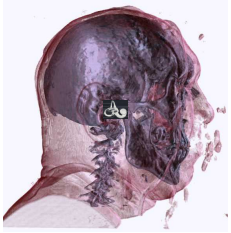
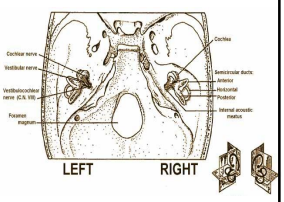
MAYO CLINIC

How the Labyrinth Works…

Inner Ear: “On Top of a Long Stalk”

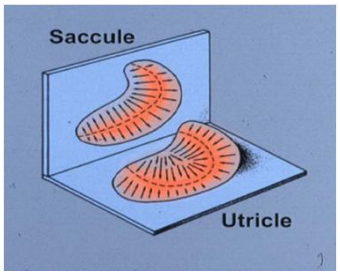




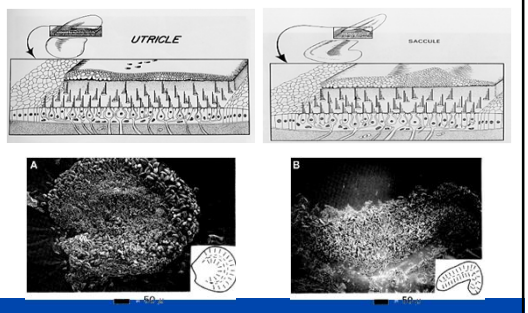
Vestibular Function SCCs:

- Semicircular canals
  - Translates angular rotation movements of the head around the pivot point of the neck
  - Information used by the CNS to coordinate:
    - Eye movements
    - Upper torso movement
    - Hand movements while moving
    - *See aVOR app in the iTunes Store*

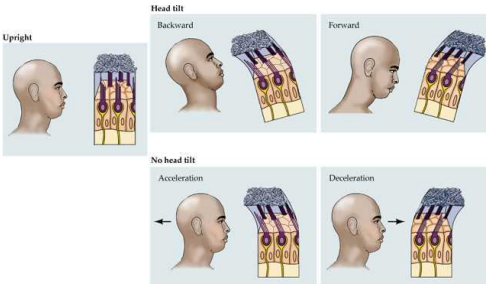
Vestibular Function Otoliths:



Micro-Structure of the Macula



Utricle Encoding: Static Tilt and Acceleration



www.utdallas.edu/~tres/integ/sen5/sense_5.html

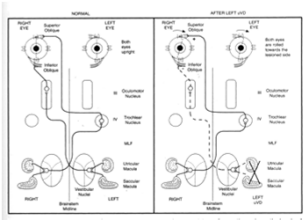
Primary Goal of Otolith Organs

- Anti-gravity muscle tone
  - Vestibular Spinal Reflexes (VSR)
- Vestibular Ocular Reflexes :
  - Maintain registration of the retina with gravitational vertical
    - Horizontal meridian of the retina aligns automatically with the horizon

Macula: Linear Translations and Low Frequency Tilts

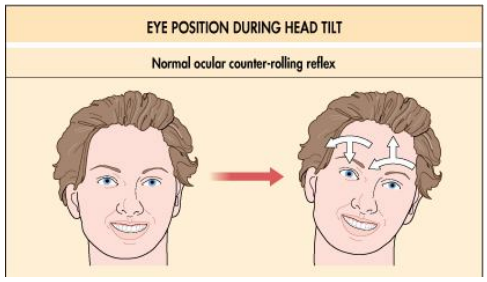
- Sensitive to movements about the...
  - Hips
  - Ankles
- Play an important role in maintaining upright stance

Ocular Tilt Reaction



Modified from: Brandt & Dietrich, 2000, in S.J. Herdman, Vestibular Rehabilitation

Vestibulo-Macular Ocular Reflex

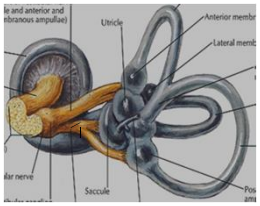


Goal: Keep eyes aligned with gravitational vertical

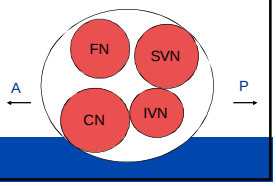
Common Otolith Disorders

- BPPV
  - Most common cause of vertigo in adults
- Superior vestibular nerve "neuro-laybrinthitis"
  - Second most common cause of dizziness
    - Clinically:
      - "Neuronitis"
        - Vestibular symptoms only
      - "Labyrinthitis"
        - Auditory and vestibular symptoms

Major Nerves In The Internal Auditory Canal (IAC)



Facial N. - Superior & Anterior
Cochlear N. - Inferior & Anterior
Superior Vestibular N.
Inferior Vestibular N.



Vestibular Tests and Eighth Nerve Branches

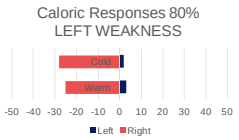
We can now measure all sensory structures and nerve branches of the inner ear

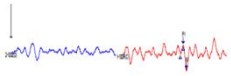
- Audiological Evaluation
- Caloric response
- oVEMP
- cVEMP
- vHIT

- Cochlea
- Horizontal SCC (SVN)
- Utricle (SVN)
- Saccule (IVN)
- All SCCs (SVN/IVN)

Vestibular Study

- Normal
  - Ocular motor
  - (-) positional nystagmus





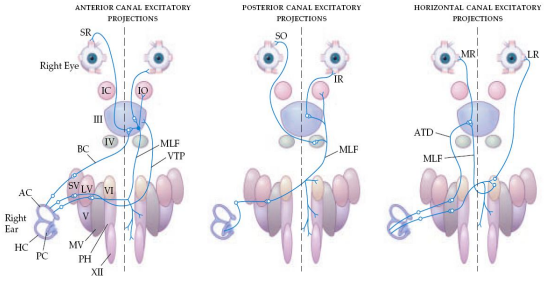
Absent cVEMP on LEFT

Absent oVEMP on LEFT

Summary Points

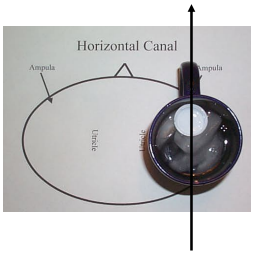
- Three SSC
  - Encode angular rotation about cervical spine
- Two otolith organs
  - Encode linear translations and drive strong neck and spine muscle reflexes.
- Vestibular Nerve:
  - LSU on top!
- Vestibular nuclei (VN) and cerebellum involved with VOR / VSR / autonomic tone

Ways to Understand the Vestibulo-Ocular Reflex



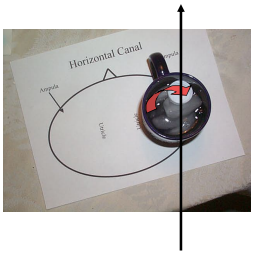
Right Semi-Circular Canal Cup

- Cup is in the place of the right SSC
  - Handle is in the position of the ampulla
  - Cap represents endolymph position before any head movement
- Note position of the utricle (medial)



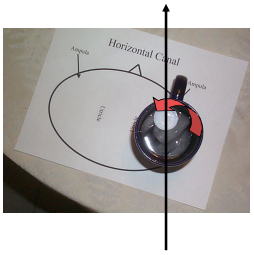
Head Moves to the left...

