Hearing

The Vestibular system

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Ear

- Has three functional parts:
  - 1) external ear
    - Auricle (acts as reflector to capture sound and focus it into the external auditory meatus or ear canal)
    - Membrane tympani or tympanum
  - 2) middle ear (air filled pouch extending from the pharynx to which it is connected with Eustachian tube)
    - Three bones: malleus (or hammer), incus (or anvil) and stapes (or stirrup) inserts in an opening-the oval window- in the boning covering of the cochlea
    - Fenestra ovalis (vestibuli), fenestra rotunda (cochleae)
  - 3) inner ear – bony labyrinth, the membranous labyrinth, and cochlea is embedded within the dense structure of the temporal bone; scala vestibuli, scala tympani, scala media (organ of Corti)
1. Eardrum
2. Malleus
3. Incus
4. Stapes
5. Semicircular canals
6. Auditory nerve
7. Vestibular nerve
8. Cochlea
9. Eustachian tube
External ear

- The sound waves travel through auditory canal and vibrate the tympanic membrane located at the end of the canal.
- Total surface of the tympanic membrane is about 85 mm².
- Physiologically active is about 55 mm² of the surface.
- It is positioned in an angle of 45 - 50°.
Middle ear

- Eustachian tube – connects middle ear to the nasopharynx
- It helps to:
  1) equalize air pressure on the inner and outer surface of the tympanic membrane
  2) to drain any fluid from the middle ear to the nasopharynx
Middle ear ossicles

- Malleus, incus, stapes
- Musculus tensor tympani and m. stapedius
- *(muscle) Tensor tympani* inserts on the manubrium malei and it is innervated by a branch of the trigeminal nerve (CN V)
- *(muscle) Stapedius* inserts on the stapes ossicle and is innervated by the branch of the facial nerve (CN VII)
- It has been calculated that because of the ossicles that act as levers total amplification of the pressure transmitted to the inner ear is about 22x
Inner ear

- Bony labyrinth
- Membrane labyrinth
- Cochlea (organ of Corti within the scala media)
**Bony labyrinth**

- Surrounds the inner membranous labyrinth and has **three regions:**
  1. Central region called vestibule
  2. Three semicircular canals
  3. Cochlea
    - Shaped like conical snail shell
    - Has a central tubular conical axis, modiolus, surrounded by a spiral cochlear canal which is divided into a
      - Upper scala vestibuli
      - Lower scala tympani
      - Scala media

**Peripheral part of the vestibular system**
- Communicate at modiolar apex called **helicotrema**
Membranous labyrinth

• Is located within the cavities of the bony labyrinth
• Is filled with endolymph (intracellular like, high K⁺ low Na⁺)
• Sacule and utricle
• Three semicircular canal ducts
• Cochlear duct (known as scala media; contains endolymph)
Scala media

- Is bound by two membranes:
  1. **Vestibular membrane (Reissner membrane)**
  2. **Basilar membrane (organ of Corti)**
- In the lateral wall lies the stria vascularis
  \( \text{Na}^+ / \text{K}^+ \text{ pumps sodium ion out of and potassium into the endolymph} \)
Organ of Corti

- IS THE SITE OF MECHANOELECTRICAL TRANSDUCTION IN THE COCHLEA
- Contains *inner and outer hair cells*
- About 100 stereocilia and single kinocilium are attached to the apical border of the cell
- Stereocilia is shorter than kinocilium
- Tips of stereocilia of the outer hair cells are embedded in the overlying *tectorial membrane*
- Inner hair cells are not attached to the tectorial membrane (movement of the endolymph results in movement of their stereocilia)
Inner hair cell

- Single row
- 3500 cells
- 95% of afferent axons end on inner cell
- Efferent axons are predominantly axoaxonic at the end of afferent nerve fibers

Outer hair cell

- Three or four rows
- 12,000 cells
- Few afferent axons of small caliber end on outer cells
- Efferent axons directly innervate outer cells
Stereocilije vanjskih osjetnih stanica poređene su u obliku sluva V.
Excessive noise exposure is one of the leading causes of hearing loss. The tiny hair cells in the inner ear are easily damaged by loud noise and once you lose them, they never grow back!
Mechanism of sound conduction

• Pressure waves cause tympanic membrane to vibrate.
• Movement of the footplate of the stapes against oval window.
• Pressure wave forms in the perilymph in the scala tympani and vestibuli.
• Result is vibration of the basilar membrane.
UPWARD DISPLACEMENT

