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Vestibular Evoked Myogenic Potentials (VEMP)

Faith Wurm Akin, Ph.D. and Owen D. Murnane, Ph.D.

Biographies

Faith Akin, Ph.D. is Director of the Vestibular/Balance Laboratory at the James H. Quillen VA Medical Center, Mountain Home TN and Assistant Professor, Department of Communicative Disorders, East Tennessee State University, Johnson City, TN.

Owen Murnane, Ph.D. is Director of the Electrophysiology Laboratory at the James H. Quillen VA Medical Center, Mountain Home TN and Assistant Professor, Department of Communicative Disorders, East Tennessee State University, Johnson City, TN.

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Conventional vestibular assessment has been limited to the evaluation of one of the five peripheral vestibular end organs, the horizontal semi-circular canal. Vestibular evoked myogenic potentials (VEMP) may supplement the current test battery by providing diagnostic information about saccular and/or inferior vestibular nerve function. VEMPs are short latency electromyograms (EMG) that are evoked by high-level acoustic stimuli and are recorded from surface electrodes over the tonically contracted sternocleidomastoid (SCM) muscle.

The sensitivity of the vestibular system to acoustic stimulation is well established. Sound-evoked vestibular symptoms in humans were first described by Tullio in 1929. In some lower vertebrates such as amphibians and fish, the saccule is the organ of hearing (Popper et al., 1982; Moffat & Capranica, 1976). Although the cochlea has replaced the saccule as the primary organ of hearing in mammals, there is evidence that the mammalian saccule remains responsive to sound. Vestibular afferent nerve fibers have been found to be acoustically responsive in the squirrel monkey (Young et al., 1977), in the guinea pig (Murofushi, et al., 1995), and in the cat (McCue & Guinan, 1995).

The VEMP has been recorded from the sternocleidomastoid muscle, and studies using human subjects with well documented peripheral audiovestibular lesions have confirmed the vestibular origin of the response (Colebatch & Halmagyi, 1992). Colebatch and Halmagyi demonstrated that the VEMP is abolished following unilateral vestibular neurectomy. These studies also demonstrated that there is no correlation between the VEMP and the degree of sensorineural hearing loss suggesting that the VEMP is not mediated by the cochlear afferents (Colebatch et al., 1994). Furthermore, the saccule has been implicated as the origin of the VEMP and a response pathway has been suggested from the vestibular saccule to the inferior vestibular nucleus, the lateral (Dieter's) nucleus, and the lateral vestibulospinal tract to the sternocleidomastoid (SCM) muscle where myogenic potentials are produced by the flexor neck motoneurons (Colebatch & Halmagyi, 1992).

VEMP Recording Procedures

In our laboratory, VEMPs are recorded with patients seated upright and heads turned to one side (away from the stimulus ear) to activate unilaterally the SCM muscle. A two-channel recording of the vestibular evoked myogenic potential (VEMP) is obtained using a commercially-available evoked potential unit. Non-inverting electrodes are placed at the midpoint of the SCM muscle on each side of the neck, the inverting electrodes are placed at the sternoclavicular junctions, and the ground electrode is placed on the forehead (see **Figure 1**). Click or tone burst stimuli are presented monaurally at a repetition rate of 5/s. Rarefaction clicks are presented at 100 dB nHL (0 dB nHL = 35 dB $_{peak}$SPL) and tone bursts at 500 and 750 Hz (rarefaction onset phase, Blackman gating function, 2 cycle rise/fall time with no plateau) are presented at 120 dB $_{peak}$SPL. The response is amplified (x5000) and bandpass filtered from 20-1500 Hz. A 100 ms window (including a 20 ms pre-stimulus baseline) is utilized. Responses to 128 stimuli are averaged and two or three responses are obtained from each side. Peak-to-peak amplitudes (A_L and A_R) are calculated from the mean of the three responses. Side-to-side differences are expressed as an asymmetry ratio (AR) calculated as:

$$AR = 100\ |(A_L - A_R)/(A_L + A_R)|.$$

To control for the effect of tonic EMG level on the VEMP, a two-channel electromyography (EMG) recording is obtained simultaneously with the evoked potential recordings (Akin & Murnane, 2001). An EMG stand-alone differential surface electrode is placed on the SCM muscle midway between the mastoid process and sternoclavicular junction on each side of the neck (see **Figure 1**) and a reference electrode is attached