- Ampulla moves with the head (to the left)
  - Cap does not move, but changes position relative to the ampulla due to head movement (curved arrow)
    - It "lags behind" the head movement
- Endolymph moves through the ampulla, away from the utricle



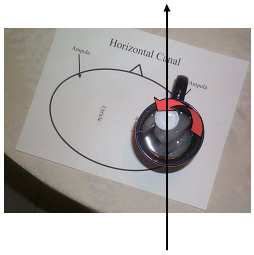
Head Moves to the Right

- Ampulla moves with the head (to the right)
  - Cap does not move, but changes position relative to the ampulla due to head movement
- Endolymph moves through the ampulla, *toward* from the utricle

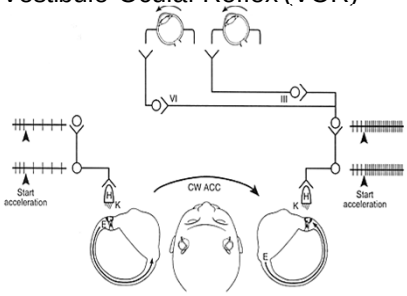


Head Moves to the Right

- The long arrow (endolymph) does not change its orientation…neither do the eyes.
- Vestibular eye movements lawfully reflect relative movement of endolymph in the SCCs



Vestibulo-Ocular Reflex (VOR)



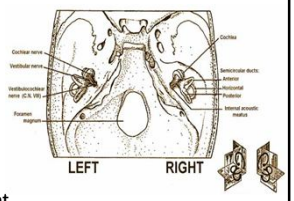
Shepard and Telian 1995

Semicircular Canal aVOR

- Goal:
  - Maintain visual stability (visual image on retina) despite "angular" head movements about cervical spine

Semicircular Canal aVOR

- Three orthogonal SSCs reflect movements in three dimensions
- Three SCCs pairs (left and right) are coplanar
  - When one SCC is stimulated, its coplanar complement is inhabited



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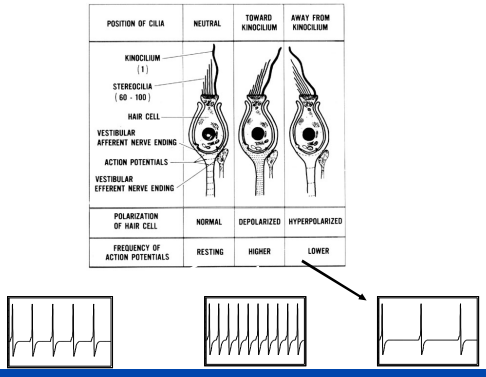
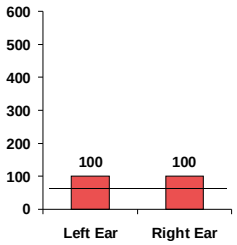
A word about nerve firing rates...

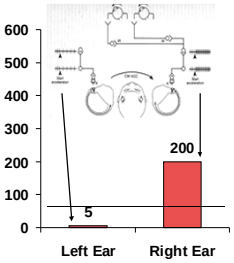


Firing Rate Example (Hypothetical)



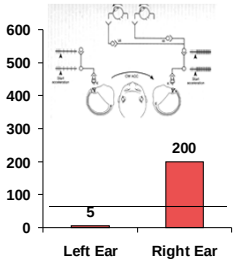
- When the head is still, both nerves fire at about 100 spikes/sec.

Firing Rate Example (Hypothetical)



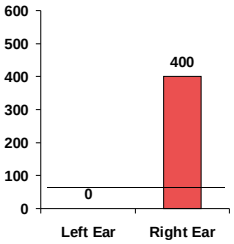
- Head turns to the right at a velocity of 40 degrees / sec,
  - Discharge rate *increases* in the right (leading) ear
  - Discharge rate *decreases* in the left (lagging) ear

Firing Rate Example (Hypothetical)



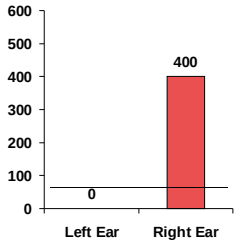
- The brain interprets this asymmetry in nerve output between ears as a head movement to the right at 40 deg/sec.
- The brain moves the eyes to the left at 40 deg/sec
  - vestibular slow phase movement of nystagmus

Firing Rate Example (Hypothetical)



- When the head turns to the right at 100 deg/sec.
  - The right nerve firing rate jumps up
  - The left ear cannot change
    - You can't fire less than zero times / sec ;-)

Firing Rate Example (Hypothetical)



- Any angular head movement that exceeds a critical velocity is encoded entirely by the leading ear.
- *The "lagging ear" contributes little to the VOR at high velocities of rotation*

(-)

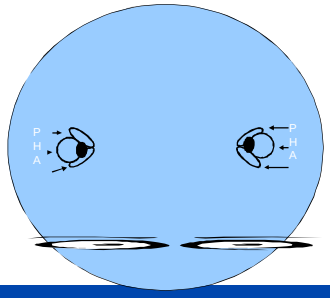
(+)

Jacobson et.al.,

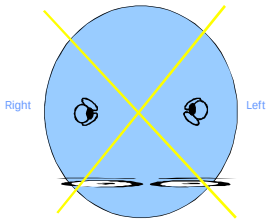
Ecological Approach to Vestibular Evoked Eye Movements

- Vestibular evoked eye movements are designed to:
  - Maintain gaze stability during unexpected head / body movements
  - Maintain eye orientation so that the horizon lines up with the horizontal meridian of the retina

A Model...

