Hearing and Deafness
1. Anatomy & physiology

Chris Darwin

Web site for lectures, lecture notes and filtering lab: http://www.lfesci.sussex.ac.uk/home/Chris_Darwin/

look under:
"Teaching material for students" "Perception & Attention"
Outer, middle & inner ear

Capture; Amplify mid-freqs
Vertical direction coding

Protection
Impedance match

Frequency analysis
Transduction
Middle ear structure
Conductive hearing loss

- Sounds don’t get into cochlea
- Middle ear problems
- Helped by surgery and by amplification
Protection
Impedance match
Capture; Amplify mid-freqs
Vertical direction coding
Frequency analysis
Transduction

Outer, middle & inner ear
Travelling wave on basilar membrane sorts sounds by frequency

- High frequencies
- Low frequencies

Distance along basilar membrane
Amplitude of vibration
Base
Apex
Reponse of basilar membrane to sine waves

Each point on the membrane responds best to a different frequency: high freq at base, low at apex.

amadeus praat
Organ of Corti
Inner hair cell
Hair Cell
Stereocilia
Auditory nerve innervation

IHC (1)
- radial afferent (blue)
- lateral efferent (pink)

OHC (2)
- spiral afferent (green)
- medial efferent (red)
Auditory nerve rate-intensity functions

The graph shows the relationship between log amplitude (dB SPL) and spikes per second. Key features include:

- **Saturation**: The highest achievable spike rate.
- **Many**: Spike rates approaching saturation.
- **High spontaneous rate**: Initial high spike rates at lower log amplitudes.
- **Low spontaneous rate**: Initial low spike rates at lower log amplitudes.
- **Few**: Spike rates as amplitudes decrease.

The graph illustrates how auditory nerve responses vary with sound intensity, from low spontaneous rates at lower amplitudes to many spikes per second at high amplitudes, eventually reaching saturation.
Phase Locking of Inner Hair Cells

Auditory nerve connected to inner hair cell tends to fire at the **same phase** of the stimulating waveform.
Phase-locking

Response to Low Frequency tones
Inter-spike Intervals

Response to High Frequency tones > 5kHz

Random intervals
Inner vs Outer Hair Cells
## Inner vs Outer Hair Cells

<table>
<thead>
<tr>
<th>Inner Hair Cells</th>
<th>Outer Hair Cells</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sensory</td>
<td>Motor</td>
</tr>
<tr>
<td>Afferent nerves</td>
<td>Efferent nerves</td>
</tr>
<tr>
<td>Single row</td>
<td>c.3 rows</td>
</tr>
</tbody>
</table>
OHC movement

Passive
No OHC movement

Active
With OHC movement
OHC activity

OHCs are relatively more active for quiet sounds than for loud sounds.

They only amplify sounds that have the characteristic frequency of their place.

- Increases sensitivity (lowers thresholds)
- Increases selectivity (reduces bandwidth of auditory filter)
- Gives ear a logarithmic (non-linear) amplitude response
- Produce Oto-acoustic emissions
### Conductive vs Sensori-neural deafness

<table>
<thead>
<tr>
<th></th>
<th>Conductive</th>
<th>Sensori-neural</th>
<th>Sensori-neural</th>
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</thead>
<tbody>
<tr>
<td>Origin</td>
<td>Middle-ear</td>
<td>Cochlea (IHCs)</td>
<td>Cochlea (OHCs)</td>
</tr>
<tr>
<td>Thresholds</td>
<td>Raised</td>
<td>Raised</td>
<td>Raised</td>
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<tr>
<td>Filter bandwidths</td>
<td>Normal</td>
<td>Normal</td>
<td>Increased</td>
</tr>
<tr>
<td>Loudness growth</td>
<td>Normal</td>
<td>Normal</td>
<td>Increased (\textit{Recruitment})</td>
</tr>
</tbody>
</table>

- Mostly a combination of OHC and IHC damage
- Becomes linear, so
- No combination tones
- Or two-tone suppression
- Mostly a combination of OHC and IHC damage
Auditory nerve
frequency-threshold curves

Characteristic Frequency
Normal Threshold
Normal bandwidth
Characteristic Frequency
Auditory tuning curves

- Normal bandwidth
- Abnormal Threshold
- Inner hair-cell damage
- Healthy ear
- Normal Threshold
- Characteristic Frequency

Log frequency
Log amplitude (dB SPL)
100
80
60
40
20

Healthy ear

Inner hair-cell damage

Characteristic Frequency

Normal bandwidth

Abnormal Threshold

Normal Threshold
Outer-hair cell damage

<table>
<thead>
<tr>
<th>log frequency</th>
<th>log amplitude (dB SPL)</th>
</tr>
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<tbody>
<tr>
<td>100</td>
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<tr>
<td>80</td>
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<tr>
<td>60</td>
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<td>40</td>
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<td>20</td>
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</tr>
</tbody>
</table>

Characteristic Frequency

Normal

Abnormal
Threshold

Normal bandwidth

Abnormal bandwidth

Normal Threshold

Characteristic Frequency
BM becomes linear without OHCs (furosemide injection)
Amplification greater and tuning more selective at low levels

Normal auditory non-linearities

• Normal loudness growth (follows Weber’s Law)

• Combination tones

• Two-tone suppression

• Oto-acoustic emissions