Neurophysiology

Vestibular system

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Equilibrium

- The ear not only detects sound, but also changes in equilibrium or balance.

- Body movements that stimulate the receptors for equilibrium include linear acceleration or deceleration, and rotational (angular) acceleration or deceleration.

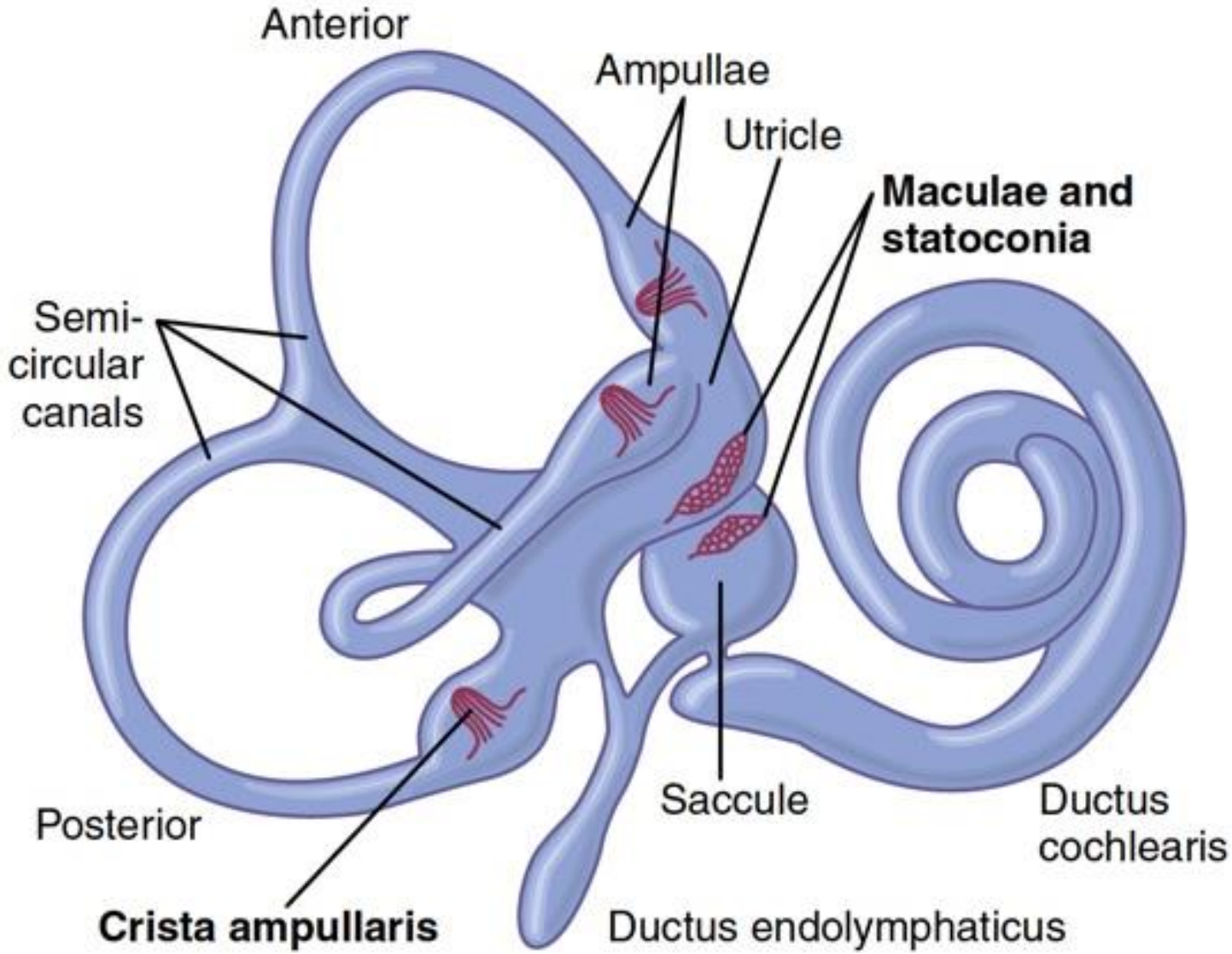
- The receptor organs for equilibrium are called the vestibular apparatus; these include the utricle and saccule of the vestibule and the semicircular ducts of the semicircular canals.

Vestibular apparatus

- It is encased in a system of bony tubes and chambers located in the petrous portion of the temporal bone, called the bony labyrinth.

- Within this system are membranous tubes and chambers called the membranous labyrinth.

- The membranous labyrinth is the functional part of the vestibular apparatus.



MEMBRANOUS LABYRINTH

Otolithic Organs: Utricle and Saccule

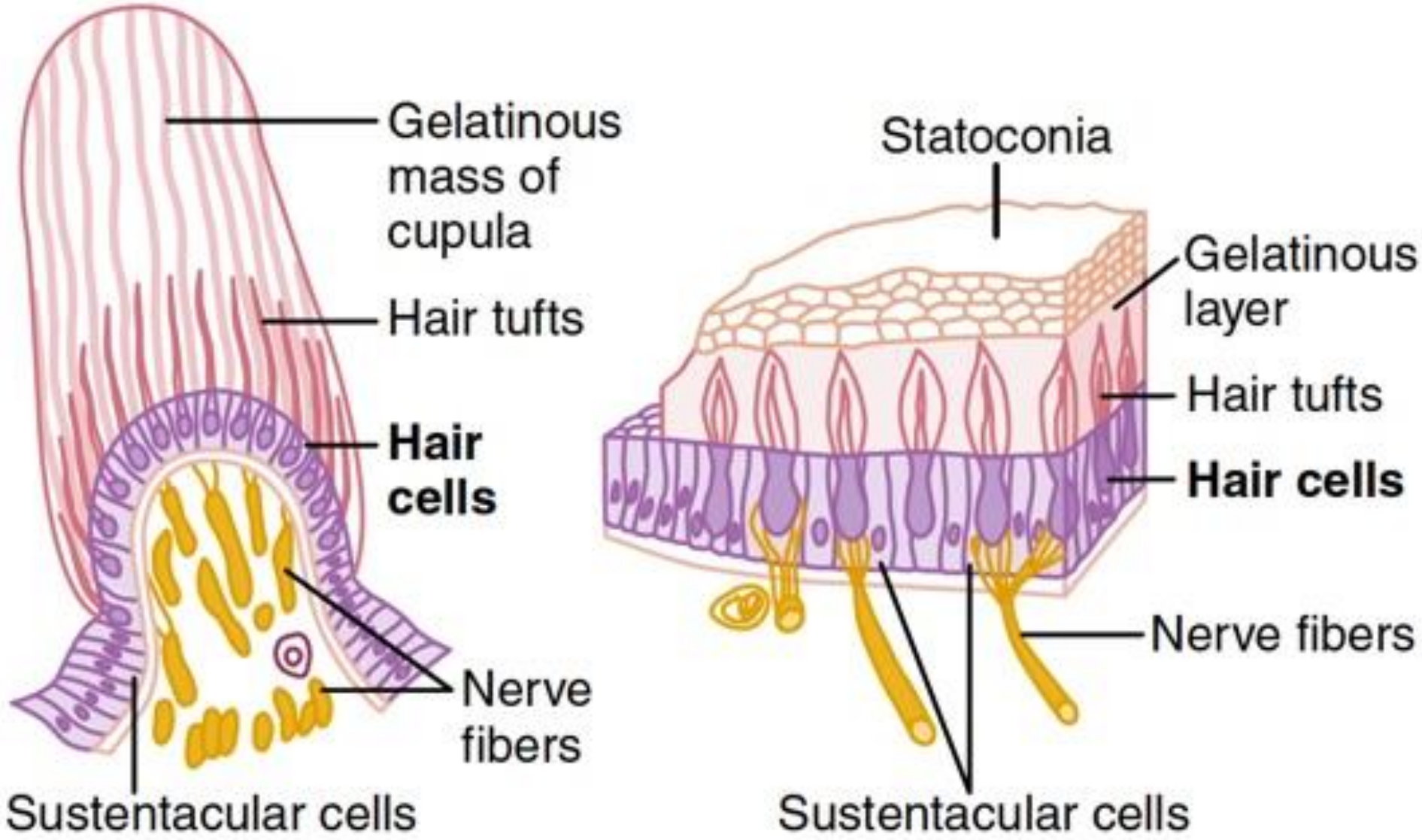
- Attached to the inner walls of both the utricle and the saccule is a small, thickened region called the macula.
- The two maculae contain the receptors for linear acceleration or deceleration and the position of the head.
- The maculae consist of two types of cells: hair cells, which are the sensory receptors, and supporting cells.