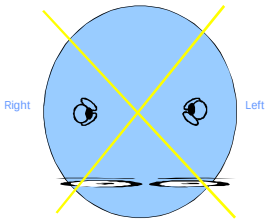


SSC Planes



- Six SSCs are matched in complement pairs -three planes…
  - Two Horizontal
  - Right Anterior and Left Posterior
    - *(RALP)*
  - Left Anterior and Right Posterior
    - *(LARP)*

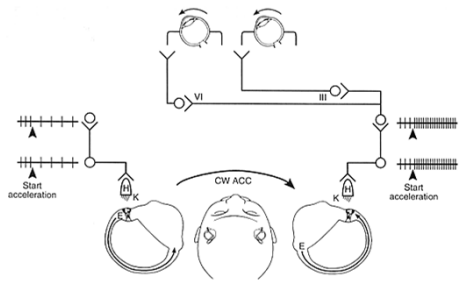
Law of Reciprocal Innervation



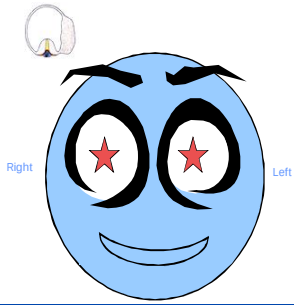
- Head movements that stimulate the nerve of one canal, inhibit output in the complementary canal
- *Leading Ear Excites*
- *Lagging Ear Inhibits*

Horizontal Canal Dynamics

- Q: Which way does the cupulla of the horizontal canal bend to excite the vestibular nerve?
- A: It “swings away from” the leading ear.
  - Ampullopetal flow - endolymph flows towards the utricle

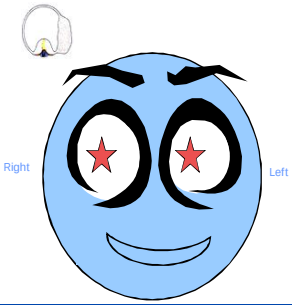


Relating Horizontal SSC Output to VOR



- So with Left Head Turn:
  - The Left Horizontal SCC *Excites* Left Vestibular Nerve
  - Right Horizontal SCC *Inhibits* Right Vestibular Nerve
- The Eyes Drift to the *Right side* of the Orbit to maintain *Gaze stability (VOR)*

Relating Horizontal SSC Output to VOR



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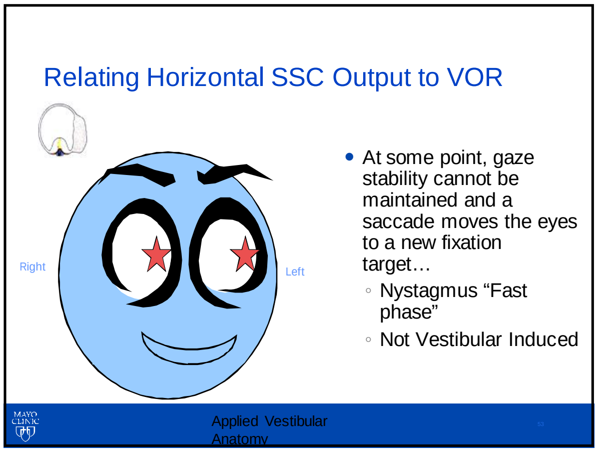
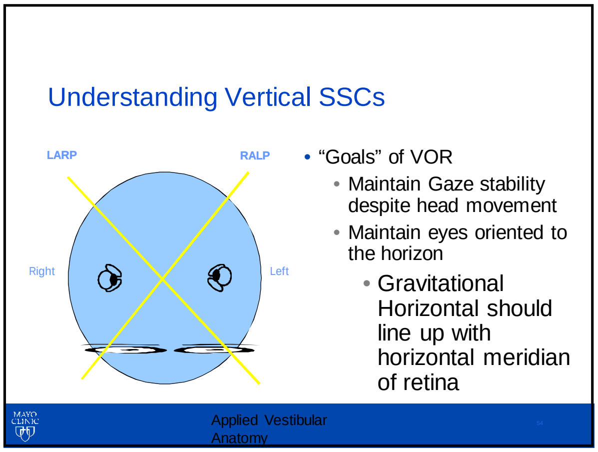


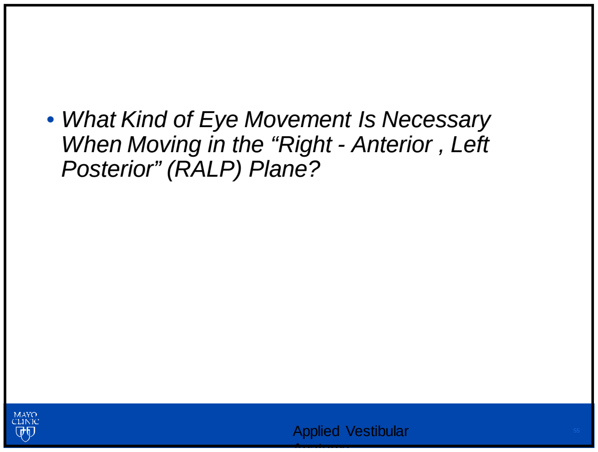
Relating Horizontal SSC Output to VOR

- At some point, gaze stability cannot be maintained and a saccade moves the eyes to a new fixation target…
  - Nystagmus "Fast phase"
  - Not Vestibular Induced

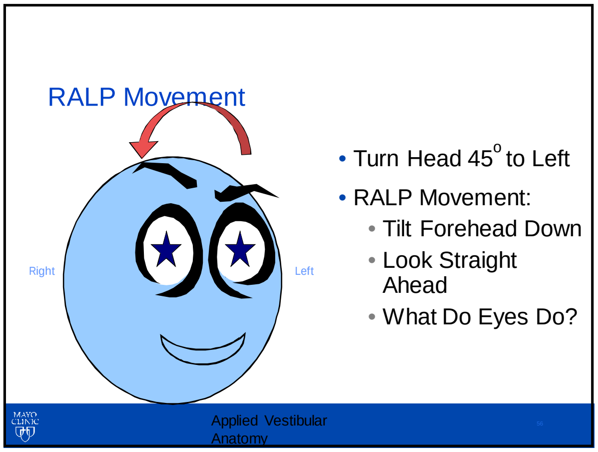


Understanding Vertical SSCs

- "Goals" of VOR
  - Maintain Gaze stability despite head movement
  - Maintain eyes oriented to the horizon
    - Gravitational Horizontal should line up with horizontal meridian of retina

