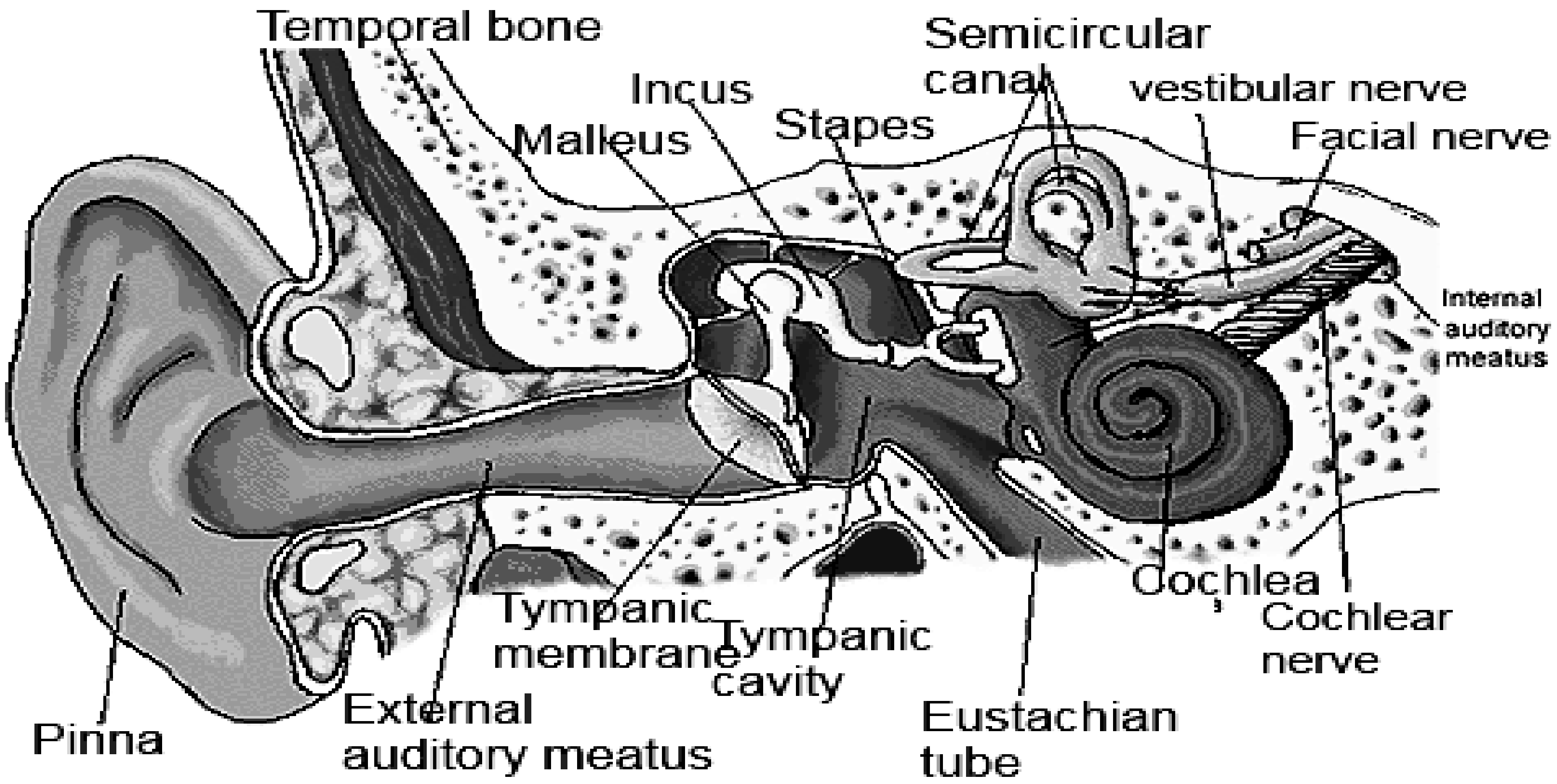
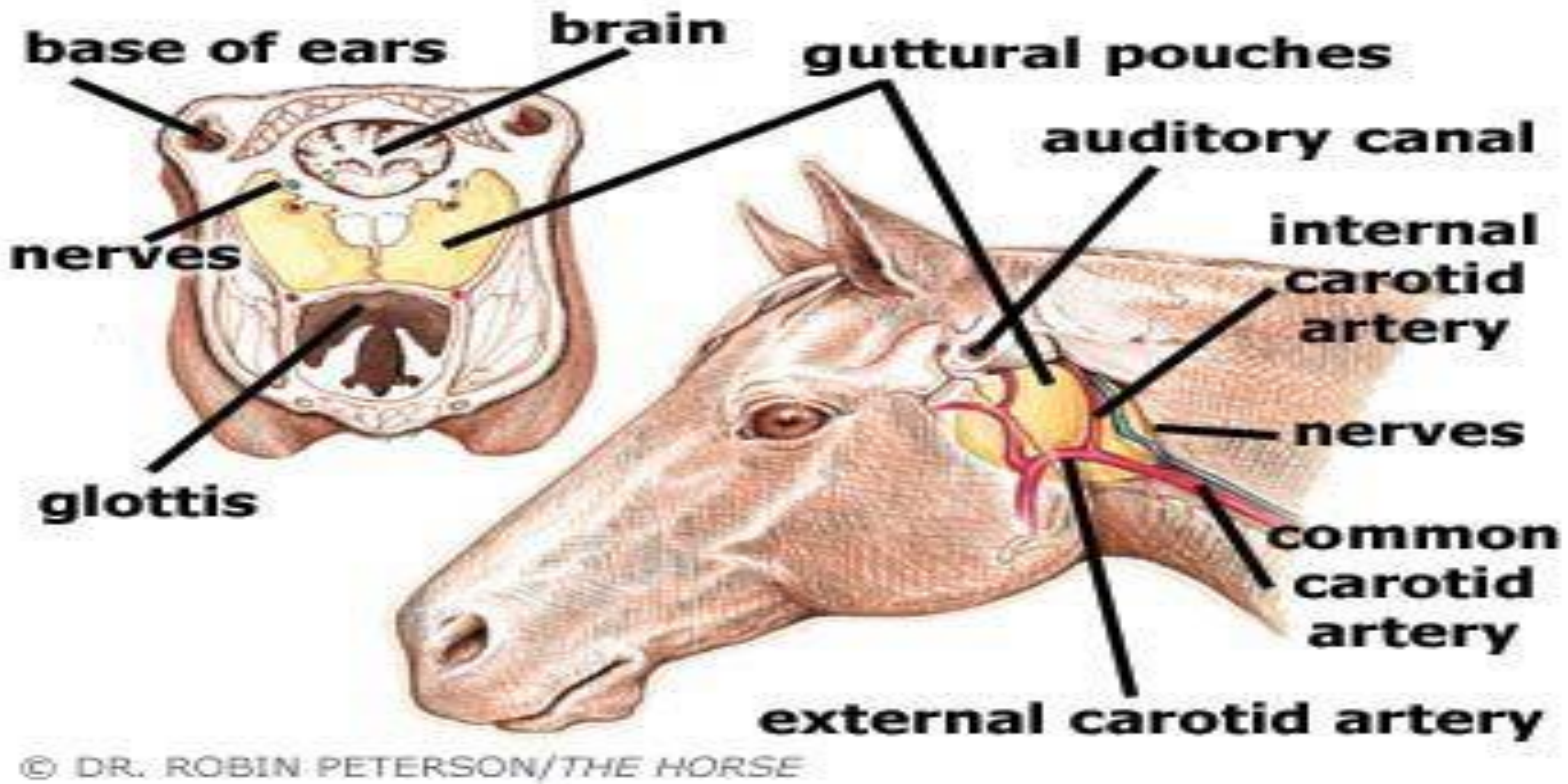
Ear

