Hearing Loss and Hearing Aid Signal Processing

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Why hearing is important: Social relationships

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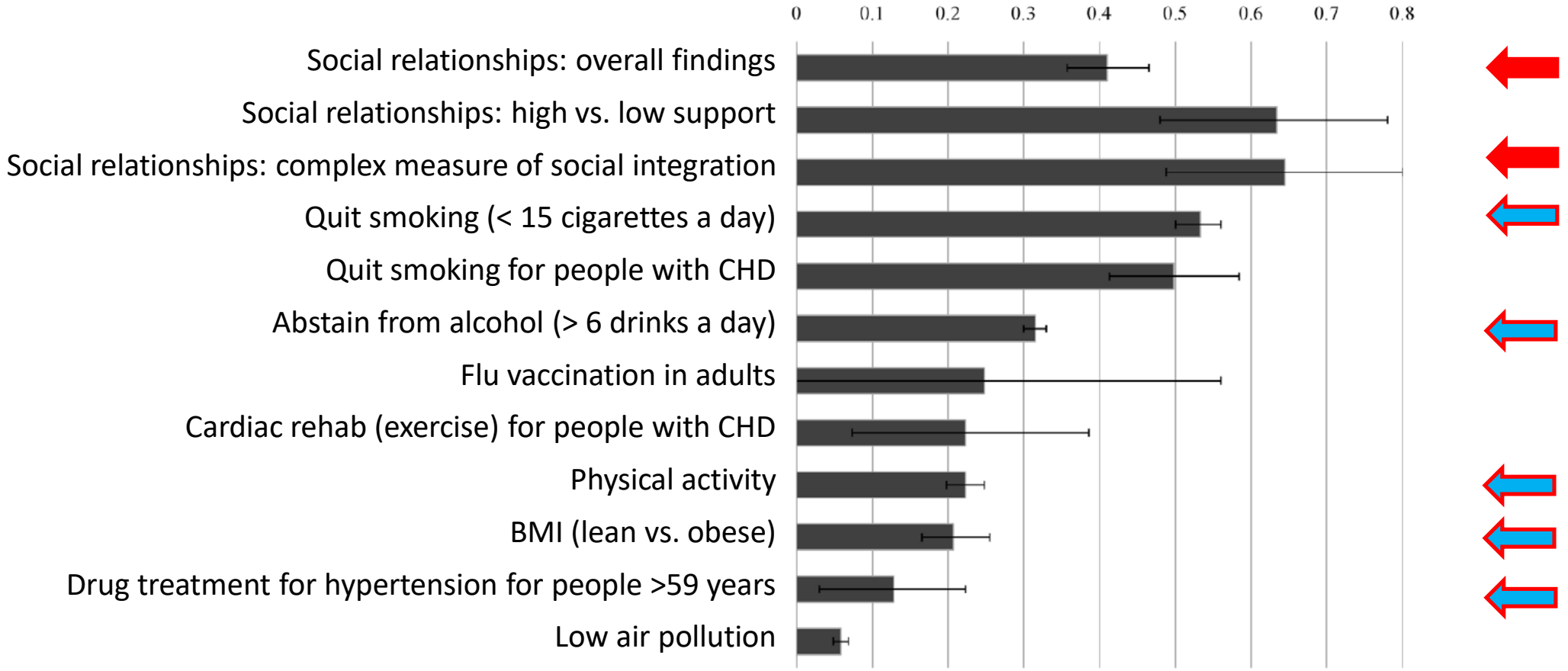
Social Relationships and Mortality Risk: A Meta-analytic Review

Julianne Holt-Lunstad[1]*, Timothy B. Smith[2], J. Bradley Layton[3]

2010

Holt-Lunstad et al.: Result and conclusion

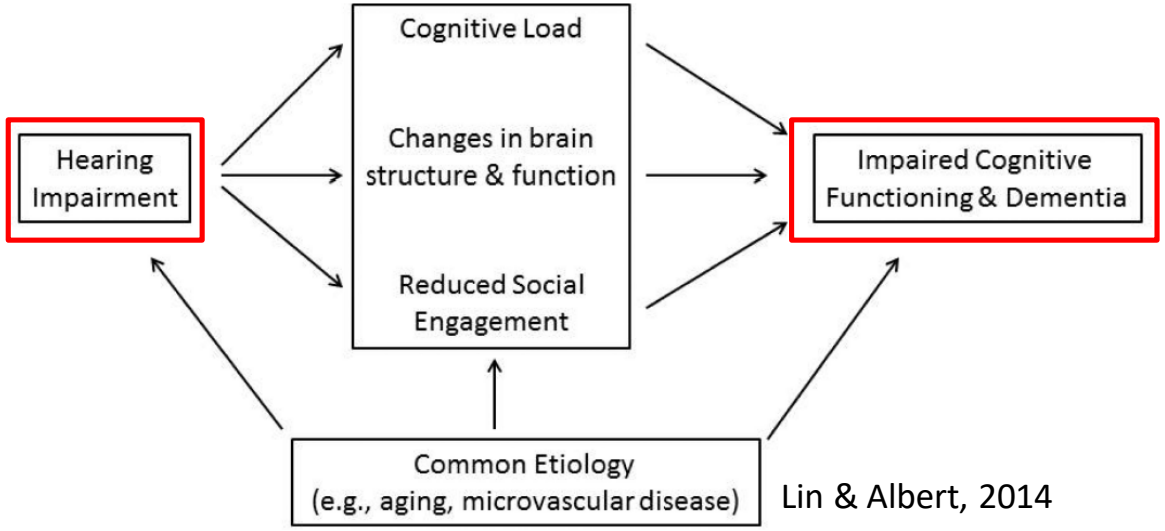


Conclusion: ”The influence of social relationships on risk for mortality is comparable with well-established risk factors for mortality”

No mention of hearing or hearing loss…

Dementia prevention, intervention and care

- The Lancet Commissions 2017 and 2020
- Hearing loss in mid and late life identified the single largest pontentially modifiable risk factor for dementia



Lin & Albert, 2014

Figure 1.
Conceptual model of the association of hearing impairment with cognitive functioning and dementia.

