AudiologyOnline

Live Expert eSeminar

Tests of Otolith Function

Faith Akin, Ph.D. & Owen Murnane, Ph.D.

Guest Editor:
Kamran Barin, Ph.D.

Welcome

Customer Service and Technical Suport: 1.800.753.2160 or submit a question using the Question Pod and include phone number.

Live Expert eSeminar AudiologyOnline

Earning CEUs

CEU Total Access members can earn CEUs for viewing this seminar

- Stay logged in for full time requirement
- Pass short multiple-choice test
- Look for e-mail from ceus@audiologyonline.com with instructions or click on "Start eLearning Here" at AudiologyOnline and log in to your account
- Must pass test within 7 days of today (2 attempts)

Not a CEU Total Access member?

Call 800-753-2160

or visit www.audiologyonline.com

Live Expert eSeminar AudiologyOnline

Monday: ***Bedside Tests of Vestibular Function*** **- Devin McCaslin**

Tuesday: ***Getting the Most of ENG/VNG Testing*** **- Kamran Barin**

Wednesday: ***Rotational Chair Testing*** **– David Zapala**

Thursday: ***Tests of Otolith Function*** **– Faith Akin & Owen Murnane**

Friday: ***Vestibular Rehabilitation*** **– Susan L. Whitney & Patrick J. Sparto**

Friday: ***Panel Discussion*** **– all**

Can't make a live seminar? View the recording!

Tests of Otolith Function

Faith W. Akin, Ph.D.
Owen Murnane, Ph.D.
VA Medical Center, Mountain Home, TN
East Tennessee State University

Limitations of Vestibular Testing

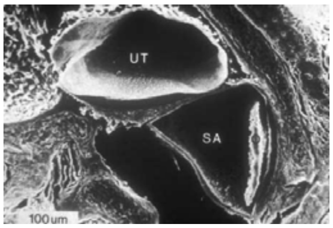
- Tests of horizontal canal function (VOR)
  - Caloric test (ENG/VNG)
  - Rotational testing
- 61% of ENGs WNL (n = 2584) *Stockwell, 2000*
- What does normal ENG mean?
- Clinical dilemma: Assessment of other vestibular organs

Otolith Organs

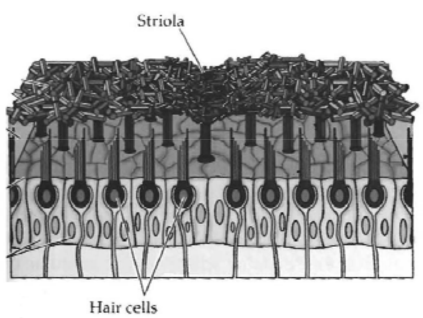
- Utricle and saccule located in vestibule
- Communicate via endolymphatic duct
- Stimulus is linear acceleration, tilt, and gravity
- Proximity of the stapes footplate

Orientation of the Otolith Organs

- Two pairs of otolithic organs sense motion in three dimensions
- The saccule lies in the vertical plane, while the utricle is positioned horizontally