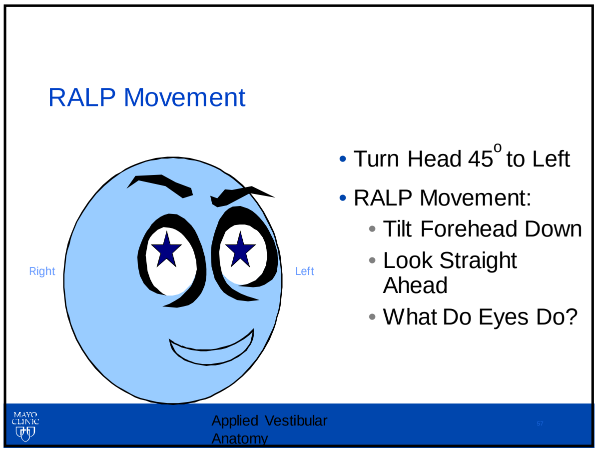


- *What Kind of Eye Movement Is Necessary When Moving in the "Right - Anterior , Left Posterior" (RALP) Plane?*



RALP Movement

- Turn Head 45° to Left
- RALP Movement:
  - Tilt Forehead Down
  - Look Straight Ahead
  - What Do Eyes Do?



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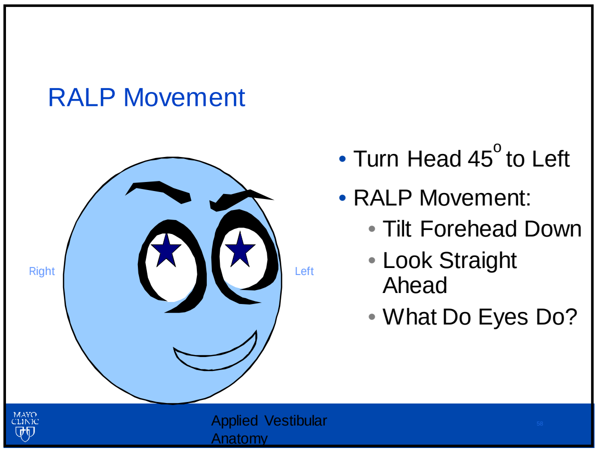


RALP Movement

- Turn Head 45° to Left
- RALP Movement:
  - Tilt Forehead Down
  - Look Straight Ahead
  - What Do Eyes Do?

RALP Movement

- *Right Eye elevates*
- *Slight Counter Clockwise Torsional eye movement (relative to the patient)*

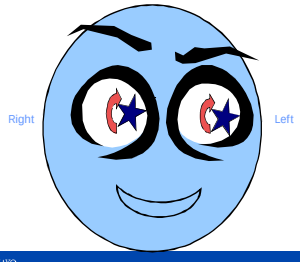
RALP Movement

- At some point, gaze stability cannot be maintained and a saccade moves the eyes to a new fixation target…
  - *Nystagmus "Fast phase"*
  - *Not Vestibular Induced*

RALP Movement

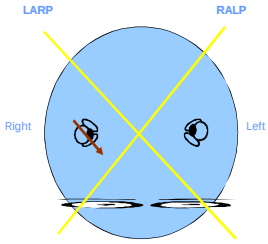
- This is the Effect of Right Anterior Canal Stimulation (When looking to the right):
  - Right Eye elevates
  - Slight Counter-clockwise Torsional "Slow phase" eye movement (relative to the patient)

RALP Movement

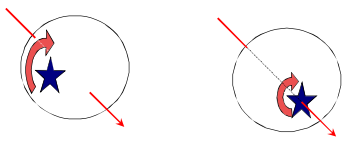


- When looking to the left of Right Anterior Canal Stimulation provokes:
  - Minimal vertical movement
  - Counter-clockwise Torsional "Slow phase" eye movement (relative to the patient)

RALP Eye Movements



- Vertical component changes with direction of gaze
- Eye movement remains "in the plane of" the dependent canals (Arrow)

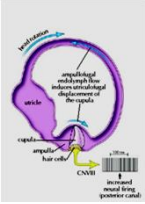


Vertical Canal Cupula

- How does the cupula of the leading vertical canal move when the head tilts in the RALP plane?

Vertical Canal Dynamics

- It "falls" toward the head tilt.
  - Ampullofugal Flow or Flow away from the utricle.



Parnes et al 2003

Summary Point: #1

- Vestibular Induced Eye Movements:
  - Maintain gaze stability during unexpected head / body movements
  - *Maintain eye orientation so that the horizon lines up with the horizontal meridian of the retina*

Summary Point: #2

- In Angular Head Movements
  - The leading canal excites the vestibular nerve
  - Lagging canal suppresses vestibular nerve firing
    - Provokes a slow eye movement in the opposite direction of the head movement (Ewald).
    - The leading canal will drive eye movements in response to fast accelerations (Ewald).

Summary Point: #3

- For horizontal or "yaw" type of excitatory movements, the cupula *lags* behind the leading ear
- For vertical movements (RALP or LARP planes), the cupula *falls* in the direction of the head movement

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BPPV Induced Eye Movements

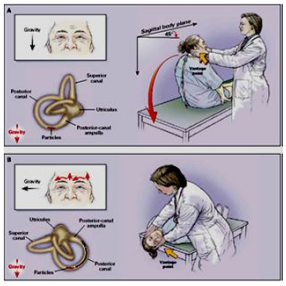
Benign Paroxysmal Positional Vertigo (BPPV)

- Intense but transient vertigo provoked by moving into specific head positions
  - Most common cause of vertigo
  - Accompanied by a characteristic nystagmus
  - Thought to be caused by debris in the semicircular canals
  - Can be treated by a simple in office procedure

Understanding BPPV Induced Eye Movements

- Simple forms are easy to recognize:
  - Posterior SSC BPPV is torsional, with the top pole of the eye rolling to the floor.
- For more complicated types of nystagmus:
  - Relate the eye movement to the type of head movement that would normally drive the eyes in that direction.
  - *"Analogous Equivalent Movement"*

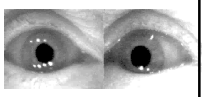
Dix-Hallpike or Nylen Maneuver



Furman and Cass "Benign Paroxysmal Positional Vertigo." NJM 1999.