2020

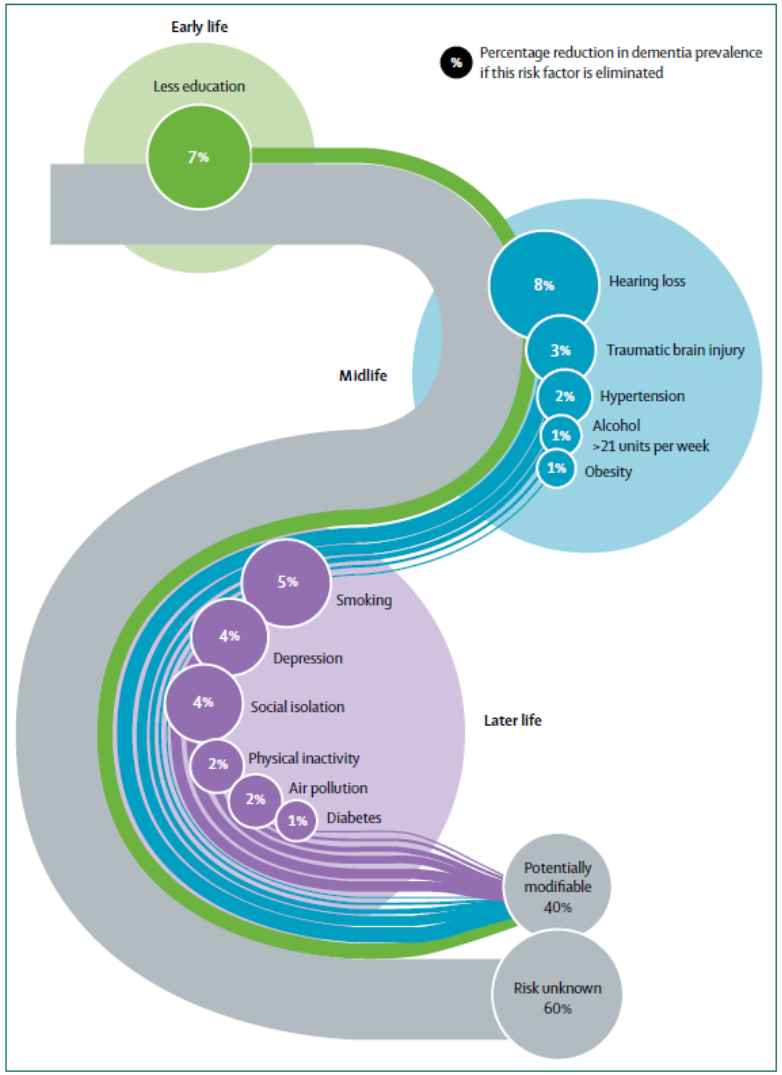
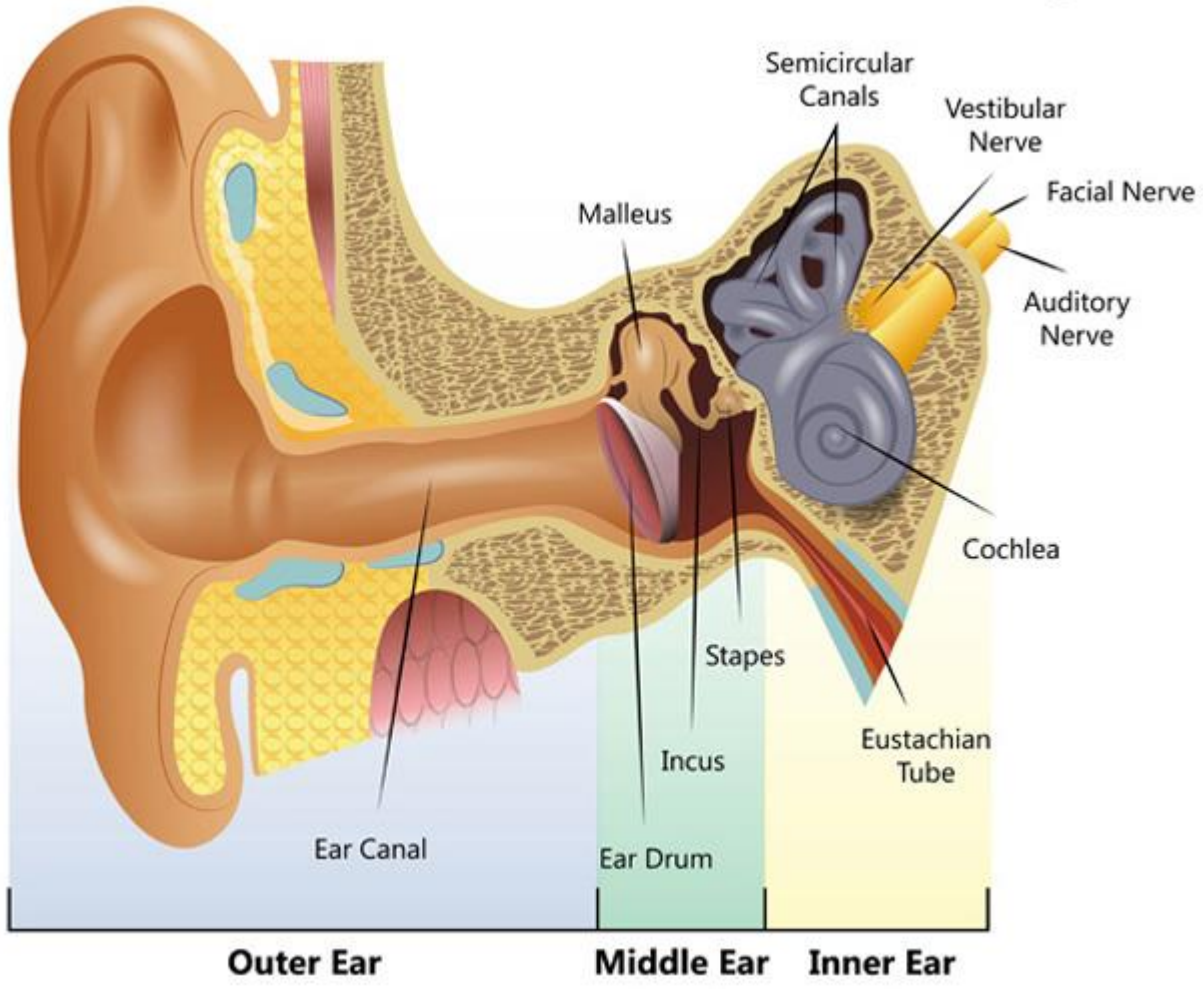


