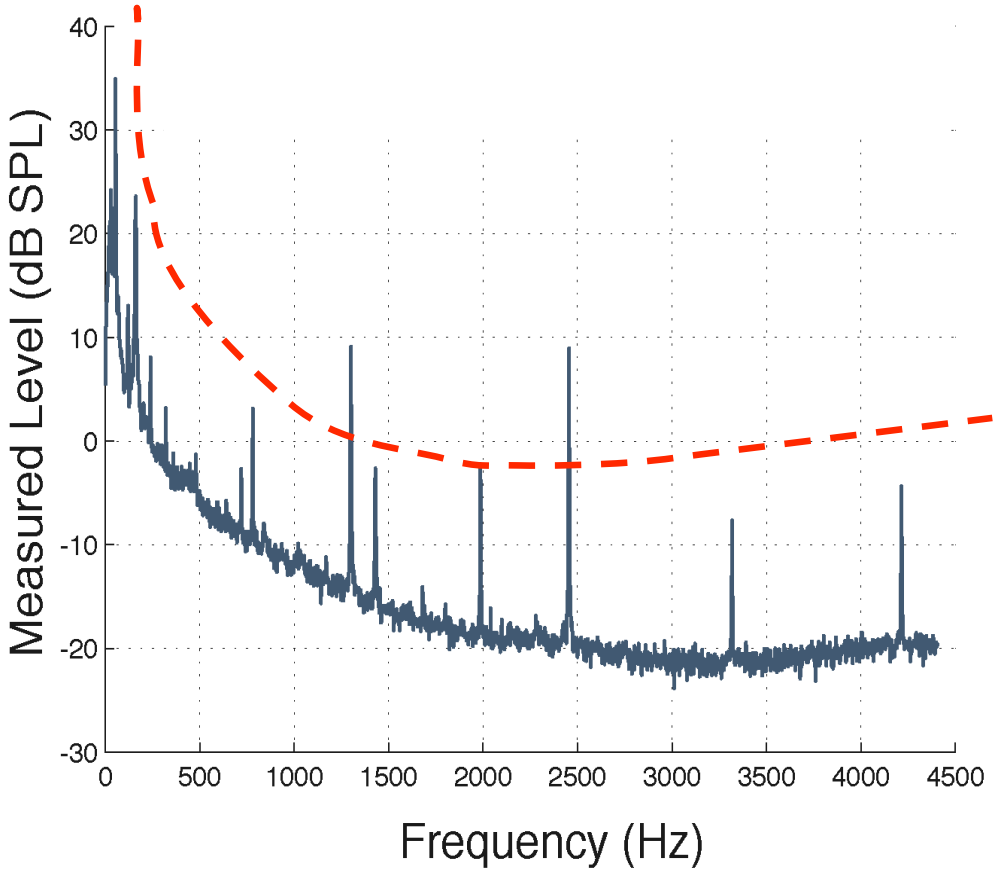
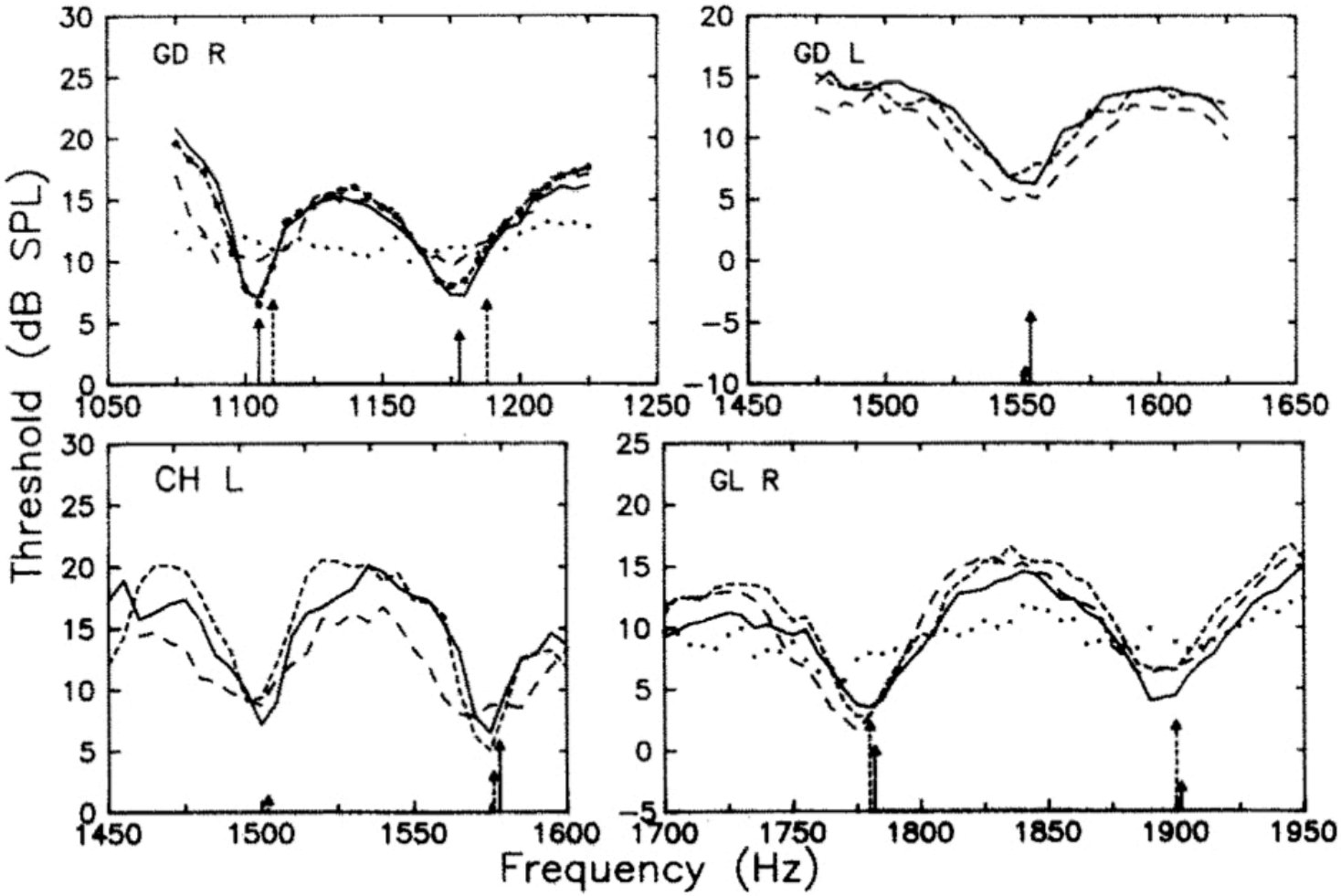
SOAEs & Threshold



human threshold curve

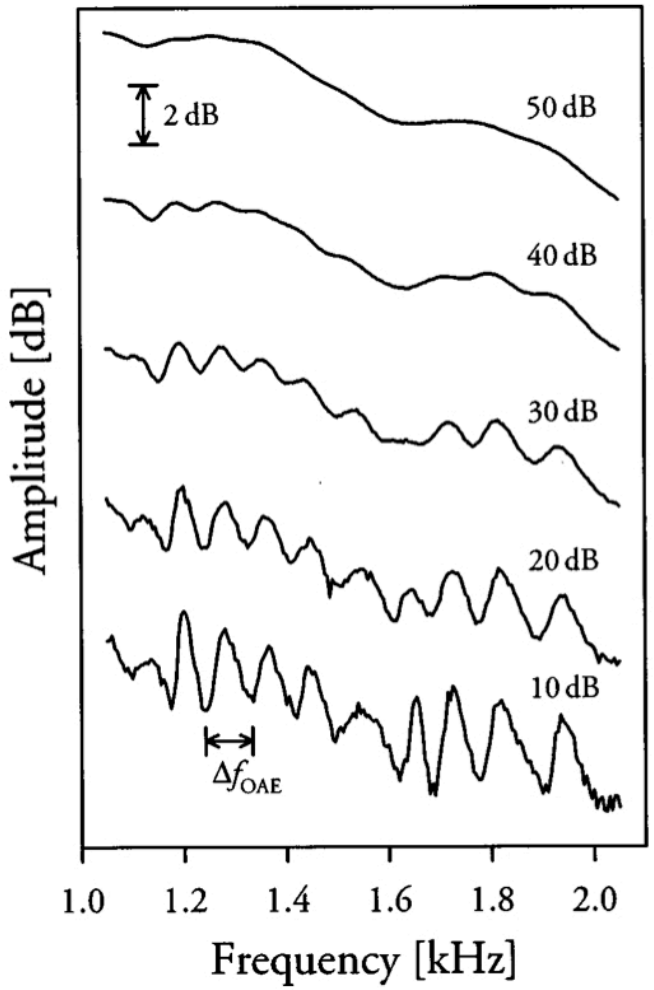
⇒ SOAEs byproduct of an *amplification* mechanism?

