THE VESTIBULAR APPRATUS AND PATHWAY

Objectives:

1. Describe structure of vestibular receptors (cristae, maculae, cupula, otolithic membrane, hair cells
2. Describe the location and function of the lateral and medial vestibulospinal tracts originating in the vestibular nuclei.
3. Describe the vestibulo-ocular reflex. When and how would you test this reflex?
4. Explain the mechanism by which the vestibular system influences extensor muscle tone?
5. Describe what is seen with a lesion of either or both medial longitudinal fasciculi (mlf). How can you distinguish it from a lesion of CN III or CN VI?
I. Introduction

A. The vestibular system functions to maintain **upright posture and balance** through **Lateral Vestibulospinal Tract.** Another goal is to **coordinate head movement** to keep the object of interest in focus on the retina, regardless of head or body position. = **Medial Vestibulospinal Tract**

B. The vestibular system **coordinates eye movement with head movements**

Connections = **mlf (medial longitudinal fasciculus) ascends to nuclei III, IV, VI.**

C. Connections to thalamus and cortex result in conscious perception of your body's **orientation in space** = Thalamocortical Sensory Radiations to Vestibular Cortex. These pathways are vague and we will not discuss.

D. In summary: This system is most **important for its reflex and brain stem connections** and its role in **coordinating eye movements and maintaining balance.** We are rarely conscious of the vestibular system unless something goes wrong, particularly peripherally.

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**VESTIBULAR SYSTEM**

![Diagram of the Vestibular System]

- **Head motion:** Angular Acceleration
- **Semicircular Canals**
- **Central Nervous System**
- **Visual, Proprioceptive, Tactile inputs**
- **Forebrain: Perceived orientation**
- **Spinal cord & Cerebellum: Postural control**
- **Oculomotor system: Eye movements**

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II. Inner Ear

A. The **bony labyrinth**. Contains the watery perilymph high in sodium, which is in contact with the subarachnoid space.

B. The **membranous labyrinth** is suspended in the perilymph inside the bony labyrinth. Contains the viscous fluid endolymph, which is high in potassium.

C. Location of the sensory **hair cells**

   1. **Saccule** contains macula on **vertical** wall covered with otoconia - transduces linear acceleration/gravity

   2. **Utricle** contains macula on **horizontal floor** covered with otoconia - transduces linear acceleration/gravity

   The two maculae are histologically identical

3. **Semicircular Canals.** Three bony semicircular canals emanate from the vestibule at right angles to each other; these contain the **membranous semicircular ducts**, which communicate with the utricle and are filled with endolymph. Cristae ampullaris are located in the semicircular canals. They are covered by gelatinous cupula transduces **angular acceleration.**

III. Sensory Transduction by Mechanoreceptive Hair Cells

A. **Histology**

   1. Sensory hair cells with **stereocilia** and a **kinocilium**

   2. Supporting cells hold hair cells in place

   3. Otolithic membrane with mass loading otoconia sits over sensory cells in saccule and utricle and a gelatinous mass lies over the hair cells in the ampullae.

B. **Transduction not to be tested on.**

   1. Fluid movements bend cilia

   2. Tiplinks connect cilia in adjacent rows

   3. Bending of cilia changes tension on tiplink

   4. Changing tension on tiplink changes the probability of opening of a Mechanically-gated cation channel in apex of cilia

   5. Cation influx depolarizes hair-cell membrane

   6. Voltage-sensitive calcium channels in hair-cell base open upon Depolarization, letting in calcium.

   7. Calcium causes release of excitatory neurotransmitter (probably glutamate) from synaptic vesicles into synaptic cleft
8. Glutamate receptors on afferent nerve endings depolarize membrane, setting up action potential carrying information into CNS.

Calciu
m carbonate crystals (otoconia) have greater specific gravity than the surrounding tissue and, thus stimulate the hair cells in utricle and saccule.

IV. Response of maculae to change in position of the head relative to gravity
V. The crista ampullaris of the semicircular canals signal angular acceleration.
   A. Cristae form a ridge in the ampulla at the base of each semicircular canal. The crista lies transverse to the course of the semicircular canal.
   B. Sensory hair cells
   C. Supporting cells
   D. Cupula = large gelatinous cap overlying the sensory hair cells. Same specific gravity as endolymph. Not pulled on by gravity.
   E. The response of the crista is to angular acceleration (turning) of the head.

http://www.biols.susx.ac.uk/home/Kristian_Flint/Alan_Owen/EDUCATIONPAGE/eduFrameset.htm
Vestib dental 2012.doc
VI. Vestibular Pathway
   A. Primary neurons lie in the vestibular ganglion in the internal auditory meatus.
      1. Innervate mechanoreceptor hair cells in the utricle, saccule, and the ampullae of the three semicircular canals.
      2. Central processes of the vestibular ganglion cells form the vestibular division of the eighth cranial nerve, which enters the lateral aspect of the brain at the caudal border of the pons.
      3. Vestibular nerve axons end in the vestibular nuclei

   ![CN VII lies medial to VIII](image1)

   ![Dorsal View of the Brain Stem with Cerebellum removed. The light blue represents the area where the vestibular nuclei would be found under the IV ventricle](image2)
Note the nuclei are found underneath the IV ventricle in the rostral medulla and pons. You do not need to be able to recognize them.