Characteristic Response

- Torsional nystagmus (rolling eye movement) & vertiginous sensation
  - Onset latency (5-45 sec)
  - Crescendo then fatigues (typically within 30 sec)
  - Symptoms extinguish (adapt) over repeated trials

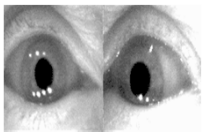


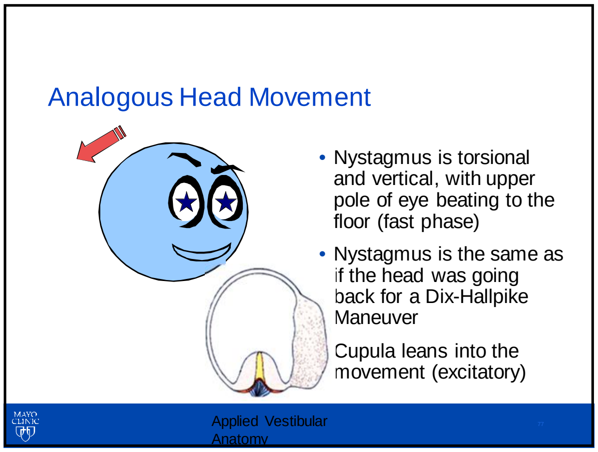
Analogous Equivalent Head Movement

- Analogous equivalent head movement
  - Visualize which semicircular canals would be stimulated or inhibited during such a movement
    - This will tell you where the debris rests in the labyrinth.

Posterior Canal BPPV

- Eye movement:
  - Top of eye rolls to the floor
    - Counter clockwise (relative to the patient)
  - Up beating component, >in the contralateral eye
- Eye movement is analogous to falling in the plane of the involved posterior canal





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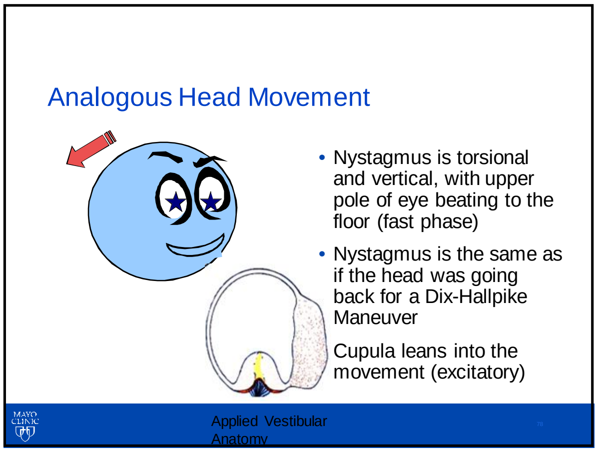
Cupula leans into the movement (excitatory)

Applied Vestibular Anatomy



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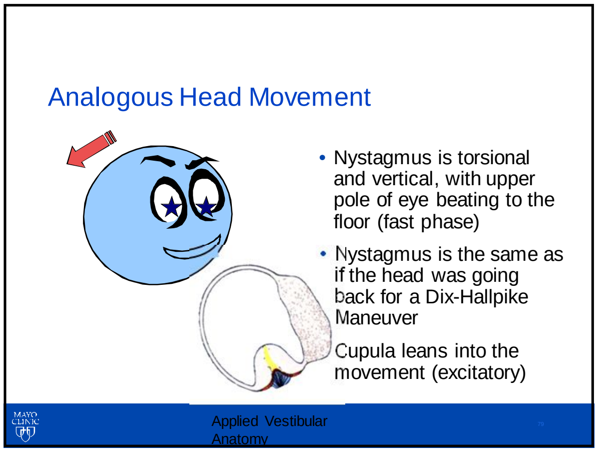

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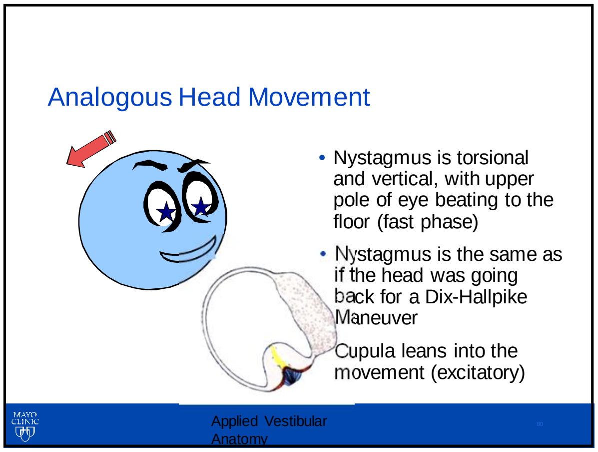

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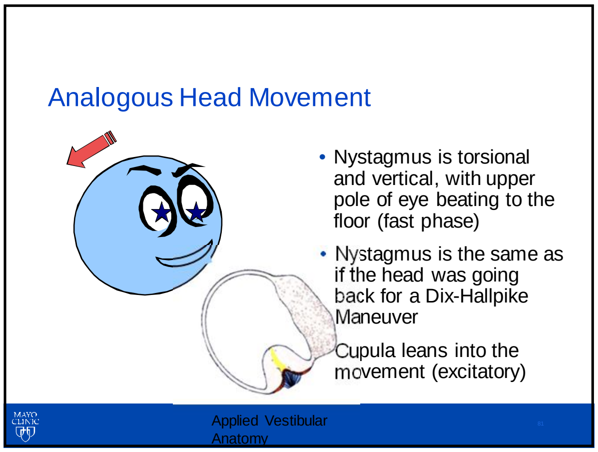

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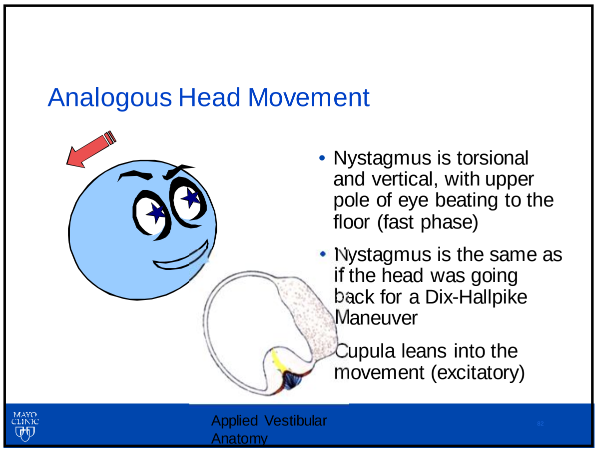

