Vestibular Anatomy and Physiology

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Objectives:

1. Describe the function of the vestibular system
2. Describe what is meant by “push-pull” system
3. Understand the role of the vestibular system in oculomotor control
4. Explain the significance of Ewald’s second law
5. Understand the role of the vestibular system in postural control
6. Understand the effect of age, chronicity, degree of deficit on vestibular function

Normal vestibular function:

Sensory receptor -
  head movement
  head position
  pull of gravity
1) Uses cues to perceive motion

2) Uses cues to maintain gaze stability

Vestibulo-ocular reflex

Purpose – to see clearly during head movements

Conjugate eye movements
Stimulus is head acceleration
Stabilizes eyes in space at 1-20 Hz and 400 d/s
Latency to response ~ 6 ms

Eyes move in the opposite direction from the head movement at an equal velocity and amplitude

Vestibular Ocular Reflexes

Torsion of eye only 5 degrees
Vestibular ocular reflex is not the only type of eye movement we have……

1. Smooth Pursuit eye movements
2. Saccades
3. Vergence
4. Nystagmus
5. Quick phases

Characteristics of smooth pursuit eye movements
1. Use to follow a slowly moving visual target
2. Eye movement should be conjugate
3. Works at velocity ranges of up to 80 d/s in exceptional conditions but in most people at up to 30 d/s
4. Decreased gain with increased age (>60yr)
5. Works at frequencies up to 1 Hz
6. Involves cerebellum, parietal lobes, PPRF

Characteristics of saccadic eye movements
1. Eye movements should be conjugate
2. Use to shift fixation from one target to another
3. Accurate – one or two saccades only to target
4. Works at velocities up to 300 d/s
5. You don’t actually see during the saccade eye movement itself
6. Doesn’t change with age
7. Superior colliculus, PPRF, cerebellum, frontal lobe
Characteristics of vergence

1. Eye movements should be **disconjugate**
2. Use to focus on very near targets
3. Decreased ability in elderly
4. Near reflex consists of vergence, pupillary constriction and accommodation
5. Exercises may help e.g. concussion
6. Nu Edinger Westphal, Oculomotor Nu

Vestibular system

3) Uses cues to -

- maintain balance

Names of the parts

**Membranous Labyrinth – filled with fluid**
Each canal has a special region called the ampulla which contains the sensory epithelium which contains the sensory receptors called hair cells.

The sensory epithelium is covered by a gelatinous mass called the cupula. The filaments of the hair cells are surrounded by this gelatinous mass.

Important concept #1: All vestibular hair cells have a spontaneous firing rate (head is not moving)

Resting firing rate ~ 90 pps

This means that the firing rate can be increased or decreased. The firing rate is related to the velocity of the eye movement generated so that 1 pps generates an approximately 1 d/s eye movement.

Clinical concept A: Sudden loss of vestibular function disrupts tonic resting rate (causes an asymmetry) and results in a spontaneous nystagmus.
Features that distinguish peripheral from central causes of nystagmus

<table>
<thead>
<tr>
<th>Finding</th>
<th>Peripheral</th>
<th>Central</th>
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<tbody>
<tr>
<td>Effect of fixation</td>
<td>Nystagmus decreases</td>
<td>Nystagmus either does not change or decreases</td>
</tr>
<tr>
<td>Plane of eye movement</td>
<td>Usually mixed plane (horizontal and torsional)</td>
<td>Usually single plane (horizontal or vertical or torsional)</td>
</tr>
<tr>
<td>Effect of gaze</td>
<td>Nystagmus increases with gaze toward direction of quick phase</td>
<td>Nystagmus either does not change or reverses direction</td>
</tr>
</tbody>
</table>

Important concept #2: Depending on which way the head moves, the short filaments of the hair cell (the stereocilia) will bend either toward or away from the longest filament (the kinocilium). Note: there are many stereocilia and only one kinocilium per hair cell. When the stereocilia move toward the kinocilium, the hair cell depolarizes and the firing rate goes up.

When the stereocilia moves away from the kinocilium, the hair cell hyperpolarizes and the firing rate goes down

Clinical concept B:
Hair cells are susceptible to ototoxins e.g. aminoglycosides

<table>
<thead>
<tr>
<th>Drug</th>
<th>Affects cochlear hair cells</th>
<th>Affects vestibular hair cells</th>
</tr>
</thead>
<tbody>
<tr>
<td>streptomycin</td>
<td>relatively little</td>
<td>major</td>
</tr>
<tr>
<td>tobramycin</td>
<td>relatively little</td>
<td>major</td>
</tr>
<tr>
<td>gentamicin</td>
<td>relatively little</td>
<td>2 - 5% healthy; 20-40% on dialysis</td>
</tr>
<tr>
<td>Vancomycin (not an aminoglycoside)</td>
<td></td>
<td>Synergistic affect</td>
</tr>
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</table>
Important concept #3:
Orientation of Semicircular Canals

Note that the horizontal canals are actually pitched up about 30 degrees from horizontal.

The two horizontal canals form a pair; the anterior canals form pairs with the posterior canals on the opposite side.

Because of this combination of canal orientations, angular head movements in all directions are detected.

Important concept #4: Each canal responds best to movement in the plane of that canal. Horizontal canals respond best to horizontal head movement. The anterior canal responds to pitch head movements forward and on an oblique. The posterior canals respond to backward pitch movements, also on the oblique.