Utricle and Saccule

- Supporting cells secrete the thick, gelatinous, glycoprotein layer, called the otolithic membrane, that rests on the hair cells.

- Each macula is covered by a gelatinous layer in which many small calcium carbonate crystals called statoconia (otolith) are embedded.

- Also in the macula are thousands of hair cells. these hair cells project cilia up into the gelatinous layer.



CRISTA AMPULLARIS AND MACULA

Statoconia (otolith)

- The bases and sides of the hair cells synapse with sensory endings of the vestibular nerve.

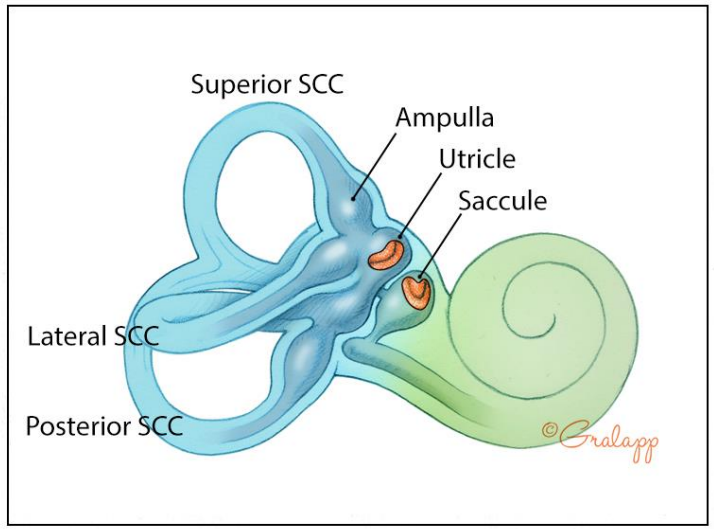
- The calcified statoconia have a specific gravity two to three times the specific gravity of the surrounding fluid and tissues.

Otolithic Organs: Utricle and Saccule

- The maculae of the utricle and saccule are perpendicular to one another.

- When the head is in an upright position, the macula of the utricle is oriented horizontally, and the macula of the saccule is oriented vertically.

- Because of these orientations, the utricle and saccule have different functional roles.


Superior SCC
Ampulla
Utricle
Saccule
Lateral SCC
Posterior SCC
©Gralapp

Utricle
Saccule
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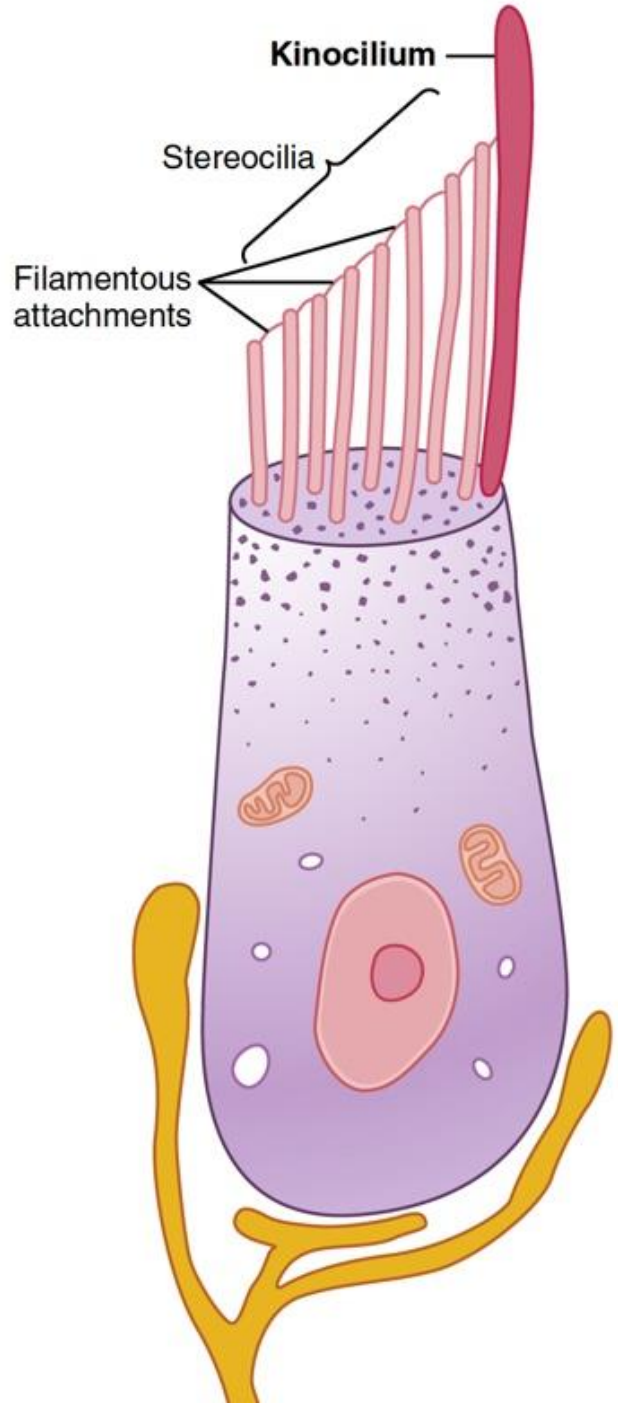
Maculae

