

Lecture 20 – Audition -- Das

1. The properties of sound and their match with the auditory system:

The auditory system is optimally designed to pick out the most salient features of sound.

Sound is a longitudinal pressure wave, causing tiny vibrations of local air pressure. The ear has to be sensitive enough to pick these up:

- barely audible sounds have an amplitude of $\sim 1 / 10^{10}$ of atmospheric pressure.
- even the loudest sounds bordering on the painful have an amplitude of $\sim 1 / 1000$ of atmospheric pressure.

Simple sounds can be described by pitch (frequency) and loudness.

Pitch:

- Pure tones (e.g. from a tuning fork) have a single frequency or pitch.
- Pitch perception follows Weber-Fechner laws, common to many sensory areas:
 - Octaves – equal steps in perceived pitch - are a logarithmic function of the physical frequency.
 - Two-tone discrimination is a function of the frequency.

Loudness:

- Loudness also follows the Weber-Fechner law. Equal steps in perceived loudness correspond to geometric increases in physical sound intensity. Sound intensity is therefore expressed using a logarithmic scale, the decibel or dB (defined by Fechner, in the 1860's in honor of Alexander Graham Bell)

Absolute intensity of a sound I , in dB = $10 \log_{10} (I / I_{th})$

where I_{th} = intensity at the threshold of hearing (20 μ Pascals at 1 kHz).

- Huge working range of loudness: a factor of 5,000,000 in power – i.e. a factor of 10^{13} in pressure amplitude between the softest audible sounds and the loudest tolerable.

Most natural sounds – speech, animal calls, music – have complex mixtures of frequencies (think of a piano chord, hitting a number of keys simultaneously). The frequencies in natural sounds also constantly change (prosody in language; trills in bird song)

Sounds carry precise timing information. This, while not perceived directly, is used by our auditory systems to locate sound sources in space.

The auditory system is designed to extract and process all these salient features of sound – to encode pitch in octaves, loudness in decibels, timing to 10 μ s accuracy and, in higher auditory centers, features of complex sounds. This auditory processing occurs in a hierarchy of auditory centers in the brain, with these features of sound transformed, at relevant centers, into maps or “place” codes similar to maps in the sensory systems of vision and touch.

2. How the ear works, transducing (converting) sounds into nerve impulses:

The pathway external ear → middle ear → inner ear. Encoding frequency, loudness, timing.

Middle ear:

Matching sounds in air to the fluid in the inner ear.

Adapting to loud sounds

Conductive hearing loss

Inner ear

Cochlea → organ of Corti → basilar membrane + tectorial membrane + hair cells, inner & outer.

Basilar membrane

The basilar membrane as a set of piano strings, picking up vibrations at different frequencies.

Place map of frequencies: tonotopy, on a logarithmic scale.

Receptive fields and two-tone discrimination.

Cochlear amplification.

Hair cells:

Inner hair cells: for transduction, sending afferent information.

Outer hair cells: getting efferent innervation, for feedback.

How transduction happens: channels on inner hair cell hair bundle, opening under tension as the hair bundle moves; cation (mainly K^+) entry to depolarize cell.

Specializations: **a**: to sharpen frequency tuning, **b**: for high temporal resolution; **c**: to adapt to high intensity signals.

Sensorineural hearing loss: damage to hair cells. Cochlear prosthesis.

3. The central auditory pathway:

Auditory nerve → cochlear nuclei; starting the processing for different auditory features
Encoding frequency, loudness, timing.

Path out from the cochlear nuclei: Multiple pathways, possibly handling different features.

Binaural interaction.

Tonotopic maps at all points.

Locating sound sources, using timing and intensity between the two ears.

Auditory cortex: multiple (>15) tonotopic areas; complex auditory features

Language areas

Central lesions: more mixed, though a number of distinct aphasias

4. Plasticity:

How nerve properties and cortical maps can reorganize with sensory experience