Psychoacoustics

Physics and cognition

Psychophysicists are able to explain the physiological functioning of our hearing system.
It is known how auditory sensations are generated from the formal definition of sound.

The cognitive functions are still under study and it is not clear how the signals from the two ears are mixed to produce the sensation of music.

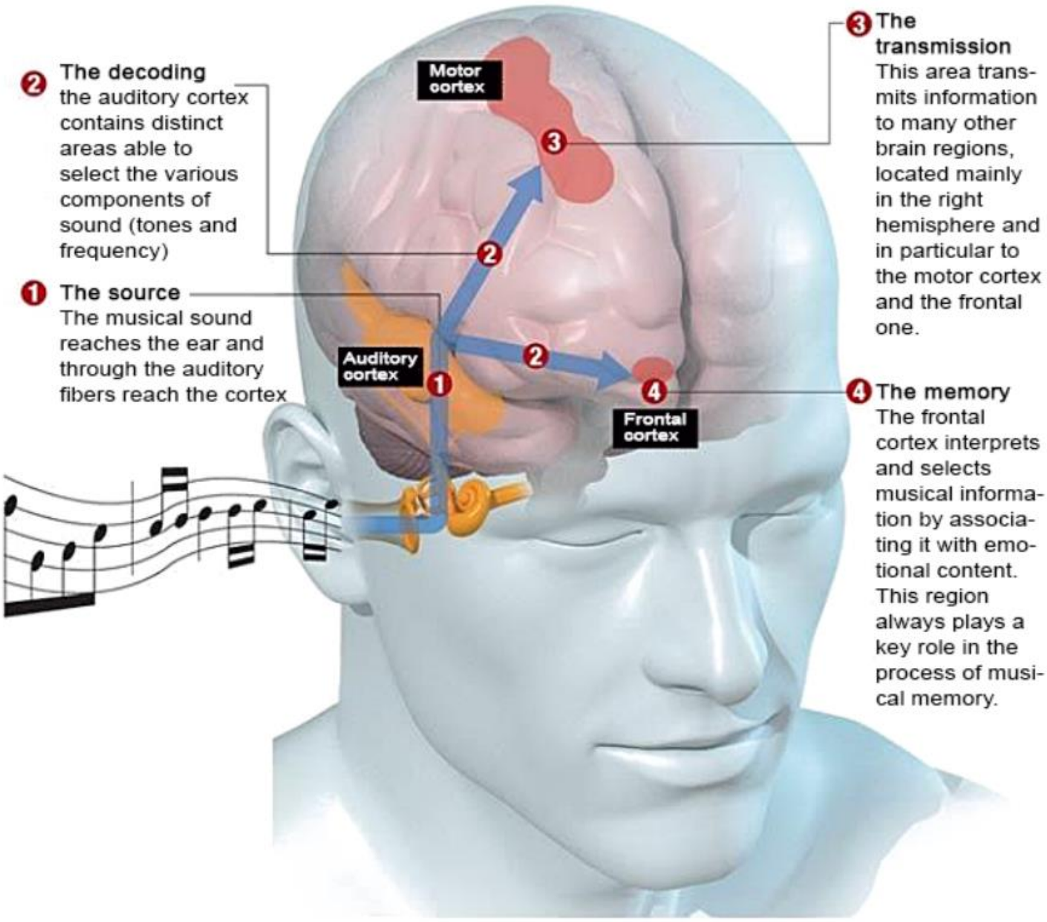
Tasks of the auditory system

The human auditory system has a complex structure and performs very advanced functions. Not only is it able to process a large set of stimuli, but it can precisely:

1. Understanding the sound message
   → Understanding of language

   → recognition of the type of sound source

   → listening to music
2. Reconstruction of the spatial map of sound sources
   → Localization of surrounding objects (also in movement)
3. Understanding the nature of the surrounding environment