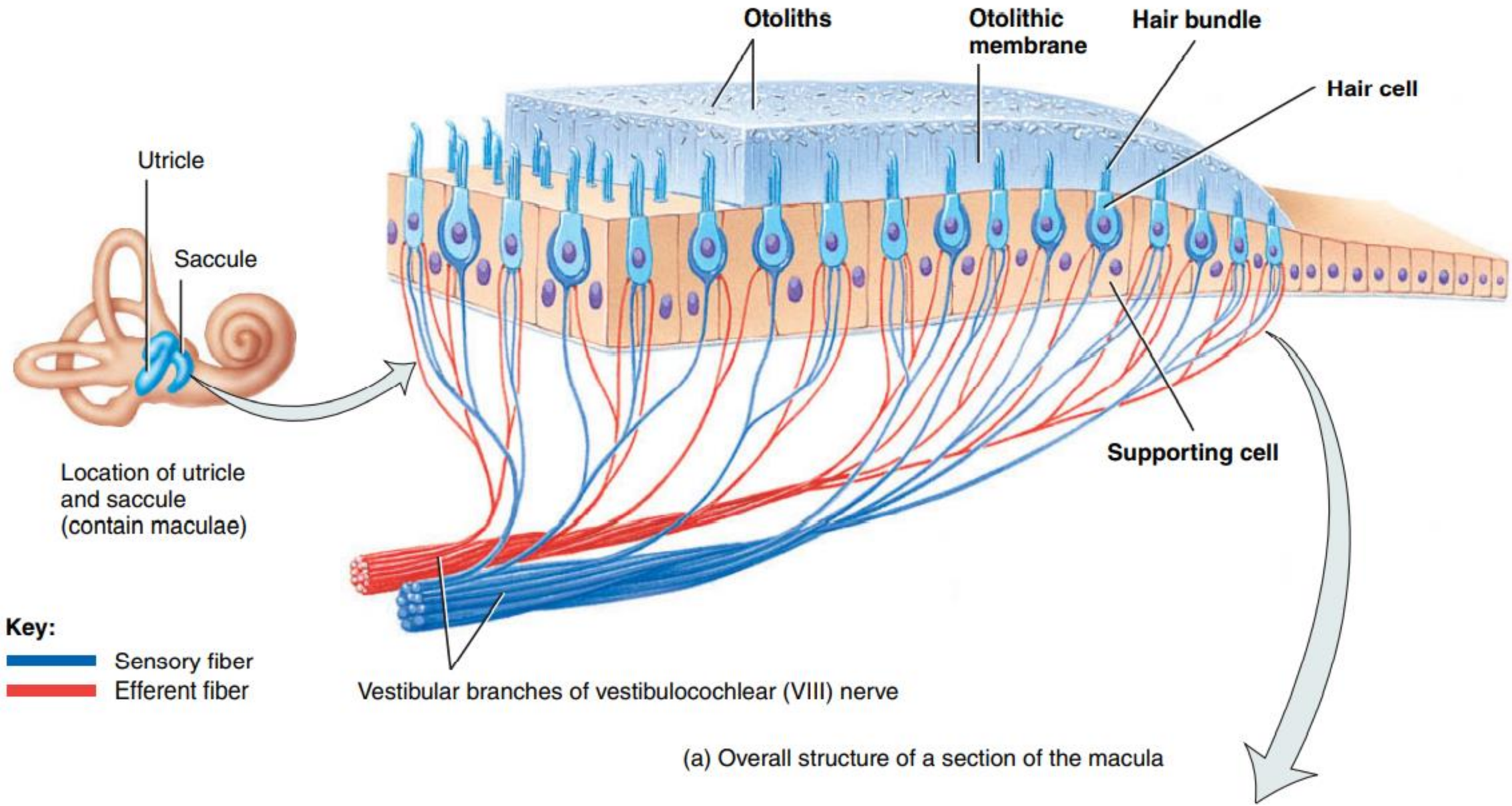
- The macula of the utricle plays an important role in determining the orientation of the head when the head is upright.

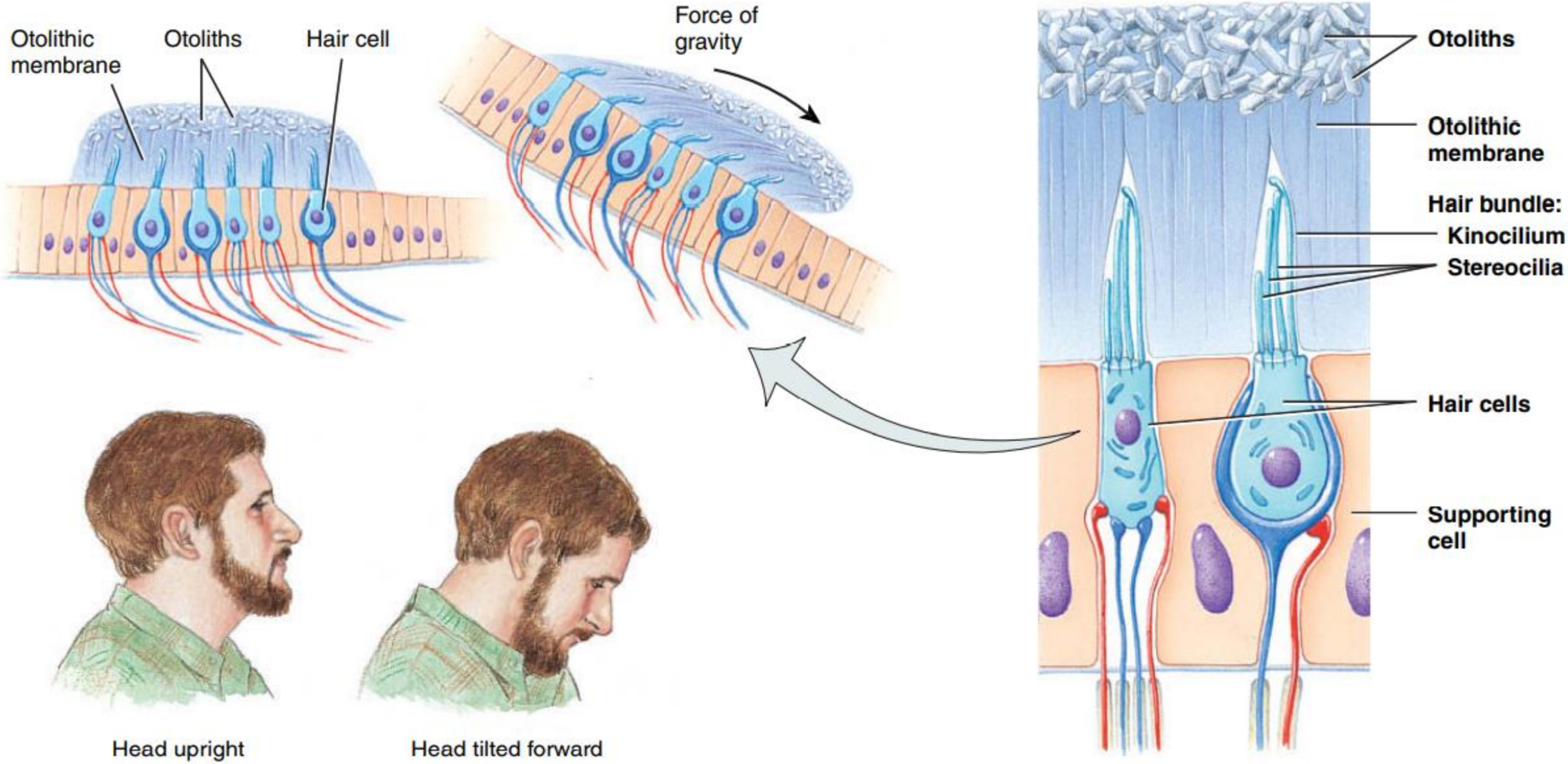
- Conversely, the macula of the saccule signals head orientation when the person is lying down.


