WHY DO HEARING AIDS FAIL TO RESTORE NORMAL AUDITORY PERCEPTION?

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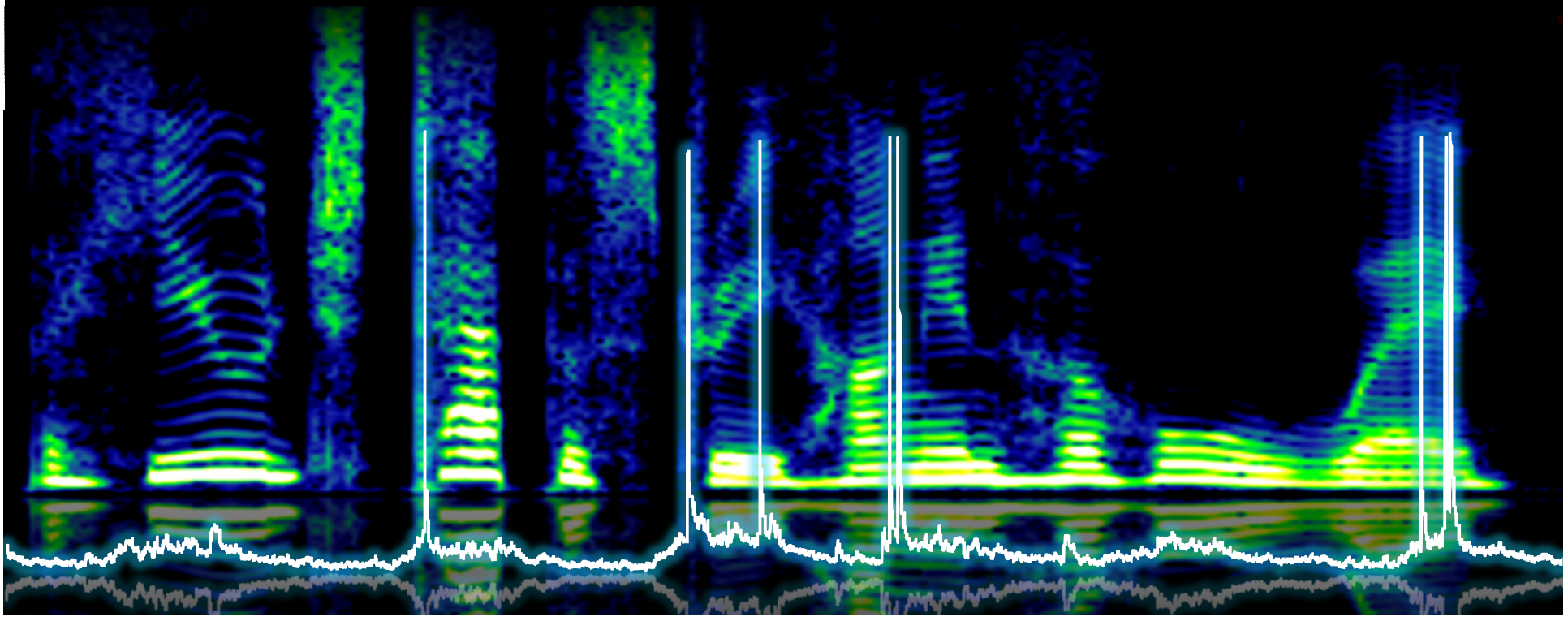

HEARING LOSS

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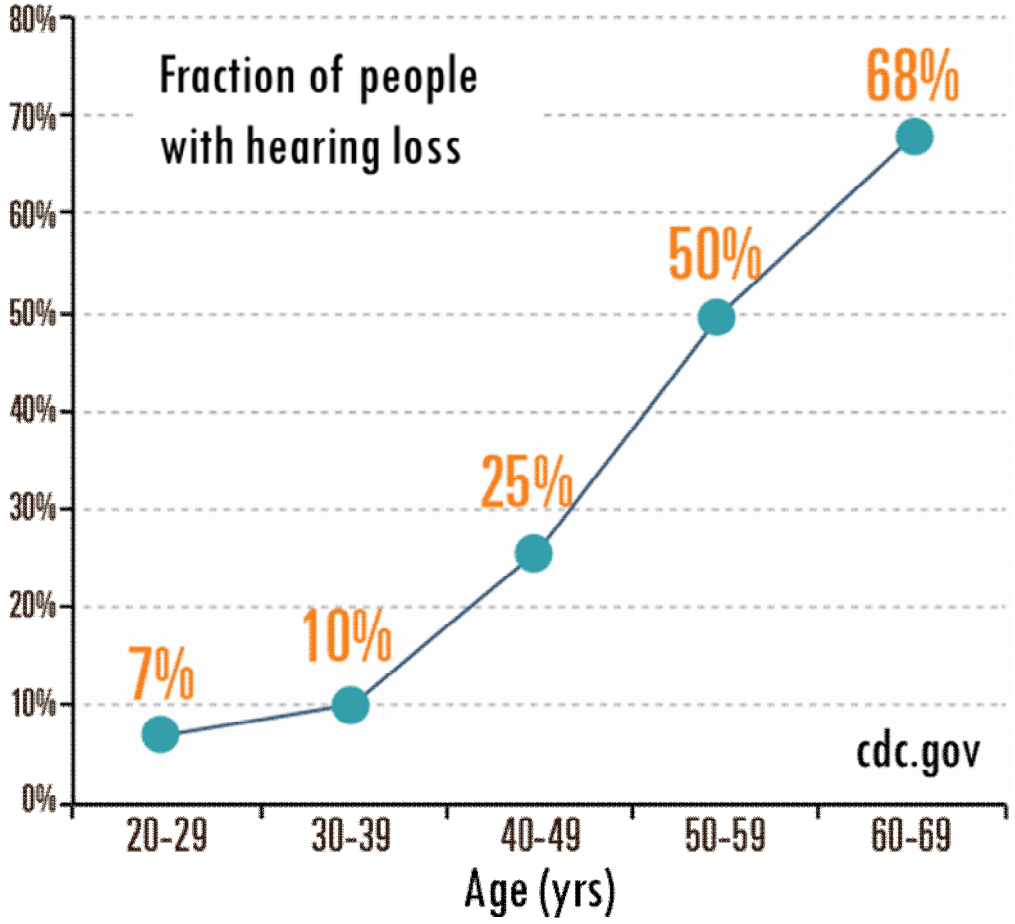
Death, taxes … and hearing loss



HEARING LOSS

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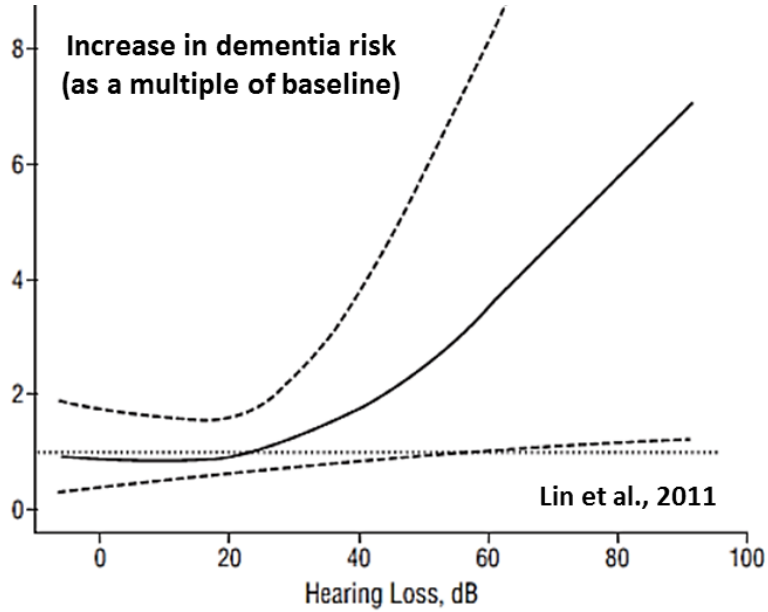
Communication problems, social isolation, and more …

Hearing loss linked to increased:

- Cognitive decline (Lin et al., 2013)
- Dementia (Lin et al., 2011)
- Mortality (Contrera et al., 2015)

Associated costs in the US expected to exceed $50 billion annually by 2030 (Stucky, 2010)



HEARING LOSS

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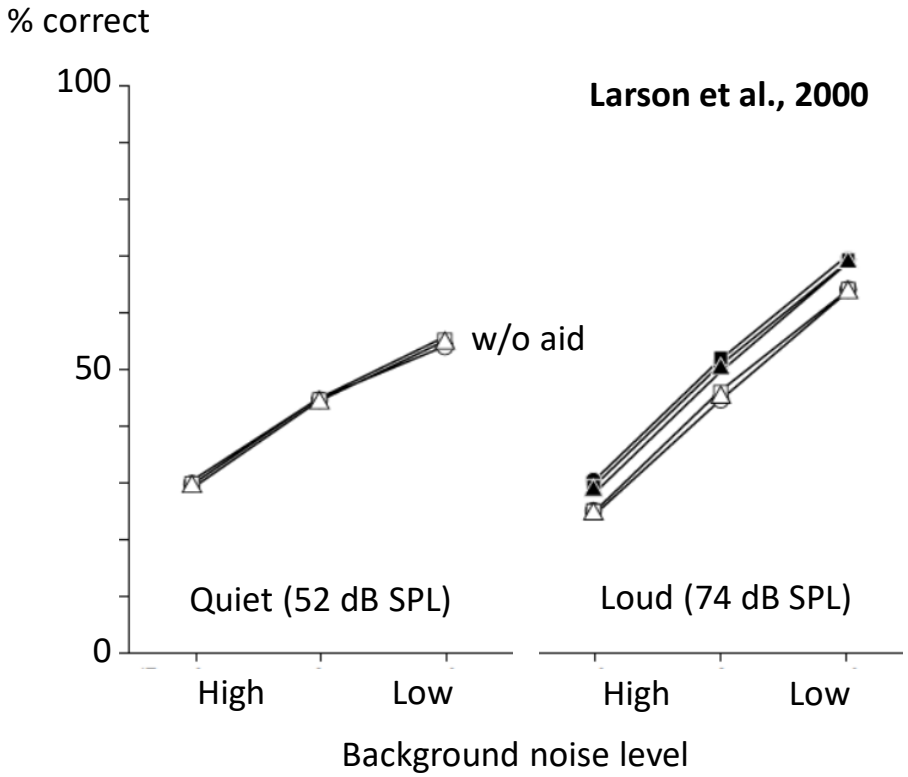
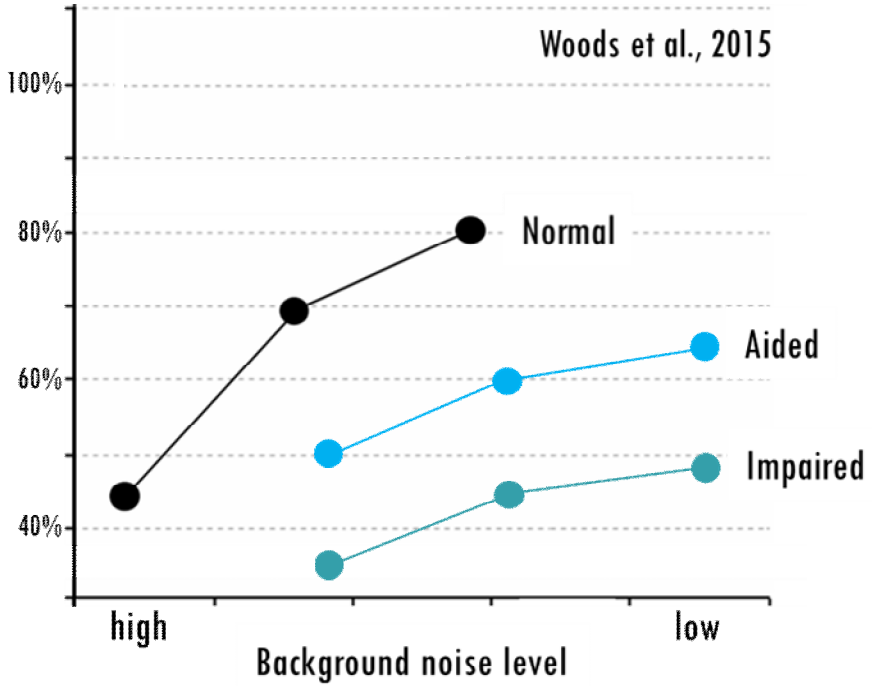
Hearing aids help, but not in noisy environments

Two studies of speech recognition performance





"I can hear you, but I can't understand you"

OVERVIEW

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Part I:

What does the ear do? The simple answer …

What is hearing loss? The simple answer …

What do hearing aids do?