Lateral displacement of the stereocilia and kinocilium

Influx of the Ca\textsuperscript{2+} = DEPOLARIZATION

Influx of the K\textsuperscript{+} = GLUTAMATE

= ACTION POTENTIAL GENERATION

DOWNWARD DISPLACEMENT

Medial displacement of the stereocilia and kinocilium

Outward flow of the K\textsuperscript{+} = HYPERPOLARIZATION

UPWARD DISPLACEMENT
CENTRAL AUDITORY PATHWAYS

• first neuron is **spiral ganglion**; axons form cochlear nerve, which joins vestibular nerve to form **VESTIBULOCOCHLEAR NERVE**

• **ventral and dorsal cochlear nuclei**

  **DORSAL COCHLEAR NUCLEI:**
  - synapse ipsilateral **superior olivary nucleus**
  - synapse contralateral **inferior colliculus** as **dorsal acoustic stria**

  **VENTRAL COCHLEAR NUCLEI:**
  - synapse contralateral superior olivary complex as ventral acoustic stria (trapezoid body)
  - synapse ipsilateral **superior olivary complex**

  **Axons of both, dorsal and ventral cochlear nuclei form intermediate acoustic stria which synapse contralateral inferior colliculus**

  **SUPERIOR OLIVARY NUCLEI** localize sound in acoustic space according to the time difference of arrival of the sound to each ear

  • **LATERAL LEMNISCUS AND ASSOCIATED NUCLEI**
  • **INFERIOR COLICULUS**
  • **MEDIAL GENICULATE NUCLEUS**
  • **PRIMARY AUDITORY CORTEX**
Auditory cortex
Descending auditory pathway

- Provide neural feedback mechanisms within the central auditory pathways
- Superior olivary nucleus form crossed and uncrossed olivocochlear bundle that innervate inner and outer hair cells
Vibrating tuning fork
Weber’s test
Rinne’s test

1. Vibrating tuning fork
2. Put it close to the patient’s ear
3. Put the base of the fork on the mastoid process
4. If the sound perceived by the patient is louder on mastoid process than in the air, the patient is diagnosed with CONDUCTIVE HEARING LOSS
• Normal sound threshold is 0-25dB.
• Mild hearing loss; threshold 30-40dB
• Moderate hearing loss: threshold 45-65 dB
• Severe hearing loss: threshold 70-85 dB
• Deafness; threshold 90dB
Vestibular system

- Consists of:
  - Saccule  
    - Detects linear acceleration
  - Utricle
  - Three semicircular canals (detects angular acceleration)
Saccule

- Small ovoid like structure
- Connected to the cochlea *(canal reuniens)* and utricle *(utriculosaccular duct)*
- Sensory organ of the saccule is called *macula of the sacule*
- There are two types of hair cells; *type I and type II*
- Cilia of the hair cells are embedded into the gelatinous matrix containing *otoliths*
- Small ovoid like structure
- Sensory organ of the utricle is called **macula of the utricle**
- *When the head is in upright position macula of the utricle is in the horizontal plane, while the macula of the sacule is in the vertical sagittal plane*
Semicircular canals

- Each of three canals is continuous with the **utricule at each end**
- Dilatation at the end is called **ampulla**
- Inside the ampulla are cone shaped structure called the **crista ampularis**
- Inside the crista ampularis are **hair cells**
Hair cells of the vestibular system

- Type I and type II
- Numerous stereocilia and one kinocilia
- When stereocilia displaced toward the kinocilium the hair cell is *EXCITED*
- When stereocilia displaced away the kinocilium the hair cell is *INHIBITED*
- Mechanisms of excitation and inhibition are identical to the mechanisms in the auditory system
Central pathways

- **Two vestibular ganglia are present:**
  - *Peripheral processes of vestibular (Scarpa) ganglion* innervate the hair cells (receptors) of the maculae saculi, maculae utriculi and ampullae of the semicircular canal
  - *Central processes of vestibular (Scarpa) ganglion* travel in the vestibulocochlear nerve
  - Afferents from the maculae of the saculi and utriculi terminate in the lateral vestibular nucleus
  - Afferents from the ampullae of the semicircular canals project to the superior vestibular nucleus and medial vestibular nucleus
• Transection of the brain at the intercollicular level result in **DECERBRATE RIGIDITY** (hyperactivity of the extensor muscle of all limbs)

• Pathways that are interrupted in such case are:
  ✓ Corticospinal
  ✓ Corticorubral
  ✓ Corticoreticular
  ✓ Rubrospinal tract
Function of the vestibular system

• Coordinate movements of the head
• Coordinate movements of the eyes, neck, trunk
The sense of balance originates from the labyrinth.

The **labyrinth** is a system of cavities in the skull that contains the sensors for the auditory and vestibular systems.

