Concussion and Dizziness: Application of Vestibular Rehab Across the Life Span

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Objectives

1. Recognize the anatomy and physiology related to normal and abnormal functioning of vestibular system in adults and pediatrics - addressing similarities and recognizing differences

2. Identify objective vestibular and oculomotor assessments

3. Identify proper clinical tests and effective treatment for vestibular involvement in pediatric and adult population

Terminology

- Vertigo
- Light-headed
- Swaying/rocking sensation
- Disequilibrium

Terminology

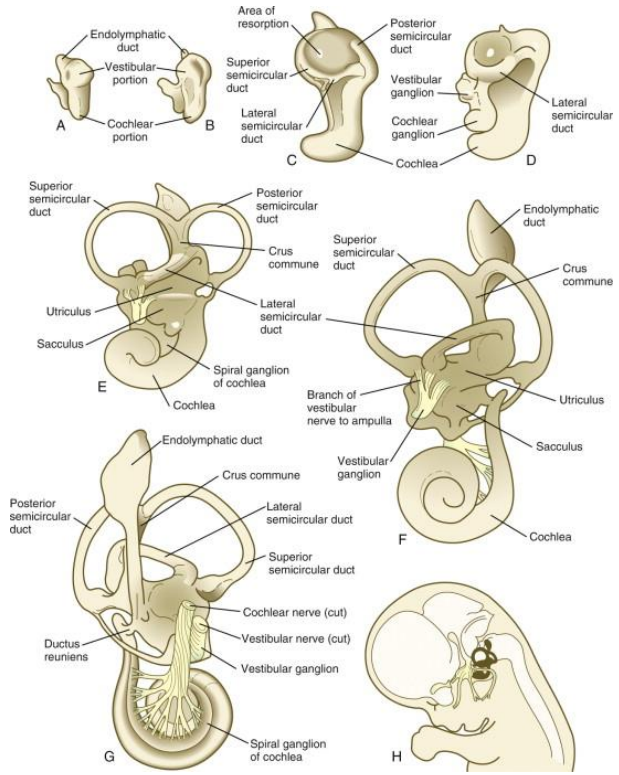
Facts

- Dizziness and disequilibrium following head trauma is about 40–60% among non-hospitalized patients
- Dizziness reported to persists in 18% patients at 2 years after the injury
- Athletes with a preexisting history of motion sensitivity may exhibit more prolonged vestibular function following sports related concussion, and may experience more affective symptoms early in recovery (Corwin 2015)
- 81% of pediatric patients after concussion had vestibular deficits at initial evaluation
  - Those patients took longer to recover and return to both school and sports (Corwin 2015)

Development of the Vestibular System

- Embryonic development
  - Vestibular systems begins in the 3rd week of life
    - Is complete by the 25th week of gestational age
    - The vestibular apparatus has achieved adult form and size by this age
    - Superior semi-circular canal develops first, followed by posterior and lateral canals

      (O'Reilly 2013)
  - Structural sensory systems are fully formed at birth (Rine 2018)

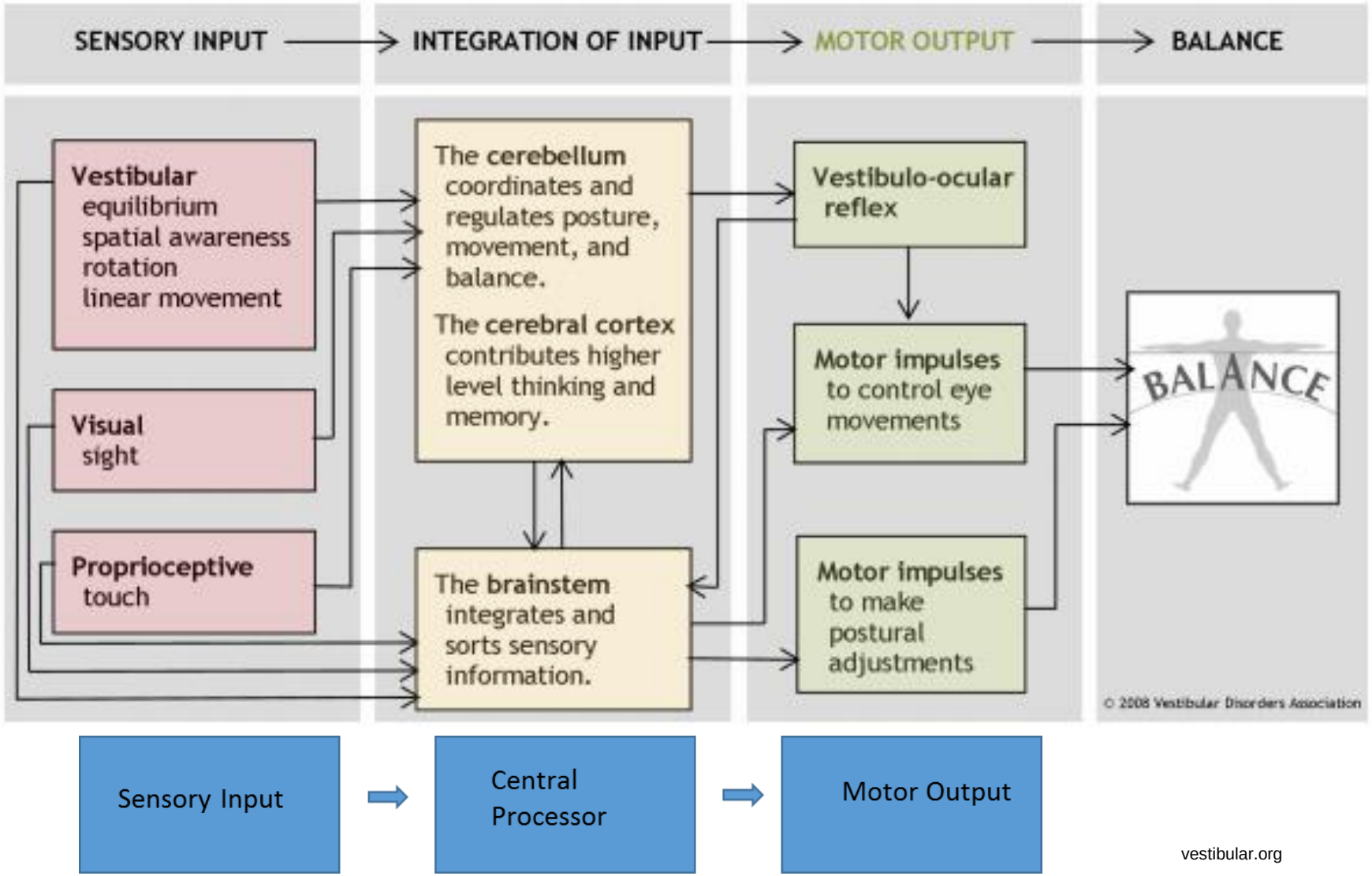


Reproduced from Carlson, B. (1996). Patten's foundations of embryology (6th edn.). New York: McGraw-Hill.

Development of the Vestibular System

- Balance function matures with the developmental sequence of motor skills
  - Develops rapidly throughout infancy and preschool years
    - Changes most pronounced when motor skills related to walking are realized
      - Postural control and coordinated movements are refined throughout achievement of motor skills
- Critical period of development = 4-6 years old
  - Children with vestibular hypofunction have been shown to have developmental delays
  - Disruption of vestibular function prior to maturation around this time can be detrimental to achievement of gross motor skills

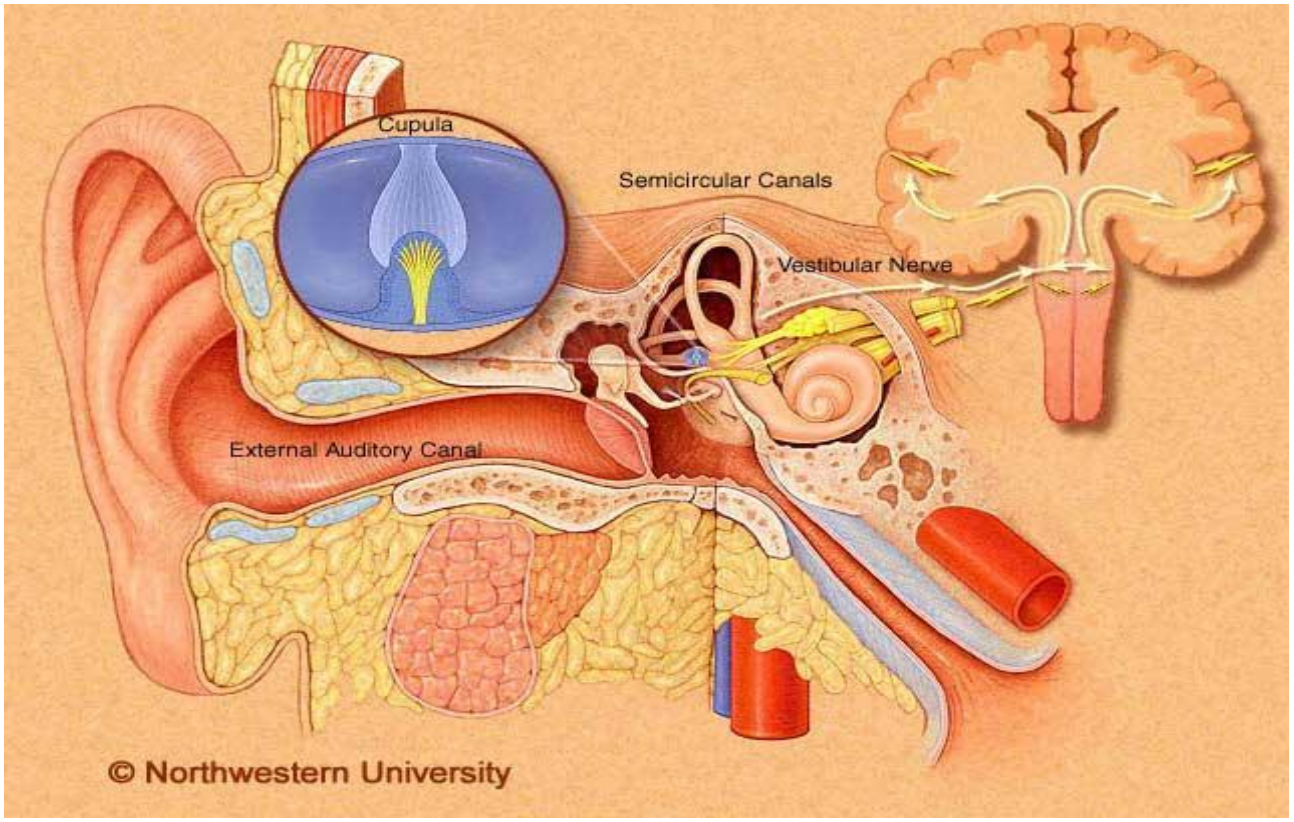
(O'Reilly 2013)


SENSORY INPUT
INTEGRATION OF INPUT
MOTOR OUTPUT
BALANCE
Vestibular
equilibrium
spatial awareness
rotation
linear movement
Visual
sight
Proprioceptive
touch
The cerebellum coordinates and regulates posture, movement, and balance.
The cerebral cortex contributes higher level thinking and memory.
The brainstem integrates and sorts sensory information.
Vestibulo-ocular reflex
Motor impulses to control eye movements
Motor impulses to make postural adjustments
BALANCE
© 2008 Vestibular Disorders Association
Sensory Input
Central Processor
Motor Output
vestibular.org

Anatomy and Physiology

- 3 Components
  - Peripheral sensory Apparatus
    - Motion sensors
  - Central processor
    - Vestibular nuclear complex and Cerebellum
  - Motor output
    - To ocular muscles and spinal cord

Peripheral Sensory Apparatus



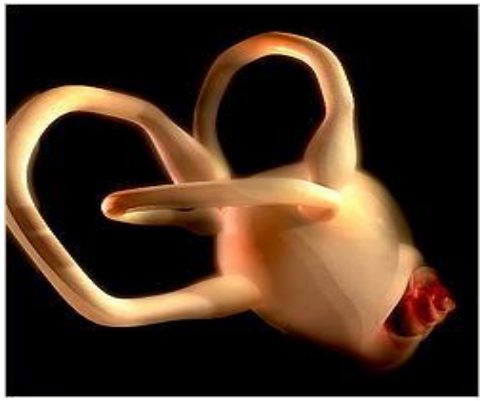
With permission. Hain T www.dizziness-and-balance.com