- The ear is divided into three parts, the external, middle and the inner ear.
- The external and the middle ear function to conduct the sound to the auditory receptors in the cochlea of the inner ear.
- The external ear consists of the **pinna or auricle** and *external auditory meatus* (ear canal) that collects and directs the sound waves to the *tympanic membrane* or eardrum (pinna absent in birds).
- The walls of the ear canal contain glands that secrete **cerumen (earwax)** which helps to prevent dust and small particles passing the canal

- The eardrum separates the external and the middle ear.
- The middle ear consists of air-filled **tympanic cavity** containing the **ossicles and the Eustachian tube.**
- The middle ear is connected to the nasopharynx by the **auditory (Eustachian) tube**.
- This tube helps to equalize pressure in the middle ear with external atmospheric pressure and to clear fluids from the middle ear.
- In horse, there is a ventral diverticulum located in the auditory tube called as **guttural pouch** (frequent infections occur here).

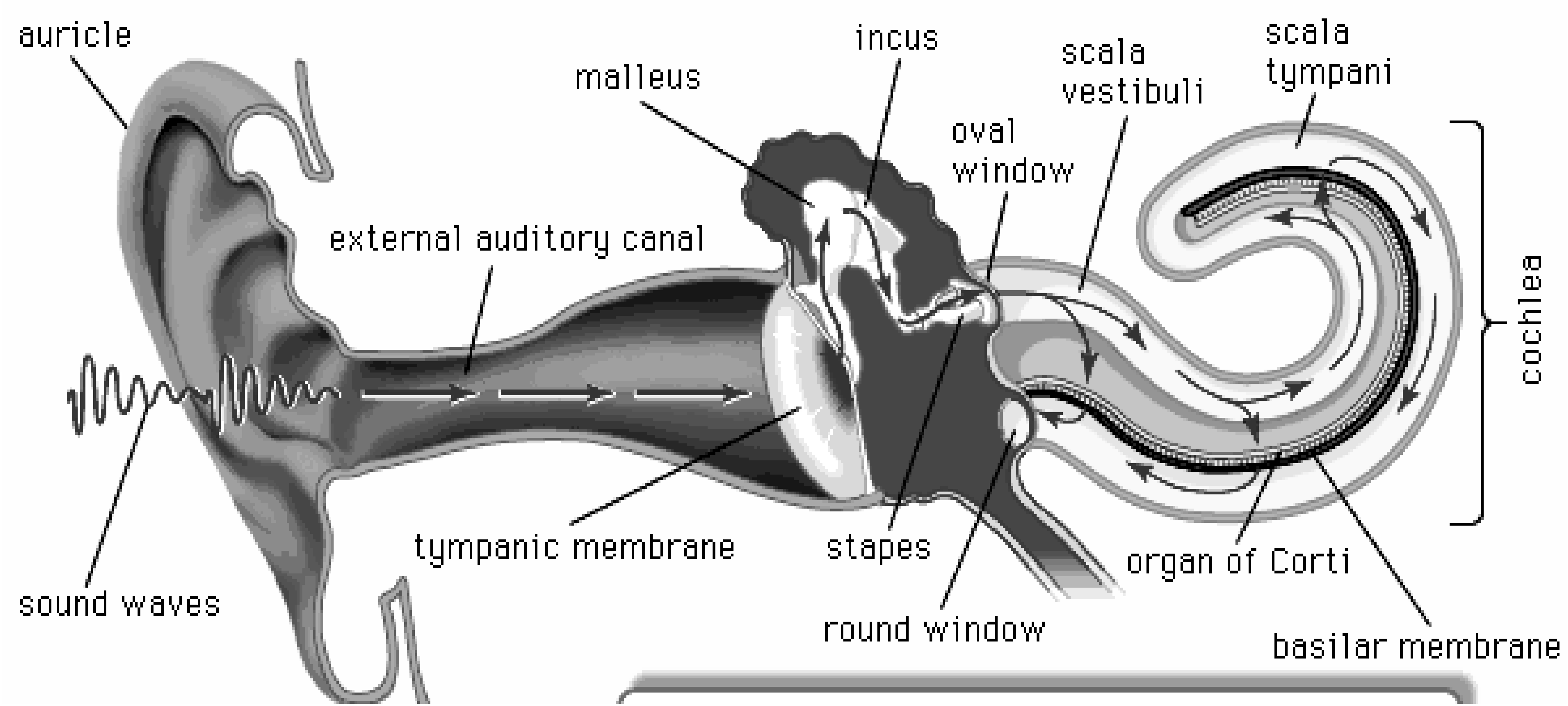

Temporal bone
Semicircular
canal
Incus
Stapes
vestibular nerve
Malleus
Facial nerve
Internal
auditory
meatus
Tympanic
membrane
Tympanic
cavity
Cochlea
Cochlear
nerve
External
auditory meatus
Pinna
Eustachian
tube



base of ears
brain
guttural pouches
nerves
glottis
auditory canal
internal carotid artery
nerves
common carotid artery
external carotid artery
© DR. ROBIN PETERSON/THE HORSE

