The Journal of Laryngology & Otology (2013), ***127***, *848–853*.

doi:10.1017/S0022215113001655

MAIN ARTICLE

Role of cervical vestibular evoked myogenic potential response in identifying vestibular dysfunction

S ISARADISAIKUL, N NAVACHAROEN, C HANPRASERTPONG, J KANGSANARAK

Department of Otolaryngology, Faculty of Medicine, Chiang Mai University, Thailand

Abstract

Objectives: To analyse cervical vestibular evoked myogenic potential response parameters in normal volunteers and vertiginous patients.

Subjects and methods: A prospective study of 50 normal subjects and 50 patients with vertigo was conducted at Chiang Mai University Hospital, Thailand. Cervical vestibular evoked myogenic potential responses were measured using air-conducted, 500-Hz, tone-burst stimuli with subjects in a sitting position with their head turned toward the contralateral shoulder.

Results: The mean ± standard deviation age and male:female ratio in the normal (44.0 ± 9.3 years; 12:38) and vertigo groups (44.7 ± 9.8 years; 17:33) were not significantly different. The prevalence of absent responses in the normal (14 per cent) and vertigo ears (46 per cent) differed significantly ($p < 0.0001$). Other cervical vestibular evoked myogenic potential parameters (i.e. response threshold, P1 and N1 latency, P1–N1 interlatency and interamplitude, inter-ear difference in P1 threshold, and asymmetry ratio) showed no inter-group differences.

Conclusion: The absence of a cervical vestibular evoked myogenic potential response is useful in the identification of vestibular dysfunction. However, patients should undergo a comprehensive battery of other vestibular tests to supplement their cervical vestibular evoked myogenic potential response findings.

Key words: Vestibular Evoked Myogenic Potentials; Vestibular Function Tests; Vertigo; Diagnosis

Introduction

Clinicians base their diagnosis of vertigo mainly on complete history taking and physical examination. In some instances, vestibular function tests are required for confirmation. Although such tests are performed to objectively and quantitatively assess the vestibular system, no single vestibular function test can assess the entire vestibular system.[1] Traditional electronystagmography (ENG) and rotatory chair testing evaluate primarily the lateral semicircular canal function, i.e. the superior vestibular nerve. The cervical vestibular evoked myogenic potential (VEMP) assesses the integrity of different vestibular pathways, i.e. the inferior vestibular nerve and saccule.[2] Other laboratory vestibular function tests, such as unilateral centrifugation, off-vertical axis rotation and galvanic stimulation, are mainly limited to research facilities.[1] Compared with other functional tests, cervical VEMP testing has the advantage of requiring less time and less patient co-operation, and is also more easily tolerated by patients. Most auditory brainstem response recording systems can be upgraded to include cervical VEMP assessment.

In 1964, Bickford *et al.*[3] described the short latency potential myogenic responses to clicks recorded with an active electrode placed just below the inion. Townsend and Cody[4] provided evidence suggesting that the inion response evoked by a 1000-Hz, pure-tone stimulation was mediated by either the saccule or the utricle. Colebatch *et al.*[5] reported an electromyography (EMG) response evoked by clicks, recorded from surface electrodes placed over the sternocleidomastoid muscles. They proposed that the first biphasic positive–negative (i.e. p13–n23, or P1–N1) response was generated by activation of vestibular afferents, possibly those arising from the saccule, and transmitted via a rapidly conducting oligosynaptic pathway to the anterior neck muscles. They believed that the second biphasic response (p34–n44, or P2–N2) probably originated from cochlear afferents. The first response was more consistent than the second response, and was present in the majority of healthy subjects.[5]

Presented at the American Academy of Otolaryngology – Head and Neck Surgery Foundation 115th Annual Meeting and Oto Expo, 11–14 September 2011, San Francisco, California, USA
Accepted for publication 14 November 2012 First published online 8 August 2013

Cervical VEMP responses represent short-latency EMG deflections recorded from surface electrodes placed over the tonically contracted sternocleidomastoid muscle, and produced in response to high-level acoustic stimuli.[6] Cervical VEMP testing assesses vestibular function through the vestibulo-collic reflex, including the receptor (the saccule), the afferent pathway (the inferior vestibular nerve) and the efferent pathway (the lateral and medial vestibulo-spinal tracts and the sternocleidomastoid muscle).[2] Cervical VEMP testing produces a more reliable and robust response, and evidence supports its clinical value above that of ocular VEMP testing.[7,8]

The cervical VEMP parameters generally used for interpretation include the presence or absence of response, threshold, latency of P1 and N1, and P1–N1 interamplitude. Less commonly used parameters include the P1–N1 interlatency, interaural difference of P1 and N1 latency, and asymmetry ratio.

The aim of this study was to compare cervical VEMP response parameters in normal volunteers and vertiginous patients.