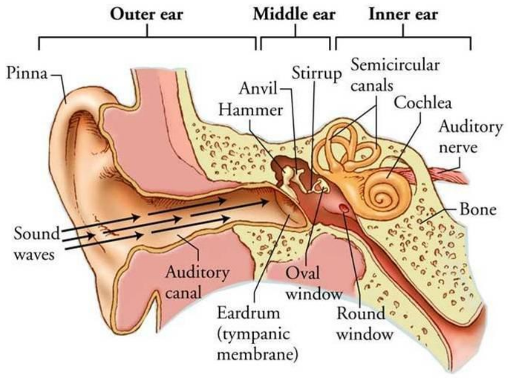


Physiology of hearing

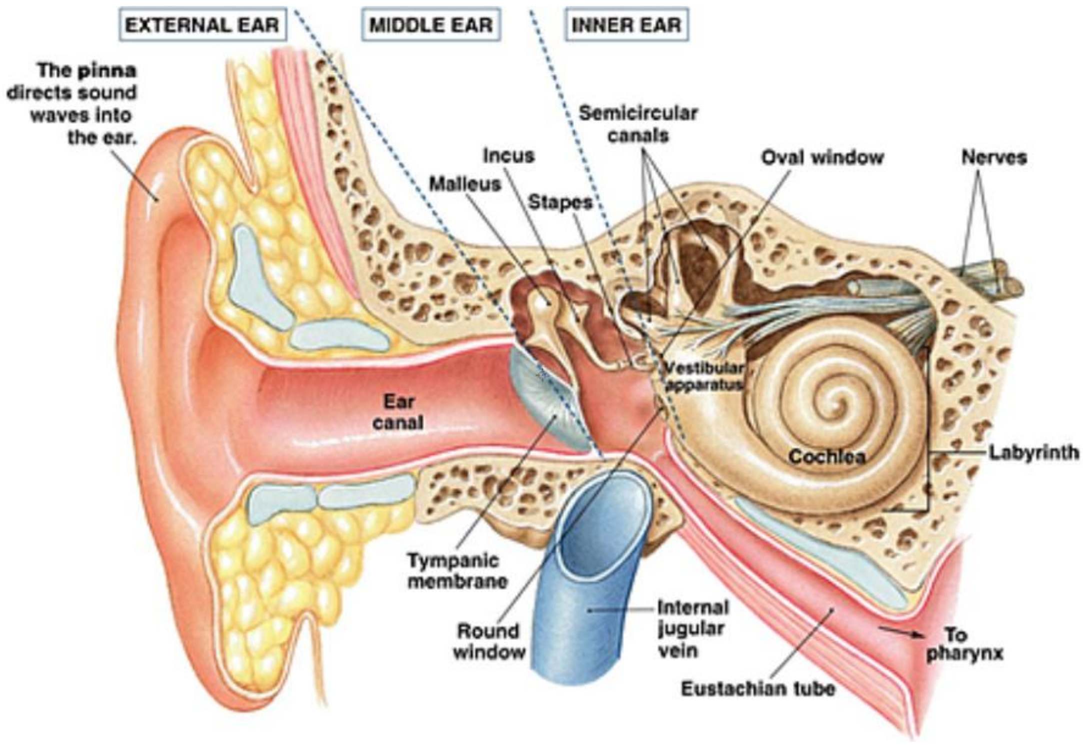
The task of the ear is to convert air pressure fluctuations into electrochemical nerve impulses that can be processed by the brain.

Anatomy

The ear is often divided into three main parts: the outer ear, the middle ear and the inner ear.



The outer ear is formed by the outer fin and the auditory canal (meatus). The middle ear begins with the tympanic membrane, to which the first of the three ossicles (called hammer, anvil and stirrup) is attached which make up this stage. The task of the latter is to amplify the motion of the eardrum (they form a system of levers) and to transfer it to another membrane, the oval window. With the oval window the inner ear begins, formed mainly by the cochlea. The cochlea contains the mechanisms to transform pressure changes at the eardrum into nerve impulses that are interpreted by the brain as sound.



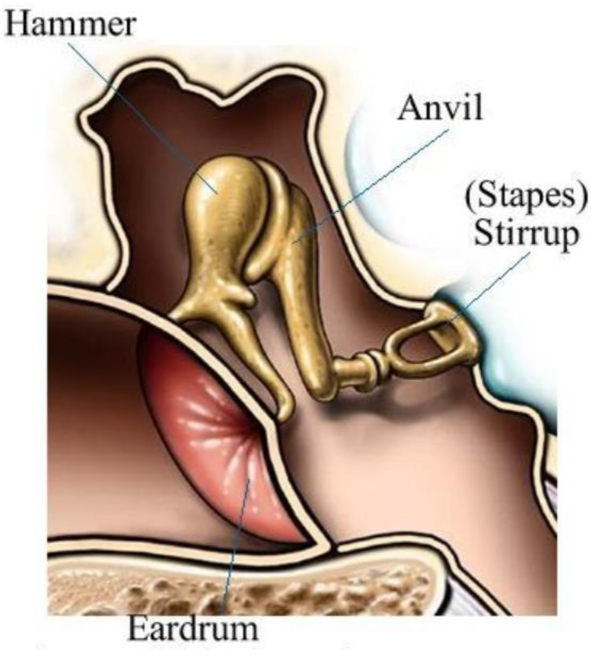
- The outer ear consists of auricle, earlobe and auditory canal. Its most important function is the directivity, that is the recoding of spatial to temporal / spectral information.
- The middle ear consists of a lever apparatus with three auditory ossicles (hammer, anvil, stirrup). Its most important function is the impedance matching and the protective function of the stapedius reflex.