Important concept #5:
Push-Pull with commissural inhibitory pathway
Important concept #6 Ewald’s 2nd Law

Ewald’s 2nd Law states that the excitatory range of the vestibular response is greater than the range of the inhibitory response.

There are two reasons:
1) You can decrease the firing rate only from 90 pps to 0 pps; however, you can increase the firing rate from 90 pps to 400 pps or more.

Ewald’s 2nd Law

2) The amount of endolymph movement is less for the short arm of the SCC than for the long arm of the canal.

Ewald’s 2nd Law and UVH

You can decrease the firing rate only from 90 pps to 0 pps; however, you can increase the firing rate from 90 pps to 400 pps or more.

TALK THRU THIS
Clinical concept C:
Head thrust test a function of canal paresis

<table>
<thead>
<tr>
<th>Canal paresis</th>
<th># of pts</th>
<th>Negative HT result</th>
<th>Positive HT Result</th>
</tr>
</thead>
<tbody>
<tr>
<td>Normal (0 – 25%)</td>
<td>76</td>
<td>76</td>
<td>0</td>
</tr>
<tr>
<td>Mild paresis (25– 50%)</td>
<td>23</td>
<td>23</td>
<td>0</td>
</tr>
<tr>
<td>Moderate paresis (50 – 75%)</td>
<td>21</td>
<td>19 (90%)</td>
<td>2 (10%)</td>
</tr>
<tr>
<td>Severe paresis (75 - 100%)</td>
<td>30</td>
<td>7 (23%)</td>
<td>23 (77%)</td>
</tr>
</tbody>
</table>

Important concept #7:
When you move your head, the signal goes to Velocity Storage System

When you move your head repeatedly, the signal is stored until you stop moving your head; then either the VSS discharges or you change the plane of your head and the VSS ‘dumps’

When the VSS discharges in a healthy person….
When the VSS discharges in a person with UVH…
When the VSS discharges in a person with BVH…
What did you see?
How would you explain this response?

Important concept #8
Dumping

• Cerebellum stops the discharge of the Velocity Storage System after HSNT when orientation of head is changed presumably because plane of nystagmus is no longer appropriate for orientation of head

• When do the HSN test, must not lift head once head shaking has stopped

Membranous Labyrinth: Otoliths
As with the semicircular canals, the otoliths have hair cells, a resting rate and are organized in a push-pull pairing.

The main difference is that the gelatinous mass that covers the hair cell filaments (called the otolithic membrane), is glue like and is covered with calcium carbonate crystals or otoconia (microscopic “rocks”).

Important concept # 9: Response of otoliths

Because of the weight of the otoconia, the otoliths respond to linear acceleration and the pull of gravity.
Clinical concept D: Otoconia age

Otoconia in Aged Humans
(Ross et al 1976)

Important concept #10: Otoliths respond to linear movement in all planes

Important concept #11: Utricle responds to head tilt with ocular counter-rolling and a shift in ocular alignment
Normal ocular tilt reaction

Clinical concept E:
What happens if there is a unilateral loss of utricular function?

Pathological ocular tilt response:
Lesion is on left

Otolith pathway
Utricle: subjective vertical
Why is that important?

Otolith function

Postural responses

Three sensory systems
- vision – retinal slip, retinal disparity
- vestibular - SCC and otoliths
- somatosensory – pressure, touch
  proprioception, kinesthesia

Multiple motor systems
Postural Stability Demands and the Capabilities of the Sensory Systems

- Frequency range of different receptors
- Frequency of head movement during

Types of stimuli used to maintain balance
- Vision
  - Change in image size with sway
  - Retinal disparity
  - Convergence of eyes
  - Movement of image on retina
  - Best when looking at objects within 1-2 meters
- Vestibular
  - Head angular acceleration
  - Head linear acceleration
  - Gravity is a really slow linear acceleration
- Somatosensory
  - Pressure, joint angles, muscle length
  - Kinesesthesia

Type of response that occurs to different sensory inputs differs

- Traditional view:
  - Labyrinthine inputs generate LE responses
  - Vestibular system maintains tone of anti-gravity muscles
  - Evidence from animal studies, from humans with brain injury and stroke - opisthotonus
Type of response that occurs to different sensory inputs differs

Vestibular system emphasizes head and trunk control
Vision plus Vestibular defines orientation in space
Somatosensory inputs can trigger LE postural responses

Somatosensory inputs can trigger LE postural responses but amplitude of the response requires vestibular input; no vestibular input, lower amplitude

Visual inputs not necessary for recovery of balance to slip, trip etc

Patients w/ vestibular loss hold neck stiffly and move it with the body – works against the normal movement - dependent torques of different body segments

No vestibular function results in disordered segmental postural responses
Postural responses differ depending on condition:
- Pushed versus trip
- Anticipatory versus unpredictable
- Self-induced or elicited

What is the difference between those people who fall and those who don’t?

Last important concept: VOR Gain Adaptation

Modification of the VOR gain
- (slow phase eye velocity/head velocity)
  up or down induced by repeated stimulus in the light.
- (sinusoidal oscillation, use of lenses or use of prisms)

VOR Gain Adaptation

Lisberger, SG. Trends Neurosci 11:147, 1988
VOR Gain Adaptation Circuit