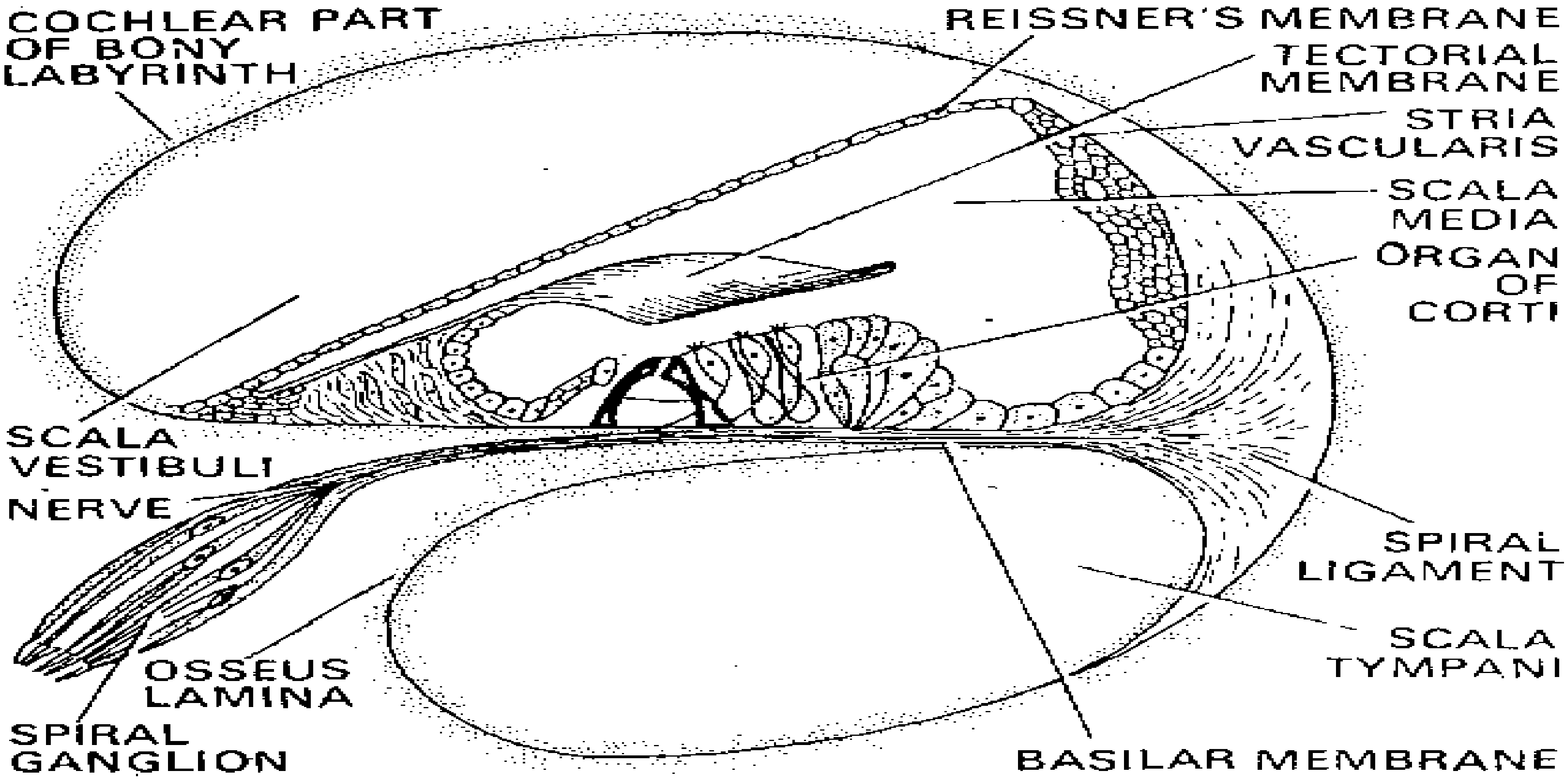
- The vibrations produced on the tympanic membrane by the sound waves are transmitted through the middle ear by the three bones or ossicles, which are known as the *malleus* (hammer), *incus* (anvil) and the *stapes* (stirrup).
- The malleus is attached to the tympanic membrane, while the stapes contact the oval window membrane, in the cochlea of the inner ear.

- Two small skeletal muscles are located in the middle ear, which alters the transmission of vibrations between the eardrum and the oval window. These muscles help to dampen high intensity sound waves (sudden loud noise) and thereby protects the inner ear
- **In birds, only one bone – *columella*** is present in the middle ear, which connects the eardrum and the oval window and transmission of sound is less efficient.


auricle
incus
malleus
scala
vestibuli
scala
tympani
oval
window
external auditory canal
cochlea
tympanic membrane
stapes
organ of Corti
sound waves
round window
basilar membrane