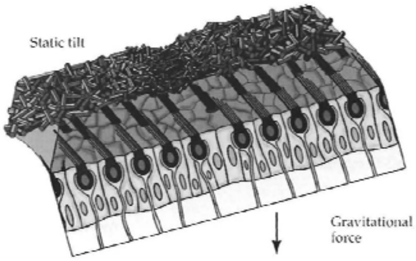


Contents of the Maculae



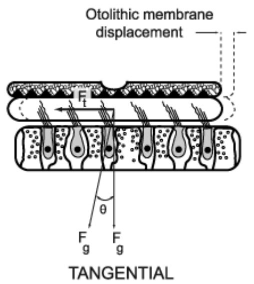
from Purves et al., 2001

Hair Cell Activation in the Maculae: Static Tilt



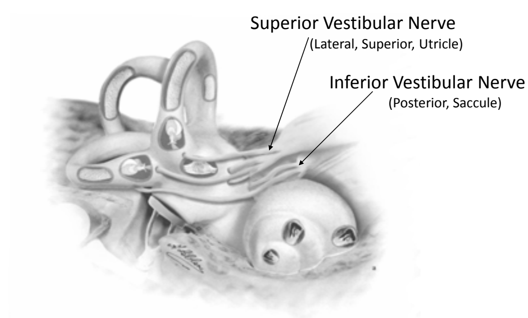
from Purves et al., 2001

Hair Cell Activation in the Maculae:
Linear Acceleration



Adapted from Honrubia and Hoffman, 1993

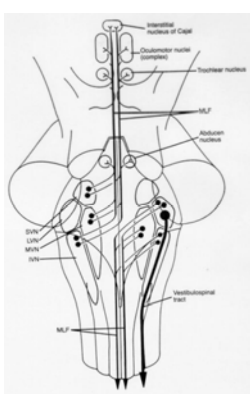
Labyrinth and Vestibular Nerves



Lateral Vestibulospinal Pathway

Descending pathway (modulation of posture):

- Otoliths →
- Lateral vestibular nucleus→
- Lateral vestibulo-spinal tract (ipsilateral) →
- Anterior horn cells of the spinal cord at all levels →
- Antigravity muscles



Tests of Otolith Organ Function

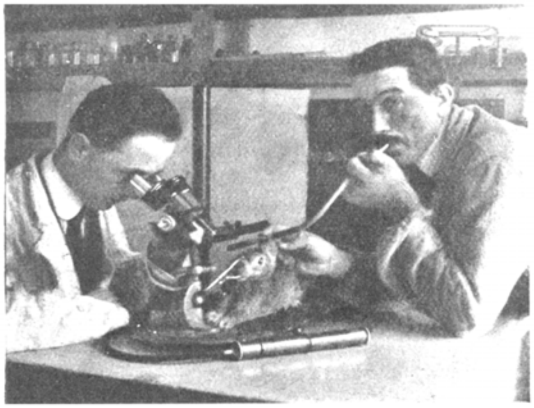
- Swings and Sleds
  – Not clinically practical
  – Not sensitive to unilateral otolith hypofunction
- Vestibular Evoked Myogenic Potentials (VEMPs)
- Subjective Visual Vertical Test (Off-axis rotation)

Stimuli Used to Activate the Vestibular System

- Physiologic or natural stimuli
  – angular acceleration (SCC)
  – linear acceleration (otoliths)
  – head tilts (otoliths)
- Non-physiologic stimuli
  – caloric
  – galvanic
  – skull taps
  – acoustic

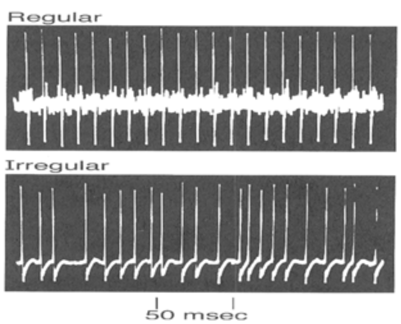
Vestibular Responses to Sound: Historical Framework

- Fenestration of bony labyrinth of alert animals
  – Head movement
  – Eye movement
  – Postural changes
- Tullio’s phenomenon
  – Vertigo
  – Nystagmus
  – Oscillopsia
  – Postural imbalance



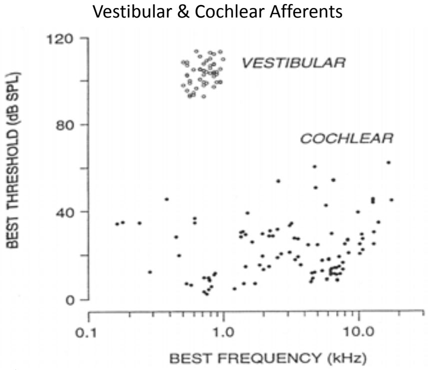
from Halmagyi et al. 2005

Acoustically Responsive
Irregular Discharge (ARID) Units



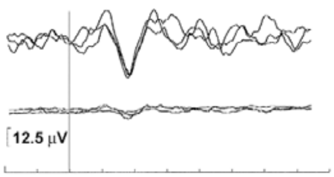
Lysakowski and Goldberg, 2004

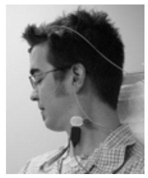
Best Threshold/Best Frequencies for
Vestibular & Cochlear Afferents



McCue and Guinan, 1995

Cervical Vestibular Evoked Myogenic Potential (cVEMP)