Figure 7: **Population attributable fraction of potentially modifiable risk factors for dementia**

- Can early treatment of hearing loss delay cognitive decline and dementia? Currently unknown.

The ear and cochlear hearing loss



https://www.hearinglink.org/your-hearing/about-hearing/how-the-ear-works/

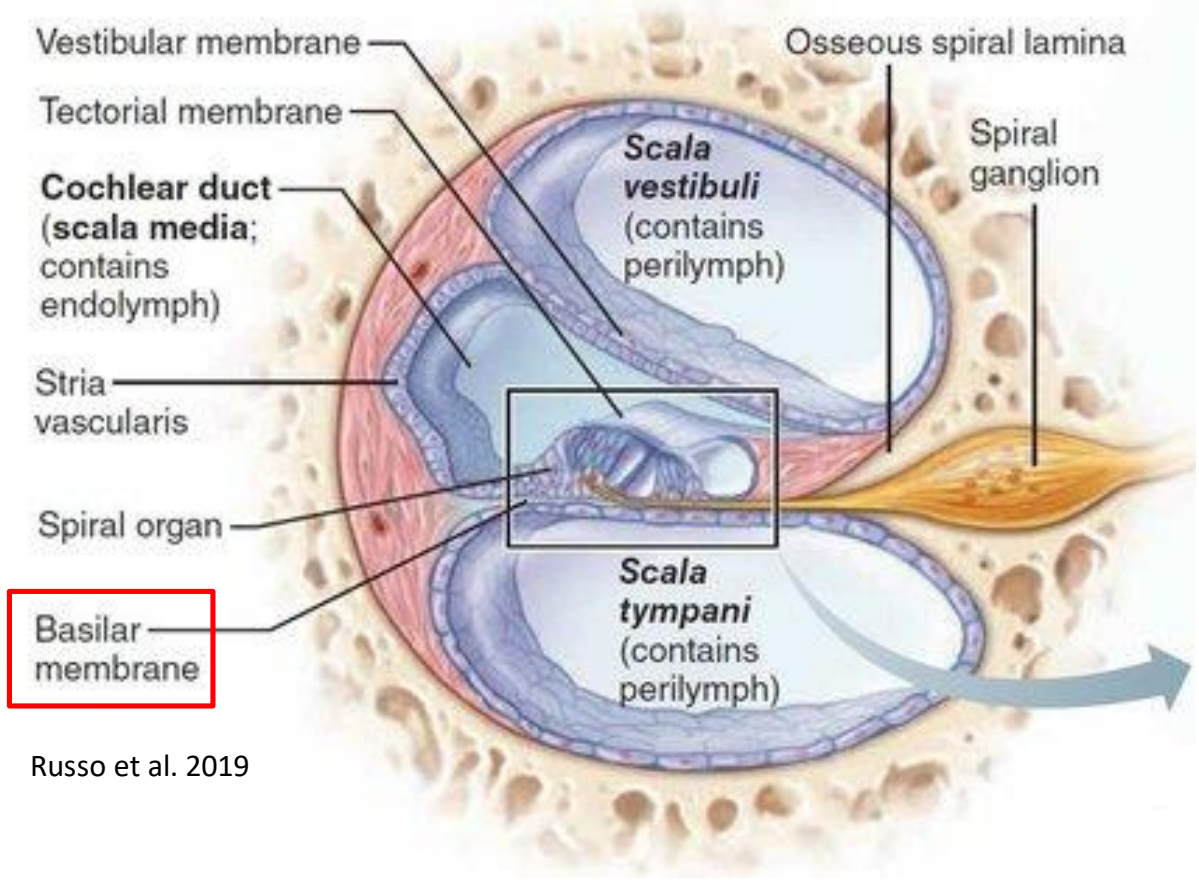
Focus: Cochlear (sensorineural) hearing loss