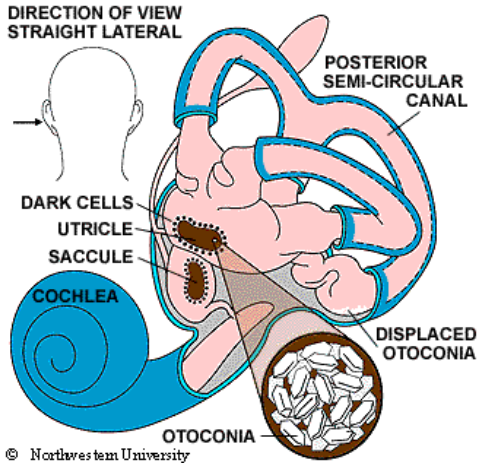
Peripheral Sensory Apparatus

Sensory Input

- Three Semicircular Canals
  - Lateral, Anterior (superior)
  - and posterior

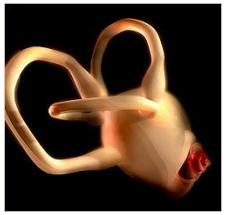
- Otolith Organs
  - Utricle
  - Saccule

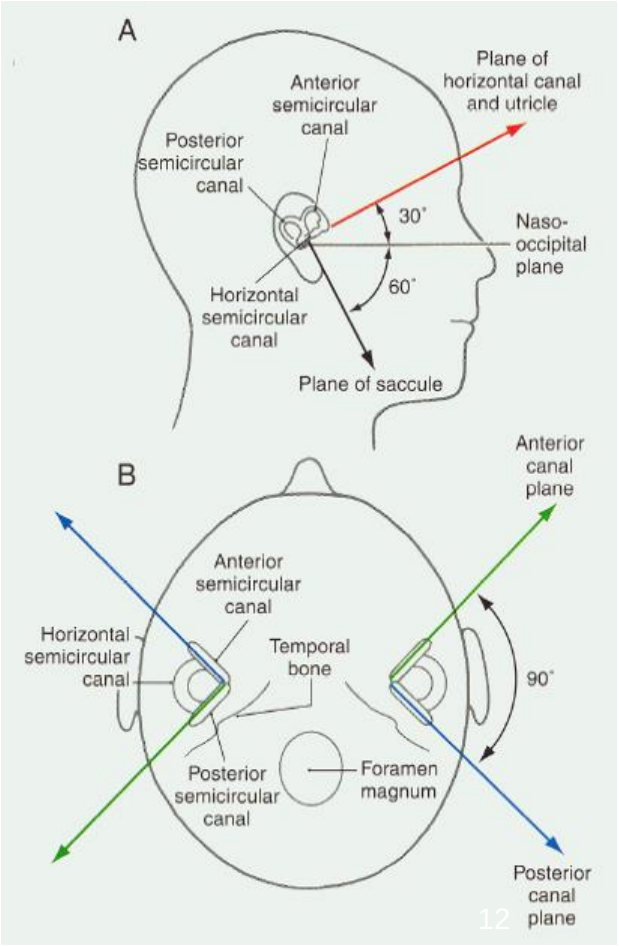




Semicircular Canals

- Lateral Canal: Angled 30°
- Anterior and Posterior canals: Oriented vertically
- Work in Complimentary pairs

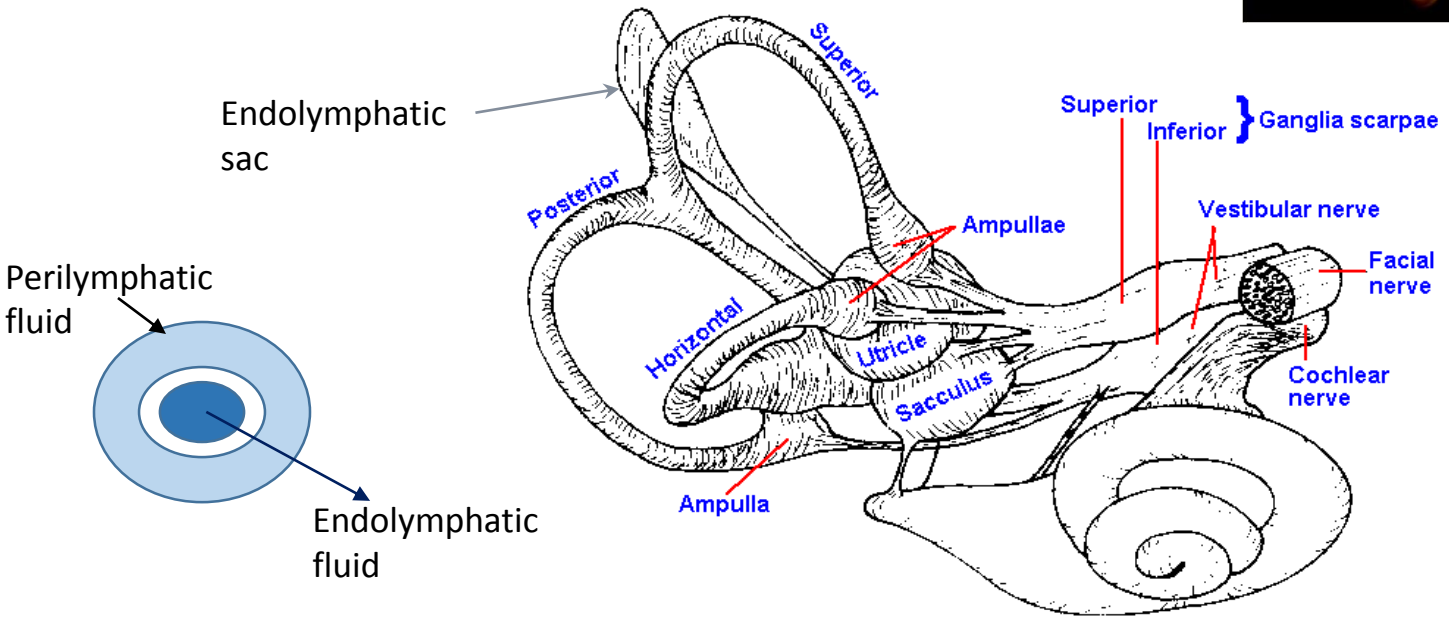




http://www.ohsubooks.com/objectives/index.php?title=Dizziness

Semicircular Canals

- Bony labyrinth
- Membranous Labyrinth



Lateral view of the right human labyrinth. (Hardy M: *Anat Rec* 59:403-418)

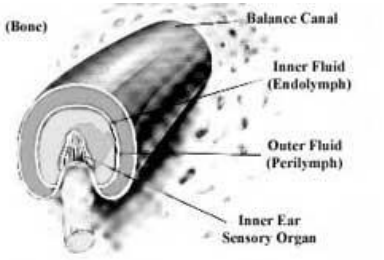
Fluid

Perilymphatic fluid

- Between Bone and membrane
- Communicates with subarachnoid space
- Low viscosity
- High Sodium
- Low Potassium

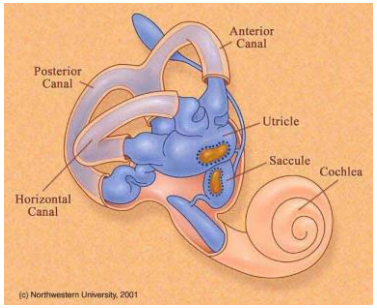
Endolymphatic Fluid

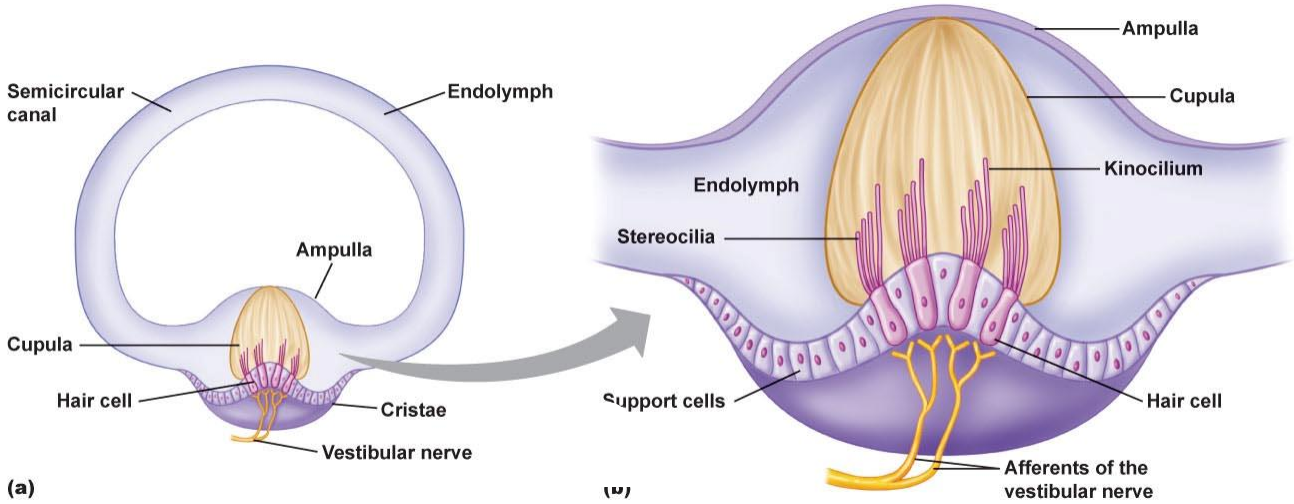
- Within membranous Labyrinth
- Does not communicate with perilymph
- High Viscosity
- Low Sodium
- High Potassium



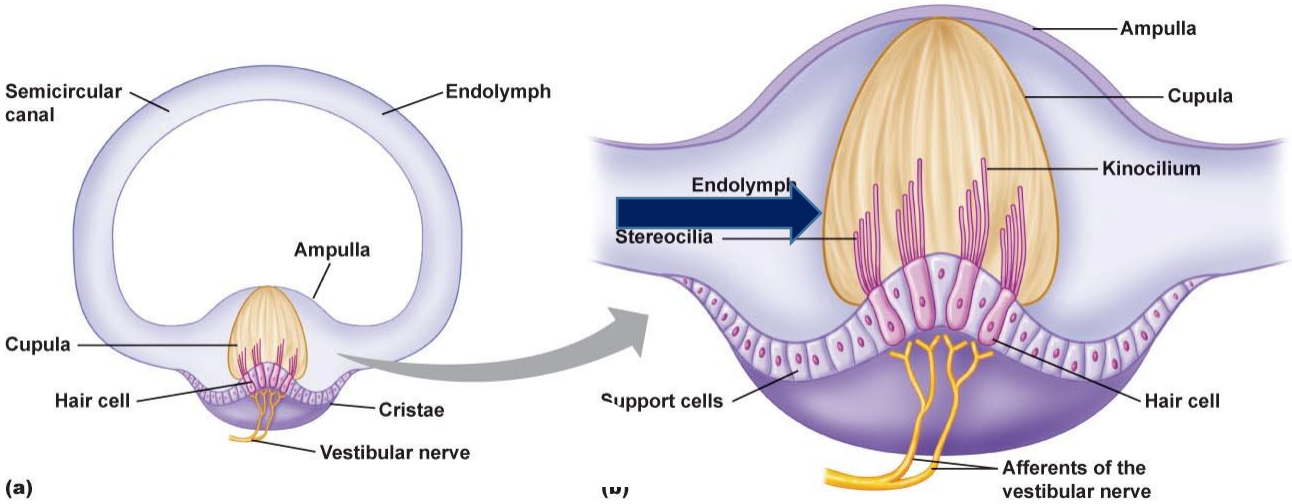
Ampulla

- Sensory epithelium (crista)
- **Crista** houses hair cells (stereocillia)
- Longest hair cells is called **kinocilium**
- **Cupula** gelatinous mass that bridges the width of ampulla