Inner Ear

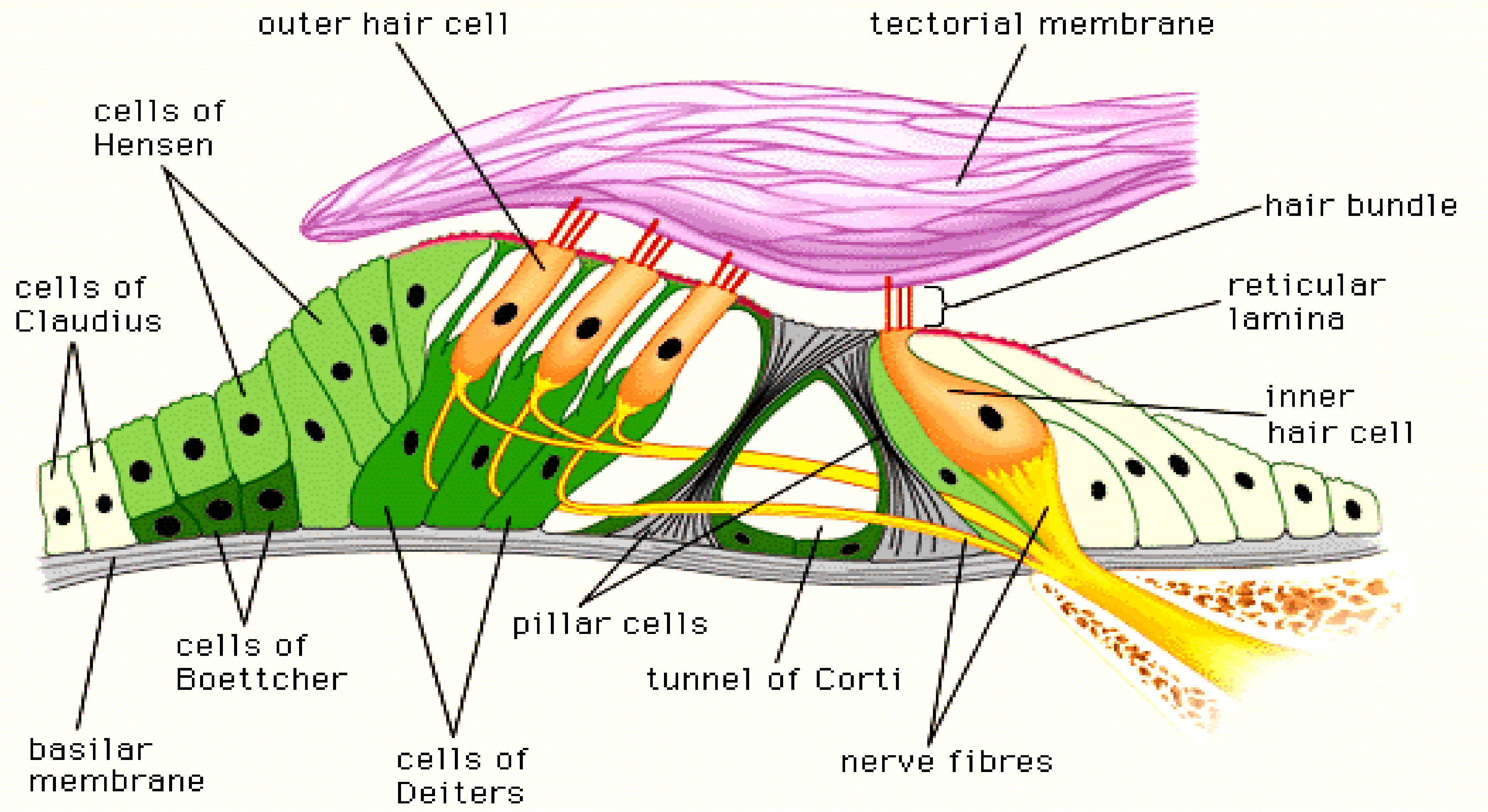
- The inner ear or **labyrinth** consists of an acoustic part, the ***cochlea*** and a non-acoustic part, the **vestibular organ**.
- The inner ear is made of a bony labyrinth; located with in the temporal bone, within the bony labyrinth is located the **membranous labyrinth** which is surrounded by **perilymph**.
- The receptor cells of the auditory system are located within the cochlea.
- The cochlea is formed by the coiling of three fluid-filled tubes known as **scala vestibuli, scala media (cochlear duct) and the scala tympani.**
- These three tubes are coiled around a central bony axis
- The uppermost canal is *scala vestibule* which starts from **the oval window** and ends at the apex of cochlea where it is connected to the lowest canal – ***scala tympani*** which ends at the **round window**; these two canals are filled with *perilymph* which is similar in composition to extracellular fluid.


COCHLEAR PART OF BONY LABYRINTH
REISSNER'S MEMBRANE
TECTORIAL MEMBRANE
STRIA VASCULARIS
SCALA MEDIA
ORGAN OF CORTI
SCALA VESTIBULI
NERVE
SPIRAL LIGAMENT
SCALA TYMPANI
OSSEUS LAMINA
SPIRAL GANGLION
BASILAR MEMBRANE

- Scala media is the middle canal and it is filled with **endolymph** which is similar in composition to intracellular fluid with K^+ concentration and positive electric potential
- The scala media is separated from the **scala vestibubi** by the **Ressiner's membrane** or **vestibular membrane**.
- Basilar membrane separates the scala media from the scala tympani. Along the floor of the scala media, on the basilar membrane, 4-6 rows of hair cells are located from the oval window to the apex of cochlea
- The cochlea of birds is short, almost straight and hair cells are not arranged in rows.

Organ of Corti

- The sensory hair cells located on the basilar membrane are arranged in two rows – a row of *inner hair cells* arranged near the central axis of cochlea and the remaining hair cells form the *outer hair cells*.
- The hair cells are surrounded by supporting cells. The hair cells have stiff microvilli called **stereocilia**; shearing movement of the stereocilia stimulate the hair cells.
- Directly above the hair cells is located a gelatinous membrane called **tectorial membrane**
- **The hair cells, tectorial membrane and basilar membranes with cochlear nerve terminals form the *organ of Corti*.**
- The auditory receptors are the hair cells embedded in the basilar membrane and their apical surface contains hair-like cilia - *stereocilia* that project into the endolymph filled scala media.
- The base of each hair cell synapses with afferent neurons whose cell bodies are located in the **spiral ganglion**. Axons of spiral ganglion form the **cochlear (auditory) branch of vestibulocochlear nerve.**


outer hair cell
tectorial membrane
cells of
Hensen
hair bundle
reticular
lamina
cells of
Claudius
inner
hair cell
pillar cells
cells of
Boettcher
tunnel of Corti
basilar
membrane
cells of
Deiters
nerve fibres

Mechanism of Hearing

- *Sound* is a travelling pressure wave; anything that produces vibrations (alternate phases of compression and rarefaction) in air, water or gas produces sound.
- *Frequency of sound* i.e. oscillations per second, determines the pitch of sound and it is measured in ***hertz* (Hz);** the distance between two peak pressure is called *wavelength*. Loudness (intensity) of sound is determined by the amplitude of sound wave (it is the sound pressure difference). The loudness is usually measured in **decibels (dB)**
- Sound waves from the external environment cause vibrations of the tympanic membrane, which are transmitted through the middle ear by the auditory bones and produce similar vibrations of the oval window.
- This sets up travelling waves in the perilymph of scala vestibuli. These waves in turn cause vibrations in the basilar membrane.

