Auditory System

1) Physical properties of sound
2) Peripheral mechanisms in audition
   ear structure
   transduction
3) Coding

Functions of the Auditory System

1) Sound identification  (What is it?)
   Frequency
   Intensity
2) Sound localization  (Where is it?)
   Interaural timing differences
   Interaural frequency differences
3) Communication

10% of the population has hearing disorders
1 in 1000 children have congenital deafness
1 in 3 people over the age of 60 has hearing loss
40% of the cells that detect sound are destroyed by age 65
Health cost in America is $56 billion/year
Physical Properties of Sound

Sound is energy produced by vibrating bodies, which produces a disturbance in air molecules.

The disturbance travels as a longitudinal wave, which has a region of condensation (close together) and a region of rarefaction (far apart).

Movement of a single pulse of sound

Region of rarefaction
Region of condensation

Properties of Sound

Speed:
In air, the speed of sound is 344 m/s.

Frequency (wavelength/s):
The number of sound pulses that travel past a fixed point in a second.

<table>
<thead>
<tr>
<th>Species</th>
<th>Frequency Range</th>
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<tbody>
<tr>
<td>Humans</td>
<td>20 - 20,000 Hz</td>
</tr>
<tr>
<td>Bats</td>
<td>1000-100,000 Hz</td>
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Pitch:
Perception of frequency. High frequency sound is heard as a high pitch.

Intensity (amplitude):
Amount of air pressure.

- Normal breathing is about 10 dBs
- A typical conversation is 60 dB
- A jet taking off is 140 dB

Loudness
Perception of intensity. Loudness proportional to log (Intensity)

Sound Illusion: Doppler Shift

The frequency of sound that reaches our ears changes when the sound source is moving.

The change in perceived pitch due to movement is known as the Doppler shift.
THE EAR

Outer---funnels sound; converts sound into physical vibration
Middle---transmits vibrations to the inner ear
Inner---converts fluid movements into neural firing

The EAR

OUTER MIDDLE INNER

External Auditory Meatus
Tympanic Membrane

Function of Middle Ear

1. Three bones in the middle ear transmit the signal
   malleus-hammer
   incus-anvil
   stapes-stirrup

2. The middle ear amplifies signal by increasing the pressure on the oval window

3. Inner ear muscles provide adjustable intensity control (dampen sounds)
INNER EAR

Scala vestibuli-contacts oval window
Scala media-enclosed by other 2, contains endolymph
Scala tympani-in contact with round window

Inner Ear: Chambers of the Cochlea

The Cochlea Unwound
 Fluid movement in “unwound” cochlea

- Fluid flows from oval window to round window

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Cochlear Representation Of Sound - Theories

Place theory:
Frequency is represented by the location of the mechanical response. Low frequency sounds are closer to the helicotrema. High frequency are closer to the oval window.

Frequency Theory:
This theory postulates that the cochlea vibrates in synchrony with the sound.

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Georg Von Bekesy
1961 Nobel prize

Von Bekesy studied cochlear response by opening a window to the cochlea and observing the effect of frequency on movement of the basilar membrane.

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Discovery One: Basilar membrane has very tiny vibrations

Sound caused a traveling wave, with a maximum point of deflection that varied as a function of frequency.

Tuning Curves for various frequency signals

Discovery Two: Different sounds produce vibrations at different places

Different sounds produce vibrations at different places.
Resonance properties of basilar membrane tune it to different frequencies

- **Basal**
  - Thick
  - Stiff
  - High frequency
- **Apical**
  - Thin
  - Floppy
  - Low frequency

A TONOTOPIC MAP!!!

Shape of Cochlear Response to Sound

- **Actual Response**
- **Response seen by Von Bekesy**
- **Difference between actual response and response predicted by von Bekesy is the active response.**

Active Response is caused by outer hair cells, which inject energy back into vibration of cochlear membranes

Transduction of Sound by Hair Cells

- **Structure of Organ of Corti**
- **Tectorial membrane**
- **Inner Hair Cells**
- **Outer Hair Cells**
- **Basilar Membrane**
The hair bundle of hair cells

How do hair cells sense mechanical stimulation?

60 dB causes 10 nm deflection

Tip Link Hypothesis of Activation and Adaptation

1) The stereocilia are connected together through tip links. The tip links end on gating springs.
2) Fluid movement in one direction puts pressure on gating links, leading to ion channels opening.
3) Fluid movement in opposite direction reduces pressure on gating links, leading to ion channels closing.
Tip Link Hypothesis

- Channel connected to a sliding motor
- Motor moves channel, changes tension on tip link
- Allows the channel to rapidly open and rapidly adapt

The channel is a potassium channel!!!

<table>
<thead>
<tr>
<th></th>
<th>&quot;normal&quot; cell</th>
<th>hair cell</th>
</tr>
</thead>
<tbody>
<tr>
<td>extracellular</td>
<td>Na⁺ 1 0 mV</td>
<td>K⁺ 1 +80 mV</td>
</tr>
<tr>
<td>intracellular</td>
<td>K⁺ 1 -45 mV</td>
<td>K⁺ 1 -45 mV</td>
</tr>
</tbody>
</table>

Hearing aids or cochlear implants?
What’s the difference?
Beyond the Ear...How sound is encoded in the brain

• Basics of the auditory pathways
• Properties of higher order auditory cells

Auditory Pathways - The highlights

Coding of Auditory Information

Lower Levels (cochlea, auditory nerve, cochlear nuclei)
Tonotopic Organization

Superior Olive—Sound location

receives input from both ears

Interaural timing differences—sound reaches one ear first, determine sound location by the difference in time

Interaural frequency differences—sound frequency gets distorted by head, another way to determine location
Processing of Location in Inferior Colliculus

Cells show varying kinds of binaural interactions.

- Some show an excitatory response to input to both ears (EE cells).
- Others show excitation to input to one ear, and inhibition to input to the other ear.
- Interaural phase difference cells fire maximally when the input to the two ears is out of phase by a specified amount.
- Cells sensitive to temporal order of input to two ears.

Major concepts for hearing

1. Ear is specialized to detect sounds
2. Cochlea has a tonotopic map
3. Hair cells transduce sound information quickly
   - Direct gating of ion channels
   - Rapid adaptation
4. Brain retains maps of different frequencies
5. Brain computes sound location by differences in frequency and timing between the two ears