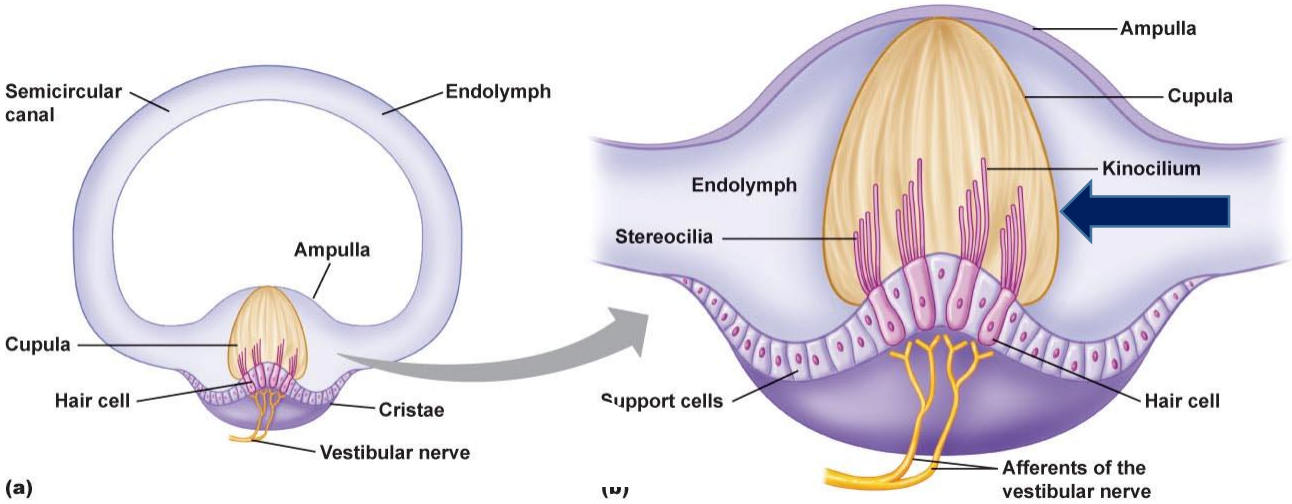




Ampulla



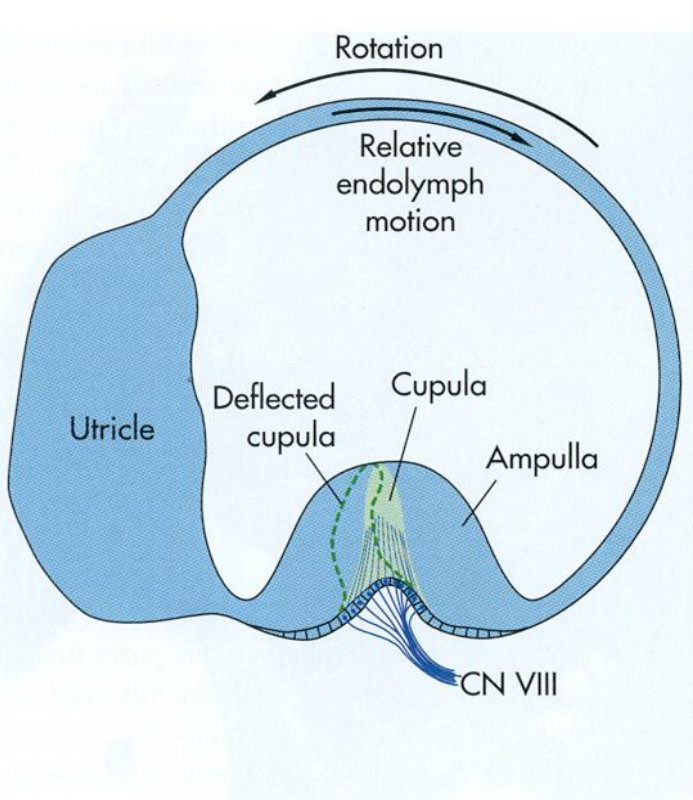
Ampulla



Canal Physiology

Head Rotation to Left

- In left lateral canal endolymph lags (movement is towards the cupula) pushes cupula to deflect ➡ bend hair cells ➡ send ➡ excitatory impulse to vestibular nerve on that side

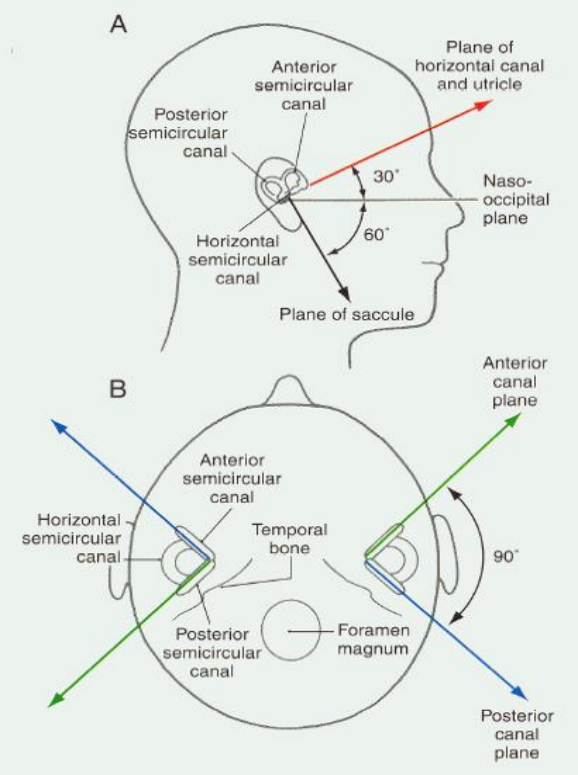


Canal Physiology

Canals are paired in PUSH PULL arrangement
Equal and opposite response of complimentary canals

Canals are mirror images to each other

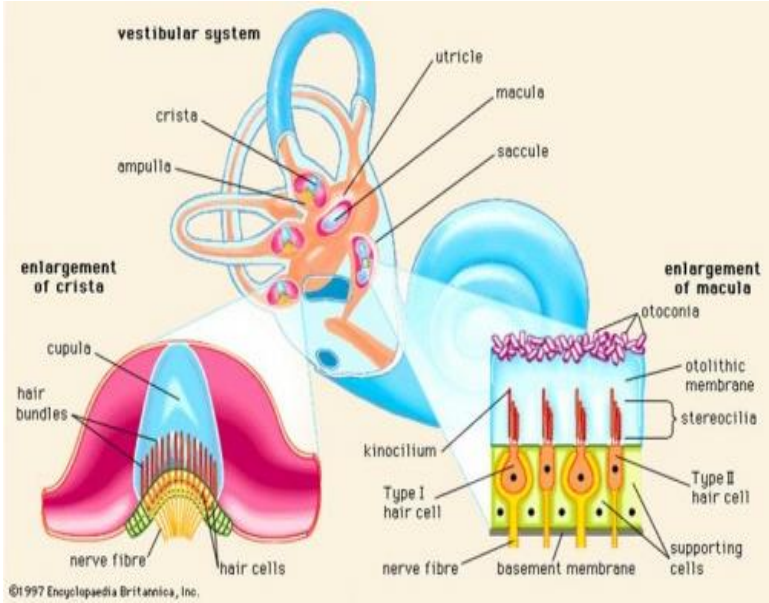
So, right lateral canal……

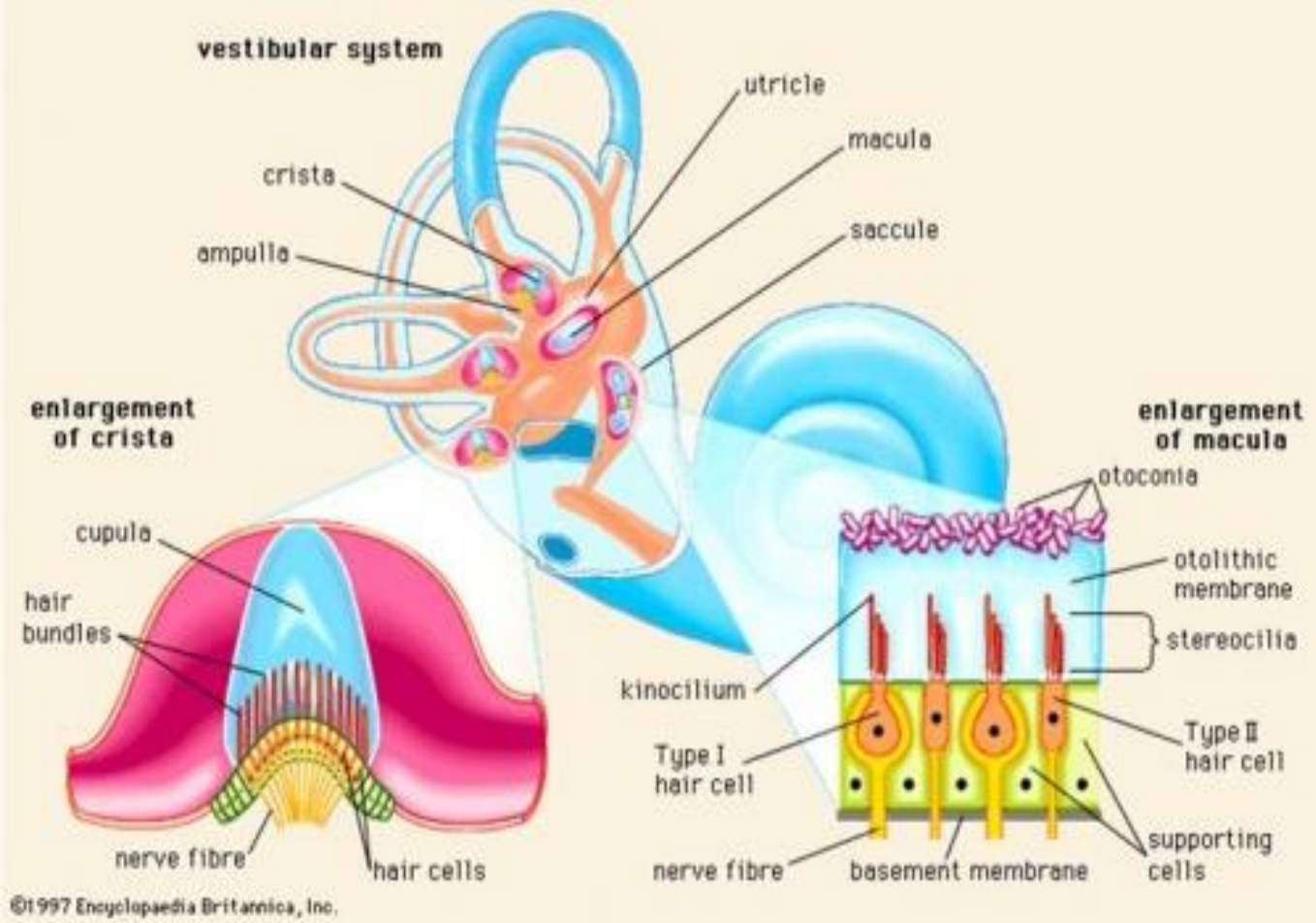


Otoliths

- Saccule – Vertical Plane
- Utricle –Horizontal Plane

- Receptor area is called macula
- Detect linear acceleration and vertical head position




vestibular system
utricle
macula
crista
saccule
ampulla
enlargement of crista
enlargement of macula
otoconia
cupula
otolithic membrane
hair bundles
stereocilia
kinocilium
Type II hair cell
Type I hair cell
supporting cells
nerve fibre
hair cells
nerve fibre
basement membrane
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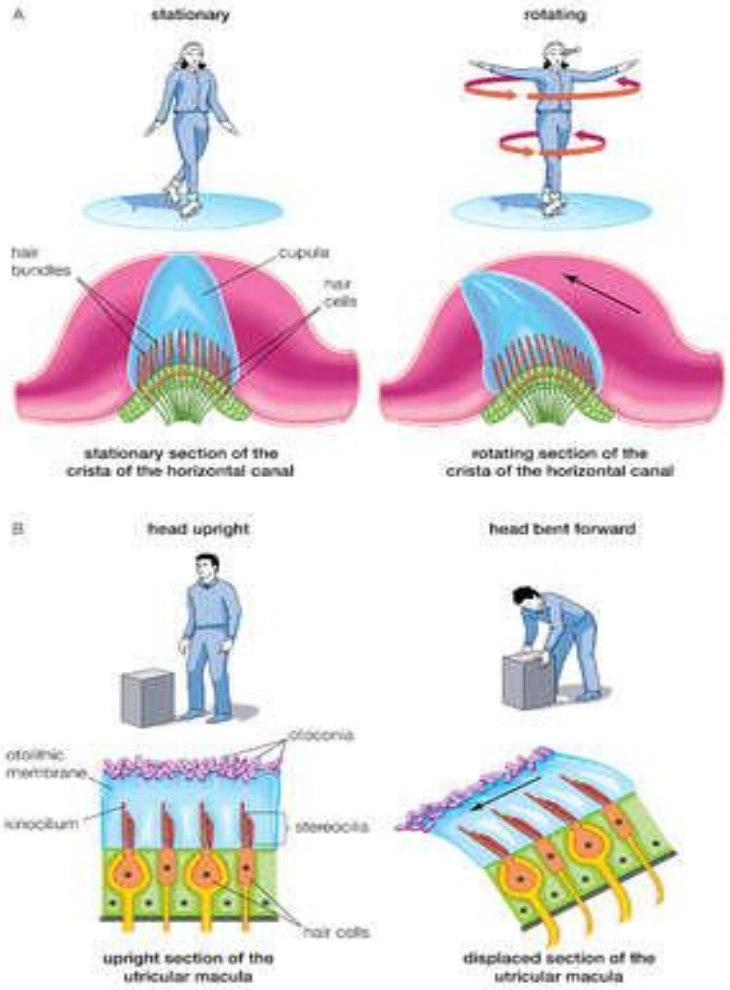
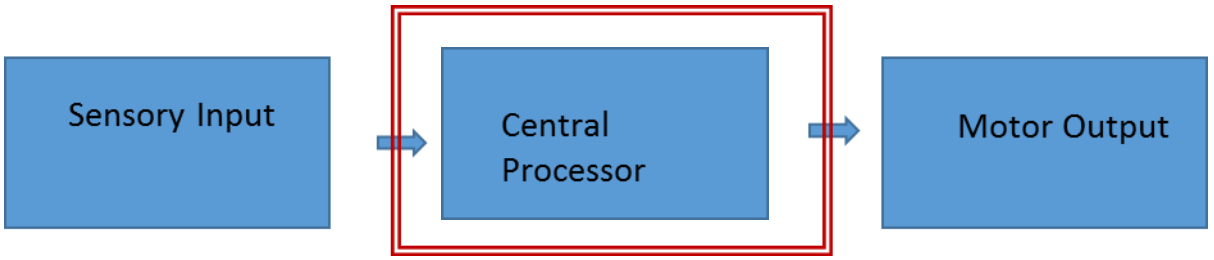

