EAR
EMBRYOLOGY AND PHYSIOLOGY

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Embryology

- Parietal and occipital bones derived from paraxial mesoderm.
- All other bones of skull and face are derived from neural crest.
- The pharyngeal arches arise from the dorsal and most cephalic portion of the embryo.
- Each pharyngeal arch is lined externally by ectoderm and internally by endoderm.
- Each arch contains a core of mesenchyme derived from mesoderm and neural crest tissue.

Embryology

- By the end of the 4th week of development, four pairs of pharyngeal arches are visible
- The fifth quickly regresses
- 1-4 and 6 form, but 6 is not visible
- Pharyngeal clefts are found on the ventral surface of the embryo, opposite the arches.
- They arise from ectoderm.
- The first pharyngeal cleft forms the external auditory meatus.
- The second through fourth clefts develop as a communicating invagination of the embryo.
- This will later close as mesenchyme fills the sinus.

Embryology

- The oropharyngeal membrane develops in a cleft between the two parts of the first arch .
- It is composed of an outer layer of ectoderm and an inner layer of endoderm.
- This membrane eventually ruptures and produces an opening from the pharynx to the amniotic cavity.
- The first membrane forms the tympanic membrane. The other membranes regress.

Embryology

- Pharyngeal pouches arise from the endoderm.
- The first of four pouch pairs gives rise to the tympanic cavity, mastoid antrum, and the auditory tube.
- After birth the tympanic cavity invades the mastoid process.
- The apex of the pharyngo-tympanic tube is attached to the bone, fixed to the base of the skull between the greater wing of the sphenoid and the petrous temporal bone.
- The tensor veli palatini separates it from infra-temporal fossa.
- Some fibers of tensor are attached to the tube.

Middle ear

- Middle ear includeS tympanic cavity and epi-tympanic recess.
- Anteriorly, connects to the pharynx via the pharyngo-tympanic (Eustachian) tube.
- Posteriorly, connects to mastoid cells via the mastoid antrum.
- Innervation of the middle ear cavity including the inner surface of the tympanic cavity and membrane is from the tympanic nerve (CN IX).

Middle ear

- Tensor tympani attached to handle of malleus.
- Tenses tympanic membrane and attenuates sound.
- Innervated by CN V_3 (mandibular division).
- Stapedius attaches to neck of stapes.
- Limits excessive movement. Innervated by CN VII.