B. Vestibular Nuclei – Second Order Neuron
1. Four vestibular nuclei lie just beneath the floor of the fourth ventricle. You do not need to be able to distinguish one from the other or name them.
2. Primary afferent connections. All the vestibular nuclei receive primary afferents from the vestibular nerve.
3. Axons from the vestibular nuclei give rise to 3 tracts: the descending medial and lateral vestibulospinal tracts and the ascending mlf (medial longitudinal fasciculus).

From Fundamental Neuroscience, Duane E. Haines, Churchill Livingston, 1997 ©

C. The Vestibulospinal Tracts (descending)

1. **Lateral vestibulospinal tract** facilitates motor neurons associated with extensor **antigravity** muscles. An **ipsilateral** pathway located in the ventral funiculus of the spinal cord is important in regulating postural changes, especially for the **legs and axial muscles**. Stimulation of this pathway excites motor neurons that supply extensor muscles of ipsilateral lower limb. Flexors are inhibited and the foot is pressed more firmly on ground. Normally these extensor motor neurons are held in check by other descending tracts such as the corticospinal tract. A lesion of the CST disinhibits this pathway and results in increased extensor tone in legs. You do not need to be able to identify either of these tracts.
2. The medial vestibulospinal tract stabilizes head position. It descends bilaterally as far as the upper thoracic levels of the cord. Recognition of this minor tract is not necessary. You do not need to be able to identify either of these tracts.

From The Digital Anatomist Interactive Brain Syllabus. John Sundsten and Kate Mulligan, Univ. Washington School of Medicine. 1998 ©

D. Connections with oculomotor structures (ascending) = medial longitudinal fasciculus (mlf). The cell bodies for this tract are in the vestibular nuclei and their axons enter the mlf of both sides.

Axons from the vestibular nuclei ascend in the medial longitudinal fasciculus (mlf) of both sides to end in the nuclei of cranial nerves III, IV and VI. These projections are both crossed and uncrossed and are involved in the production of conjugate eye movements during movement of the head. This is an important pathway.

E. Vestibulo-ocular reflex pathway. (Normal = eyes move in opposite direction of head movement.

1. **Afferent** arm: 1° sensory neurons in vestibular part of VIII n
2. **Interneurons**: cell bodies in the vestibular nucleus whose axons travel to contralateral nucleus of VI.
3. **Another interneuron** in nucleus of VI crosses back and travels in the mlf to oculomotor nucleus on same side as stimulated semicircular canal.
4. **Efferent** arm: a combination of III, (IV) and VI nerves.
F. The importance of the *vestibulo-ocular reflex* also called the *oculocephalic reflex* (Doll’s Eyes) response is that it can be done on a comatose patient. This *tests for the integrity of the brain stem from the pontomedullary junction to the midbrain*. (It involves the mlf, cranial nerves III and VI, and VIII, and all their interconnections.) Turning the patient's head produces the stimulus and results in counter rolling of the eyes. Consequently, if "dolls eyes" are present, the vestibular system and much of the brain stem between pontomedullary junction and the superior colliculus, including nuclei III, and VI are intact and functional. This is good news in the bad situation of a comatose patient! In a conscious patient, retinal input overrides the response, so the test is not done. Do not move the head if you suspect spinal cord injury.
(VII. Connections with the Cerebellum for balance and eye movements but we will not discuss.)

(VIII. Connections with the Thalamus and Cortex.  
The vestibular nuclei project to the ventral intermediate nucleus of the thalamus near VPM. This area projects to an area of the postcentral gyrus that is adjacent to the "face" region of primary somatic sensory cortex. and to the parietal lobe aiding in spatial orientation.)

IX. Some clinical aspects of vestibular function.

A. The most important clinical sign of vestibular dysfunction is nystagmus. **Nystagmus** is a rhythmic conjugate movement of the eye(s). The movement is slow in one direction, and rapid in the other direction. Nystagmus results from lesions of the vestibular nerve and mlf pathway as well as cerebellar disease and drugs.

B. **Vertigo** is a sensation of whirling. The patient may have a feeling that his body is rotating or it may seem that external objects are spinning around. The patient may describe his vertigo as "dizziness", a nonspecific term that could also mean faintness or lightheadedness; so you must clarify what the patient means.
C. **Internuclear Ophthalmoplegia (INO)** seen most often with multiple sclerosis. We will draw on diagram below.

Internuclear Ophthalmoplegia
*A Disease of the MLF*

**Convergence is intact.**
Horizontal gaze to the right is impaired because nuclei VI and III are disconnected. *Nystagmus* in right eye.

**Note:** This is a view from behind.