- Vibrations of the basilar membrane displace the tectorial membrane relative to the hair cells.
- This causes the stereocilia to move back and forth and this movement affects the stretch-sensitive ion-channels of the hair cells
- Bending the hairs to one side opens the ion channels and bending in the opposite direction closes the ion channels
- When channels are open, K^+ from the endolymph (higher concentration) enters inside and depolarizes the hair cell
- This in turn opens the voltage-gated Ca^{2+} channels allowing Ca^{2+} influx
- Which causes release of neurotransmitter that sets up nerve impulse in the sensory nerve

- Hair cells at different locations along the basilar membrane respond to different frequencies of sound waves.
- High frequencies stimulate the basilar membrane near the oval window and low frequencies stimulate the membrane near the tip of the cochlea
- Stimulation of nerve fibres from different regions of the basilar membrane provides the CNS about the frequency of the sound (pitch of the sound)
- Loudness is transduced as intensity of stimulation at a given site on the basilar membrane

- Humans can detect sounds in the range of 20 to 20,000 Hz. Regarding sensitivity (lowest frequency that can be heard), dogs and humans are equal at low frequency, but the dogs are superior at frequencies between 1,000 and 8,000 Hz. Frequencies of about 98,000 Hz produce potential changes in the cochlea of bats.
- Sound *waves wit*h frequency lower than 20 *Hz are ca*lled *infrasound* and above 20,000 Hz are *ultrasound*.
- Dogs, horses and cattle can hear up to 40,000 Hz while the upper limit for hearing in cat is 80,000Hz. Rodents like mice and rats can hear up to 1,00,000 Hz frequencies while elephants can hear lower than 20 Hz sound (lower the frequency of sound farther it can travel). Birds have lesser hearing ability than mammals

Auditory Pathway

- **Spiral ganglion**

↓

- **Cochlear nucleus** of the medulla

↓

- **Superior olivary nuclei**

↓

- **Inferior colliculus**

↓

- **Median geniculate body (thalamus)**

↓

- **Temporal lobe (primary auditory cortex).**

MAINTENANCE OF EQUILIBRIUM

- Equilibrium is the sense of balance, the sense of position and movement of the body in relation to environment. It is important for maintaining posture and locomotion. The eyes (visual system), ears (vestibular system) and the body's sense of where it is in space (proprioception) work closely to maintain balance.
- **Vestibular System:**
- The **vestibular system** is the sensory system that contributes to maintaining balance and sense of spatial orientation and provides input to brain about movement and equilibrium.
- It is located in the internal ear
- Two labyrinths are present in the inner ear, one inside the other—the membranous labyrinth located within the bony labyrinth.
- The bony labyrinth is a complex of three interconnecting chambers or spaces (cochlea; vestibule; and semicircular canals) present in the temporal bone.
- Within the bony labyrinth lies the membranous labyrinth which is a complex of sacs and tubules (cochlear duct; saccule and utricle; and semicircular ducts) forming a continuous space. The membranous labyrinth is filled with a fluid called endolymph
- Surrounding the membranous labyrinth and filling the space between the membranous and bony labyrinth is the watery fluid called perilymph.
- The vestibular system comprises of two components - the semicircular canal system, which provides information about rotational movements and the otolith organs (utricle and saccule), which indicate linear accelerations.