- short latency EMG evoked potential
- vestibular origin: saccular receptors/irregular IVN afferents
- ipsilateral inhibitory response
- sacculo-collic pathway

Evidence of Vestibular Origin

Response is abolished following unilateral vestibular neurectomy

Cody et al., 1964; Townsend et al., 1971; Colebatch & Halmagyi, 1992; Colebatch et al., 1994

Not Mediated by Cochlea

No correlation between response and degree of sensorineural hearing loss

Colebatch et al., 1994

Cervical VEMP Pathway

Saccular Macula

↓

Saccular Afferents
(Inferior Vestibular Nerve)

↓

Vestibular Nucleus

↓

Medial Vestibulospinal Tract

↓

Spinal accessory nerve

↓

Motoneuron of the SCM m.

Brainstem midline

Recording Parameters

- No. of Channels: 2
- Amplifier Gain: 5,000 x
- Response Filter: 10 – 1000 Hz
- Sweep Time: 100 ms
- No. of Sweeps: 128
- Artifact rejection: Off

Stimulus Parameters

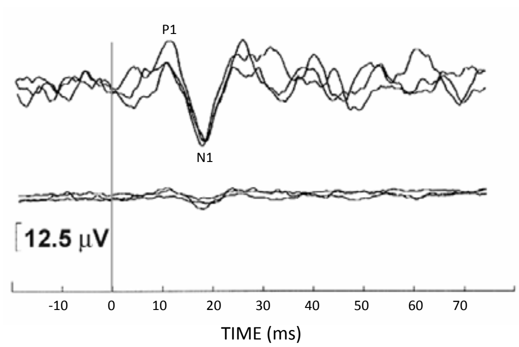
- Type: ***Click***
- Polarity: Rarefaction
- Duration: 100 μs
- Level: 100 dB nHL
- Repetition Rate: 5/s

- Type: ***Tone burst***
- Phase: Rarefaction
- Rise/Fall: 2 cycles
- Plateau: 0 cycles
- Gating: Blackman
- Level: 120 dB pSPL
- Repetition Rate: 5/s

Unilateral SCM m. activation / Monaural stimulation

Bilateral SCM m. activation / Binaural stimulation

VEMP Latency and Amplitude



Normative Data: P1 and N1 Latency (ms)

	Mean	SD	**Min**	**Max**
Clicks (100 dB nHL) *(n = 38, 22-51 yrs)*				
P1	12.1	1.5	**9.9**	**17.3**
N1	19.1	1.5	**16.1**	**22.3**
500-Hz Tone Bursts (90 dB nHL) *(n = 29, 22-50 yrs)*				
P1	15.4	1.2	**13.1**	**18.3**
N1	23.1	1.8	**19.9**	**26.7**

** 50 µV EMG target*

Normative Data: Threshold

Clicks: (*n = 38, 22-51 yrs)*
- Mean = 91 dB nHL (125.5 dB $_{peak}$SPL)
- SD = 5.2
- **Range** = **80 - 100 dB nHL**

500-Hz Tone Bursts: (*n = 20, 22-23 yrs)*
- Mean = 78 dB nHL (108.8 dB $_{peak}$SPL)
- SD = 4.6
- **Range** = **75 - 85 dB nHL**

** 50 µV EMG target*

Normative Data: P1-N1 Amplitude (µV)

	Mean	SD	**Min**	**Max**
Clicks (100 dB nHL) *(n = 38, 22-51 yrs)*	61	34	**12**	**179**
500-Hz Tone Bursts (90 dB nHL) *(n = 29, 22-50 yrs)*	97	61	**15**	**337**

** 50 µV EMG target*

Clinical Interpretation

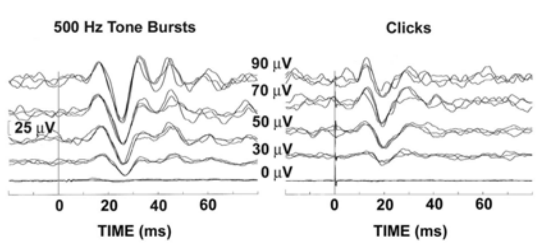
Asymmetry Ratio (AR):

