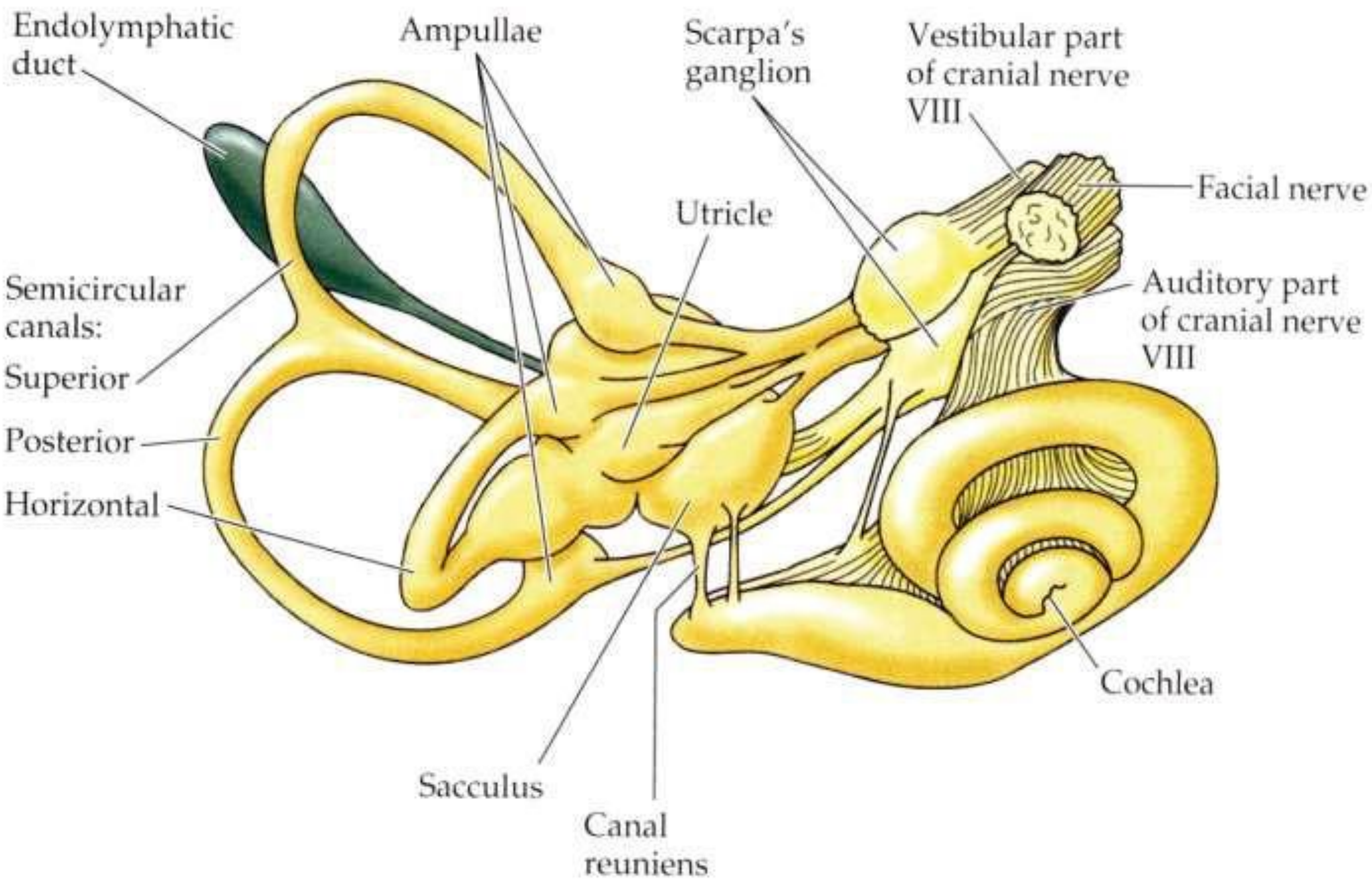
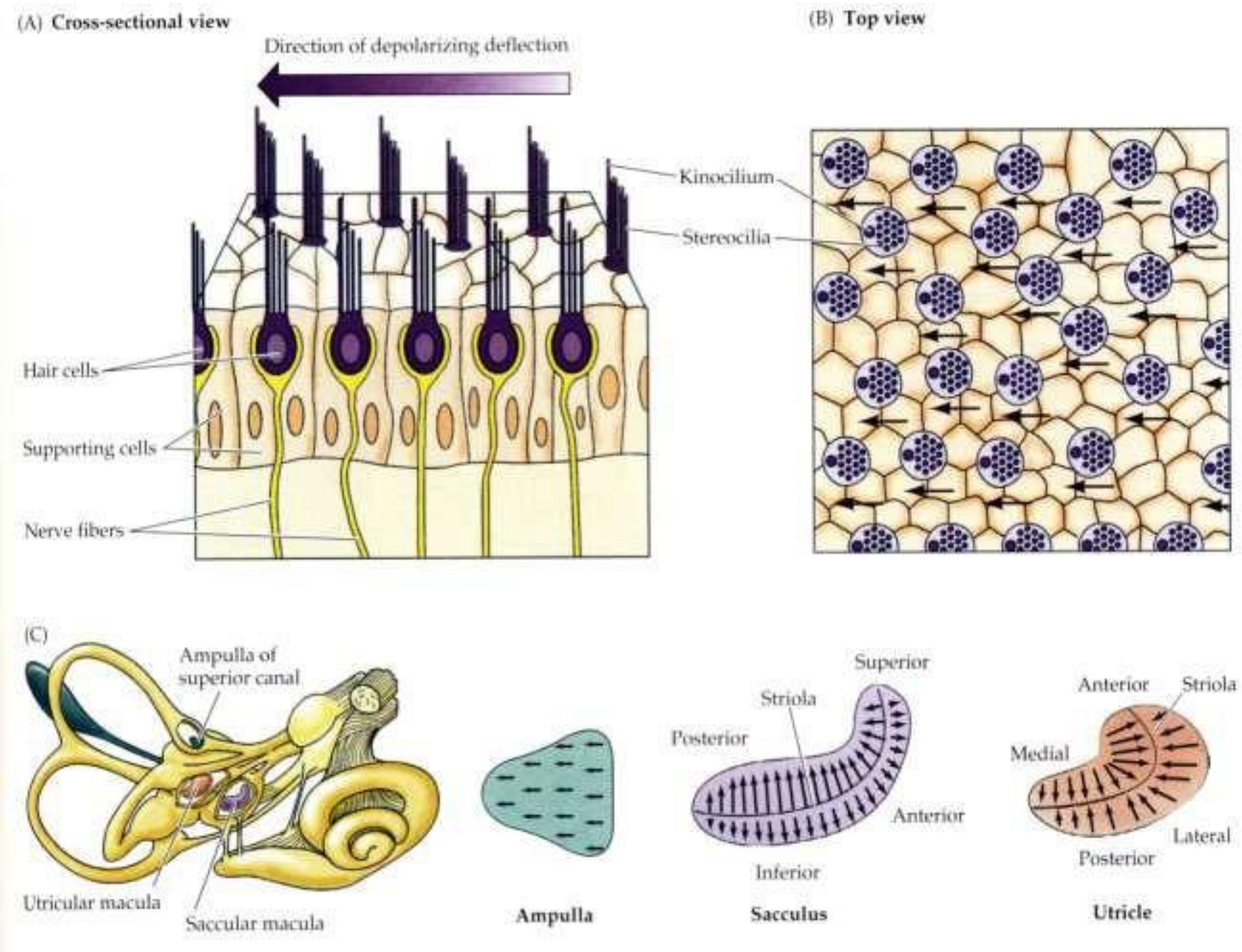
# THE VESTIBULAR SYSTEM

