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Can Vestibular-Evoked Myogenic Potentials Help Differentiate Ménière Disease from Vestibular Migraine?

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Abstract

Objectives—To characterize both cervical and ocular vestibular-evoked myogenic potential (cVEMP, oVEMP) responses to air-conducted sound (ACS) and midline taps in Ménière disease (MD), vestibular migraine (VM), and controls, as well as to determine if cVEMP or oVEMP responses can differentiate MD from VM.

Study Design—Prospective cohort study.

Setting—Tertiary referral center.

Subjects and Methods—Unilateral definite MD patients (n = 20), VM patients (n = 21) by modified Neuhauser criteria, and age-matched controls (n = 28). cVEMP testing used ACS (clicks), and oVEMP testing used ACS (clicks and 500-Hz tone bursts) and midline tap stimuli (reflex hammer and Mini-Shaker). Outcome parameters were cVEMP peak-to-peak amplitudes and oVEMP n10 amplitudes.

Results—Relative to controls, MD and VM groups both showed reduced click-evoked cVEMP ($P < .001$) and oVEMP ($P < .001$) amplitudes. Only the MD group showed reduction in tone-evoked amplitudes for oVEMP. Tone-evoked oVEMPs differentiated MD from controls ($P = .001$) and from VM ($P = .007$). The oVEMPs in response to the reflex hammer and Mini-Shaker midline taps showed no differences between groups ($P > .210$).

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Author Contributions

M. Geraldine Zuniga, designed protocol and conducted VEMP testing in the participants, drafted the final manuscript and approved its final version; **Kristen L. Janky**, collaborated with VEMP testing session, critically reviewed the manuscript's drafts, and approved final version; **Michael C. Schubert**, collaborated in designing the protocol and provided input regarding symptoms and other tests of vestibular function in vestibular migraine, reviewed and approved the final version of the manuscript; **John P. Carey**, principal investigator, designed the research protocol, obtained funding and institutional review board (IRB) approval, provided key concepts in VEMP physiology, oversaw experimental design, training, and execution, and critically reviewed the drafts, and approved the final version of the manuscript.

Disclosures

Competing interests: John P. Carey is a consultant for Otonomy, Inc, in the investigation of a new drug for the treatment of Ménière disease and a consultant for a drug trial for Pfizer. There are no conflicts of interest with the present study.

Conclusions—Using these techniques, VM and MD behaved similarly on most of the VEMP test battery. A link in their pathophysiology may be responsible for these responses. The data suggest a difference in 500-Hz tone burst–evoked oVEMP responses between MD and MV as a group. However, no VEMP test that was investigated segregated individuals with MD from those with VM.

Keywords

vestibular migraine; Ménière disease; VEMP; utricle; saccule; otolith; hydrops

Vestibular migraine (VM) is an emerging diagnosis for a syndrome of vertigo and/or disequilibrium in patients with current or previous headache and migraine characteristics.^{1–3} Diagnostic criteria for VM represent a significant step in its clinical identification and in studies to validate the diagnosis.⁴ However, establishing the diagnosis remains challenging. One of its most vexing aspects is the overlap of key features (eg, vertigo, aural fullness) with those of Ménière disease (MD). Furthermore, some authors have suggested that MD may coexist with migraine.^{5–8}

Without a biomarker to objectively make the diagnosis of VM, several studies have used laboratory vestibular tests to characterize possible abnormalities.^{9–12} Specifically, cervical vestibular-evoked myogenic potential (cVEMP) testing in response to air-conducted sound (ACS) has been investigated.^{11,13–16} The cVEMP evaluates the sacculus by measuring an inhibitory potential from the sternocleidomastoid (SCM) muscle ipsilateral to the ear stimulated with ACS.^{17–19} Abnormal cVEMP responses in VM have been described, including reduced peak-to-peak amplitudes, shifts in frequency tuning, and reduced response rates.^{11–13,15,16} Interestingly, these abnormalities are also reported in MD, attributed to the saccular dysfunction resulting from saccular hydrops.^{20–25}

More recently, investigations of VEMP testing in patients with MD have been extended to include the use of the ocular VEMP (oVEMP).^{24,26,27} The oVEMP, in response to taps on the midline forehead, putatively examines the utricle by measuring an excitatory potential from the inferior oblique muscle of the contralateral eye.^{28–32} The exact vestibular endorgan(s) responsible for the sound-evoked oVEMP remains a subject of controversy.^{33–35}

In the present study, we sought to investigate both cVEMP and oVEMP responses to both ACS and midline taps—measures of saccular and utricular reflexes, respectively—in controls and patients with MD or VM. Our goal was to determine whether the cVEMP or oVEMP responses could differentiate VM from MD.

Methods

We conducted a prospective cohort study at a tertiary academic medical center.

Subjects

Subjects included patients with definite unilateral MD, as defined by the American Academy of Otolaryngology–Head and Neck Surgery (AAO-HNS) 1995 guidelines³⁶; patients with either probable or definite VM (with modifications to the original criteria),⁴ as suggested by Radtke et al³⁷ (Table 1); and age-matched healthy controls with no history of neurotological symptoms.