- The inner ear consists of cochlea and equilibrium organ. Its most important function is the frequency-local transformation by a traveling wave on the basilar membrane, on which the Corti organ is.

Ossicles

The ossicles are, in order from the eardrum to the inner ear (from the outside to the inside of the skull), the hammer, the anvil and the stirrup.

• The hammer articulates with the anvil and is attached to the tympanic membrane that transmits motion to the chain of ossicles.
• The anvil is connected to both other ossicles.
• The stapes is articulated with the anvil and is connected to the membrane of the oval window, the elliptical or oval opening existing between the middle ear and the vestibule of the inner ear.

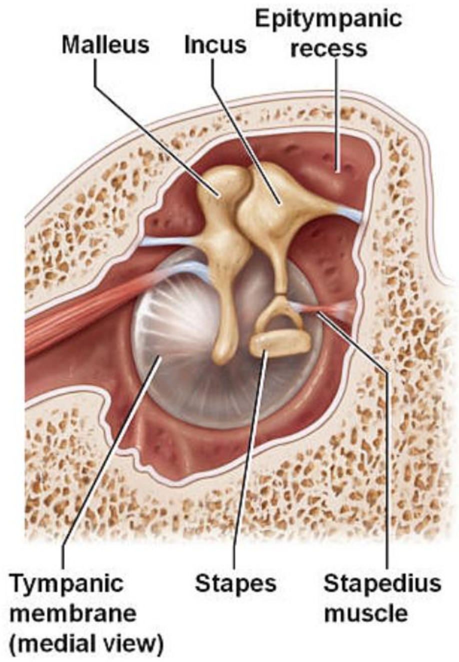


When the sound waves make the tympanic membrane (tympanum) vibrate, it sets in motion the handle of the hammer, to which it is solidly tied. The head of the hammer consequently vibrates in turn, transmitting the sound to the other two ossicles. The vibration of the base of the stirrup through the oval window sets in motion the Perilymph of the vestibule and therefore of the cochlea, causing the movement of the cilia of the sensory cells present here. The ossicles allow the vibrations of the eardrum to be transmitted without reduction of strength to the oval window. However, the extent of the movements of the ossicles is controlled (and regulated) by some muscles connected to them (the tympanic tensor and stapedius).

Stapedius muscle

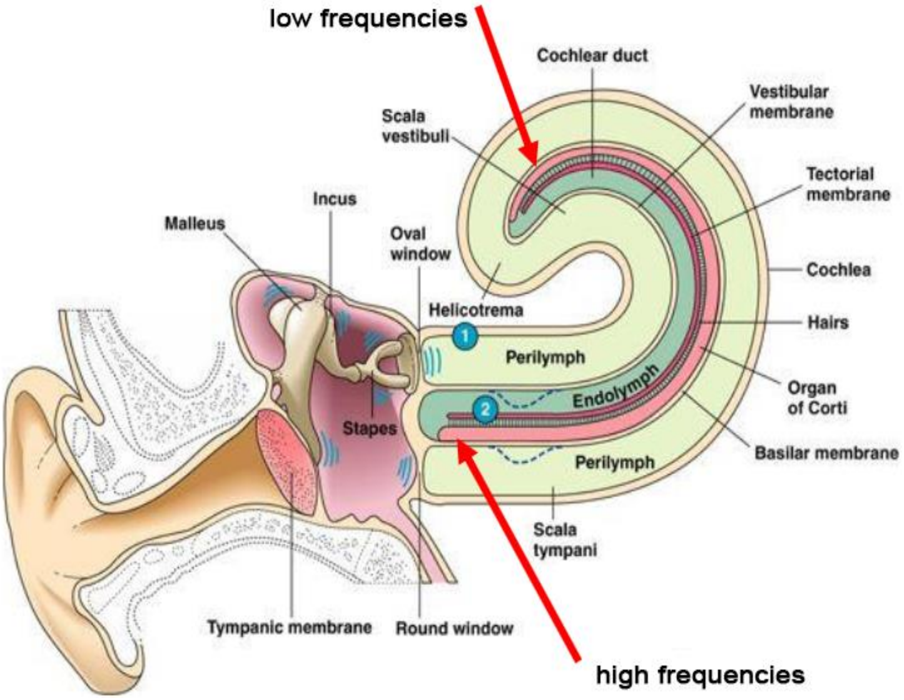
The stapedius is the smallest of the striated muscles of the human body and has an appearance whose fibers agree on a central tendon.