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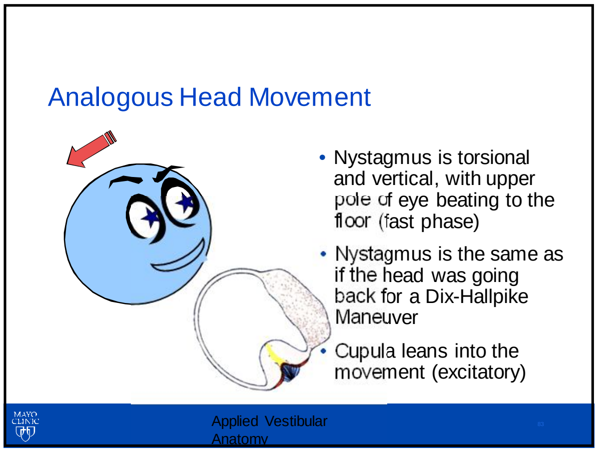

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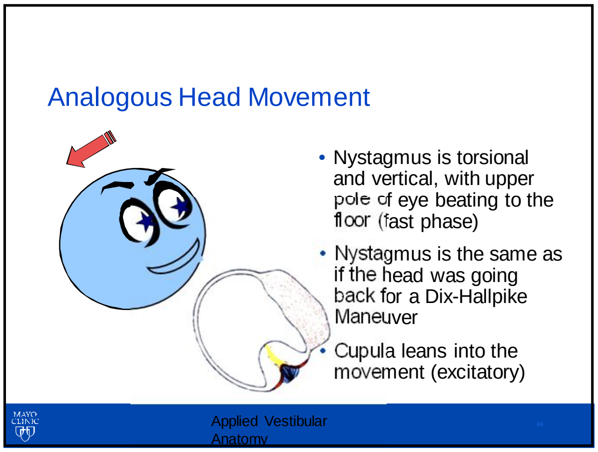

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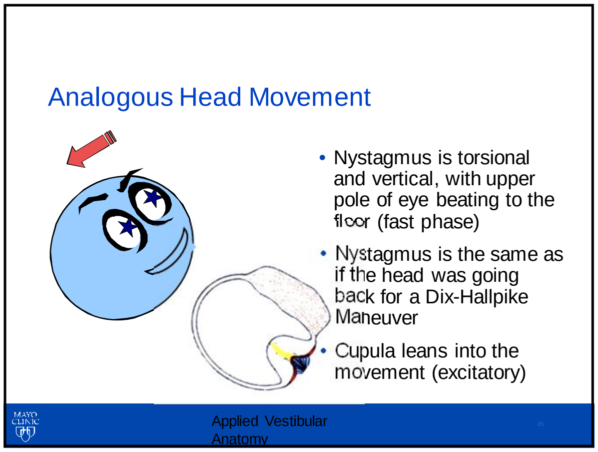

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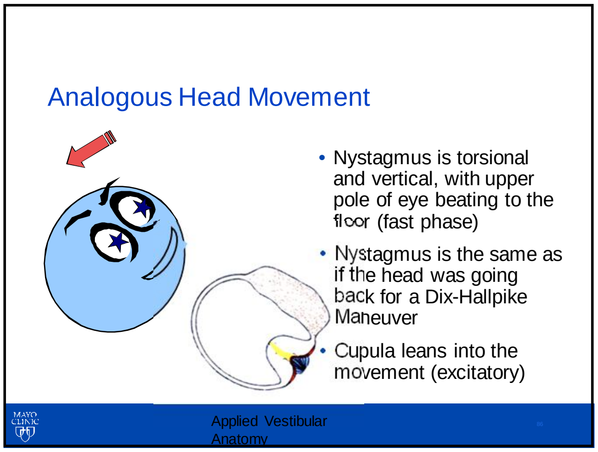

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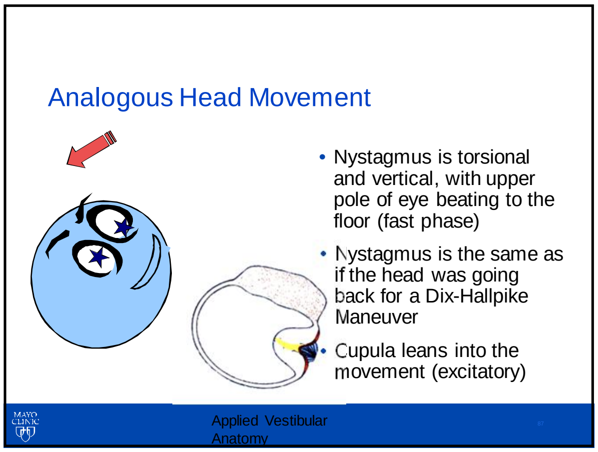

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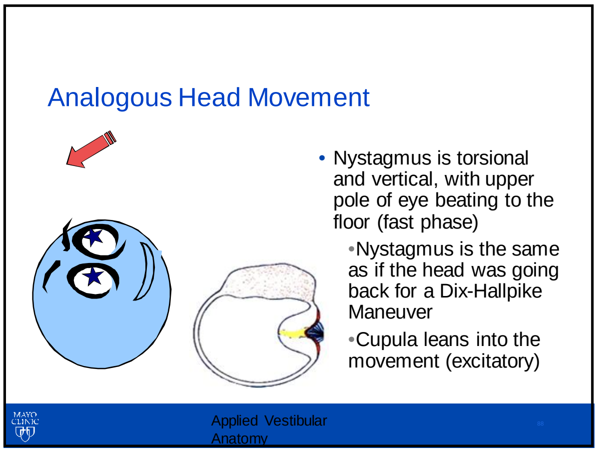

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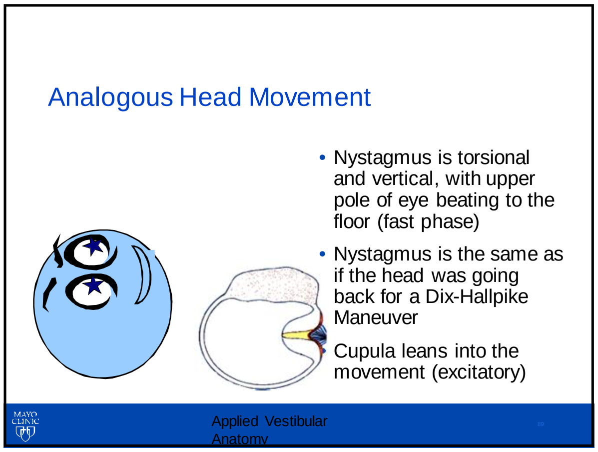

