Vestibular Evoked Myogenic Potentials (VEMP) and Other Electrophysiologic Techniques in the Evaluation of the Vestibular System
Exposed January 29, 2013

Ken Henry, PhD
The Dizziness and Balance Center
Falls Church, Virginia 22044

Vestibular Evoked Myogenic
Potentials

And Other Electrophysiologic Techniques in the
Evaluation of the Vestibular System

Agenda

- Current Vestibular Assessment
  - Evaluation of the VOR
  - The Vestibulogram
  - Genesis of VEMP
  - Protocol
    - Stimulus and Recording Parameters
    - Recording Technique
  - Diagnostic Utility
    - Dehiscence Syndrome
    - Superior Semicircular Canal Dehiscence
    - Perilymphatic Fistula
    - Spontaneous
    - Traumatic PLF
    - Case Studies
    - Alternative/Augmentative Test Techniques

Current Vestibular Assessment – VNG and Rotational Tests

- VNG and rotation testing assess horizontal semicircular canal function
- Angular acceleration
- Hallpike assessment – posterior semicircular canal
  - In BPV the post canal is typically the “innocent bystander”
- CNS and Brainstem connections
  - Tests of Ocular Control
Current Vestibular Assessment – VNG and Rotational Tests

- The VOR Responds to Natural Head Movements Over a Broad Frequency Range (Frequency Response)
  - Frequency Range of VOR From .05 to 5Hz for Normal Head Movements
  - VOR Can Respond Efficiently Up to Frequencies Approaching 8 Hz (Gresty, Hess & Leech; Sayer et al.)

Vestibulo-Ocular Reflex Function

"Vestibulometry"

- Low Frequency Testing
  - Caloric Testing – Evaluation of the low frequency response of VOR
    - Analogous To A Head Movement Below Range of VOR

- Mid Frequency Testing
  - Rotary Chair Testing Is Used To Evaluate The Horizontal Vestibulo Ocular Reflex Below .64 Hz

- High Frequency Testing
  - Autorotation (VAT or VORTEQ) Testing Is Used To Evaluate Horizontal VOR from 2 to 6 Hz.
Vestibulo-Ocular Reflex Function

- Inferences are made about the integrity of the vestibular labyrinth based on the caloric test (ABBT).
- Analogous to evaluating hearing using only low frequency tones (e.g., 125 Hz) and inferring integrity of the auditory system on the basis of the findings.

Other Techniques to Evaluate the VOR

- Halmaygi
- Head Shake Nystagmus
- VOR Cancellation
- Dynamic Visual Acuity Exam (with Snelling chart)
  - Test for Oscillopsia

Vestibular Evoked Myogenic Potentials (VEMP) and Other Electrophysiologic Techniques in the Evaluation of the Vestibular System
Recorded January 29, 2013
Vestibular Evoked Myogenic Potentials (VEMP) and Other Electrophysiologic Techniques in the Evaluation of the Vestibular System
Recorded January 29, 2013

**VEMP – Why Do We Need It?**
- Normal ENG?
  - Indicates that the horizontal semi-circular canal is functioning normally infer normal function
- Normative Range for RVR
  - < 20% asymmetry
- Bilateral RVR***
  - combined SPEV < 20 deg
- Otolith Assessment Not Possible via ENG or Rotation Testing

So What is the VEMP?
- Short Latency EMG (Electromyographic Response)
- Can Be Evoked by:
  - high level acoustic stimulation
  - Electrical Stimulation
  - Mechanical Simulation (Skull Taps)
- Recorded from surface electrodes over the contracted sternocleidomastoid muscle
- Presumed to originate in the saccule of the vestibular system
Vestibular Evoked Myogenic Potentials (VEMP) and Other Electrophysiologic Techniques in the Evaluation of the Vestibular System
Recorded January 29, 2013

So What is the VEMP?

Intense sound pressure
Saccule stimulation produces
Vestibulo-spinal tract response
Myogenic potential

VEMP – Clinical Indications

- When it’s the only vestibular test you can do
  - Young children
  - Patients with severe to profound HL – ABR/EcoGm
- Especially useful in the presence of otherwise normal findings
- Routine component of the vestibular test battery

Before We Begin…. A Little Anatomy Review

- What Are the Five Sensory Structures of The Peripheral Vestibular System?
  - Three Cristae of the Semicircular Canals
  - Two Maculae of Saccule and Utricle
- Larger Structure in Inner Ear: Cochlea or Vestibule?
  - 2/3 of the “Inner Ear” Is Dedicated to Vestibular Function
- Phylogenetically Older: Cochlea or Vestibule?
Vestibular Evoked Myogenic Potentials (VEMP) and Other Electrophysiologic Techniques in the Evaluation of the Vestibular System
Recorded January 29, 2013

Semicircular Canals
- Sense rotational acceleration in their plane
- Semicircular canals are orthogonal to each other
- Each lateral canal is at 30 degree inclination
- Superior/posterior canals 45 degrees off sagittal plane
  - Superior canal is in the same plane as contralateral posterior canal
- Ampullae contain cupula and neuroepithelium = Cristae ampullaris

Saccular Origin
- Seo & Yoshida (1999)
- Semicircular Canals
  - Sense rotational acceleration in their plane
  - Semicircular canals are orthogonal to each other
  - Each lateral canal is at 30 degree inclination
  - Superior/posterior canals 45 degrees off sagittal plane
    - Superior canal is in the same plane as contralateral posterior canal
  - Ampullae contain cupula and neuroepithelium = Cristae ampullaris
Cristae Ampullaris