# THE LABYRINTH AND ITS INNERVATION



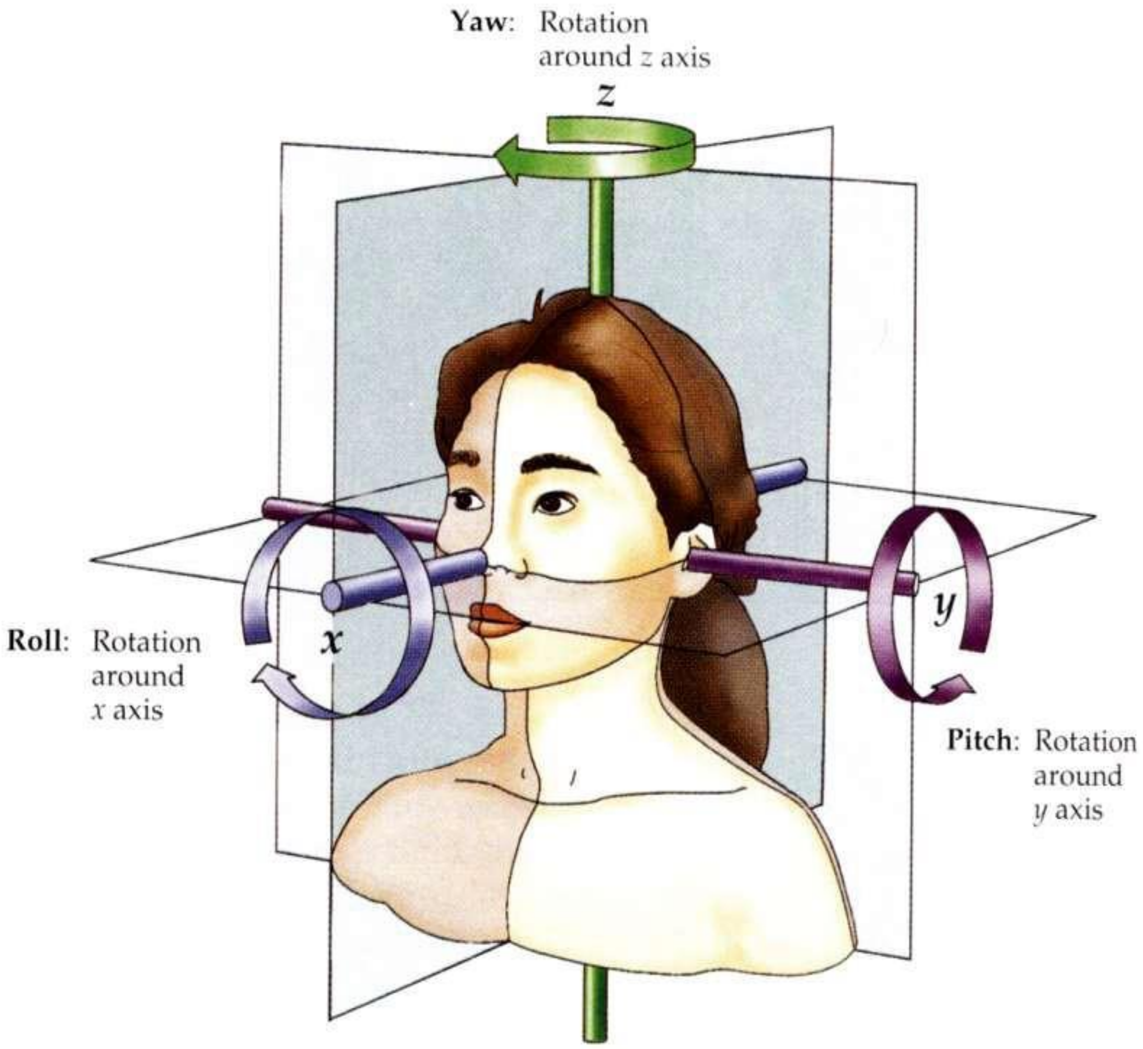

The vestibular and auditory portions of the eighth nerve are shown; the small connection from the vestibular nerve to the cochlea contains auditory efferent fibers.