Part II:

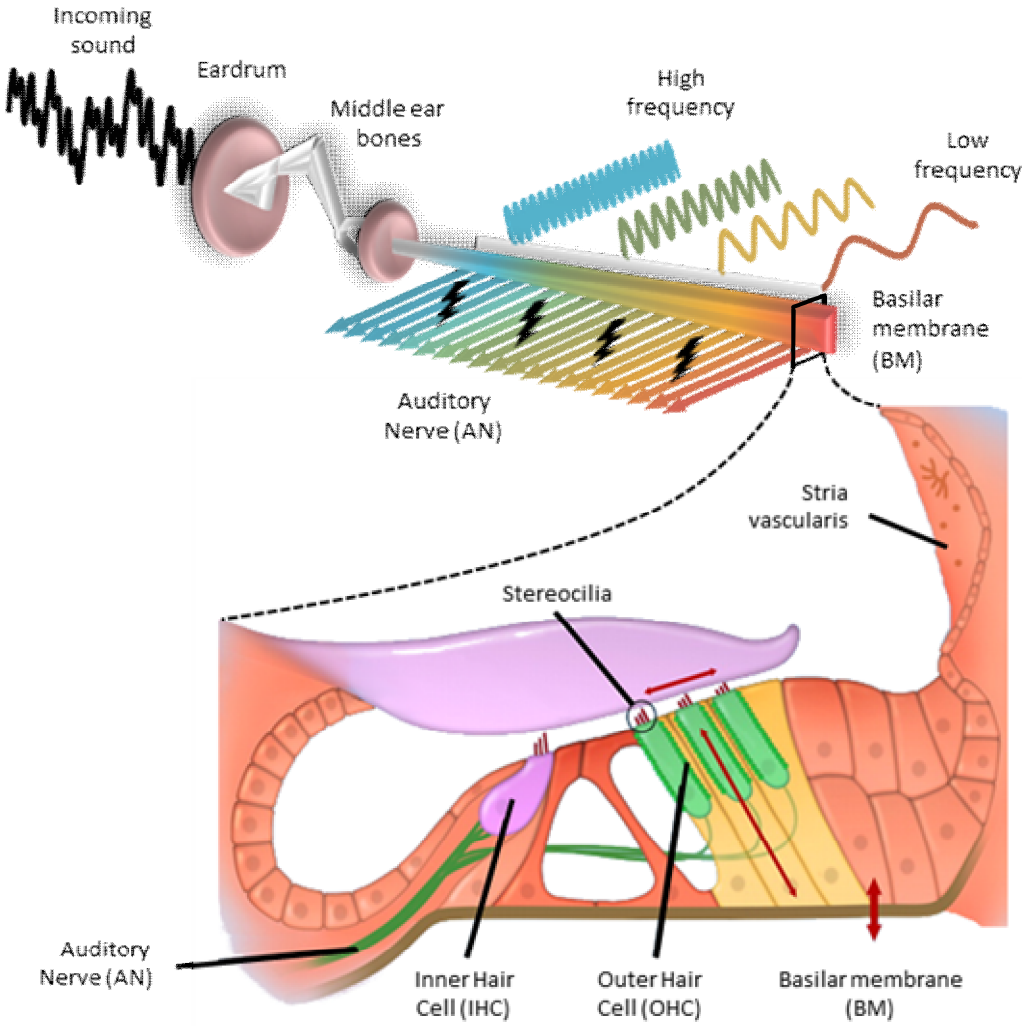
What does the ear do? The real answer …

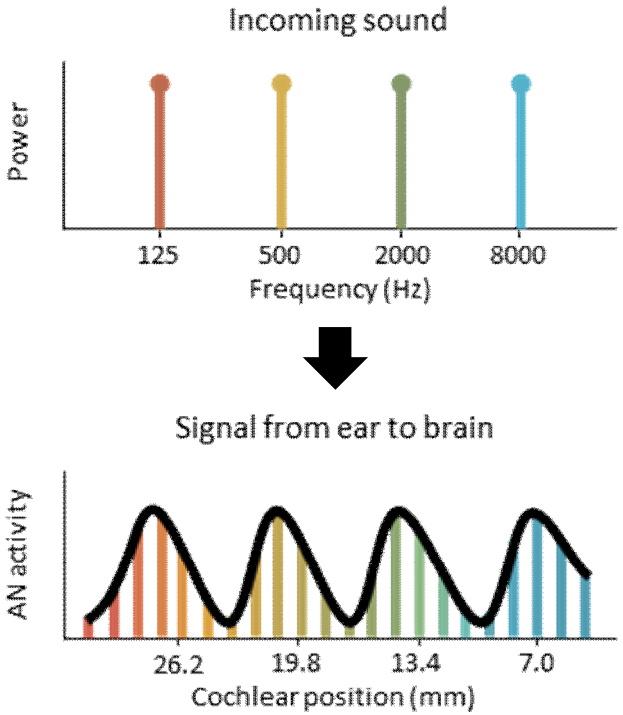
What is hearing loss? The real answer …

What should hearing aids do?

WHAT DOES THE EAR DO?

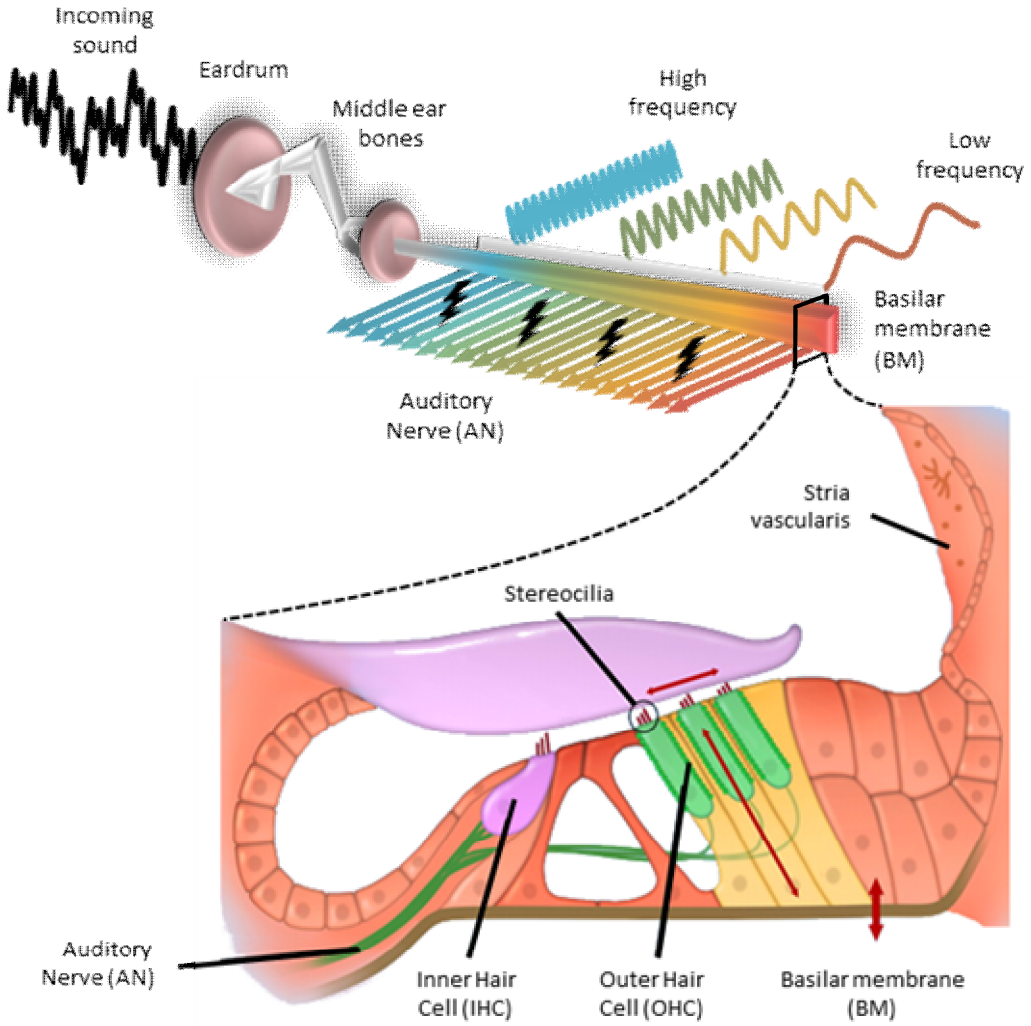
The simple answer: frequency analysis and amplification/compression



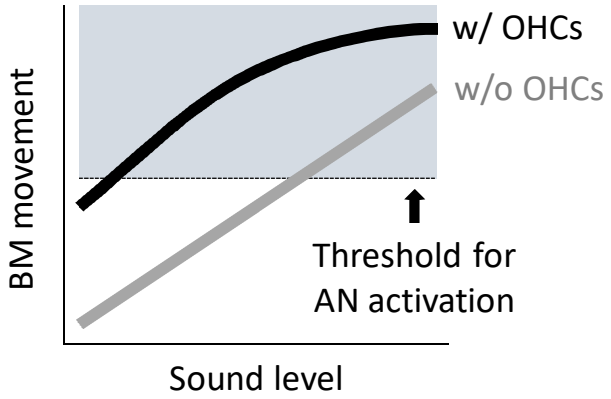


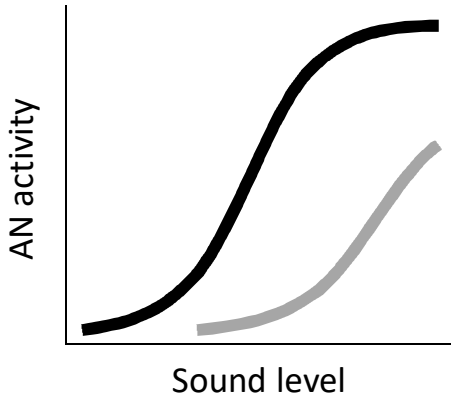
WHAT DOES THE EAR DO?

The simple answer: frequency analysis and amplification/compression



Outer hair cells (OHCs) amplify weak sounds





WHAT IS HEARING LOSS?