To avoid confound between VM and MD, patients with hearing thresholds worse than 20 dB HL in the frequency range of 250 to 500 Hz were excluded from the VM group. Subjects

with hearing loss in this range were not automatically considered to have MD unless they met all of the criteria for definite unilateral MD. Participants with VM were subclassified based on whether their aural symptoms (ie, aural fullness, tinnitus) could be lateralized (VML) consistently to one ear or instead were perceived as alternating between both ears (VMB). One VM patient could not lateralize symptoms to either ear and was thus included in the VMB group.

This study (protocol NA_00035749) was reviewed and approved by the Institutional Review Board at the Johns Hopkins University School of Medicine. All participants gave informed consent.

VEMP Testing

The VEMP stimuli and recording techniques have been described elsewhere.³⁸ Briefly, a commercial electromyographic (EMG) system (Medelec Synergy, software version 14.1, Care Fusion, Dublin, Ohio) was used. Air-conducted sound stimuli were delivered monaurally via intra-auricular speakers from VIASYS Healthcare (Madison, Wisconsin) with foam ear tips (Aearo Company Auditory Systems, Indianapolis, Indiana). Two types of ACS stimuli were delivered: (1) 0.1-ms, 105-dB normal hearing level (nHL), (140-dB peak sound pressure level [SPL]) clicks of positive polarity at a repetition rate of 5 per second and (2) 500-Hz, 125-dB SPL tone bursts (TB) of positive polarity, with a linear envelope (1-ms rise/fall time, 2-ms plateau), at a repetition rate of 5 per second. Two types of midline taps were delivered at F_z (in the midline at the hairline, 30% of the distance between the inion and nasion): (1) manual taps delivered with the VIASYS system's reflex hammer fitted with an inertial microswitch trigger, and (2) "mini taps," as described by Iwasaki et al,²⁸ were delivered with a Brüel & Kjær (Nærum, Denmark) Mini-Shaker Type 4810 (1-ms clicks of positive polarity), with a repetition rate of 5 per second, delivering a force of approximately 147 dB force level (24 Newtons per tap).²⁴ The EMG signals were amplified (2500 μ V) and band pass filtered (20–2000 Hz). One hundred sweeps and 50 sweeps were averaged for each ACS and midline tap test, respectively.

VEMP Recording Techniques

Participants lay semi-recumbent on an examination table with the torso elevated at 30 degrees from horizontal for cVEMP and oVEMP testing.³⁸ The VEMP responses were recorded with disposable, self-adhesive, pregelled Ag/AgCl electrodes with attached 100-cm safety leadwires from GN Otometrics (Schaumburg, Illinois).

For cVEMP, the electrode montage consisted of a noninverting electrode placed at the midpoint of the SCM muscle belly, an inverting electrode placed on the sternoclavicular junction, and a ground electrode placed on the manubrium sterni. The cVEMPs were recorded in response to click stimuli. Participants were instructed to lift their heads, which provided tonic background muscle activity. To ensure adequate SCM activation, the rectified EMG activity was monitored at a magnitude of 50 μ V or greater. The p13 potential was identified as the first distinctive trough in the waveform, approximately 10 to 14 ms after stimulus onset. The n23 potential was identified as the first negative peak in the waveform, 19 to 23 ms after stimulus onset. The peak-to-peak amplitude was the sum of the p13 and the n23 amplitudes.

For oVEMP, the electrode montage included a noninverting electrode centered 5 mm beneath the pupil, an inverting electrode centered 2 cm below the noninverting electrode, and a ground electrode placed on the manubrium sterni. The oVEMPs were recorded in response to both ACS and midline taps. Participants were instructed to fix their gaze 30 degrees up from their primary gaze position by looking at a line placed on the ceiling.

Before testing with ACS or midline taps, 20-degree vertical saccades were recorded from both eyes. If the signal change showed >25% asymmetry, the electrodes were replaced. The n10 potential was identified as the first negative peak in the waveform and occurred 7 to 11 ms after stimulus onset. The n10 amplitude was measured at the maximum negative voltage of the n10 potential.³⁸

Statistical Analysis

SPSS version 18 (SPSS, Inc, an IBM Company, Chicago, Illinois) and Excel 2007 (Microsoft, Seattle, Washington) were used for statistical analyses. Symptom prevalence between VMB and VML groups was compared with a discriminant analysis using univariate analyses of variance (ANOVAs). A power analysis using preliminary click-evoked cVEMP and oVEMP responses determined a necessary sample size of 18 ears in each arm to detect, with a power of 0.8, significant differences ($P < .05$) between controls and VM.

For VEMP results, 6 groups of ears were considered for comparisons: (1) control ears; (2) affected ears in MD; (3) VM, both ears; (4) VML, subjectively affected ears (VML-affected); (5) VML, subjectively unaffected ears (VML-unaffected); and (6) VMB, both ears. VEMP results showed nonnormally distributed amplitudes in controls with the exception of the oVEMPs in response to the midline taps. For the nonnormally distributed data, a Kruskal-Wallis test was used to compare different ear groups, followed by the Mann-Whitney U post hoc tests for multiple comparisons, with a Bonferroni adjustment for the P value. The n10 amplitude of the Mini-Shaker oVEMP and latencies from all VEMPs were distributed normally and analyzed using 1-way ANOVA and Tukey's honestly significant difference (HSD) post hoc tests for multiple comparisons. Of note, absence of VEMP response was assigned an amplitude of zero microvolts, and latency was considered missing data. All results were considered significant at the $P < .05$ level.

