Relative diagnostic value of ocular vestibular evoked potentials and the subjective visual vertical during tilt and eccentric rotation


Postprint available at: http://www.zora.uzh.ch

Posted at the Zurich Open Repository and Archive, University of Zurich. http://www.zora.uzh.ch

Relative diagnostic value of ocular vestibular evoked potentials and the subjective visual vertical during tilt and eccentric rotation

Yulia Valko¹, Stefan CA Hegemann³, Konrad P Weber¹, Dominik Straumann¹,
Christopher J. Bockisch¹,²,³

Departments of Neurology¹, Ophthalmology², and Otorhinolaryngology, Head & Neck Surgery³,
University Hospital Zürich

Corresponding author:

Christopher J Bockisch, Ph.D.
Neurologische Klinik
UniversitätsSpital Zürich
Frauenklinikstrasse 26
CH-8091 Zürich
Tel ++41-44-255-3996
Fax ++41-44-255-4533
chris.bockisch@usz.ch

Running title: Relative diagnostic value of OVEMPs and the SVV

ACKNOWLEDGEMENTS

We would like to thank Albert Züger and Marco Penner for providing technical support, Ian Curthoys for his support with the implementation of the OVEMP measurements, and Martina Heidemann and Corinne Britschgi for assistance in data collection. This study was financially supported by the Federal Commission for Scholarships for Foreign Students, Switzerland; the Swiss National Science Foundation; the Betty and David Koetser Foundation for Brain Research, Zurich, Switzerland; and the Center of Integrative Human Physiology, University of Zurich, Switzerland.
Abstract

Objective: We compared vibration-induced ocular vestibular evoked myogenic potentials (OVEMPs) with the visual vertical during whole-body roll tilt and eccentric rotation in healthy subjects and patients with unilateral vestibular loss, to determine which test was most sensitive in discriminating impaired utricle function.

Methods: OVEMPs and the visual vertical were measured in 11 patients and 11 healthy subjects. Visual vertical was measured during roll tilts between -9.6 and 9.6°, and during rotation at 400°/s with the head upright and the vertical rotation axis located between ±3.5 cm from the head center.

Results: OVEMPs in patients were strikingly asymmetric, whereas they were approximately symmetric in healthy subjects. Patients showed impaired visual vertical gain during eccentric rotation and increased errors for both roll tilt and eccentric rotation tests. OVEMPs were superior at discriminating between patients and healthy subjects, although eccentric rotation performed nearly as well.

Conclusions: OVEMPs provide a powerful test for discriminating between healthy subjects and patients with chronic unilateral vestibular loss, and testing the visual vertical testing during eccentric rotation was superior to testing during whole-body roll tilt.

Significance: OVEMPs are easier to administer, less demanding on patients, and in general are more effective at identifying chronic unilateral vestibular loss than visual vertical measurements.

Keywords: vestibular; utricular; otoliths; VEMP; subjective visual vertical; eccentric rotation
Introduction

Our sense of head orientation in space is heavily dependent upon gravity sensors in the inner ear, the otoliths. These are comprised of two sensors that are approximately planar structures most sensitive to changes in linear acceleration parallel to their plane. The utricle is positioned roughly in the transverse (horizontal) plane, whereas the saccule is oriented roughly in the sagittal (vertical) plane. A change in head roll will change the response of each otolith, and the combined output of these sensors is the primary determinate of perceived head roll.