# THE POLARIZATION MAPS OF THE VESTIBULAR ORGANS



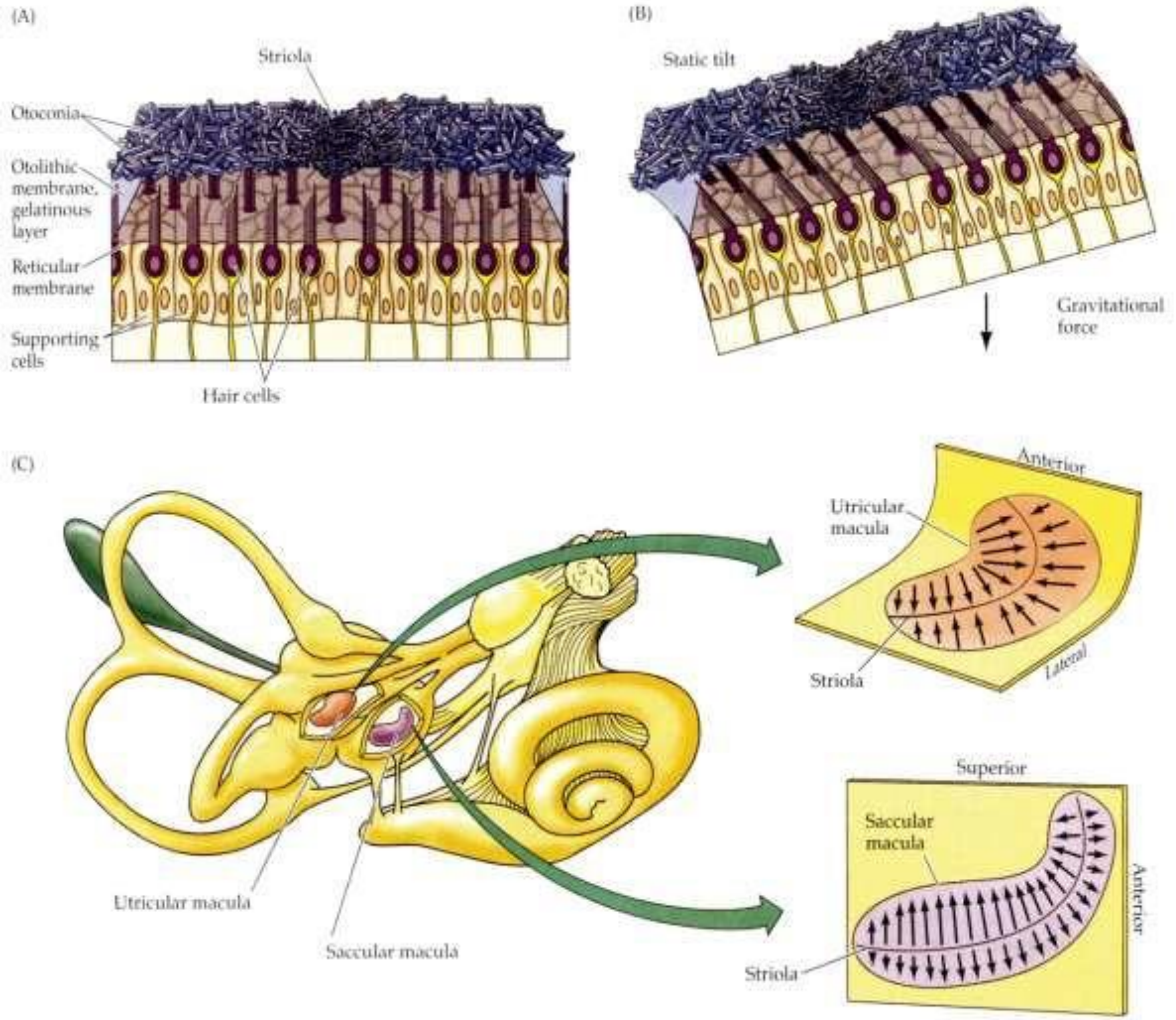

(A) A cross section of hair cells shows that the kinocilia of a group of hair cells are all located on the same side of the hair cell. The arrow indicates the direction of deflection that depolarizes the hair cell. (B) View looking down on the hair bundles. (C) In the ampulla located at the base of each semicircular canal, the hair bundles are oriented in the same direction. In the sacculus and utricle, the striola divides the hair cells into populations with opposing hair bundle polarities.

# VESTIBULAR NAVIGATION



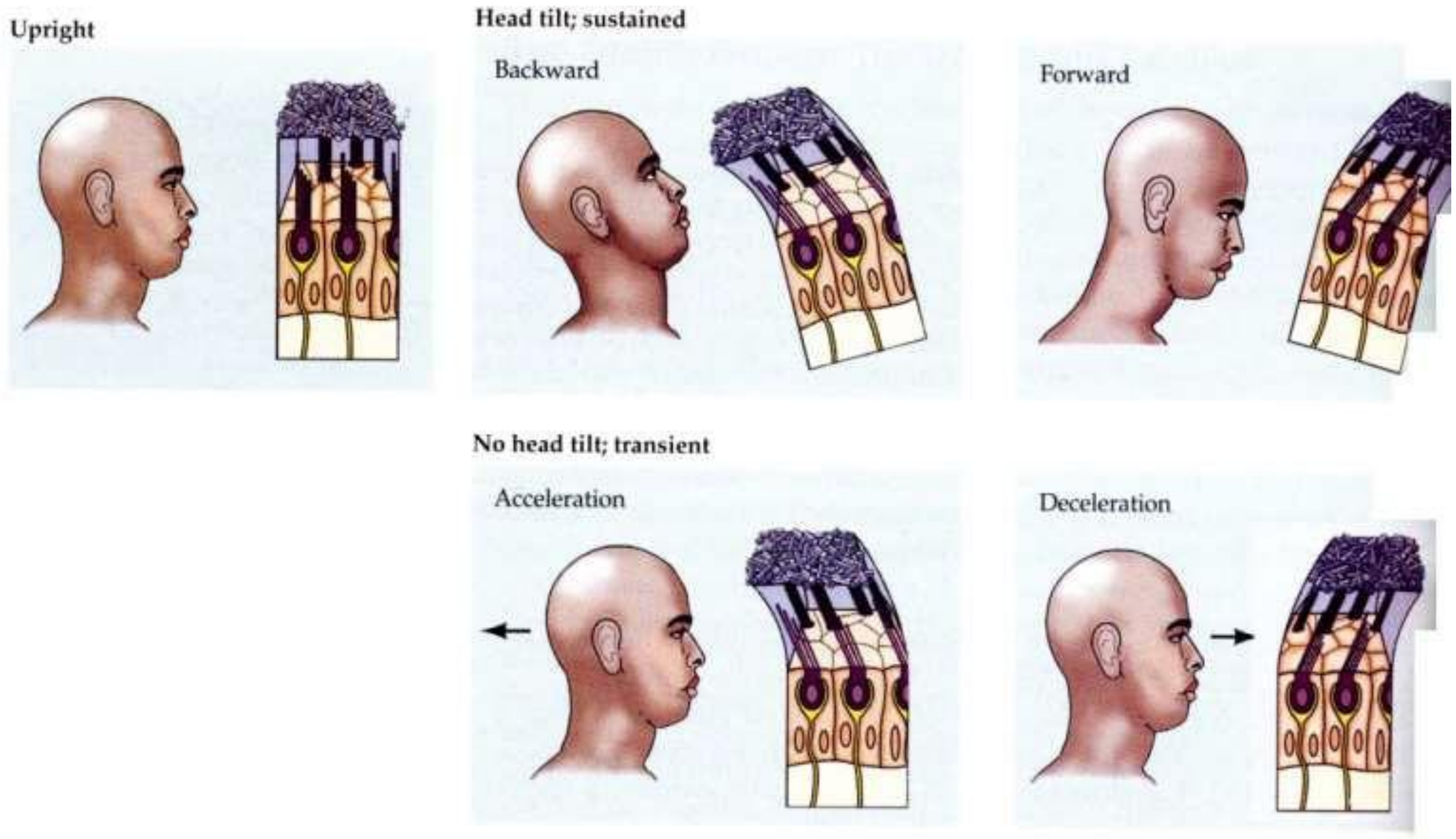

The function of the vestibular system can be simplified by remembering some basic terminology of classical mechanics. All bodies moving in a three-dimensional framework have six degrees of freedom: three of these are translational and three are rotational. The translational elements refer to linear movements in the x, y, and z axes (the horizontal and vertical planes). Translational motion in these planes (linear acceleration and static displacement of the head) is the primary concern of the otolith organs.

