“Hidden” hearing loss:
The search for the origin of common hearing disorders

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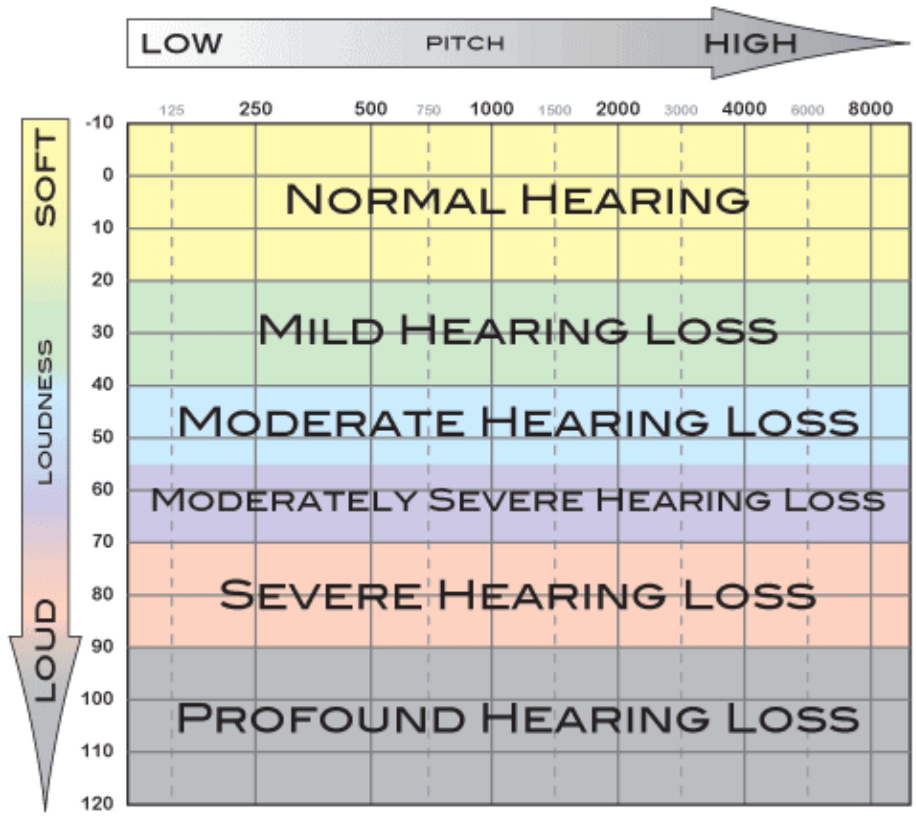
Audiograms plot hearing response to low intensity, pure tones

The "normal" range is very broad.



"I can *hear* you, but I can't *understand* you."
Normal to moderate hearing loss may be associated with more severe functional difficulties.

“Auditory aging occurs independently of lifestyle…”

Gordon-Salant, 2013

A normal audiogram can “hide” many hearing abnormalities, including:

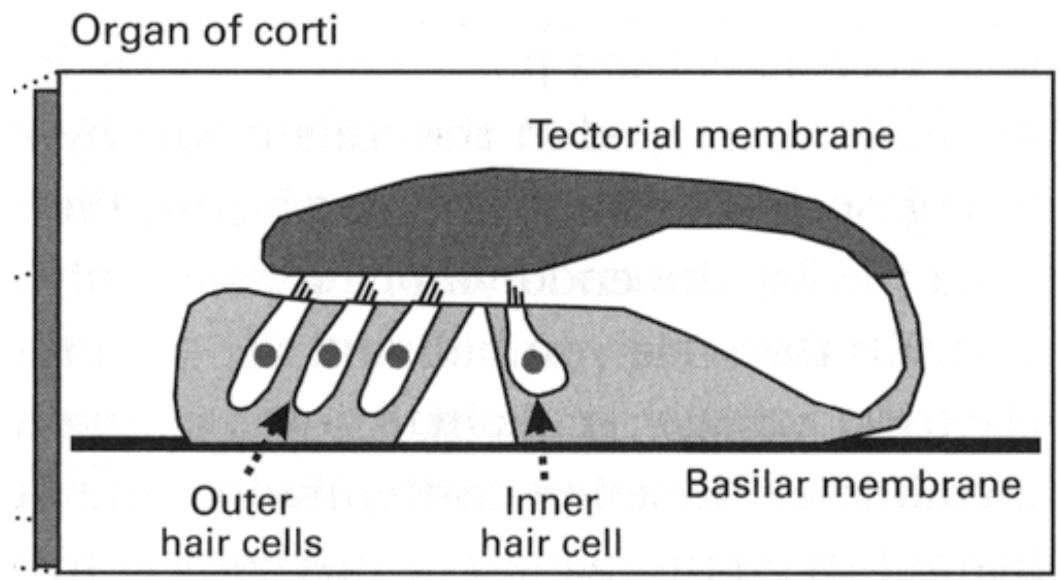


Fig. 2.7. *Auditory Neuroscience.* 2012. MIT Press.

- tinnitus
- hyperacusis
- poor temporal processing
- poor speech-in-noise (SIN) discrimination

“Auditory aging occurs independently of lifestyle…”

Gordon-Salant, 2013

Four forms of presbycusis:

(Schuknecht, 1974):

- Sensory
  ✓loss of cochlear hair cells
- Metabolic
  ✓atrophy of stria vascularis
- Cochlear conductive
  ✓stiffening of the basilar membrane
- Neural
  ✓deterioration of the auditory branch of cranial nerve VII