A traditional test of otolith function is the subjective visual vertical (SVV), where patients adjust a visible line to perceived vertical. The SVV can reliably identify acute vestibular disorders (Dieterich and Brandt, 1993), because an asymmetric otolith response produces a perceived head tilt. The SVV reflects the processing of otolith information by cortex. More recently, the SVV has been used during eccentric rotation (Clarke, Schonfeld, 2001; Hong, Yeo, 2009), which has the benefit that the centrifugation can selectively stimulate the left or right otolith, whereas tilting stimulates both otoliths. The somatosensory vertical during eccentric rotation has also been suggested as a test to identify unilateral vestibular dysfunction (Clement and Deguine, 2010). These tests have several limitations, most notably the requirement of patient participation and cost (in the case of eccentric rotation), but also the possibility that the other healthy sensory systems could compensate for otolith dysfunction in chronic cases (“central compensation”) (Cnyrim, Rettinger, 2007; Hong, Yeo, 2009; Strupp, Arbusow, 1998).

New tests of otolith function have been recently discovered which could overcome some of these problems. Ocular vestibular evoked myogenic potentials (OVEMPs) are the electromyographic responses from the inferior oblique and inferior rectus extraocular muscles as a result of loud, short duration sound or vibration (Jombik and Bahyl, 2005; Rosengren, McAngus Todd, 2005; Todd, Rosengren, 2007). Vibration-induced OVEMPs are thought to predominately assess utricular function (Curthoys, 2010; Iwasaki, Chihara, 2009), and are promising because they allow the selective testing of the response of
either the right- or left-sided utricle (healthy subjects produce symmetric responses (Iwasaki, McGarvie, 2007); patients with unilateral vestibular response loss show asymmetrical responses (Iwasaki, McGarvie, 2007; Iwasaki, Smulders, 2008), and patients with bilateral vestibular loss do not show OVEMPs (Iwasaki, Smulders, 2008)), they require little active participation by the patient, and can be performed in most patients.

Our purpose was to evaluate the diagnostic value of vibration-induced OVEMPs compared to the visual vertical under various conditions by measuring patients with chronic unilateral vestibular loss, and comparing the results with healthy subjects.

Methods

Subjects

Eleven healthy subjects (mean age = 43, standard deviation = 10) with no reported history of vestibular, auditory, neurological, or visual problems were studied. Eleven patients (mean age = 51, standard deviation 16), in whom medical history and ancillary tests indicated persistent peripheral vestibular hypofunction, and who experienced symptoms of unilateral vestibular loss for at least 3 months participated (Table 1). The age difference between the patient and control groups was not significantly different (t-test, t=1.4, p>0.15). In each patient, vestibular loss was diagnosed by means of caloric irrigation, search-coil head-impulse test, and air conducted sound cervical VEMPs. Impaired hearing or deafness was found in the patients with vestibular schwannoma, Ménière’s disease, Zoster oticus, and otitis media with involvement of the inner ear. Some of these patients were repeatedly examined in our vestibular outpatient clinic, particularly those with Ménière’s disease; in this case, the results of the most recent examination was considered and included in Table 1. Overall, however, head impulse testing, cervical VEMPs, and caloric testing were not re-administered immediately prior to the OVEMP and SVV, because peripheral vestibular dysfunction was regarded as irreversible and persistent.
The experiments conformed to the principles of the Declaration of Helsinki and were approved by the local ethics committee. Subjects gave written consent after the experimental procedure had been explained.

**OVEMPs**

**Equipment**

Subjects lay supine with their head supported on a small pillow. The skin beneath the eyes and on the chin was cleaned with Abrasive Skin Prepping Gel (Nuprep, USA), and 5 surface electrodes were applied. For each eye the active (-) electrode was placed with the center of the electrode approximately 1 cm below the lower eyelash line. Reference electrodes (+) were placed 2 cm below the active electrodes. The center of each electrode was placed in line with the pupils, while the subjects were fixing straight ahead at point on the ceiling. Grounding was done with an electrode on the chin, or in patients with beards, on the chest.