# POLARIZATION OF HAIR CELLS IN THE UTRICULAR AND SACCULAR MACULAE



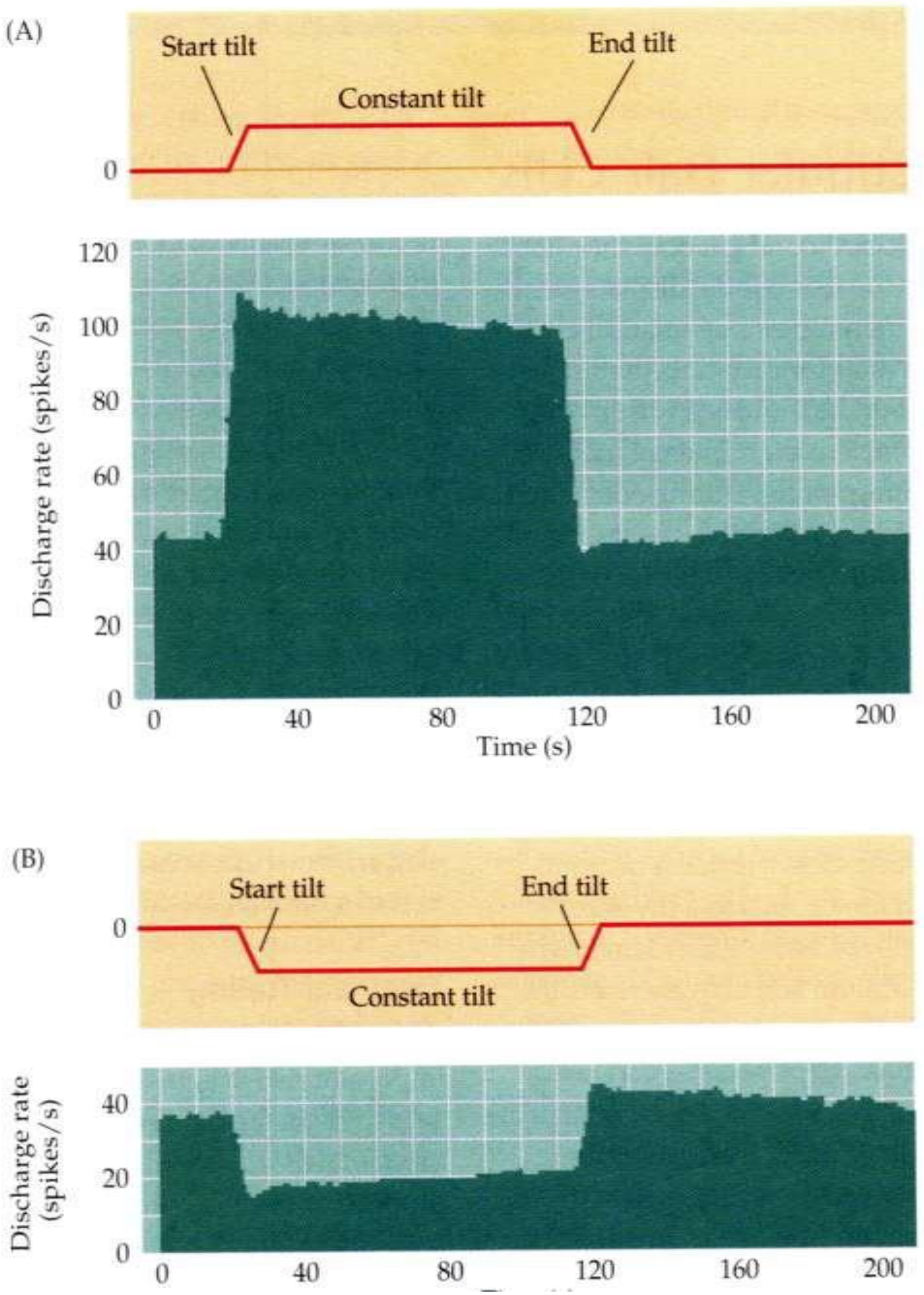

(A) Cross section of the utricular macula showing hair bundles projecting into the gelatinous layer when the head is level. (B) Cross section of the utricular macula when the head is tilted. (C) Orientation of the utricular and saccular maculae in the head; arrows show orientation of the kinocilia. The saccules on either side are oriented more or less vertically, and the utricles more or less horizontally. The striola is a structural landmark consisting of small otoconia arranged in a narrow trench that divides each otolith organ. In the utricular macula, the kinocilia are directed toward the striola. In the saccular macula, the kinocilia point away from the striola.

# DISPLACEMENTS OF THE OTOLITHIC MEMBRANE



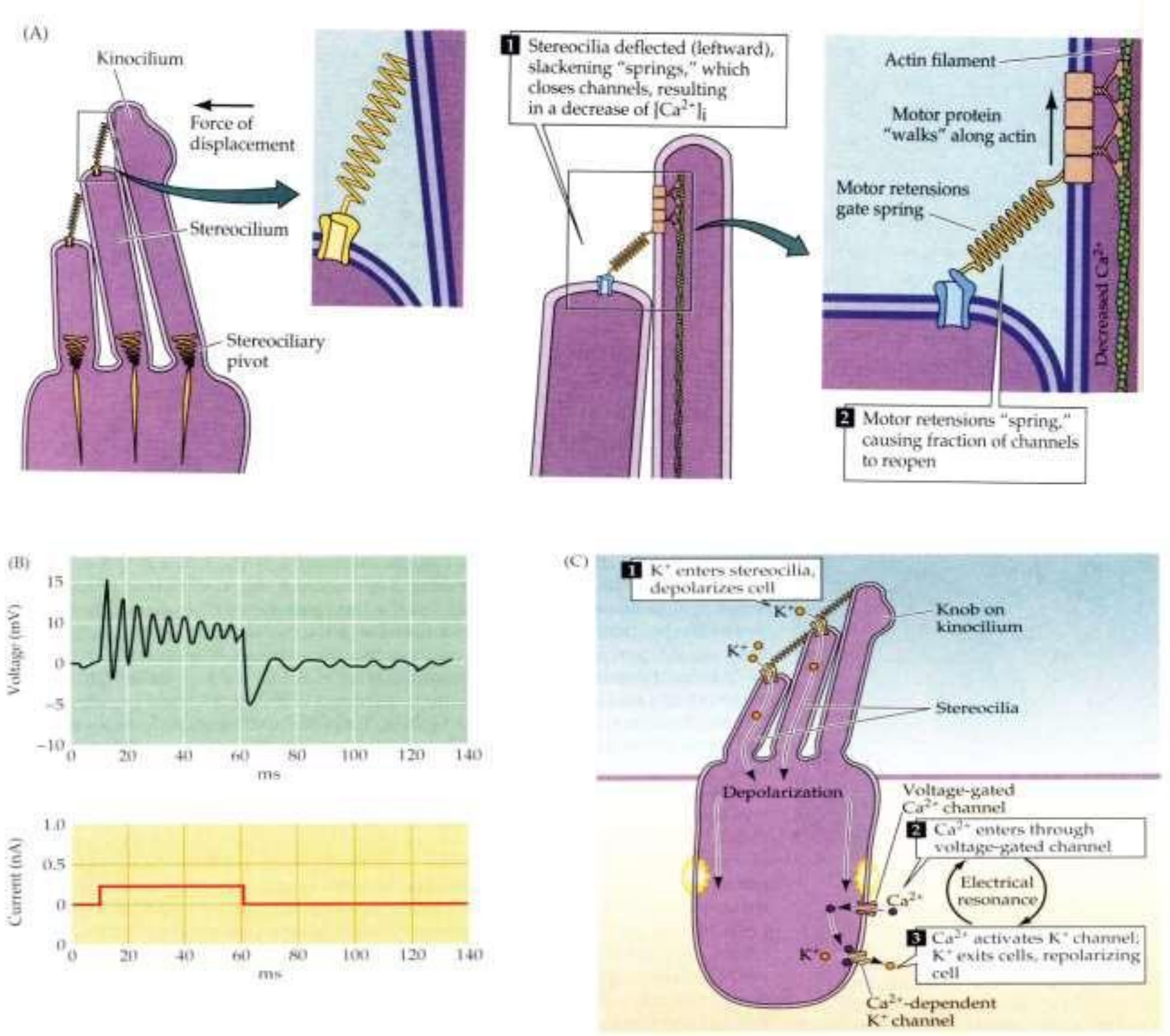

For each of the positions and accelerations due to translational movements, some set of hair cells will be maximally excited, whereas another set will be maximally inhibited. Note that head tilts produce displacements similar to certain accelerations.