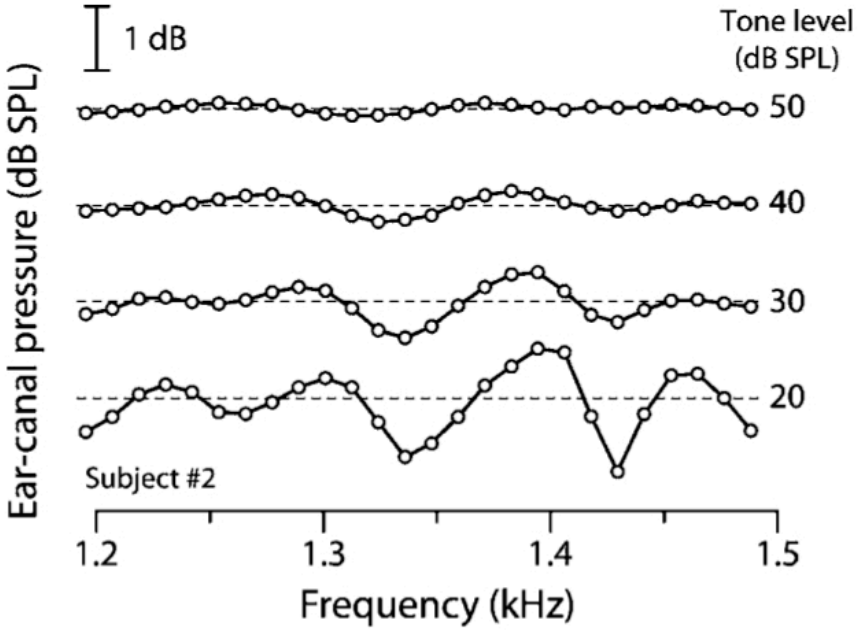
SOAEs & Threshold



Long & Tubis (1988)

OAEs Interact w/ External Tones





Shera & Guinan (1999)

Kalluri & Shera (2007)

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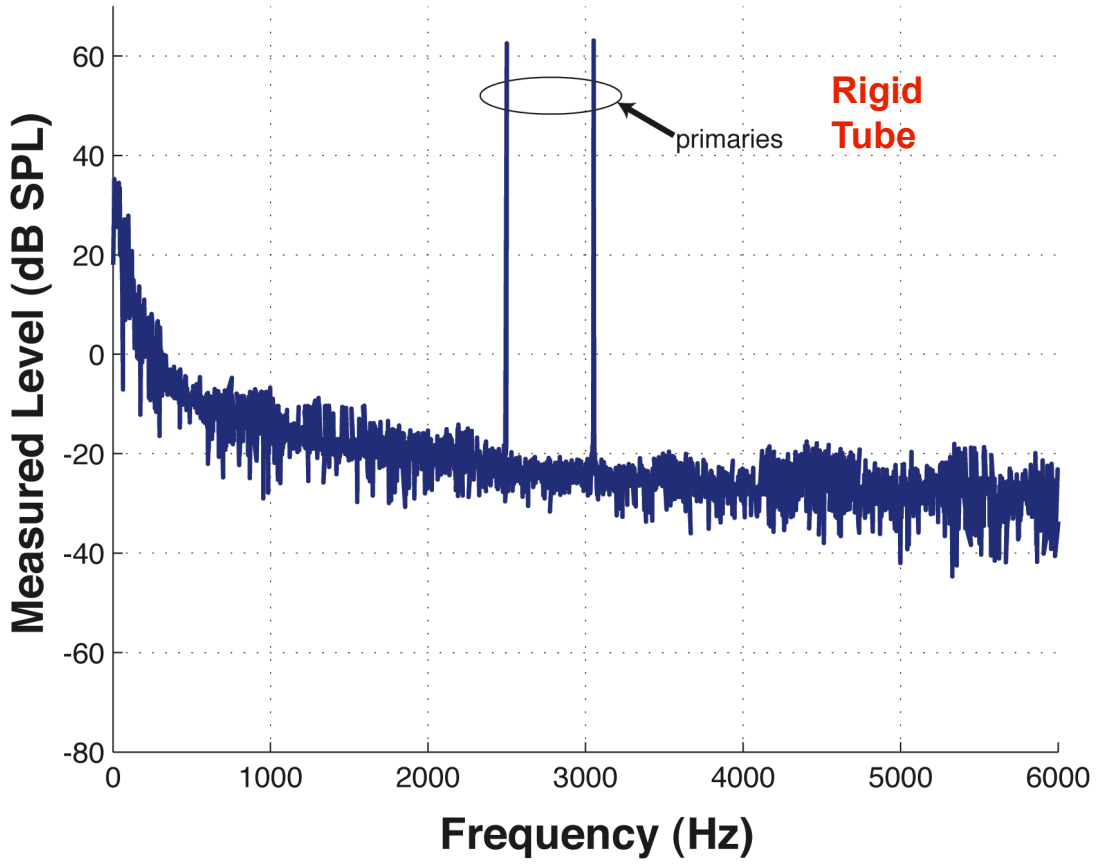
Two-Tone Distortion