Vibration stimuli were produced with a hand-held 4810 mini-shaker (Bruel and Kjaer, Naerum, Denmark). A 15mm long bolt was attached to the mini-shaker, and capped with 17mm diameter Bakelite cap that was the contact point with the head. The vibration produced by the mini-shaker was 3 cycles of a 500 Hz stimulus, repeated 3.1 times per second for approximately 21 seconds. To estimate the intensity of the stimulus, an accelerometer was attached to the skin behind the ear in one subject, and we recorded peak accelerations of about 5 m/s² in the interaural direction, 3.7 m/s² in the naso-occipital direction, and 2.6 m/s² in the dorsal-ventral direction.

**Recording**

Proper placement of the electrodes was checked by having subjects make small vertical saccades; if the responses from the electrodes beneath the left and right eyes were markedly different, the electrodes were removed and re-applied, and the proper placement checked again. During OVEMP measurements,
subjects were asked to remain relaxed and to look up to a target on the ceiling about 28° up from straight ahead. The mini-shaker was placed on the forehead, in the midline about at the level of the hairline. Stimulations were performed at least twice.

**Analysis**

Signals were bandpass-filtered (1-250 Hz), and voltages from each electrode were aligned with vibration onset and averaged. We measured the difference between baseline voltage, measured just after the delivery of the stimulus, to the negative potential peak 10 msec after stimulus onset (N10), and the positive trough about 5 msec later (P15) (See Figure 1A). P15 was occasionally difficult to identify (Figure 1B, for example), in which case we took the first trough no earlier than 15 msec after stimulus onset. The neural projections underlying vibration induced OVEMPs are thought to be primarily crossed, (Iwasaki, Chihara, 2009), so potentials from the left eye represent right utricular function and vice-versa. We used a standard Jongkees-type formula for asymmetry calculations in vestibular testing by comparing the magnitude of the n10 response in the left and right eyes:

\[
\text{Base-to-N10 Asymmetry Ratio (BN)} = \frac{\text{larger N10} - \text{smaller N10}}{\text{larger N10} + \text{smaller N10}} \times 100\%
\]

We computed a similar ratio to describe the size of the potential change from N10 to P15 (NP). OVEMP results for patients and healthy subjects were statistically compared with the Mann-Whitney U test.
Visual vertical

Equipment

Subjects sat on a chair that could be rotated with three servo-controlled, motor driven axes (Acutronic, Jona, Switzerland). Subjects were secured in the chair with safety belts, and the head was fixed to the back of the chair with individually adjusted masks (Sinmed BV, Reeuwijk, The Netherlands). The mask, made of a thermoplastic material (Posicast), was molded to the contour of the head after warming, with openings in the mask made for the face. The center of the head was positioned near the intersection of the earth-vertical axis of the turntable and the horizontal axis of the turntable, which was aligned with the nasal-occipital axis.

A chair fixed screen was positioned 80 cm in front of the subject. An arrow, with a visual angle of 10° x 0.25°, was projected onto the screen by a laser and two-axis galvanometer. The line was drawn at 200 Hz with a resolution of 0.1°. A potentiometer placed in front of the subject could be turned to adjust the arrow orientation, and subjects pressed a button to indicate they were finished with adjusting the arrow orientation.

Head position could be moved at 0.375 cm/s along the interaural axis with a stepper motor attached to the mask, with maximum excursions of ±3.5 cm. Subjects could make adjustments to align the body with the head, though small head-on-body misalignments likely occurred.

Procedure

In all trials, subjects were instructed to adjust the luminous arrow to the perceived vertical with the arrow pointing upward, and to press the confirm button when finished. If trials were not completed within 6 s, the trial was discarded and repeated at the end of the block of trials. The arrow disappeared at the end of each trial (button press or time-out), and was repositioned to a random orientation after a 2 second delay. Nothing except the arrow was visible to the subject.
For eccentric rotation trials, subjects were accelerated about an earth-vertical axis (yaw) at 5 °/s² to
400 °/s. Trials began after waiting an additional 2 minutes to allow for the decay of semi-circular canal-
based rotation cues. Assuming a vestibular time constant of 15 s (canal+velocity storage) and a vestibular
gain of 1, the expected sensed velocity at the end of the acceleration period is 60 °/s, and after 2 minutes
at constant velocity the expected sensed velocity is less than 0.05 °/s. Seven head positions along the
interaural axis were used (0, ±1.7, ±2.3, ±3.5 cm), chosen in a random order. We waited 15 s after the
head was translated before starting a trial. Subjects completed 10 successful trials at each head
eccentricity, and then the head was moved to the next position. All eccentric rotation trials were
completed before stopping the rotation, and the duration was about 10 minutes.