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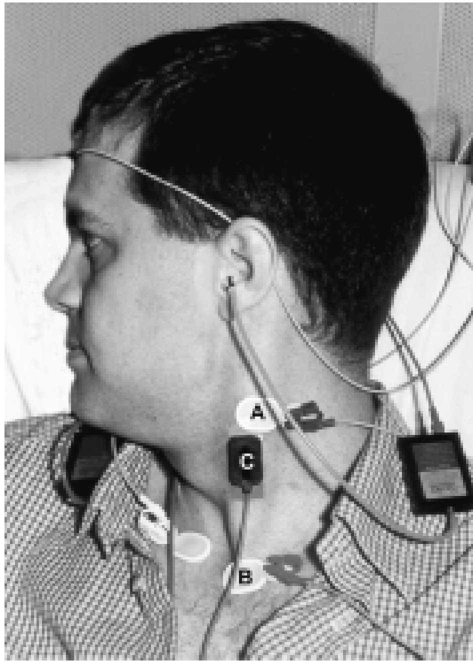


Figure 1. Electrode sites for recording vestibular evoked myogenic potentials (VEMP): (A) noninverting electrode on the sternocleidomastoid (SCM) muscle, (B) inverting electrode on the upper sternum, and (C) the EMG differential surface electrode. The ground electrode is located on the forehead.

to the wrist. The EMG signals from each channel are amplified, filtered, and digitized by a battery-powered computer and portable EMG unit. After rotating the head to one side, patients are provided visual feedback of their rectified EMG amplitude via the computer monitor and EMG software. An example of the visual feedback display of EMG amplitude provided to a subject during 30 s of head rotation to the left (i.e., activation of the right SCM muscle) is shown in **Figure 2**. During right SCM muscle activation, the subject was able to maintain EMG amplitude at the ~50 µV target. In contrast, the EMG amplitude recorded from the unactivated left SCM muscle was ~0 µV. Patients are instructed to maintain the rectified EMG rms amplitude at 50 µV during the recording of each evoked potential waveform to control for the effect of tonic EMG level on the VEMP.

Representative VEMP waveforms obtained from one subject are shown in **Figure 3**. The VEMP waveform is characterized by a positive peak (P1) at 11 ms, and a negative peak (N1) at 18 ms. A second positive peak is observed at ~26 ms, but previous studies have suggested that only P1 and N1 are of vestibular origin (Colebatch & Halmagyi, 1992), and the later components may originate from cochlear afferents (Colebatch et al., 1994) or a cochleovestibular source (Wu & Young, 2002). The presence of a VEMP in subjects with normal vestibular function is dependent upon adequate acoustic stimulation and ipsilateral activation of the SCM muscle. **Figure 4** illustrates two channel VEMP recordings for left ear and right ear stimulation with 100 dB nHL clicks during right SCM muscle activation. In the upper panel of **Figure 4**,

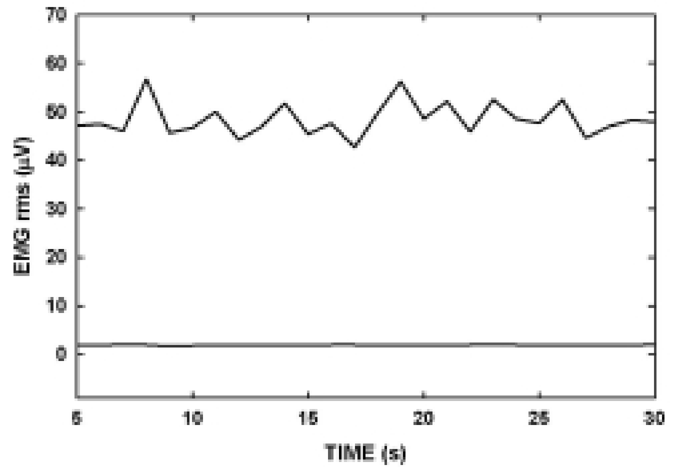


Figure 2. An example of rectified EMG rms amplitude level measured during a VEMP recording while the SCM muscle was activated on one side (head turned laterally). This display provides each subject with the visual feedback necessary to maintain the target EMG amplitude.

