Structure and function of the ear

Two different senses are located in the ear:
the sense of hearing and the sense of balance.

- Human beings use their sense of hearing to perceive sound waves in the shape of music, speech, sounds, etc.
- Human beings use their sense of balance to recognize their spatial position and movements.

Entire ear

The **entire ear** consists of three sections:
the outer ear, the middle ear, and the inner ear.
The **hearing organ** is composed of:
the outer ear, the eardrum, the middle ear, and as part of the inner ear – the cochlea. The cochlea has two openings, which are covered with a thin membrane. They are named after their shape, namely, the round and the oval window.
The **sense organ of balance**
is also located in the inner ear. It consists of the semi-circular canals and the vestibule of the inner ear.

Outer ear

The outer ear consists of the **pinna** and the **ear canal**.

Pinna

The pinna is composed of cartilage and is covered with a fold of skin that surrounds the exit of the ear canal.
The pinna varies greatly from individual to individual, as is characteristic for rudimentary organs or parts of organs. The differences are based on the shape and curvatures of the cartilage. The human pinna does not have a very marked roll at the top edge, something that is considerably more developed in lots of animals (rodents, bats, horses etc).
The **earlobe,** in contrast, is typical of human beings and otherwise is found only in a much-reduced form in apes. It is composed of fatty tissue and not cartilage.
The **pinna** works, to a certain degree, together with the ear canal, like a sound funnel, i.e. it has an amplifying effect. However, size and shape of the pinna are not important for the hearing process. People with ears that stick out, for example, hear just as well as people with ears that do not stick out. Floppy ears may be aesthetically not so pleasing but they are in no way harmful. A total lack of a pinna may make a difference to hearing, possibly through a reduction of directional hearing. With spatial hearing, the sense of hearing evaluates, among other things, the composition of frequencies, and consequently the sound, which changes according to the direction of incidence.
Many animals can vary the **position of the pinna** by moving muscles (a cat, for example, pricks its ears up). Human beings do have these muscles (musculi auricularii), but they are rudimentary, i.e. they have involuted through the course of evolution. That is why not everybody can waggle their ears.

Ear canal

The **ear canal** is up to 3 cm in length. It follows a spiral course and has two bends. In order to see the eardrum at the end of the ear canal, it is necessary to pull the pinna back and up. Because of its length, shape, and volume, the ear canal has very good resonance for sounds of around 3 000 Hz. The speech-frequency range is thus increased in the ear canal.
In the wall of the ear canal, there are hair follicles and sebaceous glands: the **sebaceous and ceruminous glands** combine to produce a brownish wax-like substance (cerumen). The **hair follicles** are cylindrical folds of skin, out of which the hairs grow. The hairs in the ear serve to a slight extent to prevent water or foreign bodies from entering the ear canal.

Middle ear

The middle ear consists of the eardrum and the air-filled tympanic cavity with the ossicles.
The **eardrum** is a 0.1-mm thick membrane that separates the ear canal from the middle ear. A ligament to the malleus joins it. That makes it taut and it has the shape of a funnel.
(This tautness makes it more sensitive to high frequencies.)
The **Eustachian tube** connects the tympanic cavity to the back of the nose and throat (nasopharynx) and makes it possible to equalize pressure.

Tympanic cavity with ossicles

The tympanic cavity is an air-filled cavity surrounded by bone. The three ossicles (malleus, incus, and stapes) are located there.
The **malleus** is attached to the eardrum, the wall of the middle ear, and the incus. The joints between the ossicles are loose.
The **incus,** for its part, is attached to the stapes via small joints.
The **stapes** has a footplate, which is seated in an opening of the inner ear called the oval window.
The ossicles' task in the hearing process is to pick up the vibrations of the eardrum and to transmit them to the oval window of the cochlea in the inner ear.

Eustachian tube

The Eustachian tube serves to ventilate the middle ear and connects the tympanic cavity to the back of the nose and throat (nasopharynx). It is normally closed, and opens only when a person swallows or yawns. This will ensure that air pressure is equal on both sides of the eardrum.
Sometimes the Eustachian tube cannot open properly anymore, for example when a person has a cold, or in the event of quick changes of air pressure (when flying, or in tunnels). This may lead to lower pressure in the tympanic cavity because the mucous membrane of the tympanic cavity uses up oxygen. The low pressure causes the eardrum to tighten, so that it cannot vibrate efficiently. Hearing ability is greatly reduced as a result. In such cases, conscious swallowing or yawning should cause the Eustachian tube to open, thus equalising air pressure in the tympanic cavity.

Crucial role of the middle ear in the hearing process

If sound were to hit the oval window of the cochlea immediately, it would lead to almost 100% reflection. The seemingly very complicated construction of the middle ear prevents this reflection and thus enables us to conduct virtually all the sound energy to the cochlea. It is a well-known fact that in the animal kingdom, too, animals with a well-developed middle ear like dogs or desert foxes hear particularly well.

Inner ear with hearing organ

Both the **sense of balance and the sense of hearing** are situated in the inner ear.
The inner ear lies in a complicated cavity system of the petrous bone, which is part of the temporal bone. This system of bony tubes is known as the "bony labyrinth".
The bony labyrinth consists of three parts: the vestibule, the three semi-circular canals and the cochlea.
The **sense of hearing is in the cochlea**, and the sense of balance in the vestibule and in the semi-circular canals.