Results

Demographics

We enrolled 20 patients with definite unilateral MD (mean age 50 years; range, 15–72 years), 21 patients who met criteria for probable or definite VM (mean age 48 years; range, 21–76 years), and 28 age-matched healthy controls (mean age 48 years; range, 27–71 years) (Table 2). Of the VM group, 13 subjects constituted the VML subgroup and 8 the VMB subgroup. In the VM group, the average pure-tone hearing thresholds from both ears at 250 and 500 Hz were 13 and 14 dB hearing level (HL), respectively. In the MD group, the mean stage of disease was III, with average pure-tone thresholds in the affected ear at 250 and 500 Hz of 52 dB HL for both frequencies. Five patients with MD also met criteria for probable VM.

VML and VMB Symptoms

Symptoms reported by both subgroups of VM (VML and VMB) are illustrated in Figure 1. Symptoms were no more likely to occur in either group. However, there was a trend for headache during dizziness to be more common in VML and for position change-related symptoms to be more common in VMB ($P = .07$ for each).

VEMP Results

cVEMP and oVEMP: Click stimuli—The cVEMP and oVEMP response rates to clicks are depicted in Table 3. Bilateral absence of response was observed for cVEMPs only in 1 patient in the VML subgroup and for oVEMPs in 5 (38%) patients of the VML subgroup and in 3 (38%) patients of the VMB subgroup.

The cVEMP latencies were not different in VM or in MD relative to controls (p13: $F_{2,94} = 1.764$, $P = 1.777$; n23: $F_{2,96} = 2.641$, $P = .076$). The oVEMP latencies were different between controls, VM, and MD (n10: $F_{2,79} = 7.600$, $P = .001$) (Table 4), but post hoc analyses revealed that only the MD group showed slightly longer n10 latencies compared to controls ($P = .001$) and VM ($P = .028$).

A Kruskal-Wallis test comparing cVEMP peak-to-peak amplitudes showed significant differences between VM, MD, and control ears ($H(2) = 49.145$, $P < .001$) (Figure 2A). Mann-Whitney U tests revealed that (1) compared with controls, peak-to-peak amplitudes were reduced in VM ($U = 302.5$, $P < .001$) and in MD ($U = 109.5$, $P < .001$), whereas (2) no significant difference existed between VM and MD ($U = 388$, $P = .625$). Within VM, each subgroup of ears (VML-affected, VML-unaffected, VMB) also had reduced peak-to-peak amplitudes compared with controls ($H(4) = 51.06$, $P < .001$; $U = 81-119$, $P < .001$).

Likewise, mean rank n10 amplitudes were different between controls, VM, and MD ($H(2) = 35.683$, $P < .001$) (Figure 2B). Mann-Whitney U tests demonstrated that (1) compared with controls, n10 amplitudes were reduced in VM ($U = 307$, $P < .001$) and in MD ($U = 149.5$, $P < .001$), whereas (2) no significant differences were observed between VM and MD ($U = 323.5$, $P = .213$). A separated analysis, including the subgroups VML-affected, VML-unaffected, and VMB, revealed that the n10 amplitudes were all reduced compared with controls ($H(4) = 31.561$, $P < .001$; $U = 102-178$, $P < .002$).

oVEMP: 500-Hz TB stimuli—The latency of the n10 response was longer only for the subjects with MD ($P = .041$) (Table 4). The n10 amplitudes between controls, VM, and MD were significantly different ($H(2) = 13.483$, $P < .001$) (Figure 2C). The MD group had lower amplitudes compared with controls ($U = 238.5$, $P = .001$) and to VM ($U = 221$, $P = .007$), whereas no differences were found between controls and VM ($U = 830$, $P = .068$). Mann-Whitney U tests revealed that only MD showed significantly reduced amplitudes compared with controls ($U = 238.5$, $P = .001$).

oVEMP: Reflex hammer midline taps—No significant differences were found between the n10 latencies and amplitudes of controls, VM, or MD in response to this stimulus (n10 latency: $F_{2,104} = 0.129$, $P = .879$; n10 amplitude: $H(2) = 3.126$, $P = .210$) (Table 4; Figure 2D).

oVEMP: Mini-Shaker midline taps—In response to the Mini-Shaker, no significant differences were observed between n10 latencies and amplitudes of controls, VM, or MD (n10 latency: $F_{2,108} = 0.518$, $P = .597$; n10 amplitude: $F_{2,114} = 1.547$, $P = .217$) (Table 4; Figure 2E).

Discussion

Abnormalities in VEMP responses have been documented in both MD and VM. In MD, cVEMP peak-to-peak amplitudes are reduced,^{20–22,24,26} a finding attributed to a hydropic sacculus. This was recently supported by abnormal VEMP recordings using a mouse model with hydrops and known vestibular abnormalities.³⁹

In VM, cVEMP peak-to-peak amplitudes are also abnormally reduced compared with controls.^{11,16} In addition, Baier et al¹³ found no significant differences between cVEMP peak-to-peak amplitudes of VM patients and MD patients. Although they used a 400-Hz TB to elicit cVEMP responses and we used clicks as stimulus for cVEMPs, our results corroborate theirs. Furthermore, our results from click-evoked oVEMP in VM are similar to those of click-evoked cVEMP: the response amplitude in VM is significantly reduced

compared with controls. Therefore, we found no significant differences between VM and MD in click-evoked cVEMP or oVEMP results.