$100 \times \left| (Amp_L - Amp_R) / (Amp_L + Amp_R) \right|$

Asymmetry Ratio (%): Normative Data (n = 30)

	Mean	SD
Clicks	14.8	12.5
500-Hz Tone Bursts	15.2	13.9

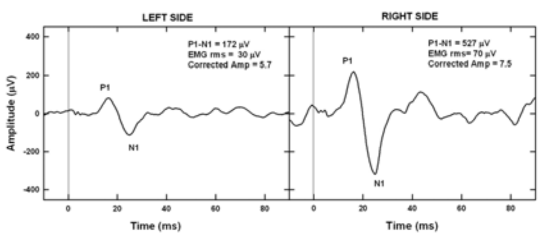
Effect of SCM m. EMG Level on cVEMP Amplitude



Strategies to account for the effects of EMG level on cVEMP amplitude

- Control for EMG level during cVEMP recording by providing feedback to the patient
- Correct P1-N1 amplitude after cVEMP recording by using pre-stimulus baseline as a gross estimate of EMG level

Consequences of Disregarding Effects of EMG



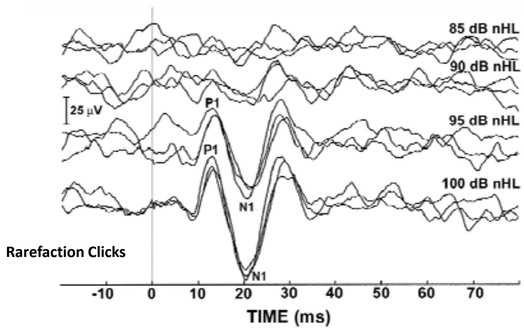
AR for *Uncorrected* EMG Level:

$$\frac{527\mu V - 172\mu V}{527\mu V - 172\mu V} \times 100 = \mathbf{51\%}$$

AR for *Corrected* EMG Level:

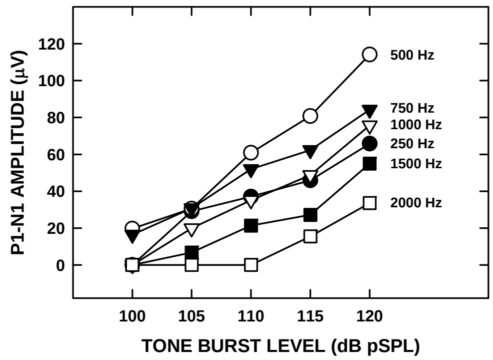
$$\frac{7.5\mu V - 5.7\mu V}{7.5\mu V - 5.7\mu V} \times 100 = \mathbf{14\%}$$

What are the effects of stimulus level?

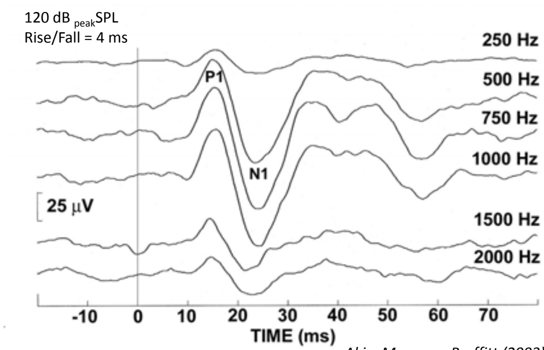


Akin, Murnane, Proffitt (2003)

Akin, Murnane, Proffitt (2003)

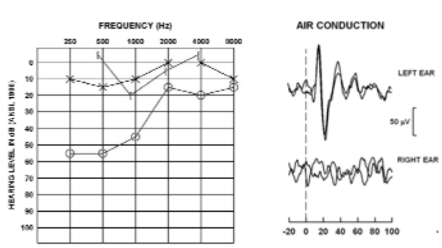


What are the effects of stimulus frequency?