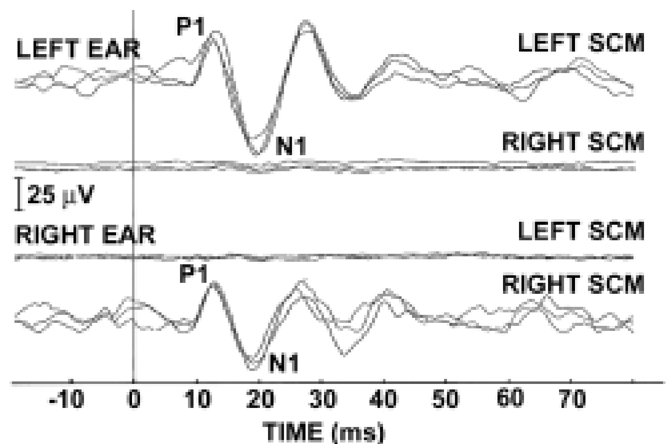


Figure 3. Two-channel VEMP recordings obtained with 100 dB nHL click stimuli delivered to the left ear during left SCM muscle activation (upper two waveforms) and the right ear during right SCM muscle activation (lower two waveforms).

the stimulus was presented to the left ear during activation of the right SCM muscle. In this condition, a VEMP was not obtained from either the left or right SCM muscle. Notice, however, that the overall amplitude of the recording from the right (activated) SCM muscle was greater than the amplitude from the left (unactivated) SCM muscle. This difference in overall amplitude reflects the difference in the level of tonic muscle activation (see **Figure 2**). In the lower panel of **Figure 4**, the stimulus was presented to the right ear during activation of the right SCM muscle (head turned left). In this condition, a VEMP was obtained only from the right (activated) SCM muscle and no response was obtained over the left (unactivated) SCM muscle. Thus, VEMPs were only obtained when the stimulus was ipsilateral to the activated SCM muscle.

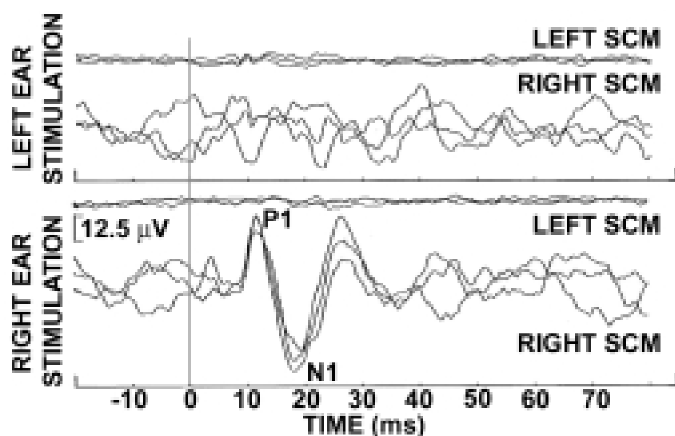


Figure 4. Two-channel VEMP recordings obtained with 100 dB nHL click stimuli delivered to the left ear (upper two waveforms) and the right ear (lower two waveforms). For all conditions the subject's head was turned to the left that activated the right SCM. The vertical line at 0 ms indicates the onset of the stimulus. Note that VEMPs are only present when the acoustic stimulus is delivered to the ear (right) ipsilateral to the side of SCM muscle activation.

Effects of Stimulus Parameters

The VEMP amplitude is influenced by the stimulus level, stimulus frequency, and tonic EMG level, whereas VEMP latency is independent of these variables (Colebatch et al., 1994; Robertson & Ireland, 1995; Lim et al., 1995; Bath et al., 1998; Li et al., 1999; De Waele et al., 1999; Murofushi et al., 1999; Todd et al., 2000; Ochi et al., 2001; Welgampola & Colebatch, 2001; Akin et al., 2003; Akin et al., in press). **Figure 5** demonstrates the effect of stimulus level on click-evoked VEMPs in one subject. As the level of the click increased there was a corresponding increase in the VEMP amplitude, a finding that has been observed in previous studies (Colebatch et al., 1994; Ochi et al., 2001). In contrast to VEMP amplitude, the VEMP latency does not vary as a function of click level. Colebatch et al. (1994) suggested that this finding is consistent with the reflexive nature of the response and reflects a simple neurophysiological pathway. The neurophysiological and clinical data suggest that VEMPs are generated by activation of vestibular afferents arising from the saccule and rapidly transmitted through the lateral vestibular nucleus to the lateral vestibulospinal tract and the motoneurons of the ipsilateral SCM muscle (Halmagyi & Curthoys, 2000).