The cochlea

The **cochlea,** with a length uncoiled of about 32 mm, is that part of the bony labyrinth where the sense of hearing is situated. It has two and a half coils and consists of three fluid-filled chambers separated longitudinally by membranes.
The cochlea has two windows facing the tympanic cavity: the oval, and the round windows. There is a thin membrane in front of each of these two windows.
The footplate of the stapes lies in front of the **oval window**. Sound is introduced via this window.
The **round window** is covered with a membrane. This window, or rather the elastic membrane, serves as a kind of "sound exit". If the end of the cochlea were "hard", it would reflect the sound, and there would be echoes in the ear.
The cochlea consists of two winding canals, one of which is bony and the other membranous. These canals are also known as the "membranous” and the “bony” cochlea.
The **bony cochlea** is divided into an area leading upward and another leading downward.
The part beginning at the oval window, leading upwards, is called the **scala vestibuli**. This is where the sound is introduced.
The part leading from the tip of the cochlea down to the round window is called the **scala tympani**. This is where the sound makes its sort of "exit".
Between these two scala in the bony cochlea, there is a thin tube, the **membranous cochlea,** which appears triangular-shaped in cross-sections. It is filled with fluid called **endolymph**.

The organ of Corti, with the cochlear hair cells

The organ of Corti, which is the actual hearing organ, is situated in the middle chamber of the membranous cochlea. It is made up of the basilar membrane, hair cells, and the tectorial membrane. The hair cells lie on the basilar membrane, seen longitudinally: an inner row of 5,000 cells and three outer rows of altogether 15,000 cells. The tectorial membrane encapsulates these hair cells.
If a sound signal is introduced as a travelling wave via the oval window to the vestibular canal, its movement is conveyed to the basilar membrane. The movement of the endolymph causes relative movement to the tectorial membrane. The hairs that lie in-between (cilia) are stimulated, or they are pushed against the tectorial membrane. That sets off an electrochemical process in the sensory cells that leads to the auditory centre of the brain through electrical charges from the sensory cells via the sensor neurons to the auditory centre of the brain. This is done with the help of the hair-like extensions of the sensory cells, which are connected with the gelatinous tectorial membrane. At their bases, these hair cells are connected with nerve VIII, the auditory nerve.
It is not until the impulses actually reach the brain that the left and right ear actually work together; this is the perception, recognition, interpretation and possibly understanding of the sound signal.

Vestibule and semi-circular canals of the sense-of-balance organ

The inner ear contains both the organs of hearing and of balance, with the vestibule and the semi-circular canals. With the organ of balance, distinction is made between the **sense of position** and the **sense of rotation**:

- The **sense of position** consists of the **vestibule** with its two sacs, called the utricle and the saccule, used for perception of **spatial position** und **linear movements**.
- The **sense of rotation** consists of the three semi-circular canals, which are for the perception of **rotational movements**.

Sense of position (vestibule)

The vestibule consists of two interconnected sacs: the utricle and the saccule.
Each of these contains endolymph and a gelatinous mass (cupola), which contains calcium carbonate crystals. The gelatinous mass forms a bed for sensory hairs.
Both the gelatinous masses (cupola) are perpendicular to each other.

This is how the sense of position functions:

- Changes in the position of the head cause the **gelatinous mass (cupola)** to move.
- The **calcium carbonate crystals** in the cupola are like a kind of "ballast" which increases the sensitivity for the perception of gravity. (The endolymph surrounding the cupola is like a hydraulic absorbing element, similar to the liquid filling of a good compass.)
- This movement of the crystals and the cupola causes the **sensory hairs** to be stimulated. Every movement of the head’s position leads to a change in the cupola, and as a result, the sense of position is stimulated.
- This stimulation of the sensory hairs produces an electrical charge in the sensory cells, a **nerve impulse**.
- This nerve impulse is transmitted to the **brain** and evaluated there. In coordination with the sense of sight and the sense of touch (effect of gravity on the surface of the skin, for example soles of the feet), the change in position or the actual position is recognized.

Sense of rotation (three semi-circular canals)

If you rotate quickly and then stop abruptly, the endolymph continues to flow for a while, The three semi-circular canals of the sense of rotation are oriented at right angles to each other, so they correspond to a 3D system of coordinates. The semi-circular canals begin and end in the vestibular region. They contain "endolymph", which moves back and forth in the respective canal, depending on movement of the head.
The movement of endolymph, which is registered in the so-called ampulla, occurs when the body rotates. Each semi-circular canal has dilation called ampulla, which is directly connected to the vestibule. The ampulla contains a gelatinous mass, out of which fine sensory hairs project. These sensory cells lead to nerve cells, which in turn, are connected to the brain.
The semi-circular canals help human beings to perceive rotational movements:
During rotation of the head, the liquid (endolymph) moves in the semi-circular canals. The movement sets the gelatinous mass in motion, where the sensory hairs are stimulated. This stimulation of the hairs leads to a stimulation of the nerve cells. These nerve impulses are then transmitted to the brain, which then recognizes the rotation of the head.
If you rotate slowly around your own axis, the endolymph moves with you, stopping when you stop. which means that the sensory hairs continue to move as well, although the rotational movement of the body has stopped. This is the cause of dizziness.