Audiometry (2. LF UK)

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Audiometry

Audiometry is a diagnostic method, that monitors hearing impairment to help doctors determine the degree of hearing loss. Depending on the type of auditory disability, it can then partly determine its cause. We distinguish between subjective and objective audiometry. Subjective audiometry, relies on data provided by the patient such as how the patient perceives tones and then signals them. Objective audiometry, which is the method used in older patients or with patients with reduced mental state.

Theoretical introduction

Acoustics is defined as a science of **audible sound**, i.e. of sound of frequency ranging from 16– 20 000 Hz. In a broader sense acoustics includes also **infrasound**, i.e. sound below 16 Hz, and **ultrasound**, i.e. waves at frequencies higher than 20 000 Hz. As sound we describe not only the audible impression registered by the auditory organ but also its external cause that can be described as a coordinated vibration of particles in the environment through which the sound propagates, e.g. air.

	Quantity	Symbol	Unit	Value range
Objective	Acoustic pressure	*p*	Pa	$2{\cdot}10^{-5}$–60
Objective	Sound intensity	*I*	$W{\cdot}m^{-2}$	10^{-3}–10
Objective	Sound intensity level	*L*	dB	–10–130
Subjective	Loudness level	*λ*	Ph	–10–130

Quantities in the acoustics.

The **energy level of a sound** can be expressed by different quantities:

Intensity *I* (W/m^2) expresses the magnitude of the acoustic energy passing through unit area per second

Level of intensity *L* (dB) compared to a reference value of 10^{-12} W/m^2; in medicine, often labelled as dB_{HL} – decibels hearing level

Loudness *λ* in phons (Ph) expresses the level of the perceived hearing of the average healthy human.

While sound intensity and the level of sound intensity are objectively measurable physical quantities, the level of loudness is associated with the different sensitivity of the human ear at different frequencies. The relationship with the level of intensity is determined statistically on the basis of testimony of a large number of tested individuals.

The intensity of sound *I* is related to the level of intensity *L* by $L = 10\log(I/I_0)$ where $I_0 = 10^{-12} W/m^2$ serves as the reference value with which other sounds can be compared and it is considered to be the lowest (threshold) audible intensity at a frequency of 1 kHz. At other frequencies the threshold values of intensity are different, usually higher, only in the interval of 1 kHz – 6 kHz the threshold intensities can drop below the value of I_0 (the ratio of I/I_0 is then lower than 1 and the level of intensity in dB is negative).

It follows from the definition of sound level intensity that:

an increase of the level by 10 dB corresponds to a ten-fold increase of sound intensity, an increase of 20 dB to a hundred-fold increase; an increase of 30 dB to a thousand-fold increase.

Auditory organ

Perception of sounds by our hearing apparatus is individual and substantial differences can exist even between healthy individuals. Moreover, the perception changes with age. In humans the perception range is about 16–16 000 Hz. For each frequency the audible range of intensities is different. The human ear is most sensitive at frequencies ranging from 2–5 kHz largely due to the resonance of the ear canal and the transfer efficiency of the ossicles of the middle ear.

The range of hearing is bounded below by the **hearing threshold**, above by the **pain threshold**. For every audible frequency there is an intensity where we stop registering it and when we begin to feel pain. To bring about a hearing perception at a frequency of 1 kHz we need a sound intensity of 10^{-12} W/m^2 while at other frequencies the threshold intensities are different. Because a person can estimate when he or she hears two sounds with equal loudness we can construct curves, points on which are perceived at equal loudness. Such curves are called **isophons**; a zero isophon is the hearing threshold while the isophon at 120 level is the pain threshold.

The **auditory organ** has two parts, an outer and inner part. We hear by funneling sound from the environment into the outer ear and causing the tympanic membrane to vibrate. Those sound waves vibrations are transferred into mechanical vibrations of the ossicles. Those mechanical vibrations cause the oval window to move back and forth causing the perilymph of the inner ear to begin wave-like motions. The perilymph fluid motion is transferred to the endolymph and the wave motion is transformed into electrical impulses picked up by the hairy cells of Corti and sent to the brain via the cochlear nerve. The round window is responsible for absorbing the fluid wave vibrations and releasing any increased pressure in the inner ear caused by the wave motion.