# RESPONSE OF A VESTIBULAR NERVE AXON FROM AN OTOLITH ORGAN




(A) The stimulus (top) is a change that causes the head to tilt. The histogram shows the neuron's response to tilting in one direction. (B) A response of the same fiber to tilting in the opposite direction.

# RESPONSES OF THE HAIR CELLS

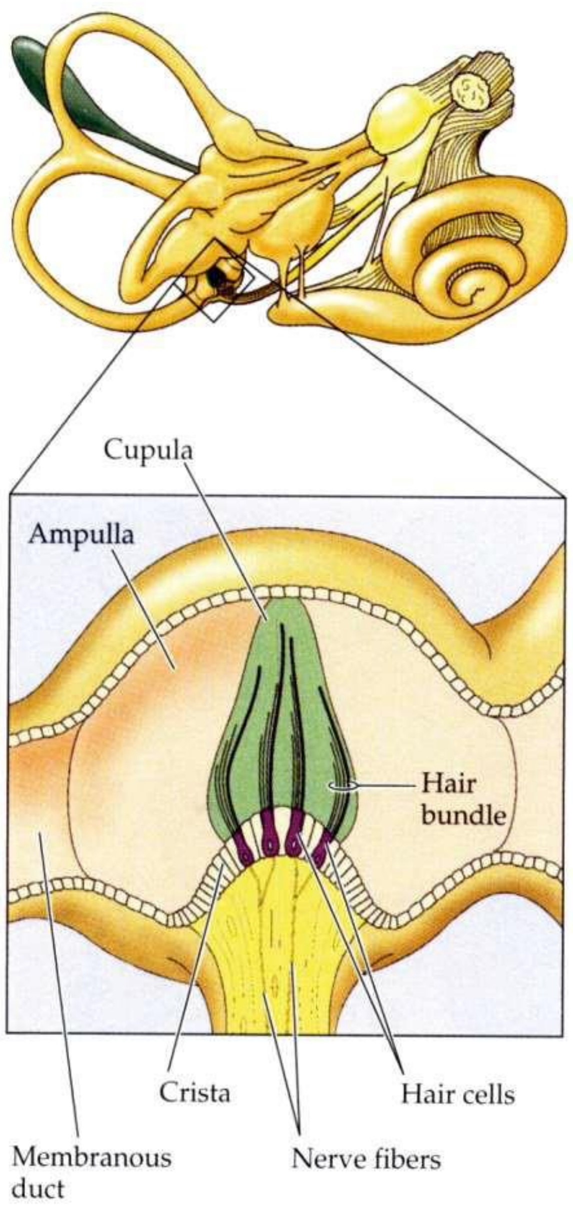



(A) Adaptation is explained in the gating spring model by adjustment of the insertion point of tips links. Movement of the insertion point up or down the shank of the stereocilium, perhaps driven by a Ca2-dependent protein motor, can continually adjust the resting tension of the tip link.

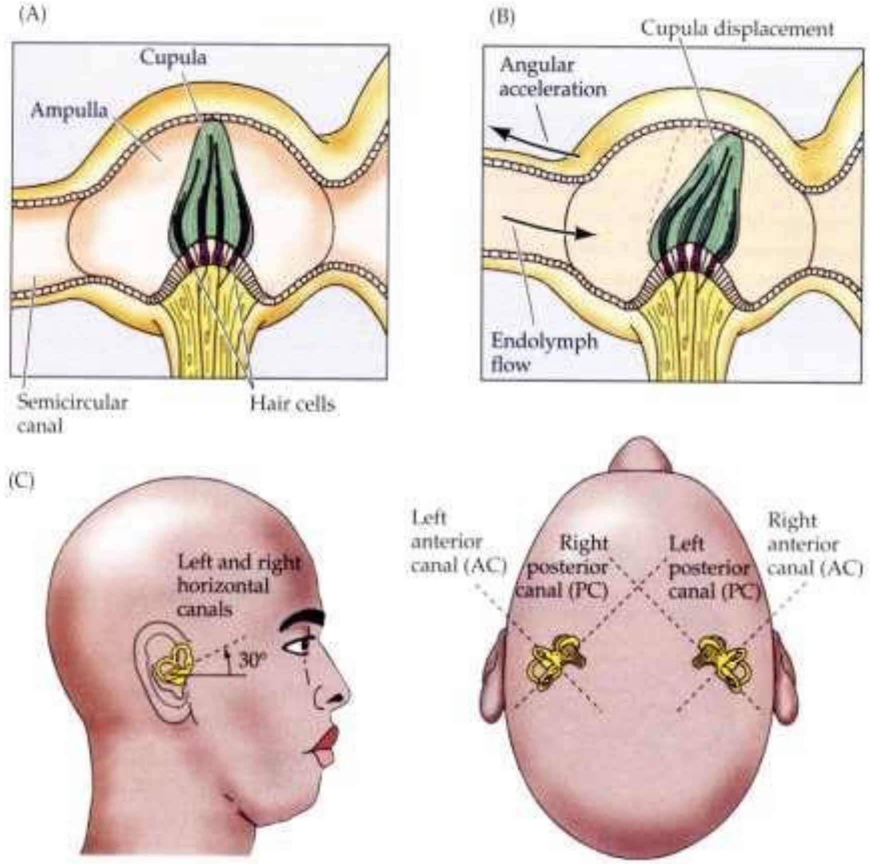
(B) Voltage oscillations (upper trace) in an isolated hair cell in response to a depolarizing current injection (lower trace).

(C) Proposed ionic basis for electrical resonance in hair cells.