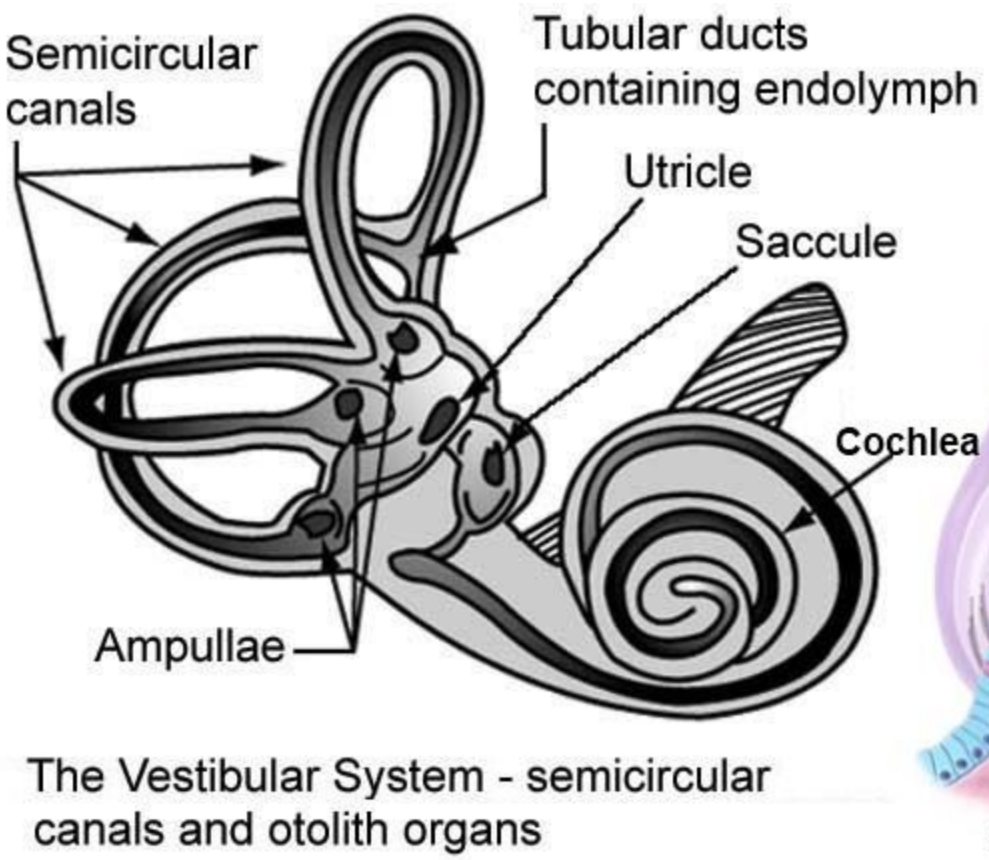
Otolith Organs

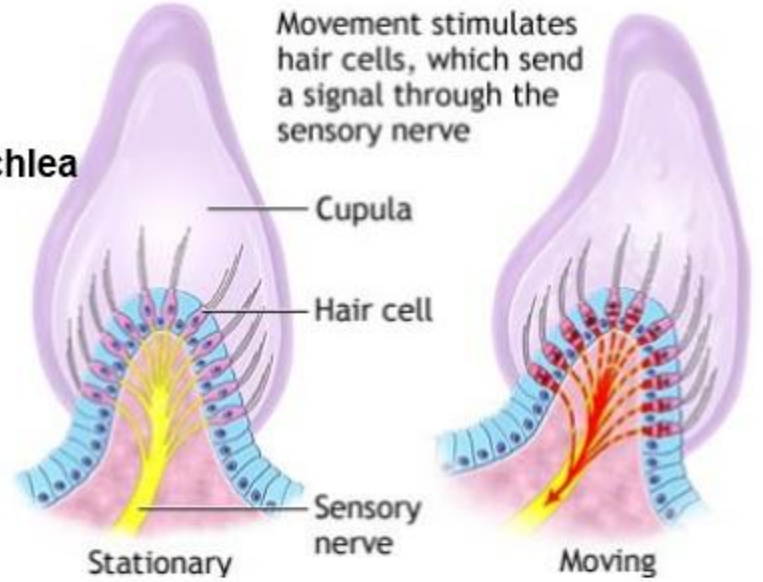
- The two otolith organs are the **utricle and saccule**.
- They consist of endolymph filled membranous sacs and sensory epithelium having hair cells.
- The wall of both utricmade of thousands of sensory hair cells which project their stereocilia into a gelatinous layer. The gelatinous mass (in the endolymph) contain large numbers of otoliths called **statoconia ot otoconia**, which are made up of $CaCO_3$ crystals – the gelatinous mass with otoliths have a higher density that the endolymph and thus has greater inertia.
- When the head is subjected to linear acceleration, the utricle and saccule are thickened at an area called ***maculae*** that are the sensory areas of utricle and saccule
- The macula consists of a bottom layer move to the same extent, but the gelatinous mass owing to greater inertia lacks the movement, creating a relative movement which is in a direction opposite to the direction of acceleration; this causes the stereocilia of hair cells to bend and stimulate the hair cells.
- The hair cells send signals down the sensory nerve fibres (vestibular branch of VIII cranial nerve), which are interpreted by the brain as motion.
- Because of higher density, the otoliths are influenced to a greater extent by gravity than the endolymph.

- When the head is in a normal horizontal position, the macula of utricle is also horizontal and the otolith presses on the sensory hair cell receptors. This pushes the hair cell processes down and prevents them from moving side to side. However, when the head is tilted, the pull of gravity on statoconia shift the hair cell processes to the side, distorting them and sending a message to the CNS that the head is no longer level but now tilted.
- Macula detects the orientation of the head with respect to the direction of gravitational pull.
- The bases and the sides of the hair cells synapse with the sensory axons of the **vestibular nerve**. Bending the cilia one-side increases impulse frequency in its nerve end and bending the cilia in the opposite direction decreases the impulse frequency. As the orientation of the head changes, the weight of the otoconia bends the cilia and appropriate signals are taken to the brain.

- *Maculae detect orientation of head in respect to gravity and linear acceleration of the head*. It acts as a receptor for tonic labyrinthine reflex or the righting reflex

Semicircular canals





Semicircular canals:

- Semicircular canals are fluid-filled membranous sacs. The three semicircular canals -superior, posterior and the external (horizontal or lateral) are interconnected and arranged at right angle to each other and represent all three planes in space.
- Near the base of each semicircular canal there is an enlargement known as *ampulla*. The inner membranous canal within the semicircular canal is filled with a fluid endolymph.
- Sensory hair cells called ***crista ampullaris*** are located on the walls of the ampulla. The flow of endolymph excites hair cells
- On the top of *crista ampullaris* is a gelatinous mass known as the ***cupula.*** This gelatinous mass has the same density as endolymph. The cupulla can move back and forth within the ampulla
- Thousands of hair cells project their cili*a* into the cupula and the base of these hair cells i*s* connected by sensory nerve fibres of the vestibular nerve.
- Bending the cupula to one side caused by flow of endolymph in the semicircular canal stimulates the hair cells, while bending in the opposite direction inhibits them.
- *Rotary acceleration of the head* is detected by the crista.