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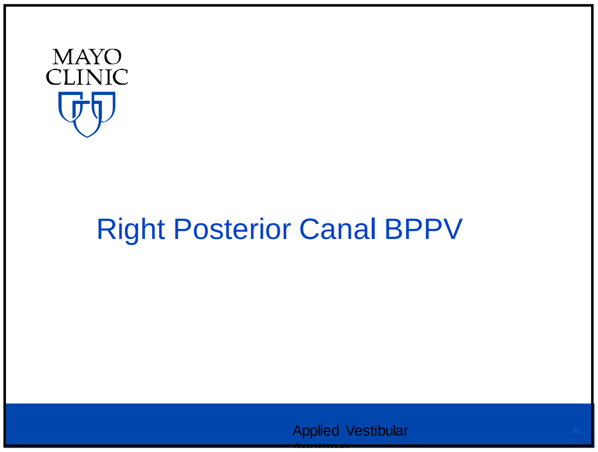
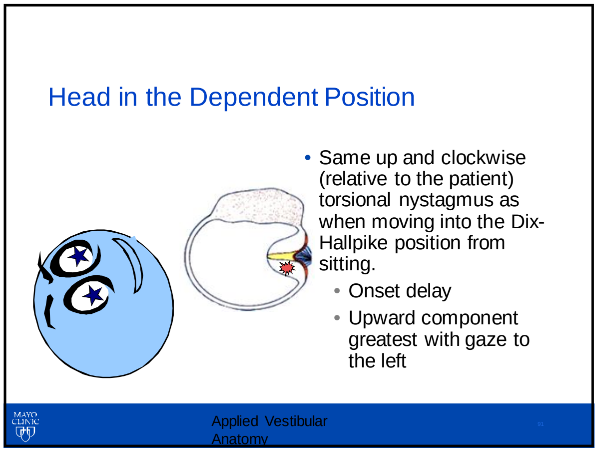
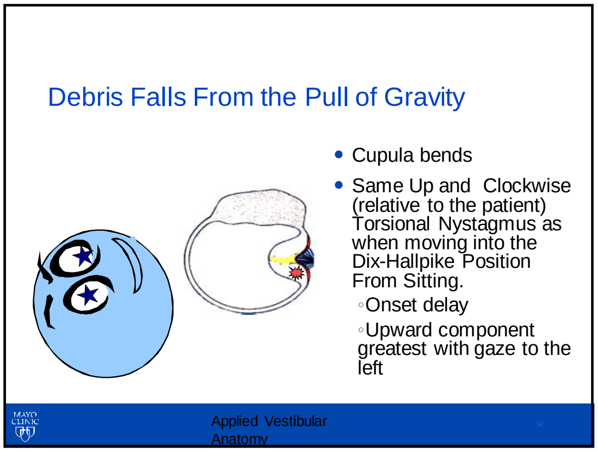


Right Posterior Canal BPPV



Head in the Dependent Position

- Same up and clockwise (relative to the patient) torsional nystagmus as when moving into the Dix-Hallpike position from sitting.
  - Onset delay
  - Upward component greatest with gaze to the left



Debris Falls From the Pull of Gravity

- Cupula bends
- Same Up and Clockwise (relative to the patient) Torsional Nystagmus as when moving into the Dix-Hallpike Position From Sitting.
  - Onset delay
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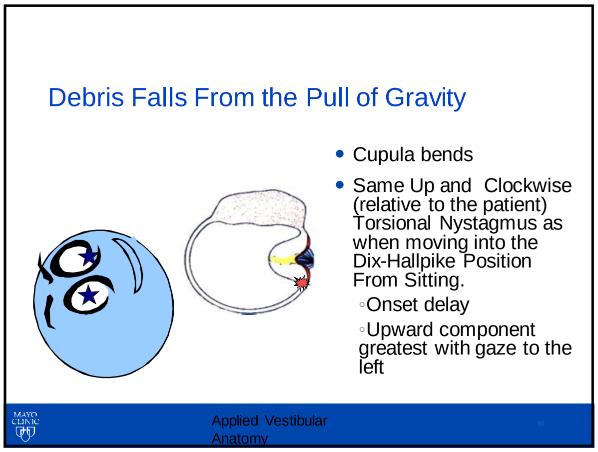

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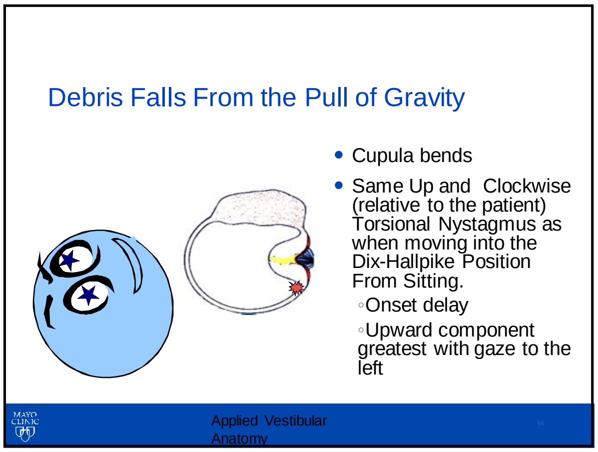

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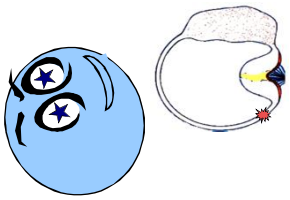

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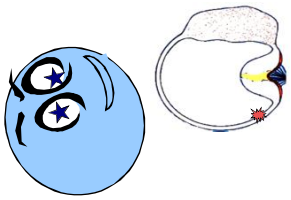

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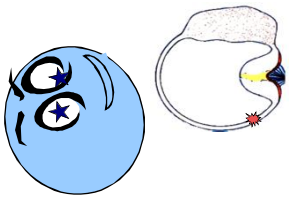

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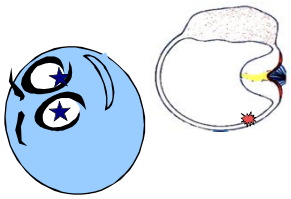

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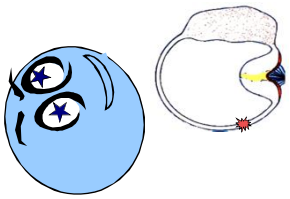

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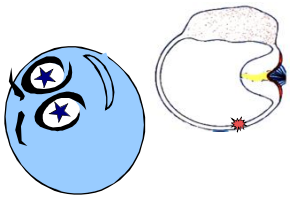

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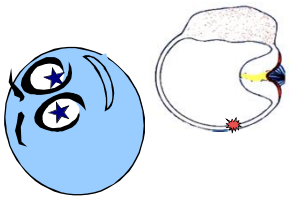