The **vestibular** system is responsible for one’s sense of balance.

The vestibular system has two parts: the otoliths and the semicircular canals. Each has different functions.

The **otoliths** have two functions:

1. They sense the head’s **linear** motion (e.g. moving forward or to the side).
2. They are also able to sense the head’s position relative to **gravity**. These are the organs that tell us which way is down.

The **canals** sense the head’s **angular** motion (e.g. rotation to the right).

Reference to Neuroscience Purves et al 4th Edition
Disorder of the vestibular system

• **NYSTAGMUS**
  ✓ Refers to repetitive movements of the eyes produced by movements of the visual field
  ✓ When the head and the body rotate the eyes move in the opposite direction (*controlled by vestibular nuclei*), which is followed by a rapid movement in the direction of rotation (*saccadic movement, controlled by pontine gaze center*)
  ✓ In the absence of movements of the visual field indicates the presence of a lesion in the brainstem or cerebellum
  ✓ It can be tested using a *caloric test*
Classifying nystagmus

**Jerk nystagmus**
*Convergence-retraction nystagmus* refers to the irregular jerking of the eyes back into the orbit during upward gaze. It can indicate midbrain tegmental damage.

**Downbeat nystagmus** refers to the irregular downward jerking of the eyes during downward gaze. It can signal lower medullary damage.

**Vestibular nystagmus**, the horizontal or rotary movement of the eyes, suggests vestibular disease or cochlear dysfunction.

**Pendular nystagmus**
*Horizontal, or pendular, nystagmus* refers to oscillations of equal velocity around a center point. It can indicate congenital loss of visual acuity or multiple sclerosis.

**Vertical, or seesaw, nystagmus** is the rapid, seesaw movement of the eyes: one eye appears to rise while the other appears to fall. It suggests an optic chiasm lesion.
"Cold opposite, warm same (COWS)", which means that cold water pouring into the left ear leads to eye movement to the left and a direction of the nystagmus is on the right (opposite side). Pouring of warm water into the left ear leads to eye movement to the right and a direction of the nystagmus is on the left (same side).
Vertigo

- Is a sensation of turning or rotating in space in absence of actual rotation
- Is often accompanied by nausea, vomiting and gait ataxia
- It can be caused by peripheral vestibular lesions that affect the labyrinth of the inner ear, or the vestibular division of CN VIII; intermittent, lasts for brief periods of time, accompanied by unidirectional but not vertical nystagmus
- It can be caused by central lesions; accompanied by vertical, unidirectional or multidirectional nystagmus
- Can be treated by H1 receptor antagonists such as Promethazine
Motion sickness

• Afferents from the vestibular system stimulate reticular formation of the pons and medulla
• Activation of autonomic centers results in motion sickness
• **ADVICES:**
  • Focus on the horizontal or on a distant, stationary object. Don't read.
  • Keep your head still, while resting against a seat back.
  • Don't smoke or sit near smokers.
  • Avoid spicy and greasy foods and alcohol. Don't overeat.
  • Take an over-the-counter antihistamine, such as meclizine (Antivert), or one containing dimenhydrinate (Dramamine), at least 30 to 60 minutes before you travel. Expect drowsiness as a side effect.
  • Consider scopolamine (Transderm Scop), available in a prescription adhesive patch. Several hours before you plan to travel, apply the patch behind your ear for 72-hour protection. Talk to your doctor before using the medication if you have health problems such as asthma, glaucoma or urine retention.
  • Eat dry crackers or drink a carbonated beverage to help settle your stomach if you become ill.
Inflammation of the vestibular labyrinth

- Vestibular neuronitis
- Usually there is no hearing loss
- Symptoms include vertigo
- Postural imbalance
- Nausea
- Nystagmus
SCHWANNOMA

- is a tumor of the tissue that covers nerves, called the nerve sheath.
- develop from a type of cell called a Schwann cell, which gives them their name.
- Schwannomas are often not cancerous (benign). The most common type of benign schwannoma is the acoustic neuroma. This can cause deafness.
- When these tumours are cancerous they are called malignant schwannomas. They can start anywhere in the body.
Meniere’s disease

• Intermittent relapsing vertigo
• Hearing disorder such as tinnitus (ringing noise in the ear) are present
• The reason is unknown, but histological there is an excessive accumulation of the endolymph and damage to the hair cells; trauma, infection of the inner ear
• Administration of steroids and diuretics relieves the symptoms, H1 receptor antagonist are also beneficial
• Surgery is optional

Figure 2a: Normal membranous labyrinth
Figure 2b. Dilated membranous labyrinth in Meniere's disease (Hydrops)