The external ears

The external ears are pair of structures adjacent to the head at an angle of 20-45 degrees. They are characterized by a an elastic cartilage (cartilago auriculae). The external auditory canal is another continuation of the auditory organ. It is a bent oval tube approximately 2.5 cm long facing the medial cavity ventromedially. It consists of the outer cartilage and the inner bony part.

Middle ear

The middle ear is composed of the drum, the cavity of the drum and auditory bones. The drum is a thin, pinkish gray membrane set into the sulcus tympanicus ossis tympanici. In the stria mallearis from the middle side, the hammer handle is attached to the drum. The drum is built obliquely, with the front facing in and the back side out. The drum thickness is approximately 0.1 mm. The drum area is about 55 mm^2. The transition to the inner ear consists of two membrane windows (oval and circular window). The membrane area is 3 mm^2. The drum cavity is a space located medially behind the drum. It is filled with air and covered with a thin mucosus membrane. In addition to three auditory bones, the medial cavity also contains two muscles that have a protective function (prevents damage to the auditory organ during excessive sounds). These are the tensor of the drum (tensor tympani) and the stirrup muscle (m. Stapedius). Hearing bones create a movably (articulated) chain between the drum and the oval window. Its main task is to transmit the vibration of the drum, caused by sound waves, into a perilymphi filled with a nitrificial labyrinth.

Among the auditory bones are the malleus - the kyac shape, the incus, which forms the middle part of the string of the acoustic bones and the stapes connected to the incus and carries the sound waves to the oval window of the inner ear. Hearing bones act as a lever, which increase pressure to overcome the acoustic resistance of the fluid in the snail (15.7 Mpa * s * m-1). If we compare this resistance with the acoustic resistance of air (390 Pa * s * m-1), we can see that in the air the sound wave has a great deflection and low pressure and the liquid environment has a small deflection, but the pressure is large. This means that if the bones did not have the lever function, there would be an energy loss of about 30 dB. The middle ear also includes the Eustachian tube, which connects the medial cavity with the nasopharynx. Its task is to bring air into the middle and to compensate for any pressure differences. Its length is approximately 3 cm.

Inner ear

The inner ear is made up of a petite labyrinth in the rock bone. It has two parts: the vestibular apparatus and the snail. The connection between the middle and the inner ear is realized by two windows. The windows are made of a flexible fibrous membrane, which response to the acoustic waves. The first one is oval, which is already described above and serves for the input of sound waves. The second is a circular window that allows the fluid to vibrate in the snail and hence the hearing itself. The inner ear is filled with endolymph and perilymph (fluid). Hearing is mediated either by the above-mentioned transfer system or by the bone conduction, where sound waves are transmitted over the rock bone, and this causes that the endolymph is blurred. The snail consists of two and a half threads of decreasing radius. The bony bone of the snail has the shape of a cone (modiolus). The snail is divided into three parts: scala vestibule (with perilymph), ductus cochlearis (with endolymph) and scala tympani (with perilymph). The scala vestibule begins behind the oval window and in the apex of the snail it continuously passes into the scala tympani, which enters to the circular window. The inner chamber cointains ductus cochlearis which is blindly terminated in the apex of the snail. Ductus cochlearis is separated from the scala vestibuli by a Reissner membrane and from a scala tympani by a basilar membrane. In the ductus cochlearis, the Corti organ is located on the basilar membrane. It consists of three rows of outer and one row of internal hair cells with cilia. The cilias communicate by gently touching the membrane of the tectoria exiting at the site between the basilaris membrane and the vestibularis. The irritation of the auditory cells results in the generation of action potentials that are guided by the auditory nerve into the brain. Due to the properties of the basilar membrane, the velocity of the procedure with the distance from the oval window decreases, the amplitude of the wave increases, to the point where it reaches the maximum. The place where the sound wave reaches maximum diaphragm curvature (maximum amplitude) depends on the frequency of the sound wave. The higher frequency causes the earlier (that is closer to the oval window) reaching to the maximum. Such a place of maximum amplitude is characteristic for each frequency. This phenomenon is called the principle of tonotopy. The sound volume level is then given by the frequency of action potentials.

Sound spreading through the auditory organ

Sound is the longitudinal mechanical vibration caused by the vibration of the sound source. In audiometry, we only deal with audible sound. This spreads in our hearing organ in two ways: air conduction and bone conduction

Air conduction

Air conduction is the sound line passing through the outer ear canal via the drum into the inner ear. Practically all the sounds at a normal hearing, with the exception of one's own voice, are transmitted in this way. In the case of airway dysfunction, we talk about conductive hearing loss. These are only seen in airborne conduction, while bone management is normal. Losses are usually within the whole hearing field.