- Ageing
- Noise or acoustic trauma
- Ototoxic drugs

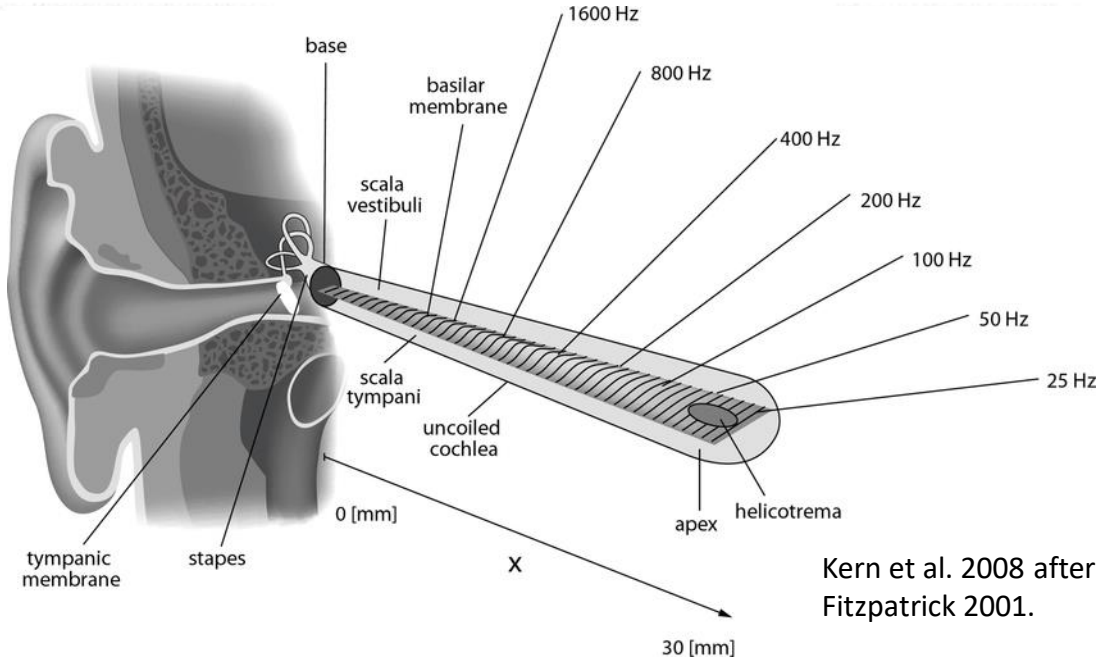
Some consequences of cochlear hearing loss

- Audibility (raised hearing thresholds)
- Loudness perception (reduced dynamic range)
- Frequency selectivity (separate components in compex sound)

The cochlea

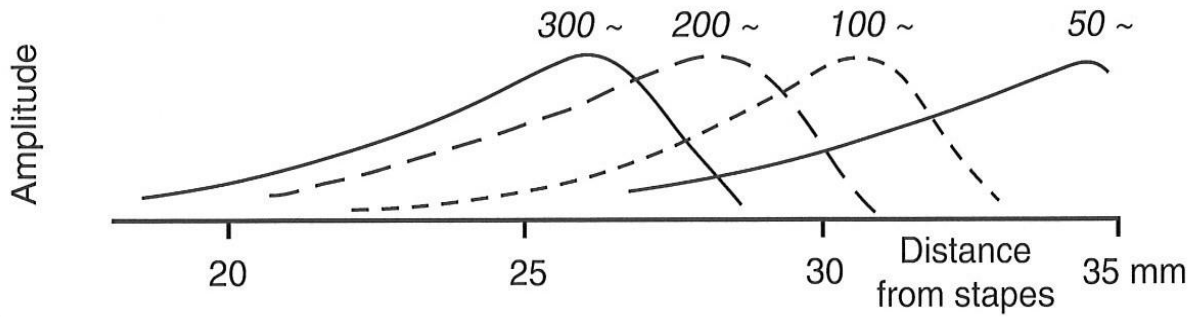


Russo et al. 2019



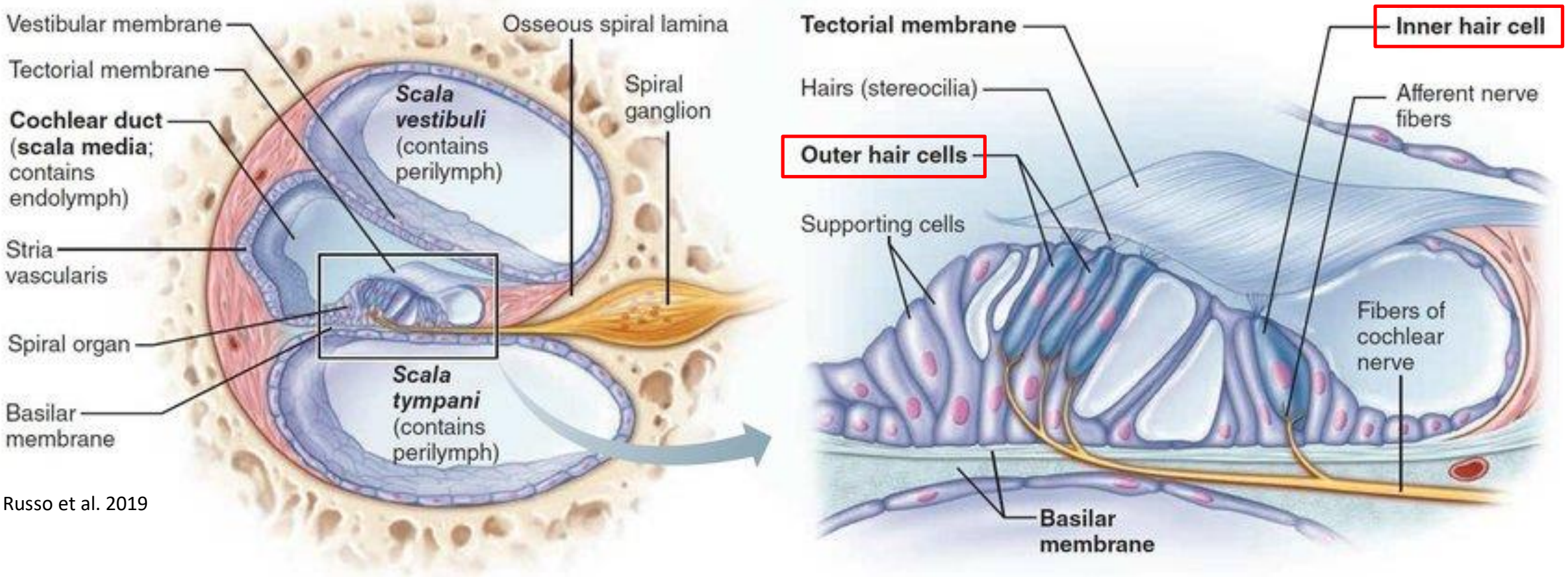
Kern et al. 2008 after Fitzpatrick 2001.