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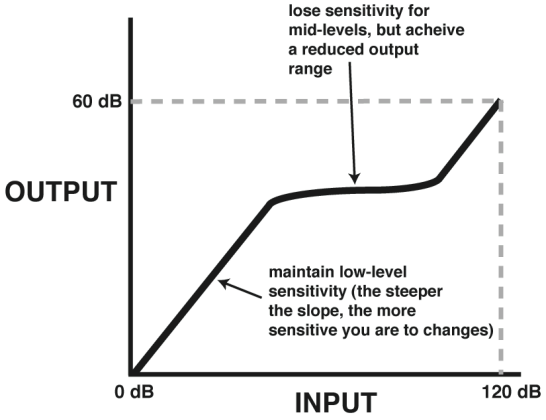
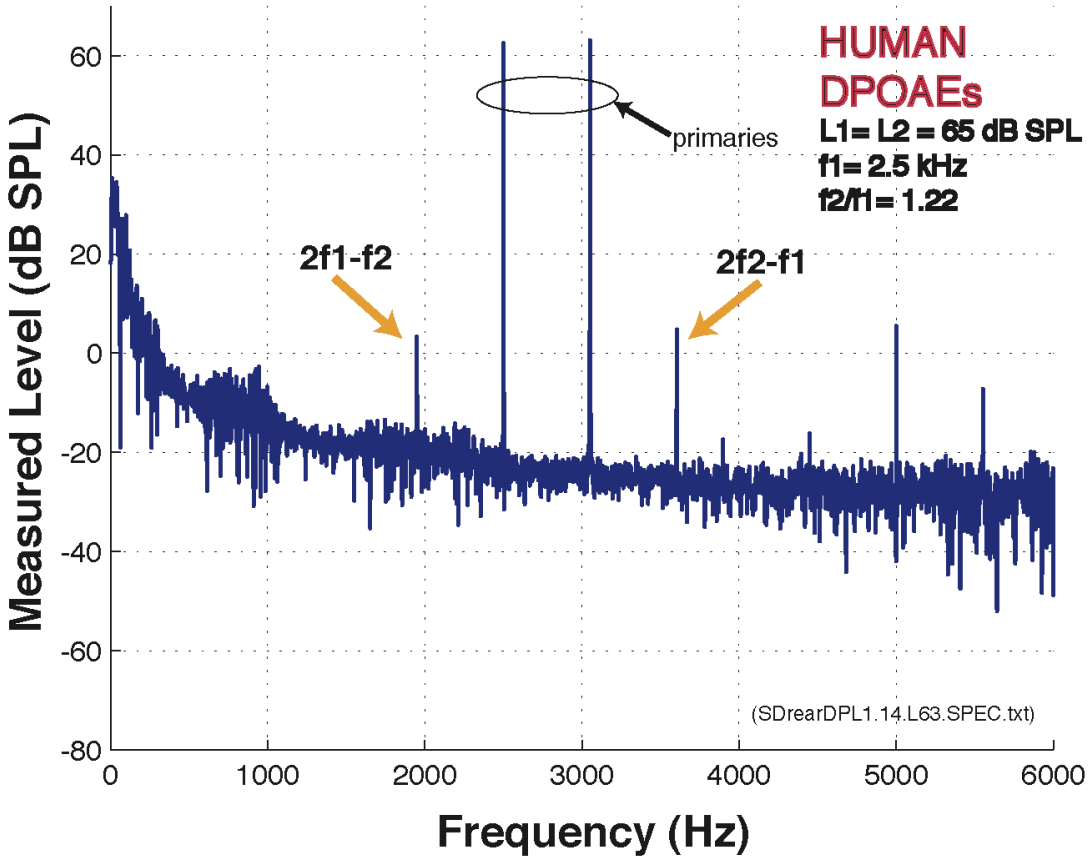
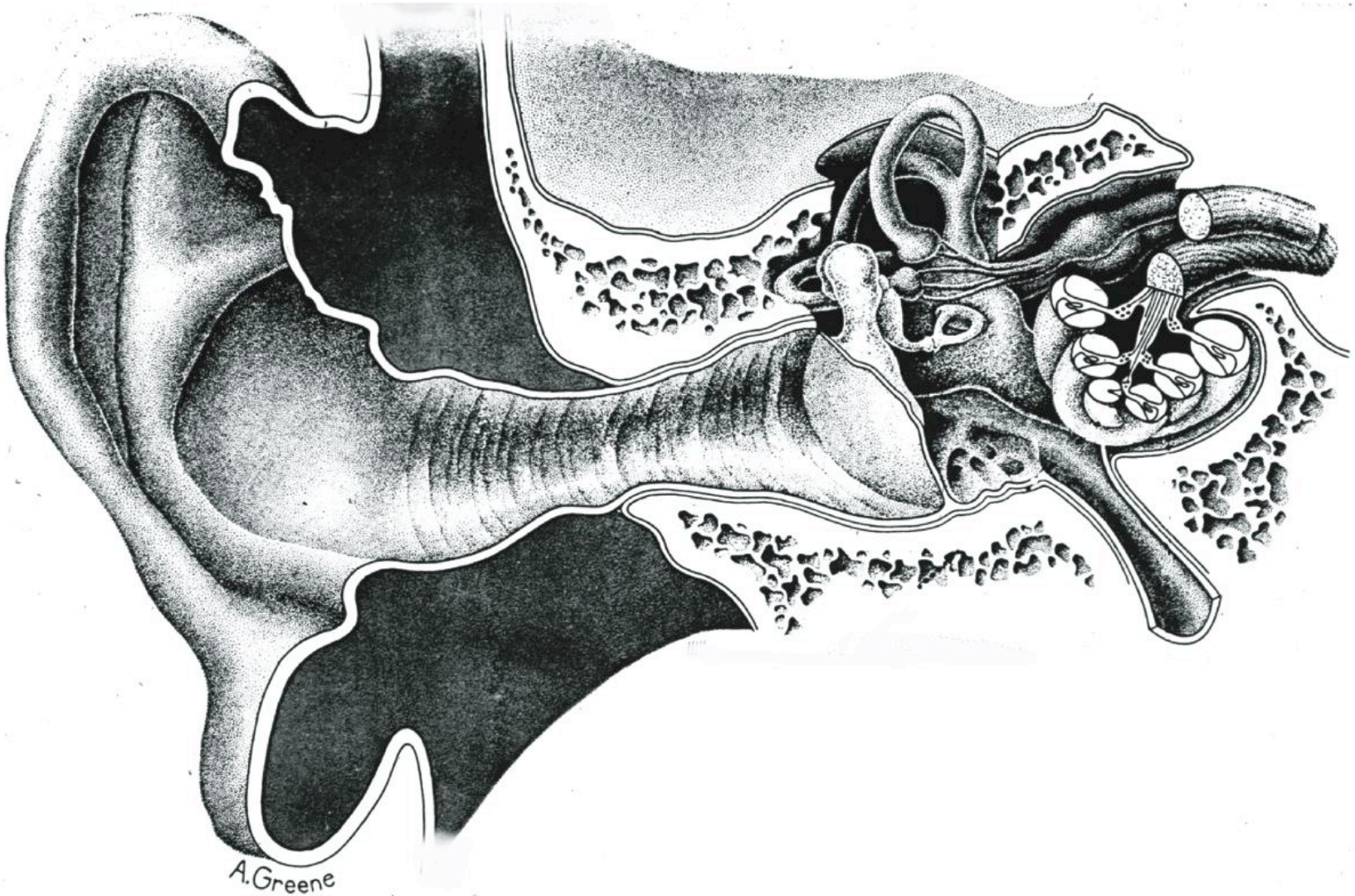
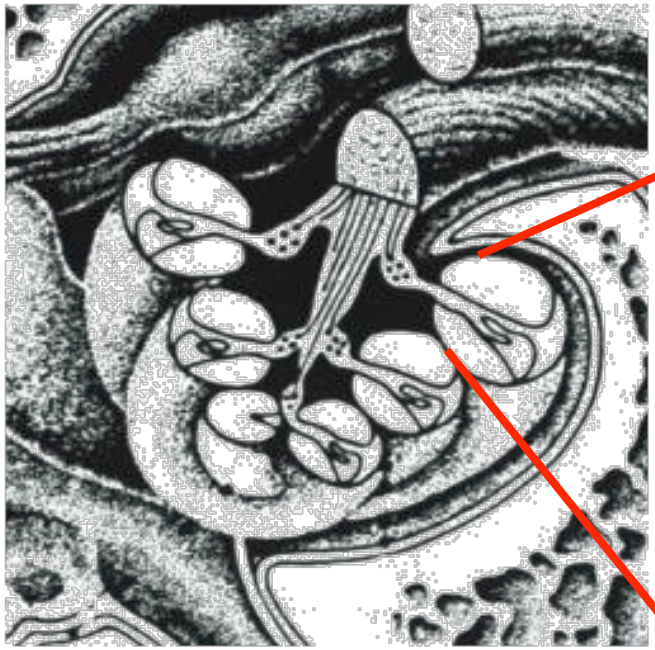
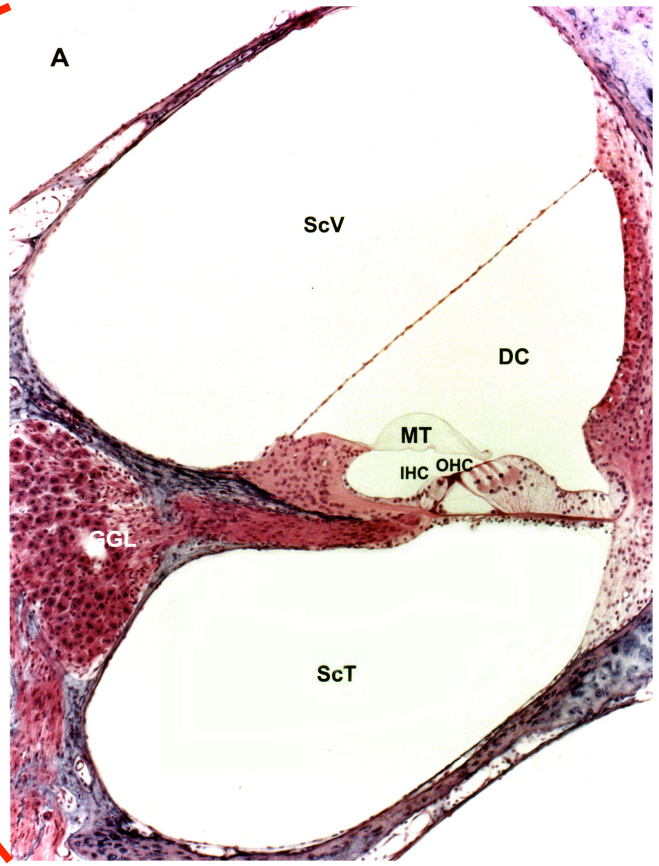


