Vestibular System & Balance

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The Vestibular System

- The vestibular system is a part of sensory system but involved with motor functions
- It gives us our sense of balance and equilibrium.
- It provides brain with information about head position and spatial orientation.
- Sensory receptors for vestibular system are in inner ear with auditory receptors.

The Vestibular System

(Auditory System)

- Sense of audition (hearing) is ability to perceive sounds by detecting vibrations in air.
- Vibrations pass through the ear canal, middle ear bones and reach to cochlea.
- Cochlea is a spiral-shaped, fluid-filled tube that consists auditory receptors

The Vestibular System

(Auditory System)

- Hearing receptors are called «hair cells» and they are mechanoreceptors which sensitive to mechanical stimuli.
- Sound vibrations cause motion of the fluid inside the cochlea.
- Movement of the fluid causes bending of cilia on the hair cells.
- This bending opens the cation channels mechanically and receptor depolarizes.
- Action potential is carried to the brain by the vestibulocochlear nerve as sound signals

The Vestibular System

- Vestibular and auditory systems are both placed in inner ear
- Both of these systems use hair cells as receptor.
- Both of these system are sensitive to movements
- Both of these systems share same sensory neuron (vestibulocochlear nerve)

The Vestibular System

- Auditory and vestibular system have common origins.
- Balance and hearing organs of mammalian evolved from lateral line organs present in fish.
- Lateral line organ is small pits along animal's side and each pit has hair cells which sensitive to vibrations in the water (similar to the hair cells in our inner ear)

The Vestibular Labyrinth

- All hair cells contained within chambers that called «vestibular labyrinth»
- It includes two types of structures:
  - Otolith organs
  - Semicircular canals
- Both of these structures transmit mechanical energy from head movement to the hair cells
- Each structure sensitive to different movements

The Vestibular Labyrinth

- Otolith organs
  - are large chambers (saccule and utricle) at the center of the labyrinth.
  - Sensitive the force of gravity and tilts of the head.

- Semicircular canals
  - Are three arching structures which lie orthogonally
  - Sensitive the head rotation

Vestibular Hair Cells

- Hair cells transduce mechanical stimuli into receptor potential; each one has 10-300 stereocilia at its top
  - Tip of each stereocilium has ion channels that is induced to open or close by bending of cilia
  - When cilia are straight, some channels are open and allow small amount of K^+ flow into the cell.
  - Bending in one direction increase the rate of open channels; bending in another direction closes the channels

Vestibular Hair Cells

- K^+ ion open the Ca^{++} channels and cause depolarization of the cell
- Movement to one direction depolarize the cell; movement to another direction hyperpolarize the cell
- In each vestibular organ, hair cell bundles have spesific orientation. As a result, system is responsive to movements in all directions

Otolith Organs

- Otolith organs provide information about linear acceleration or changes in head position relative to the forces of gravity.
- Linear acceleration generates force (riding in an elevator)
  - At constant velocity, there is no force so otolith organ does not detect movement but if there is a change at velocity there would be force which can detect by otolith organs
- Gravitational effect of head position (moving from lying to standing position)

Otolith Organs

- Otolith organ contains a sensory epithelium = macula
- Macula contains hair cells and their stereocilia project into a gelatinous substance.
- There are calcium carbonate cristals at the surface of gelatinous cap which are called otoconia (otoliths)
- Otoconia have high density and they are the key to tilt sensitivity of otolith organs

Otolith Organs

- When the angle of head changes (or head accelerates);
  - Force of movement is exerted on the otoconia
  - Otoconia exerts the force into gelatinous cap
  - Gelatinous cap moves slightly
  - Bend the stereocilia of hair cells

Otolith Organs

- Each hair cells has one tall cilium =kinocilium
- Bending of stereocilia toward the kinocilium, opens more mechanically gated ion channels and depolarize the cell
- Bending of the stereocilia away from the kinocilium closes the channels and hyperpolarizing the cell
- Hair cells on otolith organs are direction-selective

Otolith Organs

- Hair cells of utricle and saccule are oreiented to respond all direction of head movements.
- Direction preferences of hair cells are vary systematically
- Otolith organ can cover all directions.

Semicircular Canals

- Otolith organ can sense linear acceleration but semicircular canals sense angular acceleration (rotations)
- They detect turning movements of the head along three axes.

➢ Horizontal axis (nodding the head to say ‘yes’)
➢ Vertical axis (shaking the head to say ‘no’)
➢ Anterior-posterior axis (tipping the head to the shoulders)

Semicircular Canals

- Semicircular canals have a slight bulge = ampulla
- Each ampulla contains crista ampullaris which contains hair cells and gelatinous substance
- Stereocilia of hair cells are encapsulated within gelatinous cap (cupula).
- Duct of semicircular canals are filled with fluid which called endolymph

Semicircular Canals

- When the head moves, semicircular canals move with it
- But, endolymph tends keep its original position and lag behind because of the inertia
- Moving ampulla is pushed against the stationary fluid and stereocilias bend.
- Bending to one direction cause depolarization and to other direction cause hyperpolarization.

Semicircular Canals

- If head continuously rotates at a steady velocity, endolymphs begins to move and catches up.
- Stereocilia return their resting position and stop responding
- When the rotation stopped, endolymph continue to move because of the inertia and bend the stereocilia to other direction = temporary sensation of counter rotation

Semicircular Canals

- Three semicircular canals can detect all possible head rotation angles.
- Each canal is paired with another on the opposite side of head.
- If rotational acceleration causes depolarization in one side, causes hyperpolarization on the other
- This mechanism optimize the ability of brain to detect rotational movements

Vestibular Pathways

- Vestibular information is used in three ways:

1. Contributing motor system for maintaning upright posture and balance

2. Providing conscious awarenes of the position and acceleration of the body, spatial perception

3. Controlling the eye muscles; so in spite of changes in head position, eyes can remain fixed at same point.

- Primary vestibular axons from cranial nerve VIII make synapses with vestibular nuclei and vestibular nuclei send this singal to a variety of targets for these three functions

Vestibular Pathways

1.1. Axons from otolith organs project to the lateral vestibular nucleus, which then projects via vestibulospinal tract to control muscles to maintain posture

1.2. Axons from semicircular canals project to the medial vestibular nucleus, which then project to the neck muscles that orient the head

Vestibular Pathways

2. Vestibular nuclei send signal to the thalamus and then to cortex.

- At the cortical level, this information is integrated with other sensory information (vision, proprioception etc)

- Cortex maintains the conscious representation of body position and orientation in space

Vestibular Pathways

3. Vestibulo-Ocular Reflex (VOR)

- Responsible for keeping eyes pointed in particular direction even body is moving.
- VOR sensing rotations of the head and make compensatory movement of the eyes in the opposite direction.
- VOR depends on connections between semicircular canals and craniel nerve that control extracoular muscles

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