Mechanical frequency analyser, but different when all physiological structures are intact

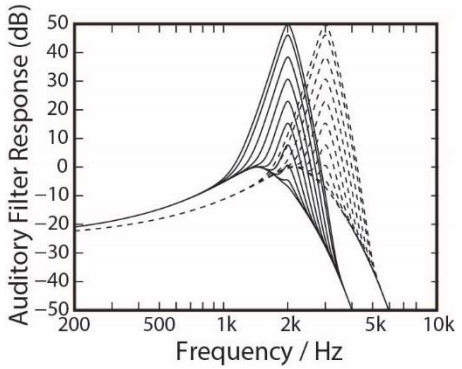


Pickles 2008 after Békésy 1947

Organ of Corti



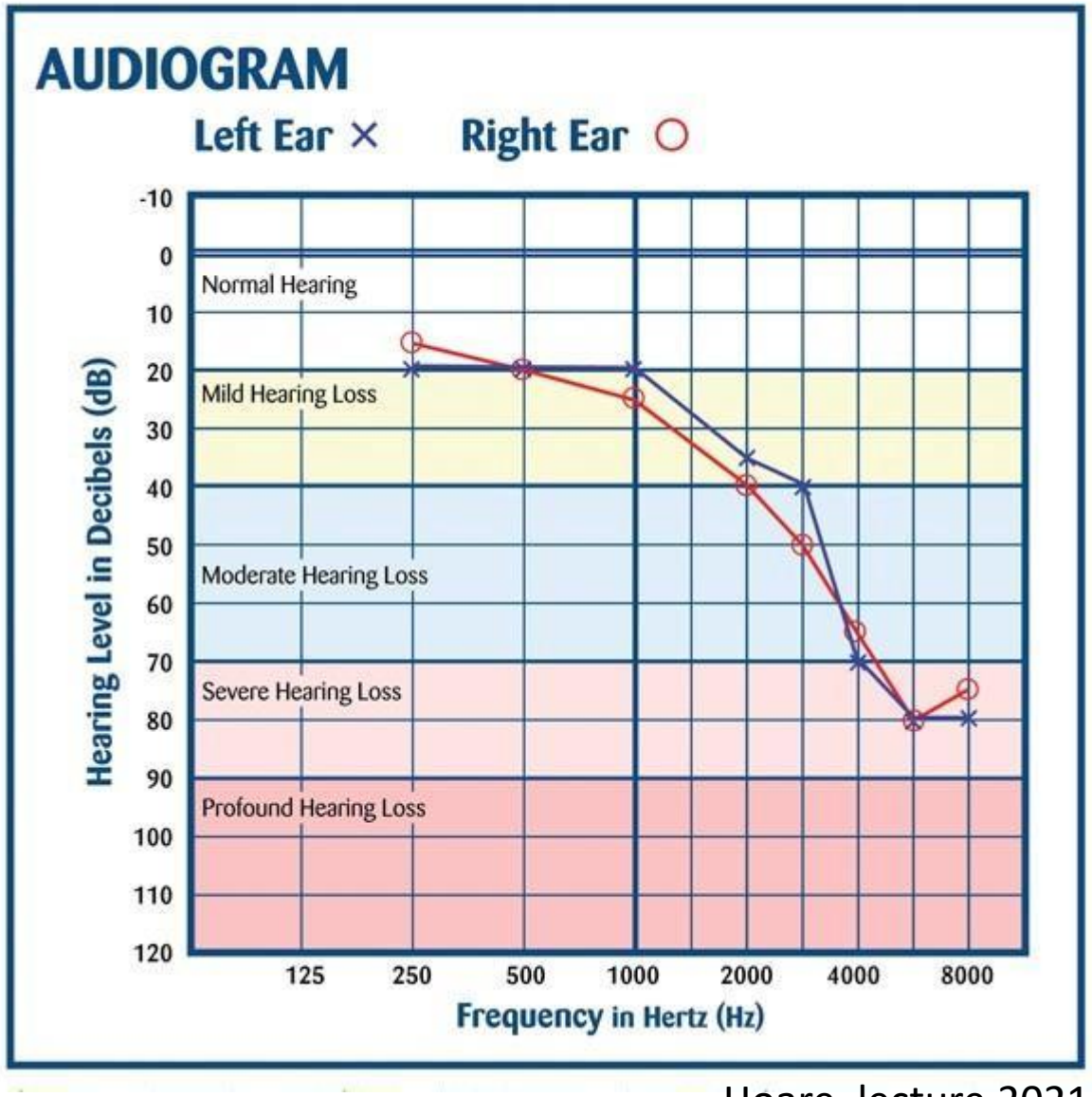
Russo et al. 2019



Smeds &Leijon. 2011
Redrawn from Johnston et al. 1986
Robles and Ruggero 2001

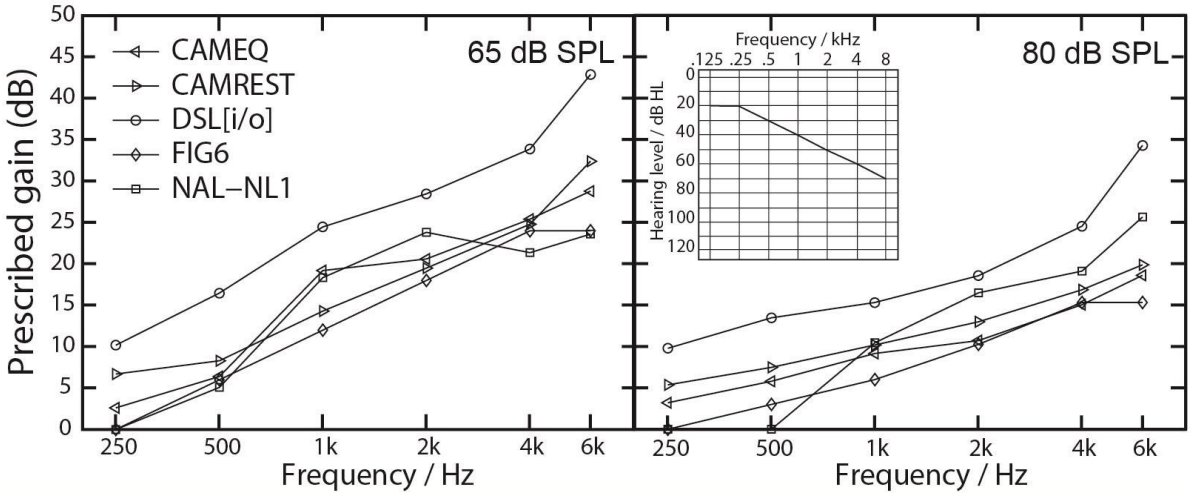
- Inner hair cells: - Information from cochlea