- Angular acceleration in one direction results in deflection of cupula in contralateral direction from inertia of endolymph


Utricle and Saccular Maculae

- Maculae: contain neuroepithelium and otolithic membrane
- Utricle: senses linear acceleration in the horizontal plane (MU)
- Saccule: senses linear acceleration in the vertical plane (MS)


Stiola

- Stiola: curved central portion of otolithic membrane
- Anatomical curvature allows for sensation of linear acceleration along multiple trajectories
- Utricle: kinocilia polarized toward striola
- Saccule: kinocilia polarized away from striola

Vestibular Evoked Myogenic Potentials (VEMP) and Other Electrophysiologic Techniques in the Evaluation of the Vestibular System
Recorded January 29, 2013

Maculae
- Hair cells extend to otolithic membranes which contain otocoria (calcium carbonate)
- Specific gravity of otocoria 2.71-2.94
- Linear acceleration displaces otolithic membrane resulting in deflection and depolarization/hyperpolarization of hair cells


Hair Cell Response
- Displacement of sensory hairs relative to kinocilium determines change from resting activity


Vestibular Reflexes
- Reflex Projections from Cristae

Vestibular Evoked Myogenic Potentials (VEMP) and Other Electrophysiologic Techniques in the Evaluation of the Vestibular System
Recorded January 29, 2013

Vestibular Reflexes

- Reflex Projections from Saccule
  - Also referred to as...
    - Vestibulospinal reflex
    - Vestibulocollic reflex

Vestibular Reflexes

- Reflex Projections from Utricle

Vestibular Response to Sound?

“An Evolutionary Perspective”

- Presumed original function of inner ear: monitor rotational and linear movements of head and orientation of head relative to earth (propiroception)
- The sacculus evolved to become the receptor of sound and vibration (exteroception) in some amphibians and fish
- Precursors of the mammalian cochlea have evolved from recesses within the sacculus
  - May still “respond to sound”
  - In Man innervates the antigravity muscles
Vestibular Response to Sound: Historical Framework

- Tullio (1928): fenestration of bony labyrinth of alert animals (pigeons, rabbits, and dogs) produced head movement, eye movement, and postural changes in response to sound
- Sound-evoked vestibular symptoms or signs (Tullio’s phenomenon)
  - Vertigo
  - Nystagmus
  - Oscillopsia
  - Postural imbalance

Vestibular Response to Sound: VEMP Generators

- Bickford, et al (1964) described click evoked potentials of the neck muscles.

VEMP Lateral Vestibulospinal Pathway

- Saccule to the
  - inferior vestibular nerve,
  - lateral vestibular nucleus,
  - medial vestibulospinal tract, and finally to the motoneurons of SCM.
The VEMP Reflex Arc

- The saccule is the organ that modulates the antigravity muscles. This pathway descends from the saccule to the SCM and down to the legs.

Clinical Parameters

- Latency of P1 (P13) and N1 (N23)
- Absolute amplitude of P1-N1
- Amplitude asymmetry of P1-N1 amplitudes
  - Asymmetry Ratio (AR): 
    \[ \frac{(P1 \text{ to } N1 \text{ Amp } L) - (P1 \text{ to } N1 \text{ Amp } R)}{(P1 \text{ to } N1 \text{ Amp } L + P1 \text{ to } N1 \text{ Amp } R)} \]

VEMP

- P1 latency is around 12-15 msec
- N1 latency is around 20-25 msec
Vestibular Evoked Myogenic Potentials (VEMP) and Other Electrophysiologic Techniques in the Evaluation of the Vestibular System
Recorded January 29, 2013

<table>
<thead>
<tr>
<th>Study</th>
<th>Author(s) Year</th>
<th>Amplitude</th>
<th>Latency p13</th>
<th>Latency n23</th>
<th>N</th>
</tr>
</thead>
<tbody>
<tr>
<td>FVDD</td>
<td>Ferber-Viart, Duclaux, et al 1997</td>
<td>2.2</td>
<td>2.8</td>
<td>17.0</td>
<td>21</td>
</tr>
<tr>
<td>FVDD</td>
<td>Ferber-Viart, Duclaux, et al 1997</td>
<td>2.7</td>
<td>2.8</td>
<td>18.5</td>
<td>11</td>
</tr>
<tr>
<td>RI95</td>
<td>Robertson &amp; Ireland 1995</td>
<td>10.2</td>
<td>14.6</td>
<td>21.3</td>
<td>18</td>
</tr>
<tr>
<td>SUHYC</td>
<td>Su, Huang, Young, &amp; Cheng 2004</td>
<td>70.2</td>
<td>11.9</td>
<td>19.3</td>
<td>12</td>
</tr>
<tr>
<td>TSKA</td>
<td>Takeichi, Sakamoto et al 2001</td>
<td>106.8</td>
<td>20.0</td>
<td>21.4</td>
<td>16</td>
</tr>
<tr>
<td>PRV</td>
<td>Patko, Vidal, Vibert et al 2003</td>
<td>107.0</td>
<td>11.7</td>
<td>19.4</td>
<td>10</td>
</tr>
<tr>
<td>SUHYC</td>
<td>Su, Huang, Young, &amp; Cheng 2004</td>
<td>110.6</td>
<td>11.6</td>
<td>19.0</td>
<td>9</td>
</tr>
<tr>
<td>CHY</td>
<td>Cheng, Huang, &amp; Young 2003</td>
<td>119.6</td>
<td>11.5</td>
<td>19.2</td>
<td>72</td>
</tr>
<tr>
<td>SUHYC</td>
<td>Su, Huang, Young, &amp; Cheng 2004</td>
<td>124.6</td>
<td>11.5</td>
<td>19.1</td>
<td>81</td>
</tr>
<tr>
<td>SUHYC</td>
<td>Su, Huang, Young, &amp; Cheng 2004</td>
<td>126.7</td>
<td>11.3</td>
<td>18.2</td>
<td>51</td>
</tr>
<tr>
<td>SLS &amp; L</td>
<td>Sartucci &amp; Logi 2002</td>
<td>141.1</td>
<td>12.3</td>
<td>20.8</td>
<td>14</td>
</tr>
<tr>
<td>LCM</td>
<td>Lim, Clouston, et al 1995</td>
<td>142.0</td>
<td>12.0</td>
<td>20.7</td>
<td>13</td>
</tr>
<tr>
<td>IKM</td>
<td>Itoh, Kim et al 2001</td>
<td>143.1</td>
<td>13.2</td>
<td>21.4</td>
<td>16</td>
</tr>
<tr>
<td>SLS &amp; L</td>
<td>Sartucci &amp; Logi 2002</td>
<td>186.4</td>
<td>12.5</td>
<td>21.3</td>
<td>15</td>
</tr>
<tr>
<td>OHHN</td>
<td>Ochi, Ohashi, &amp; Nishino 2001</td>
<td>293.4</td>
<td>11.3</td>
<td>20.5</td>
<td>3</td>
</tr>
<tr>
<td>TM</td>
<td>Takegoshi &amp; Murofushi 2000</td>
<td>11.4</td>
<td>20.8</td>
<td>6</td>
<td></td>
</tr>
<tr>
<td>MSWM</td>
<td>Murofushi, Shimizu, et al 2001</td>
<td>11.8</td>
<td>20.8</td>
<td>11</td>
<td></td>
</tr>
<tr>
<td>CHY</td>
<td>Colebatch, Halmagyi, &amp; Skuse 1994</td>
<td>13.3</td>
<td>22.6</td>
<td>17</td>
<td></td>
</tr>
</tbody>
</table>