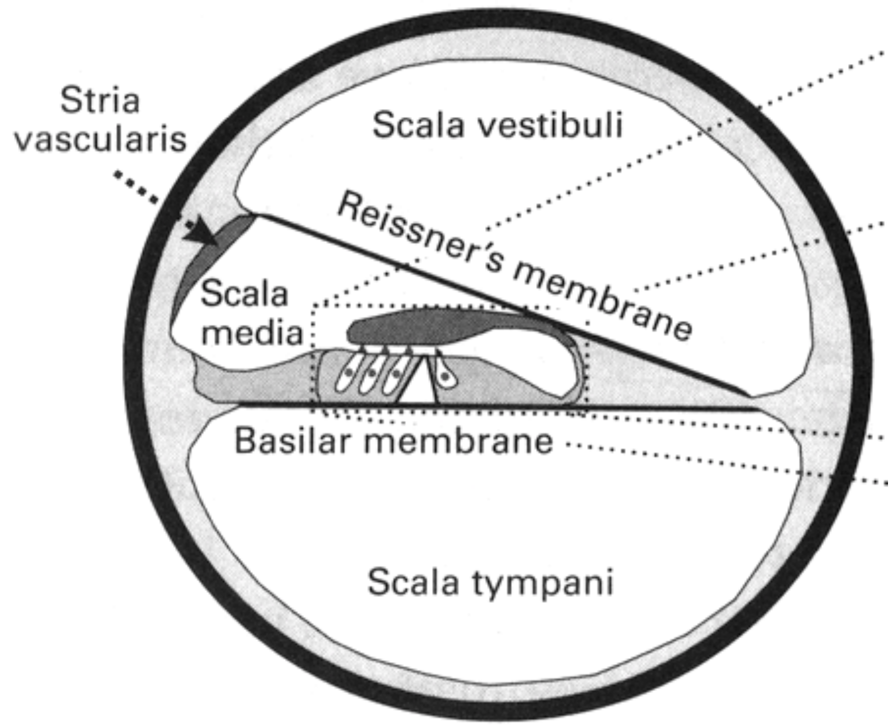
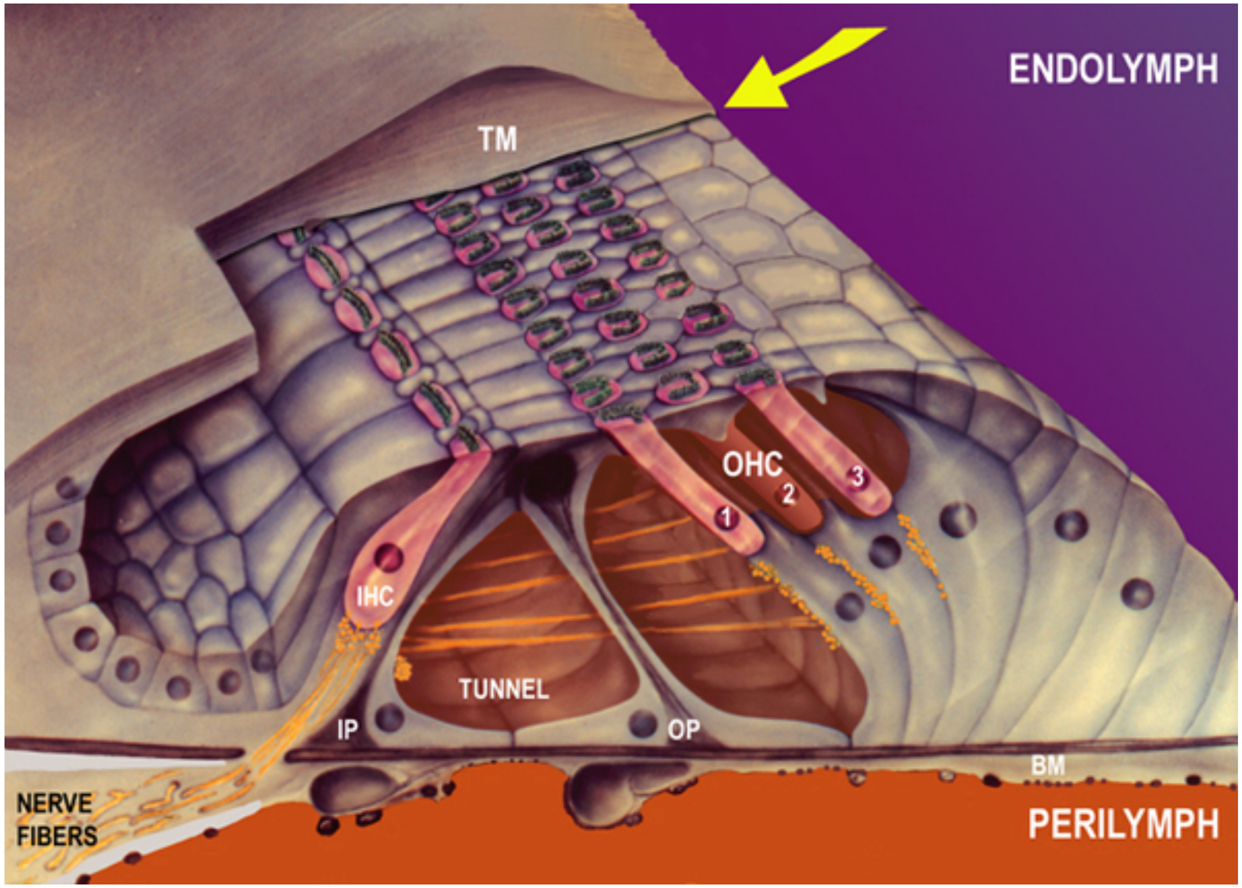


Fig. 2.7. *Auditory Neuroscience.* 2012. MIT Press.

Inner hair cells (IHC) send audio signals to the brain
Outer hair cells (OHC) receive signals from the brain



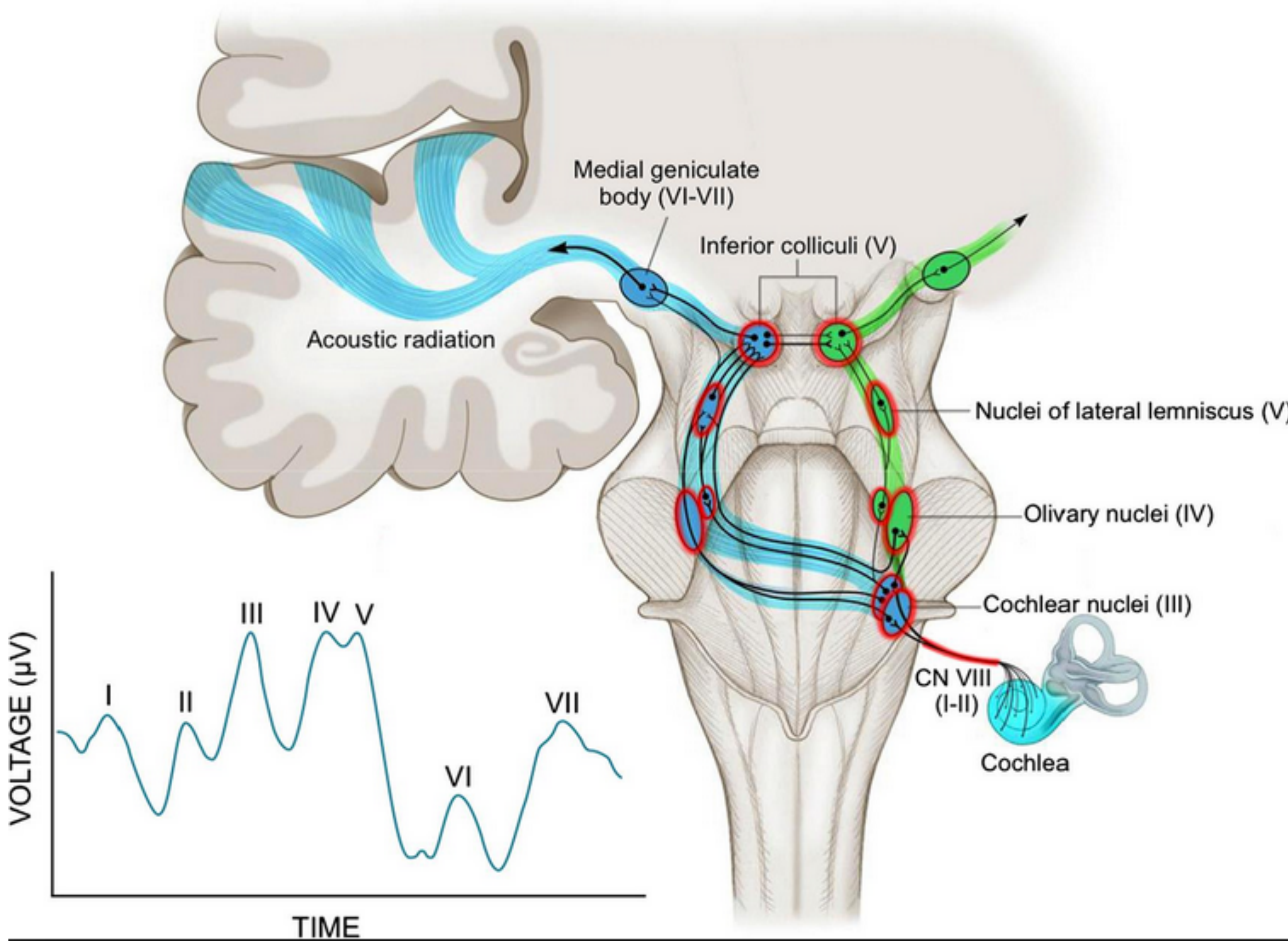
~ 30,000 **auditory nerve fibers** (in humans) innervate IHC and OHC.

