Medical Neuroscience | Tutorial Notes

Vestibular System—Central Processing

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. Discuss the neuroanatomy and function of the vestibulo-ocular reflex.
2. Characterize the contributions of vestibulo-spinal projections in postural control.
3. Discuss the contributions of vestibular sensation to proprioception.

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 position and linear accelerations are sensed by hair cells in the **otolith organs**
  2. rotational accelerations are sensed by hair cells in the **semicircular canals**
- B. vestibular signals are relayed to integrative centers in the brainstem and cerebellum, where it is used to adjusted postural reflexes and eye movements
- C. 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. Central vestibular processing

- A. central processes of ganglion cells project via the vestibular division of the eighth cranial nerve to **vestibular nuclei** in the rostral medulla and caudal pons, and directly to the "vestibulocerebellum" (flocculonodular lobe of the cerebellum)
- B. one major function of the vestibular nuclei is to *coordinate movements of the eyes and head to allow for stable visual fixation during head or whole body movements*

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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]

C. vestibulo-ocular reflex

1. rotational movements of the head induce eye movements opposite to the direction of rotation, thus allowing maintained visual fixation of both eyes
2. pathway (see **Figure 14.10**)
    a. input from the horizontal canals reaches the vestibular nuclei on the two sides of the medulla/pons
    b. each vestibular nucleus in turn sends a *excitatory* projections to the *contralateral* abducens nucleus
    c. the abducens nucleus directly innervates the ipsilateral lateral rectus muscle, which pulls that eye toward the lateral side (i.e., abduction)
    d. other cells in the abducens nucleus cross the midline again and project to the opposite oculomotor nucleus, which innervates the ipsilateral medial rectus causing that eye to turn toward the midline (i.e., adduction)
    e. to facilitate this excitatory action, there are also *inhibitory* projections from the vestibular nuclei to the *ipsilateral* abducens nucleus
    f. this inhibitory projection turns off the excitatory output of the cranial nerve nuclei (opposite abducens and oculomotor nuclei) that drive the antagonistic muscles
3. vestibular nystagmus
    a. **nystagmus** = rhythmic form of reflexive eye movements composed of slow component in one direction interrupted repeatedly by fast saccadic-like movements in the opposite direction
    b. vestibular nystagmus is normally driven by persistent rotation of the head; the slow component is driven by the vestibulo-ocular reflex and the fast ("saccadic", see below) component that resets eye position
    c. the balance between the activities of VIII n. afferents that arise from the functional pairs of semicircular canals determines the type and direction of nystagmus expressed
    d. pathological alteration in the balance of activity between the two sides can cause the expression of nystagmus (and other vestibular-evoked signs and symptoms) under conditions that normally would not induce this ocular motor behavior

D. postural reflexes

1. another major function of the vestibular nuclei is to make *reflexive adjustments of posture that compensate for movements of the head*
2. descending projections from the vestibular nuclei reach the *medial* aspect of the ventral horn of the spinal cord via medial and lateral vestibulospinal pathways (see **Figure 14.11**)

a. medial vestibulospinal projection to the upper cervical cord that regulates head and neck position

b. "lateral" vestibulospinal projection to motor neurons in the *medial* ventral horn that excite extensor muscles in the trunk and limbs; this pathway mediates balance and maintenance of an upright posture

E. vestibular perception

1. vestibular signals also ascend to the cerebral cortex where they reach conscious perception (see **Figure 14.12**)

2. vestibular nuclei sends axons bilaterally that synapse in the ventral posterior complex of the thalamus on both sides of the brain

3. these vestibular-receptive neurons in the thalamus project to the lateral part of the somatic sensory cortex (specifically, Brodmann's Area 3a and a part of Brodmann's Area 2), near the face representation; these same areas also represent other somatic sensory modalities, so it is not clear if there is a dedicated "primary vestibular cortex"

4. other thalamic projections to parietal area 5 also contribute and, together with higher-order connections in parietal cortex, integrate somatic sensory proprioception, visual information about movement, and vestibular proprioception to construct a body schema relative to 3D space

F. other vestibular connections

1. vestibular nuclei also receive input from most other sensory modalities in order to guide orienting movements of the head toward relevant stimuli

2. vestibular nuclei receive input from the cerebellum (cortex and deep nuclei) that modulate vestibular output to ocular motor nuclei and spinal cord

3. vestibular output is also directed toward certain autonomic centers in the reticular formation of the medulla, which mediate nausea sensations and influence states of consciousness

STUDY QUESTION

Stare straight ahead at some frontal fixation target. Now turn your head to the right without breaking fixation. What just happened?

A. The left horizontal semicircular canal was phasically activated during the rightward turn of your head.
B. The motor neurons in your right oculomotor nucleus that innervate the right medial rectus muscle just increased their firing rate.
C. The motor neurons in your right abducens nucleus that innervate the right lateral rectus muscle just increased their firing rate.
D. An inhibitory neuron projecting from the left abducens nucleus to the right oculomotor nucleus just suppressed the activation of the right lateral rectus muscle
E. Your eyes rotated in the orbits to the right along with your head turn.