Physiology of Hearing

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Is hearing important?

- Communication
  Hearing is essential to Language

- Localization
  Determining the location of unseen sound sources
How do we hear?

Hearing is not so simple!!

The ripples in a lake analogy

You have to tell what's in the lake by just seeing the ripples in the two pieces of paper in two channels at the lake's edge
What needed for normal hearing?

- **Adequate stimulus** (SOUND)
- **Conduction** of stimulus to sensory organs of hearing
- **Sensory transduction** of stimulus at organs of hearing
- **Neural transmission** of the signal
- **Central auditory processing** of the signal at the brain

What is sound?

SOUND: (perception of) **pressure waves** generated by **vibrating** air molecules

Sound source | Listener
Sound waves:

- Sound travels in waves through media.
- Alternating compression (dense molecules) & rarefaction (loose molecules) waves.
- The simple sound is the sinusoidal wave or pure tone.

What properties of sound does the ear detect?

<table>
<thead>
<tr>
<th>Physical Dimension</th>
<th>Perceptual Dimension</th>
</tr>
</thead>
<tbody>
<tr>
<td>INTENSITY</td>
<td>Loudness</td>
</tr>
<tr>
<td>FREQUENCY</td>
<td>Pitch</td>
</tr>
<tr>
<td>COMPLEXITY</td>
<td>Timbre</td>
</tr>
</tbody>
</table>

1- Pressure level (dB)
2- Frequency (cycle/sec = Hz)
3- Complexity
Frequency of sound:

**Low frequency tones**

- 300 Hz tone

**High frequency tones**

- 3000 Hz tone

Tones may be of different amplitudes and same frequency

Intensity of sound:

<table>
<thead>
<tr>
<th>SOUND</th>
<th>dB SPL</th>
</tr>
</thead>
<tbody>
<tr>
<td>Rocket Launching pad</td>
<td>180</td>
</tr>
<tr>
<td>Jet plane</td>
<td>140</td>
</tr>
<tr>
<td>Gunshot blast</td>
<td>130</td>
</tr>
<tr>
<td>Car horn</td>
<td>120</td>
</tr>
<tr>
<td>Pneumatic drill</td>
<td>110</td>
</tr>
<tr>
<td>Power tools</td>
<td>100</td>
</tr>
<tr>
<td>Subway</td>
<td>90</td>
</tr>
<tr>
<td>Noisy restaurant</td>
<td>80</td>
</tr>
<tr>
<td>Busy traffic</td>
<td>75</td>
</tr>
<tr>
<td>Conversational speech</td>
<td>66</td>
</tr>
<tr>
<td>Average home</td>
<td>55</td>
</tr>
<tr>
<td>Library</td>
<td>40</td>
</tr>
<tr>
<td>Soft whisper</td>
<td>30</td>
</tr>
</tbody>
</table>
Complexity of sound:

**PURE TONE**
Simple periodical, regular sound of single frequency

**MUSIC TONE**
A fundamental frequency with many harmonics

**NOISE**
Non-periodical sound of no characteristic frequency

\[ i = \text{intensity}, \ p = \text{period}, \ t = \text{time} \]

How sensitive the ear to sounds?

- The human ear is sensitive to sounds over a **wide range** of:
  - **Frequencies**: 20 - 20,000 Hz
  - **Amplitudes**: 0.0002 - 200 dyne/cm²

- The human ear can detect the **difference** between two sounds occurring 10 µsec apart in **time**

**Note:** The wide sensitivity range of human hearing necessitates the use of **Logarithmic (Ratio) scales** rather than **Linear (Numerical) scales**
Logarithmic scales:

- **Decibel (dB) scale** for sound pressure levels:
  - 0 dB = 0.0002 dyne/cm² (threshold)
  - 120 dB = 200 dyne/cm² (limit)

So, the range of hearing is reduced to only 120 units of measurement (instead of $10^6$ units)

- **Octave scale** for sound frequency in Hz:
  frequency range is measured in octave bands
  i.e. each frequency is double the previous one
  e.g. 250, 500, 1000, 2000, 4000 Hz, ... etc.

Human auditory field:

Note: The human ear is *not* equally sensitive across frequency range
Sound conduction in the ear:

- Sound waves are collected by the pinna and focused into the EAC.
- The vibration pass down the EAC and strike the TM.
Sound conduction in the ear:

- TM vibrates in response to sound and moves the ossicles
- The **ossicles** vibrate the OW membrane

Sound conduction in the ear:

The **OW membrane** vibrations are transmitted to the **inner ear fluids** in scala vestibuli, scala tympani and scala media (cochlear duct) where the **organ of Corti** vibrates in turn.
External ear functions:

- Collecting sound waves
- Amplification of frequencies 2000 – 4000 Hz (resonant frequency of EAC)
- Providing cues about the vertical localization of a sound source (by the degree of sound waves reflection over the pinna)

Middle ear functions:

Structure of the middle ear

Air filled
3 ossicles
2 muscles
3 nerves
Eustachian tube
Middle ear functions:

- ME matches the relatively low impedance of airborne sounds to the higher impedance of inner ear fluids:
  - Focusing the force at the large diameter TM onto the much smaller diameter OW
  - Mechanical advantage gained by the ossicular lever action

Middle ear mechanics:

- Malleus and Incus behave as 1st degree lever

\[
\frac{\text{Diameter of TM}}{\text{Diameter of OW}} = \text{Area ratio} \, 21:1
\]
Sound processing in inner ear:

Structure of the inner ear

Sound processing in inner ear:

Organ of Corti (Sense organ of hearing)
The inner ear has 2 main functions:

- **Mechanical frequency analysis:** Decompressing complex acoustical waveforms into **simpler** elements.

- **Sensory transduction:** Acoustically generated pressure waves are transformed into **neural** impulses.

**Sound processing in inner ear:**

**Frequency analysis in inner ear:**

Cochlea unrolled to show basilar membrane.
Frequency analysis in inner ear:

The BM vibrations create the traveling waves which peak on characteristic place on the basilar membrane according to the frequency of the stimulating sound.

This is called PLACE THEORY of hearing.
Frequency analysis in inner ear:

Thus, the inner ear acts as a:
- Complex
- Multichannel
- Mechanical

FREQUENCY ANALYZER

Sensory transduction in inner ear:

The tectorial membrane picks up the sound pressure waves in the inner ear fluids, and pushes down on the hairs (cilia) of the sensory cells (mainly outer hair cells).
Sensory transduction in inner ear:

The cilia of sensory Cells move according to the incoming sound waves making some intracellular chemical changes causing a release of neurotransmitters at the synaptic junctions that generate nerve impulses in the auditory nerve fibers.

Neural transmission in auditory nerve:

Innervation of IHCs and OHCs
So, what is the role of the ear?

Again ... the ripples in a lake analogy

You (or the ear) can only describe the ripples (TM vibrations) in a way your boss (the brain) wants and understands.

Central auditory processing:

Ascending auditory pathways
Central auditory processing:

Auditory cortical areas

(A) Frontal and parietal lobes removed
(B) Lateral sulcus
Secondary auditory cortex
Wernicke's area
Primary auditory cortex
Left hemisphere
Wernicke's area

Central auditory processing:

Tonotopic organization in AI, areas 41 and 42

(A) Primary auditory cortex
Secondary auditory cortex
(B) Corresponds to apex of cochlea
Corresponds to base of cochlea
THANK YOU