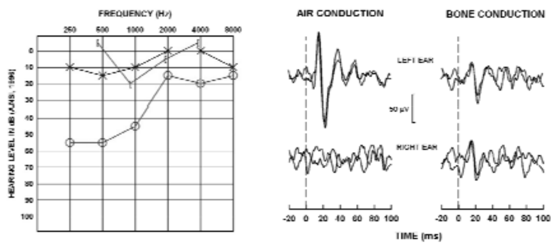
Akin, Murnane, Proffitt (2003)

Effect of Conductive Hearing Loss
on Air Conduction cVEMPs



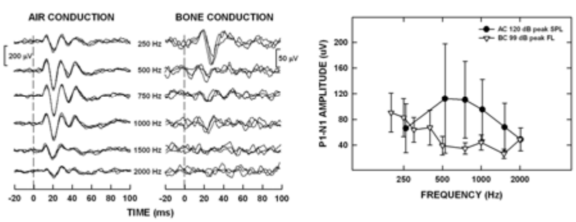
Tampas, Clinard, Murnane, Akin, 2006

Bone Conduction cVEMPs



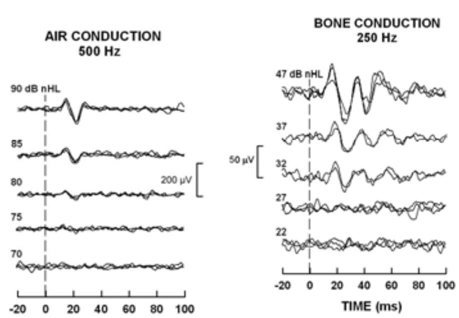
Tampas, Clinard, Murnane, Akin, 2006

Stimulus Frequency Effects on Air vs Bone Conduction cVEMPs



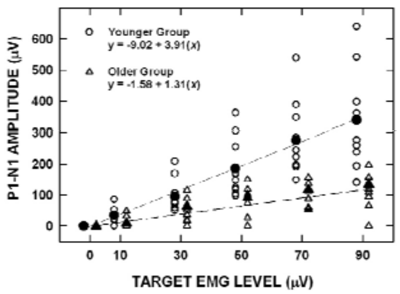
Tampas, Clinard, Murnane, Akin, 2006

Stimulus Level Effects on Air vs Bone Conduction cVEMPs



Tampas, Clinard, Murnane, Akin, 2006

Effect of Aging on cVEMP Amplitude



Tampas et al., 2006

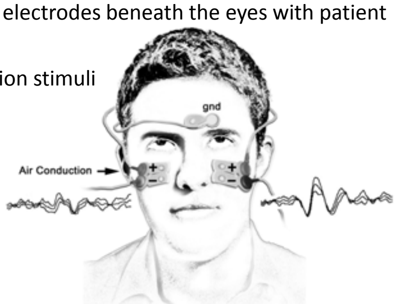
Effects of Audiovestibular Pathologies: Literature Review (1994-2006)

	cVEMP Response	
Pathology	Normal	Abnormal
Superior Canal Dehiscence	0	64*
Tullio Phenomenon	1	12*
Vestibular Neuritis/Labyrinthitis	50	49
Meniere's Disease	162	121
Vestibular Schwannoma	68	238
Sudden SNHL	42	4
Multiple Sclerosis	66	101

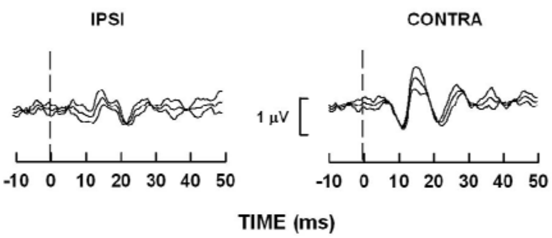
* abnormally low threshold

Ocular VEMP (oVEMP)

- Recorded from electrodes beneath the eyes with patient looking up
- Sound or vibration stimuli



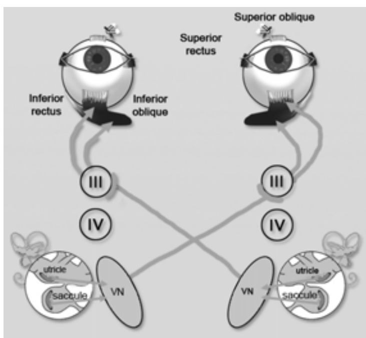
- Predominantly a crossed excitatory response
- Initial negativity (10-12 ms) and a subsequent positivity (15-20 ms)



Presumed oVEMP Pathway

- based on known otolith-ocular projections
- electrical stimulation of the utricular and saccular maculae and utricular nerve
- activate the contralateral IO and IR muscles