In our laboratory, click-evoked VEMP thresholds ranged from 80 to 100 dB nHL in subjects with normal audiovestibular function, and the average threshold was 91 dB nHL (Akin et al., 2003). For the subject whose data are shown in Figure 5, no response was obtained at 85 dB nHL and a questionable response was obtained at 90 dB nHL. The VEMP threshold for this subject was 95 dB nHL with the largest amplitude response obtained at 100 dB nHL. Other studies have reported similar mean VEMP thresholds (Colebatch et al., 1994; Welgampola & Colebatch, 2001).

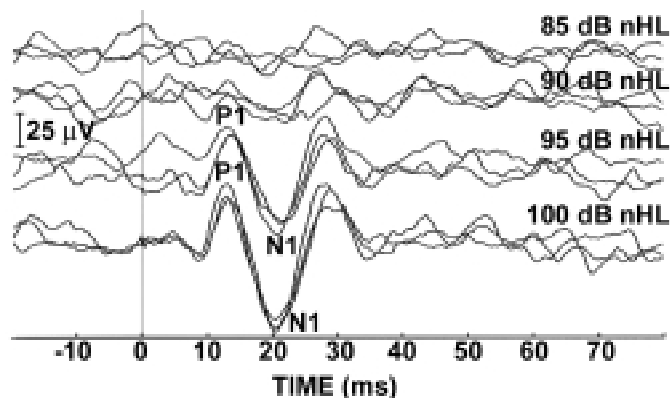


Figure 5. VEMPs obtained from the left SCM muscle of one subject illustrating the effect of click stimulus level on VEMP amplitude. Stimuli were delivered to the left ear and the stimulus levels are indicated beside each waveform. Target EMG rms amplitude was maintained at 50 µV.

Although most investigators have recorded VEMPs in response to broadband clicks, animal studies suggest that the saccular nerve fibers are most sensitive to low frequency stimuli (McCue & Guinan, 1994; Murofushi et al., 1995). We, therefore, examined the response characteristics and thresholds of tone burst-evoked VEMPs (Akin et al., 2003). An example of tone-evoked VEMP recordings obtained from one subject is shown in **Figure 6**. In this subject, VEMPs were present at each tone burst frequency, and robust responses were recorded with 500, 750 and 1000 Hz tone bursts. The largest P1-N1 amplitudes were obtained at 500 Hz, 750 Hz and 1000 Hz and VEMP amplitude was markedly reduced for 2000 Hz tone bursts. In a group of subjects with normal audiovestibular function, VEMP thresholds ranged from 100 to 120 dB $_{peak}$SPL across frequency with the lowest thresholds obtained at 500 and 750 Hz and the highest thresholds obtained at 2000 Hz. The results of this study were consistent with the neurophysiological findings that acoustically responsive afferent fibers in the mammalian inferior vestibular nerve have

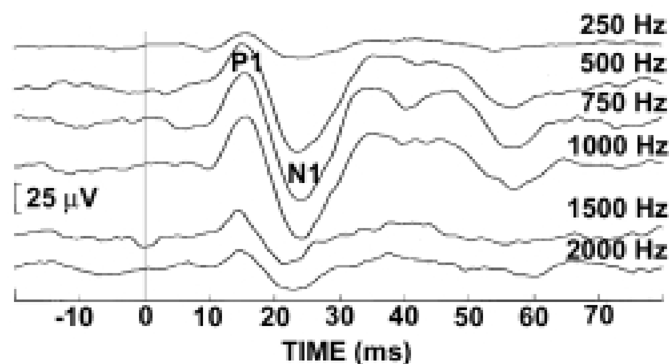


Figure 6. VEMPs obtained from a single subject for six tone burst frequencies. Responses are shown for tone burst levels from 100 to 120 dB $_{peak}$SPL. Each waveform represents the mean of three responses. The vertical line indicates the stimulus onset at 0 ms.

broad, V-shaped tuning curves with best frequencies between 500 and 1000 Hz (McCue & Guinan, 1995).