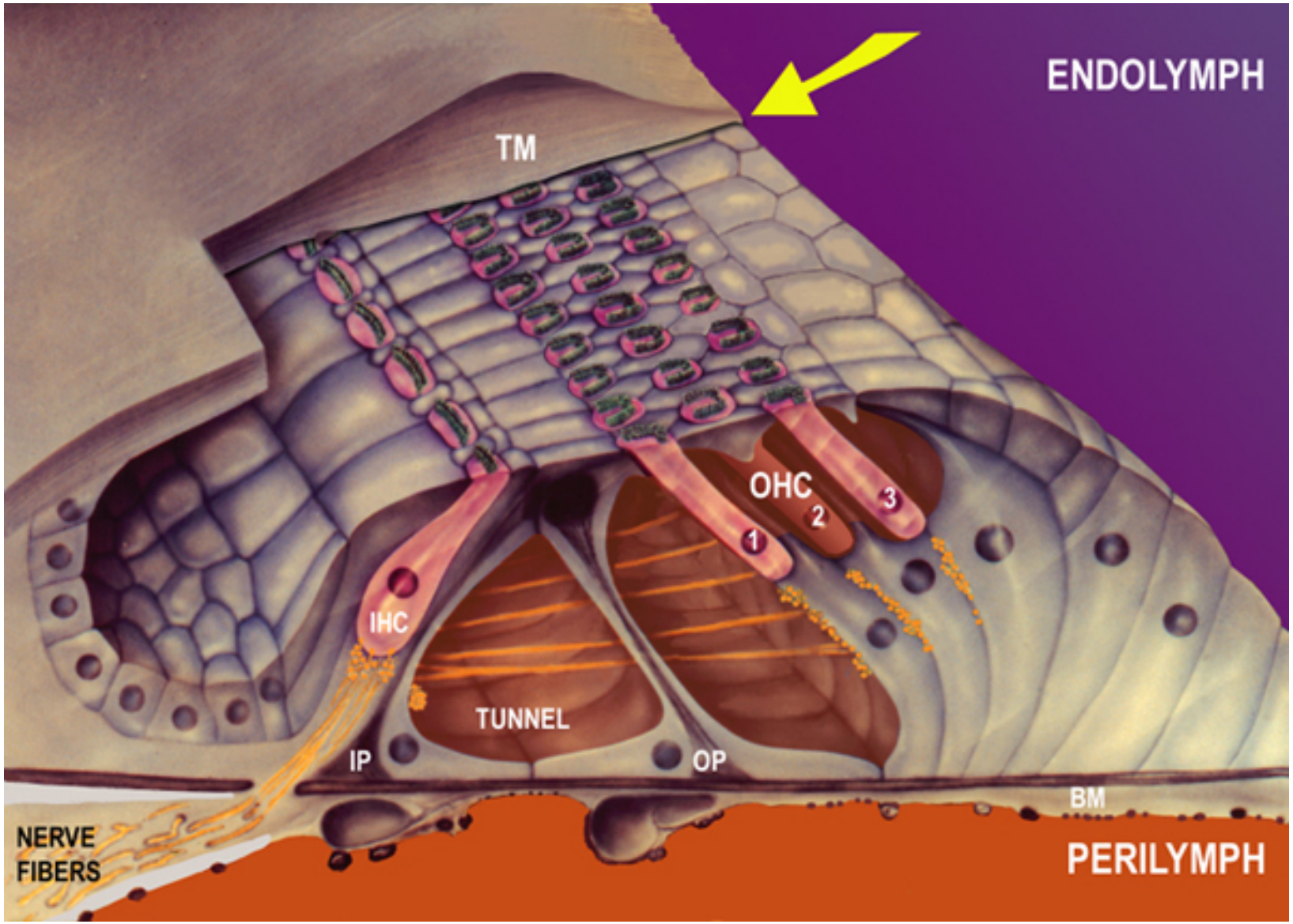



A. Greene

Inner ear - Organ of Corti

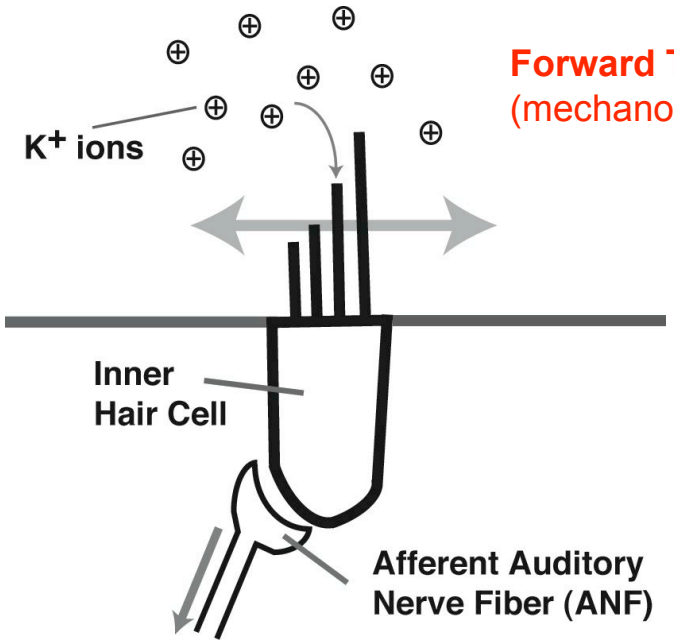




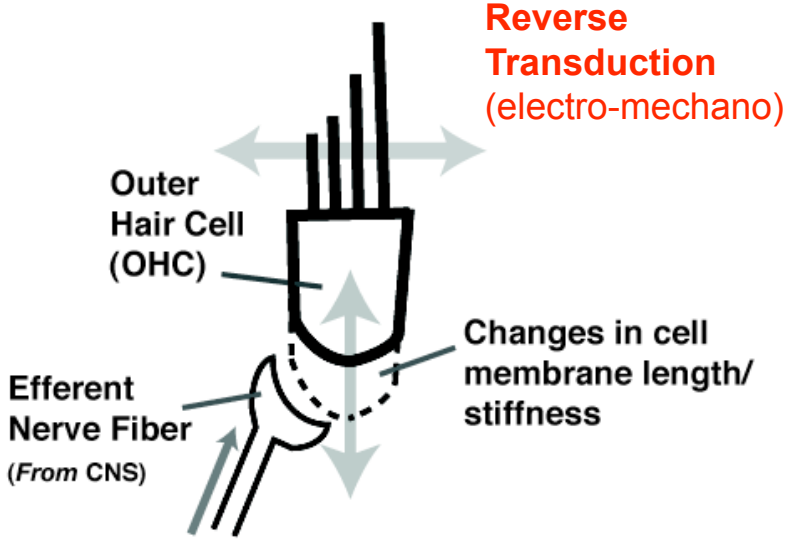

ENDOLYMPH
TM
OHC
1
2
3
IHC
TUNNEL
IP
OP
BM
NERVE
FIBERS
PERILYMPH

Bohne

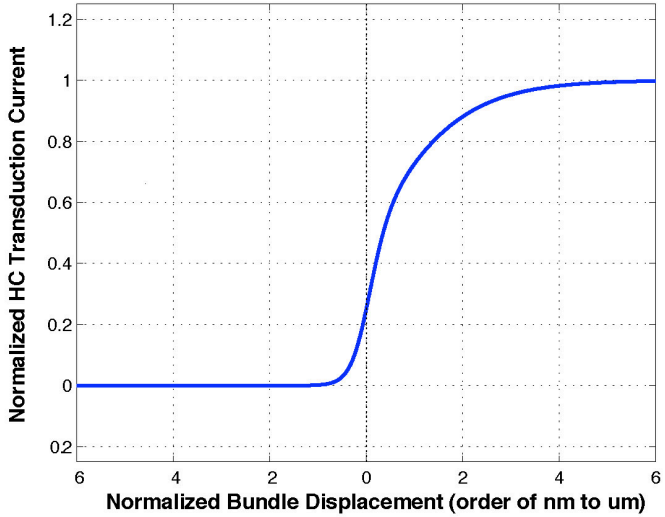
Auditory Transduction



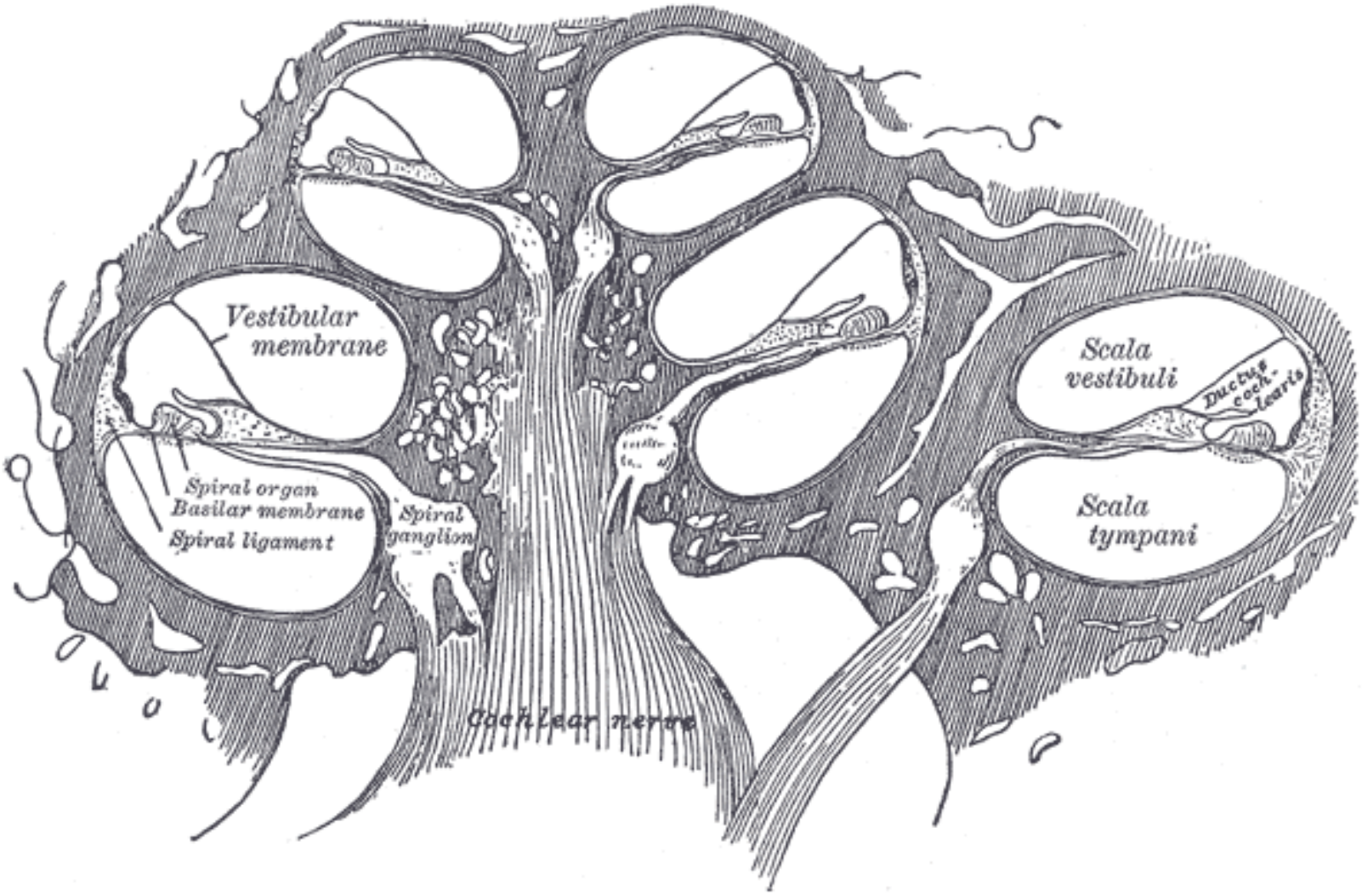
Forward Transduction
(mechano-electro)



Reverse Transduction
(electro-mechano)