Clinical Application:
Halmagyi, et al., 2002
- 2 patients with "vestibular neuritis"
  - Diagnosis: inferior vestibular neuritis (of posterior canal origin)
  - ENG - Normal
  - VEMP – Abnormal
  - ABR results not reported

Clinical Application:
Murofushi, et al. (2001)
- Abnormal VEMP found in
  - 77% of acoustic neuroma
    (n=48)
  - 51% of patient w/ Meniere’s Disease
    (n=22)
  - 25% of pts w/ MS
    (n=6)
Vestibular Evoked Myogenic Potentials (VEMP) and Other Electrophysiologic Techniques in the Evaluation of the Vestibular System
Recorded January 29, 2013


<table>
<thead>
<tr>
<th>Pathology</th>
<th>VEMP Response</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Normal</td>
</tr>
<tr>
<td>Meniere's Disease</td>
<td>57</td>
</tr>
<tr>
<td>Vestibular Schwannoma</td>
<td>65</td>
</tr>
<tr>
<td>Superior Canal Dehiscence</td>
<td>0</td>
</tr>
<tr>
<td>Tullio Phenomenon</td>
<td>1</td>
</tr>
<tr>
<td>Vestibular Neuritis/Labyrinthitis</td>
<td>39</td>
</tr>
<tr>
<td>Sudden SNHL</td>
<td>20</td>
</tr>
<tr>
<td>Multiple Sclerosis</td>
<td>0</td>
</tr>
</tbody>
</table>

* abnormally low threshold

Diagnostic Utility of The VEMP

- Peripheral Vestibular Disease
  - Saccular (Otolith) Involvement
  - Inferior Vestibular Nerve
    - e.g. Vestibular Neuritis
    - Vestibular Schwannoma/AN
    - Determination of Total Vestibular Loss
  - Menieres Disease

- Dehiscence Syndrome
  - Perilymphatic Fistula
  - Spontaneous PLF
  - Traumatic PLF

- Vestibular assessment of patients with low vision or congenital nystagmus
Recording the VEMP

Stimulus Parameters

Recording Parameters

Stimulus Parameters

Click
- Polarity: Rarefaction
- Duration: 100 usec
- Intensity: 100 dB nHL (134 dBpSPL)
- Stim Rate: 5.1/sec

Tone Burst
- Polarity: Rarefaction
- Rise/Fall: 2 cycles
- Plateau: 0 cycles
- Ramp: Blackman
- Intensity: 95 & 75 dB nHL (120 dBpSPL)
- Stim Rate: 5.1/sec
- Tone Burst Frequency:

Stimulation Parameters

<table>
<thead>
<tr>
<th>Presentation Level</th>
<th>RIGHT Response</th>
<th>LEFT Response</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>250-Hz</td>
<td>500-Hz</td>
</tr>
<tr>
<td>120 dBpSPL</td>
<td></td>
<td></td>
</tr>
<tr>
<td>125 dBpSPL</td>
<td></td>
<td></td>
</tr>
<tr>
<td>130 dBpSPL</td>
<td></td>
<td></td>
</tr>
<tr>
<td>100 dBpSPL</td>
<td></td>
<td></td>
</tr>
<tr>
<td>90 dBpSPL</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Testing should be completed @ Minimum 2 frequencies and At recommended intensity levels per frequency...