Subjects and methods

Fifty patients with vertigo and 50 normal subjects, aged between 18 and 60 years, were recruited for the study. The distribution of age and gender was similar in the two groups. There was no significant difference in the mean age in the normal group (mean age ± standard deviation (SD), 44.0 ± 9.3 years) versus the vertigo group (44.7 ± 9.8 years) ($p = 0.708$), nor in the male:female ratio in the normal (12:38) versus vertigo groups (17:33) ($p = 0.271$). None of the normal subjects had any history of ear disease or vestibular or neurological disorders, and all had normal otological and audiometric examinations. All vertigo group patients had a confirmed diagnosis of vertigo based on clinical symptoms, physical examination and the further investigations required for each disorder.

Electrode positioning sites were cleaned with alcohol and scrubbed with an abrasive skin preparation. Gold cup electrodes filled with conductive paste were placed over the middle of the sternocleidomastoid muscle (active electrode), the upper sternum (reference electrode) and the forehead (ground electrode). Air-conducted, alternating, 500-Hz tone-bursts, starting at 120 dB sound pressure level (dBSPL) intensity (with 98 dB taken as the normal hearing level (dBnHL)), were presented unilaterally via an ER3A inserted earphone (Etymotic Research, Elk Grove Village, Illinois, USA). Subjects were placed in a sitting position with their head turned toward the contralateral side, maintaining tonic contraction of the sternocleidomastoid muscle at 30–75 μV with visual feedback. Subjects underwent a minimum of two cervical VEMP response replications, resting between each recording. The EMG signals were amplified (×5000) and filtered (bandpass 10–1500 Hz). The recording was made with a time window of −20 to 80 milliseconds, using the Intelligent Hearing System (Miami, Florida, USA). Response thresholds were determined using a 'down 10 dB, up 5 dB' step procedure, to obtain the lowest stimulus intensity that evoked a cervical VEMP response. Cervical VEMP measures were calculated by averaging responses to 200 stimuli at an intensity of 120 dBSPL (98 dBnHL).

The cervical VEMP parameters analysed included response threshold, P1 latency, N1 latency, P1–N1 interlatency, P1–N1 interamplitude, absolute inter-ear difference in P1 threshold, and asymmetry ratios. The asymmetry ratio was calculated by dividing the inter-ear difference for the P1–N1 interamplitude by the sum of both ears.[9,10]

Data were analysed using the Statistical Package for the Social Science (SPSS) software package (SPSS Inc, Chicago, Illinois, USA). Differences in cervical VEMP response (i.e. presence or absence) were analysed using the chi-square test, and other parameters using the Student *t*-test. A p value of 0.05 or less was considered statistically significant.

The research protocol was approved by the Ethics Committee of the Faculty of Medicine, Chiang Mai University. The study was conducted with the understanding and consent of all subjects.

Results

Fifty-nine of the 100 ears in the vertigo group had confirmed diagnoses, for a total of 11 different vestibular disorders. The duration of patients' symptoms ranged from 1 day to 6 years. The right ear was affected in 19 cases, the left in 22 and both in 6, while the affected side was unidentified in 3 cases. Two cases had a different diagnosis for each ear. Diagnoses included benign paroxysmal positional vertigo (BPPV; 16 ears), Ménière's disease (23 ears), idiopathic sudden sensorineural hearing loss (SNHL; 4 ears) and acoustic neuroma (4 ears). Other diagnoses included otosyphilis, autoimmune inner ear disease, migraine-associated vertigo, vestibular neuritis, superior canal dehiscence syndrome, Ramsay Hunt syndrome and delayed endolymphatic hydrops.

No other vestibular function tests were conducted in the control group. Electronystagmography was performed in two Ménière's disease cases. The ENG results were not correlated with the VEMP results. Patients with asymmetrical SNHL were evaluated for retrocochlear pathology using auditory brainstem response (ABR) testing. If ABR results were abnormal, further assessment was performed involving magnetic resonance imaging (MRI) of the internal acoustic canal.

The patients with BPPV presented with brief episodes of recurrent vertigo. All cases were confirmed by positive Dix–Hallpike testing. Ménière's disease was diagnosed following the 1995 American Academy of Otolaryngology–Head and Neck Surgery criteria. Idiopathic sudden SNHL was diagnosed in cases with abrupt onset of decreased hearing

https://doi.org/10.1017/S0022215113001655 Published online by Cambridge University Press

TABLE I
CERVICAL VEMP RESPONSES: NORMAL *VS* VERTIGO GROUP

Response	Normal ears (*n*)	Vertigo ears (*n*)	
		Affected	Non-affected
Absent (*n*)	14	27	10
Present (*n*)	86	32	31
Total (*n*)	100	59	41
Absent (%)	14	46	24