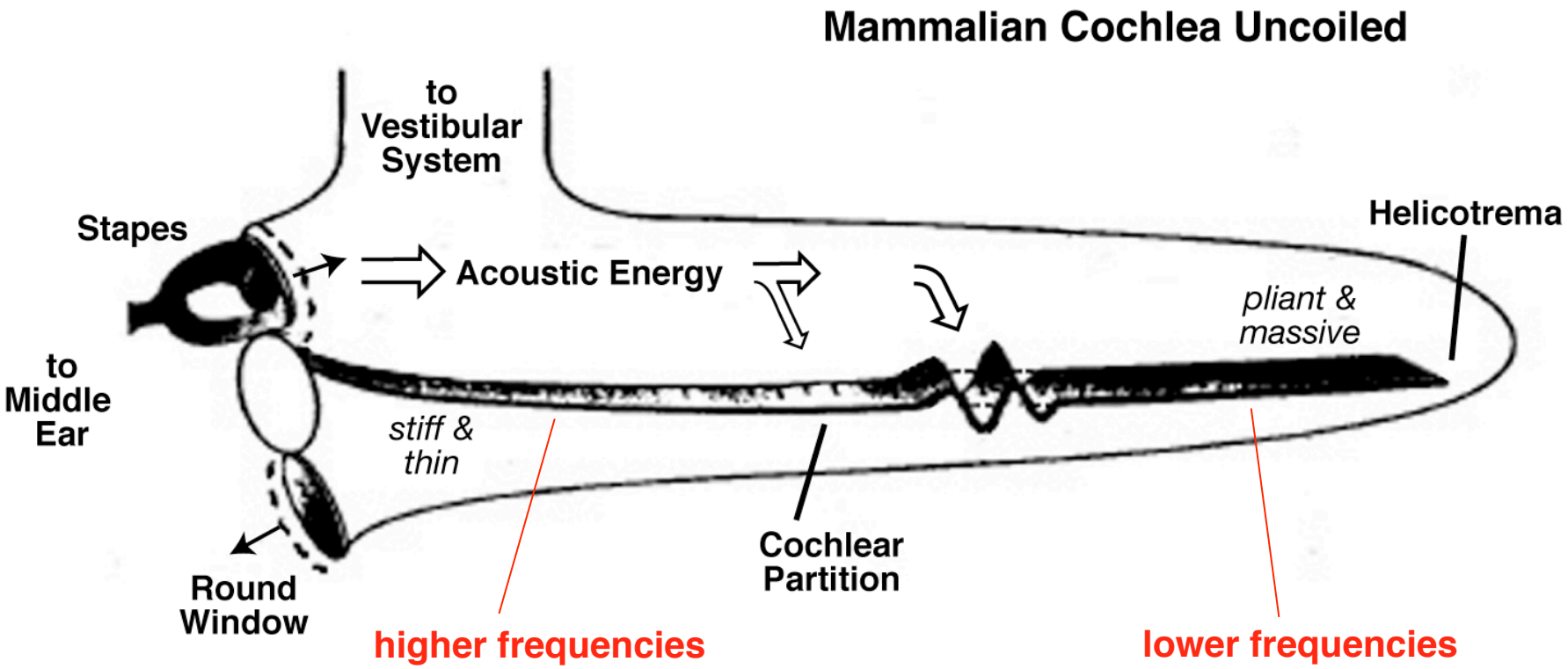


⇒ Transduction is highly *nonlinear*

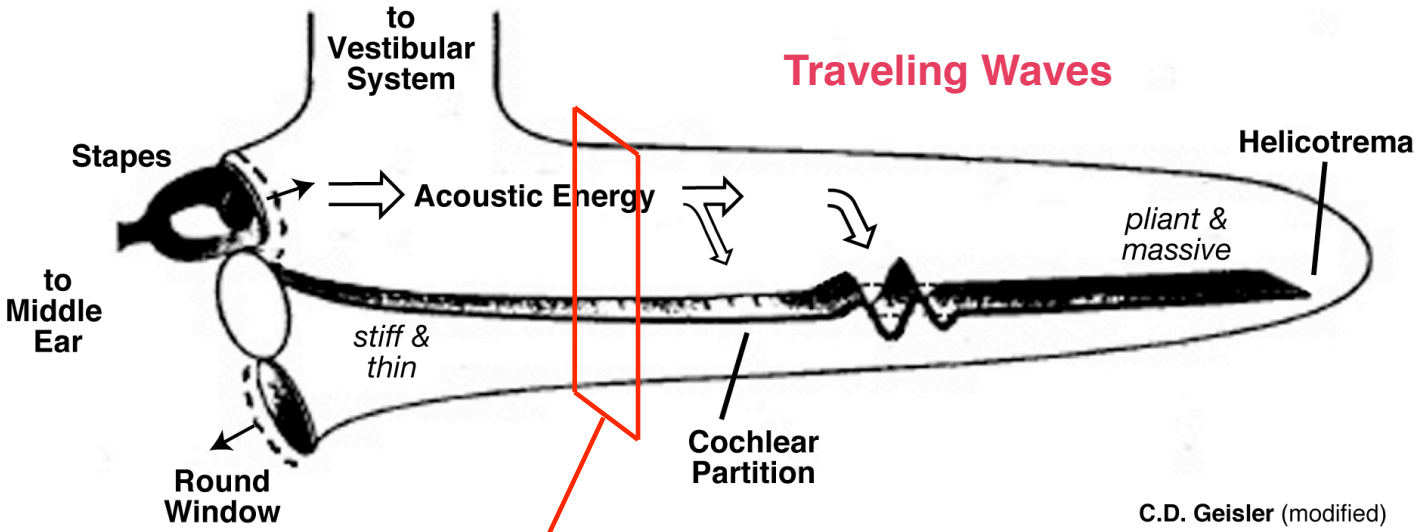


Grey's Anatomy

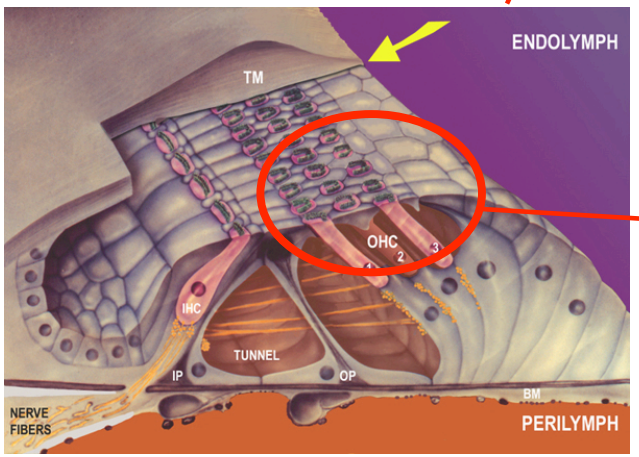
BM Traveling Waves & Tonotopicity

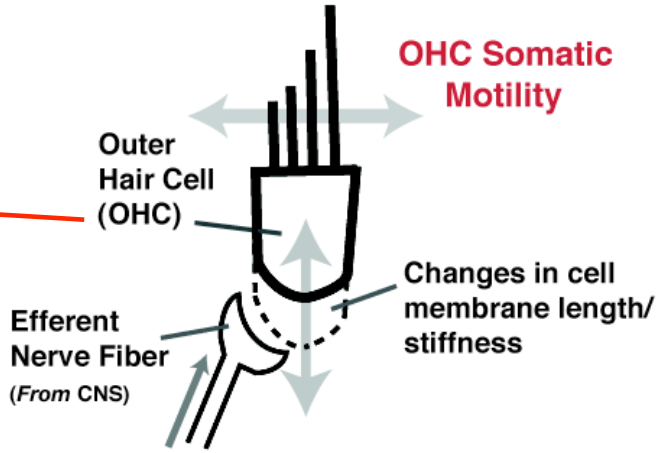


Mammalian Cochlea Uncoiled



