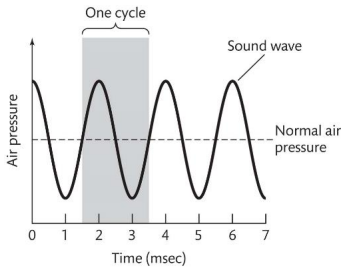
L11: AUDITORY AND VESTIBULAR SYSTEM

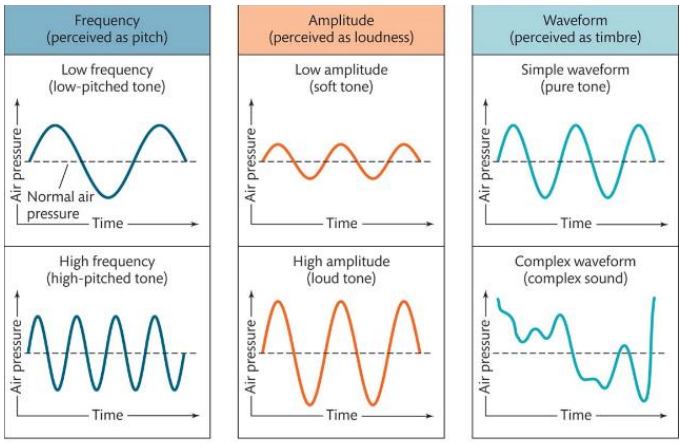
PHYSICAL AND PERCEPTUAL DIMENSIONS OF SOUND

- **Sound waves:** waves of pressure changes in air caused by the vibrations of a source.
  - **Cycle:** in a sound wave, a repeating segment of air pressure changes.



Three dimensions of sound

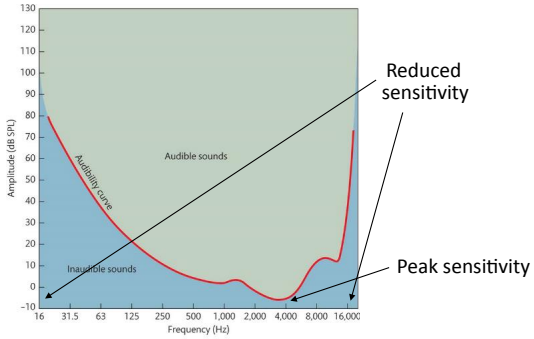
Physical Property	Perceptual Correlate	Unit of Measurement
Frequency (how close waves occur)	Pitch	Hertz (Hz) – cycles per second
Amplitude (height)	Loudness	Decibels (dB)
Waveform (quality)	Timbre	None



- The **frequency** of a pure tone is the physical dimension related to the perceptual dimension of **pitch** and expressed in **hertz (Hz)**.
  - Young adult sound detection range = ~20-20,000 Hz.
  - The loudest sounds a human can hear are approximately 1 million times the amplitude of the softest sounds that can be heard.
- **Amplitude:** difference between the maximum and minimum sound pressure in a sound wave; the physical dimension of sound that is related to the perceptual dimension of **loudness**.
  - **Loudness:** perceptual dimension of sound that is related to the physical dimension of amplitude; how intense or quiet a sound seems.
  - **Decibels (dB):** Physical unit used to measure sound amplitude; logarithmically related to sound pressure measured in micropascals.
    - Prolonged exposure above 85 dB can cause noise-induced hearing loss.

Audibility curve

- **Audibility curve:** the absolute threshold for hearing – relates physical amplitude to the perceptual loudness.
  - Absolute threshold is the intensity of the least intense sound that can be heard.
  - Auditory sensitivity is maximal in middle range – range of frequencies present in most human speech sounds.



- **Pure tones:** sound wave in which air pressure changes over time according to a mathematical formula called a sine wave, or sinusoid.
  - **Hertz (Hz):** number of cycles per second of a sound wave; the physical unit used to measure frequency.

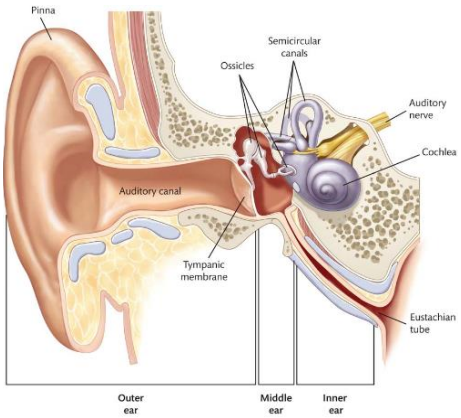
Fourier analysis

- Fourier proved that waveforms of most periodic sounds have a more complex shape than a sine wave.
  - **Fourier analysis** breaks down complex things to determine what its components are.
  - **Fourier spectrum** represents the Fourier analysis.
    - Things that aren't presented have no energy/ amplitude so don't show up on a spectrum,.
  - **Fundamental frequency** is the lowest represented amplitude frequency (base frequency) – the first five wave with an amplitude greater than 0.
- Example: even though the same notes are played on two different instruments, they do not sound the same.