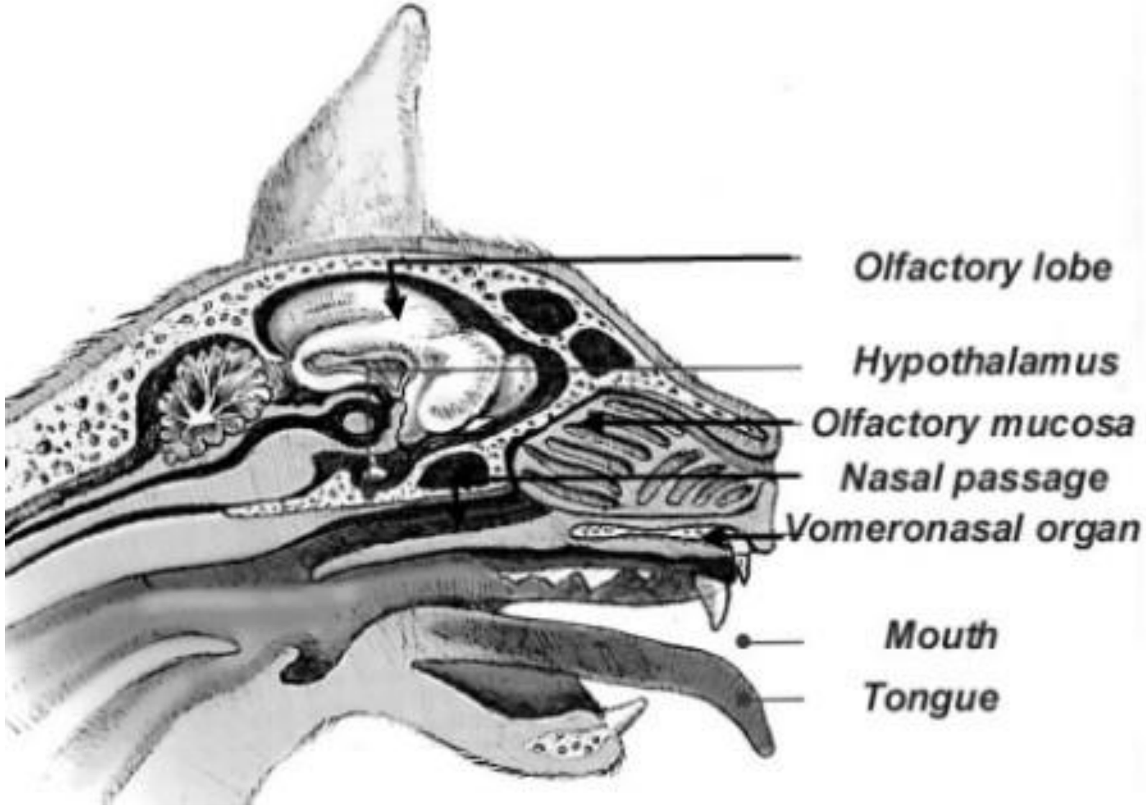
- During the starting of rotation of the head, the wall of the semicircular canal follow the rotation while the endolymph because of it s *inertia* lacks behind and hence a fluid flow is created in the canal *relative* to the movement of the canal wall and the direction of flow is in the opposite to the rotation. The fluid pushes on the cupula and moves it which in turn bends the hair cells.
- When the rotation becomes constant, the fluid moves at the same speed as the body, the cupula returns back to its position.
- When the rotation is stopped, endolymph displaces in the direction of rotation and cupula is displaced in the opposite direction and again bend the hair cells but in the opposite direction
- Most of the vestibular nerve fibres from the otolith organs and semicircular canals end in vestibular nuclei present at the junction of medulla and pons; some fibres pass directly to cerebellum.
- The fibres that end in the vestibular nuclei send second order neurons to the cerebellum, cerebellar cortex, vestibulospinal tract and other areas of the BSRF.

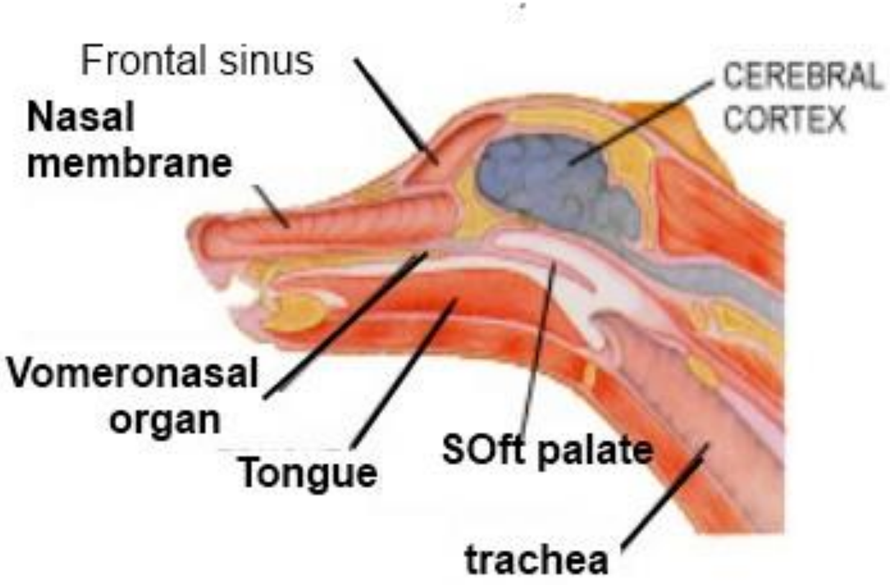
- The *vestibule-ocular reflex* (afferent impulses from semicircular canals through vestibulospinal tract to extraocular muscles) controls the extraocular muscles of the eye and coordinates eye and head movements. This reflex helps to keep the image on the retina during rapid rotation of head
- These vestibular movements of the eye may occur under certain pathological conditions even when the head is not rotating leading to spontaneous oscillating movements of the eye even when the head is at rest are called ***nystagmus*** *(*rhythmic to and fro movement of the eyes).
- **Motion sickness** is a condition that develops in animals subjected to prolonged intermittent stimulation of otolith organs (linear acceleration) or semicircular canal receptors (rotary acceleration). Such stimulation occurs in moving automobiles, airplanes or in ships during transportation. The syndrome is characterised by salivation, swallowing and vomiting.
-