Source: http://www.lipscomb.umn.edu/music_cognition

Auditory Brainstem Response (ABR) measures IHC and auditory nerve health

Normal ABR consists of five prominent waves that occur during the first 10 ms following a transient sound.

Knipper *et al*, 2013



Source: http://pharmaceuticalintelligence.com

Otoacoustic emission tests measure OHC health

- Outer hair cells amplify basilar membrane action, especially to soft sounds.

- Healthy ears show a DPOAE (distortion product otoacoustic emission) when stimulated with tones.

Where does noise-induced hearing loss originate?

Kujawa & Liberman, 2009

Mice, gerbils, chinchillas, and cats have typical mammalian ears…

Mice exposed to:

2 hours of noise

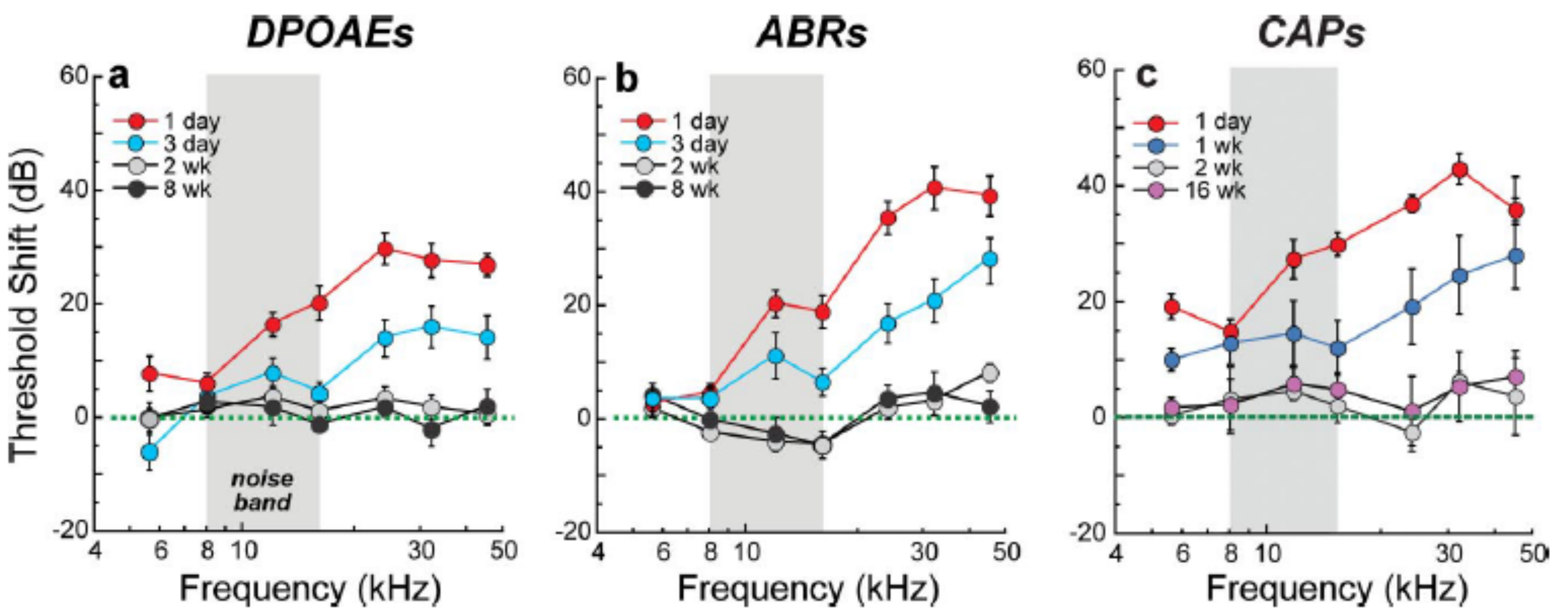
100 dB SPL

8 k - 16 kHz

(~ human 2.5 k to 5 kHz)

Temporary threshold shift (TTS) observed

Kujawa & Liberman, 2009

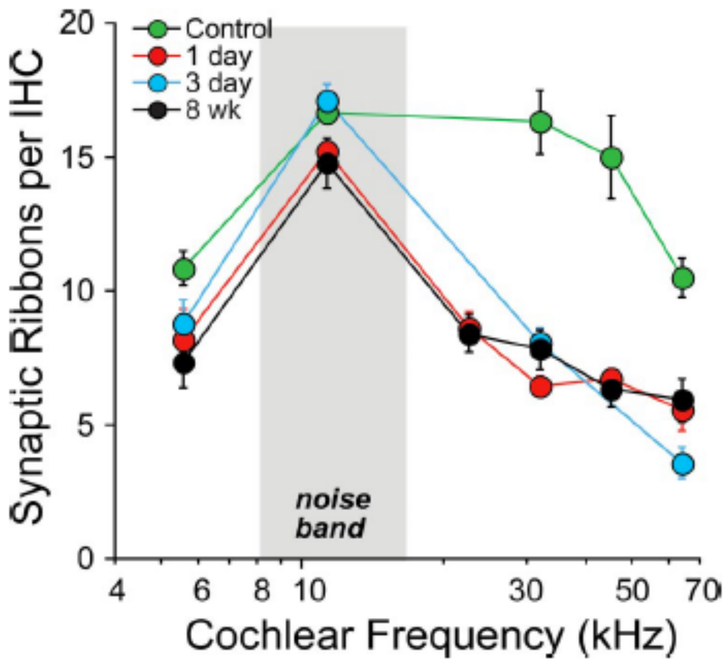


Hearing appeared to have recovered 8 weeks after exposure….

Tests indicated that after a period of TTS, this amount of noise exposure did not cause permanent threshold shift (PTS).

Responses in the exposure band recovered after exposure.
Higher frequencies did not.

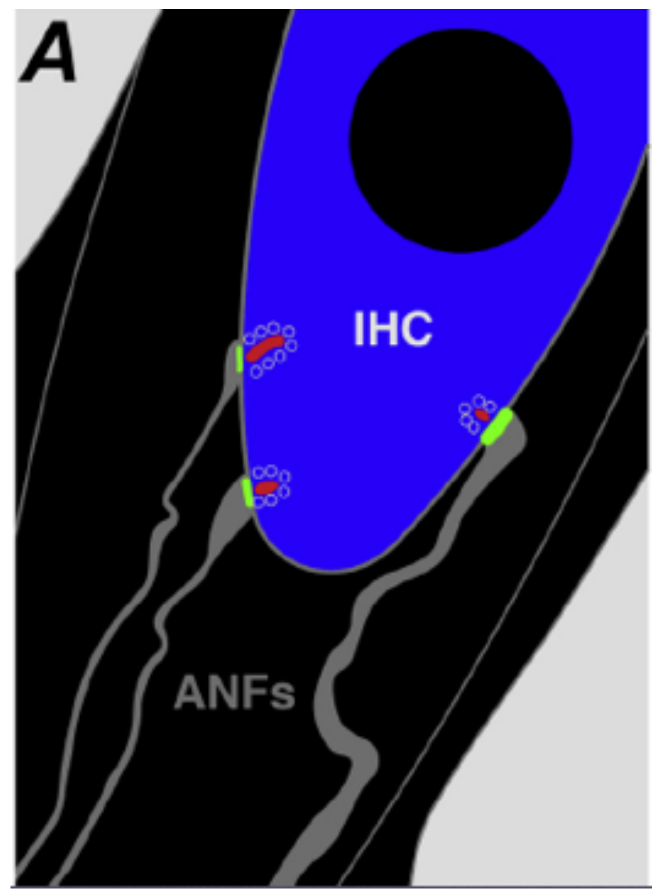
Kujawa & Liberman, 2009



~ 50% of synaptic ribbons were damaged after noise exposure.