- Outer hair cells: - Information to cochlea
  - Active, nonlinear feedback mechanism
    - sharpens tuning (frequency analysis)
    - enhances low-level signal components
  - Most easily damaged

Loss of audibility



Hoare, lecture 2021

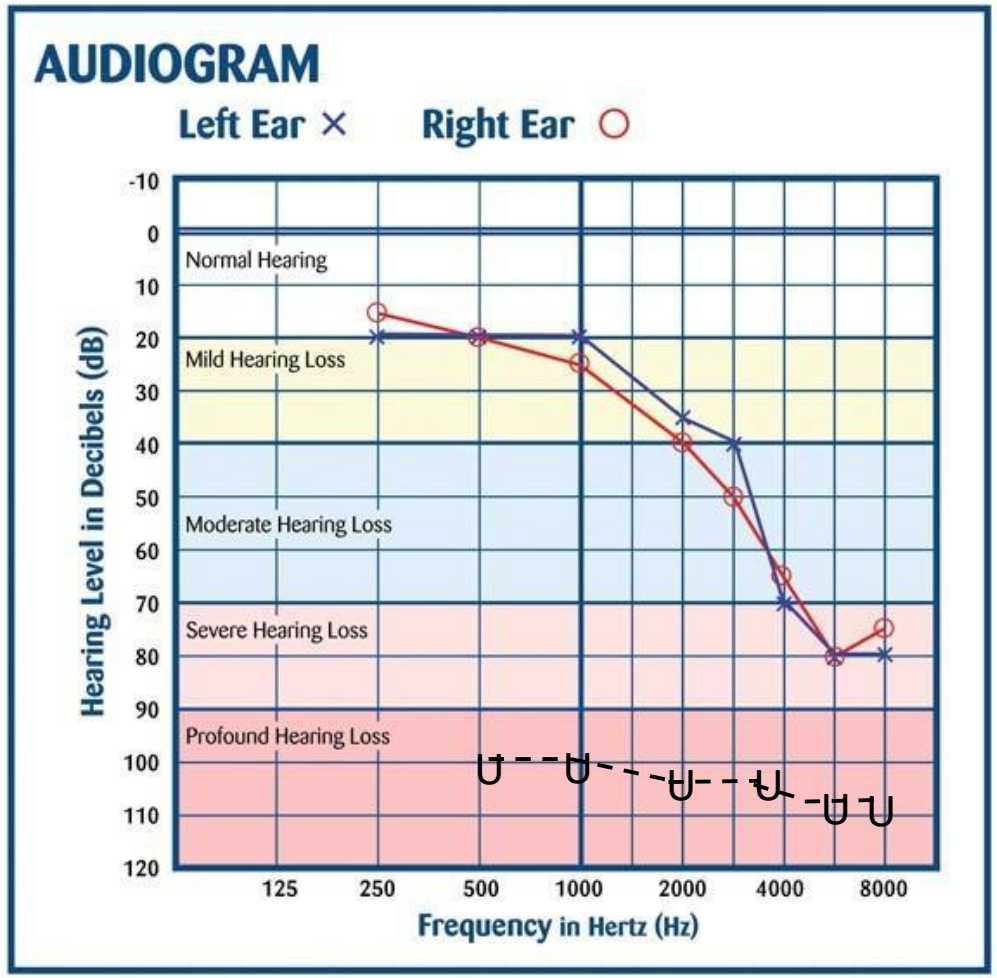
- Loss of audibility, raised thresholds
- Solution: Frequency-specific amplification