# FUNCTIONAL ORGANIZATION OF THE SEMICIRCULAR CANALS

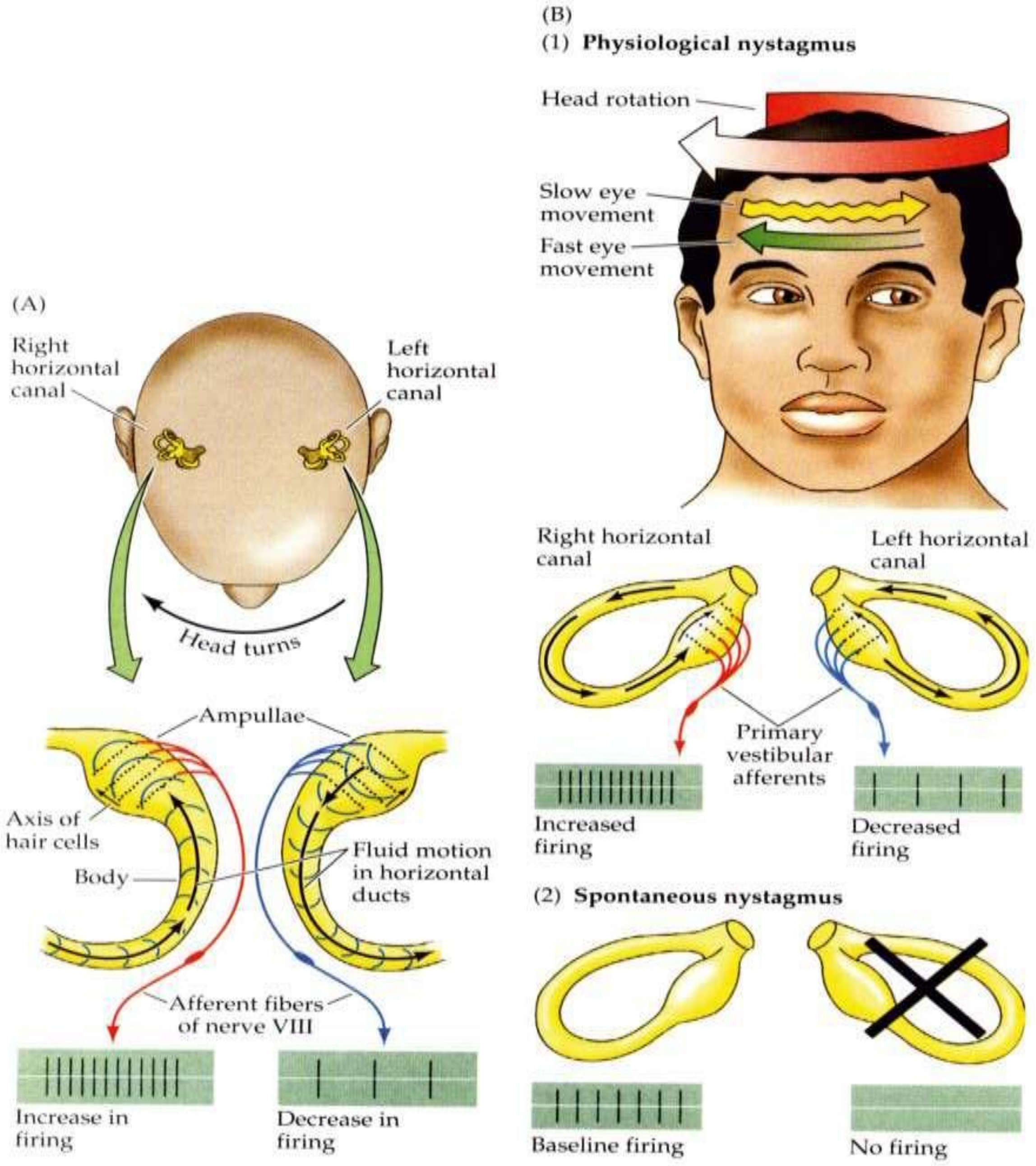



The ampulla of the posterior semicircular canal showing the crista, hair bundles, and cupula. The cupula is distorted by the fluid in the membranous canal when the head




(A) The position of the cupula without angular acceleration. (B) Distortion of the cupula during angular acceleration. When the head is rotated in the plane of the canal (arrow outside canal), the inertia of the endolymph creates a force (arrow inside the canal) that displaces the cupula. (C) Arrangement of the canals in pairs. The two horizontal canals form a pair; the right anterior canal (AC) and the left posterior canal (PC) form a pair; the left AC and the right PC form a pair.