We can predict the roll tilt angle sensed by the otoliths during the eccentric rotation trials. The gravito-
inertial acceleration vector sensed by the otoliths is the sum of the acceleration due to gravity and that due
to eccentric rotation. The centrifugal acceleration sensed by an otolith is \( r*\omega^2 \), where \( r \) (radius) is the
distance from the rotation axis, and \( \omega \) is the rotation velocity, and is oriented perpendicular to gravity (see
Figure 2). The otoliths are located ~3.5 cm from the head centre. When the rotation axis is midway
between the two otoliths, the centrifugal accelerations on the otoliths are equal but oppositely directed
(Figure 2C). Because the interaural accelerations are in opposite directions and equal in size, the bilateral
otolith responses in healthy subjects would cancel, and the gravito-inertial acceleration angle would be 0°.

In patients with a unilateral under function, however, an asymmetric otolith response may lead to a
perceived tilt towards the healthy side. If the head is displaced 3.5 cm, so that the rotation axis is centred
on one otolith, there will be an asymmetric stimulation of the otoliths (Figure 2D). Our assumption is that
the two otoliths contribute equally to perceived tilt, and so the sensed tilt will be the average tilt estimated
by each otolith.

For tilt trials, subjects were tilted about the nasal-occipital axis with accelerations of ±10°/s², to one of
seven tilt positions, 0° ±3.3°, ± 6.5°, ± 9.6°, in a random order. These angles were chosen to correspond to
predicted roll tilt angles from the eccentric rotation experiment. In addition, we translated the head in the
same way as the equivalent eccentric rotation trials. For example, for the 9.6° tilt trials the head was
3.5cm, thus controlling for any effect of the head position on the difference between tilt and
eccentric rotation trials. Subjects completed 10 successful trials at each orientation, and then were tilted to
the next position. After all 7 blocks of tilt trials were completed, the room lights were turned on and
subjects were allowed a short break before continuing with the eccentric rotation trials (tilt trials were
always completed first).

Analysis

Trials in which the subject responded too slowly (> 6s) were discarded. Perceived vertical is always
reported as the angle relative to the head, so a perfectly compensatory response (arrow tilt/head tilt) has a
gain of -1, a gain between 0 and -1 indicates under compensation, and a gain less than -1 is
overcompensation. We used linear regression of perceived vertical versus gravito-inertial acceleration
angle to calculate gain (slope of the fit) and bias (intercept of the fits). We call the absolute value of the
bias the visual vertical error. We also calculated an asymmetry measure based only on the maximum roll
angles, for tilt trials, or maximum effective tilt angle in eccentric rotation trials.

\[
\text{Asymmetry} = \frac{SVV_{\text{left}} - SVV_{\text{right}}}{SVV_{\text{left}} + SVV_{\text{right}}} \times 100\%
\]

A value of 100% represents perfect performance, and values less than 100% indicate under-compensation
for the roll tilt angle or the eccentric displacement. We compared the results for patients and healthy
subjects with the Mann-Whitney U test.

To evaluate how well the different tests discriminate between healthy subjects and patients, we used the
means and standard deviations of each test to estimate how much of the patient distribution was more
than 2 standard deviations greater then the normal mean. This criterion fixes the expected false positive
rate to 2%. Ninety-five percent confidence intervals on the estimates of the percentage of patients that
would be correctly identified were found by bootstrapping. A test becomes better at discriminating between patients and healthy subjects as the difference between the average values of patients and normal subjects increases, and as the variability of the test within each group decreases.