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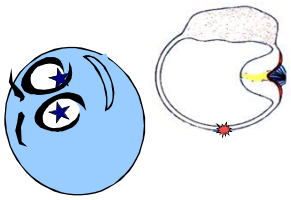

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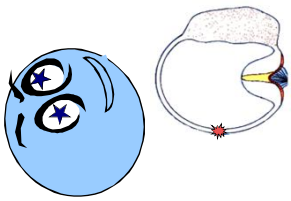

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Posterior Canal Variety

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  - Top of eye rolls to the floor
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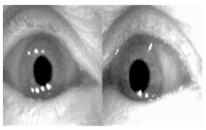
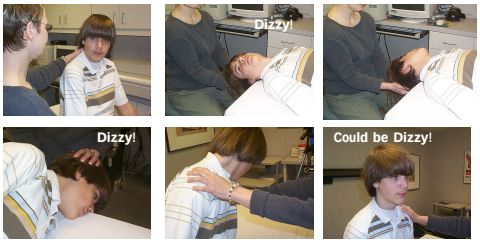
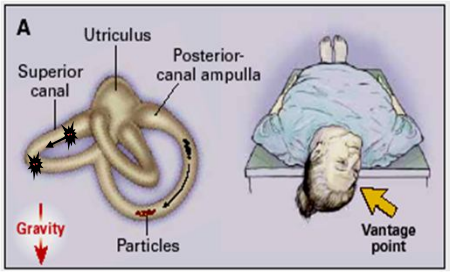


Epley Maneuver
Right Posterior Canal

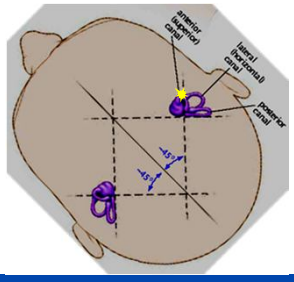


Superior Canal Variations



Modified from: Furman & Cass Benign Paroxysmal Positional Vertigo. NJM, 341:21 1999

Contralateral SC-BPPV

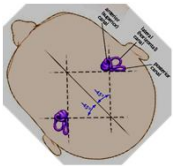


Quick Rules of Thumb

- For vertical / torsional nystagmus…
  - Up-beating eye implies the contralateral posterior canal
  - Down-beating eye implies the ipsilateral anterior canal

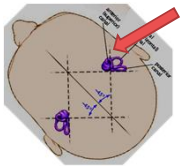
Back to our Case

- Why the Down Beating Nystagmus on Dix – Hallpike?

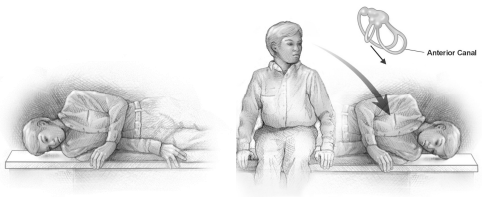


Back to our Case

- Right Anterior Canal BPPV



Detecting Anterior Canal BPPV

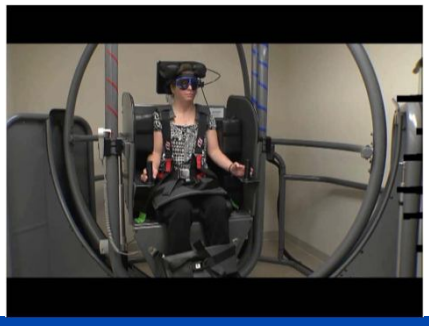


Side Lying Maneuver with the Nose Down

AC-BPPV

- Try a reverse Epley Maneuver
  - Example is for left anterior canal...

Epley Omniax® System



Down Beating Positional Nystagmus

- Central:
  - Enhances with hyperventilation
  - Enhances with lateral eye position
  - Seldom with torsional Component
  - Rare
- Anterior Canal
  - Torsional component variably present with eye position
  - More common

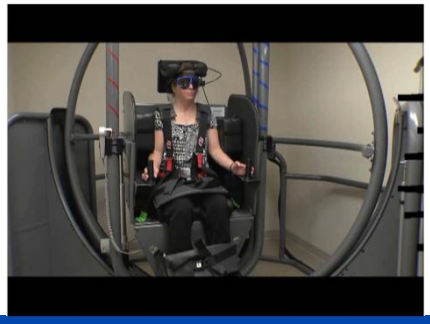
Canalithiasis Treatments (Bed Side):

- Posterior Canal
- Horizontal Canal
- Anterior Canal

- Epley
- Barrel roll
- Reversed Epley
- Deep Head tilt

From: Baloh, R. W. (1998) "Dizzy Patients: The Varieties of Vertigo" in: Hospital Practice, http://www.hosppract.com/issues/1998/06/dmmbal.htm

Epley Omniax® System



Treatment Outcome

- Down beating nystagmus diminished with Epley Chair Treatment.
  - Patient not so unsteady when first getting up in the morning.
  - Still unsteady on feet

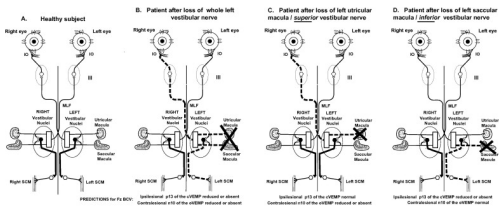


Fig. 9 Simplified schematic diagram of some of the possible pathways underlying the cVEMP and oVEMP responses and the pattern of the asymmetry of n10 and p13 after complete and partial unilateral vestibular loss. It is consistent with the evidence from <ce...

Ian S. Curthoys

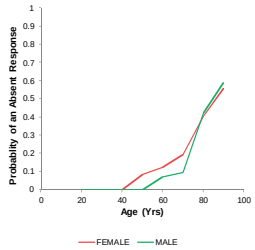
A critical review of the neurophysiological evidence underlying clinical vestibular testing using sound, vibration and galvanic stimuli

Clinical Neurophysiology, Volume 121, Issue 2, 2010, 132 - 144

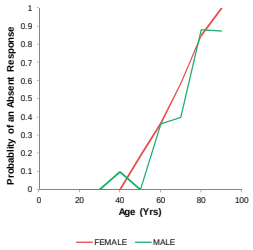
http://dx.doi.org/10.1016/j.clinph.2009.09.027

VEMP Response Absence by Age

cVEMP

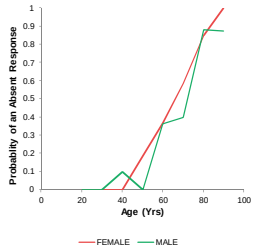


oVEMP



oVEMP and BPPV Age of Onset

oVEMP



BPPV