In addition to stimulus level and frequency, VEMP amplitude is influenced by the ongoing EMG level of the SCM muscle. A recent experiment was performed in our laboratory to determine the ability of subjects to achieve EMG target levels over a range of target levels typically utilized during VEMP recordings (Akin et al., in press). In addition, the influence of target EMG level on the latency and amplitude of the click- and tone-evoked VEMP was examined. Representative waveforms obtained from one subject at each EMG target level and for each stimulus are shown in **Figure 7**. The responses to the 500-Hz tone burst are shown on the left and responses to the click stimulus are shown on the right. The target EMG levels are indicated in the middle of the figure. VEMP amplitude increased as a function of EMG target level, whereas VEMP latency is relatively constant. No response was recorded when the SCM muscle was not activated (EMG target level = 0 µV). EMG target levels ranging from 30 – 50 µV are suggested for clinical application of the VEMP for unilateral activation of the SCM muscle (Akin et al., in press).

Test interpretation

The clinical interpretation of the VEMP has focused primarily on amplitude or threshold asymmetries between the right and left sides, yet methods for calculating asymmetry have varied. These differences are the result of several techniques used to control or monitor the tonicity of the SCM muscle. The tonic state of the SCM muscle is a critical parameter in the recording method of the VEMP (Colebatch et al., 1994; Colebatch, 2001; Lim et al., 1995). Thus, controlling the level of tonic EMG is a prerequisite for the accurate interpretation of interaural amplitude difference. To account for the effect of the EMG level, some laboratories have controlled directly the magnitude of tonic neck muscle activity by monitoring the amplitude of the rectified EMG at a constant target level during activation of the SCM muscle (Lim et al., 1995; Todd et al., 2000; Akin & Murnane, 2001). In contrast, others have calculated a corrected or normalized amplitude by dividing the peak-to-peak VEMP amplitude by the mean rectified EMG level following activation of the unmonitored SCM muscle (Robertson & Ireland, 1995; Murofushi et al., 1999; Colebatch et al., 1994; Welgampola & Colebatch, 2001). In a recent experiment, we compared these two techniques, and found that both techniques yielded similar VEMP asymmetry ratios (Fillon, et al., 2004). It should be noted, however, that direct EMG monitoring of the SCM muscle activation during VEMP recordings is necessary to differentiate between inadequate activation of the SCM muscle and saccular and/or inferior vestibular nerve involvement in patients with absent VEMPs.

Case Studies

The diagnostic utility of the VEMP has been examined for various audiovestibular and neurological disorders including vestibular labyrinthitis, Ménière's disease, benign paroxysmal positional vertigo, superior canal dehiscence, the Tullio phenomenon, vestibular schwannoma, multiple sclerosis, and spinocerebellar degeneration (Murofushi et al., 1996; Colebatch et al., 1998; Brantberg et al., 1999; de Waele et al., 1999; Heide et al., 1999; Matsuzaki et al., 1999; Seo et al., 1999; Shimizu et al., 2000; Watson et al., 2000). The following case studies are presented to illustrate VEMP recordings in patients with various audiovestibular disorders. Patient 1 is a 59 year old male who experienced loss of hearing and vestibular function in his left ear following removal of a left cerebellopontine angle tumor. The hearing evaluation of the right ear revealed normal hearing through 2000 Hz and a moderate to profound high frequency sensorineural hearing loss. The left ear had profound sensorineural hearing loss (**Figure 8**). Nystagmic responses to bithermal caloric irrigation were present in the right ear and absent in the left ear. VEMP responses to 100 dB nHL click stimuli were present on the right side and absent on the left (see **Figure 8**). For this patient, both the VEMP and the caloric responses were absent which is consistent with decreased vestibular function presumably caused by the loss of vestibular nerve function.