Ear

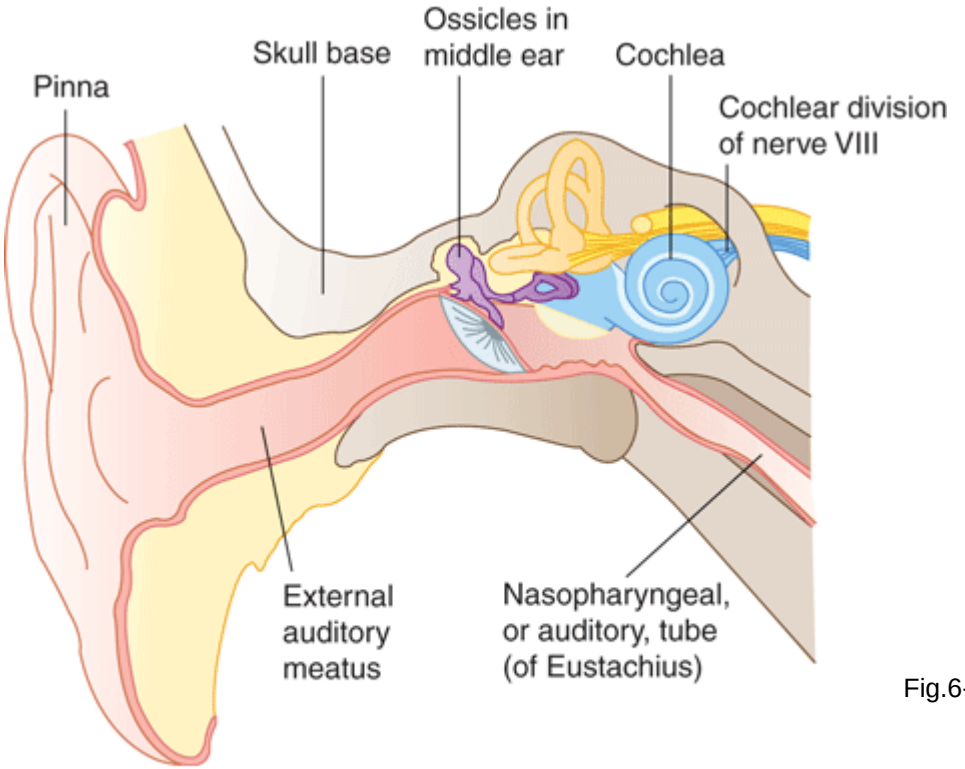


Fig.6-1 Accessed 07/01/2010

Impedance matching

- The malleus and the incus act together as a single lever
- When the malleus moves, the footplate of the stapes applies pressure at the oval window.
- The handle of the malleus is pulled inward by the tensor tympani and leads to better transmission at the tympanic membrane.
- Attenuation reflex is the result of contraction of stapedius muscle.
- Impedance matching between sound waves in air and sound vibrations in cochlear fluid (perilymph) works extremely well for frequencies between 30 and 3000Hz.

Audition

- Tonotopic deflection of basilar membrane causes it to move relative to the tectorial membrane.
- High frequency pressure waves (high pitch) produce resonance in the basal turn of the cochlea.
- Low frequency, in the apical turn.
- The Organ of Corti sits on the basilar membrane and contains the principal sensory epithelium, hair cells bathed in perilymph.

Audition

- Tympanic membrane vibrations in response to sound waves are transmitted along the ossicular chain.
- Stapedic vibrations are converted into pressure waves in the scala vestibuli and are transmitted through the vestibular membrane to reach the basilar membrane (impedance matching).
- 40-80 msec following exposure to loud sound, the stapedius and tensor tympanus muscles contract, increasing ossicle rigidity in the middle ear.
- Masks loud, low sensitivity sounds as well as decreases sensitivity to one’s own voice.

Audition

- Pilar cells are stiff.
- High content of microtubules.
- Act as fulcrum for the movement of the tectorial membrane.
- Stereocilia of the outer and inner hair cells (embedded in the tectorial membrane) undergo sheer stress (and depolarize).
- Hair cells in humans do not regenerate.

Audition

- Peripheral processes of bipolar neurons in the spiral ganglion contact hair cells.
- Central processes travel via the cochlear nerve to the anterior (ventral) and posterior (dorsal) cochlear nuclei.
- Second order neurons send axons to the nucleus of the trapezoid body and the superior olivary nucleus.
- Some neurons project rostrally via the lateral lemniscus to the inferior colliculus.
- Others project to the opposite olivary nucleus.

Audition

- Neurons from the nucleus of the trapezoid body that receive ipsilateral input from the cochlear nuclei project axons rostrally in the contralateral lateral lemniscus.
- The superior olive contains binaural neurons.
- Ipsilateral, excitatory
- Contralateral, inhibitory
- Mediated by the internuncials in the nucleus of the trapezoid body.
- Interaural timing disparities indicate spatial direction.

Audition

- Fibers ascend via the lateral lemniscus to the central nucleus of the inferior colliculus.
- Integrate:
- Spatial information (superior olive)
- Intensity (ventral cochlear nucleus)
- Pitch (dorsal cochlear nucleus).
- Fibers are projected to the medial geniculate body.
- Through the collicular commisure, the inferior colliculus inhibits its opposite number.

Audition

- Bilateral projections serve to localize sound in space by comparing input to the two ears.
- Neurons of the inferior colliculus project to the medial geniculate nucleus via the brachium of the inferior colliculus.
- Bilateral connections exist between the inferior colliculi.
- The medial geniculate nucleus projects to the transverse temporal gyrus (Herschel’s gyrus, Area 41).

Audition

- The medial geniculate body of the thalamus and the primary auditory cortex (Herschel's gyrus) are tonotopic (frequency coded).
- The cortex responds to auditory stimuli within the contralateral found field.
- Fibers entering motor nuclei of CN V and VII link with motor neurons supplying tensor tympani and stapedius, respectively.
- Damp ossicles.
- Olivocochlear bundle (descending tract) is involved in enhancement of faint sounds.