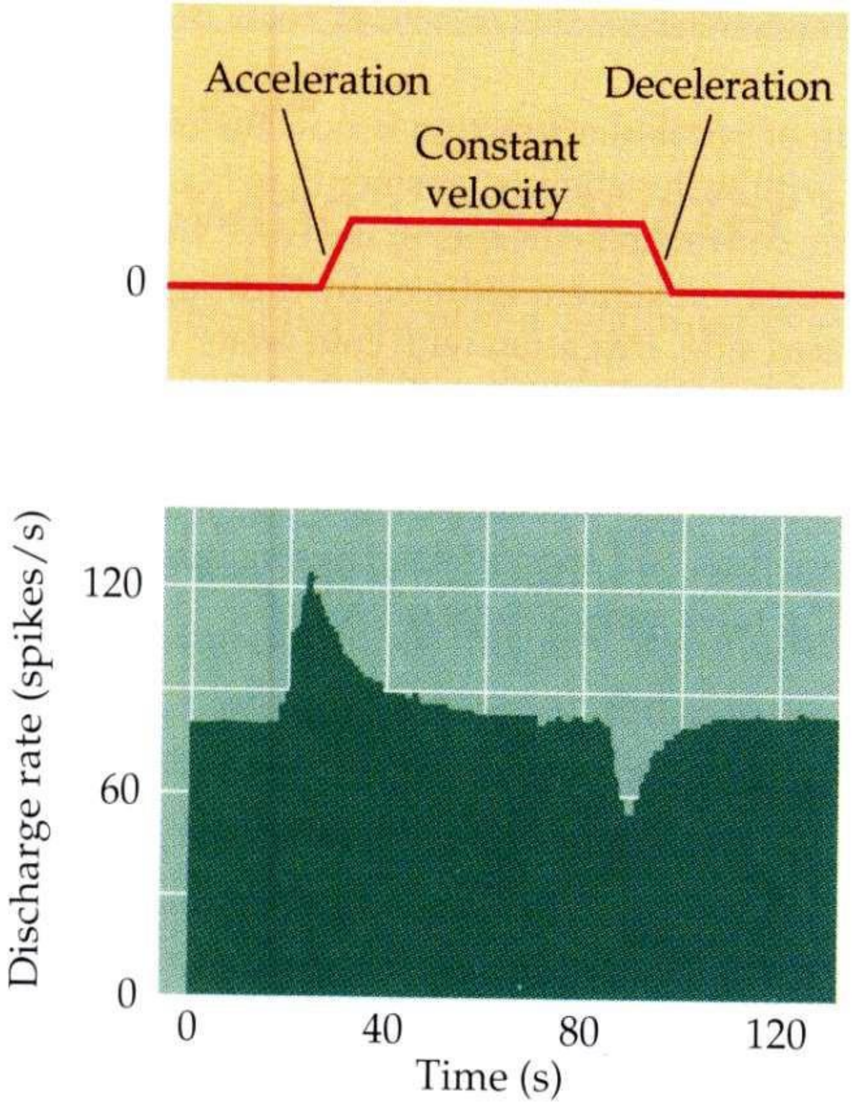
# PHYSIOLOGICAL NYSTAGMUS



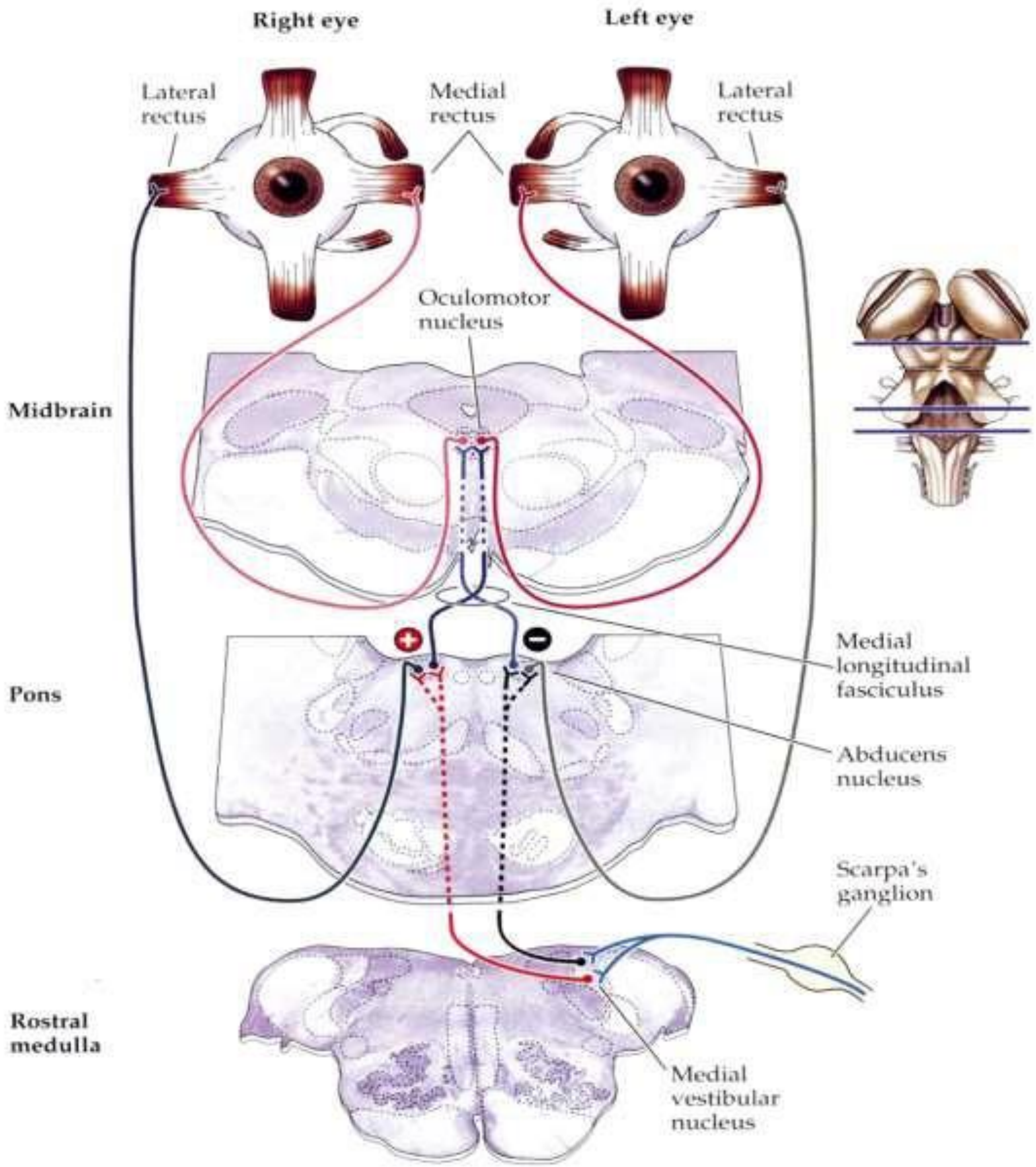

(A) View looking down on the top of a person's head illustrates the fluid motion generated in the left and right horizontal canals, and the changes in vestibular nerve firing rates when the head turns to the right.

(B) In normal individuals, rotating the head elicits physiological nystagmus (1), which consists of a slow eye movement counter to the direction of head turning. The slow component of the eye movements is due to the net differences in left and right vestibular nerve firing rates acting via the central circuit. Spontaneous nystagmus (2), where the eyes move rhythmically from side to side in the absence of any head movements, occurs when one of the canals is damaged. In this situation, net differences in vestibular nerve firing rates exist even when the head is stationary because the vestibular nerve innervating the intact canal fires steadily when at rest, in contrast to a lack of activity on the damaged side.