With just one millimetre in length, its purpose is to stabilize the smallest bone in the body: the stapes. The stapedius is located in the middle ear and has the task of preventing excessive movement of the stapes, thus helping to control the amplitude of sound waves from the external environment into the ear. It is comparable to the role of the tensor tympanic muscle, which primarily weakens those sounds associated with chewing.



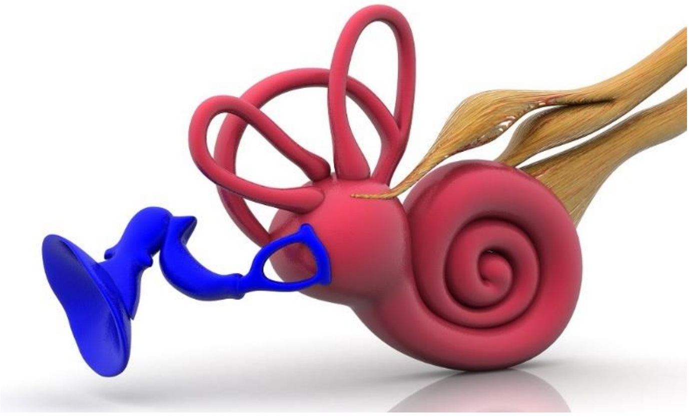
Cochlea

The cochlea helps us to perceive the height (pitch) of a pure sound.



This organ consists of a cavity divided in two by a membrane (basilar membrane) and containing an incompressible liquid (Perilymph) that passes from one side to the other of the membrane through an opening. The vibrations transmitted by the middle ear to the oval window are transmitted to the fluid of the cochlear duct, which in turn causes a movement of the basilar membrane similar to that of a flag. The cochlea is filled with a watery liquid, the Endolymph, which moves in response to the vibrations coming from the middle ear via the oval window. Along the basilar membrane, about

30,000 nerve receptors (hair cells) convert the membrane motion into signals that are in turn transmitted to the neurons of the acoustic nerve.



The inner ear also contains the organ of balance (**vestibular apparatus**). The organ of balance comprises three semicircular canals (ductus semicirculares). Each of the semicircular canals has a so-called sensory ledge on which the sensory cells (cristae ampullares) lie. The archways are each perpendicular to each other at a 90 ° angle and thus capture the three dimensions of the room.

Summary

The outer ear: It has a pavilion that acts as a funnel to convey the sounds inside the auditory meatus, especially the high-frequency ones.

The middle ear: Solves problems due to different resistance between the air in the outer ear and the fluid in the cochlea. It amplifies the perception of weak signals and reduces the risks associated with loud sound with high frequency.

The inner ear: The cochlea it contributes to the resolution of different pitches. It generates nerve signals and transmits them to the cortex. Through the labyrinth (vestibular apparatus) it allows balance.

The hair cells: They flex in quantities proportional to the amplitude (intensity) of the vibration.

Noise Tolerance Thresholds

Regarding the protection of health and safety in the workplace, "based on current knowledge, noise exposure up to 80 decibels is not considered at risk. The fundamental regulatory reference in the field of noise risk prevention is the legislative decree 81/2008 which prescribes the "minimum requirements for the protection of workers against health and safety risks deriving from exposure to noise during work".

In particular it establishes “three levels of exposure (80, 85 and 87 decibels, i.e. the average value, weighted over time, of the levels of exposure to noise for a working day) and the corresponding obligations to which employers are required if they are exceeded the levels themselves.