In contrast, using 500-Hz TBs, n10 amplitudes seemed to separate VM and MD, with decreased amplitudes found only in MD (Figure 2C). Thus, the answer to the question, “Can VEMPs help differentiate MD from VM?” is yes, but only insofar as to separate the 2 groups. However, one can see from the raw data that there is considerable overlap of individual oVEMP amplitudes between the MD, VM, and control data. Therefore, data from a single individual cannot be used to discriminate VM vs MD. A low oVEMP result in response to a 500-Hz TB does not rule out VM nor clinch the diagnosis of MD. This is true for both cVEMPs and oVEMPs in response to ACS. Furthermore, one could conclude that an n10 amplitude above 5 microvolts would rule out MD. However, there are reports demonstrating some cases of MD with larger oVEMP amplitude, probably resulting from a transient state of vestibular hyperactivity in the excitatory phase of MD.^{24,40} Thus, an oVEMP amplitude >5 microvolts must be interpreted with caution.

A limitation of this study is that we used only click noise for ACS stimuli and not TB to investigate the cVEMP response. Instead, we sought to streamline the testing and limit fatigue of the SCM muscle. Differences between cVEMPs in response to TB stimuli in MD vs VM have been reported in the literature but with conflicting results. Murofushi et al¹⁵ did not observe reduced TB-evoked cVEMP amplitudes in VM compared to controls but did report differences between MD and VM cVEMP amplitudes, contrary to the findings of Baier et al.¹³

We observed that the oVEMP response to midline taps at F_z does not result in useful separation between controls, VM, or MD. These findings do not seem unexpected because the involvement of the utricle has been reported to be less than that of the saccule in MD.^{25,41–43} Furman et al¹⁰ found normal oVEMP results in evaluating utricular function in patients with migraine, patients with VM, and controls. Moreover, the midline taps are relatively vigorous stimuli that may require greater utricular impairment to show abnormal responses.²⁴

Overall, we observed that, as groups, VM and MD behave similarly on most VEMP tests. There are several possible explanations for this observation. (1) MD and VM may reflect a spectrum, with a possible covert labyrinthine disease in VM.^{2,6,7,44–46} The work of Vass et al^{47,48} has provided evidence to support changes in inner ear vascular permeability that may result from trigeminovascular stimulation in migraine. They suggest the release of vasoactive peptides with consequent stimulation of transient receptor potential vanilloid type 1 (TRPV1) could produce labyrinthine symptoms in VM. Furthermore, some authors have suggested that when these changes recur, the inner ear is damaged and endolymphatic hydrops results.^{2,7,49} (2) Although 5 of our MD patients met criteria for probable VM, subclinical migraine may have been present in other MD patients. Previous studies have reported a higher incidence of migraine (34%–76%) in patients with MD than in controls (13.2%–25%)^{6,45,50} and a higher incidence of MD (7.5%) in migraineurs than in the general population (1%).⁵¹ Nevertheless, our results in MD patients are comparable with the results of other studies in patients with MD.^{24–26,52,53} (3) In both MD and VM, there may be central changes in the otolith-ocular and otolith-cervical reflexes that decrease the gain of the reflexes to reduce the symptoms of vertigo that result during attacks of either disorder. The result in VEMP testing would therefore be similar between the groups, regardless of labyrinthine pathology. (4) There exists a possibility that our VML cases are actually MD with an audiometric hearing loss insufficient to meet AAO-HNS criteria for definite unilateral MD. We think this is unlikely given that 77% of VM patients reported the presence of triggers, a feature that improves diagnostic accuracy,⁵⁴ and that each subject

with VM met rigorous criteria for the diagnosis. Nevertheless, it is important to bear in mind that the diagnoses of VM and MD are based solely on clinical criteria and that key features for the differentiation between these have not yet been identified. Therefore, there is a possibility that we have grouped as separate entities what is part of the same pathophysiology (see possibility [1] above).

More studies are needed to determine whether VM is a disorder with central or peripheral pathology. In our work, we provide evidence of possible peripheral vestibular abnormalities in VM occurring not only in the vestibulospinal tract but also in the vestibulo-ocular pathway, as shown by reduced cVEMP and oVEMP amplitudes. Furthermore, the latency of VEMPs in VM was not different from those of controls. Prolonged latencies have been reported in the damaged brainstem.^{55–58} The stability of VEMP latency in VM relative to controls might argue against a central pathology but only insofar as it does not include structural damage such as demyelination. Nondestructive central changes, such as spreading depression or alteration in brainstem nuclear sensitivity, cannot be ruled out. Indeed, as argued by Baier et al,¹¹ a central abnormality may explain the high prevalence of bilaterally reduced or absent VEMP responses. A central reduction in vestibular reflex gain might be an adaptive brainstem response to vertigo, one that would affect reflex output bilaterally. Ironically, we found oVEMP latencies to be slightly increased in MD in response to ACS, which a central adaptation to a peripheral source of vertigo in MD might explain. However, one must be careful not to overinterpret latency values because the response amplitudes were low in both MD and VM at the highest stimulus levels. Thus, the reliability of the associated latency estimates was not as high as in control responses.