Kinocilium
Stereocilia
Filamentous attachments

Maculae

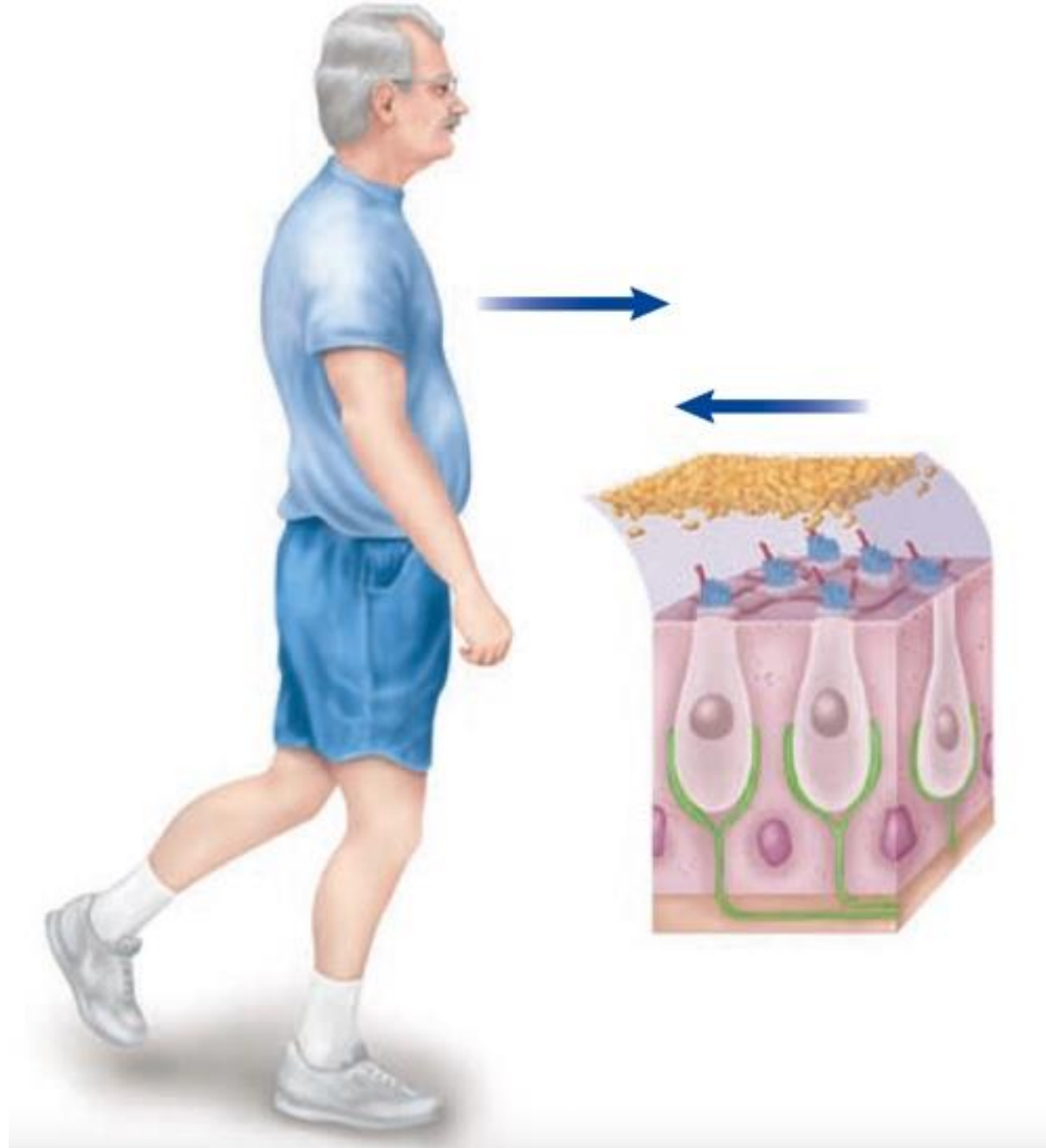
- The hair cells are all oriented in different directions in the maculae of the utricles and saccules so that with different positions of the head, different hair cells become stimulated.
- The “patterns” of stimulation of the different hair cells apprise the brain of the position of the head with respect to the pull of gravity.
- In turn, the vestibular, cerebellar, and reticular motor nerve systems of the brain excite appropriate postural muscles to maintain proper equilibrium.


Otoliths
Otolithic membrane
Hair bundle
Hair cell
Utricle
Saccule
Location of utricle and saccule (contain maculae)
Supporting cell
Key:
Sensory fiber
Efferent fiber
Vestibular branches of vestibulocochlear (VIII) nerve
(a) Overall structure of a section of the macula



(c) Position of macula with head upright (left) and tilted forward (right)