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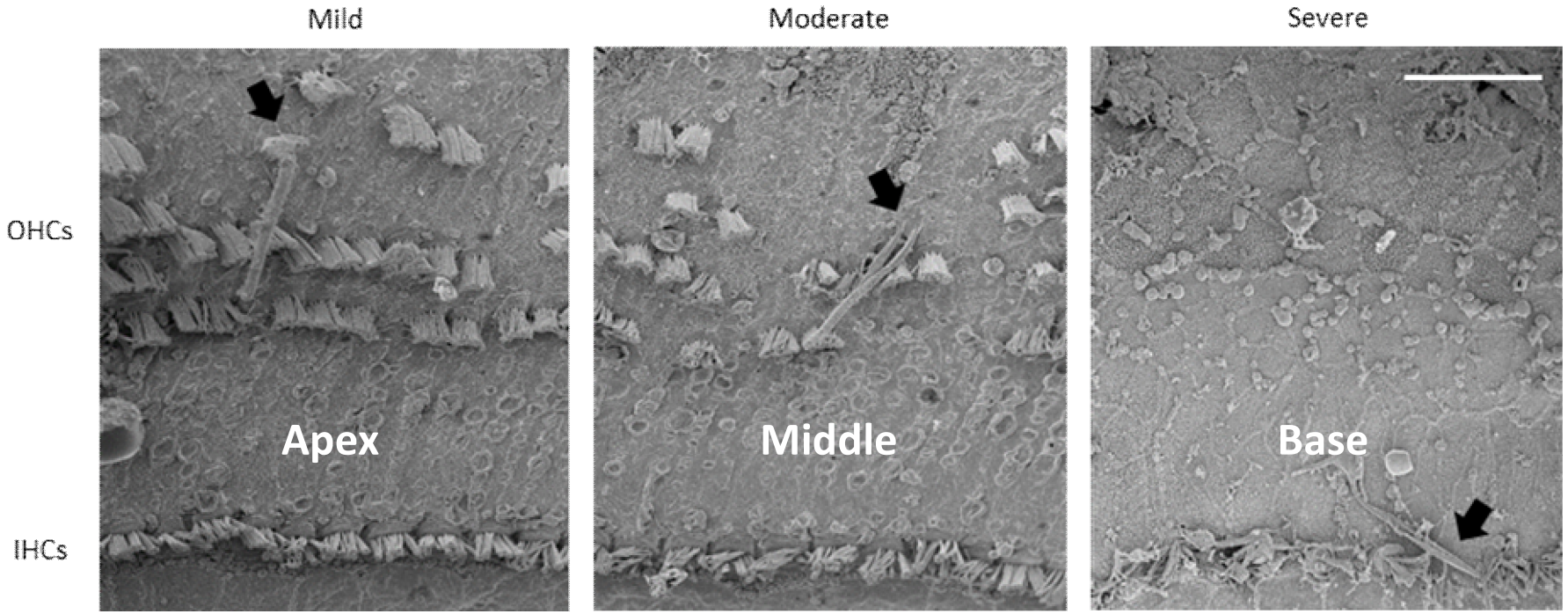
The simple answer: a decrease in sensitivity

Hair cell pathologies in older people



From UCL Ear Institute

- OHCs more vulnerable than IHCs
- Base (high freq.) more vulnerable than apex (low freq.)

WHAT IS HEARING LOSS?

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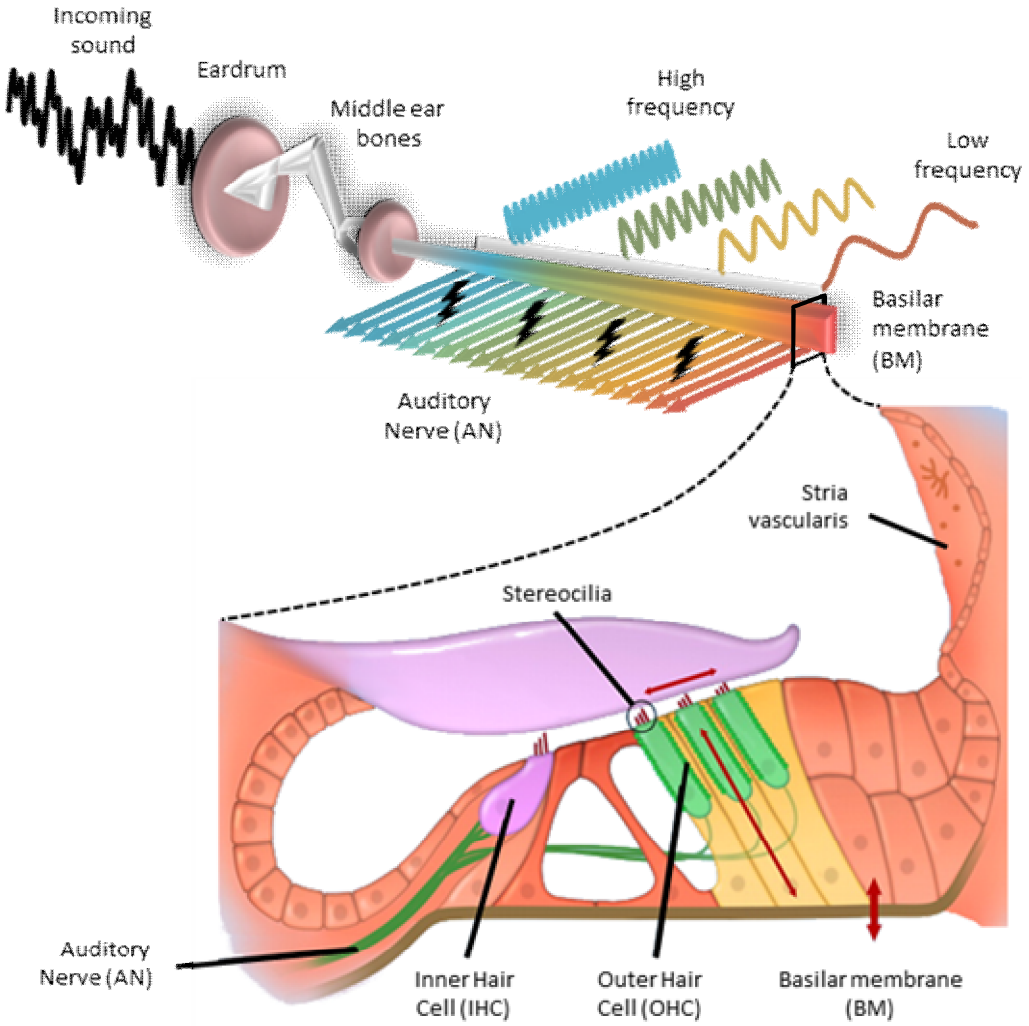
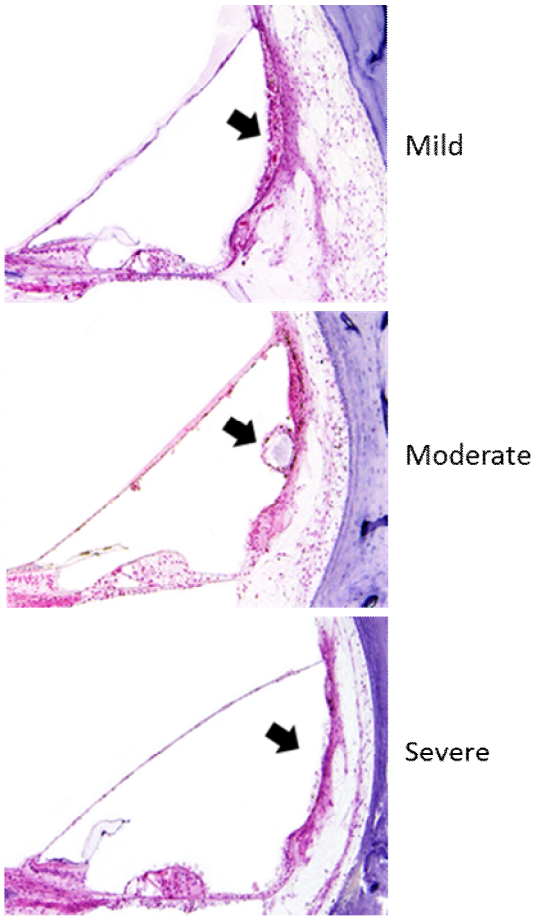
The simple answer: a decrease in sensitivity



Strial degeneration in older people



From Mass Eye and Ear

WHAT IS HEARING LOSS?

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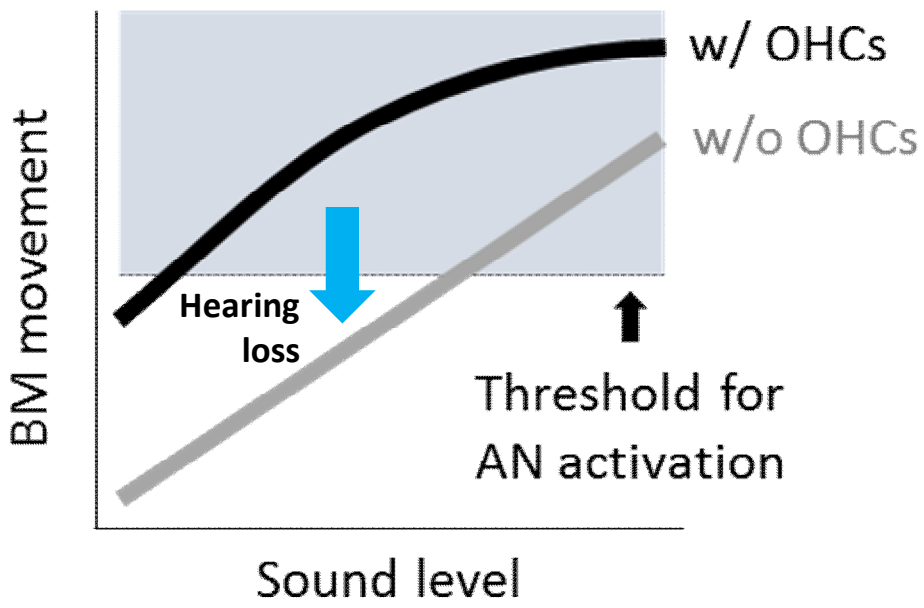
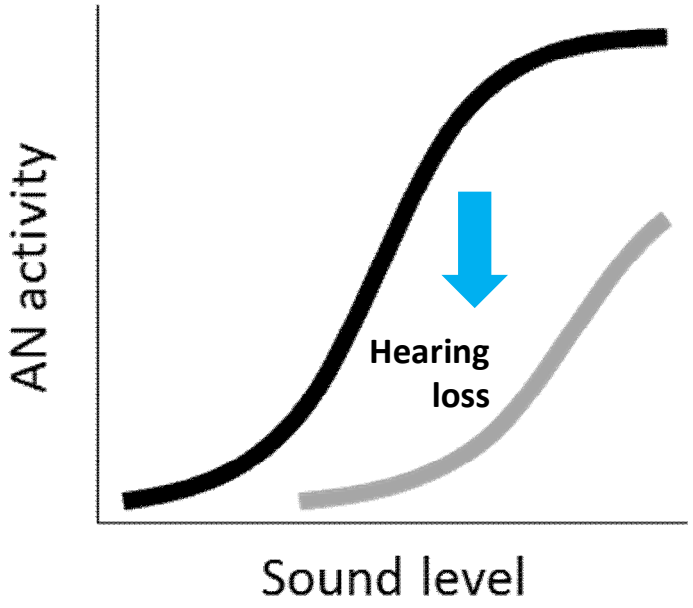
The simple answer: a decrease in sensitivity