Suzuki et al., 1969; Curthoys, 1987



Adapted from Frohman et al., 2008

Vestibular Origin of oVEMPS

- Response is abolished following unilateral vestibular neurectomy
- Response is present in patients with profound sensorineural hearing loss and normal vestibular function

Myogenic Origin of oVEMPs

- oVEMPs absent in patients with exenteration of eyeball including extraocular muscles
- oVEMPs present in patient with exenteration of eyeball and preserved extraocular muscles

Chihara et al., 2009

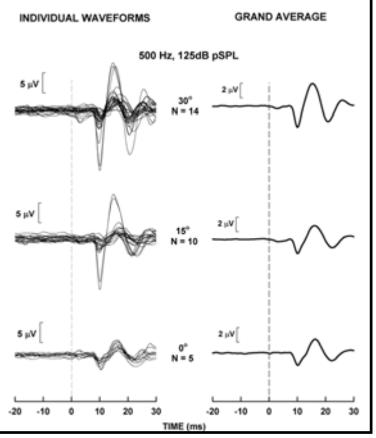
oVEMP Recording Parameters

- No. of channels: 2
- Amplifier gain: 100,000 x
- Response filter: 1 – 1000 Hz
- Sweep time: 50 ms
- No. of sweeps: 250-500 (AC)
  25-100 (BC)
- Artifact rejection: 36 µV
- Vertical gaze angle: ~20-30°

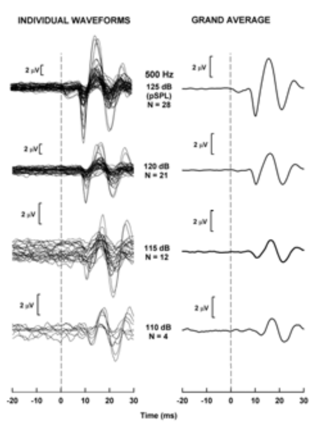
oVEMP Stimulus Parameters

- Type: Tone burst
- Onset Phase: Alternating (AC); positive or negative (BC)
- Rise/Fall: 2-4 ms
- Plateau: 0 ms
- Gating: Blackman
- Level: 105-130 dB pSPL (AC)
- Repetition Rate: 5 Hz

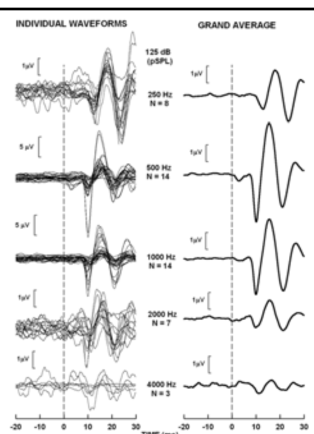
Effect of
Gaze Angle
on AC oVEMP



Effect of
Stimulus Level
on AC oVEMP



Effect of
Stimulus Frequency
on AC oVEMP



AC oVEMP Normative Data
N1-P1 Amplitude (µV)

500-Hz	Mean	SD	**Min**	**Max**
AD	6.4	4.5	**1.2**	**25.7**
AS	5.7	4.4	**0.6**	**19.8**

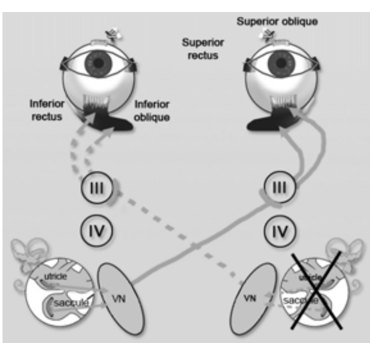
(n = 38, 18-34 yrs)*

AC oVEMP Normative Data
N1 and P1 Latency (ms)

500-Hz (125 dB pSPL) *(n = 38, 18-34 yrs)*

		Mean	SD	**Min**	**Max**
AD	N1	10.6	1.1	**9.2**	**14.6**
	P1	15.8	1.2	**13.3**	**19.4**
AS	N1	10.5	0.9	**9.6**	**13.8**
	P1	15.9	1.0	**14.1**	**18.4**

