# Medical Neuroscience | Tutorial Notes

## Vestibular System—Peripheral Mechanisms

### MAP TO NEUROSCIENCE CORE CONCEPTS[1]

NCC1. The brain is the body's most complex organ.

NCC3. Genetically determined circuits are the foundation of the nervous system.

### LEARNING OBJECTIVES

After study of the assigned learning materials, the student will:

1. Describe the anatomy of the vestibular labyrinth.
2. Describe the biomechanics of sensory transduction in the vestibular labyrinth, including the biophysics of hair cell sensory transduction.

### TUTORIAL OUTLINE

I. Overview

  A. vestibular labyrinth is an extension of the inner ear designed to sense the motions that arise from head movements and the inertial effects due to gravity (see **Box 14A**[2])

    1. static head position and linear accelerations of the head are sensed by hair cells in the **otolith organs**

    2. rotational accelerations are sensed by hair cells in the **semicircular canals**

  A. vestibular signals are relayed to integrative centers in the brainstem and cerebellum, where it is used to adjusted postural reflexes and eye movements

  B. vestibular signals also reach parts of the parietal cortex, where our normal sense of orientation in three-dimensional space is constructed and (should pathology present) a sense of dizziness with abnormal vestibular stimulation

II. Peripheral vestibular systems

  A. anatomy of the vestibular labyrinth (see **Figure 14.1**)

    1. set of interconnected canals that arise from the same embryological precursor (otic placode) as the cochlea

    2. canals are filled with **endolymph** (high $K^+$ / low $Na^+$) and surrounded by **perilymph** (low $K^+$ / high $Na^+$)

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[1] Visit **BrainFacts.org** for *Neuroscience Core Concepts* (©2012 Society for Neuroscience ) that offer fundamental principles about the brain and nervous system, the most complex living structure known in the universe.

[2] Figure references to Purves et al., *Neuroscience, 5th Ed.*, Sinauer Assoc., Inc., 2012. [click here]

3. two classes of sensory structures in each side of the head:
   a. two **otolith organs**: the **utricle** and **sacculus**
   b. three **semicircular canals** arranged orthogonally to one another
4. within each sensory structure, there are **hair cells** that transduce motion signals into neural impulses
5. hair cells are innervated by the vestibular division of cranial nerve VIII (cell bodies reside in Scarpa's ganglia)

B. vestibular hair cells
   1. sensory transduction (see **Figure 13.8, 14.2 A,B**)
      a. deformation of stereocilia *toward* the largest stereocilium leads to *depolarization* and *increased* release of neurotransmitter on peripheral endings of afferent fibers
      b. deformation *away* from the largest stereocilium leads to *hyperpolarization* and *decreased* release of neurotransmitter
   2. orientation of hair cells in sensory structures (see **Figure 14.2C**)
      a. common principle: hair cells (stereocilia) are arranged in parallel to the direction of biomechanical motion within the sensory structure
      b. semicircular canals
         (i) hair cells in **ampullae** are arranged in one orientation so that motion of endolymph in one direction will depolarize hair cells, and motion in the opposite direction will hyperpolarize
      c. otolith organs
         (i) hair cells in the **maculae** of the utricle and sacculus are arranged into two populations with opposing orientations along an axis of mirror symmetry
         (ii) motion in one direction will depolarize one subpopulation of hair cells and hyperpolarize the other

C. mechanism of otolith organ function
   1. **macula**: sensory epithelium of the otolith organs
      a. consists of a hair cells and supporting cells, and an overlying gelatinous layer (the otolithic membrane) upon which are embedded crystals of calcium carbonate, called **otoconia**
      b. the hair cells protrude into this gelatinous layer, which is heavier than the surrounding epithelium and fluids
   2. when the head is tilted, gravity causes the gelatinous membrane to shift relative to the underlying epithelium; this displaces the hair cell stereocilium and leads to *tonic* depolarization and hyperpolarization (see **Figure 14.5**)

3. with linear acceleration, the same sort of shearing motion is induced because the heavier otolithic membrane transiently lags behind the sensory epithelium; this leads to *phasic* depolarization and hyperpolarization of the hair cells
4. the utricular maculae are orientated more or less horizontally and, therefore, sense movements of the head in the horizontal plane
5. the saccular maculae are oriented roughly vertically and sense up and down movements of the head, as well as head tilts in the sagittal plane

D. mechanism of semicircular canal function

1. **ampulla**
    a. bulbous expansion at the base of the semicircular canals that contains the sensory epithelium (called the crista) and an overlying gelatinous mass (called the cupula) into which the stereocilium of the hair cells protrude (see **Figure 14.7**)
    b. the cupula creates a barrier for the flow of endolymph around the semicircular canal
2. when the head is rotated in the plane of the semicircular canal, the inertia of the endolymph produces a transient force that distends the cupulla away from the direction of rotation (see **Figure 14.8A,B**)
3. distension of the cupulla deflects the stereocilia of the hairs cells, which leads to depolarization or hyperpolarization of the hair cells within any given crista
4. semicircular canals are paired on the two sides of the head (see **Figure 14.8C**):
    a. left horizontal and right horizontal
    b. left anterior (superior) and right posterior
    c. left posterior and right anterior (superior)
5. rotation of the head in one direction will depolarize the hair cells in one member of the pair and hyperpolarize the hair cells in the other (see **Box 14C**)
    a. thus, pairs of horizontal canals function in a “push-pull” manner
    b. *the central processing of vestibular afferents reflects the balance of activity arising from the paired semicircular canals*

## *Study Questions*

Q1. When looking up into the night sky (while standing), which of the following events happened deep in the vestibular labyrinth?

A. The superior (anterior) semicircular canals on both sides of your head were phasically activated during the backward tilt of your head.
B. The horizontal semicircular canals on both sides of your head were phasically activated during the backward tilt of your head.
C. The posterior semicircular canals on both sides of your head were phasically activated during the backward tilt of your head.
D. All of the hair cells in the utricles on both sides of your head were depolarized while you maintained your head in a backward tilt.
E. About half of the hair cells in the sacculus on both sides of your head were depolarized while you maintained your head in a backward tilt.

Q2. When riding a “merry-go-round” (that rotates in the counterclockwise direction), which of the following events happened deep in the vestibular labyrinth?

A. The superior (anterior) semicircular canals on both sides of your head were phasically activated during the acceleration of the ride.
B. The posterior semicircular canals on both sides of your head were phasically activated during the acceleration of the ride.
C. The left horizontal semicircular canal was activated.
D. The right horizontal semicircular canal was activated.
E. All of the hair cells in the utricles on both sides of your head were depolarized while the ride was at full operating speed.