Patient 2 is a 61 year old female who was diagnosed with labyrinthitis. The hearing evaluation indicated bilateral mild high frequency sensorineural hearing loss (**Figure 9**). Nystagmic responses to bithermal caloric irrigation yielded an 80% unilateral weakness to the left. **Figure 9** shows that VEMP responses to 100 dB nHL click stimuli were absent on the left side and present on the right. In this

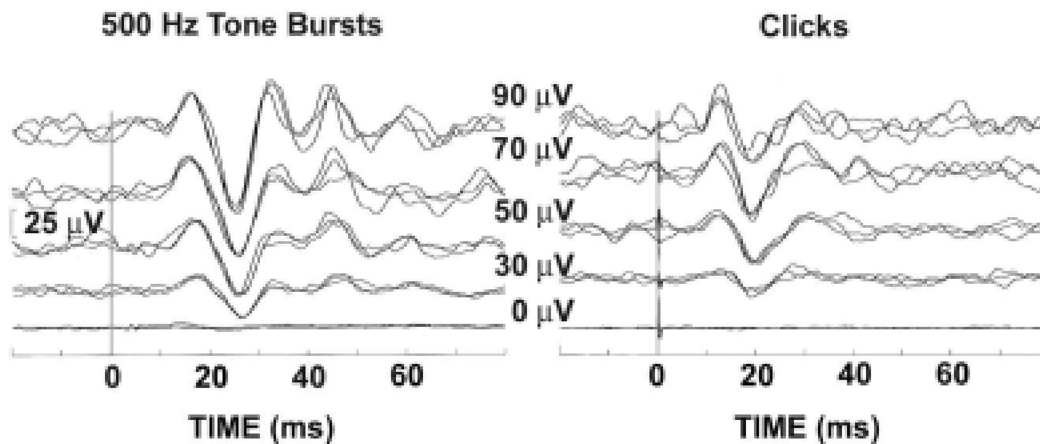
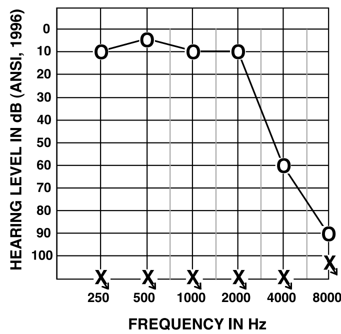


Figure 7. VEMPs obtained from a single subject at five EMG target levels for 500-Hz tone bursts at 100 dB nHL (left) and clicks at 120 dB $_{peak}$SPL (right). The target EMG levels are indicated in the middle of the figure.



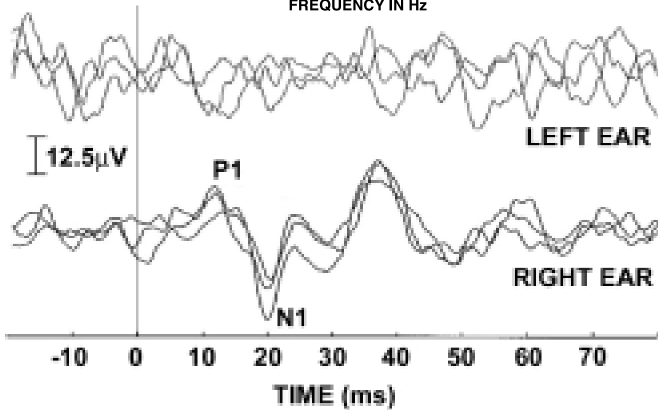
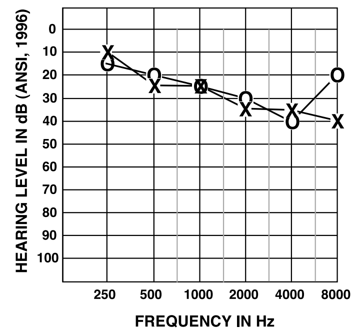


Figure 8. The audiogram for Patient 1 revealed profound sensorineural hearing loss on the left following removal of a left CPA tumor, and the caloric test yielded a 100% left unilateral weakness. VEMP responses to 100 dB nHL clicks were absent with left ear stimulation and present with right ear stimulation (Asymmetry ratio = 100%).

case, both the VEMP and the caloric responses were consistent with decreased vestibular function, whereas auditory function remained relatively intact.