** Grey = Recommended / White = Optional / Black = DNT
Vestibular Evoked Myogenic Potentials (VEMP) and Other Electrophysiologic Techniques in the Evaluation of the Vestibular System
Recorded January 29, 2013

250 and 500 Hz VEMP

[Graphs and images]

[Graphs and images]
Vestibular Evoked Myogenic Potentials (VEMP) and Other Electrophysiologic Techniques in the Evaluation of the Vestibular System
Recorded January 29, 2013

Parameters of VEMP

I. Rate: 5.1 – 13.1
II. Scale: 10-50 uV
III. Gain: 2k
IV. Sweeps: 50-150
V. High pass filter: 10 Hz
VI. Low pass filter: 1k Hz.
VII. Artifact: OFF
Time base: 50 msec
Vestibular Evoked Myogenic Potentials (VEMP) and Other Electrophysiologic Techniques in the Evaluation of the Vestibular System
Recorded January 29, 2013

Recording Technique: Electrode Montage

One Channel Recording
Channel 1
- Input 1 (non-inverting aka "positive" or "active")
  - Upper 1/3 of the SCM of stimulus ear
- Input 2 (inverting aka "negative" or "reference")
  - Sternum – Below Clavicular notch
- Ground
- Forehead (Fpz)

Two Channel Recording
Channel 1
- Input 1 (non-inverting)
  - Upper 1/3 of the SCM of stimulus ear
- Input 2 (inverting)
  - Sternum

Channel 2
- Input 1 (non-inverting)
  - Upper 1/3 of the SCM of contralateral side
- Input 2 (inverting)
  - Sternum (jumper or electronically synched)

Recording Technique
- Patient turns head 90 degrees away from the stimulated side.
- Head should be elevated to produce maximum contraction of the SCM muscle.
- Recording cycle duration: typically 30 seconds (128 repetitions)
**Recording Technique**

- Two repeatable recordings obtained for each stimulus condition
- Patients given 30 to 60 seconds to relax between each recording
  - Issue of response fatigue

**Standard Intensity Levels**

- 95 dB nHL
- 75 dB nHL

**Normal VEMP Response**

- 500 Hz Tone Burst
- 120/100 dB SPL
Vestibular Evoked Myogenic Potentials (VEMP) and Other Electrophysiologic Techniques in the Evaluation of the Vestibular System
Recorded January 29, 2013

VEMP Response

- The VEMP response is an amplitude measure, and therefore, the influence of the tonic level of the EMG must be taken into account

- If no correction is made to account for R/L differences in tonic level of EMG, VEMP amplitude data will not be accurate for comparing symmetry

VEMP Response Amplitude

- Ongoing EMG of SCM
  - Tonic Contraction
- Stimulus Level
  - Click intensity should be about 134 dB pSPL for VEMP optimal amplitude measurements,
  - Toneburst stimulus only requires 120 dBpSPL and therefore, is a better default stimulus
- Stimulus Frequency
  - Highest amplitude for 500 Hz Toneburst

VEMP Response Amplitude

- SCM Activation
  - Head Turn – Unilateral
  - Head Raised – Bilateral
  - Head Bar (Hand) – Bilateral
  - BP Cuff – Bilateral
  - EMG Monitor – Unilateral or Bilateral
Vestibular Evoked Myogenic Potentials (VEMP) and Other Electrophysiologic Techniques in the Evaluation of the Vestibular System
Recorded January 29, 2013

VEMP – Technical Issues
EMG Rectification

- EMG Rectification available with some AEP Systems
- For the EMG rectification, there is a 20 ms prestimulus baseline - the amplitude for each point is averaged together - that value is divided into each of the 256 points on the VEMP recording

VEMP – Technical Issues
EMG Rectification

- Highlight the collected wave to be corrected and click on “Pre-stim Rectify” icon
- Pre-stim Rectify appears as last icon on “Calculations” toolbar

Technical Issues Summary
If The VEMP Is Absent

- Monitor for EMG
  - Is absent response secondary to inadequate activation?
  - Conductive Hearing Loss
- Increase EMG level
  - can tilt chin downward
  - use of hand on cheek to provide isometric resistance if response is low amplitude/absent
Vestibular Evoked Myogenic Potentials (VEMP) and Other Electrophysiologic Techniques in the Evaluation of the Vestibular System
Recorded January 29, 2013

**Summary**

**Stimulus And Recording Parameters**

- **Stimulus Level** – Amplitude increases with stimulus level
- **EMG Level** – Amplitude increases with EMG rms amplitude
- **Stimulus Frequency** – Largest amplitudes obtained at 500 and 750 Hz
- **Latency** of VEMP is not affected by changes in stimulus level, EMG rms amplitude

**Normative Findings**

**Laboratory Norms**

- **Latency**
  - P I (P 13)
    - < 12.5 ms or >19.5 ms = abnormal
  - N I (N 23)
    - < 19.7 ms or >27.7 ms = abnormal
- **Amplitude**
  - <25 uV or >185 μV
Vestibular Evoked Myogenic Potentials (VEMP) and Other Electrophysiologic Techniques in the Evaluation of the Vestibular System
Recorded January 29, 2013

### Descriptive Statistics

<table>
<thead>
<tr>
<th>Wave</th>
<th>Mean</th>
<th>SD</th>
<th>Min</th>
<th>Max</th>
</tr>
</thead>
<tbody>
<tr>
<td>Wave I</td>
<td>RE</td>
<td>15.97</td>
<td>2.97</td>
<td>12.00</td>
</tr>
<tr>
<td></td>
<td>LE</td>
<td>16.31</td>
<td>1.64</td>
<td>14.75</td>
</tr>
<tr>
<td>Wave II</td>
<td>RE</td>
<td>23.79</td>
<td>1.94</td>
<td>20.750</td>
</tr>
<tr>
<td></td>
<td>LE</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

P1 (Wave I) and N2 (Wave II)