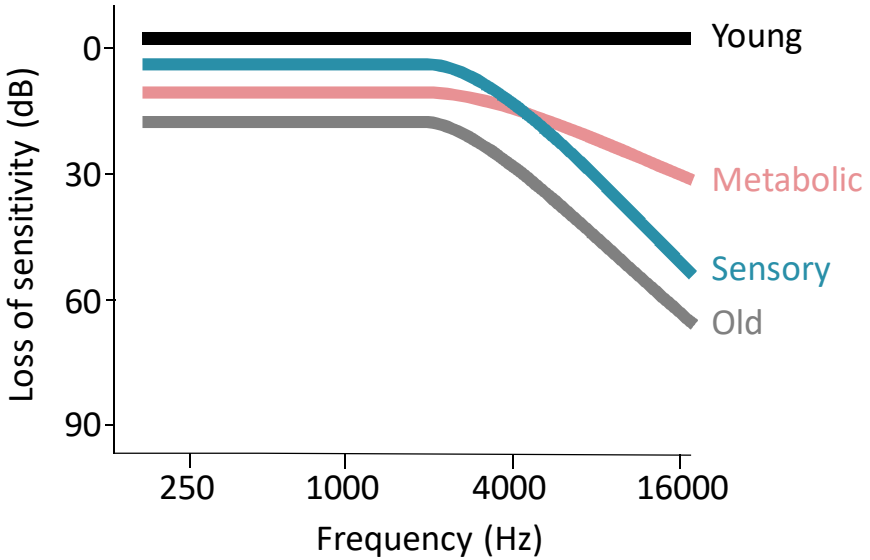


WHAT IS HEARING LOSS?

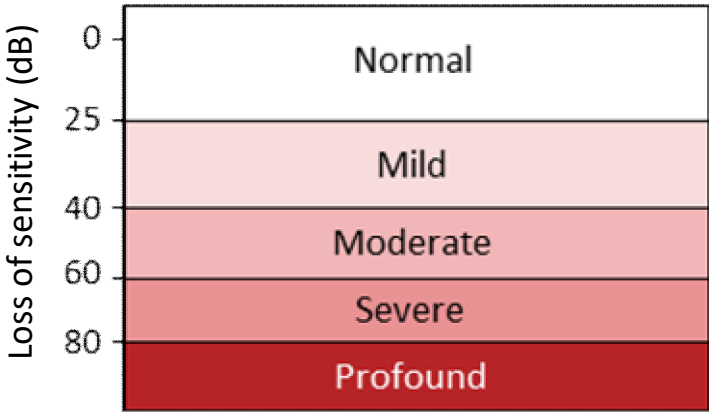
UCL

The simple answer: a decrease in sensitivity

Frequency dependence of sensitivity loss

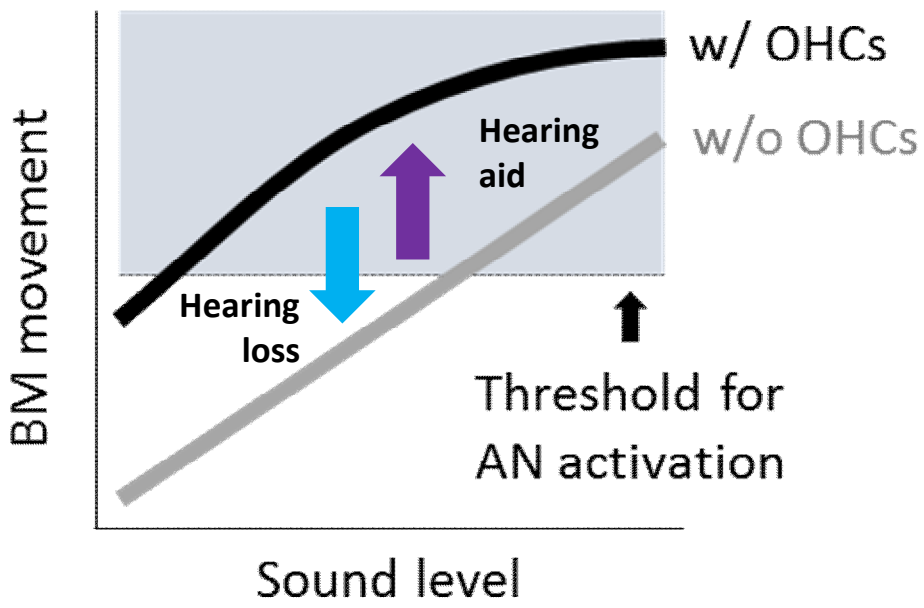


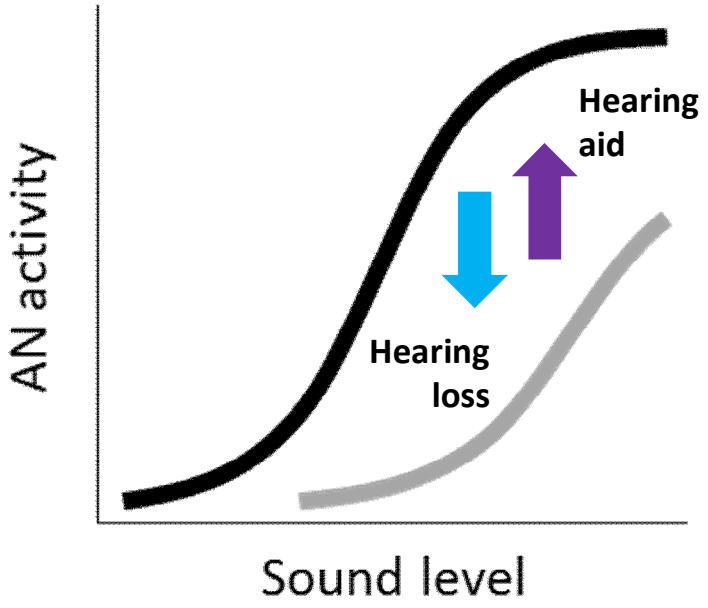
WHO hearing loss grades



WHAT DO HEARING AIDS DO?

The answer: restore sensitivity … but not much else

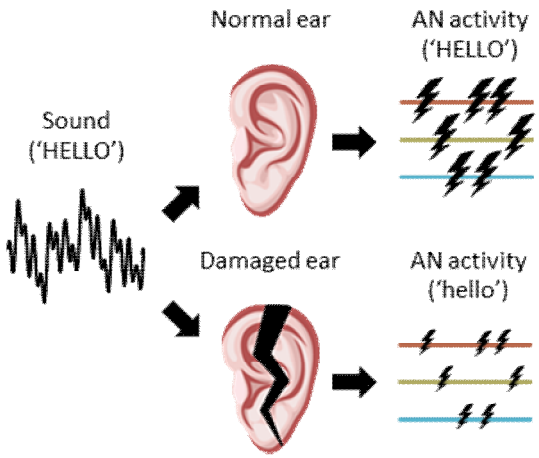


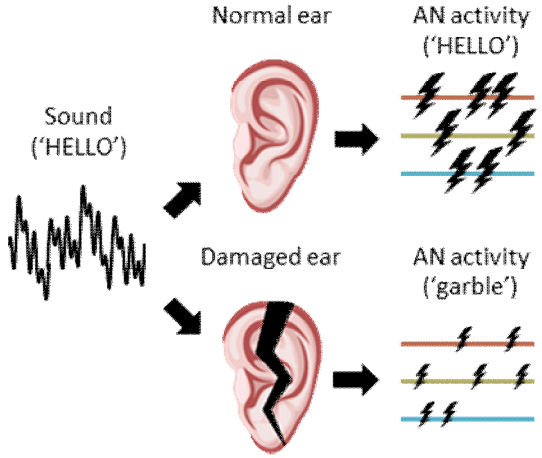


- Most modern hearing aids implement frequency-dependent ‘wide dynamic range compression’
- Other bells and whistles – speech enhancement, frequency lowering, directional microphones – provide little real-world benefit

WHY DO HEARING AIDS FAIL?

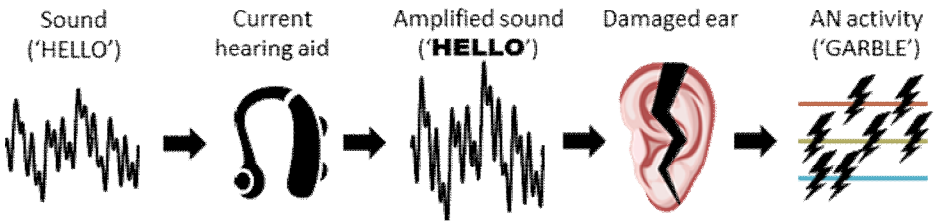
Hearing loss is much more than just a sensitivity problem





… it is a profound distortion of the signal from ear to brain

… that hearing aids fail to correct



WHAT DOES THE EAR DO?

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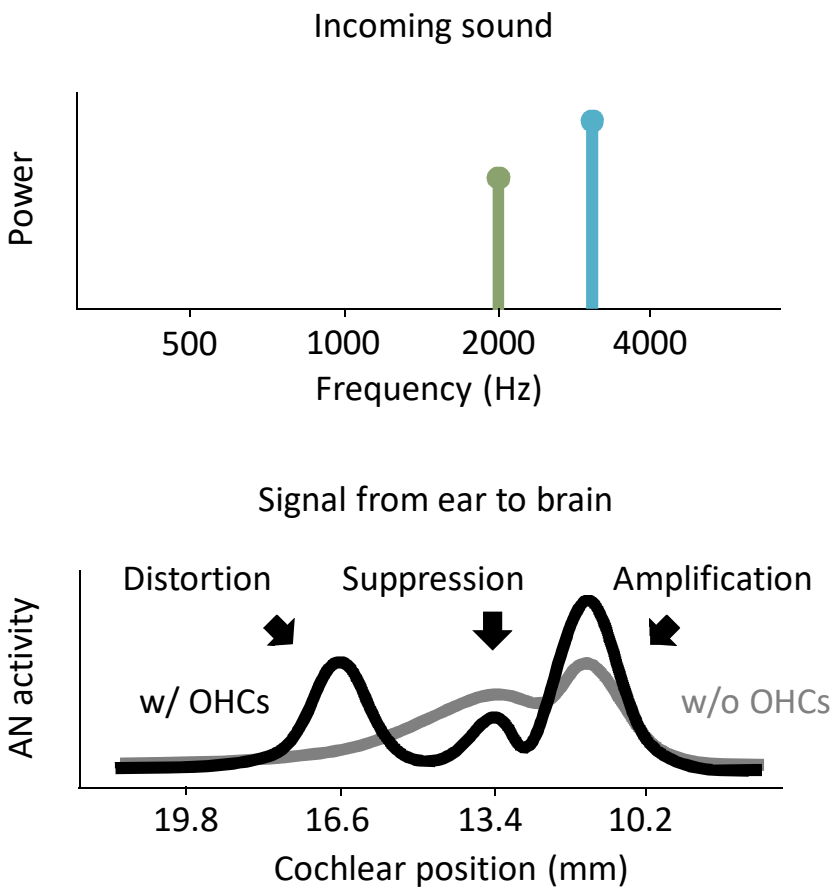
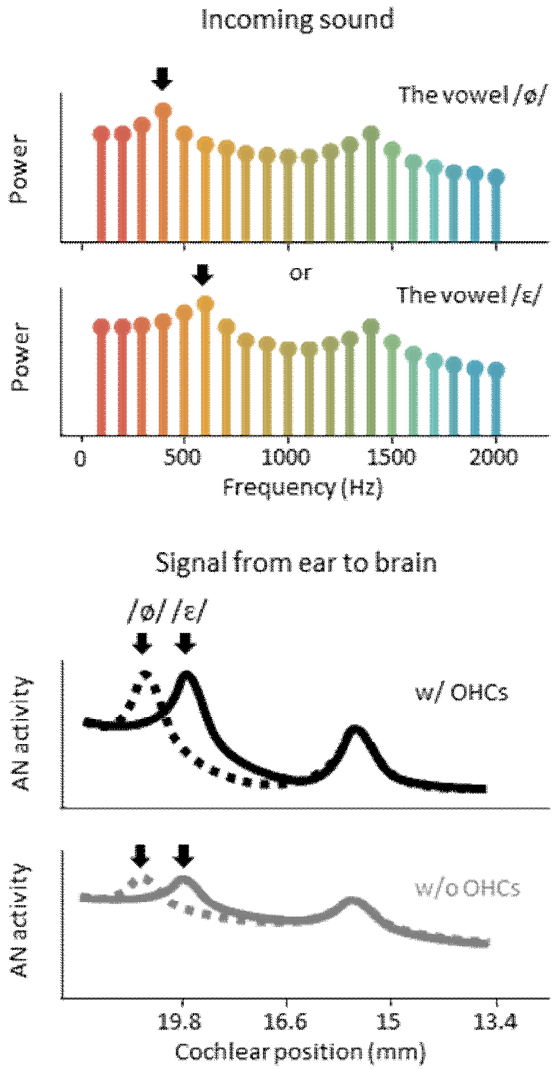
The real answer: complex, nonlinear signal processing