**Results**

**OVEMP**

Example OVEMP responses are shown in Figure 1. Figure 1A shows a healthy subject with a BN asymmetry of 10%. Figure 1B shows an example from a patient (#10, see Table 1) that showed no response from the left extraocular muscles (100% asymmetry for the BN ratio), but a prominent response from the right side. Figure 1C shows a patient (#11) with a stronger N10 response from the left side (42% BN asymmetry ratio).

Table 2 and Figure 3(A-B) summarize the OVEMP responses from all patients and healthy subjects. The average BN asymmetry for patients was 66.2% (standard deviation = 24%), whereas for healthy subjects the average was 15.5 % (standard deviation = 11%). The average NP ratios were 65.8 % and 12.1% for patients, and healthy subjects respectively.

**Subjective visual vertical**

Most subjects had little difficulty completing the visual vertical task in the required time for both tilt and eccentric rotation trials, and less than 3% of trials were discarded due to slow responses for both healthy subjects and patients. Figure 4 shows example visual vertical results from a healthy subject and a patient (#1) with a right-side vestibular loss. The plots depict the average visual vertical setting for both tilt and eccentric rotation trials, plotted as a function of the gravito-inertial acceleration angle. The healthy subject showed a small over compensation during tilt trials, with a gain of -1.2 (slope of best fit line), and a very small bias at upright (-0.33°). The gain during eccentric rotation trials was -1.03, with a bias of -1.3°.

Since we did not measure the otolith locations, the small bias during eccentric rotation could be due to
either a misalignment of the rotation axis and the midpoint of the otoliths, or to an asymmetry in the otolith responses. In contrast, the patient showed under-compensation during both tilt (gain = -0.67) and eccentric rotation (gain = -0.30) trials. In addition, the patient had biases of 9° and 6° in the tilt and eccentric rotation conditions, respectively. The healthy subject in Figure 4A had a near symmetric OVEMP response (BN asymmetry = 8%), whereas for the patient in Figure 4B we could not obtain a right-sided OVEMP, resulting in an BN asymmetry = 100%.

Average visual vertical values are show in Table 2 and Figure 3(C-H). Average tilt errors were 4.1° for patients and 1.6° for normal subjects. The eccentric rotation error was 8.7° for patients, but only 2.0° for healthy subjects. Eccentric rotation gain and roll tilt gain were both similar for patients and healthy subjects. The tilt asymmetry difference was marginally significant (Mann-Whitney U test, p = 0.07), but the eccentric rotation asymmetry was not.

**Discriminatory power of OVEMP and visual vertical**

We used the means and standard deviations of each test to predict the number of patients that would be correctly identified if we fixed the false positive rate to 2% (see Methods), and the results are shown in Figure 5. The OVEMP tests would correctly find about 92 (NP) and 88 (BN) % of patients. The eccentric rotation error also performed well, with an expected correct identification rate of 72%. The performance of the other tests was noticeably poorer.

**Discussion**

The asymmetry of vibration-induced OVEMPS was the best discriminatory test for distinguishing patients with severe chronic unilateral vestibular loss from healthy subjects. Most of the subjective visual vertical measures were not as powerful in discriminating between patients and healthy subjects, probably because all our patients had experienced their unilateral vestibular loss for at least 3 months. For these patients, the remaining healthy otolith, or proprioception, likely provided the necessary sensory
information to perform the task (Cnyrim, Rettinger, 2007; Strupp, Arbusow, 1998). The upright and static visual vertical test remains a simple and effective method of detecting acute onset vestibular imbalance (Dieterich and Brandt, 1993; Zwergal, Rettinger, 2009).