Basilar membrane

- Frequency sensitivity of the basilar membrane varies by location.
- As fluid is non-compressible, action of the footplate of the stapes at the oval window creates a traveling wave that runs along the basilar membrane.
- The frequency of the wave corresponds to the frequency components of the stimulus.
- The basilar membrane vibrates according to the frequency of the traveling wave.

Cochlea

- Cochlea is a spiral. 2.5 turns over 35mm length.
- The central core is the modulus, a bony structure that contains the spiral ganglion and the acoustic portion of CN VIII.
- Suspended within the bony cochlea is the membranous cochlear duct (scala media). Contains endolymph.
- Scala vestibuli is above the cochlear duct.
- Scala media is the level of the cochlear duct.
- Scala tympani is below the dochlear duct.
- Scala vestibuli and tympani contain perilymph and are part of the bony labyrinth.

Cochlea

- Hair cells have vertical stereocilia projecting from their apical surface.
- The tips of adjacent stereocilia are connected by tip links.
- Deflection of the stereocilia towards the tallest member results in the opening of cation channels and depolarization.
- Spiral ganglion spirals about modiolus.
- Cells myelinated in both directions.

Cranial nerve VIII

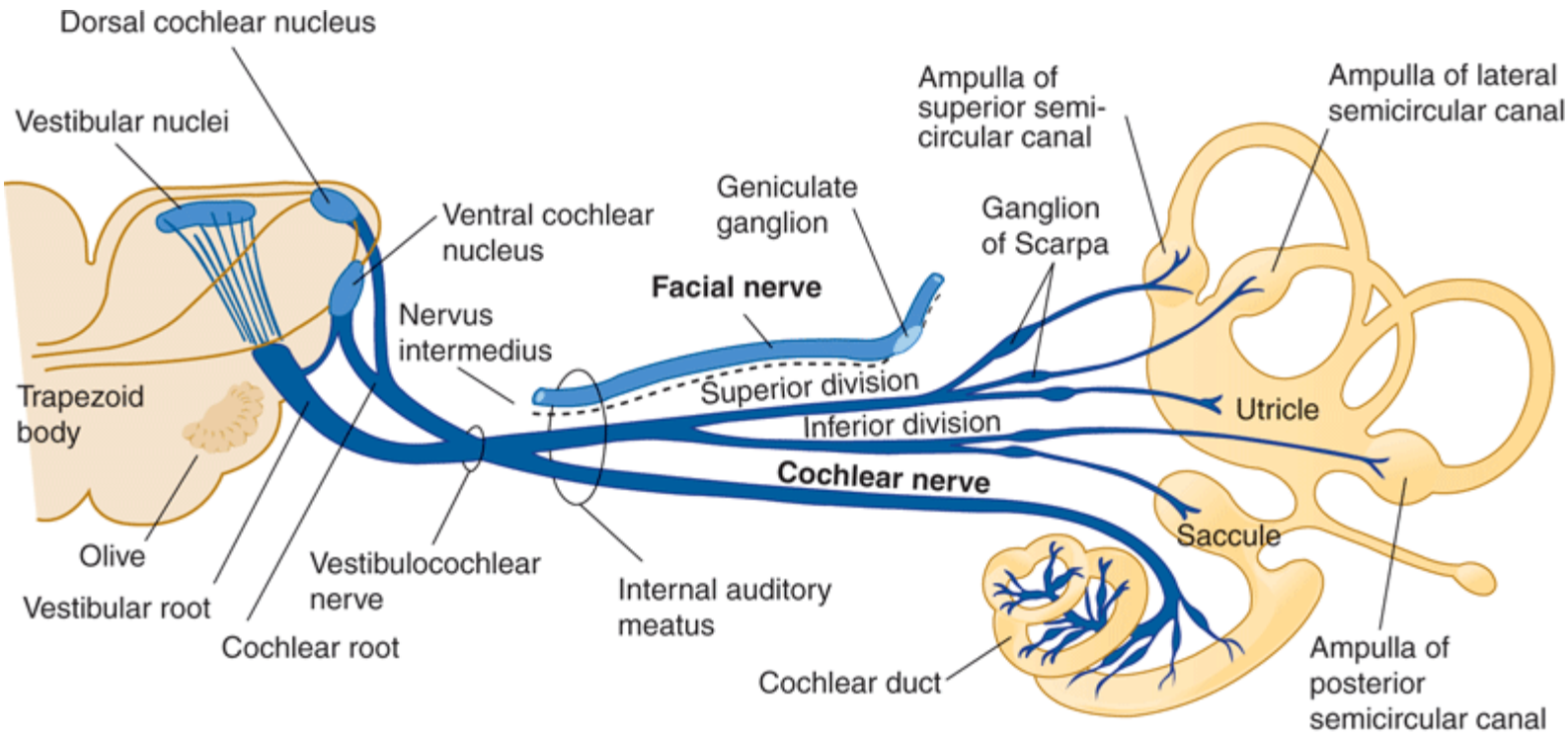
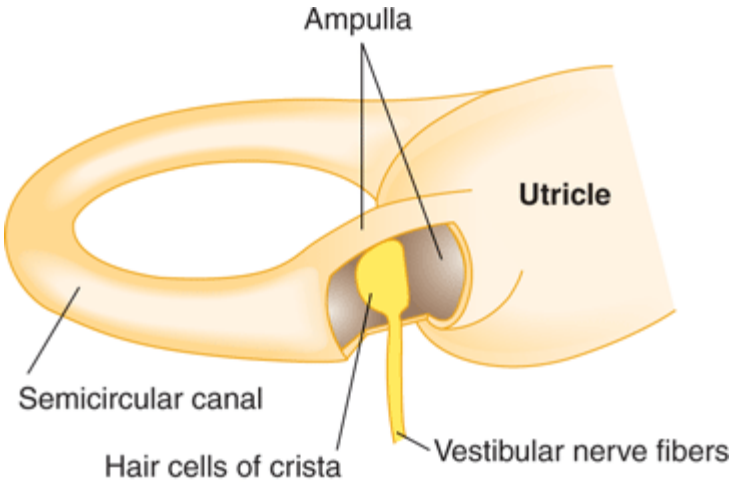