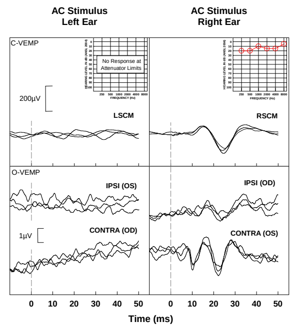
Unilateral Vestibular Loss



Adapted from Frohman et al., 2008

Case Study

- 53 y/o male
- Vestibular schwannoma AS
- Calorics: 100 % UW AS

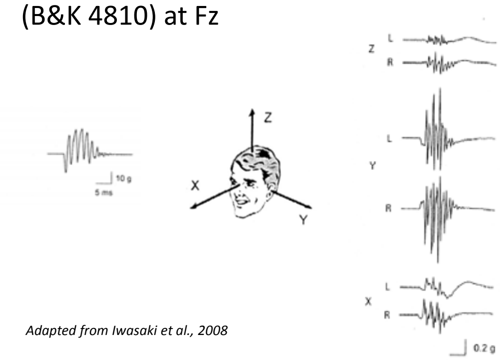


Bruel and Kjaer 4810 Minishaker

- Bone conduction vibration (BCV)
- Placed at Fz
- Produces equal acceleration at both mastoids
- Relatively large response magnitude
- Stimulus calibration

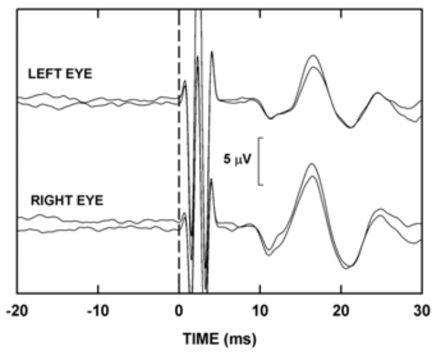
From Rosengren et al., 2009

Accelerometry for BC vibration (B&K 4810) at Fz

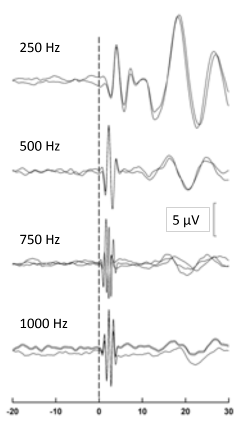


Adapted from Iwasaki et al., 2008

Normal BC oVEMPs



Effect of
Stimulus Frequency
on BC oVEMP



Subjective Visual Vertical (SVV)

- The angle between the gravitational axis (true vertical) and the position of a visual linear marker (light bar) adjusted vertically by an individual.
- Patient is seated upright and stationary in darkened booth with no visual cues.

Static SVV

- Normal subjects in an upright static position:
  - SVV does not deviate more than ±2.5° from true (gravitational) vertical (0˚)

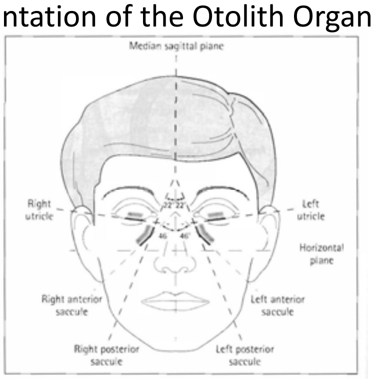
Wetzig, et al., 1990; Bohmer & Rickenmann, 1995

- Pts. with acute unilateral vestibular dysfunction may shift the static SVV up to 21° toward the affected side.

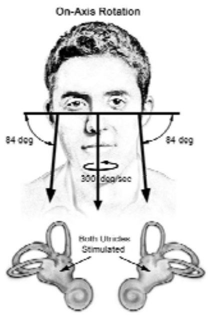
Bohmer & Rickenmann, 1995; Vibert, et al., 1999

- Following vestibular compensation, static SVV returns to normal (±2.5°) *Bohmer & Rickenmann, 1995*
  - Static SVV is not sensitive for chronic vestibular dysfunction

Orientation of the Otolith Organs

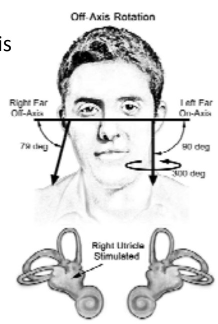


from Cohen and Gizzi, 2003



- VOR diminishes at constant velocity
- Bilateral centrifugation
- Both utricles receive equal and opposite force (= GIF)
  - Cancellation of stimulus
  - No perception of tilt

