HST 721 Auditory Nerve Lecture
October, 2004
Hair Cell Afferent Innervation

Type I: peripheral axon takes radial course to IHCs
each contacts only 1-2 IHC
95% of ANFs
myelinated axons

Type II: peripheral axon spirals basalwards among OHCs
each contacts 10-100 OHCs
5% of ANFs
unmyelinated axons
Unmyelinated type-II axons are too small to record from
All ANF data are from Type-I / radial fibers innervating IHCs
Each radial fiber (RF) contacts a single IHC by a single terminal swelling.

Each terminal swelling consists of a single synaptic plaque.

Each synaptic plaque is continuous sheet of specialized (thickened) membrane pre- and post-synaptically, with a synaptic ribbon and associated halo of vesicles.
IHC Afferent Innervation

Each IHC is contacted by 10 to 30 radial fibers

# Fibers/IHC varies from base to apex
Rate Coding in the Auditory Nerve

- ANFs fire without acoustic stimulation: spontaneous rate (SR) varies from 0 - 120 sp/sec
- With tones at some frequency-intensity combos, ANFs increase average rate
- Although there is post-onset adaptation, response continues as long as tone continues
- Response is probabilistic: tone-off rate sometimes exceeds tone-on rate
Tuning curves, CF and the cochlear frequency map

Intracellular labeling reveals cochlear frequency map: linear distance to log frequency

Tuning curve defines iso-response contour: frequencies-intensities within curve evoke rate increase.

Characteristic Frequency (CF) defines where along cochlear spiral each radial fiber originates.
Tuning curves, CF and the cochlear frequency map

- Tuning characteristics arise largely in the cochlear mechanics stage
- BM iso-response contours show similar tuning to ANF isoresponse tuning curves.
Click Response, Latency and BM traveling waves

Constructing a Post Stimulus Time Histogram
Increasing “latency” with decreasing CF reflects BM traveling wave delay

Interpeak time in PST for low-CF fibers = 1/CF

Increasing phase delays in mechanical measurements of basilar membrane motion showed traveling wave delays
Click Response, Latency and BM traveling waves

- At low CFs (< 4 kHz), PST peaks mirror peaks in BM motion
- At high CFs (> 4 kHz), ANF cannot follow individual cycles of BM motion
Click Response: the CAP

- Compound Action Potential, recorded from round window
- Click-evoked CAP dominated by basal ANFs
Tuning and Non-linearities: two-tone suppression

- Single tone is always excitatory
- With a fixed CF tone, 2nd tone above or below CF will suppress

Two-tone suppression is seen in BM response
Tuning and Non-linearities: two-tone suppression

- A simple scheme to explain how transducer nonlinearity produces two-tone suppression
- Same scheme produces distortion products (DPs), e.g. 2f1-f2, when driven with two tones f1 and f2
- DPs are seen in BM motion, ANF response and ear canal sound pressure

Visual Basic Distortion Simulator:
http://oto.wustl.edu/cochlea/
Tuning Curves, Threshold spread and SR groups

- Threshold at CF for ANFs from one animal:
- At each CF region, >60dB threshold spread

- Threshold difference is correlated with SR
- SR vs Threshold suggests three ANF subgroups
Tuning Curves, Threshold spread and SR groups

Intracellular labeling experiments show:

- high SR fibers are large, mitochondrion-rich fibers on pillar side
- low/medium SR fibers are small, mitochondrion-poor fibers on modiolar side of IHC
Tuning Curves, Threshold spread and SR groups

Central Projections:

- Many cochlear nucleus regions receive input from all 3 SR groups
- One region, the small cell cap, only receives input from low and medium SR fibers
Information is carried in ANFs as action potentials or “spikes”
Spikes are stereotyped voltage pulses of identical amplitude
Information is coded in ANFs by changes in average rate or in fine timing of spikes
Synchrony Coding in ANFs

ANF spikes can “phase lock” with a tone

Synchronization index (SI) quantifies synchrony

Synchrony falls for \( f > 1.0 \text{ kHz} \)

irrespective of CF
Rate vs Synchrony Coding

- Synchrony also seen in INT (interspike interval) histograms
- Preferred intervals in INT histogram during tones = 1/CF
- INT histograms of SR: Poisson process with a dead time
- Interspike intervals are random.
Adaptation in AN response

- AN discharge rate adapts: onset > steady state
- Adaptation fit by two exponentials: \( \tau_1 = 3 \) msec and \( \tau_2 = 60 \) msec
- Adaptation NOT in hair cell.
- Adaptation arises in synaptic transmission: vesicle depletion

Max sustained rate: 200 - 300 sp/sec

SR suppressed after tone burst offset
Adaptation decreases ANF response to “probe” tone for at least 100 msec after “masker” tone offset.

This phenomenon is the basis for “forward masking” seen psychophysically.
Saturation and dynamic range

Dynamic range is defined as the range of SPLs over which discharge rate increases.

Dynamic range is measured by increasing level of CF tone.

Dynamic range (DR) is < 30 dB in all ANFs:
- High-SR fibers: hard saturation and small DRs (~20 dB);
- Low-SR fibers: sloping saturation and larger DRs (~30 dB)
Saturation and dynamic range

- Basilar membrane motion does not saturate
- IHC shows wide dynamic range (>50 dB)

Saturation arises at the IHC/ANF synapse
Saturation of ANF response and the “Rate-Place” code

- Cochlea is like a filter bank
- Brain might use Rate vs. Place to infer spectrum

- Saturation non-linearity compromises fidelity
Saturation of ANF response and the “Rate-Place” code

At low SPLs, formants are visible in rate-vs-place profile
At high SPLs, the formant peaks are less obvious
Spectral information is also present in synchrony of response

ANF response rate vs CF for a vowel at two SPLs

- 38 dB
- 68 dB