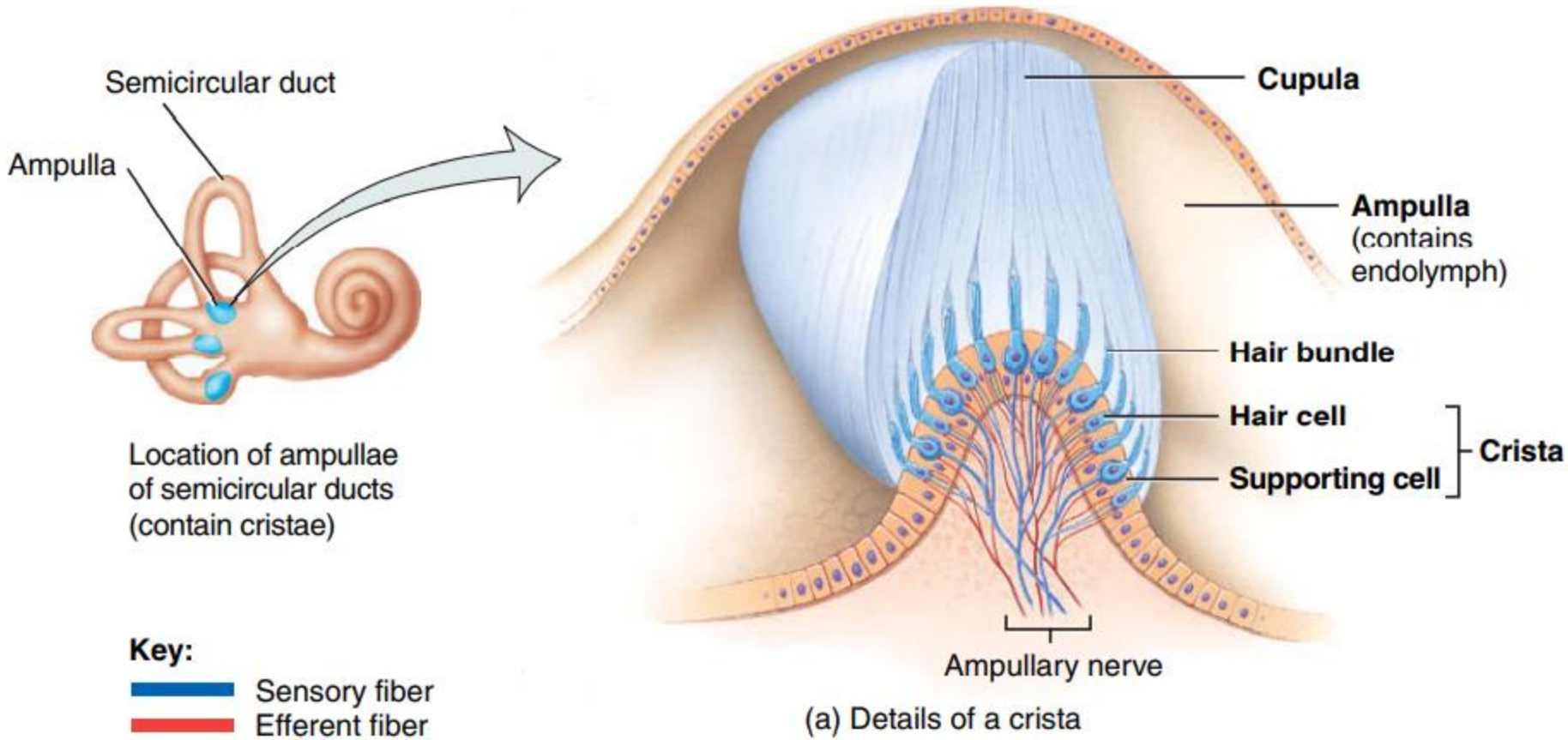
(b) Details of two hair cells

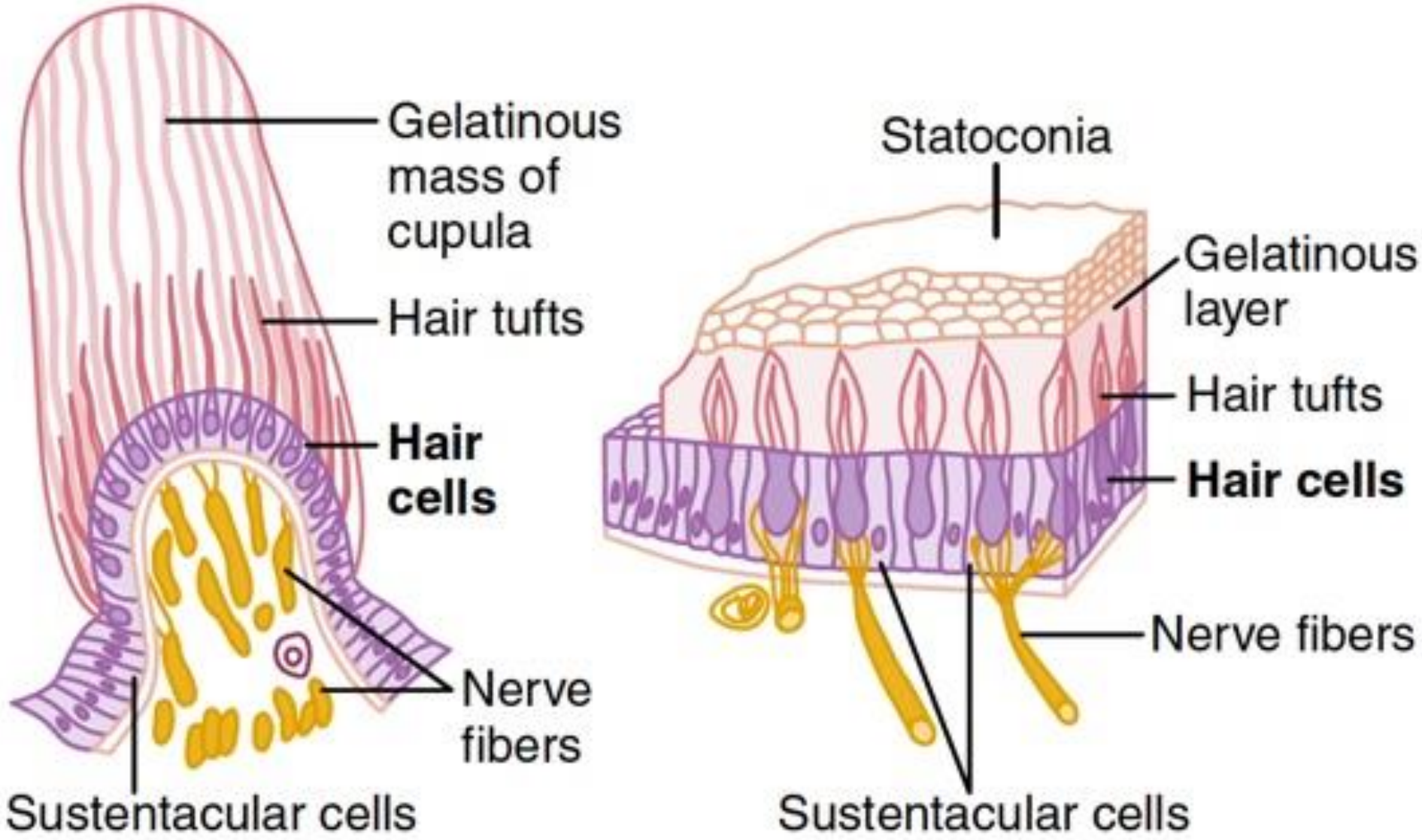


Semicircular Ducts

- The three semicircular ducts lie at right angles to one another in three planes. The two vertical ducts are the anterior and posterior semicircular ducts, and the horizontal one is the lateral semicircular duct.