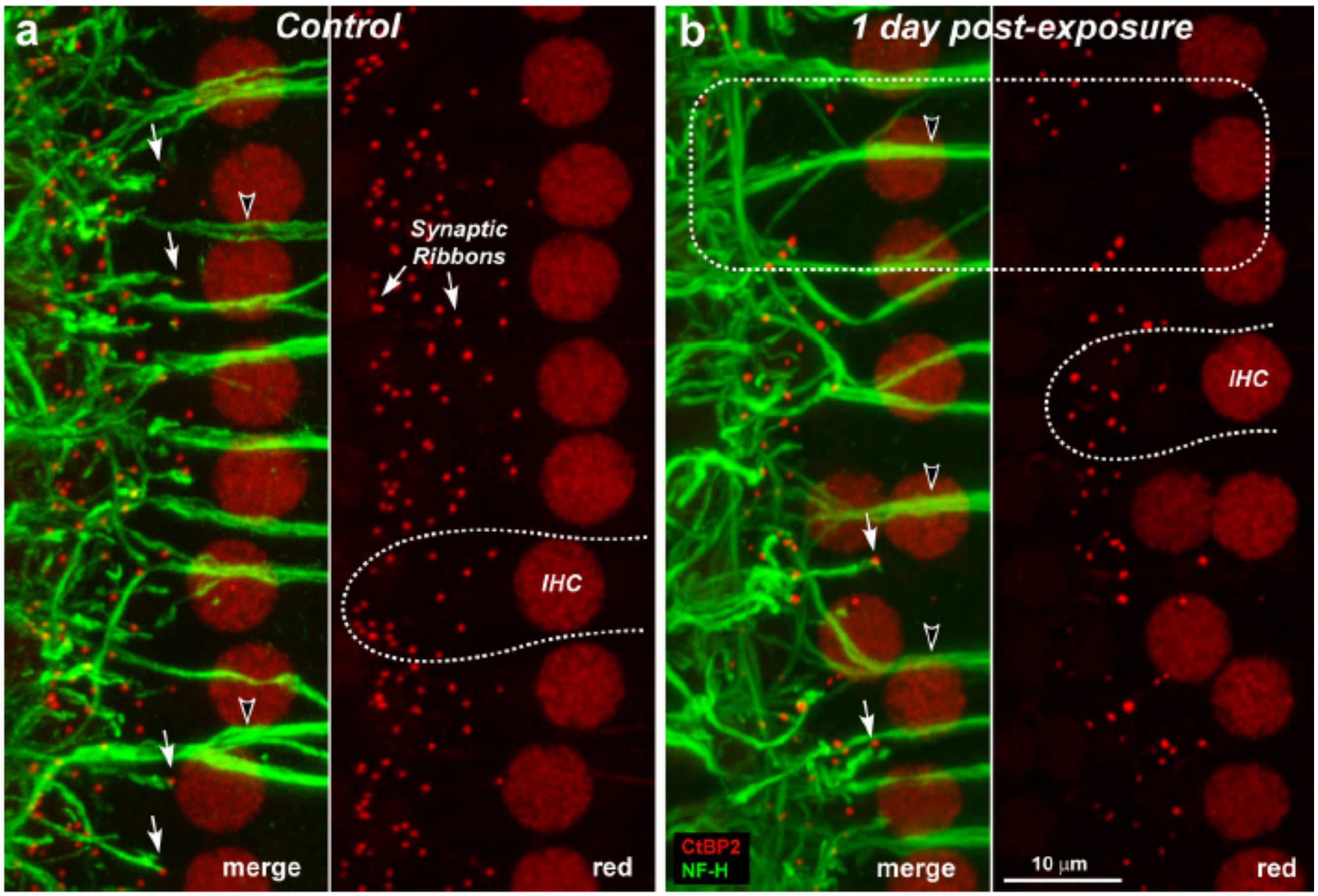
Loss of synaptic ribbons was followed by gradual loss of corresponding AN fibers.

Synaptic ribbons inside the IHC deliver neurotransmitters to synapses.



Synaptic ribbons feed neurotransmitters to the synapse, generating action potentials in the auditory nerve.