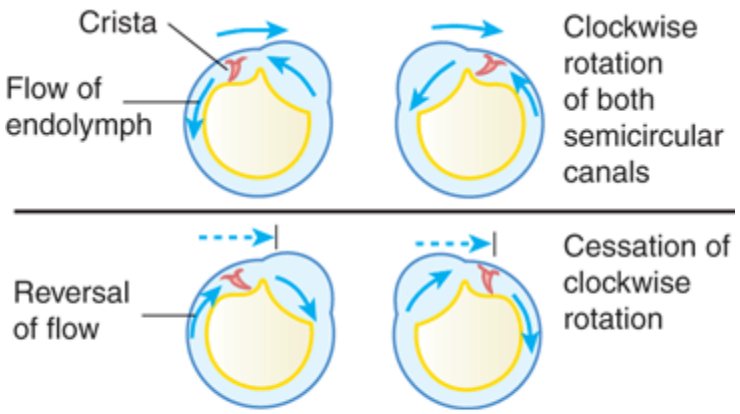
Fig. 16-5 Accessed 07/01/2010

Inner ear

- The bony labyrinth is within the petrous portion of temporal bone and contains the semicircular canals, vestibule, and cochlea.
- Contains perilymph.
- The membranous labyrinth contains the cochlear duct, saccule, utricle, semicircular ducts, and endolymphatic duct.
- Contains endolymph.