- Test ear positioned 7-8 cm off-axis
- Non-test ear positioned on-axis
- Unilateral centrifugation (UC)
- Higher GIF for test ear
- Each ear tested separately



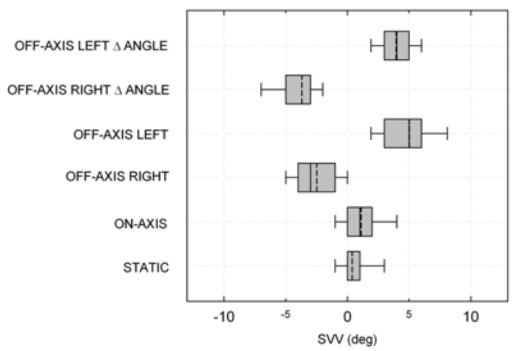
SVV Response to Unilateral Centrifugation

- The SVV tilts symmetrically during unilateral centrifugation in normals
- Offset right causes SVV tilt toward the left; offset left side causes SVV tilt the right

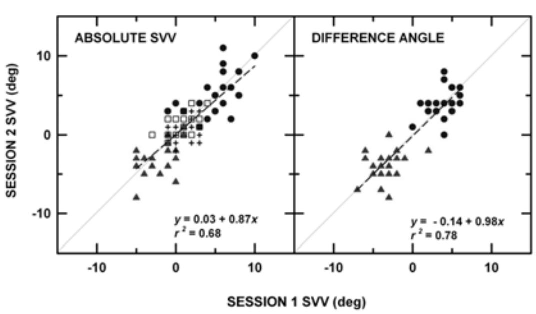
Unilateral Centrifugation Protocol

- The test ear is positioned 7-8 cm off-axis and the non-test ear is positioned on-axis
  - 60 s acceleration (acceleration = 5°/s^2) period in clockwise direction
  - 60 s constant velocity (300°/s) period
  - 3-5 SVV angles obtained during a constant velocity rotation period
  - 60 s deceleration (deceleration = 5°/s^2) period
- The UC repeated for the opposite ear.

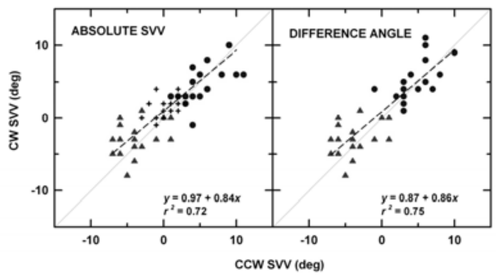
Normative Data (n = 24)



Test-Retest Reliability

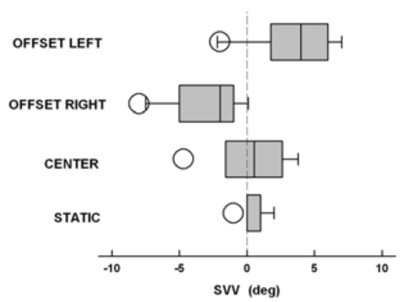


Clockwise (CW) vs. Counterclockwise (CCW) Rotation



Rotational direction (i.e., clockwise vs. counterclockwise) does not change the direction or magnitude of the SVV.

SVV for a patient with left vestibular neuritis



Diagnostic Utility of Otolith Testing

- cVEMP (AC and BCV?)
  - Saccular/inferior vestibular nerve function
- oVEMP (BCV and AC?)
  - Utricular/superior vestibular nerve function
- SVV/unilateral centrifugation
  - Utricular/superior vestibular nerve function
- Static SVV sensitive to acute UVL

Acknowledgements

- This material is based upon work supported in part by the Department of Veterans Affairs, Veterans Health Administration, Office of Research and Development, Rehabilitation Research & Development
- Research Assistants:
  Joanna Tampas, PhD, Kip Kelly, PhD,
  Chris Clinard, PhD, Stephanie Byrd, AuD
  Amber Pearson, AuD

Disclaimer

The views expressed in this article are those of the authors and do not necessarily reflect the position or policy of the Department of Veterans Affairs or the United States government.