Biophysics of hearing

Hearing is the ability of animals to *perceive sound using a specialized organ* - **the ear**. We distinguish *two types of sound conduction*: **bone conduction** and **air conduction.**

Air conduction is the conduction of sound through *the ear canal – ear drum – auditory ossicles – oval window*. In addition, it is possible to oscillate the fluids in the *inner ear* by direct transmission of vibrations of the *skull bones* - in this case we are talking about **bone conduction**. The **hearing threshold** for **bone conduction** in a healthy person is about **40 dB higher** than the *threshold for air conduction*, so bone conduction is mainly used where air conduction is *impaired*. A healthy person uses bone conduction when *perceiving his own voice or very strong sounds*.

The human ear is able to perceive sounds with a **frequency of 16 Hz–20 kHz** , a level of **0 dB** (hearing threshold) to **130 dB** (pain threshold).

Brief anatomy of the auditory system

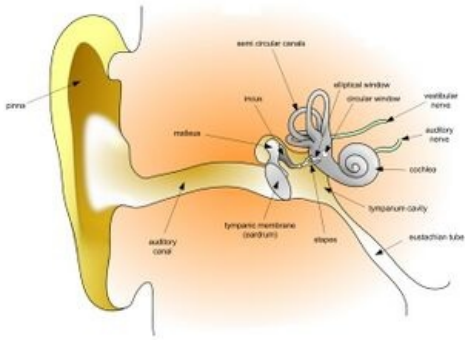
For a correct understanding of the hearing process and for a simpler description of the individual phases of sound conduction by the ear, it is necessary to at least lightly outline the **anatomical structure**.

The human ear consists of **three parts:**

1. **External ear** (auris externa)
2. **Middle ear** (auris media)
3. **Inner ear** (auris interna)

External ear

The external ear consists of the **pinna** (auricula), the **external ear canal** (meatus acusticus externus) and the **ear drum** (membrana tympani).



Auditory system

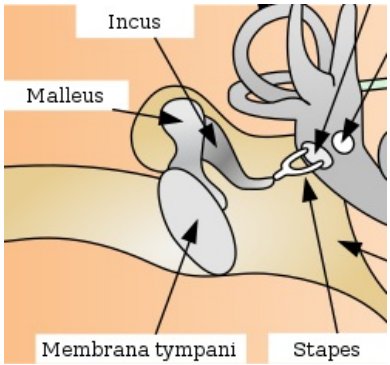
The *auditory pinna* is rudimentary in humans and its function is *minimal*. Unlike other mammals, the muscles of the human auricle are *without functional significance.* Their innervation is from **n. VII**.

The external ear canal is a partly **cartilaginous** and partly **bony tube**, beginning at the *porus acusticus externus* and ending at the *eardrum*. Its base is the **os tympanicum**. The narrowest point *(isthmus)* of the external ear canal is at the interface between the cartilaginous and bony sections and has a *diameter of 6–8 mm*. The **total length** of the external ear canal is **24–35 mm.**

The *tympanic membrane* separates the external ear canal from the middle ear cavity. It is a *thin oval membrane (9 x 10 mm)* with a *thickness of 0.1 mm*. The *auditory ossicle*, the *malleus*, connects to the *eardrum in the middle ear*.

Middle ear

The middle ear is located in **the middle ear cavity** (cavitas tympanica). It contains **3 auditory ossicles**: **malleus, incus, stapes.**



Auditory ossicles

The auditory ossicles are interconnected. The *malleus* is attached to the *eardrum*, followed by the anvil, on which the stirrup fits, which is connected to the membrane of the *fenestra vestibuli (fenestra ovalis).* The *middle ear* is connected to the *nasopharynx* by the **Eustachian tube (tuba auditory)**. *Auditory muscles* also play an important role in the middle ear: the **tensor tympani muscle** (innervation of the **V and VII nerves**), **m. stapedius** (innervation of **n. VII**).

Inner ear

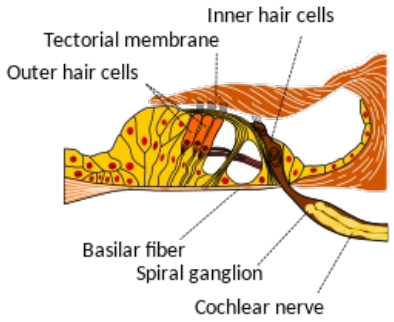
The inner ear includes a **bony labyrinth** (labyrinthus osseus) and within it a **membranous labyrinth** (labyrinthus membranaceus), which contains **endolymph**. The labyrinth has an *equilibrium part*, consisting of the *vestibule and three semicircular canals*, and an *auditory part*, which is represented by a *bony and membranous cochlea* (cochlea) with a receptive *auditory organ of Corti*, located on the *basilar membrane* (length about 3 cm). **The auditory pathway** runs from the ganglion cochleare to the upper part of the **temporal lobe** (the convolutions of Heschl).

Structue of the organ of Corti

The organ of Corti (organum spirale) is a complex system of **supporting and sensory cells**. The basis of the organ is two rows of supporting *cylindrical pillar cells* (cells of Corti), which together form the **tunnel of Corti**.

Sensory (hair) cells are located on either side of the pillar. *Medially* there is one row *(inner hair cells)*, *laterally* there are three to four rows of hair cells *(outer hair cells)*.

There are *1,500 inner hair cells*. Their apical surface contains *50–60 stereocilia* , which are in contact with the **membrana tectoria**. *Outer hair cells* are found in the number of *12–15,000,* they are also equipped with *stereocilia.* In the basal part, they are in contact with **afferent and efferent fibers**.



Organ of Corti

Biophysics of hearing

The sound wave is directed through the **pinna** into the **external auditory canal.** The pinna, as already mentioned, is rudimentary, and its loss will not fundamentally affect hearing. The **external auditory meatus** carries the captured sounds to the **eardrum**, which impinges on it and **vibrates it**.

The deflections of the eardrum are *very small* (at a frequency of 1 kHz, about 10 −11 m). The area of the *eardrum* is about *55 mm*^{2} and the area of the *membrane window* to which the vibrations are brought by means of the ossicles is only 3 mm^2.

If we assume that the energy passing through both surfaces is *the same*, the *acoustic pressure* reaches the surface of the oval window *many times greater (about 22x).* This is necessary to **overcome the acoustic resistance** of the fluid in the cochlea. As *auxiliary systems*, the Eustachian tube and ear muscles are *used in the middle ear*, which **equalize the pressure on the eardrum** from the inside to *prevent it from rupturing*.

Oscillation of the oval window is caused by **vibrations in the endolymph** (incompressible fluid), which are further *amplified* by vibrations from the **bone conduction**, which reaches it through the bones of the skull . With its vibrations, the endolymph vibrates the *membrana tectoria,* which subsequently *irritates the stereocilia* of the inner hair cells. These release a small amount of *mediator* (probably glutamate) in the basal part of the cell, which creates a **nerve signal**.

The outer hair cells have an **amplifier function**. When they are irritated, there is an *elongation and subsequent contraction* of the cells, which increases the sensitivity of the inner hair cells. This mechanism allows *very quiet sounds* to be heard.

Links

External links

- sound transmission by ear and its processing (https://www.youtube.com/watch?v=PeTriGTENoc)
- a simplified principle of ear function (https://www.youtube.com/watch?v=flIAxGsV1q0)

References

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