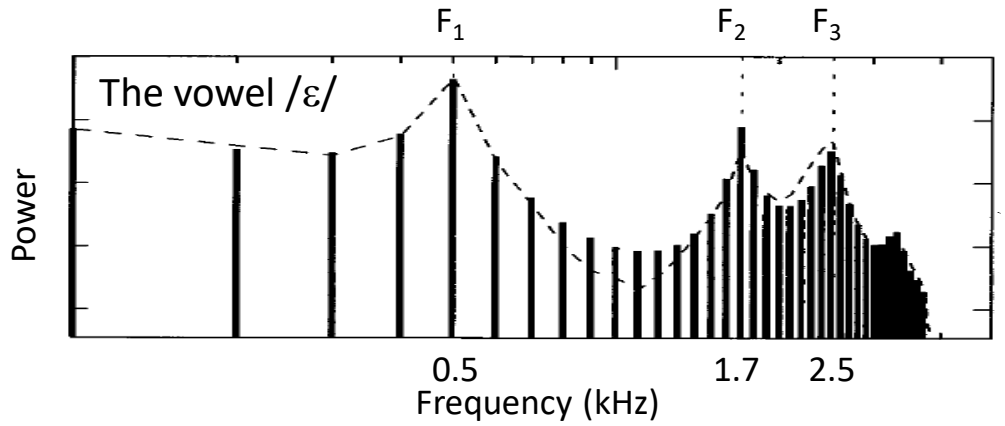




WHAT IS HEARING LOSS?

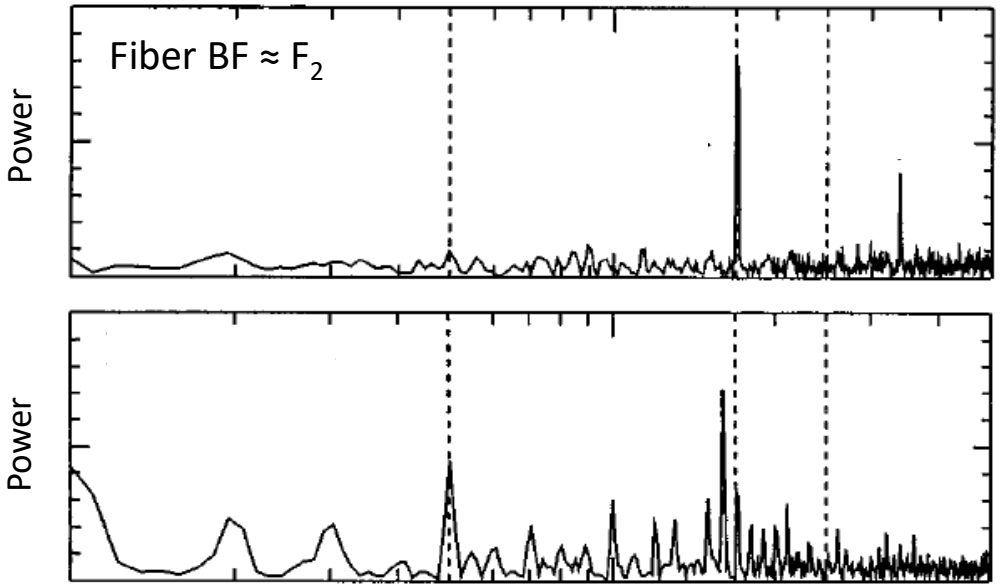
The real answer: a profound distortion of the signal from ear to brain

Power spectrum of incoming sound



From Young, 2012

Power spectrum of AN activity



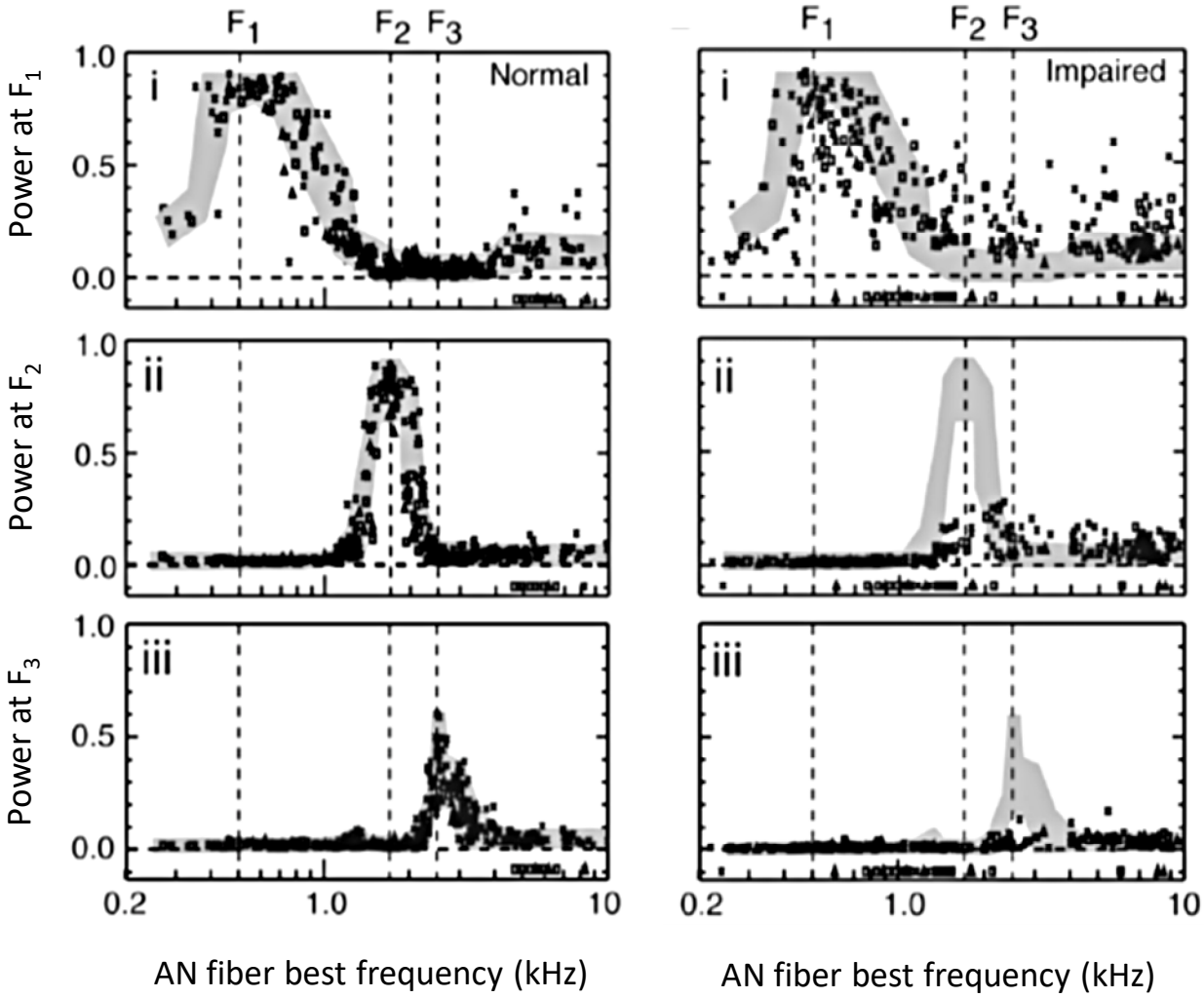
Normal ear

Impaired ear

WHAT IS HEARING LOSS?

The real answer: a profound distortion of the signal from ear to brain

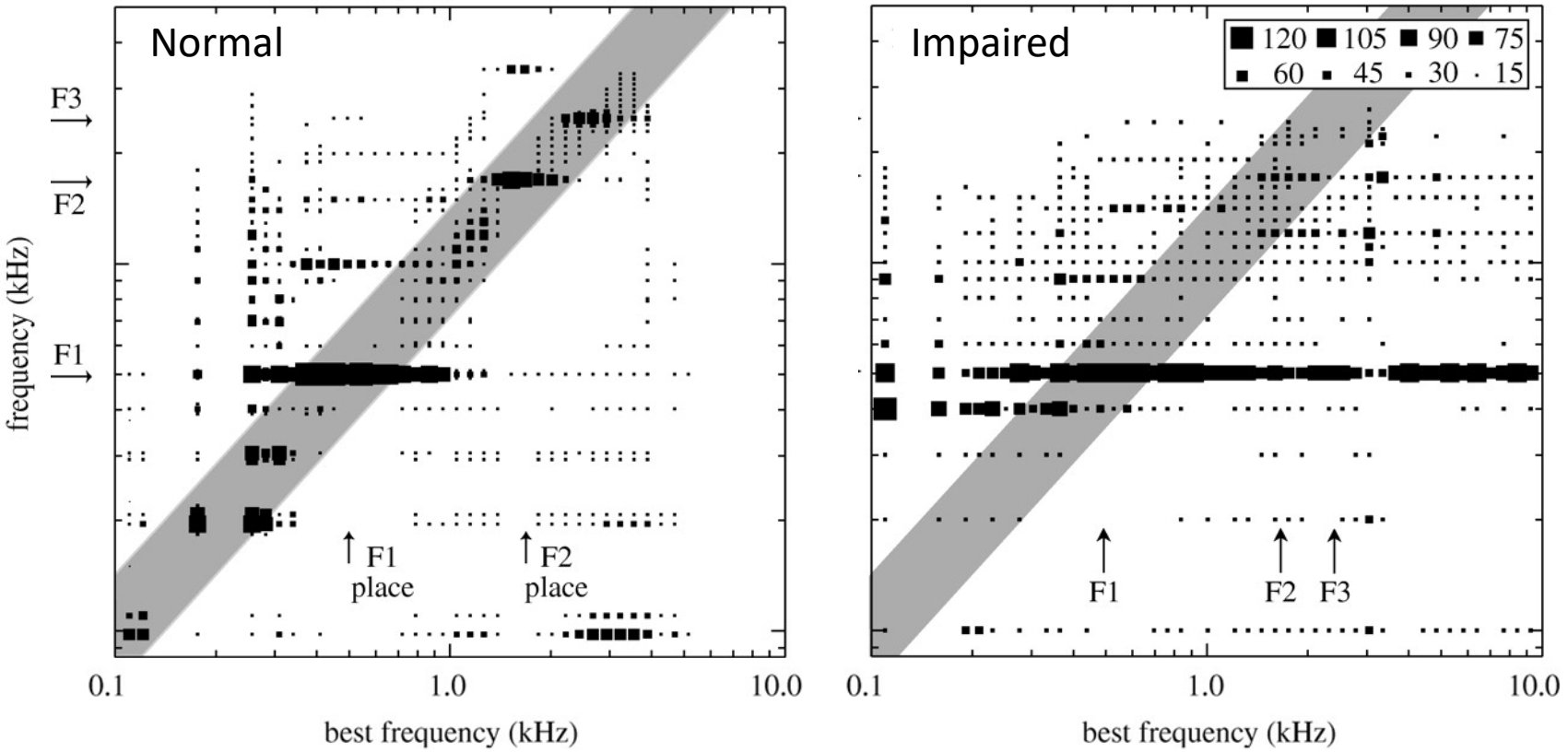
Power across AN population



WHAT IS HEARING LOSS?