A
stationary
rotating
hair bundles
cupula
hair cells
stationary section of the crista of the horizontal canal
rotating section of the crista of the horizontal canal
B
head upright
head bent forward
otoconia
otolithic membrane
kinocilium
stereocilia
hair cells
upright section of the utricular macula
displaced section of the utricular macula

Anatomy and Physiology

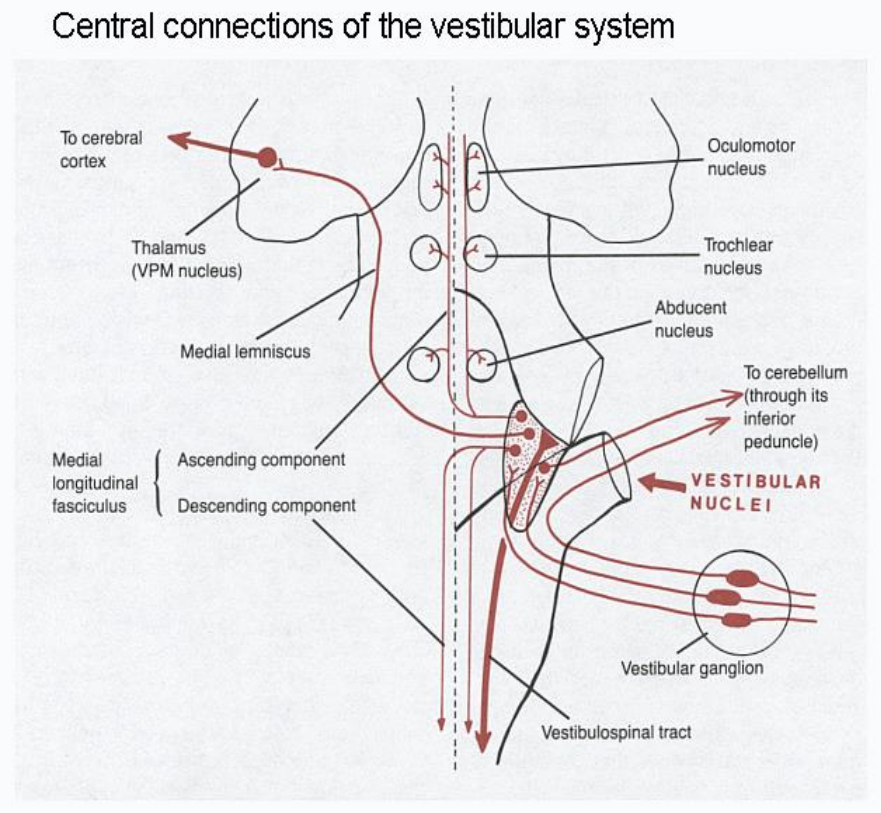
- 3 Components
  - Peripheral sensory Apparatus
    - Motion sensors
  - Central processor
    - Vestibular nuclear complex and Cerebellum
  - Motor output
    - To ocular muscles and spinal cord



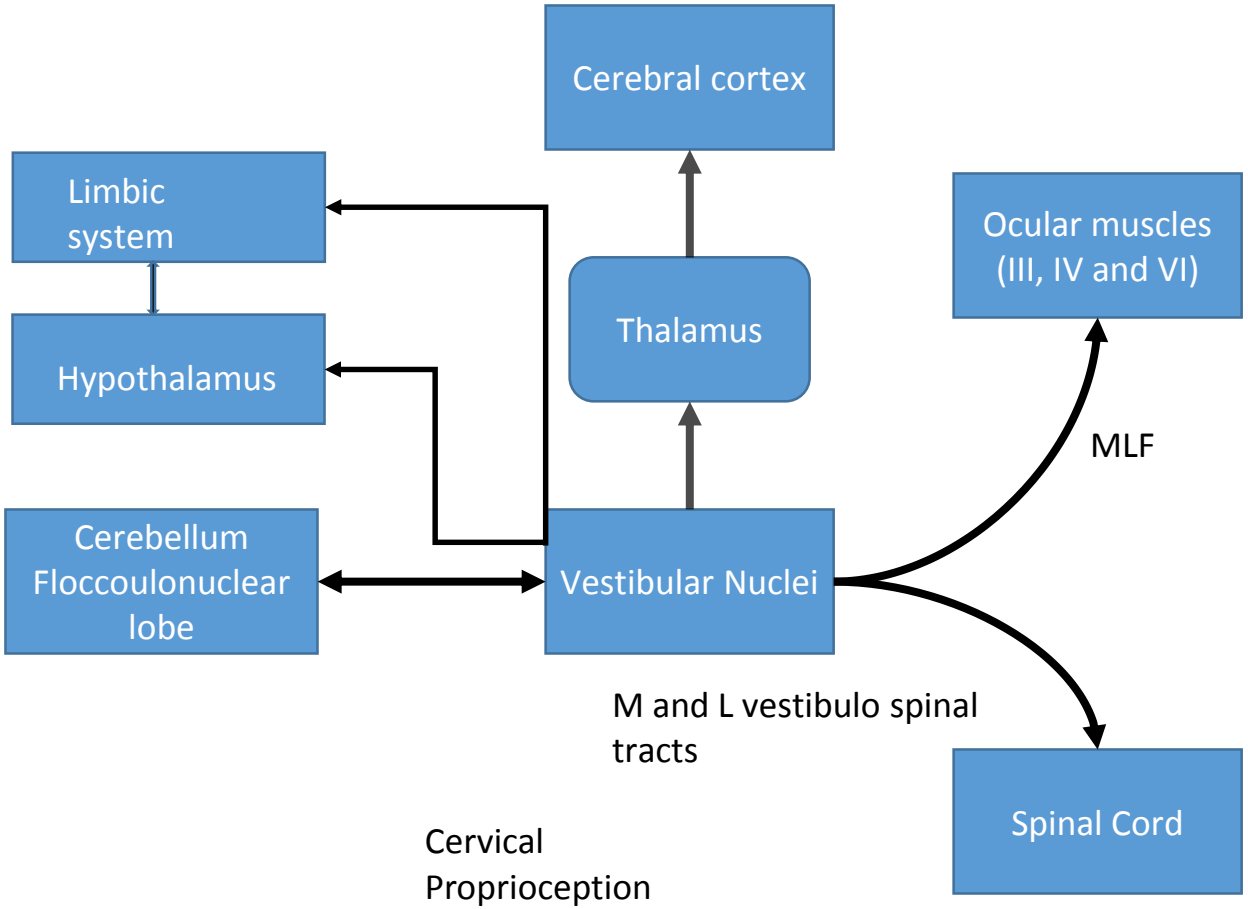
Central Vestibular Pathways

Vestibular Afferents
- Vestibular Nucleus
- Cerebellum

From Vestibular nucleus
- Extra ocular motor neuros
- Spinal cord motor neurons



Central Vestibular Pathways



Vestibulo Cerebellar Connections

- Cerebellum- adaptive processor
- Some vestibular afferents go directly to the cerebellum through the inferior cerebellar peduncle
- Calibrates Vestibulo Ocular Reflex (VOR)
- Maintain postures during static and dynamic activities

Anatomy and Physiology

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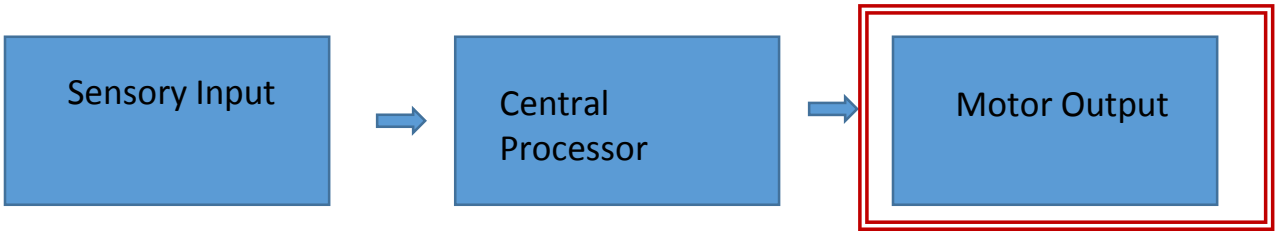


Motor Output of the Vestibular System

- Vestibulo Ocular Reflex (VOR)
- Vestibulo Spinal Reflex (VSR)

VOR

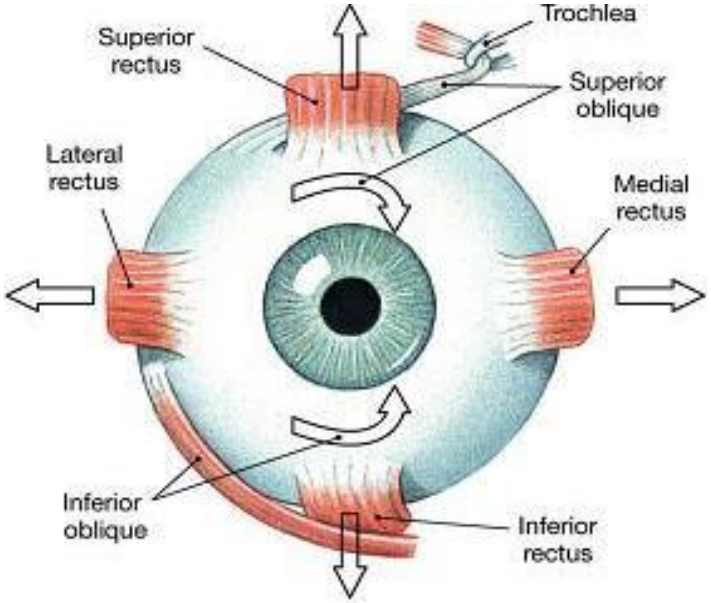
- Acts to maintain stable vision during head movement
- Angular VOR- Semicircular canals (rotation)
- Linear VOR-Otoliths (Translations)

- Head turn to L ⟶ cupula deflects to R

⟶ L tonic firing increases. These changes are transmitted via vestibular nerve.

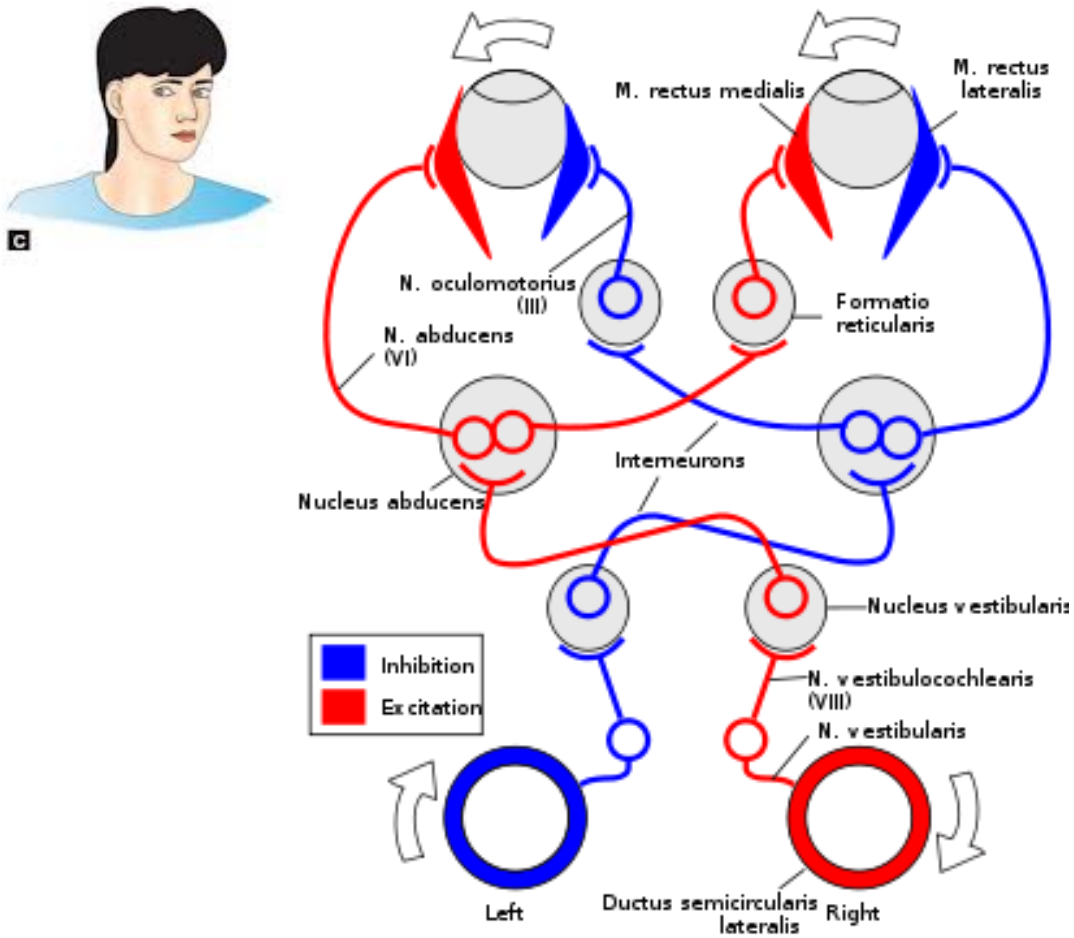
Eye Muscles

- Medial rectus -
  moves eye towards nose
- Lateral rectus -
  moves eye away from nose
- Superior rectus - raises eye
- Inferior rectus - lowers eye
- Superior oblique - rotates eye
- Inferior oblique - rotates eye



- Single pair of canal connected to single pair of ocular muscles.