# RESPONSE OF A VESTIBULAR NERVE AXON FROM THE SEMICIRCULAR CANAL TO ANGULAR ACCELERATION

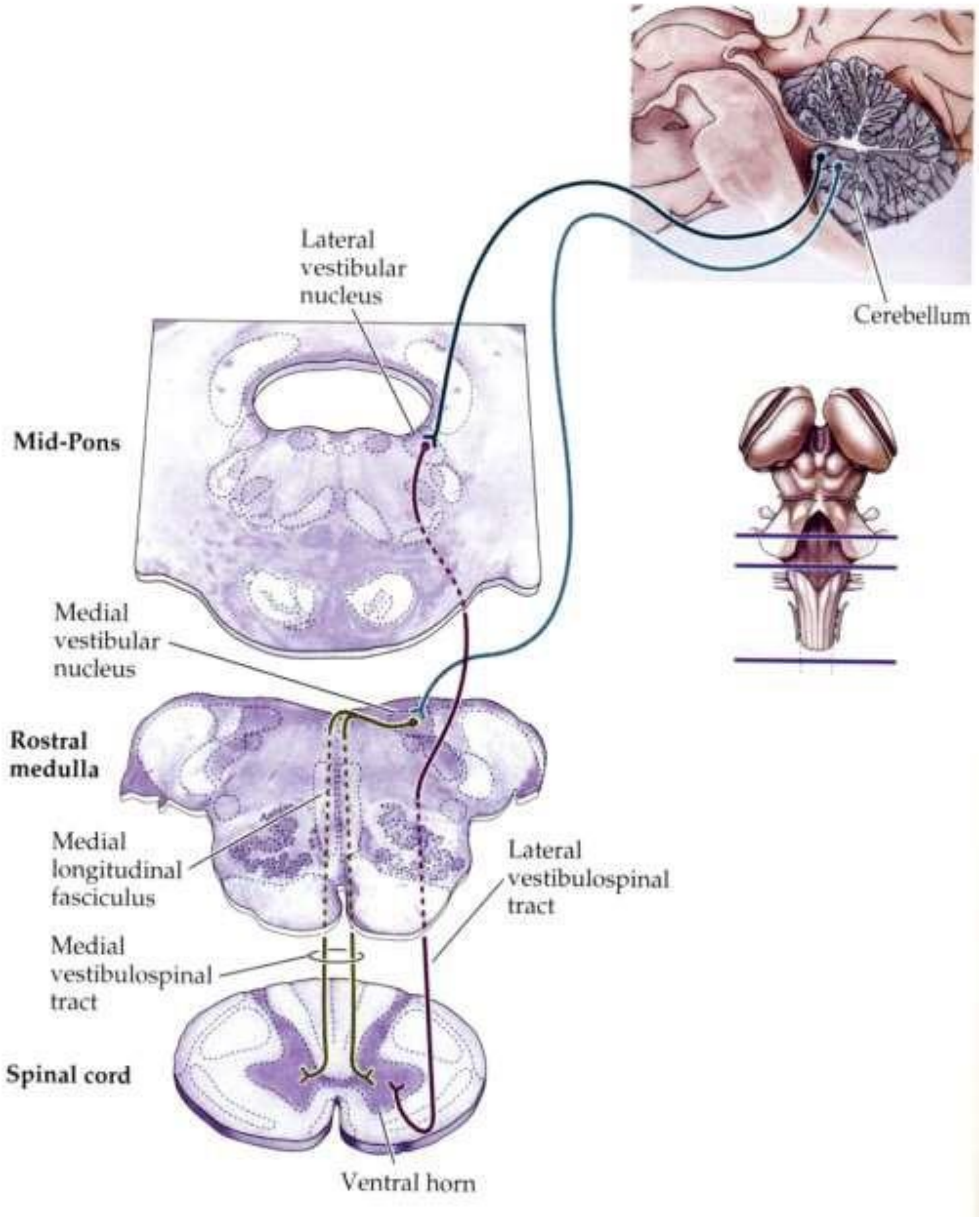



The stimulus (top) is a rotation that first accelerates, then maintains constant velocity, and then decelerates the head. The axon increases its firing above resting level in response to the acceleration, returns to resting level during constant velocity, then decreases its firing rate below resting level during deceleration; these changes in firing rate reflect inertia effects on the displacement of the cupula.



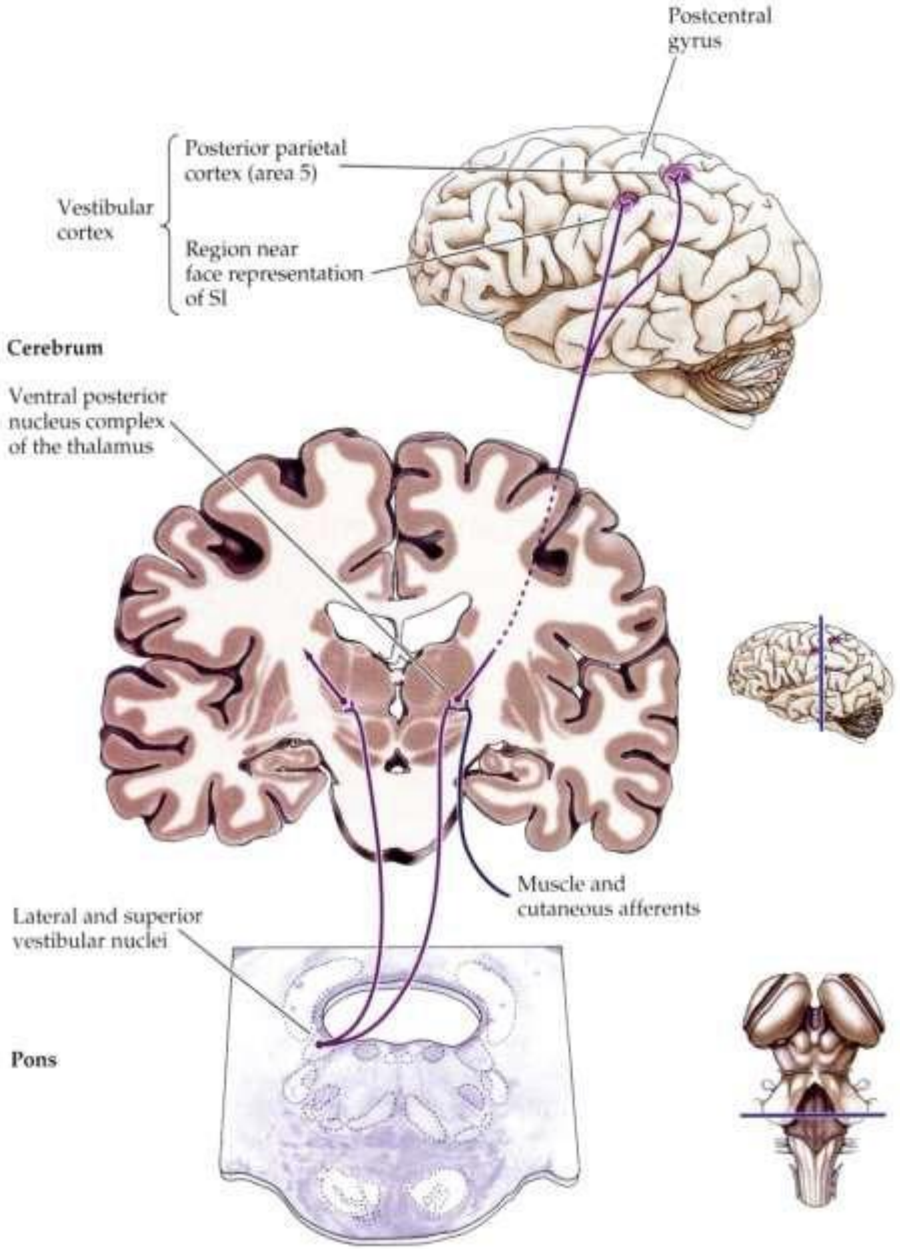

# VESTIBULOOCULAR REFLEX

Projections of the vestibular nucleus to the nuclei of cranial nerves III (oculomotor) and VI (abducens). The connections to the oculomotor nucleus and to the contralateral abducens nucleus are excitatory (red), whereas the connections to ipsilateral abducens nucleus are inhibitory (black). There are connections from the oculomotor nucleus to the medial rectus of the left eye and from the adbucens nucleus to the lateral rectus of the right eye. This circuit moves the eyes to the right, that is, in the direction away from the left horizontal canal, when the head rotates to the left. Turning to the right, which causes increased activity in the right horizontal canal, has the opposite effect on eye movements. The projections from the right vestibular nucleus are omitted for clarity.




# PROJECTIONS FROM THE VESTIBULAR NUCLEI TO THE SPINAL CORD

The medial vestibular nuclei project bilaterally in the medial longitudinal fasciculus to reach the medial part of the ventral horns and mediate head reflexes in response to activation of semicircular canals. The lateral vestibular nucleus sends axons via the lateral vestibular tract to contact anterior horn cells innervating the axial and proximal limb muscles. Neurons in the lateral vestibular nucleus receive input from the cerebellum, allowing the cerebellum to influence posture and equilibrium.




# VESTIBULAR PATHWAYS TO THE THALAMUS AND CORTEX

Thalamocortical pathways carrying vestibular information. The lateral and superior vestibular nuclei project to the thalamus. From the thalamus, the vestibular neurons project to the vicinity of the central sulcus near the face representation. Sensory inputs from the muscles and skin also converge on thalamic neurons receiving vestibular input.

# REVIEW QUESTIONS

- How is organized the vestibular system? Main components and basic principles of functioning.
- What is a role of the otolith organs?
- Descending and ascending pathways of the vestibular system.
- Dynamic components of discharge in the vestibular nerve fibers.
- Interaction of the vestibulospinal system with other descending systems. Excitatory vs. inhibitory influences of the vestibulospinal discharges on the skeletal musculature.
- Explain a role of the vestibular system in processes of the posture regulation.
- What is a functional role of physiological nystagmus?