Conclusions

Vestibular migraine and MD behave similarly on most VEMP tests, possibly reflecting a link in their pathophysiology. The oVEMP responses to a 500-Hz TB may separate MD from VM as *groups*. However, no VEMP test investigated here can presently segregate individuals with MD from those with VM.

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References

1. Cutrer FM, Baloh RW. Migraine-associated dizziness. *Headache*. 1992; 32:300–304. [PubMed: 1399552]
2. Baloh RW. Neurotology of migraine. *Headache*. 1997; 37:615–621. [PubMed: 9439080]
3. Dieterich M, Brandt T. Episodic vertigo related to migraine (90 cases): vestibular migraine? *J Neurol*. 1999; 246:883–892. [PubMed: 10552234]
4. Neuhauser H, Leopold M, von Brevern M, Arnold G, Lempert T. The interrelations of migraine, vertigo, and migrainous vertigo. *Neurology*. 2001; 56:436–441. [PubMed: 11222783]
5. Rassekh CH, Harker LA. The prevalence of migraine in Meniere’s disease. *Laryngoscope*. 1992; 102:135–138. [PubMed: 1738284]
6. Radtke A, Lempert T, Gresty MA, Brookes GB, Bronstein AM, Neuhauser H. Migraine and Meniere’s disease: is there a link? *Neurology*. 2002; 59:1700–1704. [PubMed: 12473755]
7. Ibekwe TS, Fasunla JA, Ibekwe PU, Obasikene GC, Onakoya PA, Nwaorgu OG. Migraine and Meniere’s disease: two different phenomena with frequently observed concomitant occurrences. *J Natl Med Assoc*. 2008; 100:334–338. [PubMed: 18390027]

8. Cha YH, Brodsky J, Ishiyama G, Sabatti C, Baloh RW. The relevance of migraine in patients with Meniere's disease. *Acta Otolaryngol.* 2007; 127:1241–1245. [PubMed: 17851970]
9. von Brevern M, Zeise D, Neuhauser H, Clarke AH, Lempert T. Acute migrainous vertigo: clinical and oculographic findings. *Brain.* 2005; 128:365–374. [PubMed: 15601663]
10. Furman JM, Sparto PJ, Soso M, Marcus D. Vestibular function in migraine-related dizziness: a pilot study. *J Vestib Res.* 2005; 15:327–332. [PubMed: 16614477]
11. Baier B, Stieber N, Dieterich M. Vestibular-evoked myogenic potentials in vestibular migraine. *J Neurol.* 2009; 256:1447–1454. [PubMed: 19377861]
12. Boldingh MI, Ljostad U, Mygland A, Monstad P. Vestibular sensitivity in vestibular migraine: VEMPs and motion sickness susceptibility. *Cephalalgia.* 2011; 31:1211–1219. [PubMed: 21768183]
13. Baier B, Dieterich M. Vestibular-evoked myogenic potentials in “vestibular migraine” and Meniere's disease: a sign of an electrophysiological link? *Ann N Y Acad Sci.* 2009; 1164:324–327. [PubMed: 19645919]
14. Hong SM, Kim SK, Park CH, Lee JH. Vestibular-evoked myogenic potentials in migrainous vertigo. *Otolaryngol Head Neck Surg.* 2011; 144:284–287. [PubMed: 21493432]
15. Murofushi T, Ozeki H, Inoue A, Sakata A. Does migraine-associated vertigo share a common pathophysiology with Meniere's disease? Study with vestibular-evoked myogenic potential. *Cephalalgia.* 2009; 29:1259–1266. [PubMed: 19911463]
16. Roceanu A, Allena M, De Pasqua V, Bisdorff A, Schoenen J. Abnormalities of the vestibulo-colic reflex are similar in migraineurs with and without vertigo. *Cephalalgia.* 2008; 28:988–990. [PubMed: 18624802]
17. McCue MP, Guinan JJ Jr. Influence of efferent stimulation on acoustically responsive vestibular afferents in the cat. *J Neurosci.* 1994; 14:6071–6083. [PubMed: 7931563]
18. Colebatch JG, Halmagyi GM, Skuse NF. Myogenic potentials generated by a click-evoked vestibulocollic reflex. *J Neurol Neurosurg Psychiatry.* 1994; 57:190–197. [PubMed: 8126503]
19. McCue MP, Guinan JJ Jr. Sound-evoked activity in primary afferent neurons of a mammalian vestibular system. *Am J Otol.* 1997; 18:355–360. [PubMed: 9149831]
20. de Waele C, Huy PT, Diard JP, Freyss G, Vidal PP. Saccular dysfunction in Meniere's disease. *Am J Otol.* 1999; 20:223–232. [PubMed: 10100527]
21. Rauch SD, Zhou G, Kujawa SG, Guinan JJ, Herrmann BS. Vestibular evoked myogenic potentials show altered tuning in patients with Meniere's disease. *Otol Neurotol.* 2004; 25:333–338. [PubMed: 15129114]
22. Lin MY, Timmer FC, Oriel BS, et al. Vestibular evoked myogenic potentials (VEMP) can detect asymptomatic saccular hydrops. *Laryngoscope.* 2006; 116:987–992. [PubMed: 16735912]
23. Kim-Lee Y, Ahn JH, Kim YK, Yoon TH. Tone burst vestibular evoked myogenic potentials: diagnostic criteria in patients with Meniere's disease. *Acta Otolaryngol.* 2009; 129:924–928. [PubMed: 18979269]
24. Taylor RL, Wijewardene AA, Gibson WP, Black DA, Halmagyi GM, Welgampola MS. The vestibular evoked-potential profile of Meniere's disease. *Clin Neurophysiol.* 2011; 122:1256–1263. [PubMed: 21168362]
25. Huang CH, Wang SJ, Young YH. Localization and prevalence of hydrops formation in Meniere's disease using a test battery. *Audiol Neurotol.* 2011; 16:41–48. [PubMed: 20516681]
26. Chiarovano E, Zamith F, Vidal PP, de Waele C. Ocular and cervical VEMPs: a study of 74 patients suffering from peripheral vestibular disorders. *Clin Neurophysiol.* 2011; 122:1650–1659. [PubMed: 21306945]
27. Manzari L, Tedesco AR, Burgess AM, Curthoys IS. Ocular and cervical vestibular-evoked myogenic potentials to bone conducted vibration in Meniere's disease during quiescence vs during acute attacks. *Clin Neurophysiol.* 2010; 121:1092–1101. [PubMed: 20202901]
28. Iwasaki S, McGarvie LA, Halmagyi GM, et al. Head taps evoke a crossed vestibulo-ocular reflex. *Neurology.* 2007; 68:1227–1229. [PubMed: 17420408]
29. Iwasaki S, Smulders YE, Burgess AM, et al. Ocular vestibular evoked myogenic potentials to bone conducted vibration of the midline forehead at Fz in healthy subjects. *Clin Neurophysiol.* 2008; 119:2135–2147. [PubMed: 18639490]