- This positioning permits detection of rotational acceleration or deceleration.


Semicircular duct
Ampulla
Location of ampullae
of semicircular ducts
(contain cristae)
Key:
Sensory fiber
Efferent fiber
Cupula
Ampulla
(contains
endolymph)
Hair bundle
Hair cell
Supporting cell
Crista
Ampullary nerve
(a) Details of a crista



CRISTA AMPULLARIS AND MACULA

Semicircular Ducts

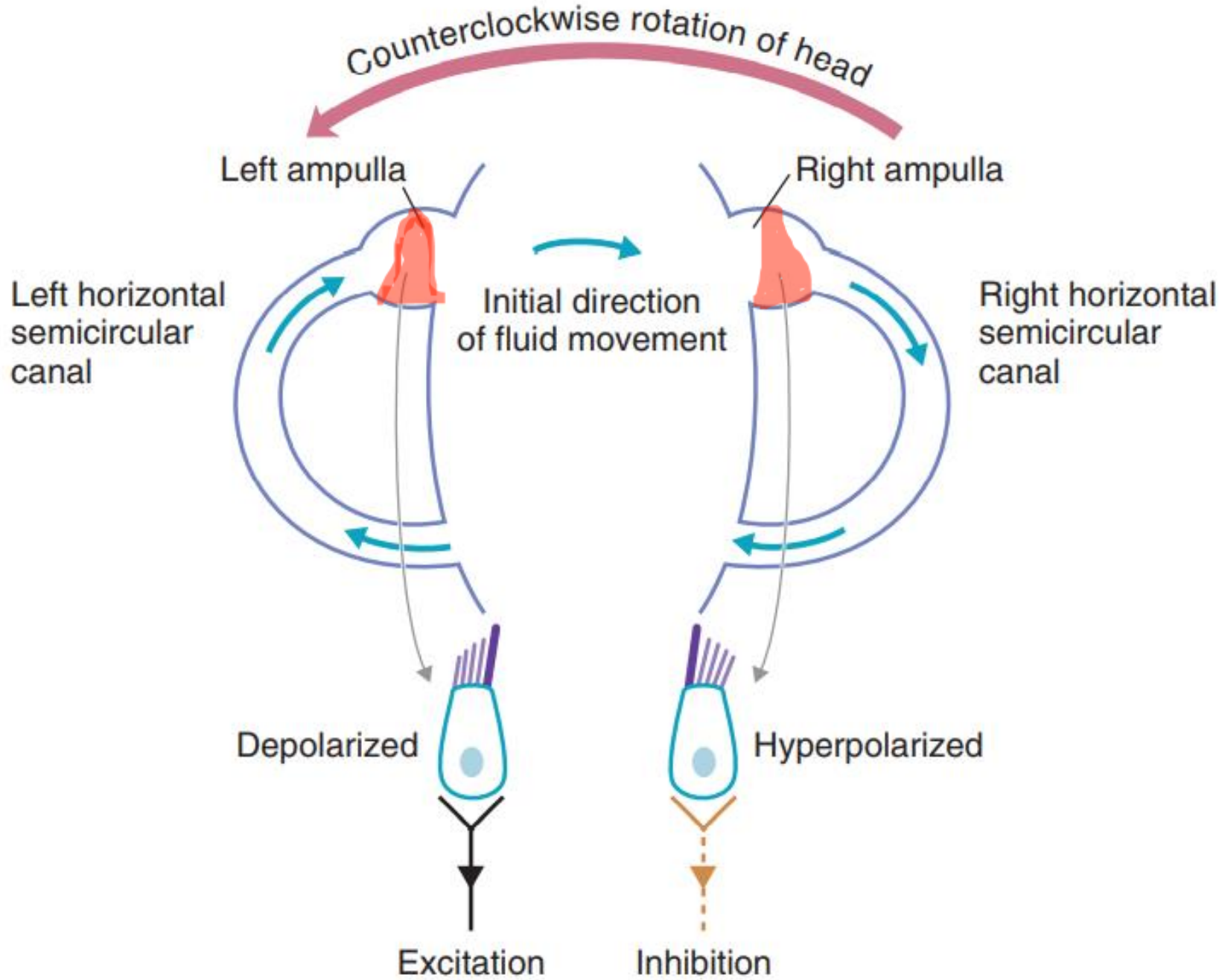
- When the head rotates, the attached semicircular ducts and hair cells move with it. However, the endolymph within the ampulla is not attached and lags behind due to inertia.

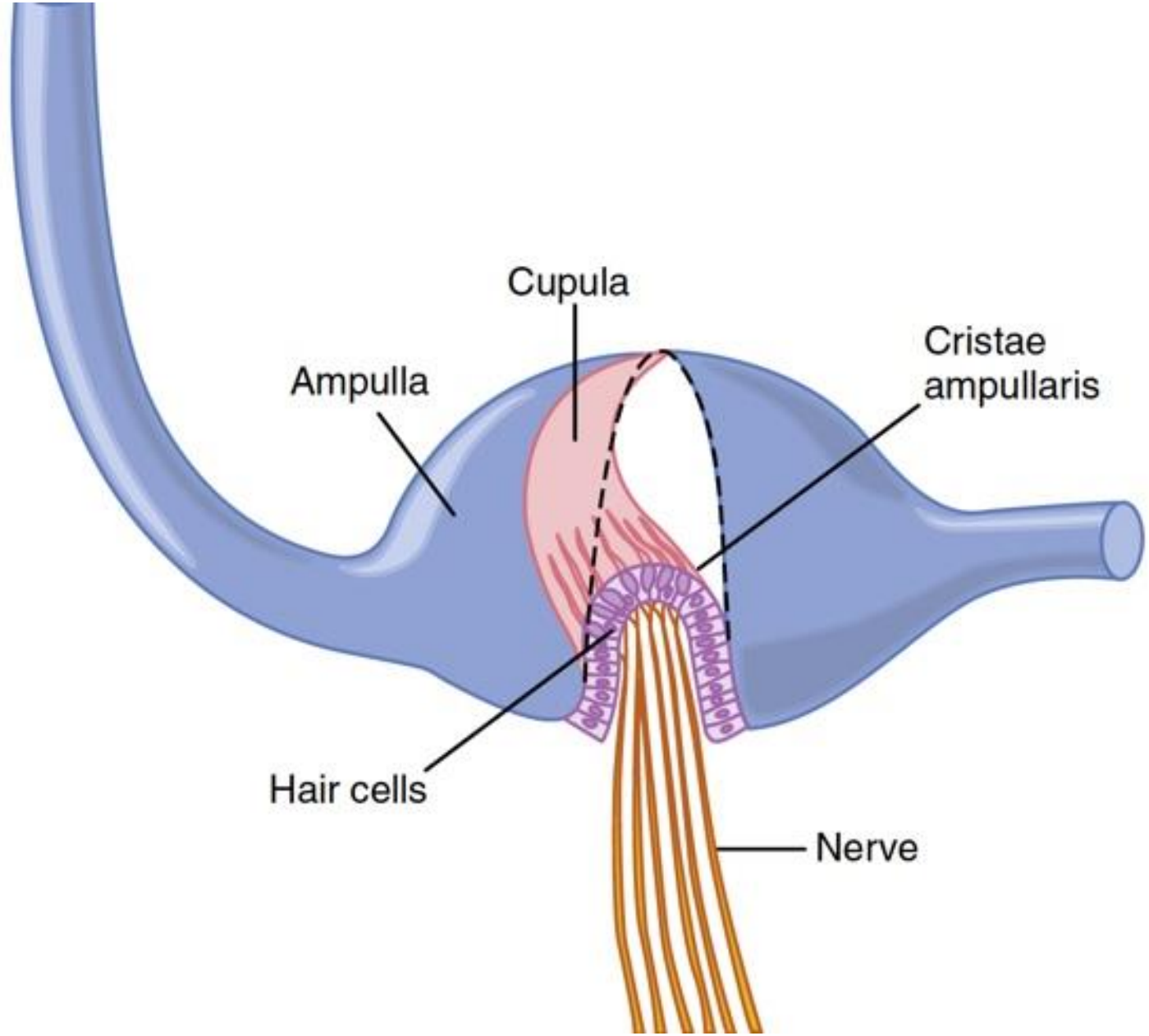
- The drag of the endolymph causes the cupula and the hair bundles that project into it to bend in the direction opposite to that of the head movement.