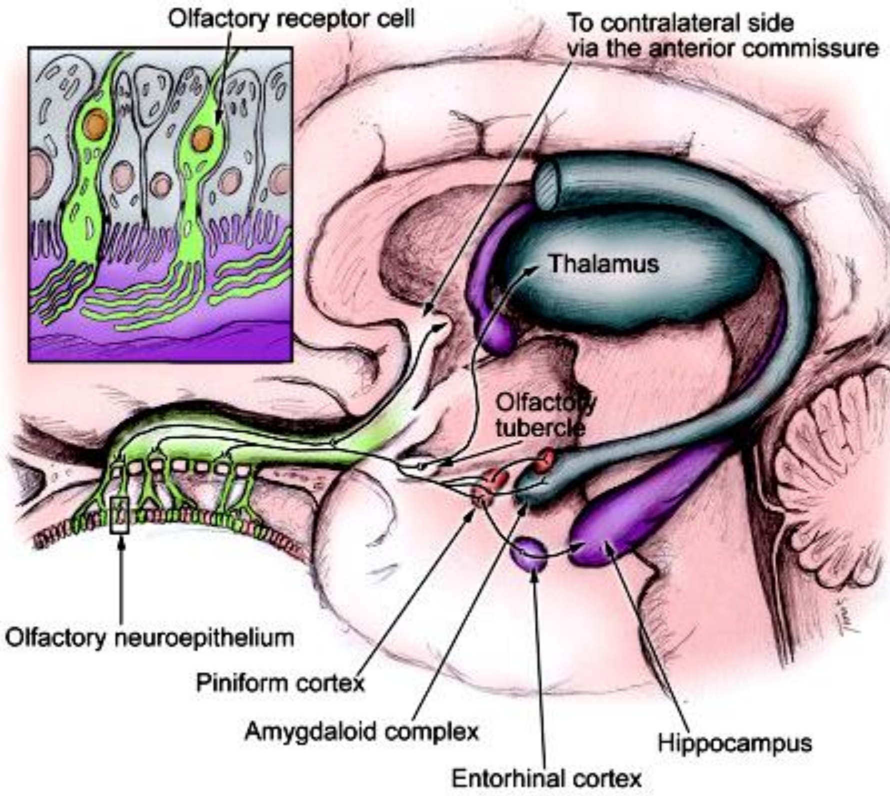
OLFACTORY SYSTEM: (Sense of Smell)

- **The sense of taste and smell are important**
- The sense of smell and taste provide information about the chemical compounds present in the environment; sense of taste requires direct contact with taste source but olfaction is influenced by distant odour sources
- **The sense of taste and smell help to discriminate between desirable and undesirable food and drink and to avoid poisonous food and spoiled microbe-infected foods.**
- Sense of smell is useful for **breeding process (to identify animals in heat).**
- Acting together, taste and smell contributes the **palatability of foods by detecting flavours**
- Olfaction helps animals to find **food, locate enemies, communicate with members of the same species and to identify sexual partner**
- **In man and domestic birds, olfaction has only a limited role in influencing the behaviour**
- Olfaction in animals is mediated by two important sensory systems-
- The main olfactory system with receptors in the **dorso-caudal part of the nasal cavity**

- Accessory olfactory system with receptors in the ***vomeronasal* or *Jacobson's organ* (VNO) located near the external nares.** This is lacking in birds, adult humans and apes. **This system mediates sex odours.**
- VNO is located along the **anterior part of the nasal septum**. The VNO opens at one end and forms a blind sac at other end.
- The location of the opening is variable; in rodents the opening is into the nasal cavity and in cows it opens into the oral cavity.
- The receptors are similar to those of the main olfactory system.


Olfactory lobe
Hypothalamus
Olfactory mucosa
Nasal passage
Vomeronasal organ
Mouth
Tongue


Frontal sinus
Nasal membrane
CEREBRAL CORTEX
Vomeronasal organ
Tongue
SOft palate
trachea



Olfactory receptor cell
To contralateral side
via the anterior commissure
Thalamus
Olfactory
tubercle
Olfactory neuroepithelium
Piniform cortex
Amygdaloid complex
Entorhinal cortex
Hippocampus

- The VNO may be involved in perception of large, non-volatile molecules that could not reach the main olfactory system. The VNO has a pumping mechanism that serves to suck molecules (pheromones) into the organ.
- ***Flehmen,*** the facial grimace (stretching the head forward, lifting the upper lips and wrinkling the nose) noticed in many species during courtship **help to draw fluids-urine into the VNO.**
- The receptors of the VNO project to the olfactory bulb.
- The most important function of the VNO is to induce sexual behaviour when stimulated by vaginal secretions and urine, which animlas take in by licking. Stimulation of VNO leads to secretion of GnRH which increases gonadotropic hormones from anterior pituitary
- The olfactory receptors are sensory neurons, sensitive to volatile and water-soluble chemicals.
- VNO is the major site for pheromone detection.

GUSTATORY SYSTEM: (Sense of Taste)

- Mammals have 4 primary taste sensations –
- *Salt* (primary example is NaCl), *sour* (acetic acid), *sweet* (sucrose) and *bitter* (quinine HCl)
- The function of taste is generally associated with ingestion of food.
- All mammals and birds have taste organs called ***taste buds***, which are concentrated on the **circumvallate and fungiform papillae.**
- Taste buds are found mainly on the upper surface of the tongue, and to some extent on the roof of the mouth, soft palate and pharynx.
- Ungulates have more taste buds than predators – cattle have 10000 to 20000 taste buds while dogs have 5000 and cats 500 taste buds; birds have very few taste buds (20-30) and has a poor sense of taste
- The taste buds are located on the **apical ends of the papillae**. Each taste bud has about 40-50 elongated receptor cells, and sustentacular or supporting cells; the taste cells are arranged around the taste pore. The receptor cell has several microvilli, or taste hairs on its apical region that extends into the taste pore. The basal surface of the receptor cell is innervated by the terminals of **gustatory nerves.**
- Taste compounds are dissolved in the water of mouth, diffuse into the taste buds and bind with the receptor molecules of the taste cells to induce the sensory nerves of the taste

- The tip of the tongue is sensitive to sweet stimuli, **salty and sour tastes are sensed by the sides of the tongue,** whereas the back of tongue is sensitive to **bitter substances**.
- Salty taste is elicited by the ionised, inorganic salts, mainly by the cations of the salts. Sour taste is caused by acids (H^+ ions); greater the acidic, stronger the sour sensation.
- The two organic substances, the long chain organic compounds with nitrogen and the alkaloids (e.g. quinine, caffeine and nicotine) are bitter stimulants.
- In humans, bitter taste is most sensitive – bitter taste can be deducted in concentrations several thousand times lower than salt or sour
- Among animals, rats have a sense of taste similar to man, ruminants, pigs and dogs prefer sweet taste but cats are indifferent to sweet taste, chicken have no defined preference to taste
- **Taste Reflex**
- **Tractus solitarius** transmits impulses to the superior and the inferior salivory nuclei, thus reflexly regulates the secretions of the submandibular, sublingual and the parotid glands.