Patient 3 is a 40 year old female with a history of congenital profound sensorineural hearing loss in her left ear and normal hearing sensitivity in her right ear (**Figure 10**). The bithermal caloric test revealed normal and symmetrical nystagmic responses. VEMP responses to 100 dB nHL click stimuli were present on both sides (see **Figure 10**). In this case, the VEMP and the caloric test results suggested normal saccular and horizontal semi-circular canal function, respectively.

Patient 4 was diagnosed with Ménière's disease and underwent a right endolymphatic shunt procedure. The audiogram in **Figure 11** shows a mild-to-moderate high frequency sensorineural hearing loss in the left ear and a severe sensorineural hearing loss in the right ear. Nystagmic responses to bithermal caloric irrigation were absent on the right side and present on the left. **Figure 11** shows VEMP responses to 100 dB nHL clicks present on both sides. For this patient, the VEMPs suggested normal bilateral saccular function, whereas the caloric test results were consistent with abnormal right horizontal semi-circular canal function.



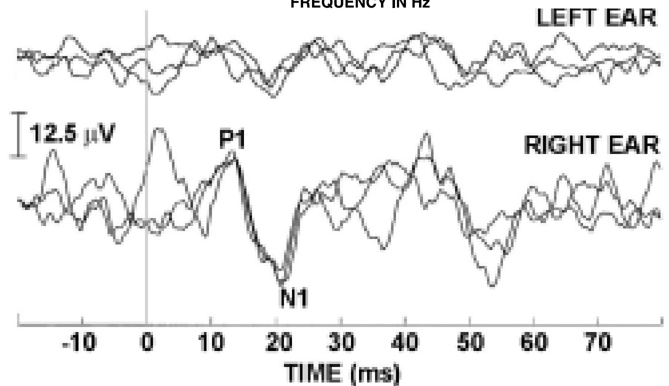
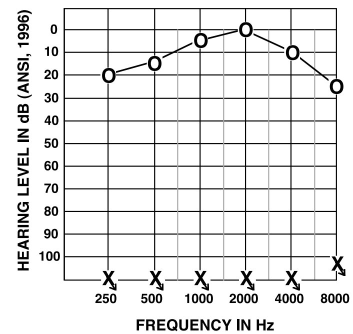


Figure 9. Patient 2 was diagnosed with labyrinthitis, and the caloric test yielded an 80% left unilateral weakness. The audiogram revealed a bilateral mild high frequency sensorineural hearing loss. VEMP responses to 100 dB nHL clicks were absent with left ear stimulation and present with right ear stimulation (Asymmetry ratio = 100%).



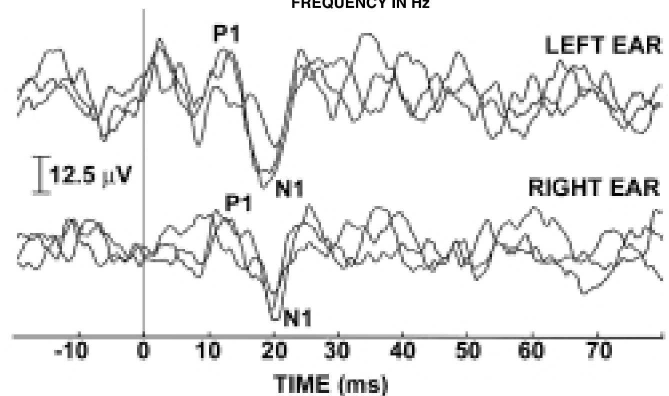
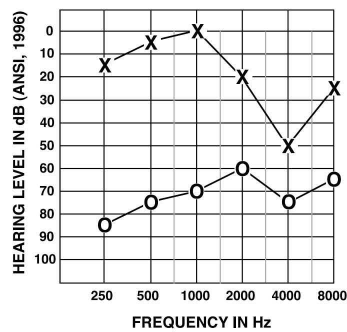


Figure 10. Patient 3 has a history of left congenital unilateral sensorineural hearing loss. The audiogram revealed profound sensorineural hearing loss on the left, and the caloric test yielded symmetrical nystagmic responses. VEMP responses to 100 dB nHL clicks were present in both ears (Asymmetry ratio = 15%).