C.D. Geisler (modified)





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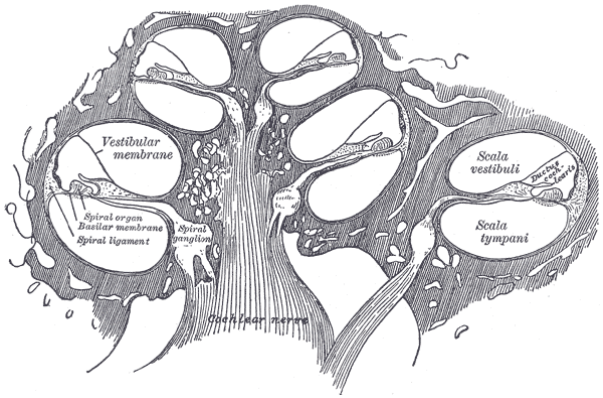
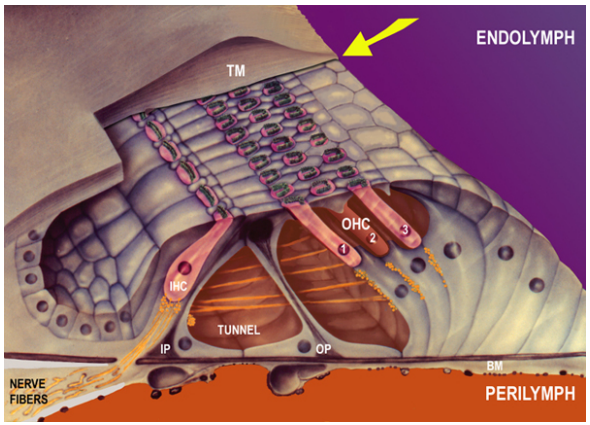
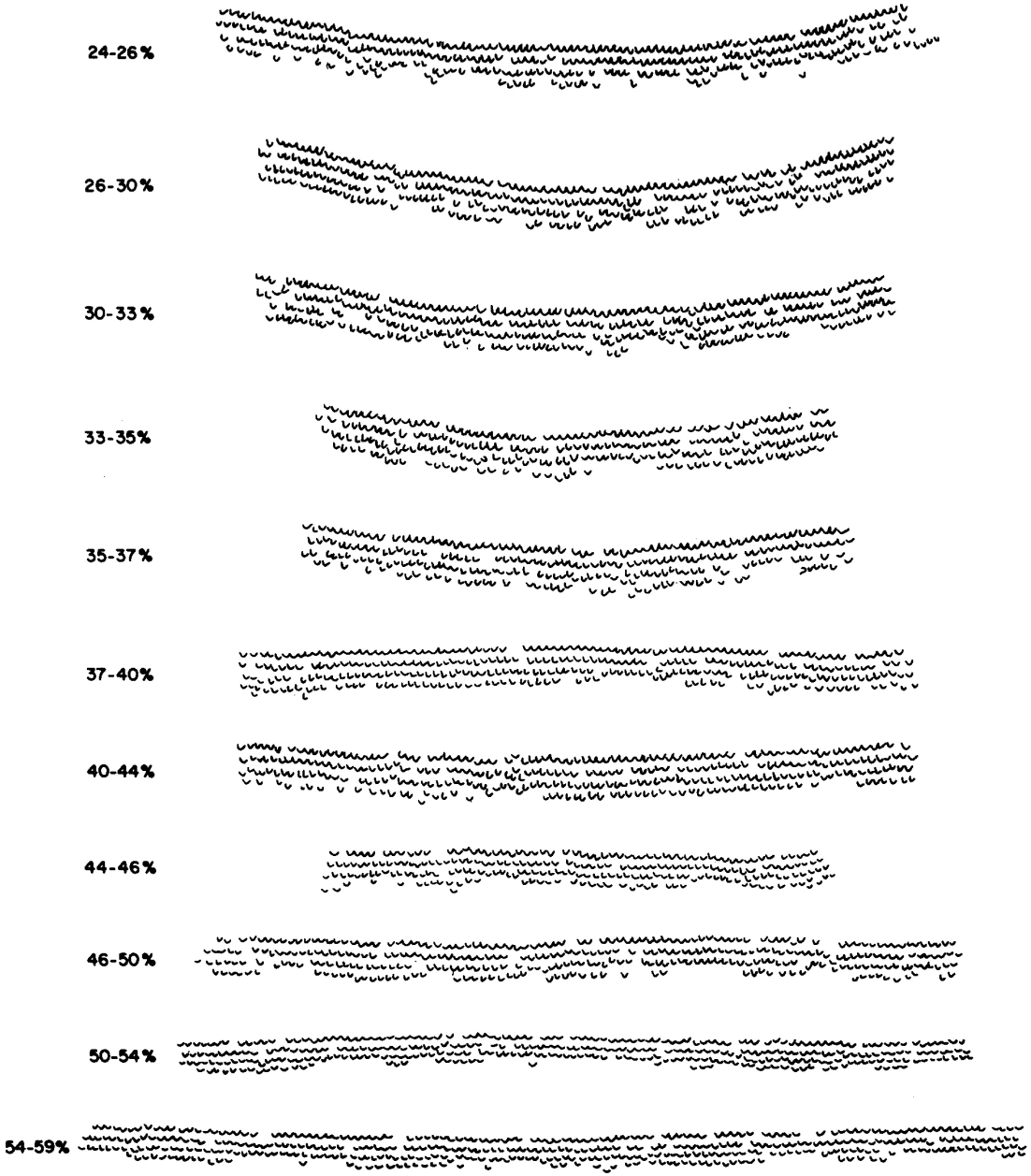
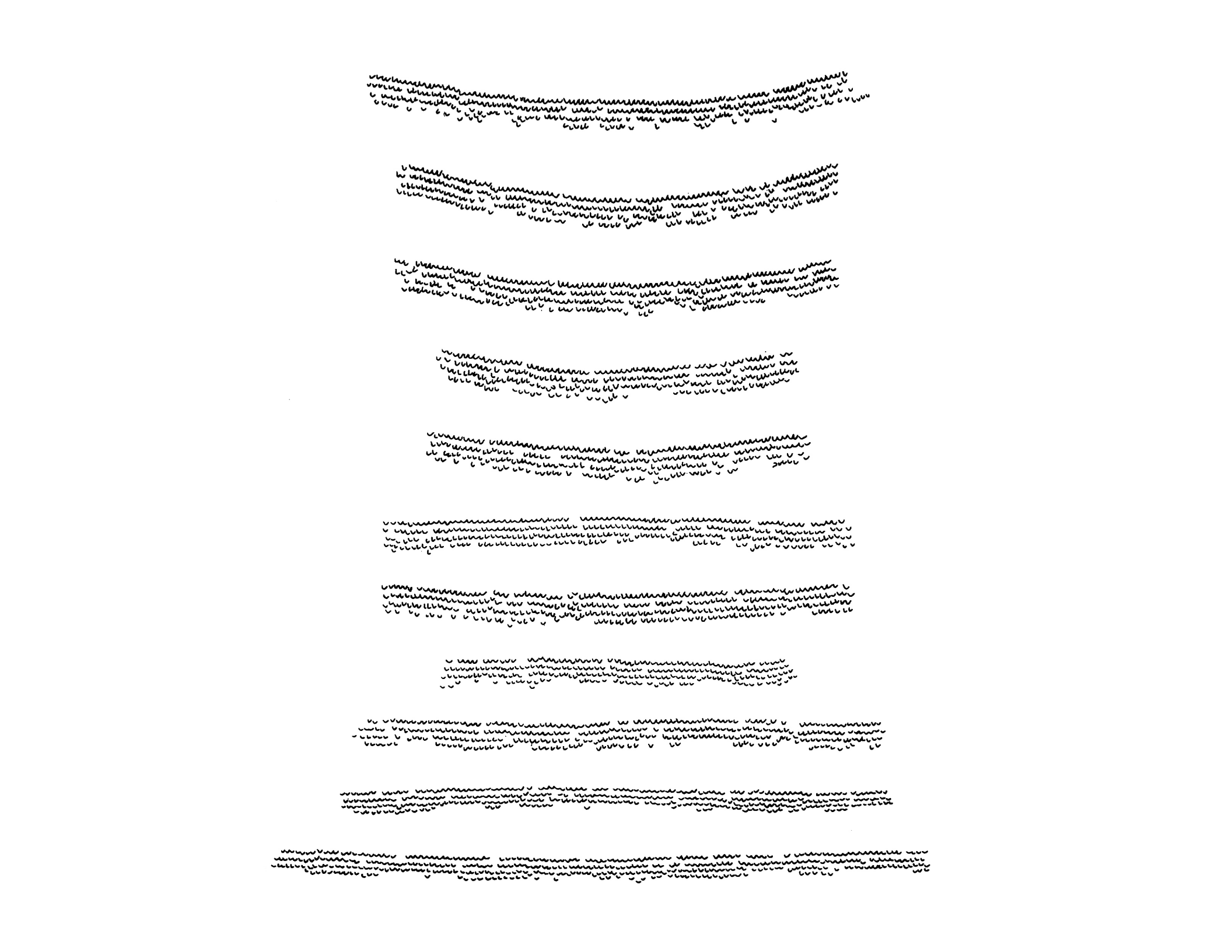
Roughness