Latency RE vs. LE Latency

![Graph showing VEMP Wave I and II Latencies](image)

Statistics

- P1 (Wave I) Latencies in comparison with "normal" data
  - N/S
- N1 (Wave II) Latencies in comparison with "normal" data
  - N/S p = 0.91
Descriptive Statistics

- Amplitude (μV) in comparison with "normal" data

<table>
<thead>
<tr>
<th>Variable</th>
<th>Mean</th>
<th>SD</th>
<th>Min</th>
<th>Max</th>
</tr>
</thead>
<tbody>
<tr>
<td>Experimental subjects</td>
<td>115.80</td>
<td>81.69</td>
<td>22.70</td>
<td>354.00</td>
</tr>
<tr>
<td>Normal controls</td>
<td>104.63</td>
<td>40.724</td>
<td>55.00</td>
<td>190.00</td>
</tr>
</tbody>
</table>

Peripheral Vestibular Disease

- Otolith Involvement
  - Absent
  - Low Amplitude VEMP
  - Elevated Threshold
  - Asymmetric VEMP Responses (Amplitude)

- Horizontal SCC Involvement
  - RVR With or Without VEMP Abnormalities
Increased VEMP thresholds - low amplitude or absent responses – may suggest a sacculus disorder such as Meniere’s syndrome
Must Rule Out Middle ear pathology or ossicular chain abnormality

Asymmetry Ratio (AR):
(P1 to N1 Amp L) – (P1 to N1 Amp R) / (P1 – N1 Amp L + P1 to N1 Amp R)
Recommendation is to collect own normative data
Significant difference = 2.5 S.D. from the mean
Most often proposed are about 30-40% difference between R & L VEMP response amplitude

Asymmetry Ratio or IAD
> .36 is abnormal
Augmented VEMP
Young, Wu & Wu, ’02
High amplitude ratio suggests sacculus hydrops (sacculus distention against the stapes footplate)
**Peripheral Vestibular Disease**

10 Meniere’s vs. 10 sudden SNHL pts.

\[
\text{interaural amplitude diff} = \frac{\text{right SCM amplitude}}{\text{left SCM amplitude}} > .36 = \text{Abnormal}
\]

Indicates saccular hydrops with saccule distention against the stapes footplate

Augmented VEMP
Young, Wu & Wu, ’02

---

**Menieres’ Syndrome Protocol**

- **Audiometry**
  - Pure Tone Audiometry
    - Assess Hearing At 125 Hz
    - Mid Octaves Above 1000 Hz
  - Speech Audiometry
    - Speech UCL and LDL
  - Recommend Serial Studies

- **ECOGm**
  - Elevated SP/AP ratio

- **VEMP**
  - Amplitude Asymmetry
  - Elevated Thresholds

- **ENG**
  - Hallpike (positive BPV)
  - Caloric Studies

---

**Superior Canal Dehisence (SCD)**

- Dizziness or unsteadiness
  - Increases with exertion or activity (relieved with rest)
  - Valsalva induced dizziness
    - Coughing, sneezing, blowing nose

- Pressure sensitivity
  - Change in air pressure in middle ear
  - Hennebret's sign

- Sound sensitivity
  - Own voice or external sound aka “Tullios phenomenon”
  - Conductive Hyperacusis

- Hearing loss
  - Low frequency hearing loss with Air-Bone gap
Peripheral Vestibular Disease
Frequency Specific VEMP (250 Hz nHL)

Augmented VEMP = 0.52

Superior Canal Dehisence (SCD)
- Bony covering over inner ear (membranous labyrinth) is missing or removed or worn away
- SCD – roof of the SSC is missing or marginal (e.g. bone defect)
- Fluid is not in direct communication with air filled cavity such as middle ear (PLF) but vulnerable to sound or pressure changes
Superior Canal Dehisence (SCD)

- Normally two points of increased compliance in the inner ear:
  - Oval window through which sound energy is *transmitted* into the inner ear via stapes
  - Round window through which sound energy is Bony *dissipated* from the inner ear after traveling around the cochlea
- A so-called third window into the inner ear (yielding to pressure or sound) results in a minute hydraulic phenomenon within the inner ear

"Hydraulic" System of Cochlea and Vestibule

- Stapes acts as a piston pushing into the perilymph of the inner ear

"Hydraulic" System of Cochlea and Vestibule

- Perilymph is not "compressible" and there must be a compensatory displacement somewhere in the system that coincides with the input to the stapes
Vestibular Evoked Myogenic Potentials (VEMP) and Other Electrophysiologic Techniques in the Evaluation of the Vestibular System
Recorded January 29, 2013

Dehiscence Syndromes
- Superior canal dehiscence
- Lateral canal dehiscence (mastoid dehiscence)
- Posterior canal dehiscence

How Is Diagnosis Made?
- High Resolution CT of the temporal bone
  - Three Consecutive Cuts on the CT Scan
  - History

Dehiscence Abnormalities
- Developmental abnormality
  - Hereditary
- Post surgical complication (aka fenestration)
- Trauma
- PLF
Vestibular Evoked Myogenic Potentials (VEMP) and Other Electrophysiologic Techniques in the Evaluation of the Vestibular System
Recorded January 29, 2013

Bilateral SCD

Figure 4, CT images of the right and left temporal bones show dehiscence of bone overlying the superior semicircular canal. The arrows show areas where bone has been removed to expose the canal. The calvarial structure of each superior canal is shown. In the normal condition, bone covers the entire surface of the canal. The arrow points to the area of dehiscence on each side. The calibration line represents 1 cm.

