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

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-labyrinthitis”
  - 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. - Interior & 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)

**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**

- 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

**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 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

A word about nerve firing rates...
• When the head is still, both nerves fire at about 100 spikes/sec.

• 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

• 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

• 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 :-(

• 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
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

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 cupula 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

- 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?
RALP Movement

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

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

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)

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

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

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

- 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
Analogous Head Movement

• Nystagmus is torsional and vertical, with upper pole of eye beating to the floor (fast phase)
• Nystagmus is the same as if the head was going back for a Dix-Hallpike Maneuver
• Cupula leans into the movement (excitatory)
Analogous Head Movement

- Nystagmus is torsional and vertical, with upper pole of eye beating to the floor (fast phase)
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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
  - 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.
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Applied Vestibular Anatomy
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.
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Applied Vestibular Anatomy

Debris Falls From the Pull of Gravity

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Applied Vestibular Anatomy

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Applied Vestibular Anatomy

Debris Falls From the Pull of Gravity

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Applied Vestibular Anatomy

Epley Maneuver
Right Posterior Canal

Dizzy!
Could be Dizzy!

Applied Vestibular Anatomy

Superior Canal Variations


Applied Vestibular Anatomy

2/3/2016
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?

Detecting Anterior Canal BPPV

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

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
VEMP Response Absence by Age

\[ \text{cVEMP} \quad \text{\&} \quad \text{oVEMP} \]

Probability of Absent Response

Age (Yrs)

FEMALE

MALE

\[ \text{oVEMP and BPPV Age of Onset} \]

\[ \text{oVEMP} \quad \text{\&} \quad \text{BPPV} \]

Probability of BPPV

Age (Yrs)

MALE

FEMALE