The best visual vertical measurement for discriminating patients and healthy subjects was the eccentric rotation error (Figure 3F and Figure 5), which was nearly as good as the OVEMP tests in identifying patients. Both OVEMPS (Curthoys, 2010; Iwasaki, Chihara, 2009) and eccentric rotation (Schonfeld, Helling, 2010) are likely indicators for utricular function. Clarke et al. (Clarke, Schonfeld, 2001) similarly reported that measuring the visual vertical during centric rotation could be used to identify a peripheral otolith deficit. Hong et al (Hong, Yeo, 2009) measured the visual vertical with eccentric rotation and cervical VEMPs (which predominately assess saccular function (McCue and Guinan, 1994)) in patients diagnosed with vestibular neuritis. The average delay between symptom onset and testing in these patients was less than 1 week, and the visual vertical during eccentric rotation was found to be significantly different from controls, but static visual vertical measurements were not. Only 1/3 of the patients of Hong et al showed abnormal cervical VEMPs, suggesting that visual vertical measurements may be superior to cervical VEMPS in identifying vestibular neuritis. Since in most patients vestibular neuritis spares the inferior division of the vestibular nerve (Aw, Fetter, 2001; Fetter and Dichgans, 1996; Schmid-Priscoveanu, Straumann, 1999), a higher sensitivity for utricular tests, such as vibration induced oVEMP or the visual vertical, than of saccular tests, such as cervical VEMPs evoked by air conducted sound, is expected. Indeed, it has recently been reported that in a large sample of patients with unilateral vestibular loss, the SVV during eccentric rotation in patients was significantly more asymmetric than cervical VEMPS (Schonfeld, Helling, 2010).

Thus, our results in a relatively small sample size demonstrate that vibration-induced OVEMPs are superior to most visual vertical measurements in identifying patients with a severe, chronic, unilateral vestibular deficit, and that subjective visual vertical is most sensitive when tested during eccentric rotation, rather than during whole-body roll tilts. Eccentric rotation is a valuable test for selectively
stimulating the utricles, especially since there remains some debate concerning the specificity of OVEMPs and the best OVEMP stimulus for achieving the highest degree of utricular specificity (Colebatch, 2010; Curthoys, 2010). The similarity of the OVEMPs and the eccentric rotation error in our study suggests that in fact they are measuring similar functions. The remaining differences could be either because the tests rely on different sensors (vibration induced OVEMPs may be sensitive to saccule stimulation (Colebatch, 2010), and the visual vertical is influenced by semicircular canal stimulation directly (Pavlou, Wijnberg, 2003) or through changes in ocular torsion (Smith, Curthoys, 1995)), or perhaps the visual vertical is simply more variable owing to the requirement of active patient participation. OVEMPs are generally easier and cheaper to administer than eccentric rotation tests, and are more comfortable for the patient, making them an attractive component of comprehensive vestibular testing, along with air conducted sound CVEMPs, which predominately test the integrity of the saccule (Curthoys, 2010; McCue and Guinan, 1994), and the head impulse test, which can selectively test all 6 semi-circular canals (Cremer, Halmagyi, 1998). In this way, all vestibular receptors can be individually tested. Such comprehensive testing should prove beneficial, for example, in identifying disorders affecting individual sensors or their pathways, such as vestibular neuritis, which often afflicts only the superior branch of the vestibular nerve and the utricular pathway, but spares the saccular pathway in the inferior branch and the pathway from the posterior semicircular canal.
References


Legends

Figure 1. Example OVEMP traces from a healthy subject (A) and two patients (B and C, patients #11 and #10, respectively). Dotted lines are responses from the left extraocular muscles, and solid lines are responses from the right extraocular muscles. Plus symbols mark the baseline value just after stimulation, circles mark the N10 response, and squares mark the P15 response.