Regulations

If the exposure is higher than 80 decibels:

- Provision of Personal Protective Equipment (PPE) by the employer

- an obligation to train and inform workers about the risks arising from the noise exposure, the actions taken and the proper use of the equipment

If the exposure level is higher than 85 decibels:

- compulsory use of Personal Sound Amplifier (PSA) for the hearing impaired

- Obligation to educate and inform workers about the hazards of noise

- Health check

If, even employing the PPEs, the exposure level is higher than 87 decibels:

- take immediate action to bring the exposure back below the limits (protective devices and / or interventions in equipment, structures or environments)

- identification of the causes of excessive exposure

- Modification of protection and prevention measures to prevent a recurrence of the situation

Sound - Human perception

The perceptual quantities with which a sound is usually described are volume, height and timbre.

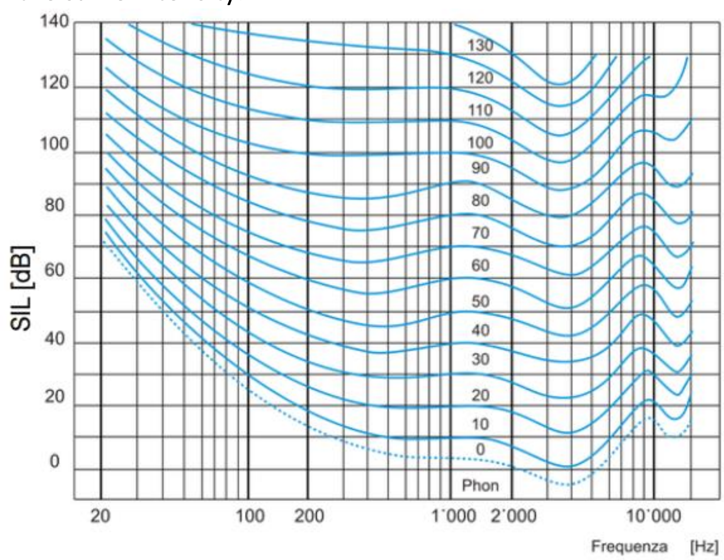
Quantity	Perception
Frequency	Sharp or severe sound
Amplitude	High or low volume
Spectrum	Timbre or harmony of sound

The volume of sound is the direct perceptive correlation of sound intensity. Frequency is mainly responsible for the height sensation of a sound. For complex sounds the perceived height depends directly on the fundamental frequency of the sound, but there are cases in which this frequency is not present in the spectrum and is completely reconstructed from our perception (we speak of phantom frequencies). Finally, timbre has a direct physical correlation of the spectrum or waveform of sound in the domain of frequency or time.

Diagram of Fletcher-Munson

Sound intensity is a physical quantity that, objectively, measures the flow of energy carried by the sound wave. This quantity does not correctly describe the perceived intensity (loudness), as it depends on the frequency of the sound and, to a lesser extent, the timbre itself.

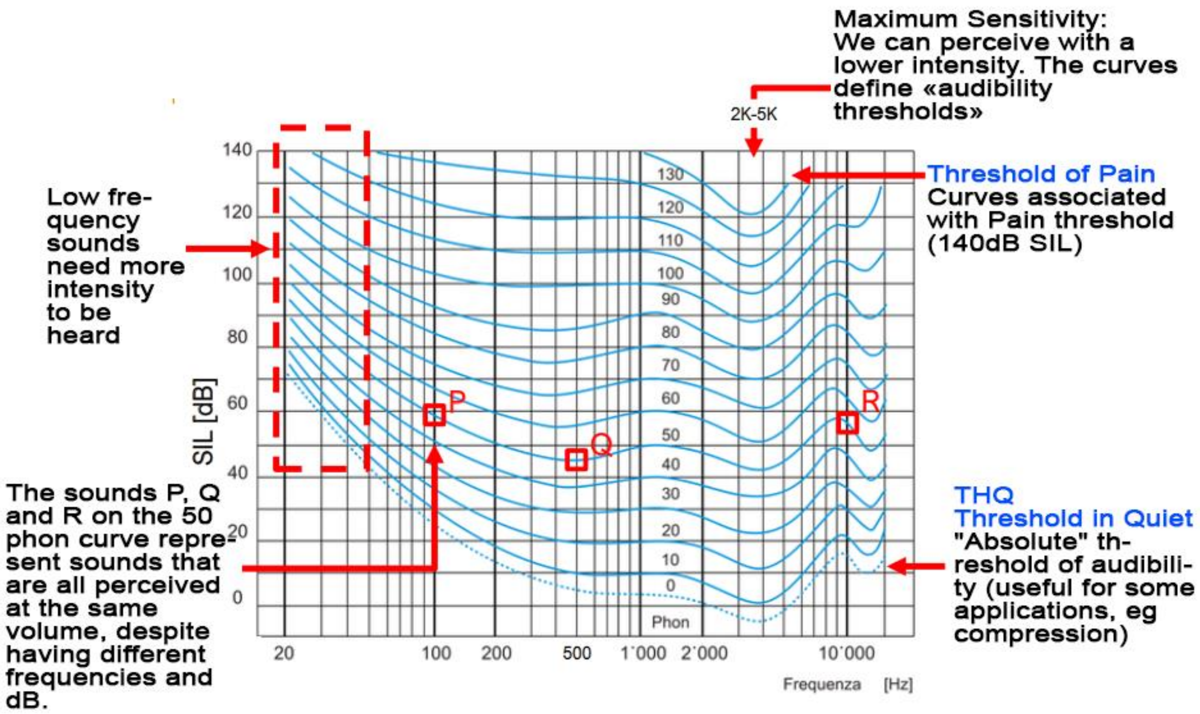
A complex relationship to the sound intensity is produced by the perceived intensity. The representation using isophonic curves is used to describe this. The frequency changes the geometric position of the points for which the perceived intensity is constant. It was obtained by asking the listener, while listening to sounds of different frequencies, to adjust the volume knob so as to perceive them with the same intensity.