VEMP and SCD

Brandtberg et al, 1999

- Low intensity VEMPs are obtained (Reduced thresholds)
- A repeatable VEMP response at low levels (75-80 dB nHL) is believed to be indicative of SCD
- The presence of VEMP's in a person with a conductive hearing loss is also suggestive of SCD.
Vestibular Evoked Myogenic Potentials (VEMP) and Other Electrophysiologic Techniques in the Evaluation of the Vestibular System
Recorded January 29, 2013

VEMP Results in SCD
- Abnormally low threshold in involved ear (< 80 dB)
- Typical threshold for normal ears 85-95 nHL
- Decreased threshold is due to increased inner ear immittance (conductance)

Recording Technique
VEMP (Screening for SCD)

VEMP Result in SCD
Left
Vestibular Evoked Myogenic Potentials (VEMP) and Other Electrophysiologic Techniques in the Evaluation of the Vestibular System
Recorded January 29, 2013
Vestibular Evoked Myogenic Potentials (VEMP) and Other Electrophysiologic Techniques in the Evaluation of the Vestibular System
Recorded January 29, 2013

Other “Dehiscent-Like Syndromes”
- Perilymph Fistula
  - Round window
  - Oval window
  - Middle ear mastoid sinus into intracranial cavity of temporal bone or otic capsule

VEMP Findings – Bilateral PLF

Perilymph Fistula (PLF)
- Audiograms – Attempts at finding specific pattern have failed.
- PTA & Word Recognition - Fluctuating PTA and/or WRS has been reported, but not consistent
- ECochG – Can not distinguish PLF from Menière’s
- Tullio – Not always positive
Vestibular Evoked Myogenic Potentials (VEMP) and Other Electrophysiologic Techniques in the Evaluation of the Vestibular System
Recorded January 29, 2013

Fistula Test Battery
- Pure tones of 500, 1000, and 2000 Hz. with intensities between 100-110 dB (use the impedance bridge and present at intensity limits at each frequency).
- Tympanometry – Wide Range
- VNG Pressure Test (or pressure on the tragus and ear canal)
- Platform Pressure Test
- Vibration Test

VNG Pressure Test (Positive)

VNG Pressure Test
Vestibular Evoked Myogenic Potentials (VEMP) and Other Electrophysiologic Techniques in the Evaluation of the Vestibular System
Recorded January 29, 2013

Platform Pressure Test

<table>
<thead>
<tr>
<th></th>
<th>Left ear</th>
<th>Right ear</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>No Pressure</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Positive</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Negative</strong></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Vibration Test

Position - Both Eyes

Supine 08/11

Perilymphatic Fistula

- Can they occur Spontaneously?
- What symptoms are specifically associated?
- What tests diagnose a fistula?
- What is the “Gold Standard” for confirming the presence of a fistula?
- How should a fistula be treated?
Vestibular Evoked Myogenic Potentials (VEMP) and Other Electrophysiologic Techniques in the Evaluation of the Vestibular System
Recorded January 29, 2013

Other Findings With PLF
- Henneberts Sign
  - Observed for nystagmus (visual or measured)
  - Questioned for dysequilibrium (subjective)
  - Tested with patient seated, standing, on a moving platform.
    - One study showed 97% sensitivity (Black et al.)
    - Another study showed 33% (Meyerhoff)
- Vestibular Test Battery
  - Hypoactive response or UW (sometimes)
  - Spontaneous/positional nystagmus (sometimes)

VEMP Abnormalities - Summary
- Decreased VEMP thresholds (below 80 dB nHL) – may indicate SCD or PLF
- Increased VEMP thresholds - low amplitude or absent responses – may suggest a saccule disorder such as Menieres’ syndrome
  - Middle ear pathology or ossicular chain abnormality
- Prolonged latencies – may suggest a vestibular n. /caudal brainstem disorder or VS disorder
- Must consider the integrity of the spinal and neck muscles – rule out neuropathy/myopathy

A Few Case Presentations
CC: 64 Year Old Male

- Severe Vertigo 5-9-2008 while exercising in gym – ambulance dispatched. Had three brief episodes prior to 5-2008
- MRI, CT negative. Diagnosis by exclusion of neuronitis or labyrinthitis
- Dizziness, lack of balance and fear of falling from 5-6 to 6-24-2008. Dizziness exacerbated by movement
- No vertigo as of July 9, 2008

CC: Audiogram (6-21-2011)

CC: Audiogram (6-25-2011)
Vestibular Evoked Myogenic Potentials (VEMP) and Other Electrophysiologic Techniques in the Evaluation of the Vestibular System
Recorded January 29, 2013


CC: Gaze Testing (2008)

CC: Caloric Findings (2008)
Vestibular Evoked Myogenic Potentials (VEMP) and Other Electrophysiologic Techniques in the Evaluation of the Vestibular System
Recorded January 29, 2013

**CC Tone Burst VEMP (500 Hz)**

![Graph showing CC Tone Burst VEMP (500 Hz)]

**CC Tone Burst VEMP (250 Hz)**

![Graph showing CC Tone Burst VEMP (250 Hz)]


> C. C. was seen in the Audiology Hearing Center on July 1, 2008 for VEMP testing and report presentation testing. Copies of results are attached for your review.

**Results:**

- VEMP testing was normal for both ears. There was no response at the upper limits of the measurement of 9000 Hz on the right side.
- The results indicate a normal function on both ears.
- A significant change in the right ear was noted on June 29, 2008, during DPOAE testing.