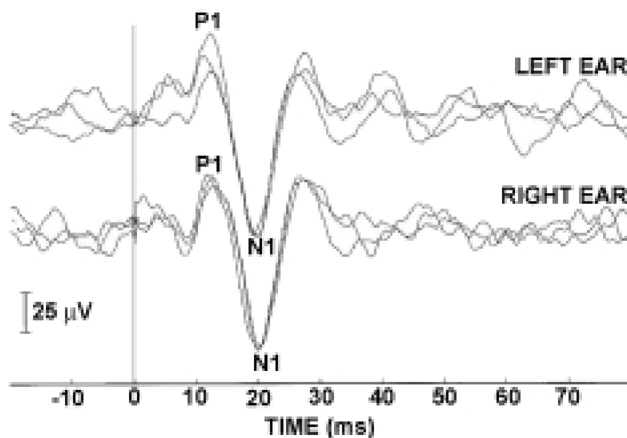


Figure 11. *Patient 4 was diagnosed with Ménière's disease and underwent a right endolymphatic shunt procedure. The audiogram revealed a severe sensorineural hearing loss on the right, and the caloric test yielded a 100% right unilateral weakness. VEMPs responses to 100 dB nHL clicks were present in both ears (Asymmetry ratio = 8%).*

Conclusions

- VEMPs may supplement the vestibular test battery by providing diagnostic information about saccular and/or inferior vestibular nerve function.
- The presence of a VEMP is dependent upon adequate acoustic stimulation and ipsilateral activation of the SCM muscle.
- In subjects with normal vestibular function, VEMPs can be recorded using clicks and low frequency tone bursts during activation of the SCM muscle.
- The VEMP amplitude is dependent on the sternocleidomastoid (SCM) muscle EMG level.
- The VEMP amplitude is influenced by the stimulus level and frequency.
- VEMPs are not influenced by sensorineural hearing loss.
- Case studies suggest that the VEMP and the caloric test most likely reflect the function of two different vestibular end organs.

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May 20-22, Las Vegas, Nevada USA
October 7-9, Chicago, Illinois USA

For additional information or to request a course brochure, visit us at www.bsure4balance.com

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Best Practices for the Evaluation and Management of Dizziness: A Workshop with Leading Clinicians – Chicago, June 25 & 26, 2004

This course follows on the hugely successful "Evaluation and Management of Dizziness: Leading Clinicians Discuss and Defend Best Practices" course held in Chicago, 2002.

For additional information or to request a course brochure, visit us at www.bsure4balance.com

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GN Otometrics is the world's leading manufacturer of hearing and balance instrumentation and software – innovative concepts designed to help healthcare professionals make the best possible decisions. Our solutions range from infant screening applications, audiologic diagnostics, and office management software, to balance testing and hearing instrument fitting.

Based in Copenhagen, Denmark, we maintain marketing and development centers in both the United States and Germany. GN Otometrics is part of the GN Resound Group.

GN Otometrics, Denmark. Phone: +45 72 111 555
In North America. Phone: 800-362-3736.
sales@gnotometrics.com
www.gnotometrics.com

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GN Otometrics North America, 125 Commerce Drive, Schaumburg, IL 60173-5329, USA

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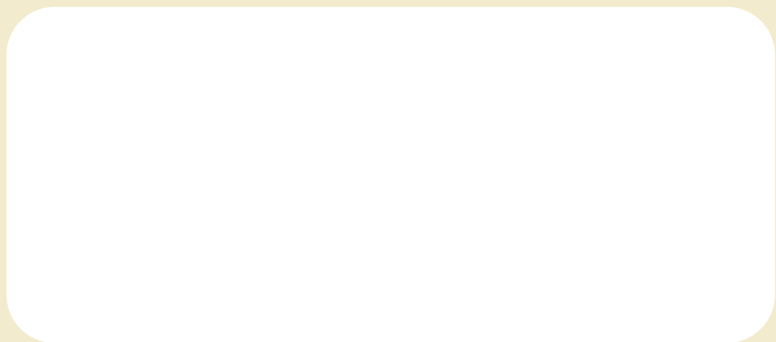

Data management | Hearing assessment | Fitting & Testing | Balance assessment

Helping you make the right decision