Bone conduction

Bone conduction is the transmission of sound waves through the skull directly into the inner ear and is accomplished by the vibration of the cranial bones behind the ear, for example by a tuner or by a bone vibrator. It is therefore mainly an indicator of the quality of the inner ear function. In dysfunction, we talk about perceptual hearing defects. These results in a hearing loss that is symmetrical in both the bone conduction and the air conduction (the disorder is in the snail self). Usually there is a larger drop in higher tones. Bone conduction is responsible for hearing your voice differently when listening to a recording. There is an amplification of lower frequencies, and therefore it seems to be deeper than it is actually perceived by others. Bone conduction can never be worse than air conduction because it acts directly over the skull. However, it has a higher threshold than air conduction (about 40-50 dB). For nerve disorders, the values for both types of conduction are the same.

Examination

The aim of your measurement is to find out whether the patient’s hearing function is lowered and to determine what is the type of the disorder in her/his case, whether it is a transactional, perceptional or a mixed defect. From the lack of hearing in particular frequential areas we can also assume the possible causes of the hearing defects. You will use the sound of a tuner or bone vibrator and clear tones of tone generator while examining. During the measurement we amplify the tone from subliminal values (too quiet tones). If the examined hears to tone, he gives a sign to examiner by pressing a button.

Examination by tuners

Examination by tuners allows the doctor to assess patient’s cochlea sensitivity on the sound lined by the bone but never by the usual way of the eardrum oscillation or by transport with auditory ossicles. This examination in case of insufficient function of hearing allows to localize the place of the disorder, which is located “in front of” the cochlea or in the outer ear or middle ear if the patient hears a sound transported by bone line alternatively in the area of the inner ear. Perhaps in the transport of signal into brain if he does not hear a sound even after the oscillation of bone by a tuner.

Tone audiometry

In tone audiometry we use clear tones from a tone generator, which usually have a sinusoidal shape and it is possible to exactly determine the intensity of the sound. That means that we can search for the patient’s lowest intensities of sound, which are still/already heard, so called limital intensities. They differ for each frequency. By measuring a sufficient amount of frequencies, we can guess the shape, the limital curves of the patient’s hearing ability and in comparison with the physiological values (physiological curve) assess whether it is a hearing disorder or not. The examination is influenced by the patient’s cooperation. The patient is examined in a ‘quiet chamber’, which should be properly isolated from any sound. He is given several investigative aids – a bone vibrator or headphones and a button in the hand by which he gives signs to the doctor whenever he hears the testing tone. Each ear is examined separately.

Hearing damage and its remedy

The harmfulness of sound

Too high intensity of sound or long-term stay in a noisy surrounding can cause hearing damage, that can be reversible or permanent. In case of reversible damage, we only talk about a temporary increased hearing limit with hearing after a while returning to normal. Permanent damage means that a certain part of the hearing organ is injured, which can have consequences such as hearing damage or even deafness. Incessant noise can also have other negative impacts. An abnormal irritation of cerebral cortex can stimulate other parts of central nervous system and by this also disturb for example the quality of sleep or it can have a negative influence on the cardio-vascular system or on the autonomic nerve system.

The remedy of hearing

Hearing aids

A hearing aid is a small electro-acoustical device, that is composed of a microphone, an amplifier and a speaker. The registration of sound and its transport into a patient's ear is the essence of how this aid functions. There are two known types of hearing aids: the ones for air line and the others for bone line (vibrator). Their purpose is to improve hearing in case of partial deafness by amplification and modulation of sound coming from the surroundings.

Cochlear implants

A Cochlear implant is a device, which stimulates the ending of an auditory nerve in the cochlea. The patient must have it at least partially preserved, so that the implant could be inserted. It has two parts:

- The inner part contains a microphone (captures the sound), a speech compressor (the encoder of sounds, which converts the sound into signals) and a transmitting coil (sends signal into the inner part of the implant).
- The inner part contains a stimulator (converts signal to electrical energy) and electrodes (stimulate nerve fibers).

