Auditory nerve

Amanda M. Lauer, Ph.D.
Dept. of Otolaryngology-HNS

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Overview

• Pathways (structural organization)
• Responses
• Damage
Basic structure of the auditory nerve
Spiral ganglion neurons (SGNs)

Mouse: ~8,000-10,000 SGNs
Human: ~50,000 SGNs

Ribbon synapse

Nouvian et al. 2005
Type I and type II SGNs

There are two types of auditory nerve fibers:

- I-myelinated; ~90%; synapse with IHCs; extensive projections to CN
- II-unmyelinated; ~5-10%; synapse with OHCs; limited projections
Ribbon synapses and fibers can be labeled using antibodies and quantified using confocal microscopy.

Each IHC has ~15-20 ribbon synapses

Each OHC has ~1-2 ribbon synapses

Green: c-terminal binding protein 2 (CTBP2)
Red: neurofilament H (NF-H)
Auditory nerve fibers bifurcate and send tonotopic projections to dorsal (DCN) and ventral (VCN) cochlear nucleus. The nerve projects anteriorly and posteriorly in VCN.

These projections form synapses with several CN principal neuron types, which we will cover tomorrow.
Normal auditory nerve physiological responses
Spontaneous activity and responses to tones

Spontaneous (no stimulus)

Tones

From Pickles (2008)
Auditory nerve fibers with high spontaneous activity have low thresholds.

Low spontaneous activity fibers have high thresholds.

Liberman and Kiang 1978; Elliott et al. 1960
Spontaneous activity and rate-level functions

Auditory nerve fibers increase firing rate with increasing sound levels up to a saturation point.

Low spontaneous activity fibers have higher saturation points than high spontaneous fibers.

http://www.lifesci.sussex.ac.uk/home/Chris_Darwin/Perception/Lecture_Notes/Hearing2/hearing2.html
Thresholds and frequency tuning

Adapted from Palmer and Evans 1975
How does the auditory nerve respond when competing sounds are present (masking)?
Types of Masking

- **Simultaneous**
- **Forward**
- **Backward**

Diagram showing the relationship between a masker, signal, and time.
The presence of one stimulus (masker) reduces the response to another (signal) when they overlap in frequency.

Auditory nerve fibers show reduced dynamic range in the presence of noise.

Costalupes et al. 1984
Forward masking: auditory nerve fibers show reduced responses (increased threshold) when a masking sound is played prior to a signal (~10-200ms).

The recovery is different for low and high spontaneous rate fibers.
Temporal coding: phase locking and the volley theory

Phase locking

Volleying

- Phase locking
- Volleying

Diagram: Comparison of nerve firing patterns for different frequencies and stimulus types.
How does the auditory nerve encode stimuli with complex stimuli that change in frequency and intensity over time?
A short lesson about speech

Time waveform

Spectrogram
A short lesson about speech

- **Glottal Pulses**
  - Source Spectrum
  - Filter Function
  - Output Energy Spectrum
Two-tone suppression

Work originally by Sachs and Kiang
The auditory nerve must convey the temporal fluctuations in amplitude and frequency from the cochlea to the brain. How does it represent this complex information?

Rate coding plus place coding (auditory nerve fibers with best frequencies closest to the speech formant will response at the highest rates.)

![Speech, ANF, Speech (higher time res), ANF (higher time res), Representation of vowel formants (Fourier transform)](Young 2008)
Speech coding

(a) dB re peak

(b) normalized rate

(c) best frequency (kHz)

Young 2008

(d) normalized rate

(e) best frequency (kHz)

(f) normalized rate

low + medium SR

high SR

F1 |

F2 |

512 Hz 1792 Hz 2432 Hz

512 Hz 3508 Hz 5391 Hz

1.0

0.5

0.1

1.0

0.5

0.1
What happens to the auditory nerve when there is damage to the cochlea?
Hearing loss primer

Deficit

Trouble hearing some conversation, clocks, birdsong

Trouble hearing conversation, dogs barking, traffic

Trouble hearing even the loudest sounds. Unaided speech perception mainly from visual cues.
What is the main problem with loss of sensitivity?

Moderate hearing loss
Loss of audibility of many speech sounds
You can still detect many sounds fairly well with mild or moderate hearing loss, but you might have trouble understanding those sounds. Why?
Cochlear damage changes auditory nerve responses

Auditory nerve tuning curves are broadened when hair cells are damaged.

This can occur as a result of intense noise exposure or ototoxic drugs.

The exact pattern of changes to the tuning curve depends on the pattern of hair cell or stereocilia damage.
Broadened auditory filters

Auditory filters are broadened in ears with sensorineural hearing loss (frequency selectivity is impaired),

Increased susceptibility to masking. Abnormal representation of components of complex sounds (see next slide).
Broadened auditory filters—effects on speech coding

Vowel spectrum on cochlear frequency scale

BM excitation pattern-normal filters

Moore, 1995
Damage can occur even when hair cells appear healthy.
Peripheral neural damage: Cochlear neuropathy & synaptopathy

ABR thresholds return to normal shortly after early age moderate noise exposure, but there is an acceleration of age-related hearing loss and SGN loss.

Kujawa and Liberman, 2006
Cochlear neuropathy & synaptopathy

Primary spiral ganglion loss in aging humans

Makary et al. 2009
Cochlear synaptopathy

ABR thresholds return to normal shortly after exposure, but there is a lasting reduction in auditory nerve synapses (30-50%).

Kujawa and Liberman 2009
Cochlear synaptopathy

Sergeyenko et al, 2013

Age-related synaptopathy
The proportion of low SR fibers is reduced in noise-exposed and aged ears. However, the same is apparently not true in C57BL6 mice around the onset of age-related hearing loss. Different effects in different forms of loss?

Perception of loud sounds, hearing in noise is probably impaired.
Perceptual consequences of synaptopathy are uncertain-possible speech in noise deficits

ABR wave 1 amplitude decreases with age in humans

Speech in noise performance is inversely related to wave 1 amp...

...but, the effect is due to an interaction with pure tone average (hearing loss).

Bramhall et al. (2015)
Perceptual consequences of synaptopathy are uncertain—possible hyperacusis

Hickox and Liberman 2014
Perceptual consequences of synaptopathy are uncertain—possible temporal processing deficit

Hickox and Liberman 2014
Summary

Two types of auditory nerve fibers

Fibers are tuned to respond to specific frequency ranges

Fibers must convey frequency, intensity, and temporal speech cues to the brain

(Primary?) damage to auditory nerve fibers may lead to hearing deficits in noise, other hearing deficits