The Fletcher-Munson normal audiogram, it is the result of studies carried out on a large number of individuals with normal and defect-free hearing.

It is limited inferiorly by a curve that corresponds to the threshold of audibility and superiorly to three types of curves called: threshold of the disturbance, threshold of pain and threshold of hearing damage that naturally cannot be determined experimentally, as this would be harmful. The area between the threshold of audibility and that of pain is called the normal area of audibility. To trace the audiogram, comparisons were made between a series of pure tones, scattered throughout the frequency band, and a pure reference tone with a frequency of 1000 Hz.

A sound has a volume of x phon, if a 1000 Hz sound that is struck with the same volume has an intensity of x dB.
For example, the sound pressure value corresponds to the 40 phono isophonic curve, for a pure sound with a frequency of 1000 Hz, it is equivalent to 40 dB while at the 500 Hz frequency it is approximately 38 dB

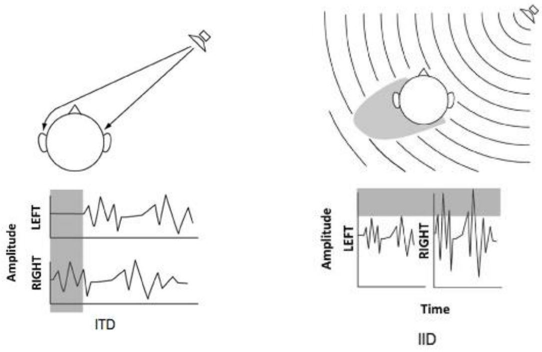


Each curve provides a different value of the subjective intensity level, whose unit of measurement is the hair dryer. The isophonic elements are graphically quite similar to each other but they are never superimposable, and their shape shows the strong non-linearity that characterizes human hearing. From the audiogram we can see how the human ear is more sensitive to medium frequencies between a few hundred and a few thousand Hz.

Place of sound sources

Through binaural hearing, that is, with both ears, our perception system is able to compare the physical properties of the sound that reaches the two ears. From this comparison, we get information about the position of the source that created it.

Example: Imagine we have a speaker that makes a sound, and a listener who turns his head so that his right ear is closer to the speaker than the left one.



Interaural Time Difference (ITD)
Interaural Intensity/Level Difference (IID o ILD)

In this situation, two effects occur:

• Since the right ear is closer than the left ear, the sound is previously recorded earlier via the right auricle. The difference in the arrival times of the sound is called ITD (Interaural Time Difference).

The greater distance is divided, which the sound must take due to the speed of sound in the air to the more distant ear (the "width of the head") and so an estimate of this size is obtained.

By turning the head, the ITD may disappear (or in any case fall below the smallest detectable value).

• The remote ear is in the "shadow zone" created by the head and receives the sound with less intensity. This intensity difference is called IID (Interaural Intensity Difference). Processing the IID gives the auditory system more information about the direction the sound came from. The smallest value for IID that our hearing system can detect is on the order of 1 dB.