30. Manzari L, Tedesco A, Burgess AM, Curthoys IS. Ocular vestibular-evoked myogenic potentials to bone-conducted vibration in superior vestibular neuritis show utricular function. *Otolaryngol Head Neck Surg.* 2010; 143:274–280. [PubMed: 20647134]
31. Manzari L, Burgess AM, Curthoys IS. Effect of bone-conducted vibration of the midline forehead (Fz) in unilateral vestibular loss (uVL): evidence for a new indicator of unilateral otolithic function. *Acta Otorhinolaryngol Ital.* 2010; 30:175. [PubMed: 21253282]
32. Yang TH, Liu SH, Young YH. Evaluation of guinea pig model for ocular and cervical vestibular-evoked myogenic potentials for vestibular function test. *Laryngoscope.* 2010; 120:1910–1917. [PubMed: 20717941]
33. Welgampola MS, Carey JP. Waiting for the evidence: VEMP testing and the ability to differentiate utricular versus saccular function. *Otolaryngol Head Neck Surg.* 2010; 143:281–283. [PubMed: 20647135]
34. Curthoys IS, Manzari L. Evidence missed: ocular vestibular-evoked myogenic potential and cervical vestibular-evoked myogenic potential differentiate utricular from saccular function. *Otolaryngol Head Neck Surg.* 2011; 144:751–752. [PubMed: 21493346]
35. Papathanasiou ES. Ocular vestibular evoked myogenic potentials (OVEMPs): saccule or utricle? *Clin Neurophysiol.* 2011 [Epub ahead of print].
36. Committee on Hearing and Equilibrium guidelines for the diagnosis and evaluation of therapy in Meniere's disease. American Academy of Otolaryngology–Head and Neck Foundation, Inc. *Otolaryngol Head Neck Surg.* 1995; 113:181–185. [PubMed: 7675476]
37. Radtke A, Neuhauser H, von Brevern M, Hottenrott T, Lempert T. Vestibular migraine—validity of clinical diagnostic criteria. *Cephalalgia.* 2011; 31:906–913. [PubMed: 21508087]
38. Nguyen KD, Welgampola MS, Carey JP. Test-retest reliability and age-related characteristics of the ocular and cervical vestibular evoked myogenic potential tests. *Otol Neurotol.* 2010; 31:793–802. [PubMed: 20517167]
39. Sheykholslami K, Megerian CA, Zheng QY. Vestibular evoked myogenic potentials in normal mice and Phex mice with spontaneous endolymphatic hydrops. *Otol Neurotol.* 2009; 30:535–544. [PubMed: 19300299]
40. Young YH, Wu CC, Wu CH. Augmentation of vestibular evoked myogenic potentials: an indication for distended saccular hydrops. *Laryngoscope.* 2002; 112:509–512. [PubMed: 12148863]
41. Paparella MM. The cause (multifactorial inheritance) and pathogenesis (endolymphatic malabsorption) of Meniere's disease and its symptoms (mechanical and chemical). *Acta Otolaryngol.* 1985; 99:445–451. [PubMed: 4013733]
42. Schuknecht HF. Endolymphatic hydrops: can it be controlled? *Ann Otol Rhinol Laryngol.* 1986; 95:36–39. [PubMed: 3947002]
43. Okuno T, Sando I. Localization, frequency, and severity of endolymphatic hydrops and the pathology of the labyrinthine membrane in Meniere's disease. *Ann Otol Rhinol Laryngol.* 1987; 96:438–445. [PubMed: 3619290]
44. Lee H, Lopez I, Ishiyama A, Baloh RW. Can migraine damage the inner ear? *Arch Neurol.* 2000; 57:1631–1634. [PubMed: 11074796]
45. Parker W. Meniere's disease: etiologic considerations. *Arch Otolaryngol Head Neck Surg.* 1995; 121:377–382. [PubMed: 7702810]
46. Teggi R, Fabiano B, Recanati P, Limardo P, Bussi M. Case reports on two patients with episodic vertigo, fluctuating hearing loss and migraine responding to prophylactic drugs for migraine. Meniere's disease or migraine-associated vertigo? *Acta Otorhinolaryngol Ital.* 2010; 30:217. [PubMed: 21253289]
47. Vass Z, Steyger PS, Hordichok AJ, Trune DR, Jancso G, Nuttall AL. Capsaicin stimulation of the cochlea and electric stimulation of the trigeminal ganglion mediate vascular permeability in cochlear and vertebro-basilar arteries: a potential cause of inner ear dysfunction in headache. *Neuroscience.* 2001; 103:189–201. [PubMed: 11311800]
48. Vass Z, Dai CF, Steyger PS, Jancso G, Trune DR, Nuttall AL. Co-localization of the vanilloid capsaicin receptor and substance P in sensory nerve fibers innervating cochlear and vertebrobasilar arteries. *Neuroscience.* 2004; 124:919–927. [PubMed: 15026132]