**Vestibular Testing:**

- A pure sound stimulus is utilized, with normal results in all positions: up, down, head right, and head left.
- Positional nystagmus was noted in the up, down, head right, and head left positions. There was a significant change in the right ear detected on June 29, 2008, during DPOAE testing.
Vestibular Evoked Myogenic Potentials (VEMP) and Other Electrophysiologic Techniques in the Evaluation of the Vestibular System
Recorded January 29, 2013

CC: Audiogram (9-2011)

“Leo” Clinical History

39 year old male
- Sx: brief positional vertigo (looking down) w/ nausea; symptoms were very brief 1 to 2 seconds
- Unilateral tinnitus left ear
- Hx of chronic headaches usually following the positional vertigo;
- Hx of dizziness when “chewing” described as “eyes move while chewing”

Differential Diagnosis
- BPPV?
- Migraine Associated Vertigo?
- Oscillopsia? (Bilateral reduced vestibular response)
- Tullio’s Phonemenon? (Superior Canal Dehiscence)
Vestibular Evoked Myogenic Potentials (VEMP) and Other Electrophysiologic Techniques in the Evaluation of the Vestibular System
Recorded January 29, 2013

“Leo” Clinical Exam
- Dynamic Visual Acuity Screening (Snellen) - Normal
- VNG – Normal
- Normal horizontal canal VOR response
- Vestibular ENG while chewing
- Fistula test was normal
- Tullio screen normal
- Audiogram – Normal (tinnitus);
  - normal tympanograms
  - elevated MEMRs
- ABR – Normal
- VEMP – significant amplitude asymmetry

“Leo” Clinical Exam

VEMP Amplitude (at 95 dB nHL)
- RE Amp = 105.96 μV
- LE Amp = 354.00 μV

95 dB
75 dB
500 Hz TB

History: KS
- 57 y/o female with dizziness that comes in spells intermittently since 2004
- Sensation of dizziness with sudden movement of Visual Surround
- Aural Pressure, fullness and tinnitus right ear.
- In 2005 had normal Audiogram, MEMR, OAEs, ABR and ECogm
Vestibular Evoked Myogenic Potentials (VEMP) and Other Electrophysiologic Techniques in the Evaluation of the Vestibular System
Recorded January 29, 2013

KS - 250 Hz Tone Burst

KS 250 and 500 Tone Burst

KS – Cochlear Hydrops Masking Technique
Vestibular Evoked Myogenic Potentials (VEMP) and Other Electrophysiologic Techniques in the Evaluation of the Vestibular System

Recorded January 29, 2013

**History: C.O.**
- 57 y/o male with history of TBI 2004 – Fell Down A Flight of Stairs
- Baltimore Shock Trauma Unit 3.5 weeks (comatose)
- Right Craniotomy for Subdural Hematoma
- Transferred to Rehab Facility

**CO Exam July 2007**
“DP” - History

- Dizziness and loss of balance since 2001
- Father was diagnosed with unilateral Meniere's disease
- Recent symptoms
  - Dizziness
  - Oscillopsia
  - Patient reports her symptoms are from right ear
  - Pressure sensitivity

“DP”- History

Initial Audiogram 12-14-2005
Vestibular Evoked Myogenic Potentials (VEMP) and Other Electrophysiologic Techniques in the Evaluation of the Vestibular System
Recorded January 29, 2013

“DP”
Initial Audiogram 12-14-2005

“DP”
Audiometric Studies 2-09

“DP” – Tympanometry and Acoustic Reflex
Vestibular Evoked Myogenic Potentials (VEMP) and Other Electrophysiologic Techniques in the Evaluation of the Vestibular System
Recorded January 29, 2013

"DP" Platform Posturography

"DP" – Platform Pressure Test

DP – Platform Posturography

**HISTORY:** Mr. P. presents with a three-year history of dizziness. She presented with a mild, low-frequency (25-50 Hz) hearing loss in the right ear, and normal hearing in the left ear. Her hearing loss is reportedly fluctuating. Mr. P. reports occasional ear pain and pressure that he connects to his dizzy spells. Results from the hearing test, DP, VEMP, ABR, ENG, and infrared fluid test are not available.

**SUMMARY TEST:** Normal results obtained on Sensory Conditions 14. A Composite score of 87% was obtained and is within the normal limits.

**MOVEMENT COORDINATION TEST:** Normal results were obtained for medium and large forward and backward translations on each side. Normal results were obtained for smooth scaling and adaptation with both ears. Normal results were obtained in 4 out of 3 conditions for adaptation with two ears.

**PRESSURE TEST:** Pressure test results were just outside the normal limits for anterior-posterior sway on the left side. Pressure test results were positive for the two standard deviations for normal sway on the right side. Pressure test results were normal for anterior-posterior sway on the right side and lateral sway on the left side.
Vestibular Evoked Myogenic Potentials (VEMP) and Other Electrophysiologic Techniques in the Evaluation of the Vestibular System
Recorded January 29, 2013

DP – Infra Red Pressure Test
2004

"DP"
Infra Red Fistula 2005

Positive and negative Pressure

"DP"
Infra Red Fistula

Interpretation:
Normal Infra Red Fistula testing. Due to the deceiving symptoms in the baseline head hanging and supine positions, this patient should be referred for a full ENG examination.
Vestibular Evoked Myogenic Potentials (VEMP) and Other Electrophysiologic Techniques in the Evaluation of the Vestibular System
Recorded January 29, 2013

“DP” 2004
Two Channel VEMP

Left ear
95 dB nHL 500 Hz

Right ear
95 dB nHL 500 Hz

“DP” 2004
VEMP – Threshold Screen

RIGHT: 70 dB

DP Fistula Test

Head Below Horizontal

Negative Pressure

Positive Pressure
Vestibular Evoked Myogenic Potentials (VEMP) and Other Electrophysiologic Techniques in the Evaluation of the Vestibular System
Recorded January 29, 2013

DP 2-09 Tullio Test (Baseline)

Findings Suggested a Right PLF Based On:
- Audiometry (ABR With Intact MEMRs)
- Platform Pressure Test
- Tullio Test.