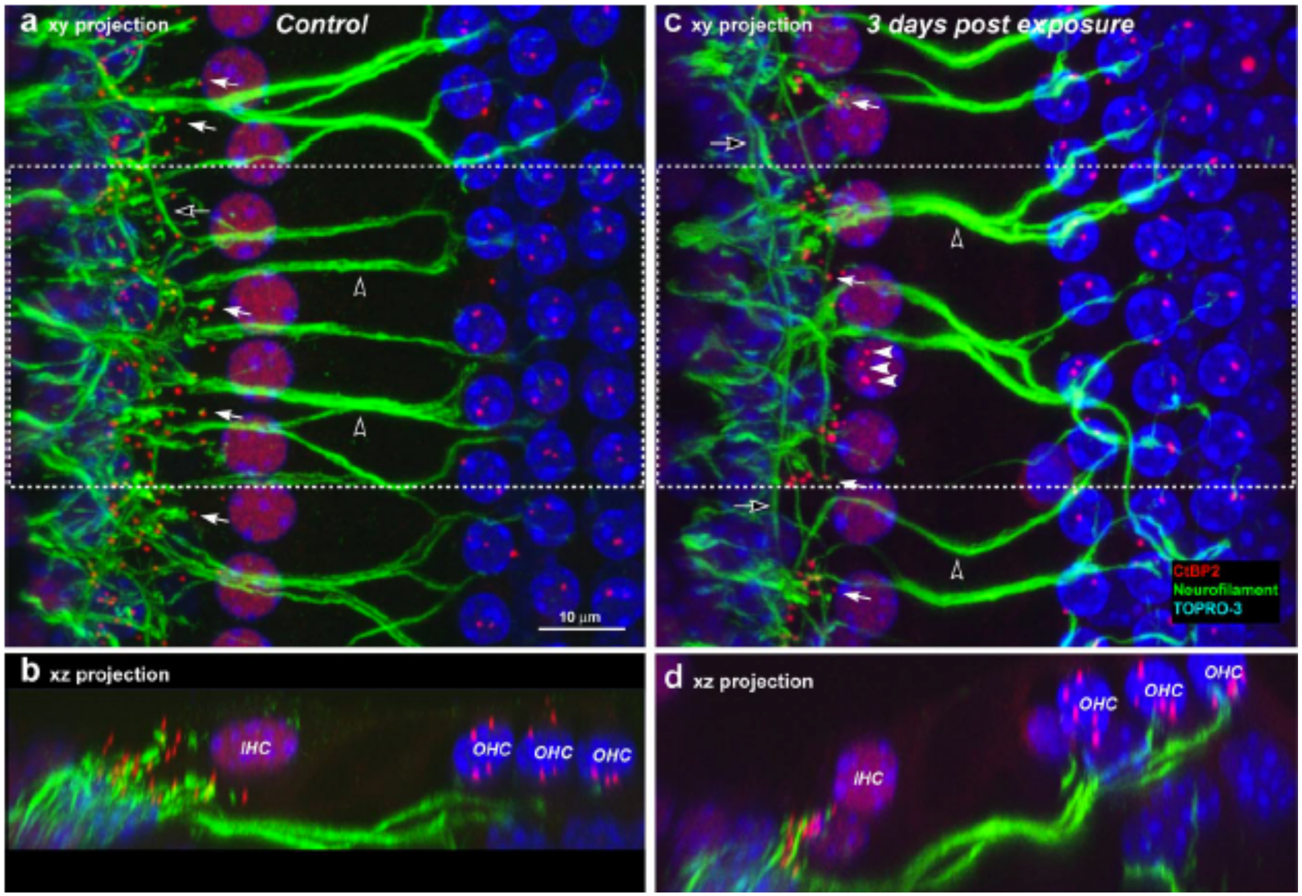
Kujawa & Liberman, 2009



Glutamate excitotoxicity can swell and rupture auditory nerve terminals, leading to cell degradation.

Healthy ear vs. exposed ear 3 days later.
Region shown is 45 kHz, higher than what the mice heard.

Kujawa & Liberman, 2009



Immunostaining revealed **synaptopathy** — loss of synapses where the IHC meets the auditory nerve. Loss was greatest in the basal end of the cochlea (high freq. region).

AN degradation after noise exposure happens gradually

Kujawa & Liberman, 2009, 2015

A thick bundle of AN fibers 2 weeks after noise (mice).

Many are gone a year later.

AN degradation is selective for low-SR, high threshold fibers.

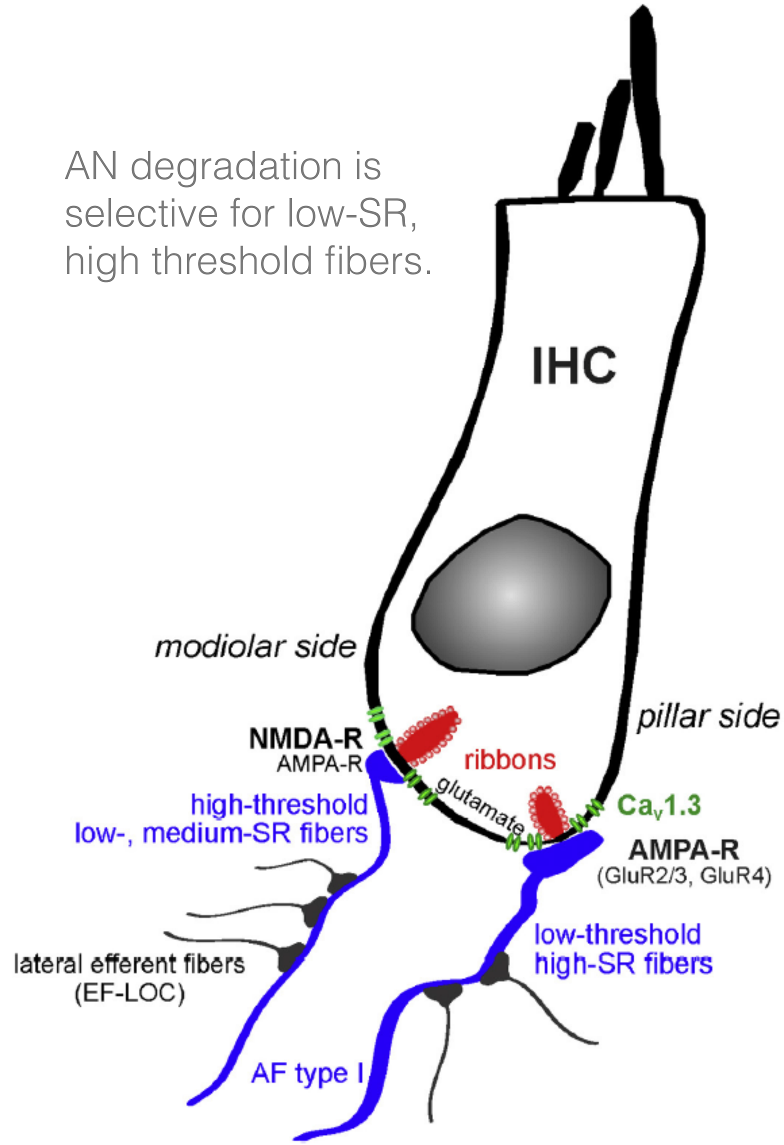
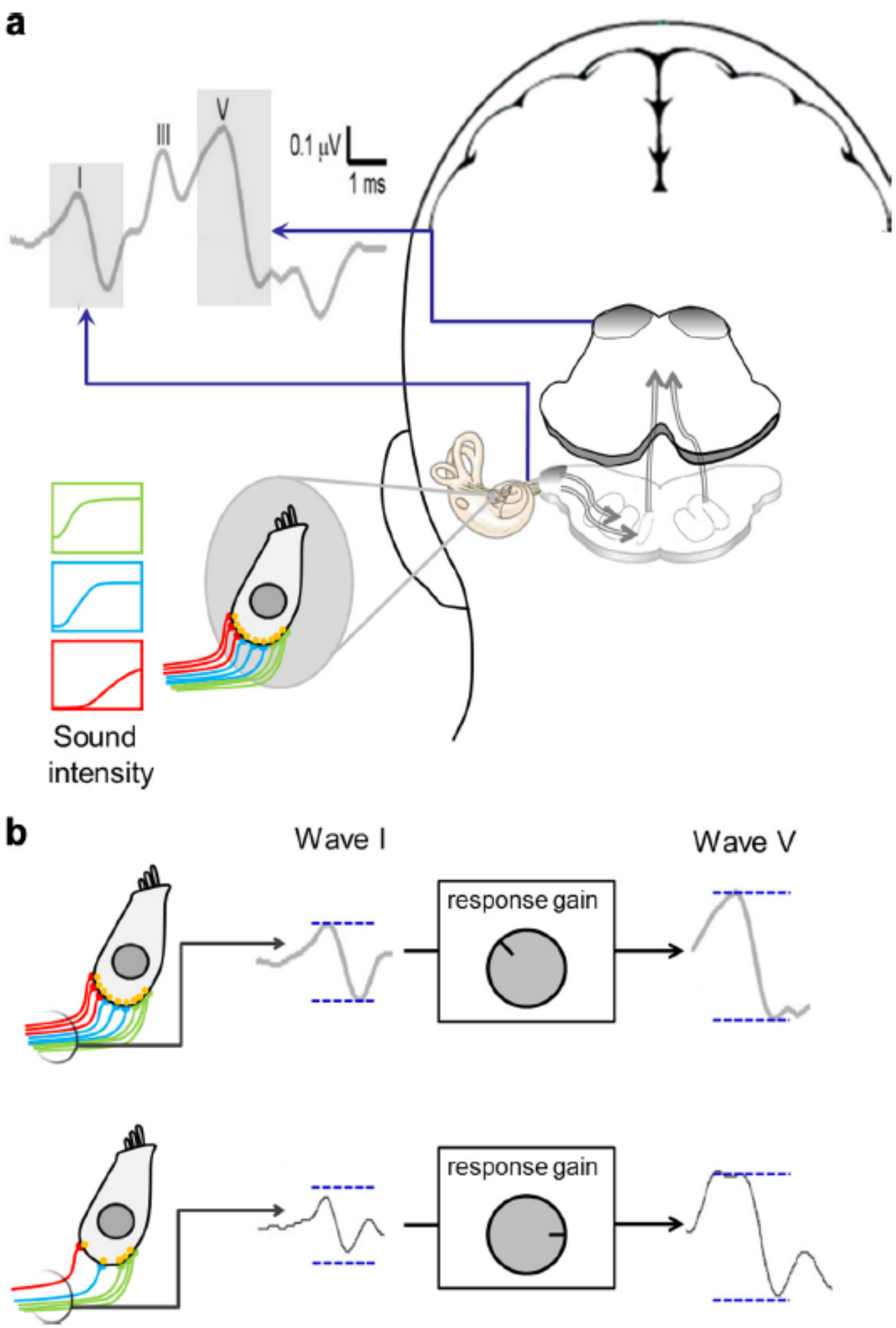