The real answer: a profound distortion of the signal from ear to brain

Population representation of /ε/



HIDDEN HEARING LOSS

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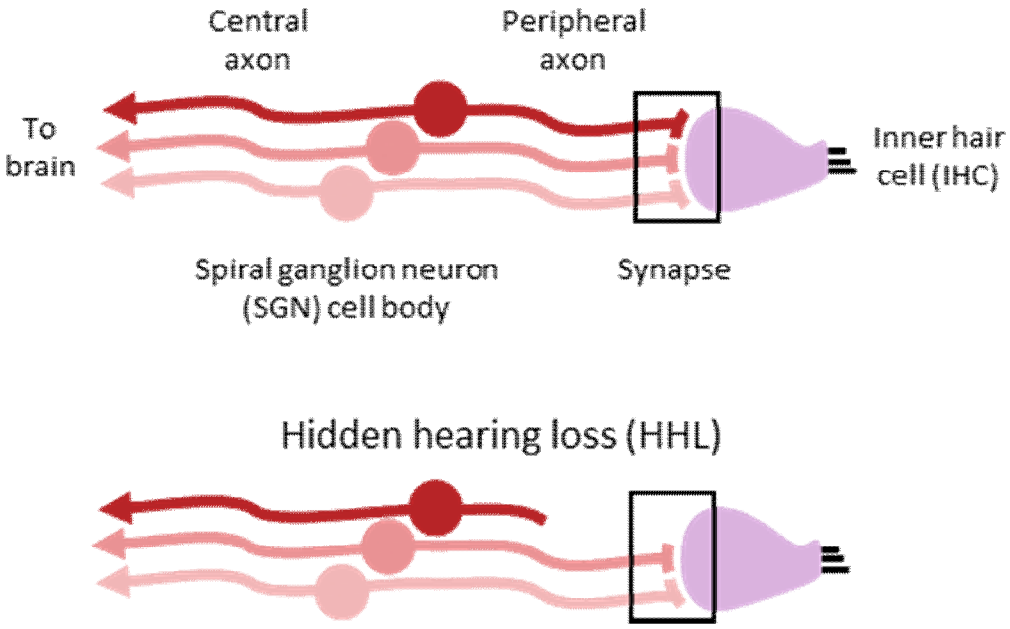
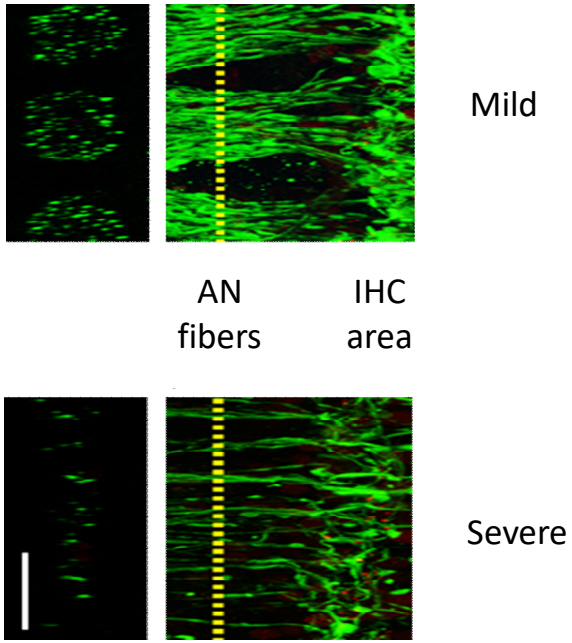
Hearing loss also arises from changes to the changes to the AN itself