Semicircular Ducts

- Once the head stops moving, the endolymph temporarily keeps moving due to inertia, which causes the cupula and its hair bundles to bend in the same direction as the preceding head movement.

- At some point the endolymph stops moving and the cupula and its hair bundles return to their resting, unbent positions.


Counterclockwise rotation of head
Left ampulla
Right ampulla
Left horizontal semicircular canal
Initial direction of fluid movement
Right horizontal semicircular canal
Depolarized
Hyperpolarized
Excitation
Inhibition


Cupula
Ampulla
Cristae
ampullaris
Hair cells
Nerve

Semicircular ducts

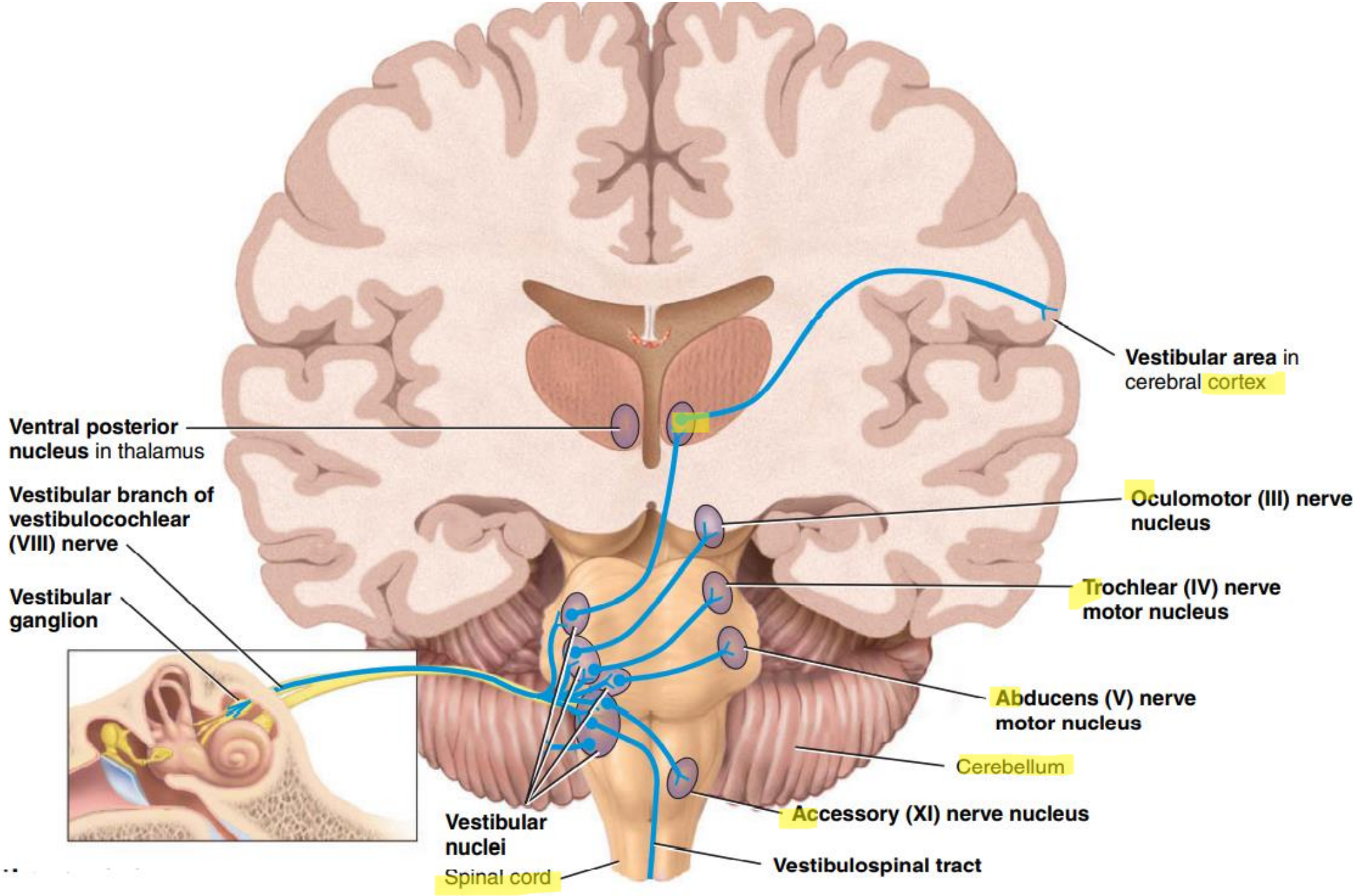
- the semicircular duct mechanism **predicts** that disequilibrium is going to occur and thereby causes the equilibrium centers to make appropriate anticipatory preventive adjustments, which helps the person maintain balance before the situation can be corrected.

Equilibrium pathways

- Most of the axons synapse with sensory neurons in vestibular nuclei in the medulla oblongata and pons.

- The vestibular nuclei also receive input from the **eyes** and proprioceptors, especially **proprioceptors in the neck and limb** muscles that indicate the position of the head and limbs.