VOR



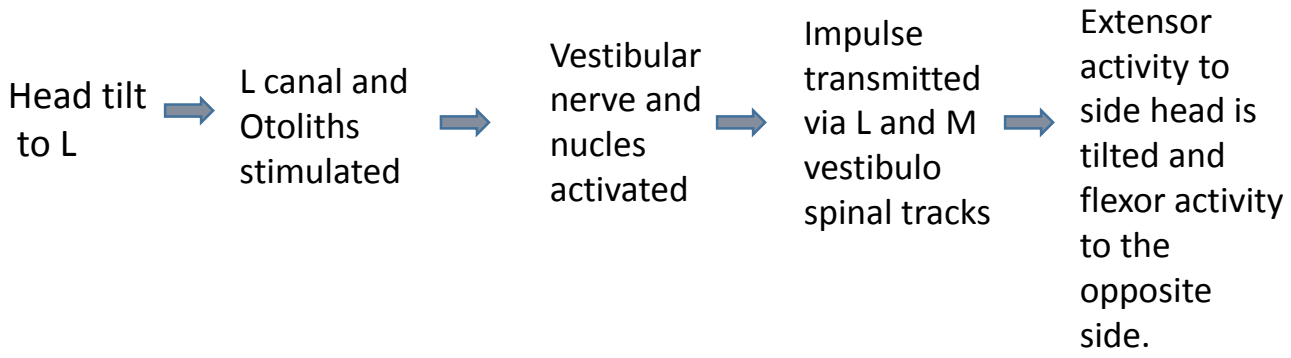
http://image.absoluteastronomy.com/images/encyclopediaimages/v/ve/vestibulo-ocular_reflex_en.svg.png

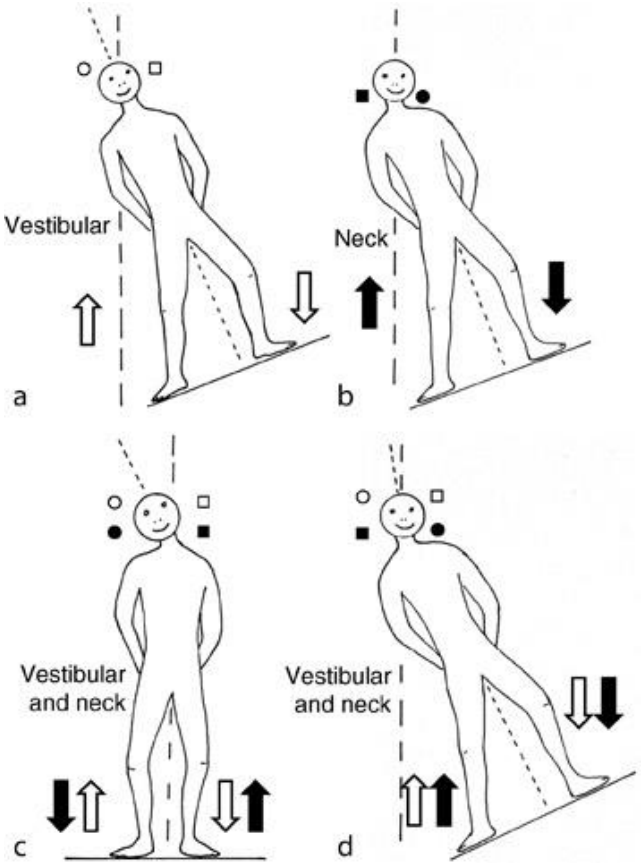
VOR

- Produces compensatory eye movement in the plane of the stimulated canal
  - Equal amplitude and speed
  - Opposite direction
  - Gain is always 1 (amplitude of eye movement/head movement)
- Helps with gaze stabilization

Vestibulo Spinal reflex (VSR)

- The purpose of the VSR is to stabilize the body





2009. B Encyclopedia of Neuroscience.
Binder, MarcD. Hirokawa, Nobutaka.
Windhorst, Uwe

Maturation of VOR and VSR

- VOR is present at birth
  - Time constants approximately ½ of normal adult values
  - Approach adult-like values by 2 months old
    - Due to the maturation of the visual pathways needed for calibration of the VOR
  - Matured by 8 years old
- VSR is developed by 7-10 years old
  - Continues to integrate into adolescence (at least 15 years old)
- Children are more dependent on visual cues and easier affected by visual stimuli than adults
  - Children exhibit longer adaptation time and greater magnitudes of postural responses in the presence of visual changes
- Saccadic system is immature at birth, matures up until 2 years old

(Quatman-Yates 2012)

Maturation of Balance and Motor Development

- Ages 2 months – 2 years old: typically developing child relies on visual cues for balance
- Ages 3-6 years old: children begin to use somatosensory information more appropriately
- Postural coordination continues to develop until 10-15 years old
  - Gait pattern reaches maturity around 7-10 years old
- Adult-like postural stability (from complete maturation of all sensory systems) is developed until 15 years of age.

(O'Reilly 2013)

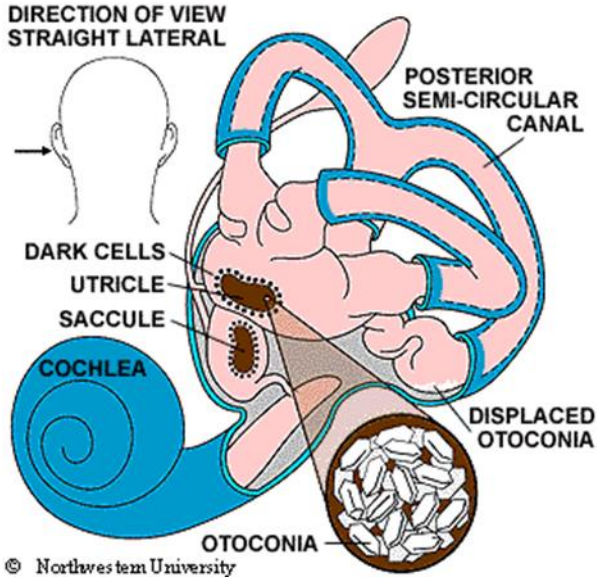
Other Reflexes

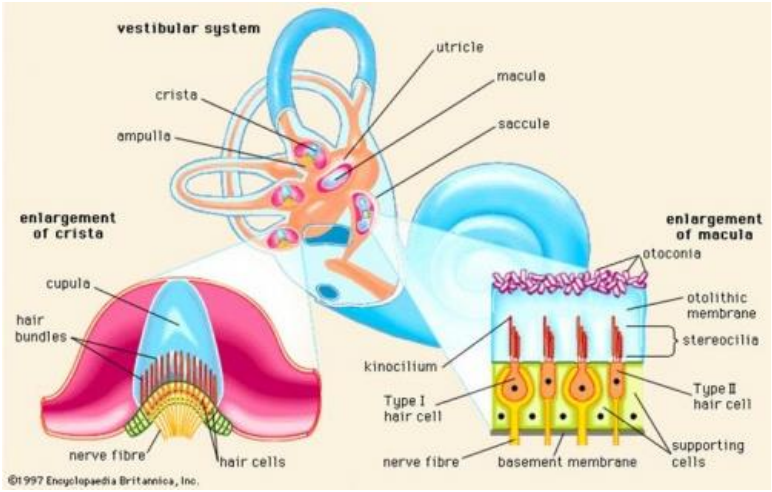
- The Vestibulocollic Reflex (VCR)
  - acts on the neck musculature in order to stabilize the head
- The Cervicoocular Reflex (COR)
  - consists of eye movements driven by neck proprioceptors (can supplement VOR)
- The Cervicospinal Reflex (CSR)
  - also known as the tonic neck reflex (TNR) (supplements VSR)
- The Cervicocollic Reflex (CCR)
  - stabilizes the head on the body

Benign Paroxysmal Positional Vertigo (BPPV)

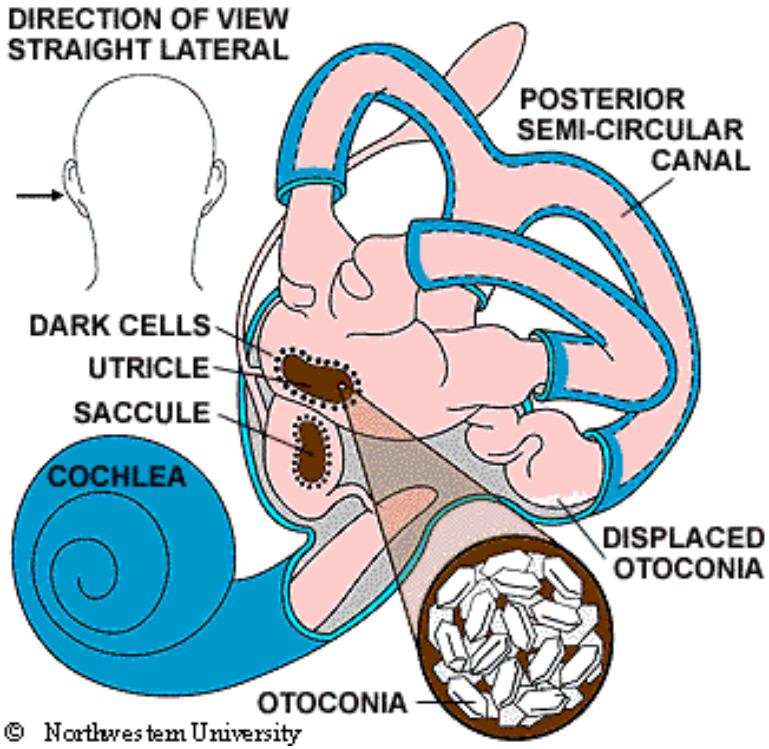
- Reports of patient as young as 8 years old ranging to the oldest at 106 years old have BPPV secondary to sports concussions, job related head impact, motor vehicle accidents, and falls.
- BPPV secondary to head trauma has a higher incidence of bilateral and multi-canal involvement.
- Treatment may be somewhat more resistant requiring more than the statistical 1.25 treatments reported (Roberts and Gans, 2006).