49. Straube A, Rauch SD. Vertigo and migraine: a more than twofold connection. *Cephalalgia*. 2010; 30:774–776. [PubMed: 20647168]
50. Victor TW, Hu X, Campbell JC, Buse DC, Lipton RB. Migraine prevalence by age and sex in the United States: a life-span study. *Cephalalgia*. 2010; 30:1065–1072. [PubMed: 20713557]
51. Kayan A, Hood J. Neuro-otological manifestations of migraine. *Brain*. 1984; 107:1123–1142. [PubMed: 6334543]
52. Young YH, Huang TW, Cheng PW. Assessing the stage of Meniere's disease using vestibular evoked myogenic potentials. *Arch Otolaryngol Head Neck Surg*. 2003; 129:815–818. [PubMed: 12925337]
53. Hong SM, Yeo SG, Kim SW, Cha CI. The results of vestibular evoked myogenic potentials, with consideration of age-related changes, in vestibular neuritis, benign paroxysmal positional vertigo, and Meniere's disease. *Acta Otolaryngol*. 2008; 128:861–865. [PubMed: 18607943]
54. Cohen JM, Bigal ME, Newman LC. Migraine and vestibular symptoms: identifying clinical features that predict "vestibular migraine". *Headache*. 2011; 51:1393–1397. [PubMed: 21649658]
55. Sartucci F, Logi F. Vestibular-evoked myogenic potentials: a method to assess vestibulo-spinal conduction in multiple sclerosis patients. *Brain Res Bull*. 2002; 59:59–63. [PubMed: 12372550]
56. Bandini F, Beronio A, Ghiglione E, Solaro C, Parodi RC, Mazzella L. The diagnostic value of vestibular evoked myogenic potentials in multiple sclerosis. *J Neurol*. 2004; 251:617–621. [PubMed: 15164200]
57. Eleftheriadou A, Deftereos SN, Zarikas V, et al. The diagnostic value of earlier and later components of vestibular evoked myogenic potentials (VEMP) in multiple sclerosis. *J Vestib Res*. 2009; 19:59–66. [PubMed: 19893198]
58. Murofushi T, Shimizu K, Takegoshi H, Cheng PW. Diagnostic value of prolonged latencies in the vestibular evoked myogenic potential. *Arch Otolaryngol Head Neck Surg*. 2001; 127:1069–1072. [PubMed: 11556854]

Figure 1.

Prevalence (%) of aural and nonaural symptoms in vestibular migraine (VM) for each subgroup: VML (patients referring aural symptoms constantly to one ear) and VMB (aural symptoms fluctuating between ears).

Figure 2.

Vestibular-evoked myogenic potential (VEMP) results in the ears (circles) of controls, vestibular migraine (VM), and Ménière disease (MD), depicted by age decade (in years: <40, 40s, 50s, >60) within each group. (A) Click-evoked cervical VEMP (cVEMP) peak-to-peak amplitudes. (B) Click-evoked ocular VEMP (oVEMP) n10 amplitudes. (C) The 500-Hz tone burst (TB)-evoked oVEMP n10 amplitudes. (D) The oVEMP n10 amplitudes in response to midline taps using the reflex hammer. (E) The oVEMP n10 amplitudes in response to midline taps using the Mini-Shaker. Dashed lines show median values, except for the Mini-Shaker amplitudes (E), where the dashed line represents the mean; squares (□) illustrate MD ears that also met criteria for VM; identical values are aligned horizontally.