Figure 2. Stimulation of the otoliths by tilt and rotation. A. When upright and stationary, the left and right otoliths both sense gravity with no interaural acceleration. The starting position of the arrows indicate the approximate location of the otoliths. [A=acceleration; r=right; l=left; y=interaural axis; z= anteroposterior axis; GIA= gravito-inertial acceleration] B. When tilted, gravity is sensed as acceleration along the anteroposterior axis (Ar and Al) and a smaller interaural acceleration (Ar and Al). The sum of these vectors (large arrows) point in the direction of gravity, which in this example is tilted 9.6° for both the left (αl) and right (αr) otoliths. C. During rotation with the rotation axis centered between the otoliths, the otoliths will sense gravity as well as an interaural acceleration due to centrifugation. Because the interaural accelerations are in opposite directions and equal in size, the bilateral otolith responses in healthy subjects would cancel, and the gravito-inertial acceleration angle would be 0° . In patients with a unilateral under function, however, an asymmetric otolith response may lead to a perceived tilt towards the healthy side. D. With eccentric rotation it is possible to differentially stimulate either otolith. If the rotation axis is centered over one otolith, that otolith would not experience any interaural acceleration, whereas the eccentric otolith would sense an acceleration that depends on the distance from the rotation axis and the rotation speed.

Figure 3. Summary plots comparing patients with normal subjects. Each symbol denotes the value for an individual, bars are group means, and error bars are ± 1 standard deviation. A. OVEMP BN (baseline to N10 peak) asymmetry. B. OVEMP NP (N10 peak to B15 trough) asymmetry. C. Visual vertical gain during tilt. D. Visual vertical gain during eccentric rotation. E. Visual vertical error during tilt. F. Visual

Figure 4. Example visual vertical data from a healthy subject (A) and a patient with a right-sided vestibular loss (#1, see Table 1). (B). Average settings of the visual line relative to the head are shown for tilt and eccentric rotation trials. The gravito-inertial acceleration (GIA) angle is the tilt angle (for tilt trials) or the predicted sensed tilt angle by the otoliths (see Figure 2) for the eccentric rotation trials. Since subjects have to rotate the bar opposite their direction of felt rotation, ideal performance is a slope of -1. Each point is the mean of 10 trials. Lines show the best linear fits for the tilt (solid) and eccentric rotation (dashed) trials.

Figure 5. Predicted performance of each test in identifying patients, using a criterion that fixes the expected false positive rate to 2%. Error bars are the 95% confidence intervals, obtained by bootstrapping. Error bars might not be symmetric about the predicted performance level, because the distribution of the test scores are not symmetric.
Table 1. Patient characteristics

<table>
<thead>
<tr>
<th>P#</th>
<th>Diagnose</th>
<th>Time since onset or surgery</th>
<th>Age/Side</th>
<th>hHIT gain, left/right</th>
<th>Canal paresis factor, (calorics)</th>
<th>CVEMP asymmetry, %</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Vestibular schwannoma</td>
<td>3 m</td>
<td>45/R</td>
<td>0.51/0.31</td>
<td>100</td>
<td></td>
</tr>
<tr>
<td>2</td>
<td>Vestibular neuritis</td>
<td>6 m</td>
<td>63/R</td>
<td>0.64/0.27</td>
<td>100</td>
<td>12</td>
</tr>
<tr>
<td>3</td>
<td>Vestibular neuritis</td>
<td>6 m</td>
<td>25/L</td>
<td>0.37/0.56</td>
<td>49</td>
<td>28</td>
</tr>
<tr>
<td>4</td>
<td>Zoster oticus with inner ear infection</td>
<td>18 m</td>
<td>73/L</td>
<td></td>
<td>100</td>
<td>100</td>
</tr>
<tr>
<td>5</td>
<td>Menière/gentamicin</td>
<td>4 y</td>
<td>55/L</td>
<td>0.36/0.65</td>
<td>100</td>
<td>100</td>
</tr>
<tr>
<td>6</td>
<td>Vestibular schwannoma</td>
<td>9 m</td>
<td>31/R</td>
<td></td>
<td>100</td>
<td></td>
</tr>
<tr>
<td>7</td>
<td>Acute otitis media with inner ear infection</td>
<td>3 y</td>
<td>37/R</td>
<td>0.72/0.33</td>
<td>100</td>
<td></td>
</tr>
<tr>
<td>8</td>
<td>Vestibular neuritis</td>
<td>3 m</td>
<td>52/L</td>
<td>0.41/1.09</td>
<td>75</td>
<td>13</td>
</tr>
<tr>
<td>9</td>
<td>Menière disease</td>
<td>32 y</td>
<td>54/R</td>
<td>0.78/0.64</td>
<td>48</td>
<td>49</td>
</tr>
<tr>
<td>10</td>
<td>Vestibular neuritis</td>
<td>14 y</td>
<td>76/L</td>
<td>0.25/0.67</td>
<td>87</td>
<td>8</td>
</tr>
<tr>
<td>11</td>
<td>Vestibular schwannoma</td>
<td>18 y</td>
<td>52/R</td>
<td>0.57/0.21</td>
<td>100</td>
<td></td>
</tr>
</tbody>
</table>