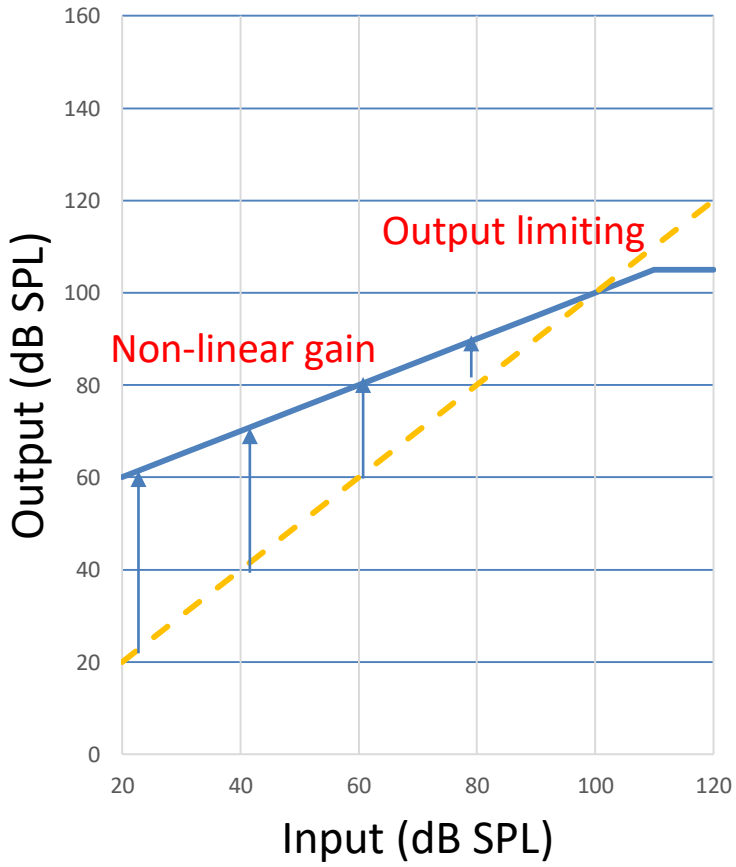
- But full restoration of hearing thresholds seldom the goal…

Loudness perception – Loudness recruitment

Loudness recruitment
Reduced dynamic range of hearing

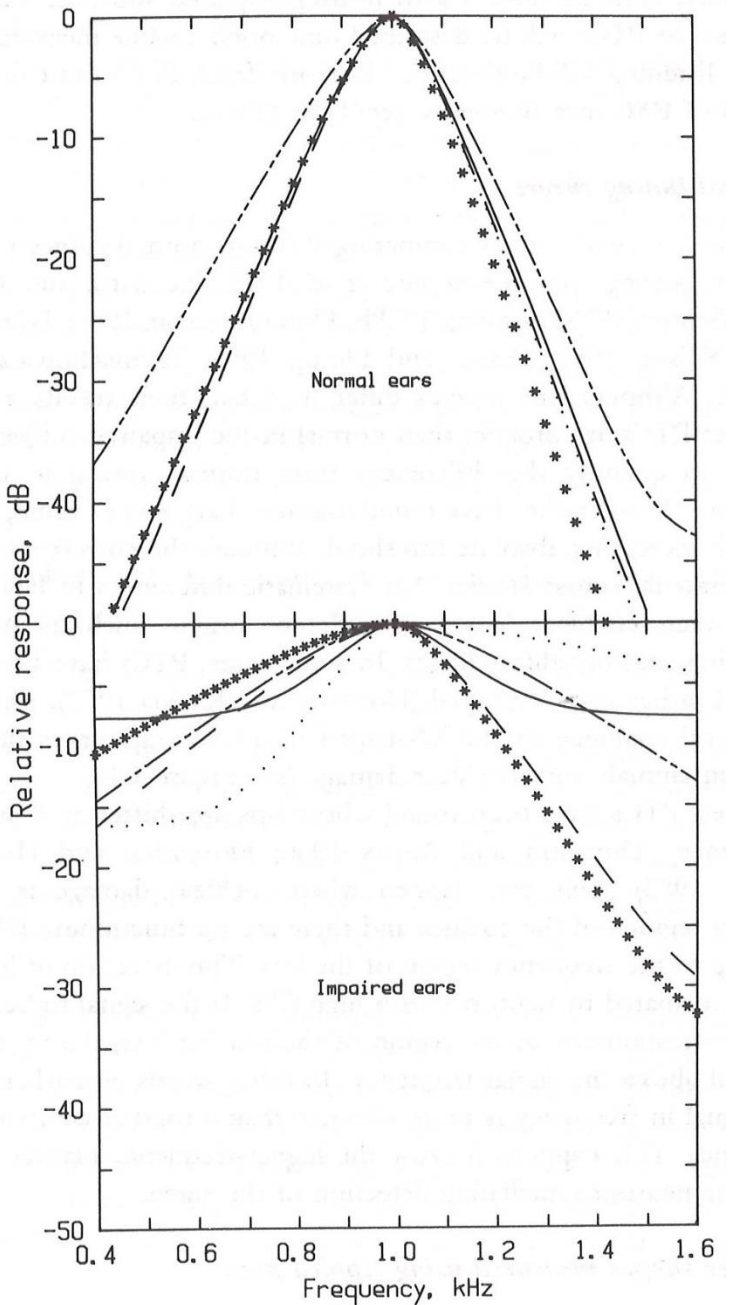


Amplification strategy:
Loudness normalisation



Smeds&Leijon, 2000

Masking



Fletcher 1940s

1. Peripheral hearing system: filter bank of overlapping bandpass filters
2. Detection of a tone in background noise: matching filter used
3. Only noise components that pass through this filter contributes to masking of the tone
4. Broader auditory filters will increase the masking effect

For speech in noise: People with cochlear damage might need the SNR to be up to 20 dB higher than for normal-hearing people!

What can be done in hearing aids?