Table 1Modified Diagnostic Criteria of Definite and Probable Vestibular Migraine (VM) by Radtke et al³⁷

	Definite VM	Probable VM
A. At least 2 attacks of vestibular vertigo ^a	Yes	Yes
B. Current or previous history of migraine with or without aura according to the International Classification of Headache Disorders (ICHD)	Yes	One of either B or C
C. Concomitant migrainous symptoms ^b during at least 2 vertigo attacks	Yes	
D. No evidence of other central or otological causes of vertigo	Yes	Yes

^aVestibular vertigo: rotational vertigo, other illusory self or object motion, positional vertigo, head motion intolerance (ie, sensation of imbalance or illusory self or object motion that is provoked by head motion).

^bMigrainous symptoms: migrainous headaches, photophobia, phonophobia, visual or other auras.

Table 2**Study Population**

	No.	Ears, No.	Age, y			Female	Male
			Mean	Minimum	Maximum		
Controls	28	56	48	26–71		15	13
MD	20	20	50	15–72		7	13
VM	21	42	48	21–76		14	7
VML	13	13	49	21–79		8	5
VMB	8	16	48	33–63		6	2

Abbreviations: MD, Ménière disease; VM, vestibular migraine; VMB, vestibular migraine patients with symptoms in both ears; VML, vestibular migraine patients who lateralize symptoms to one ear.

Table 3

cVEMP and oVEMP Response Rates (%) of Ears in the Different Participant Groups

	Control (56 Ears)	MD (20 Ears)	VM (42 Ears)	VML-Affected (13 Ears)	VML-Unaffected (13 Ears)	VMB (16 Ears)
cVEMP (clicks)	100	80	69	62	62	81
oVEMP (clicks)	96	50	50	46	54	56
oVEMP (500-Hz TB)	96	90	86	77	100	81
oVEMP (Hammer)	100	90	90	85	100	88
oVEMP (MS)	98	95	88	85	77	100

Percentages estimated based on the number of ears of each group.

Abbreviations: cVEMP, cervical vestibular-evoked myogenic potential; Hammer, reflex hammer; MD, Ménière disease; MS, Mini-Shaker; oVEMP, ocular vestibular-evoked myogenic potential; TB, tone burst; VM, vestibular migraine; VMB, vestibular migraine patients with symptoms in both ears; VML, vestibular migraine patients who lateralize symptoms to one ear.

Table 4

Latency Mean (SD) and Amplitude Median (Range) of cVEMPs and oVEMPs

	Control	MD	VM	VML-Affected	VML-Unaffected	VMB
Latency						
Click cVEMP p13	11.8 (1.2)	11.8 (1.4)	11.2 (1.2)	12.0 (1.5)	11.1 (0.5)	11.5 (1.5)
Click cVEMP n23	19.6 (3.1)	19.5 (2.5)	18.2 (2.0)	18.3 (2.2)	18.7 (1.5)	17.8 (2.3)
Click oVEMP n10	9.4 (1.5)	11.1 (2.0)	9.8 (1.1)	9.4 (1.3)	10.0 (0.8)	0.0 (1.2)
500-Hz TB oVEMP n10	10.4 (0.9)	11.1 (1.7)	10.4 (0.8)	10.5 (0.9)	10.1 (0.5)	10.4 (0.9)
Hammer oVEMP n10	8.0 (4.8)	8.0 (1.9)	7.5 (0.9)	7.5 (0.8)	7.3 (0.6)	7.7 (1.2)
MS oVEMP n10	9.6 (1.1)	9.8 (1.4)	9.8 (1.6)	10.1 (1.8)	9.6 (1.3)	9.8 (1.6)
Amplitude						
Click cVEMP peak-to-peak	102.7 (33–43)	29 (0–116)	38.1 (0–136)	37.3 (0–128)	39.4 (0–136)	39.45 (0–90)
Click oVEMP n10	1.85 (0–8.9)	0.33 (0–2.2)	0.0 (0–4)	0.0 (0–2.7)	0.14 (0–4)	0.16 (0–6.5)
500-Hz TB oVEMP n10	5.95 (0–14.2)	0.98 (0–3.7)	3.4 (0–11.5)	1.8 (0–11.5)	3.8 (0.3–9.6)	3.4 (0–7)
Hammer oVEMP n10	5.7 (0.25–37)	4.6 (0–12)	5.45 (0–18)	3.7 (0–11)	5.6 (0.22–16)	8.8 (0–28)
MS oVEMP n10 ^a	5.4 (3.9)	3.9 (4.9)	5.0 (4.7)	3.9 (3.0)	3.8 (3.7)	6.8 (6.0)

Latencies: mean (SD) expressed in milliseconds. Amplitude: median (range) expressed in microvolts.

Abbreviations: cVEMP, cervical vestibular-evoked myogenic potential; Hammer, reflex hammer; MD, Ménière disease; MS, Mini-Shaker; oVEMP, ocular vestibular-evoked myogenic potential; TB, tone burst; VM, vestibular migraine; VMB, vestibular migraine patients with symptoms in both ears; VML, vestibular migraine patients who lateralize symptoms to one ear.

^aMean (SD) Mini-Shaker amplitude.