BPPV- Pathophysiology





BPPV- Pathophysiology



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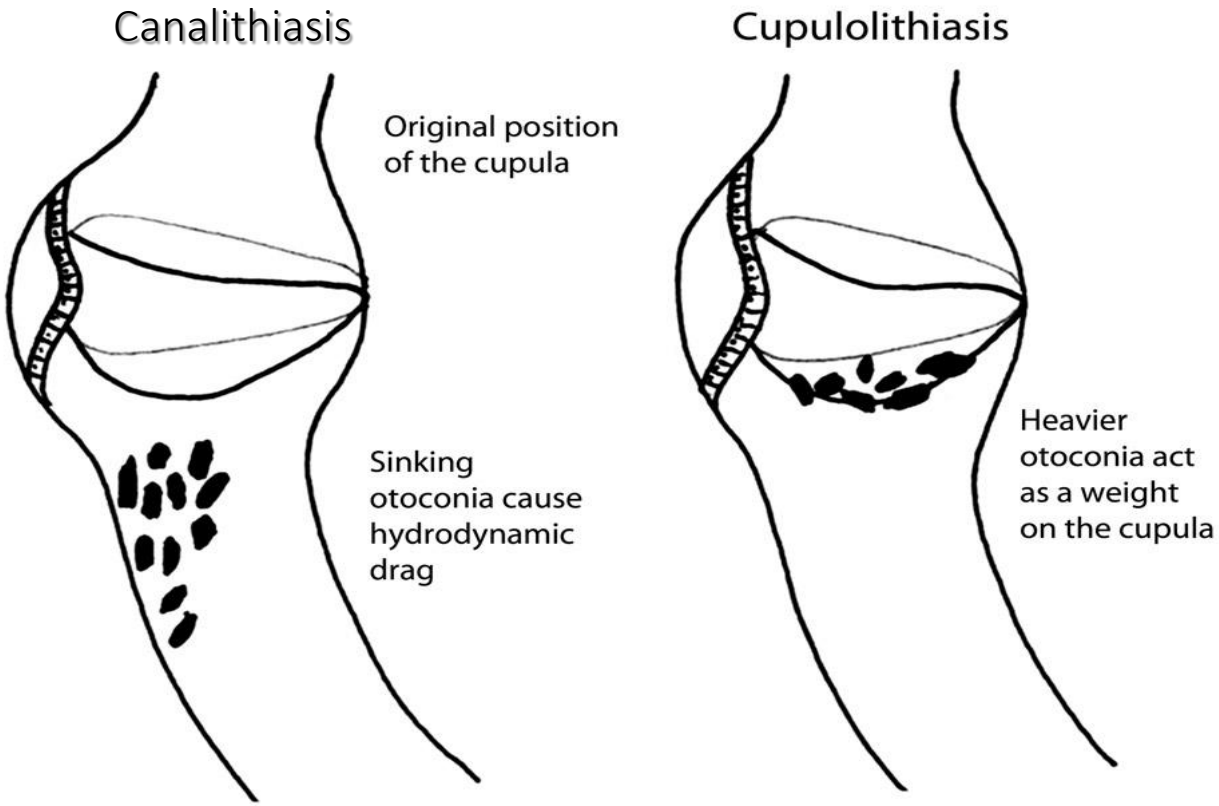
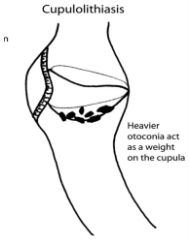
BPPV- Physiology



With permission from Dr. Fife Continuum Lifelong Learning Neurol 2012;18(5):1060–1085

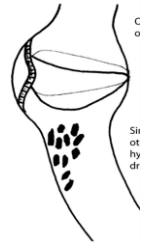


Cupulolithiasis

- Otoconia adherent to cupula
- Immediate onset
- Nystagmus persists
- Lateral canal- Apogeotropic nystagmus

Canalithiasis

- Detached otoconia with in the canal
- Delay in onset (latency –typically 5-20sec)
- Nystagmus Fatigues (crescendo-decrescendo)
- Lateral canal- Geotropic nystagmus

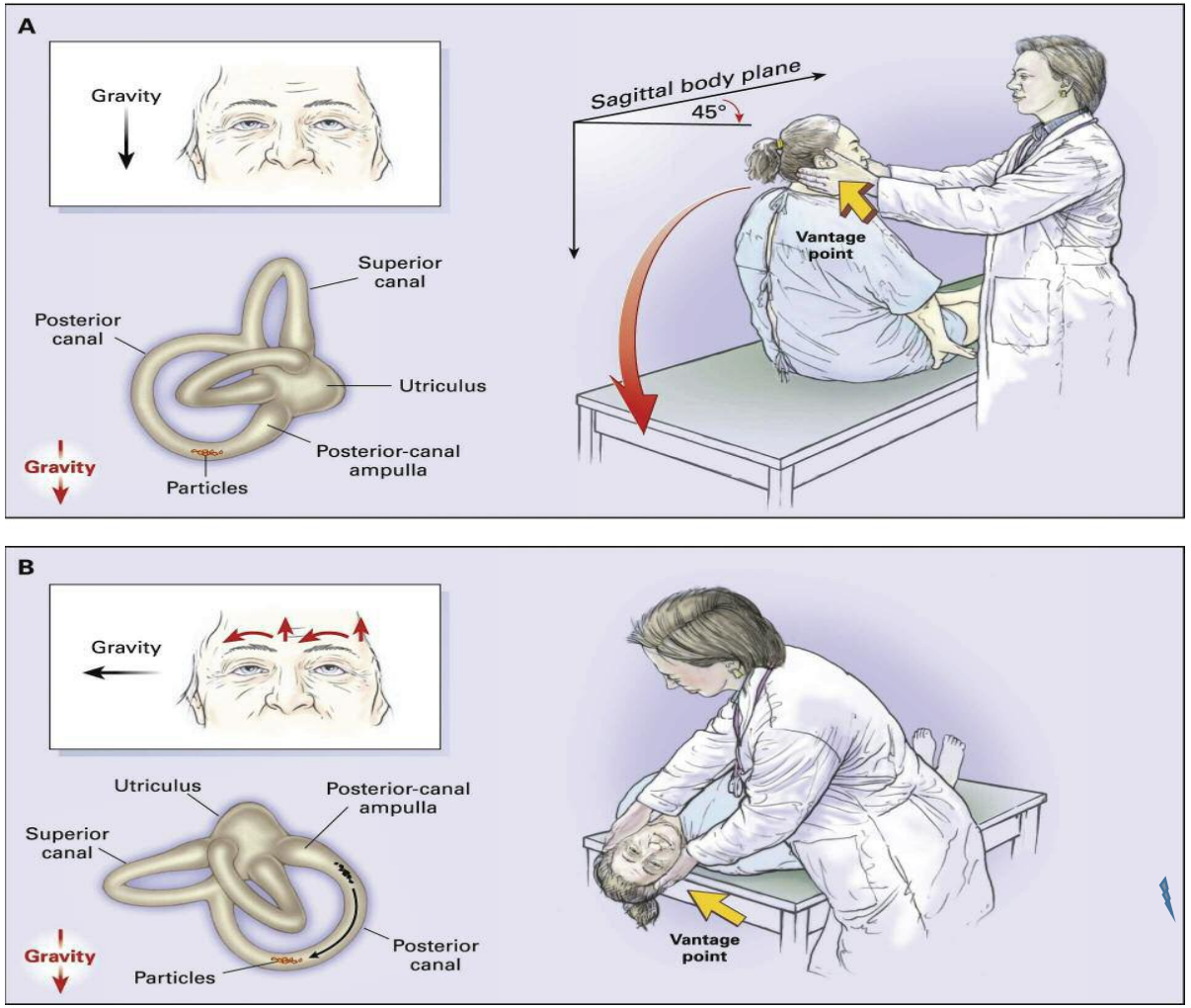


Herdman SJ, Tusa RJ. Physical therapy management of Benign Positional Vertigo. In Herdman SJ vestibular Rehabilitation. F A Davis company, Philadelphia PA 2007: 233-264

Dix Hallpike Test (DHT

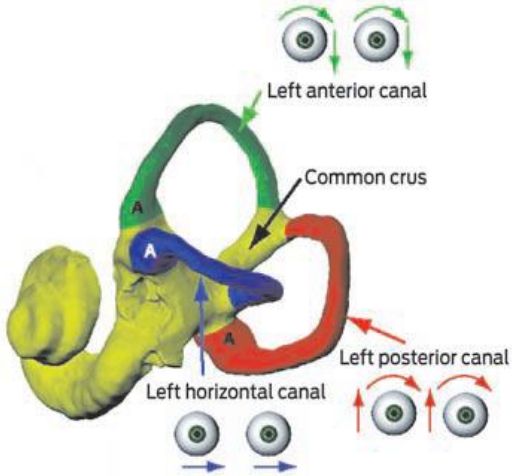
- Dix-Hallpike test continues to be the “gold standard” for diagnosing posterior canal BPPV
- Sensitivity of Dix-Hallpike test
  - Sensitivity 79%
  - Specificity 75%
- Start patient positioned in a long sitting position
- Next the examiner rotates the head 45 degrees to the side they are testing
- The patient is quickly moved into a supine position with the neck extended 20 degrees beyond the horizontal plane.
- While in this position look for subjective complain of vertigo and/or nystagmus
- Finally the person is returned to the long sitting position and the other side is tested

Dix Hallpike Test (DHT



With permission Burmeister et al. JAOA .Vol 110 .No 10 . October 2010

Nystagmus



Posterior Canal	DHT	Upbeat, torsional with top pole beating toward the down ear
Anterior Canal	DHT	Downbeat,torsional (torsional element not always visible)

BPPV

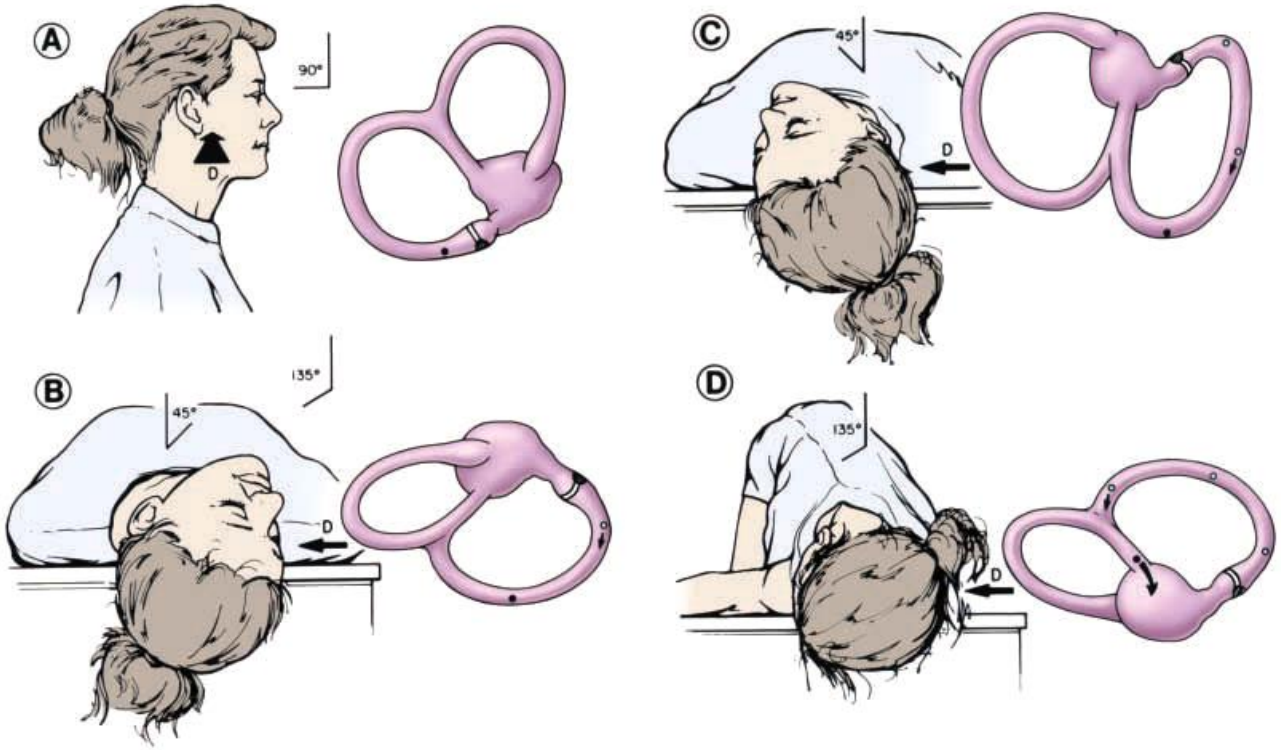
- Dix Hallpike test- Test for vertical canals
- Roll Test- Test for Horizontal Canals
- Deep ext test- Test for Anterior canal

BPPV- Maneuvers

- Vertical Canals
  - Epley maneuver (Canalith repositioning maneuver (CRM))
  - Deep extension maneuver
  - Liberatory maneuver (Semont)

- Lateral Canal
  - BBQ Roll Maneuver
  - Appianini Maneuver
  - Guffoni Maneuver

Canalith Repositioning Procedure/ Maneuver (CRP/CRM)



Parnes LS et al. Diagnosis and management of BPPV. CMAJ 2003; 169:681-93

Liberatory Maneuver (Semont Maneuver)