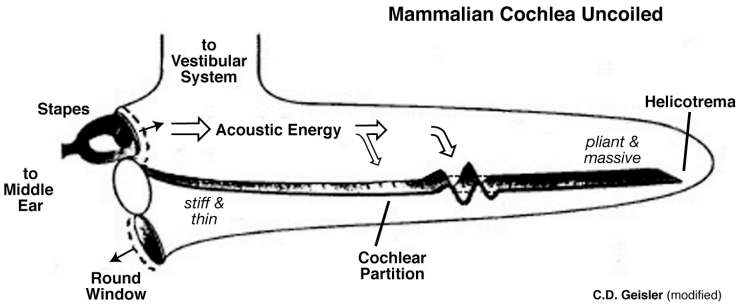


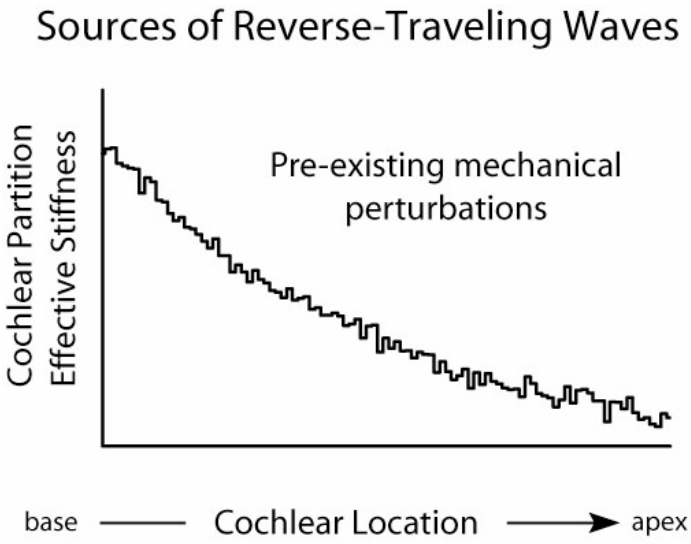
Lonsbury-Martin et al. (1988)

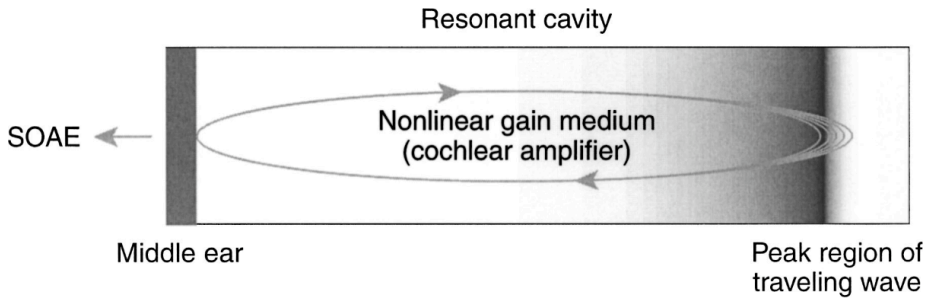


Simple Model to Explain OAEs?

⇒ Wave motion sets basis for *reflection* of energy







Idea: SOAEs arise due to standing-waves set up along the length of the cochlea, *analogous to a* ***laser cavity***

Shera (2003)