Fig. 2. Knipper *et al*, 2013.



Loss of auditory nerves reduces signal output.
Higher regions turn up the gain.

Green: High spontaneous rate (SR)

Blue: Medium SR

Red: Low SR

Damage seen in medium- and low-SR fibers.

These fibers have the widest dynamic range and are most resistant to masking.

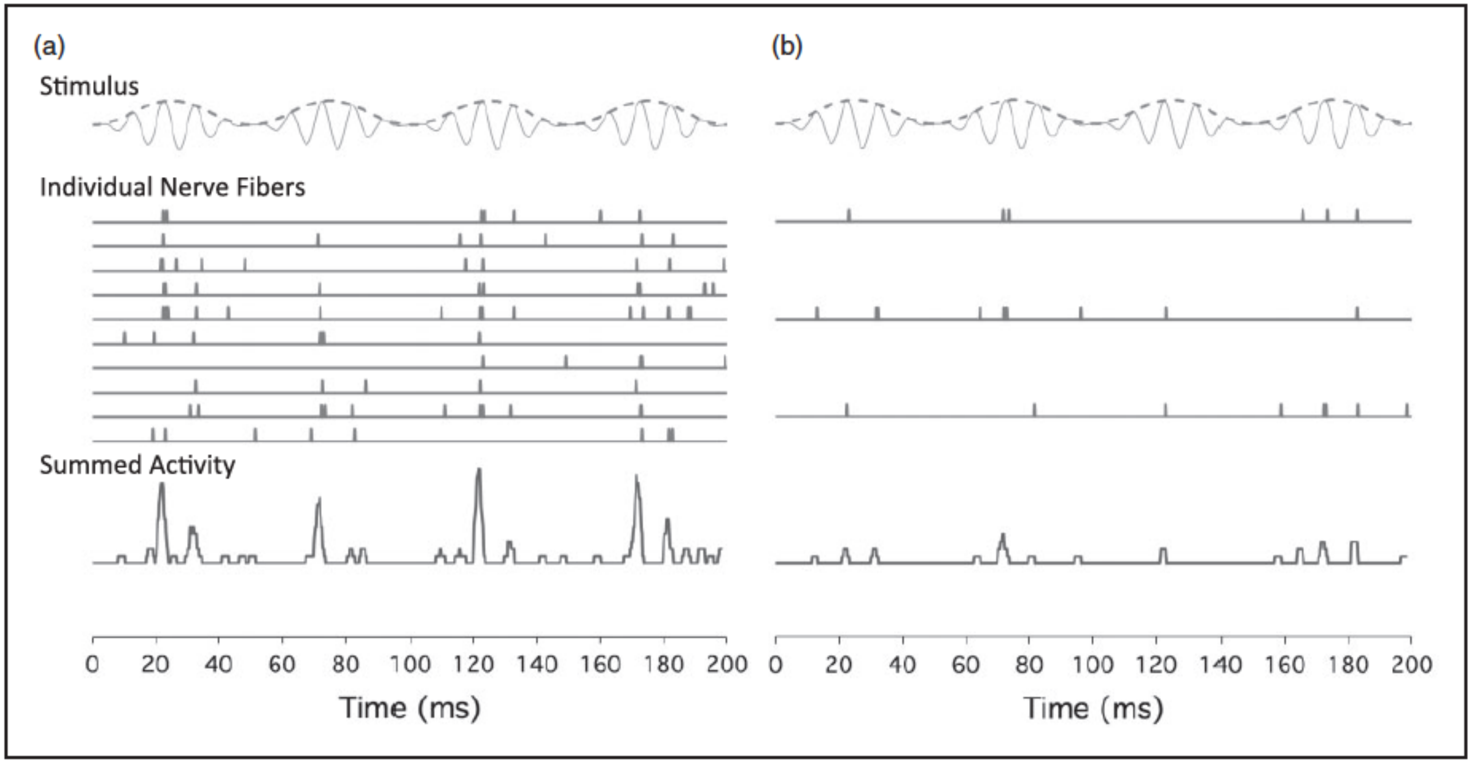
Reduced Wave I (CN) response observed but gain is recovered by Wave V (IC).

Auditory system compensates for diminished input by up regulating responsiveness later in the midbrain part of the path.

Schaette & McAlpine. (2011).

Loss of auditory nerve fibers can make it harder to perceive musical pitch, speech in noise, speech in reverb.

10 AN fibers.



3 AN fibers.

Summed response of 10 fibers clearly codes for fine structure and temporal envelope. Response of 3 fibers is lower, less distinct.