- Some fibers pass directly to the brain stem **reticular nuclei** without synapsing and also to the **cerebellar nuclei**.


Vestibular area in cerebral cortex
Ventral posterior nucleus in thalamus
Vestibular branch of vestibulocochlear (VIII) nerve
Vestibular ganglion
Oculomotor (III) nerve nucleus
Trochlear (IV) nerve motor nucleus
Abducens (V) nerve motor nucleus
Cerebellum
Accessory (XI) nerve nucleus
Vestibular nuclei
Spinal cord
Vestibulospinal tract

Equilibrium pathways

The vestibular nuclei integrate information from vestibular, visual, and somatic receptors and then send commands to:

(1) the nuclei of cranial nerves III, IV, and VI that control coupled movements of the eyes with those of the head to help maintain focus on the visual field.

(2) nuclei of the accessory (XI) nerves to help control head and neck movements to assist in maintaining equilibrium.

Equilibrium pathways

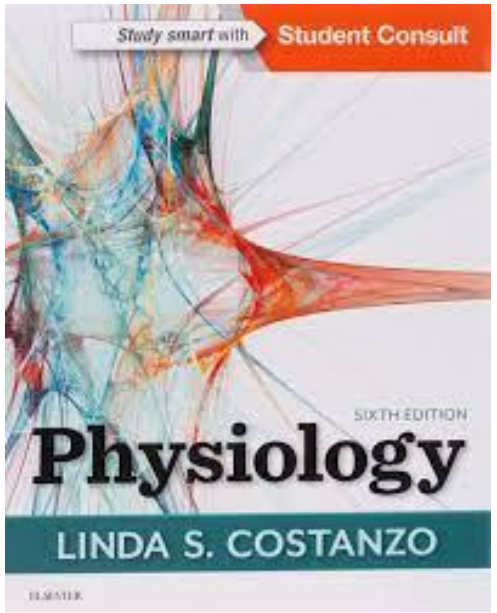
(3) the vestibulospinal tract, which conveys impulses down the spinal cord to maintain muscle tone in skeletal muscles to help maintain equilibrium.

(4) the ventral posterior nucleus in the thalamus and then to the vestibular area in the parietal lobe of the cerebral cortex to provide us with the conscious awareness of the position and movements of the head and limbs.

Loss of function

- After destruction of the vestibular apparatus, and even after loss of most proprioceptive information from the body, a person can still use the visual mechanisms reasonably effectively for maintaining equilibrium.
- Some people with bilateral destruction of the vestibular apparatus have almost normal equilibrium as long as their eyes are open, and all motions are performed slowly.
- However, when moving rapidly or when the eyes are closed, equilibrium is immediately lost.

References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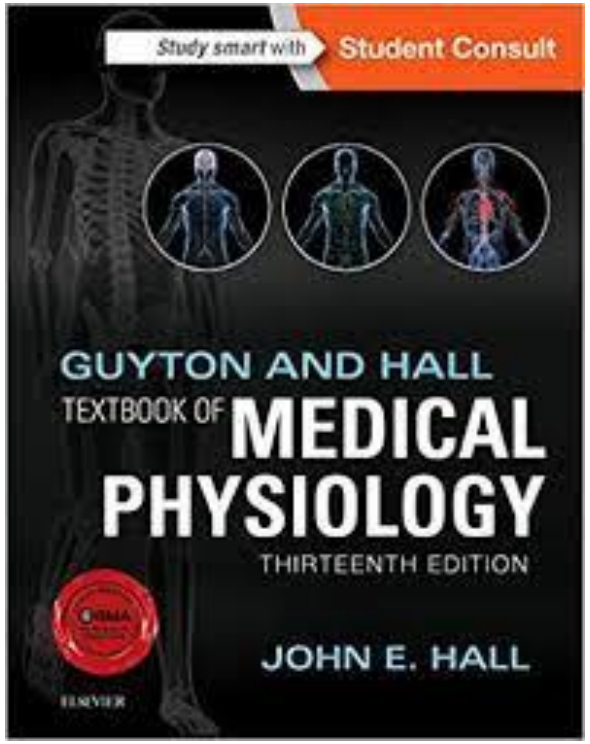
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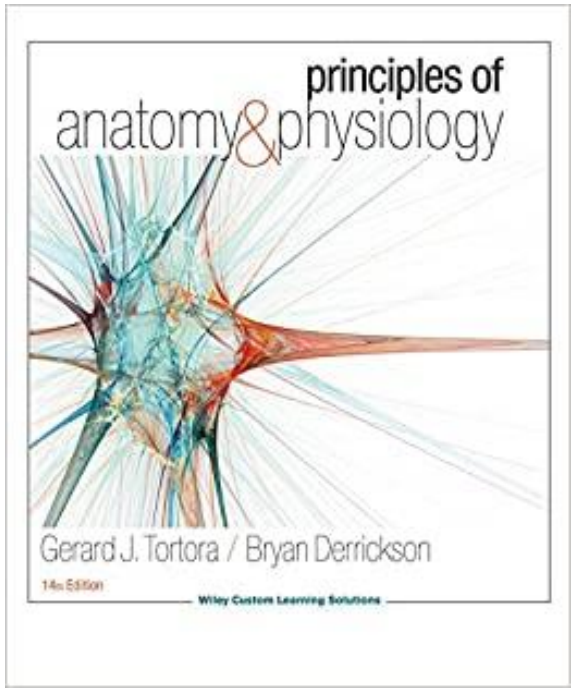
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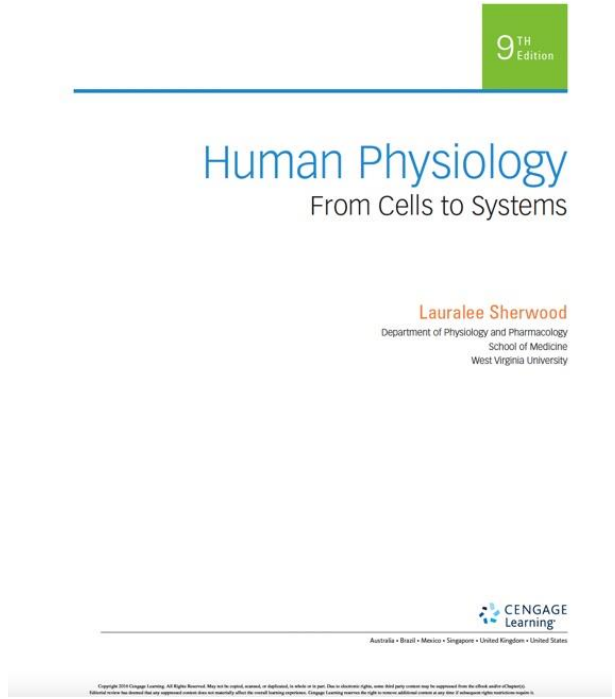
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