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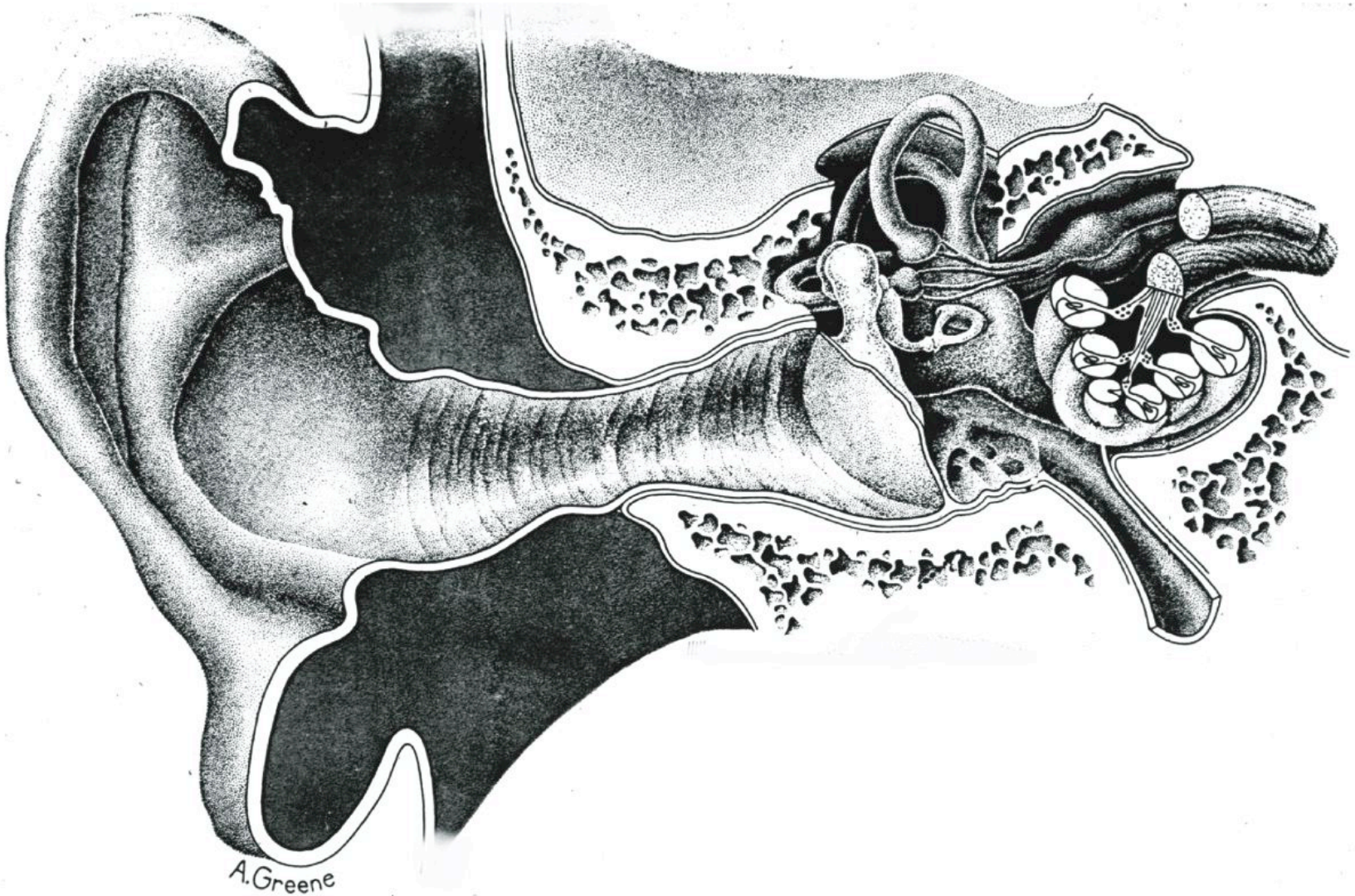
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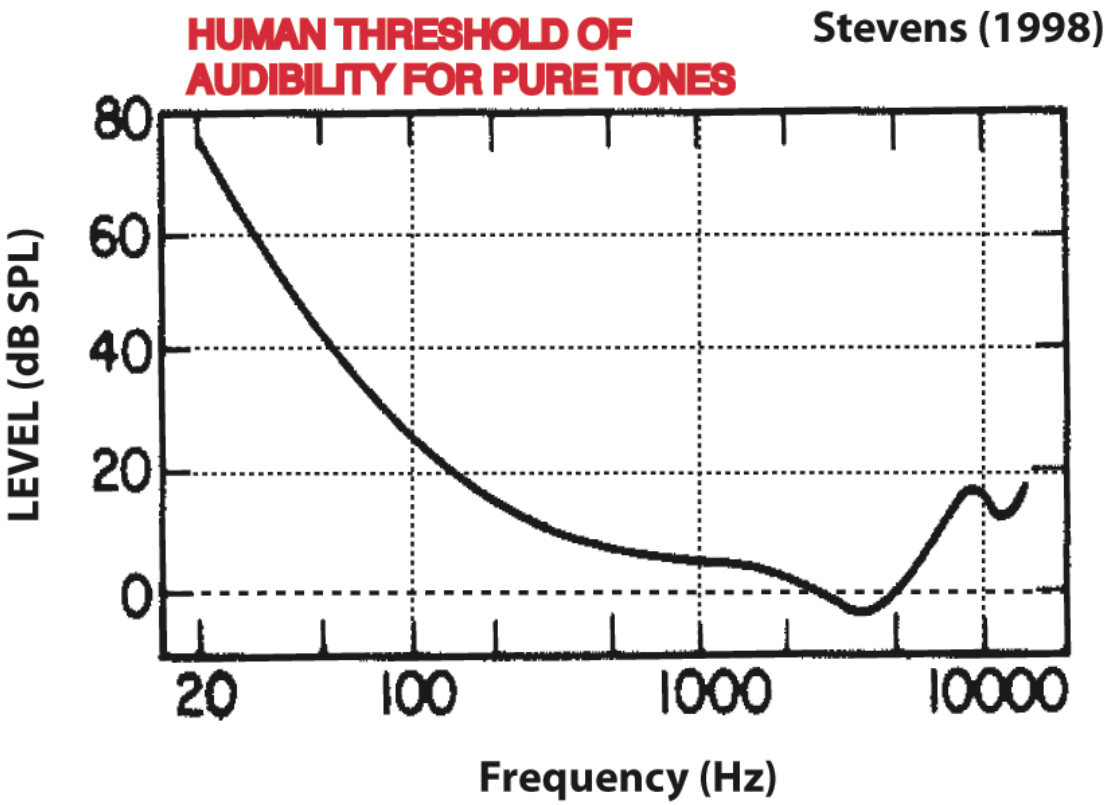
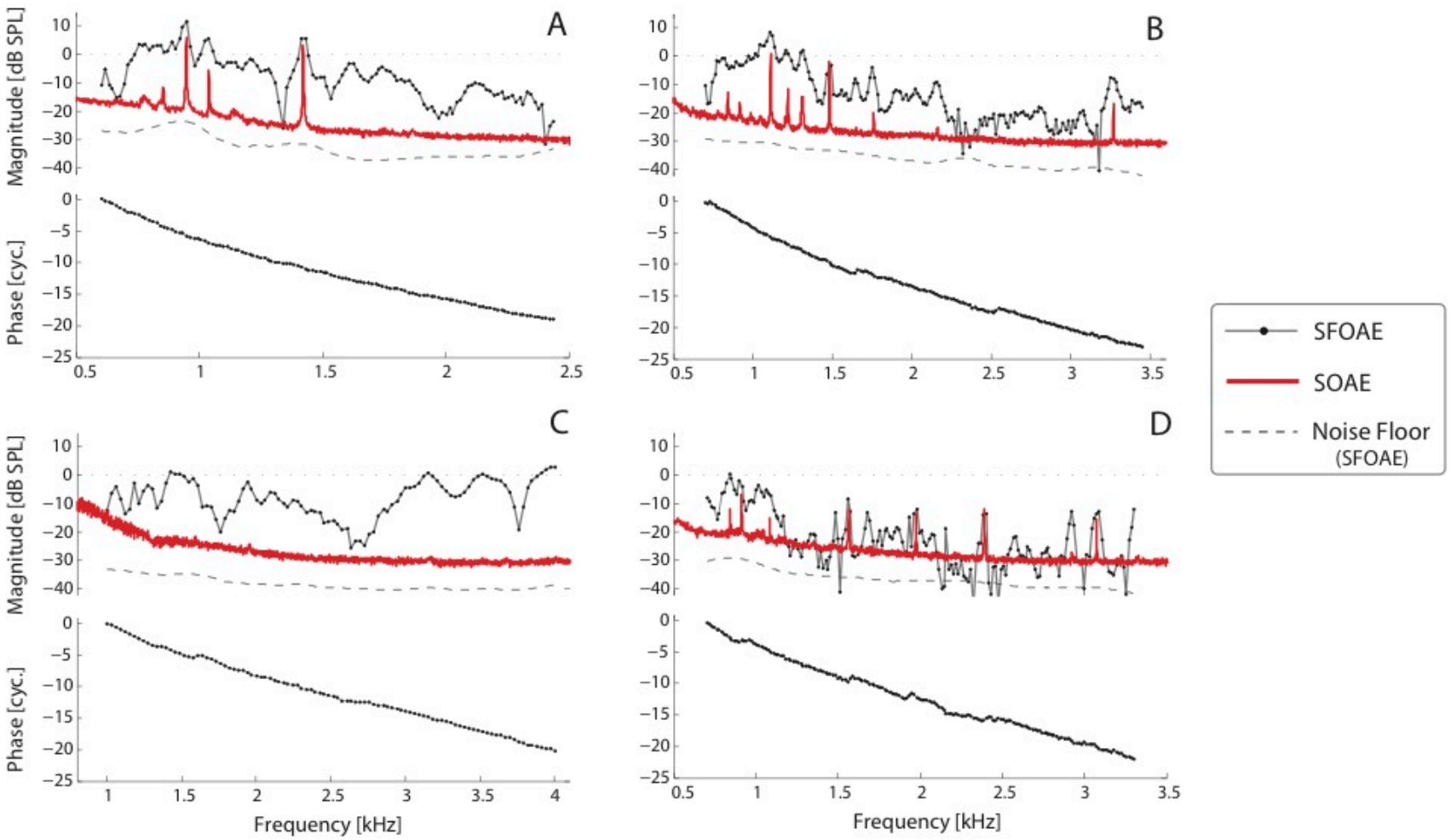

HUMAN THRESHOLD OF
AUDIBILITY FOR PURE TONES
Stevens (1998)
LEVEL (dB SPL)
80
60
40
20
0
20
100
1000
10000
Frequency (Hz)

SOAEs & Evoked Emissions



Bergevin et al. (submitted)