Recommended VNG Examination
In View of Normal VEMP Clinical Suspicion Was High Enough to Warrant Exploration

"DP" Findings

- Findings Suggested a Right PLF Based On:
  - Audiometry (ABR With Intact MEMRs)
  - Platform Pressure Test
  - Tullio Test.
- Recommended VNG Examination
- In View of Normal VEMP Clinical Suspicion Was High Enough to Warrant Exploration
Paul C.

- 33 year old male
- Longstanding unilateral hearing loss in the right ear.
- Recent reports of off balance and transient dizziness not characterized as vertigo

Paul C. - Audiogram

Paul C. - VNG
Vestibular Evoked Myogenic Potentials (VEMP) and Other Electrophysiologic Techniques in the Evaluation of the Vestibular System
Recorded January 29, 2013

Paul C. – VNG
Static Positional Testing

<table>
<thead>
<tr>
<th>Position</th>
<th>POSITIONAL TESTS (CPT 9044G, 9044N)</th>
<th>Nystagmus Direction</th>
<th>Vocal Fixation</th>
<th>Intermittent</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sitting (Spontaneous)</td>
<td></td>
<td>Yes</td>
<td>Right</td>
<td>Yes</td>
</tr>
<tr>
<td>Supine</td>
<td></td>
<td>Yes</td>
<td>Right</td>
<td>Yes</td>
</tr>
<tr>
<td>Head Right</td>
<td></td>
<td>Yes</td>
<td>Right</td>
<td>Yes</td>
</tr>
<tr>
<td>Head Left</td>
<td></td>
<td>Yes</td>
<td>Right</td>
<td>Yes</td>
</tr>
<tr>
<td>Right Lateral</td>
<td></td>
<td>Yes</td>
<td>Right</td>
<td>Yes</td>
</tr>
<tr>
<td>Left Lateral</td>
<td></td>
<td>Yes</td>
<td>Right</td>
<td>Yes</td>
</tr>
<tr>
<td>Head Hanging Right (Monocular)</td>
<td></td>
<td>Yes</td>
<td>Right</td>
<td>Yes</td>
</tr>
<tr>
<td>Head Hanging Left (Monocular)</td>
<td></td>
<td>Yes</td>
<td>Right</td>
<td>Yes</td>
</tr>
</tbody>
</table>

Paul C. – VNG
Bithermal Caloric Testing

<table>
<thead>
<tr>
<th>ALTERNATE Bithermal Caloric Testing (CPT 9354G &amp; 9354H)</th>
<th>Average Slow Phase Eye Velocity (SPV)</th>
<th>Percent Normal</th>
</tr>
</thead>
<tbody>
<tr>
<td>Left 90° 30° 60°</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Right 90° 30° 60°</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Caloric Calculations (Stauffer Formula)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Directional Preponderance (DPR)</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Patient's symptoms were elicited during testing procedures: Yes, No.
Vestibular Evoked Myogenic Potentials (VEMP) and Other Electrophysiologic Techniques in the Evaluation of the Vestibular System
Recorded January 29, 2013
Vestibular Evoked Myogenic Potentials (VEMP) and Other Electrophysiologic Techniques in the Evaluation of the Vestibular System
Recorded January 29, 2013
Vestibular Evoked Myogenic Potentials (VEMP) and Other Electrophysiologic Techniques in the Evaluation of the Vestibular System
Recorded January 29, 2013
Vestibular Evoked Myogenic Potentials (VEMP) and Other Electrophysiologic Techniques in the Evaluation of the Vestibular System
Recorded January 29, 2013

VEMP Abnormalities

- Absent
  - No Response at UL
  - No Response at limits of equipment
- Elevated Thresholds
  - No Response at UL
  - Response at upper limits of equipment
- Reduced Thresholds
  - Response at LL
  - Below 80 dB nHL
- Delayed Responses
  - Retro-labyrinthine disease
  - MS
  - Vestibular Neuritis
- Asymmetry
  - Amplitude
  - Thresholds – 10 – 15 dB
  - Latency – 4 msec.

VEMP Abnormalities - Summary

- Decreased VEMP thresholds (below 80 dB nHL) – may indicate SCD or PLF
- Increased VEMP thresholds - low amplitude or absent responses – may suggest a saccule disorder such as Menieres’ syndrome
- Prolonged latencies – may suggest a vestibular n. /caudal brainstem disorder or VS disorder
- Must consider the integrity of the spinal and neck muscles – rule out neuropathy/myopathy

VEMP Summary – Future Utilization

- Diagnostic Utility
  - Improve Sensitivity and Specificity of Vestibular Diagnostics
- Simultaneous Recording of BAEP and VEMP
- Monitoring Conditions such as Meniere's Syndrome; BPPV
- Cochlear Implant – Pre/Post OP
  - Saccule can be easily damaged
- Multiple Sclerosis Protocol
Vestibular Evoked Myogenic Potentials (VEMP) and Other Electrophysiologic Techniques in the Evaluation of the Vestibular System
Recorded January 29, 2013

So Much For Sound Pressure.....Thank You

Ken Henry, PhD
Professional Hearing Services
6231 Leesburg Pike, Suite 512
Falls Church, VA 22044
khenry@entnv.com