- **Harmonic:** component frequency of a complex waveform that is an integer multiple of the fundamental frequency.
  - **Timbre:** difference in sound quality between two sounds with the same pitch and loudness.

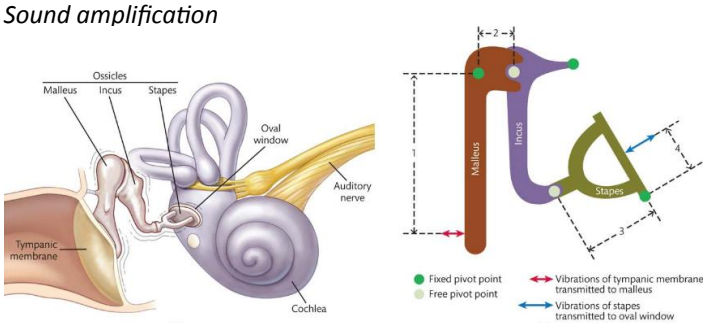
ANATOMY OF THE EAR

- **Ear:** peripheral part of the auditory system that transduces sound into neural signals that are sent to the brain.
  - *Three parts:* outer ear, middle ear, inner ear.



- **Pinna:** outermost portion of the ear; shape can modify incoming sound and contribute to sound localisation.
- **Auditory canal:** narrow channel that funnels sound waves gathered by the pinna onto the tympanic membrane and that amplifies certain frequencies in those waves and contributes to high sensitivity to those frequencies.
- **Tympanic membrane (eardrum):** thin, elastic diaphragm at the inner end of the auditory canal that vibrates in response to the sound waves that strike it; it forms an airtight seal between the outer ear and the middle ear.
- **Ossicles:** 3 small bones (malleus, incus, and stapes) in the middle ear that transmit sound energy from the tympanic membrane to the inner ear.
  - **Malleus:** transmits sound energy from the tympanic membrane to the incus.
  - **Incus:** transmits sound energy from malleus to stapes.
  - **Stapes:** transmits sound energy from the incus to the oval window.
- **Oval window:** membrane-covered opening at the base of the cochlea; vibrations of the membrane transmit sound energy from the ossicles into the cochlea.

Sound amplification



Two characteristics of ear anatomy that help compensate for loss of sound energy:

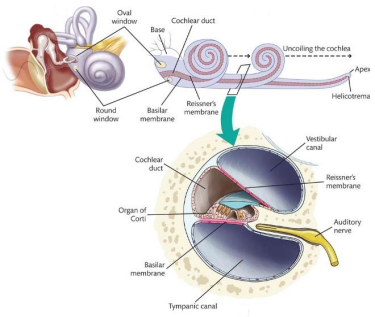
1) Larger size of tympanic membrane concentrates sound energy in much smaller area and effectively amplifies its effect.
2) Physical arrangement of ossicles produces a lever action that magnifies vibrations of tympanic membrane.

Eustachian tube

- Includes tube connecting the middle ear and the top part of the throat.
- Is normally closed but can be briefly opened (eg. by swallowing or yawning) to equalise the air pressure in the middle ear with the air pressure outside.

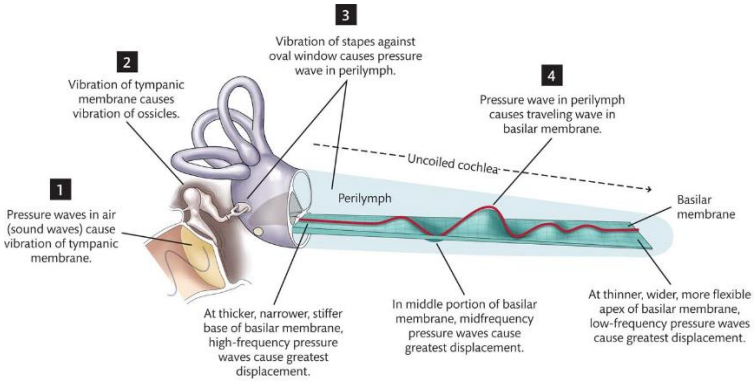
Cochlea

- **Cochlea:** coiled fluid-filled compartment, within the temporal bone of the skull.
- Contains **organ of Corti** – has mechanism to get a neural signal.

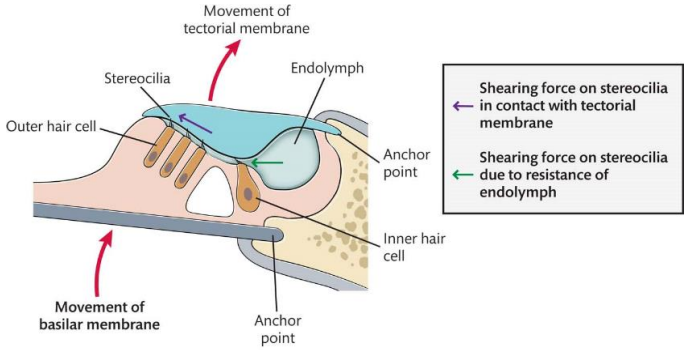


Basilar membrane

- Sound affects the basilar membrane:



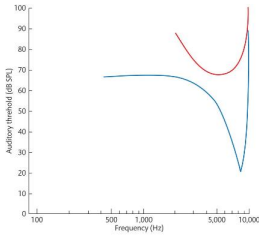
- When the basilar membrane moves, the stereocilia bend.