- Noise reduction
- Directional microphones
  - Work well in the lab
  - In everyday life, users notice little difference
  - More extreme “beamformers” used
    - Stronger directional benefit, but
    - Difficult to get environmental awareness
- External microphone placed close to the talker

Other consequences of cochlear hearing loss

- Intensity resolution
- Time resolution
- Temporal integration
- Frequency/pitch discrimination

- Binaural hearing
  - Sound localization (hearing loss, but also hearing aids)
  - Head shadow effect and best ear
  - Loudness summation
  - Binaural masking release

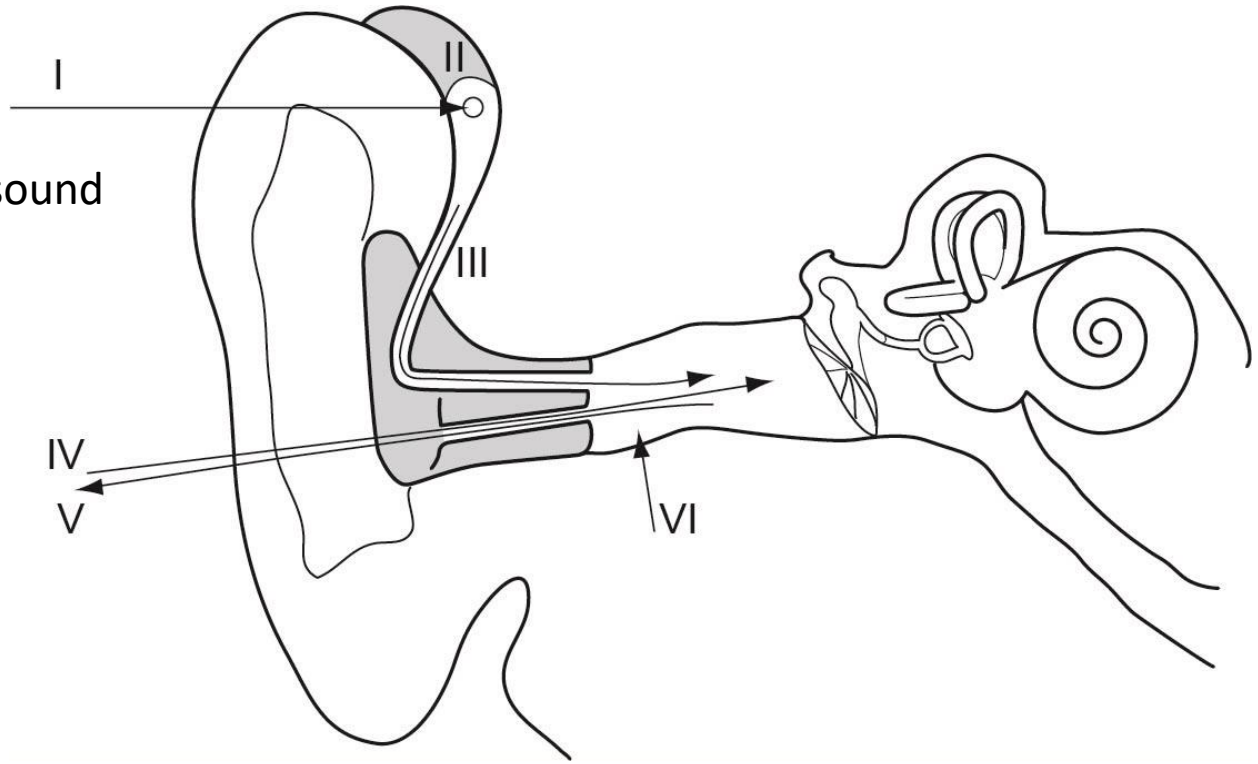
- Read more in paper by Moore (1996) ”Perceptual consequences of cochlear hearing loss”

Other important aspects of hearing aid signal processing

IV. Hearing aid signal processing – Group delay

- Group delay: 3 to 5 ms often noticeable
- Delay longer than 10 ms almost always objectionable
- Particular problem with open fittings, combined amplified sound and direct sound

II. Signal processing



V. Feedback

- Digital feedback reduction in hearing aids

VI. Occlusion

- Ventilation or open fittings reduce occlusion effect
- Lose low-frequency amplified sound
- Risk for acoustic feedback

What about speech communication?

How do we hear in complex environments?

Situation: A fairly large group of people in a conversation in a noisy pub. People know each other. Talkers and topics change quickly.

How do we cope? (Shinn-Cunningham and Best, 2008)

- Enhance source of interest and suppress other sources (while maintaining some environment awareness for rapid refocusing)
- **Formation** of auditory objects and streams, e.g.,
  - Spectrotemporal structure
  - Common onset
  - Timbre
  - Location
  - More effective over time
- **Selection** of auditory objects and streams (selective attention)
  - Need attributes that distinguishes focus object from other objects
- **Switching** of attention
  - If selective attention takes a long time, the situation will be considered challenging
  - The more people participating in a conversation, the more rapid and unpredictable the required switches of attention will be

For people with impaired hearing

- **Formation** of auditory objects and streams (builds over time), e.g.,
  - Spectrotemporal structure
  - Common onset
  - Timbre
  - Location

  - Reduced spectral and temporal acuity
  - Broader than normal frequency selectivity => fewer independent frequency channels
  - Increased masking effect
  - Slower formation

- **Selection** of auditory objects and streams (selective attention)
  - Need attributes that distinguishes focus object from other objects

  - Top-down processing has less to work with
  - Less benefit from differences in spatial location

- **Switching** of attention
  - More effective over time
  - If selective attention takes a long time, the situation will be considered challenging
  - The more people participating in a conversation, the more rapid and unpredictable the required switches of attention will be

Noise reduction

Directional microphones

- Fixed directional characteristics
- Adaptive directional characteristics

- Slow formation of objects and streams
- Miss portions of sound source of interest
- Especially problematic when attention must switch rapidly
- Repair mechanisms drain cognitive resources
- Tiredness

What about speech communication (in noise)?

- Cochlear hearing loss
  - Affects audibility and loudness perception
  - Leads to broader auditory filters → problems with masking and object formation
- Signal processing
  - Want to enhance the targeted speaker, supress other sounds (with good sound quality)
  - Want to be able to be able to switch attention between speakers
  - Want to still ”hear the environment”

Thank you for your attention!

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