Cochlear synaptopathy



Synaptopathy in older people



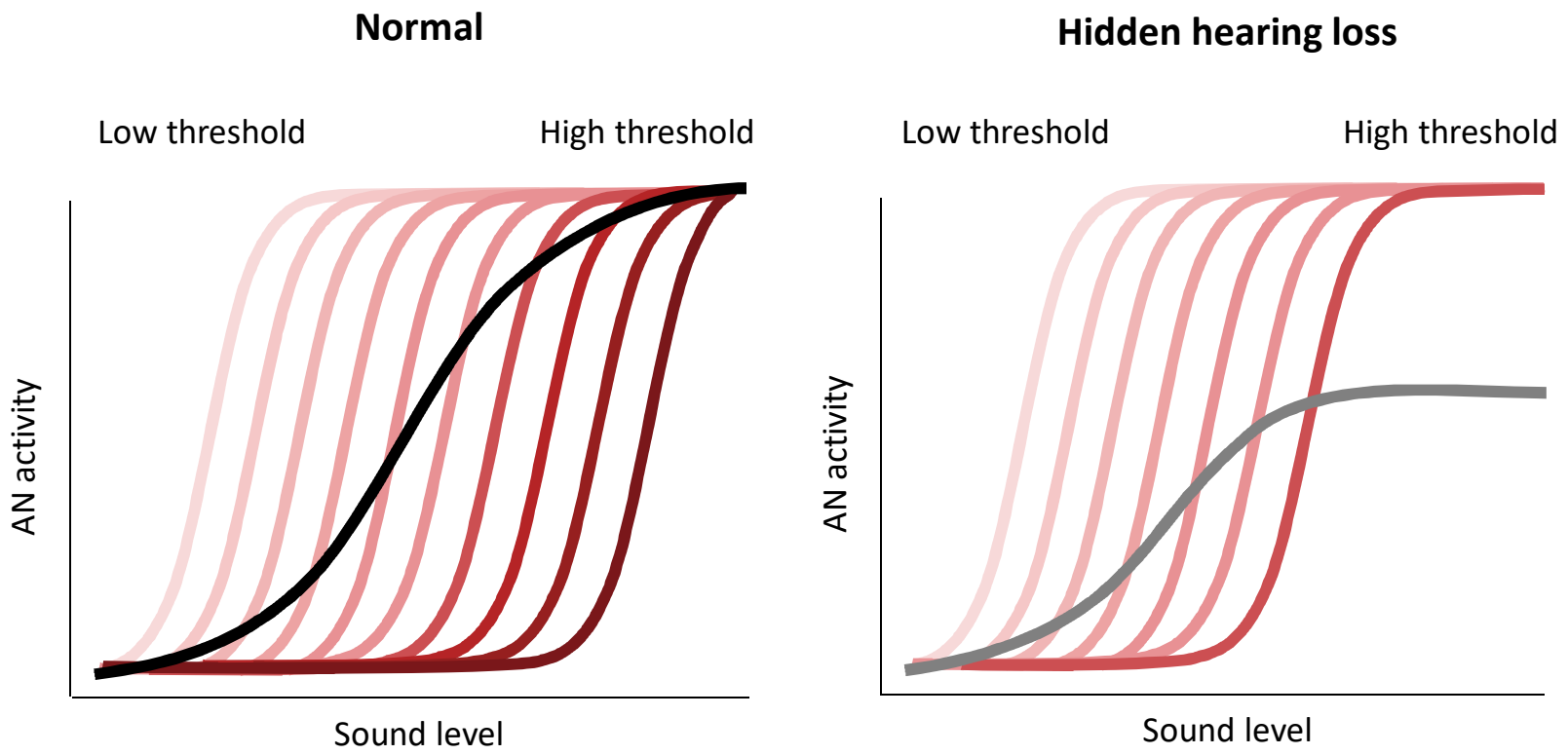
From Viana et al., 2015

Problem: high-threshold AN fibers are particularly vulnerable

HIDDEN HEARING LOSS

UCL

Hearing loss also arises from changes to the changes to the AN itself

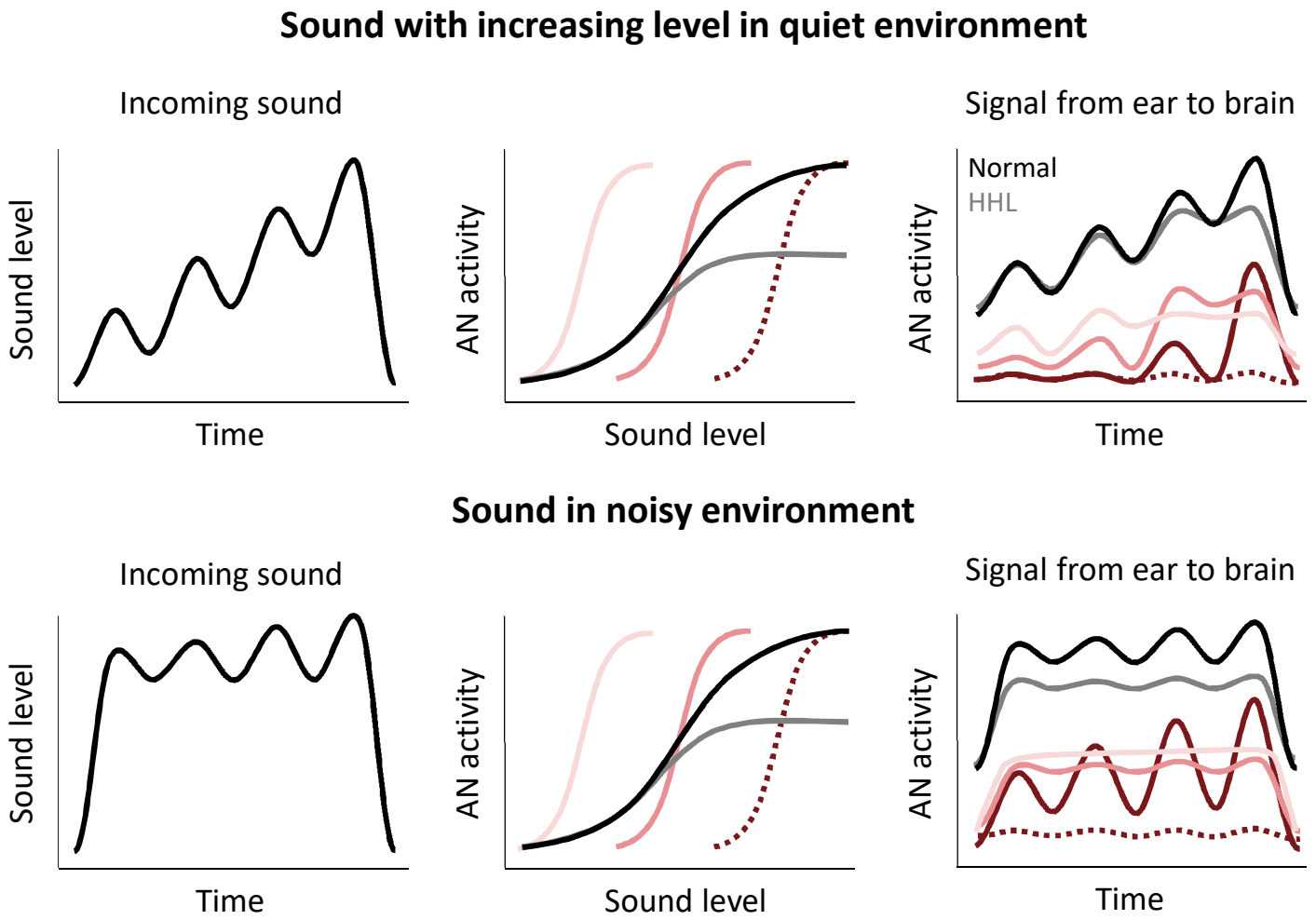


Hidden hearing loss decreases differential sensitivity at high levels

HIDDEN HEARING LOSS

UCL

Hearing loss also arises from changes to the changes to the AN itself



BRAIN PLASTICITY

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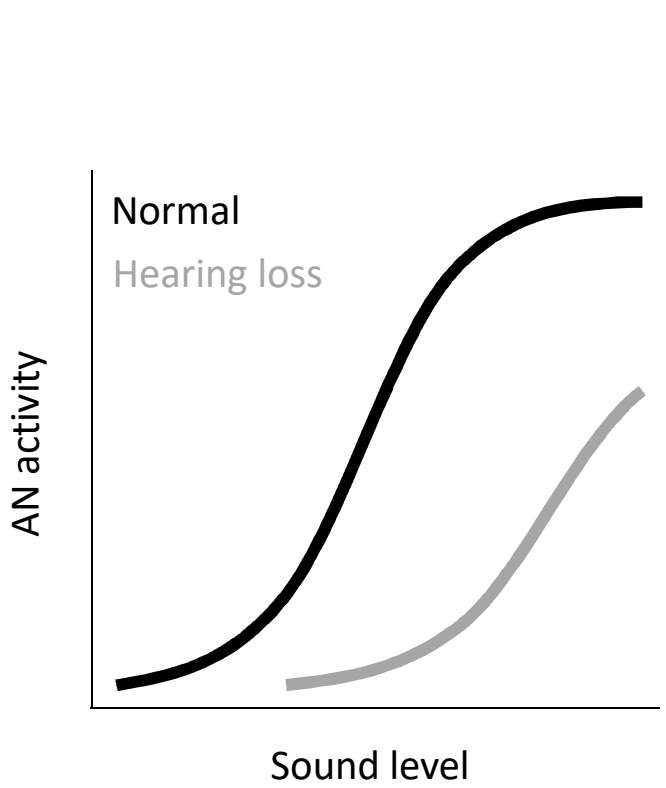
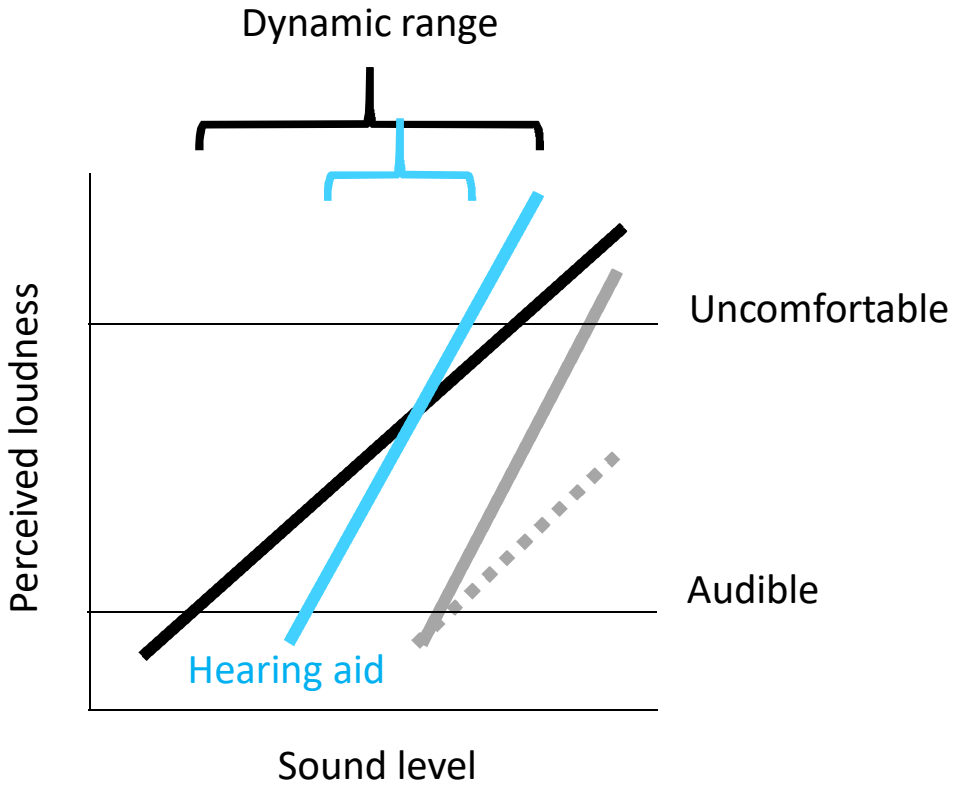
Homeostatic response to hearing loss causes “loudness recruitment”





Central changes result in rapid growth of loudness with level …
leaving little dynamic range for hearing aids

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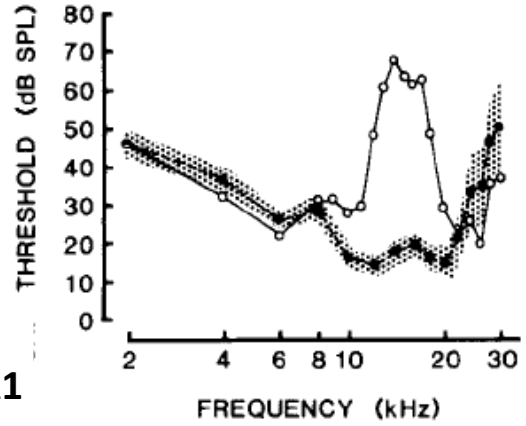
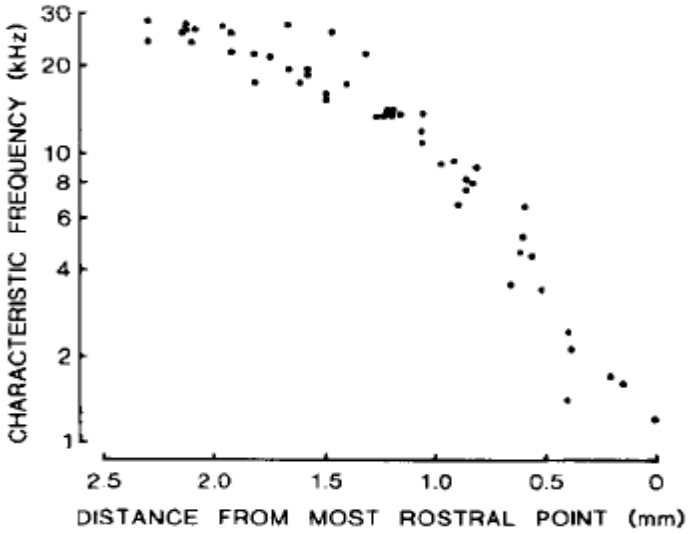
Hearing loss causes cortical map reorganization