Practical

In the practical part we are working with an audiometer MAICO ST20, designed for audiometry of all patients. At first it is important to know the controls of audiometer (see image). Lead the patient to the soundproof chamber and ensure that the surroundings are as calm as possible. Write the name of the patient, the name of the examiner and the date of measurement on the audiogram form. Attach the form to the audiometer by using two fixing pins.

Workflow procedure for airway measurement

Place the headphones on the patient, with the red side on the right, the blue on the left. Turn on the device and set the output selector for the AC airline symbol. Make sure the pulse signal is set. Start the test on your ear with better hearing, if the hearing is normal, start with your right ear. Press the red (for the right ear) or the blue button (left). The current selected ear will be lit yellow. The current frequency rate, volume level and presence of the signal are indicated by the red glowing diode under the audiogram form. If the patient hears the signal, the red diode (at the level corresponding to the intensity) starts blinking.

Start testing by first setting the test signal level to -10 dBHL, that means that the scroll button will go all the way up and check that you set the frequency to 1 kHz. Press the button to generate a test signal. Gradually add the frequency rate, always 5 dBHL up. Mark the lowest signal level to which the patient responds in the form, for the right ear with a red circle. Repeat the procedure on all of the seven remaining frequencies (2 kHz, 3 kHz, 4 kHz, 6 kHz, 8 kHz, 500 Hz, 250 Hz). You can switch over the frequencies with buttons.

Repeat the procedure for the left ear. Mark the lowest level of the signal to which the patient responded in the form into the column AC Right/Left ear.

Now combine the thresholds for the air lines of the right and left ear.

The procedure for bone conduction measurement

Set the output selector for BC bone symbol. Place the bone vibrator so that the vibrations could be transmitted to the petrosus part of the temporal bone beyond the ear .

Set the test signal level controller again to -10 dBHL. Examine in the same way as with the airline, that means test the different signal levels at seven frequencies (1kHz, 2kHz, 3kHz, 4kHz, 6kHz, 500Hz, 250Hz) on both ears. Set the lowest rate of the signal to which the respondent responds to the same form and to the column BC Right/Left ear.

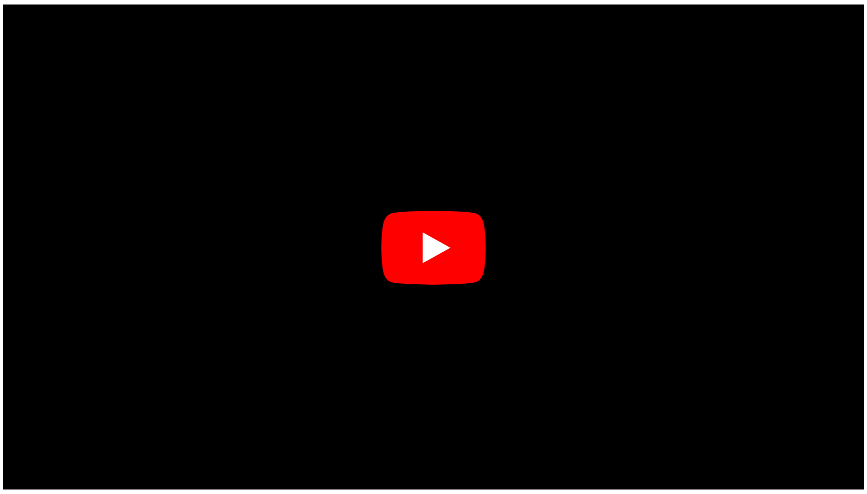
Evaluation

For clarity, similar bone and airway values are expected. If there is a larger difference in the measurement, it was probably caused by ambient noise, and you should and repeat the measurement for given frequency.

Summary

1. Attach the audiogram to the audiometer as accurately as possible.
2. Press the headset button. Check which ear you are examining. Take a pen for your ear (blue - left, red - right). Set the volume to the lowest level and the desired frequency
3. Release the tone by pressing the long black button, wait whether it blinks
4. Add the volume to 5 dB, the volume rate is on the digital display at the top right part of the audiometer. Continue until the patient signalizes that the tone has been heard and record the lowest audible tone
5. You can change the frequency with two black buttons under the audiogram
6. For bone conduction, select the bone vibrator symbol and place the bone vibrator on the patient. The wire is near the ear that is being measured.
7. Apply the same procedure as the air guide to bone conduction
8. Do not forget to fill in the date and practice number in the protocol, you can mention the condition which could influence your measurement and results

Videotutorial



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