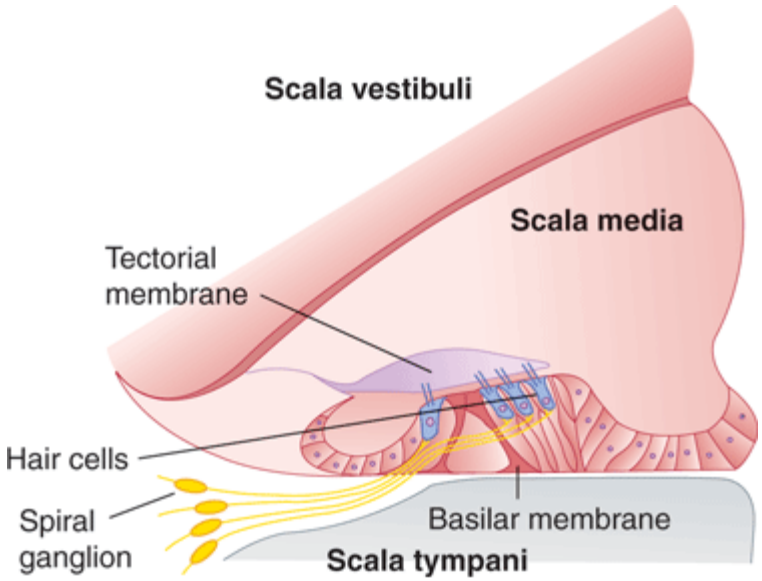
Vestibular function



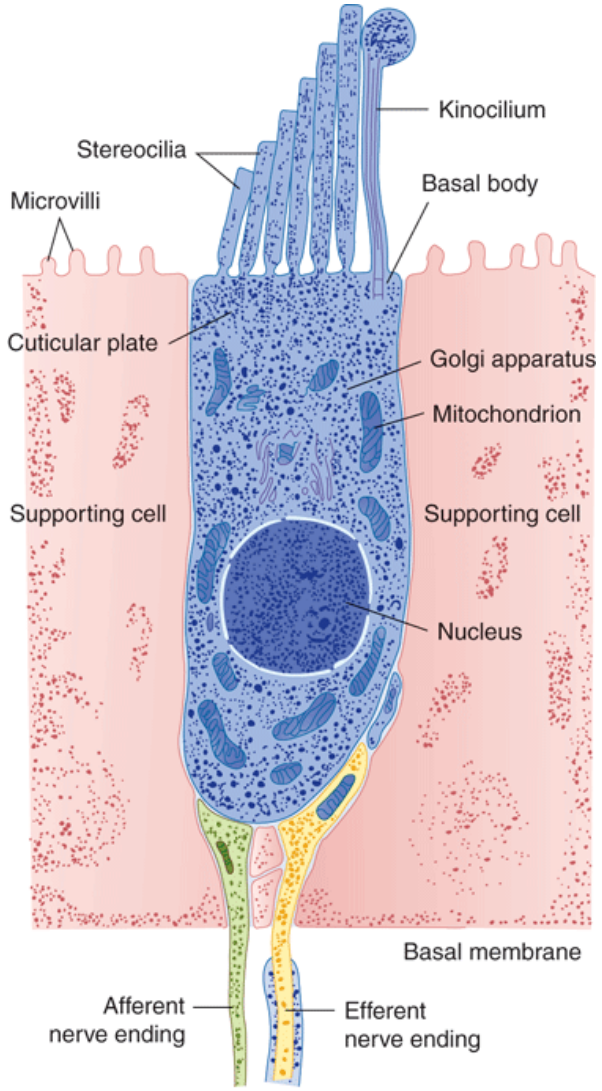


Figs. 17-4 and 17-5 Accessed 07/01/2010

Inner ear



Source: Waxman SG: *Clinical Neuroanatomy, 26th Edition*: http://www.accessmedicine.com



Source: Waxman SG: *Clinical Neuroanatomy, 26th Edition*: http://www.accessmedicine.com

Figs. 16-5 and 16-6 Accessed 07/01/2010

(Reproduced, with permission, from Hudspeth AJ: The hair cells of the inner ear. *Sci Am* 1983;248:54.)

Organ of Corti

- The scala vestibuli and the scala tympani contain perilymph (similar in composition to CSF)
- The scala media contains endolymph (made by the stria vascularis)
- This solution is high in K+ and low in Na+.
- There is a great voltage difference between endolymph and hair cell.

Labyrinth

- The bony labyrinth of the inner ear is a very dense shell containing perilymph (resembles extracellular fluid) that provides a liquid jacket for the membranous labyrinth that contains the sense organs of balance and hearing.
- The sense organs are bathed in endolymph (resembles intracellular fluid).
- The vestibular labyrinth comprises the utricle, saccule, and three semicircular canals or ducts.
- The utricle and saccule are found at the common chamber from which arise the semicircular canals.

Labyrinth

- Each utricle and saccule contains a macule
- Vestibular nerve endings are applied to hair cells whose cilia are embedded in a gelatinous matrix containing calcium carbonate crystals (otoconia).
- Each semicircular canals contains a crista at its ampulla.
- In cristae, vestibular nerve endings are applied to hair cells.
- The kinocilia of the hair cells penetrate into a gelatinous projection, the cupula.
- The cristae are sensitive to angular rotation.
- Vestibular neurons are bipolar.