Thresholds before and after noise trauma

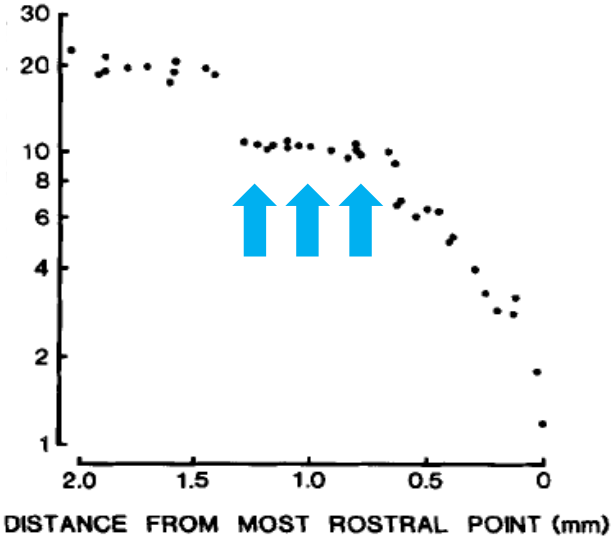


Tonotopic map in normal A1



From Robertson and Irvine, 1989

Tonotopic map after trauma



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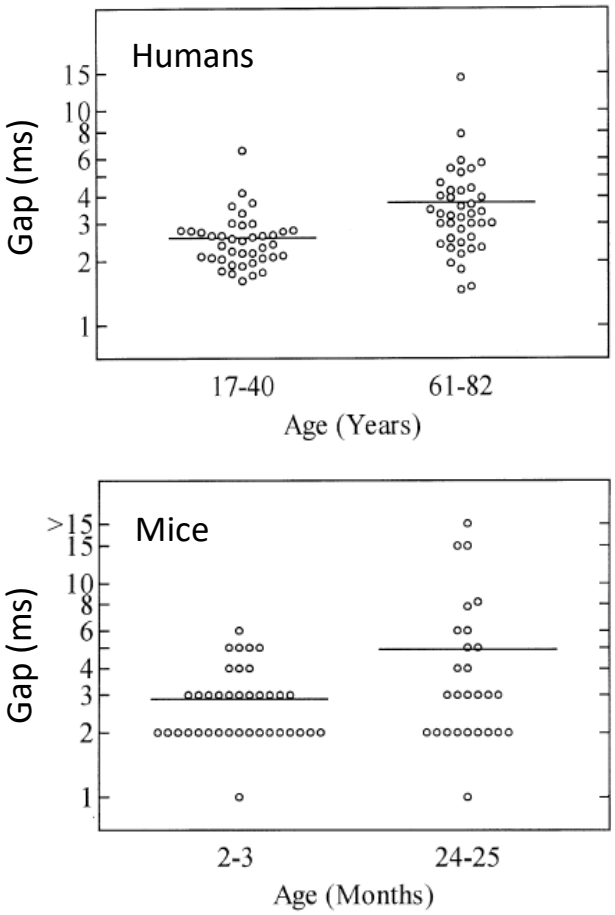
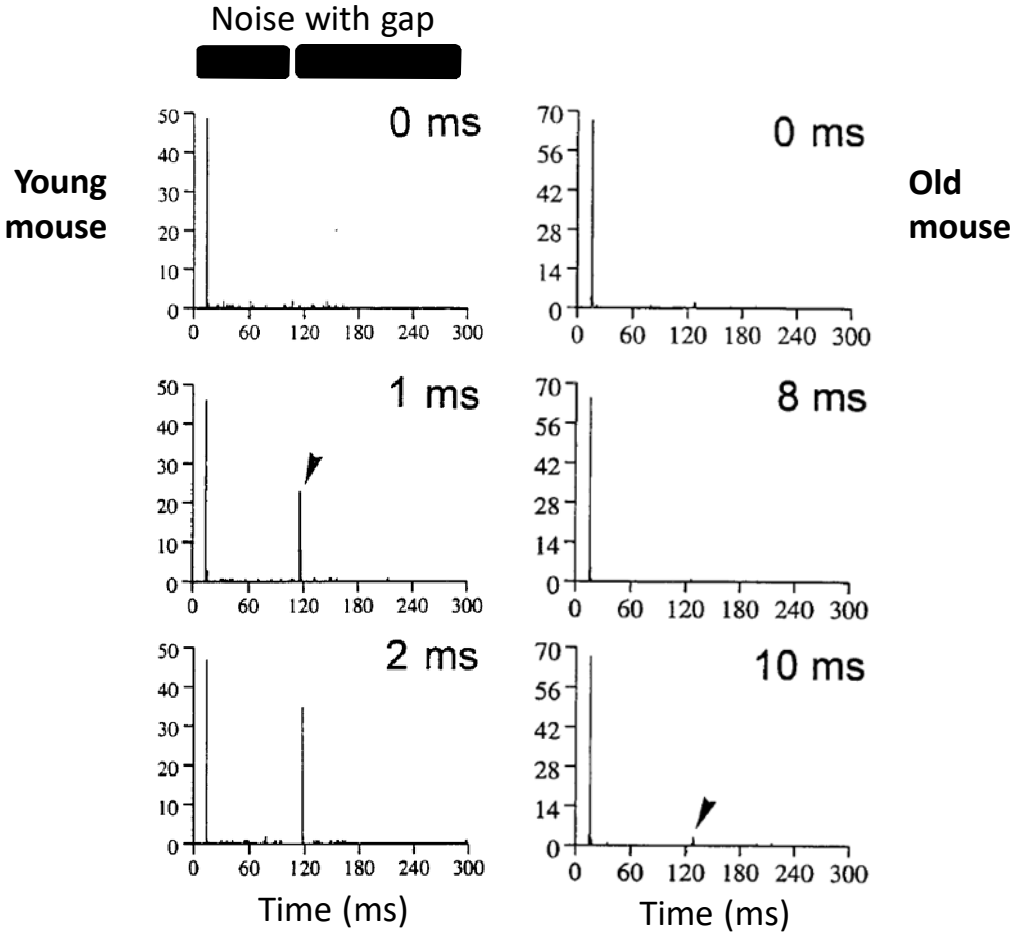
Age-related hearing loss causes a decrease in temporal acuity

Minimum detectable gap



From Barsz et al., 2002

Neural activity in inferior colliculus



From Walton et al., 1998

CHANGES IN E-I BALANCE

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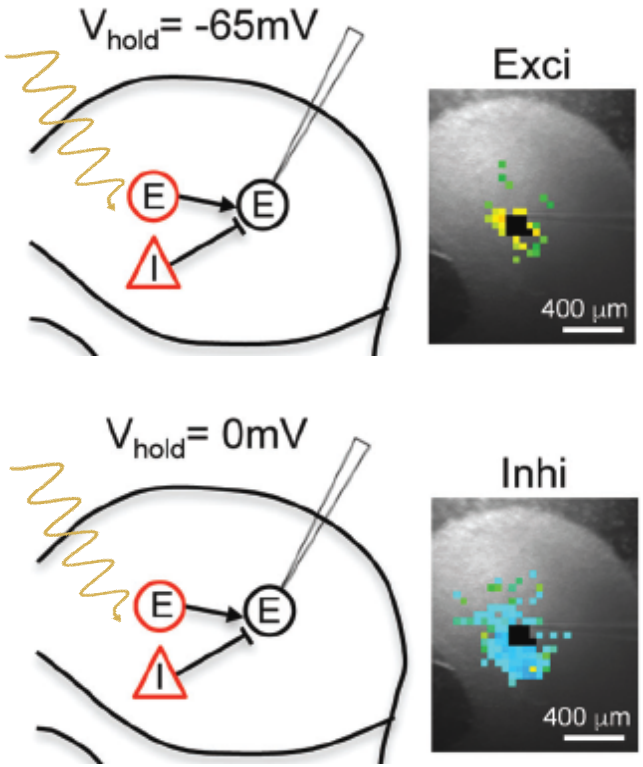
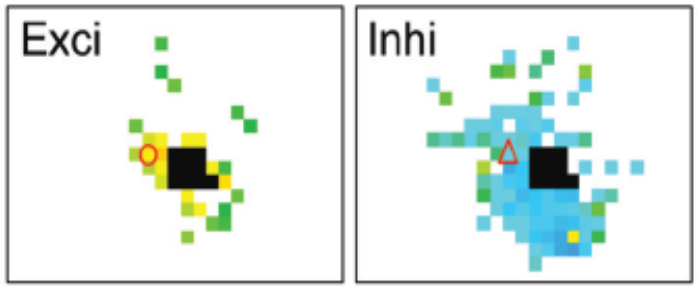
Hearing loss causes a decrease in inhibition

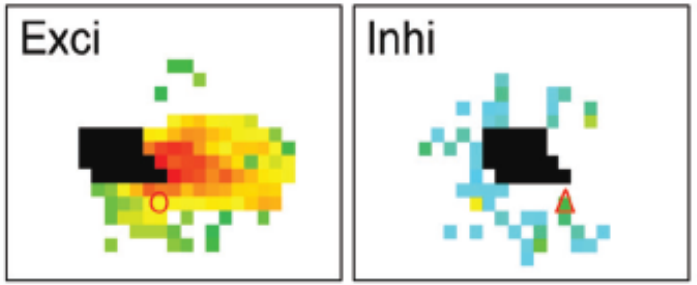
Mapping synaptic inputs



Normal



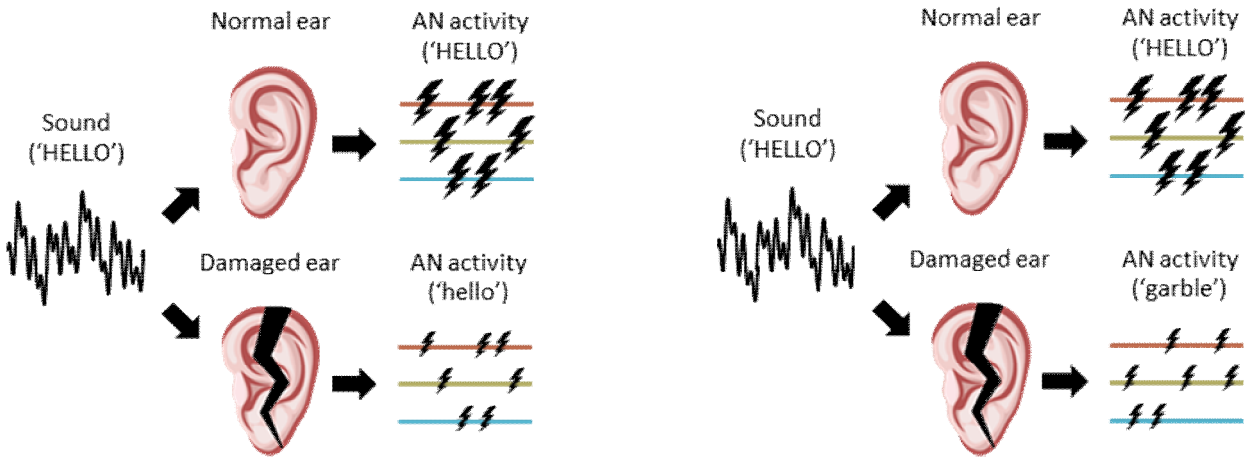
Hearing impaired w/ gap detection deficit



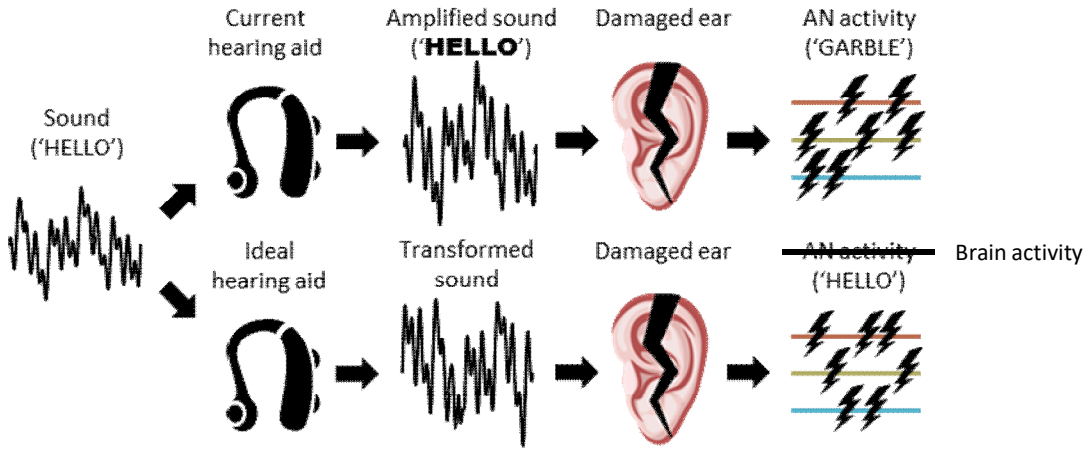
From Strum et al., 2017

WHAT SHOULD DO HEARING AIDS DO?

Hearing loss is a profound distortion of the signal from ear to brain



… that hearing aids should aim to correct



WHAT SHOULD DO HEARING AIDS DO?

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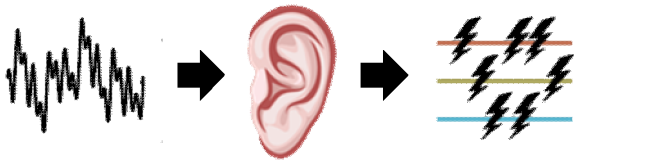
How can the necessary transformation be identified?

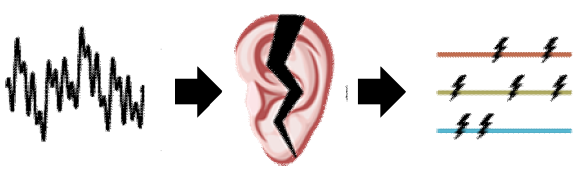
Record normal speech driven activity

$s \quad f \quad r = f(s)$



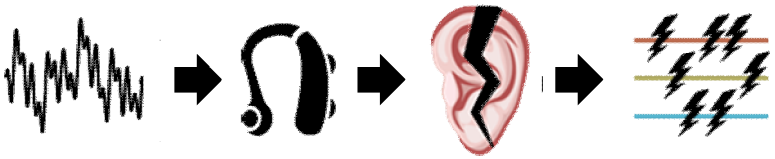
Record speech driven activity in impaired system

$s \quad f_{imp} \quad r_{imp} = f_{imp}(s)$



Infer optimal transformation

$s \quad g \quad f_{imp} \quad r_{aid} = f_{imp}(g(s))$



➡ find g that minimizes $| r_{aid} - r |$

Challenges:

- f , f_{imp} , g highly nonlinear and complex, but machine learning to the rescue?
- Huge data requirements, but large-scale recordings can meet them

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