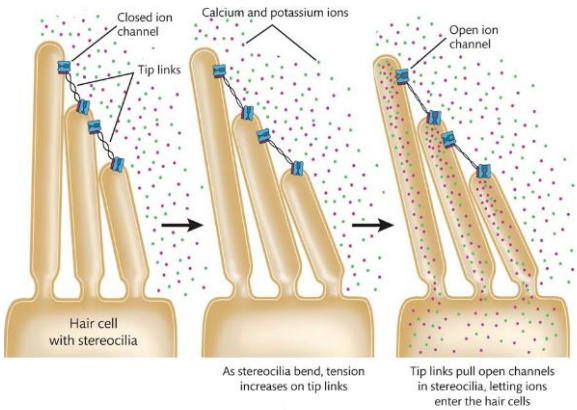
Critical components of Organ of Corti

Inner hair cells	Outer hair cells
– Pear-shaped	– Cylindrical
– Tips of stereocilia float free in endolymph	– Tips of stereocilia attached to tectorial membrane
– Responsible for transducing sound into neural signals	– Serve to amplify and sharpen responses of inner hair cells
– Connected to Type I auditory nerve fibres	– Connected to Type II auditory nerve fibres

- Outer hair cells and auditory transduction:
  - Tuning curves for an auditory nerve fibre with a
  - characteristic frequency of 8,000 Hz before (blue) and after (red) destruction of the outer hair cells by chemical injection.

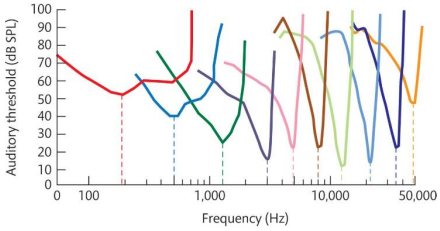


- Tip links of inner hair cells open ion channels (mechanical distortion results in AP in auditory nerve fibre).



NEURAL REPRESENTATION OF FREQUENCY AND AMPLITUDE

- Auditory system mechanisms are used to encode frequency in the neural signals sent to the brain.
- Frequency is represented by:
  - **Place code:** suggests that the neurons' firing rate matches where the fluid moves maximally within the cochlea (base and apex differences).
    - Frequency tuning of Type I auditory nerve fibres can be almost entirely accounted for by the frequency tuning of the basilar membrane (mechanical factor).
    - Place code provides relatively better frequency representation of high-frequency sounds than of low-frequency sounds.

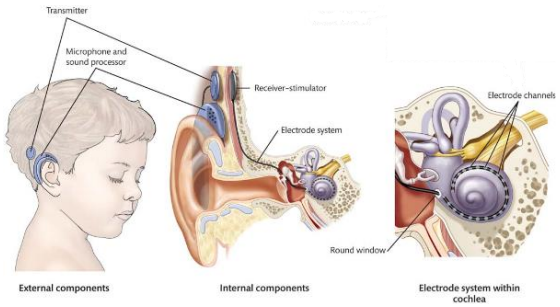


    - Correspondence between the characteristic frequency of auditory nerve fibres and the position in the organ of Corti provides strong evidence for place coding in frequency representation in the cochlea.
  - **Temporal code:** suggests that the neurons' firing rate matches the cycles per second (Hz).
    - Works only for lower frequency (~20-4,000 or 5,000 Hz) due to limitations in cell firing rates and their ability to work collectively.

Temporal code	Place code
– Based on a match between the frequencies in incoming sound waves and the firing rates of Type I auditory nerve fibre – Can precisely represent frequencies up to ~5,000 Hz.	– Based on mechanical properties of basilar membrane – Supported by location of auditory nerve fibres by frequency sensitivity – Can represent frequencies above ~5,000 Hz

APPLICATIONS

- **Cochlear implants:** designed primarily to help deaf or severely hearing impaired individuals hear speech.
  - External components: consist of a microphone, sound processor, and transmitter.
    - Essentially performs a Fourier analysis on sounds.
  - Internal components: consist of a receiver–stimulator and an electrode system that spirals around the cochlea and stimulates auditory nerve fibres, using both place coding and temporal coding.



THE VESTIBULAR SYSTEM

- Perceiving **balance** and **acceleration** – information provided by semicircular canals and otolith organs.
- Vestibular system has two main divisions:
  - **Semicircular canals:** rotary motion/balance.
  - **Otolith organs (utricle and saccule):** linear acceleration/ head tilt.
- Movement of hair cells is ultimately responsible for sending signals in each of the systems.
  - Semicircular canals sit on specific planes – movement of fluid and bending of stereocilia indicate the rate of acceleration, and head orientation.