Labyrinth

- The utricular macula is relatively horizontal
- The saccular macula, relatively vertical.
- Their primary function is to signal the position of the head relative to the trunk.
- Antigravity action is triggered mainly from the horizontal macula.
- In response to the signal, the vestibular nucleus initiates compensatory movements that maintain the center of gravity between the feet (standing) or just in front of the feet (locomotion) or of keeping the head horizontal (prone or recumbent).

Labyrinth

- Hair cells of the maculae have one cilium and 60 long sterocilia.
- The cilia are embedded in a gelatinous matrix.
- Within the surface of the matrix are calcium carbonate crystals (otoconia).
- Gravity causes the weight of the otoconia to distort the gelatinous matrix.
- This leads to firing of the receptor cells.

Labyrinth

- The lateral vestibular (Deiter's) nucleus is somatotopically organized.
- It has two way connections with the flocculondular lobe of the cerebellum.
- The lateral vestibulospinal tract descends from Deiter's nucleus via the ipsilateral anterior funiculus and synapse upon extensor (antigravity) neurons.
- Both α and γ neurons are excited.
- Muscle tone is maintained via the gamma loop.

Labyrinth

- The medial vestibulospinal tract arises in the medial and inferior vestibular nucleus and descends bilaterally in the medial longitudinal fasciculus
- Terminates upon excitatory and inhibitory internuncials in the cervical cord.
- It operates head-righting reflexes.
- The tract is also active in maintaining gaze.
- Projections from the vestibular nuclei terminate with trigeminothalamic fibers in the contralateral ventral posterior nucleus.
- Projection from the thalamus terminate immediately behind the face representation of the sensory cortex.

Labyrinth

- The lateral ampulla is activated by head turning (ipsilateral).
- Both superior ampullae are activated by head flexion
- Both posterior ampullae are activated by head extension.
- Afferents terminate in the medial and superior vestibular nuclei which maintain two way connections with the flocculonodular lobe of the cerebellum.
- Vestibulo-ocular reflexes operate to maintain the gaze on a selected target.

Vestibular pathways

- The four vestibular nuclei that receive inputs from the vestibular apparatus via neurons in the vestibular (Scarpa's) ganglion are the:
- Lateral nucleus.
- Gives rise to the lateral vestibulo-spinal tract.
- Facilitates anti-gravity response.
- Medial nucleus.
- Gives rise to the medial vestibulo-spinal tract.
- Travels in the medial longitudinal fasciculus.
- Descends bilaterally to cervical cord.
- Facilitates anti-gravity response.

Vestibular pathways

- Superior nucleus.
- Gives rise to vestibulo-ocular tract.
- Ascends rostrally in the medial longitudinal fasciculus.
- Permit eye fixation while head and body move.
- Descending spinal nucleus.

Vestibular pathways

- Some neurons in the Scarpa's ganglion project directly to the flocculonodular lobe of the cerebellum.
- Cold calorics lower temperature of endolymph.
- Flows as though the head is moving in the opposite direction.
- Warm irrigation leads to flow as though the head is moving in the same direction.

Labyrinth and eye movement

- The right horizontal canal is excited by a right turn of the head.
- The eyes move left.
- The right anterior canal is excited when the neck is flexed.
- Right upward eye movement.
- If the head is tilted to the right, eyes move to the left (counterclockwise torsion).

Labyrinth and eye movement

- The right posterior canal is excited when the neck is extended.
- Left downward eye movement.
- If the head is tilted to the right, eyes move to the right (counterclockwise torsion).

Labyrinth and movement

- The left horizontal canal is excited by a left turn of the head.
- The eyes move right.
- The left anterior canal is excited when the neck is flexed.
- Left upward eye movement.
- If the head is tilted to the left, eyes move to the right (counterclockwise torsion).
- The left posterior canal is excited when the neck is extended.
- Right downward eye movement.
- If the head is tilted to the left, eyes move to the left (counterclockwise torsion).

Nystagmus

- Loss of tonic vestibular discharge on side leads to imbalance (nystagmus and vertigo).
- Peripheral lesions (nerve or receptor destruction) result in no brainstem input.
- Fast component beats away from diseased ear.
- Compensatory mechanisms develop in a few weeks.
- Central lesions produce vertical nystagmus.