P=patient, R=right, L=left, m=months, y=years. Abnormal values in **bold**. hHIT=horizontal head impulse test, normal >= 0.7. CP= canal paresis factor, normal <= 25%. Air conducted sound CVEMP, normal <=35%.

Table 2. OVEMP and visual vertical results

<table>
<thead>
<tr>
<th>Test</th>
<th>Patient Average</th>
<th>Patient Standard deviation</th>
<th>Normal Average</th>
<th>Normal Standard deviation</th>
<th>U</th>
<th>p</th>
</tr>
</thead>
<tbody>
<tr>
<td>OVEMP BN %</td>
<td>66.2</td>
<td>24.2</td>
<td>15.5</td>
<td>11.3</td>
<td>3.8</td>
<td>0.0001</td>
</tr>
<tr>
<td>OVEMP NP %</td>
<td>65.8</td>
<td>23.1</td>
<td>12.1</td>
<td>10.7</td>
<td>3.9</td>
<td>0.0001</td>
</tr>
<tr>
<td>Tilt gain</td>
<td>-1.0</td>
<td>0.7</td>
<td>-1.1</td>
<td>0.4</td>
<td>1.4</td>
<td>0.1486</td>
</tr>
<tr>
<td>Ecc rotation gain</td>
<td>-0.6</td>
<td>0.3</td>
<td>-0.9</td>
<td>0.3</td>
<td>1.6</td>
<td>0.1150</td>
</tr>
<tr>
<td>Tilt error</td>
<td>4.1</td>
<td>2.9</td>
<td>1.6</td>
<td>1.3</td>
<td>2.4</td>
<td>0.0151</td>
</tr>
<tr>
<td>Ecc rotation error</td>
<td>8.7</td>
<td>6.3</td>
<td>2.0</td>
<td>1.5</td>
<td>3.8</td>
<td>0.0001</td>
</tr>
<tr>
<td>Tilt asymmetry %</td>
<td>117.8</td>
<td>128.6</td>
<td>112.7</td>
<td>31.6</td>
<td>1.8</td>
<td>0.0707</td>
</tr>
<tr>
<td>Ecc rotation asymmetry %</td>
<td>65.1</td>
<td>24.5</td>
<td>88.9</td>
<td>27.9</td>
<td>1.6</td>
<td>0.1134</td>
</tr>
</tbody>
</table>

Ecc=eccentric
Figure 1
Diagnostic value of OVEMPs and the SVV

Valko et al

Figure 2
Figure 3
Figure 4
Predicted percentage of correct patient identification

- NP
- OVEMP
- BN
- Eccentric rotation offset
- Tilt offset
- Eccentric rotation gain
- Tilt gain
- Eccentric rotation asymmetry
- Tilt asymmetry

Figure 5