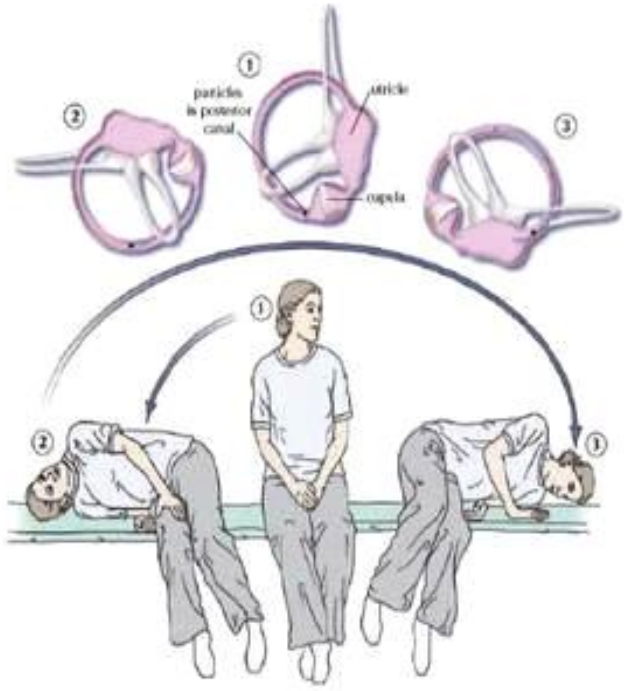
- Effectiveness 70-90%

  Soto Varela, Levrat E (2001, 2003)

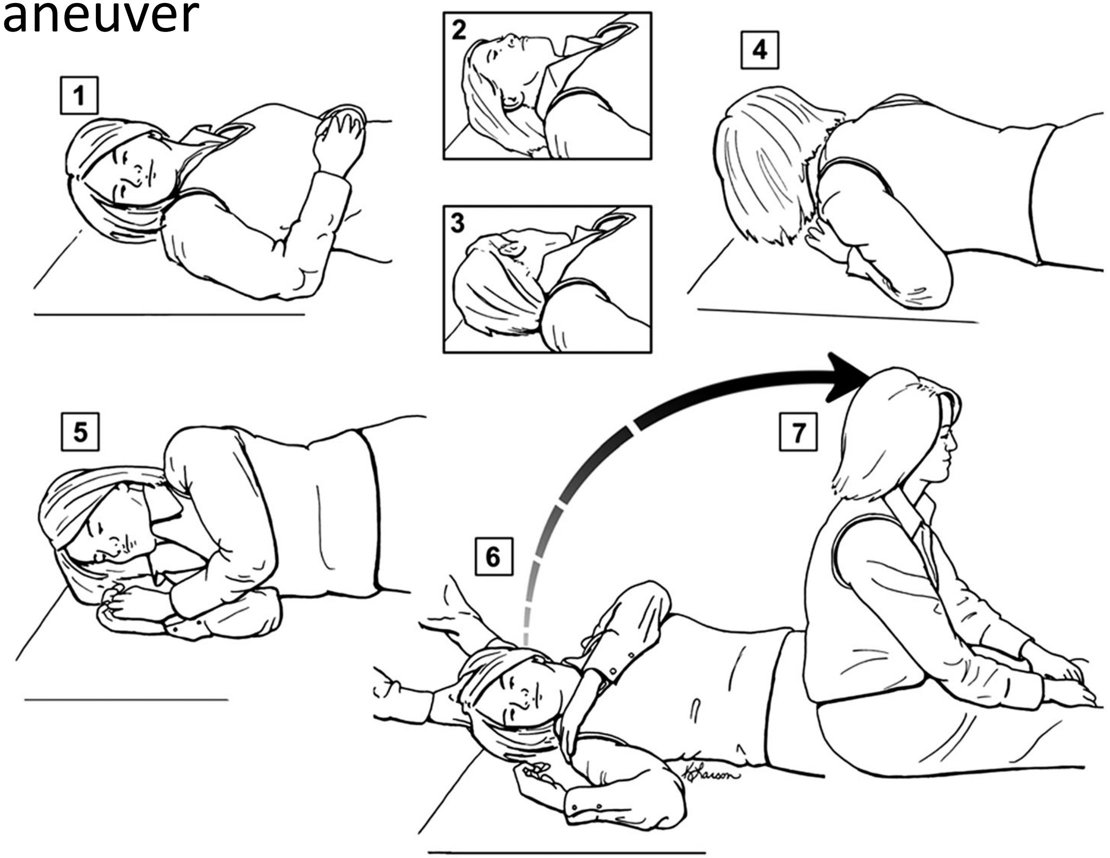
- Repeated maneuvers are needed to increase efficiency

  (40% after 1st maneuver and 58% with self maneuver)

  Kim JS (2014)



Canalith Repositioning Procedure/ Maneuver (CRP/CRM) for Lateral Canal- Roll Maneuver



Peripheral Vestibular Disorders in Pediatric Patients with Concussion

Brodsky et al

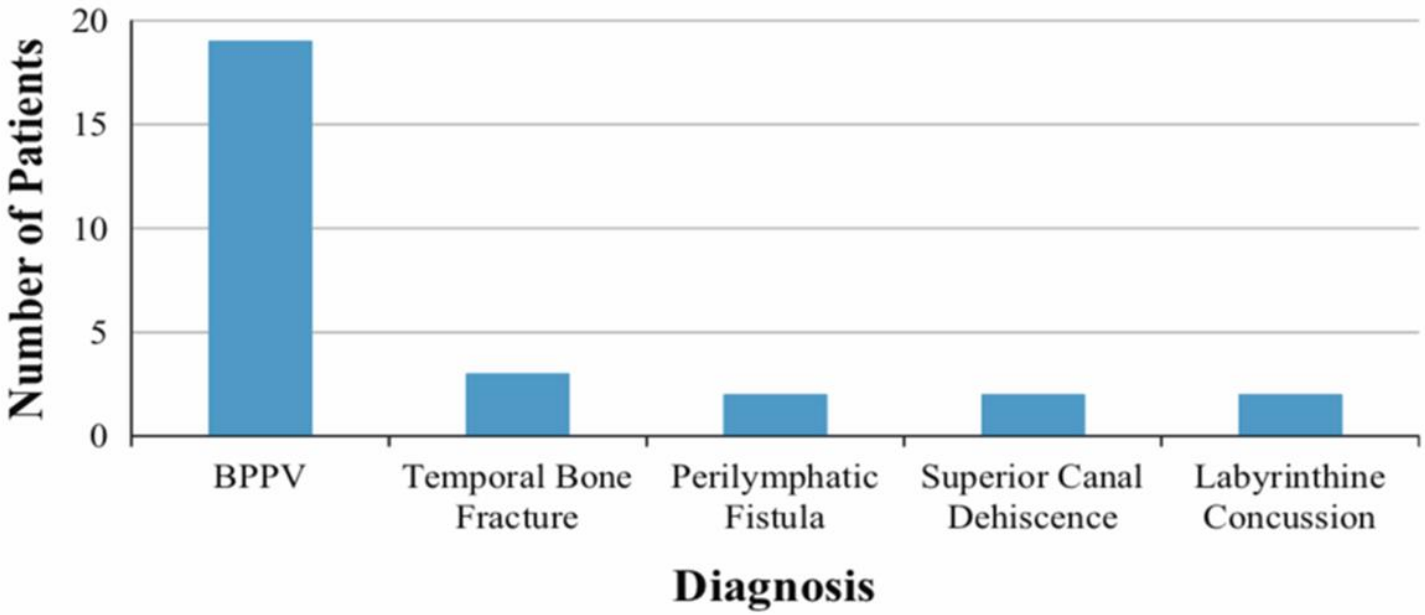


Figure 1. Peripheral vestibular disorders diagnosed in 28 patients in the setting of postconcussion syndrome in patients aged 7 to 20 years. BPPV, benign paroxysmal positional vertigo.

(Brodsky 2018)

Peripheral Vestibular Disorders in Pediatric Patients with Concussion

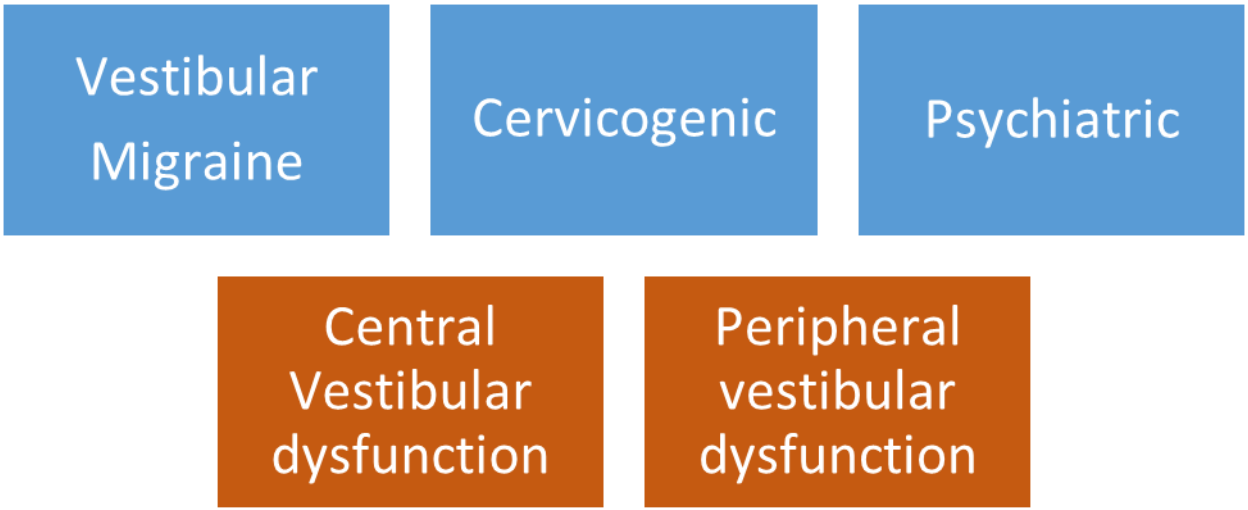
- Canal involvement:
  - Posterior canal BPPV: 16 patients
  - Lateral canal BPPV: 1 patient
  - Superior canal BPPV: 1 patient

- The patients in this study were a mean of 19 weeks post their injury before diagnosed with a peripheral vestibular disorder
  - Prolonged recoveries may be due to lack of diagnostic testing and intervention early on in pediatric patients
    - Lack of awareness of BPPV among pediatric providers?
    - Lack of experience with BPPV in pediatric patients?

- All patients in the study who were diagnosed with BPPV were successfully treated with canalith repositioning maneuvers

- Author's recommendation: "Once a patient's neck is cleared, providers should perform the Dix-Hallpike as early as possible to reduce time to diagnosis and treatment." (Brodsky 2018)

Dizziness


Vestibular Migraine
Cervicogenic
Psychiatric
Central Vestibular dysfunction
Peripheral vestibular dysfunction

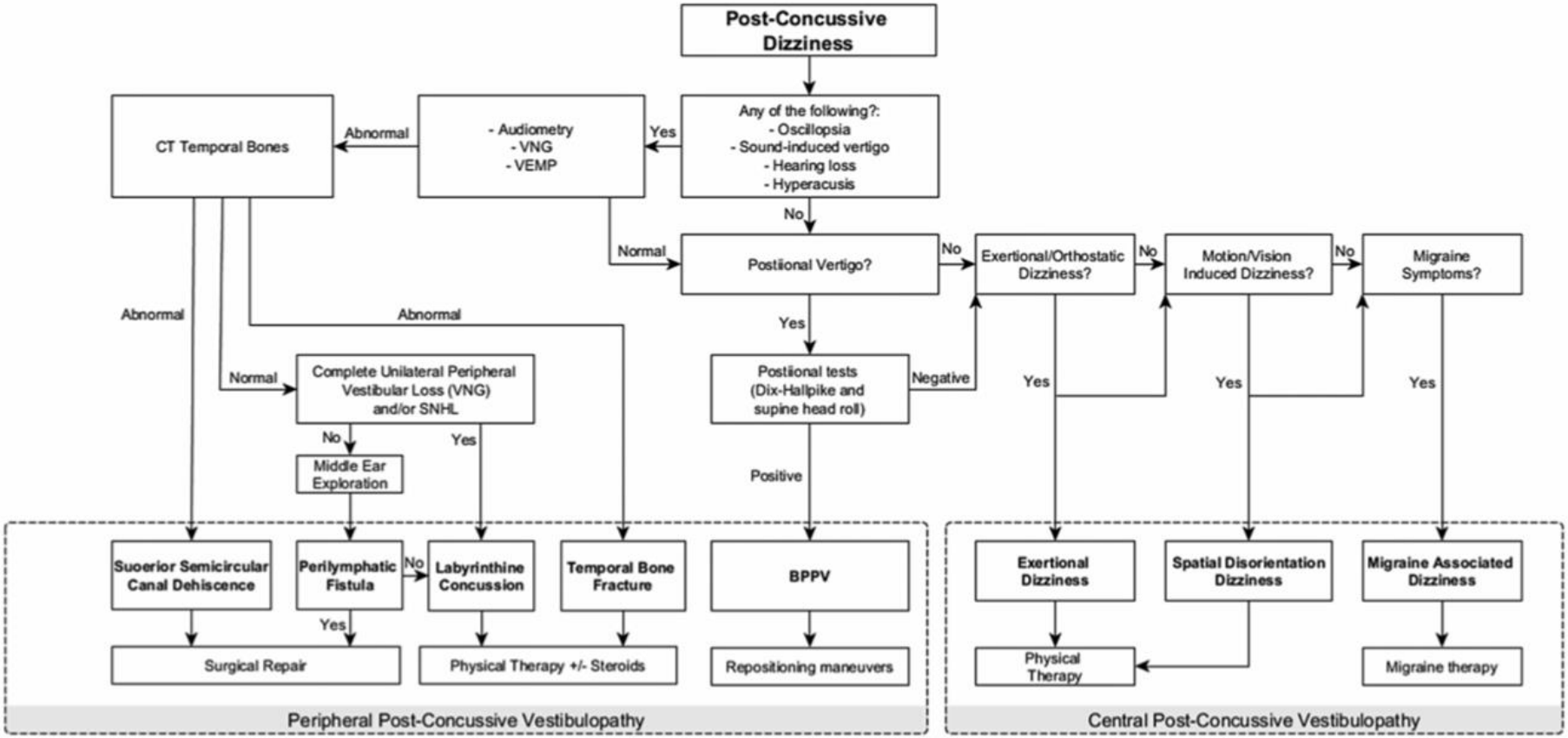


Figure 2. Proposed algorithm for the identification and management of peripheral vestibular disorders in the setting of postconcussion syndrome. BPPV, benign paroxysmal positional vertigo; CT, computed tomography; SNHL, sensorineural hearing loss; VEMP, vestibular evoked myogenic potential test; VNG, videonystagmography.