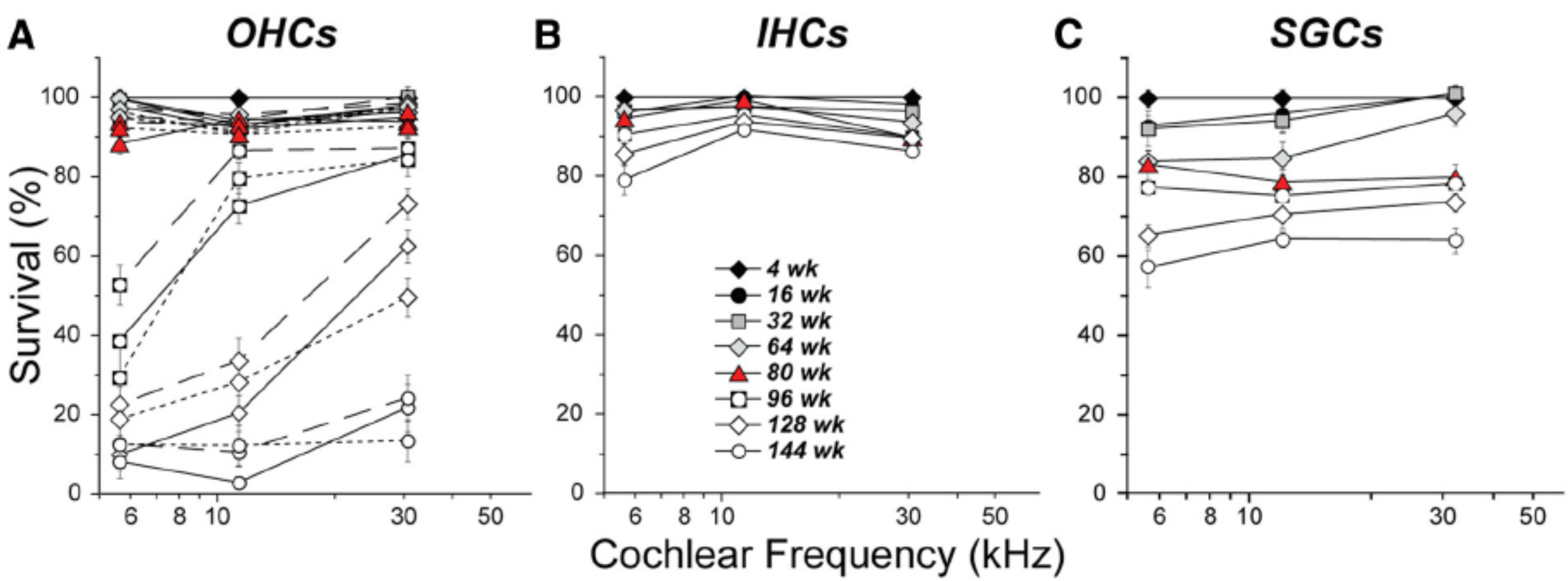
Plack, Barker, & Prendergast. (2014).

How much loss was due to noise exposure versus aging?

Sergeyenko, Lall, Liberman, & Kujawa, 2013

Follow up study looked at same strain of mouse but with no noise exposure.

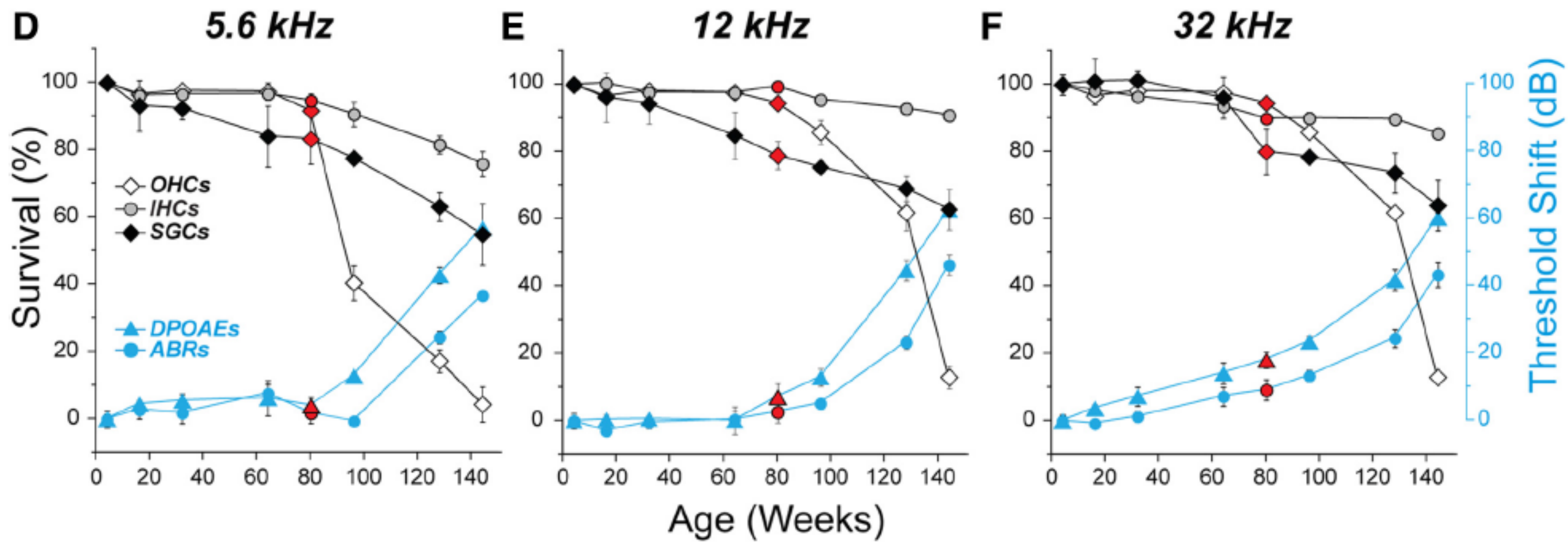
“We find significant synaptic losses long before declines in threshold sensitivity or hair cell counts.”



Spiral ganglion (SG or auditory nerve cells) loss precedes hair cell loss.

How much loss was due to noise exposure versus aging?

Sergeyenko, Lall, Liberman, & Kujawa, 2013



OHC loss precedes IHC loss and is greatest at *low frequency* end.

Suggests that OHC loss is "a major contributor to age-related threshold shifts." Changes are slow until middle age.

Some loss of auditory nerve fibers is normal, even without noise exposure.

- We lose about 100 per year. By age 91-100, we will have lost about 1/3 of auditory nerves.
- There is large variability in this observation. Persons in their 70s can have a complete set (Markay et al., 2011).
- As we age, we rely more heavily on temporal fine structure, rather than the envelope (Ruggles, Bharadwaj, & Shinn-Cunningham, 2012).
- Auditory signals with diminished temporal envelopes mimic the sound of the older listener.

Tinnitus (ringing in the ears or head) affects ~ 10% - 20% of population.

Knipper *et al*, 2013

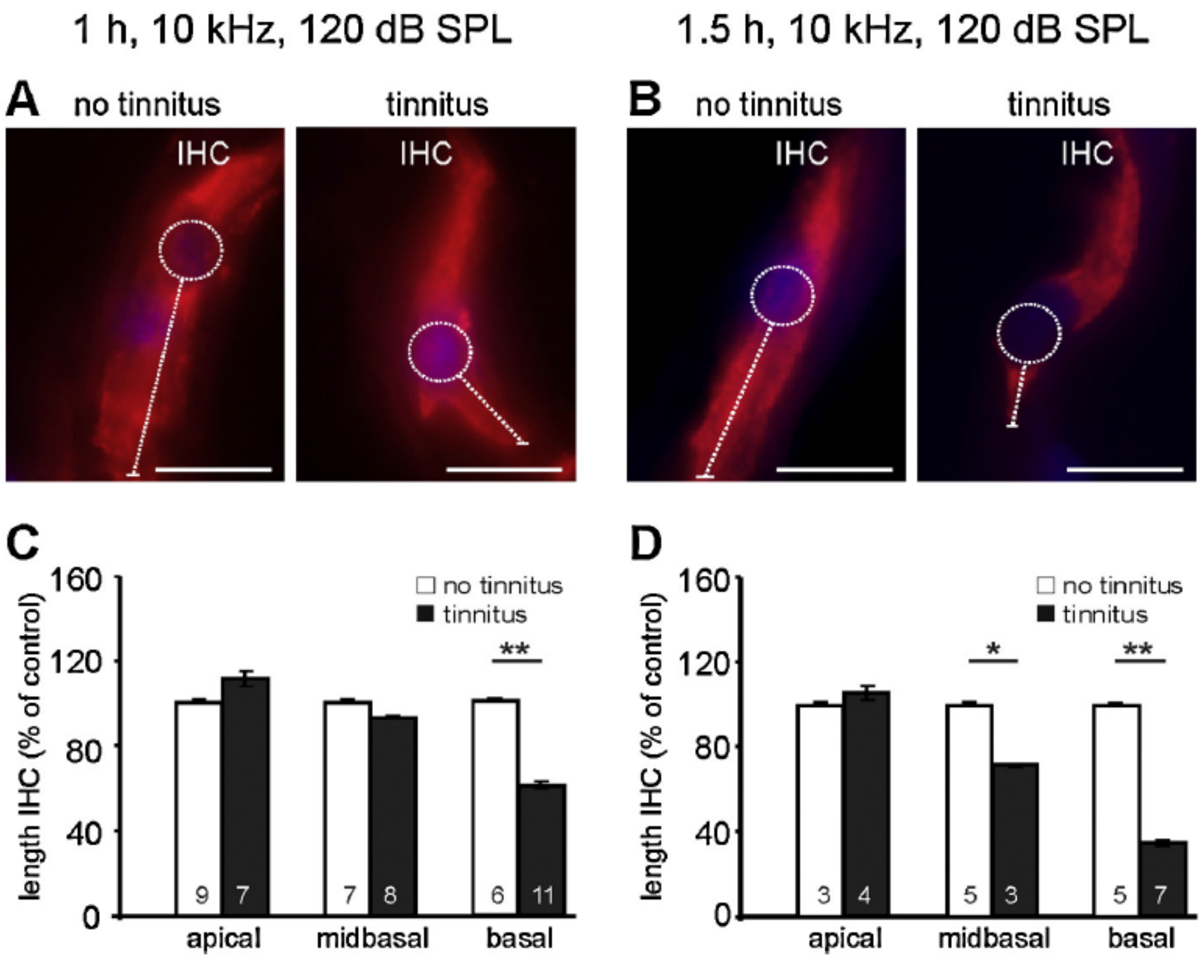


Fig. 4. Knipper *et al*, 2013.

Tinnitus may originate from auditory nerve damage.

Rats with and without tinnitus (assessed by behavioral methods) were compared (Rüttiger et al, 2013).

Differences in IHC health appeared in high frequency regions of cochlea.

If the auditory system fails to adapt to these degradations, tinnitus may result.

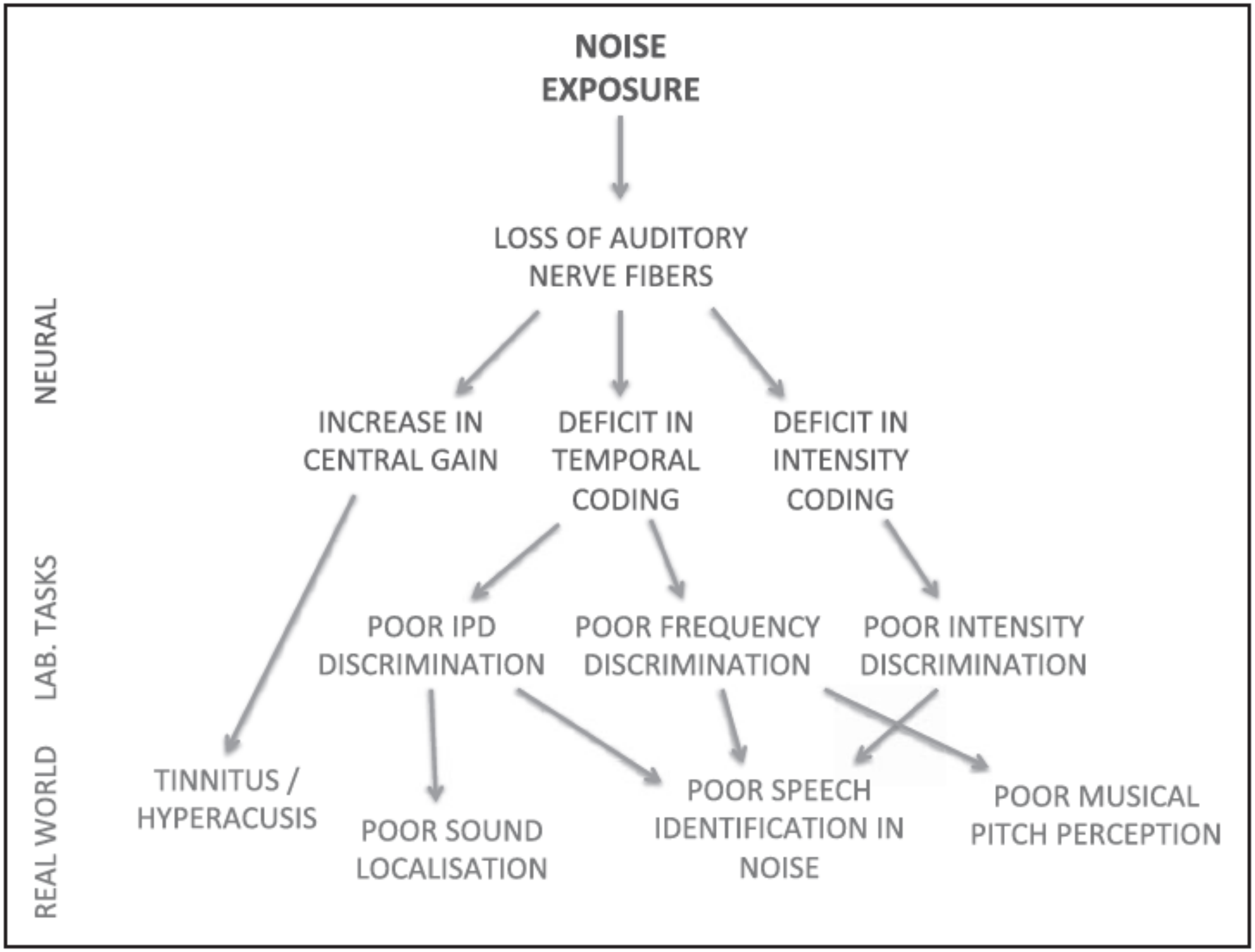
"…emotional exhaustion and long term stress are predictors of hearing disorders, including tinnitus."
Knipper *et al,* 2013

- Sound, and also stress, influence many of the same cortisol-responsive receptors in the brain.

- High stress levels at the time of noise trauma is more damaging than moderate stress levels, which actually is followed by *improved* AN response (Singer *et al*, 2013).

- Age of audio trauma is important: younger (pre-puberty) mice were shown to be more vulnerable than mature mice (Kujawa & Liberman, 2015).

Proposed links between noise exposure and perceptual difficulties



Plack, Barker, & Prendergast. (2014).

Summary of hidden hearing loss.

- Animal studies show that noise exposure can cause permanent loss of auditory nerve fibers but only temporary shift in listening thresholds.
- Damage would not necessarily appear in a hearing test but might be linked to these auditory difficulties:
  - ✳ tinnitus (Roberts et al., 2010)
  - ✳ hyperacusis (Roberts et al., 2010)
  - ✳ speech in noise perception (Plack, Barker, & Prendergast, 2014)
  - ✳ auditory attention (Bharadwaj et al,. 2014)
  - ✳ pitch perception (Plack, Barker, & Prendergast, 2014)
  - ✳ spatial localization (Briley & Summerfield, 2014)
  - ✳ emotion perception (Husain, Carpenter-Thompson, & Schmidt, 2014)

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