(Brodsky 2018)

Dynamic Visual Acuity (DVA) test

- Measures visual acuity during self generated horizontal motion of the head.

- Visual acuity with the head still is measured fist
- The patient is then asked to read the smallest possible line with the examiner manually oscillates patients head horizontally at 2 Hz

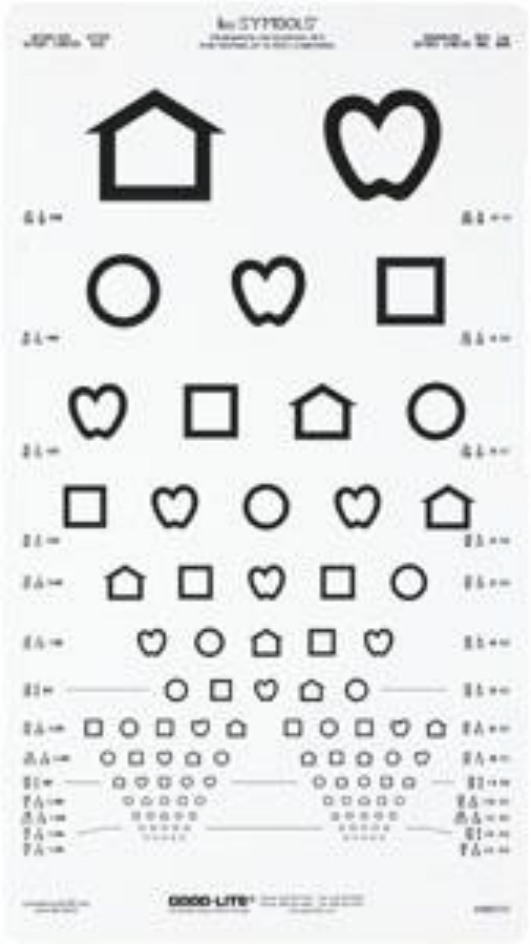
http//www.vestibularseminars.com/officeexamvideos.html

DVA

- Measures of DVA have been shown to correlate with diagnostic measures of the vestibulo-ocular reflex (VOR)
- DVA has been shown to have good to excellent sensitivity and specificity for the identification of dysfunction of the VOR in adults and children (Rine 2018)
  - Can test a child as young as 3 years old
- Normal results: a difference of 2 or less lines between static and dynamic visual acuity
- A 3 or more line difference between static and dynamic visual acuity is considered abnormal suggestive of vestibular deficit

DVA test


actual size
K V D
Z S H C
H S K R N
C H K R V D
H O N S D C V
O K H D N R C S
V H D N K U O S R C
B D C L K Z V H S R O A
H K G B C A N O M P V E S R
P K U E O B T V X R M J H C A Z D I
D K N T W U L J S P X V M R A H C F O Y Z G


SYMBOLS
GOOD-LITE

Vestibular/Ocular-Motor screening (VOMS)

	Not Tested	Headache	Dizziness	Nausea	Fogginess	Comments
Baseline Symptoms						
Smooth Pursuit						
Saccades (Horizontal)						
Saccades (Vertical)						
Convergence (Near Point)						Score#1___cm Score#2___cm Score#3___cm
VOR Horizontal						
VOR Vertical						
Visual Motion Sensitivity						

Mucha A et al. 2014

Head Impulse Test

- Must always screen for cervical ROM and neck pain prior to test
- Hold the patient's head in your hands and tell them to relax, keep their eyes on your nose
- Slowly turn their head side to side, then quickly move their head to one side
- Observe their eyes, a positive test is a corrective saccade, inability to maintain fixation on examiner's nose

Head Impulse Test

- Test in horizontal and vertical planes
- Testing children:
  - Put a sticker on your nose
  - Use a sticker on a mirror for them to look at while you are behind them moving their head quickly
  - Patient/child must be relaxed, and the movement unexpected (may see an anticipatory corrective saccade)

Modified Clinical Test of Sensory Integration on Balance (MTCSIB)

- Child stands with feet together, barefoot, arms across chest, for 30 seconds each condition:
  - 1. Eyes open, firm surface
  - 2. Eyes closed, firm surface
  - 3. Eyes open, on foam surface
  - 4. Eyes closed, on foam surface

- Time stops if child's eyes opens, they come out of testing position, or lose their balance.
- Add the time of each condition (120 seconds total).
- <110 seconds is indicative of potential vestibular dysfunction (Christy 2014).

Additional Tests & Measures in the Pediatric Population

- Dynamic Gait Index (DGI)
- Pediatric Balance Scale
- Pediatric Berg
- Peabody Motor Development Scale (PMDS-2)
- Pediatric Handicap Inventory for Patient Caregivers (pDHI-PC)
- Convergence Insufficiency Symptom Survey
- TUG, TFTS, TUDS
- Pediatric Reach Test
- BESS test
- 5 Times Sit to Stand Test

www.rehabmeasures.org

Vestibular Rehabilitation

- Vestibular Rehabilitation is a therapeutic approach to enhance functional vestibular compensation

- It is delivered to patients according to nature of the symptoms and not according to their diagnosis.

Vestibular Rehabilitation

3 phases

1. Acute or critical phase
   - Vertigo, spontaneous nystagmus, postural symptoms (static/dynamic)

2. Symptom resolution
   - High impact window of rehabilitation

3. Final phase
   - No further improvement- terminal compensation

Vestibular compensation process

- Adaptive plasticity of the CNS
- Central sensory substitution
- Habituation is the long term reduction in neurologic response to a particular noxious stimulus.

Adaptation exercise

- Goal: to assist CNS to adapt to a change or loss in vestibular system input by improving the gain of VOR

- Exercise are geared towards using a combination of head movement while fixating target to reduce error and restore VOR

Gaze stabilization exercise

Adaptation exercise

Target is either moving VORx1 or stationary VORx2

- VORx1: The patient moves their head to both sides (yaw and pitch) while keeping their eyes fixed on stationary target
- VORx2: The head and the hand holding the target both are moving in opposite direction with the eyes fixated on target.

VORx1

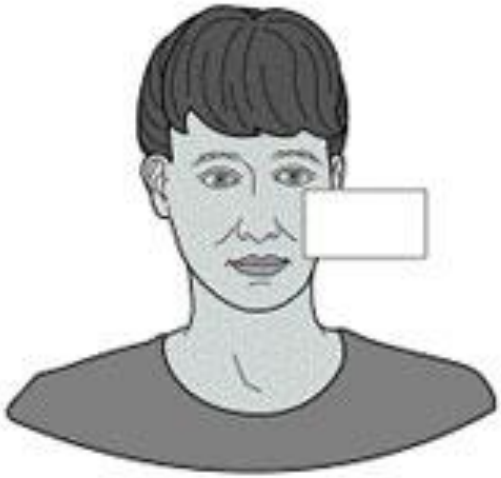


Figure 2A: Look straight ahead.

Figure 2B: Turn your head 45 degrees towards the right.

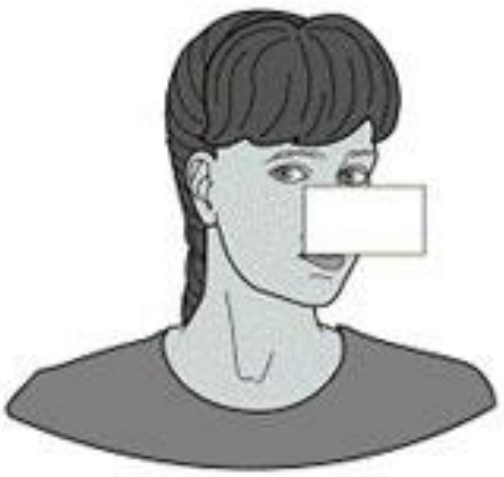


Figure 2C: Turn your head 45 degrees towards the left.

Note: Business card should be positioned at eye level.

Gaze stabilization exercises

- Begin with simpler exercises
- Start VOR x1 progress to VOR x2
- Start one plane and move to other plane
- Perform exercises with small head movements (if necessary pause).
- Speed of head movement should be increased as long as target remains in focus (very important)
- These exercise may provoke symptoms of nausea and dizziness. Work through these symptoms. Rest between so that symptoms come back to baseline before doing the next set of exercise.
- If patient reports blurry vision- either get an eye exam or reduce the speed of head movement

Treatment considerations

- Image must be stable
- Observe patient eyes
- Avoid over stimulation
- All patients will not progress through same stages
- Symptoms should not exceed 20-30 mins following HEP
- Take it slow and err on side of caution

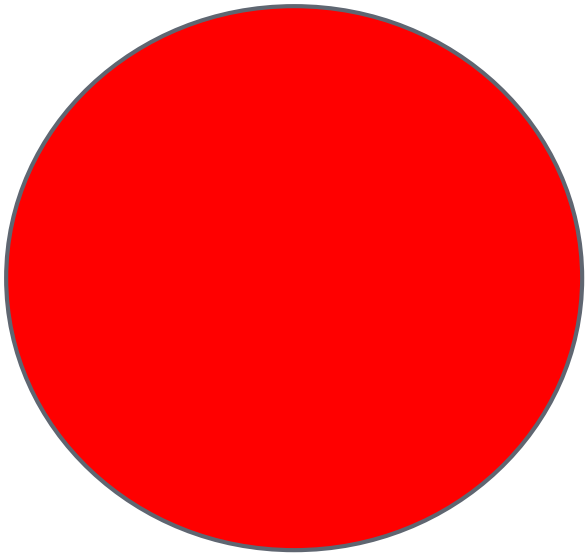
Substitution exercise

- Goal: Promote alternative strategies. Refers to the process of learning to substitute other sensory information or activities
- Example: use of other eye movements for impaired vestibular function
- Rationale:
  - These exercise take advantage of saccades to replace slow phase of VOR component.
  - Using large eye movement on a target before the head turns

Substitution exercise

- To foster the use of saccadic or pursuit strategies and central programming of eye movement.
  - Tape two targets on the wall so that when you look directly at one target you can still see the other target.
  - Look at target 1 with your eyes and your head, be sure that your head is lined up with the target.
  - Then look at target 2 with your eyes and then turn your head to the target. Keep the target focused
  - Repeat on the other side
  - Practice up to 5 mins

Imaginary targets



Incorporating vestibular training in dynamic environment

- March in place EO/EC
- Quick head turns during gait (R/L)
- Gait with narrowed BOS. Incorporate turning
- Gait on altered surface (foam/gravel)
- Walking sideways (Braiding), walking backwards
- Step up and down
- Perturbations using ankle/ hip strategies
- Reaching activities, tandem walking, SLS
- Obstacle course (cones, hurdles)
- Tossing an object or cognitive task while walking

Clinical pearls – Clinical Decision Making

- Positional Maneuvers
- Gaze stabilization (adaptation)
- Substitution
- Habituation

Gaze Stabilization Exercises in Pediatrics

- Have the child read flash cards, favorite books, or self advancing PowerPoint slides while jumping on a trampoline, bouncing on a ball, or walking on a treadmill.
- To get head movements in yaw, the parent could turn the head as the child attempts to read from a favorite story or search for pictures in a book.
- The parent could also place pictures or words around the room and time the child as he/she searches for a certain picture or word, mimicking gaze-shifting exercises.
- The exercise must include quick head movements with some way to determine whether or not the child is seeing the target clearly.

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Thank you for your attention!