For absent response percentage: $p < 0.0001$, normal ears *vs* affected vertigo group ears; $p = 0.029$, affected *vs* non-affected vertigo group ears; $p = 0.136$, normal ears *vs* non-affected vertigo group ears. VEMP = vestibular evoked myogenic potential

of unknown cause. All acoustic neuroma cases were confirmed with MRI of the internal acoustic canal; the size of the tumour varied from 1 to 3 cm. In otosyphilis cases, the Venereal Research Disease Laboratory ('VDRL') and Treponema Pallidum Haemagglutination ('TPHA') tests were positive. Autoimmune inner ear disease was diagnosed in a 38-year-old woman who suffered from rheumatoid arthritis and Graves' disease and who presented with bilateral sudden deafness. Patients with migraine-associated vertigo complained of unilateral throbbing headache with an aura; other symptoms related to basilar migraine were denied. Vestibular neuritis was diagnosed in patients with vertigo lasting for hours to days without hearing loss. Superior canal dehiscence syndrome was diagnosed in a man who had his first vertigo attack while diving; his disequilibrium was worsened by the valsalva manoeuvre, his cervical VEMP threshold was low, and computed tomography of the temporal bone showed superior canal dehiscence. The patient with Ramsay Hunt syndrome presented with right facial weakness, with groups of vesicles in the right ear, and right SNHL. Delayed endolymphatic hydrops was diagnosed in a woman with long-standing unilateral deafness who presented with vertigo and who had a normal MRI of the internal acoustic canal.

Cervical VEMP responses were absent in 14 ears (14 per cent; bilateral in 3 and unilateral in 8 subjects) in the normal group, and in 37 ears (37 per cent; bilateral in 10 and unilateral in 17 subjects) in the vertigo group. Of the latter 37 ears, 10 were non-pathological and 27 were pathological. The prevalence of absent cervical VEMP responses in the ears with vestibular disorders, within the vertigo group, (46 per cent) was significantly higher than that in (1) the ears of normal subjects (14 per cent) ($p < 0.0001$), and (2) the non-affected ears in the vertigo group (24 per cent) ($p = 0.029$). The prevalence of cervical VEMP response absence did not differ, comparing the non-affected ears of the vertigo group and the normal group (24 per cent *vs* 14 per cent, respectively; $p = 0.136$) (Table I).

Table II shows results for cervical VEMP parameters in ears with cervical VEMP responses (i.e. 86 ears in normal subjects and 32 vestibular-disordered ears in vertiginous subjects), including response threshold, P1 latency, N1 latency, P1–N1 interlatency and P1–N1 interamplitude. This table also shows *p* values for the comparison of results for normal versus affected ears.

Thirty-nine normal subjects and 23 vertiginous patients had bilateral cervical VEMP responses. Table III shows the interaural differences for various cervical VEMP parameters (i.e. comparing results for one *vs* the other ear) in subjects with bilateral cervical VEMP responses, including response threshold, P1 latency, N1 latency, P1–N1 interlatency, P1–N1 interamplitude and asymmetry ratio.

In the vertigo group, there was no statistically significant difference between the cervical VEMP parameters in ears with vestibular disorders versus non-affected ears, for response threshold ($p = 0.418$), P1 latency ($p = 0.570$), N1 latency ($p = 0.706$), P1–N1 interlatency ($p = 0.311$) or P1–N1 interamplitude ($p = 0.681$).

Discussion

This prospective study analysed cervical VEMP response parameters in normal subjects and in vertiginous patients with certain diagnosed vestibular disorders. We found an 86 per cent prevalence of cervical VEMP response in normal subjects, evoked by 500-Hz, tone-burst stimuli at 120 dB SPL (98 dBnHL), averaging responses to 200 stimuli, while the EMG level was maintained at 30–75 μV in the sitting position with head turned. Reported prevalences of cervical VEMP response to 500-Hz, tone-burst stimulation in normal subjects are shown in Table IV.

Many factors affect the cervical VEMP response. The amplitude of the cervical VEMP response

TABLE II
CERVICAL VEMP PARAMETERS*: NORMAL *VS* AFFECTED VERTIGO GROUP EARS

Parameter	Normal ears	Affected ears†	*p*
Threshold (mean ± SD; dBSPL)	115.1 ± 4.6	115.9 ± 5.4	0.380
P1 latency (mean ± SD; msec)	15.99 ± 2.04	15.96 ± 2.22	0.962
N1 latency (mean ± SD; msec)	23.08 ± 1.50	23.55 ± 2.50	0.324
P1–N1 interlatency (mean ± SD; msec)	7.10 ± 1.95	7.59 ± 2.44	0.261
P1–N1 interamplitude (mean ± SD; μV)	28.36 ± 11.65	32.41 ± 19.16	0.269

*In ears with a cervical vestibular evoked myogenic potential (VEMP) response. †In vertigo group. SD = standard deviation; dBSPL = decibels sound pressure level; msec = milliseconds

https://doi.org/10.1017/S0022215113001655 Published online by Cambridge University Press

TABLE III
CERVICAL VEMP PARAMETER INTERAURAL DIFFERENCES*: NORMAL *VS* VERTIGO GROUP

Parameter	Interaural diff (mean ± SD)		*p*
	Normal grp	Vertigo grp	
Response threshold (dBSPL)	3.6 ± 3.6	4.6 ± 4.5	0. 353
P1 latency (msec)	1.75 ± 1.41	1.21 ± 1.31	0.145
N1 latency (msec)	1.20 ± 0.83	1.83 ± 1.45	0.066
P1–N1 interlatency (msec)	1.62 ± 1.20	1.75 ± 1.17	0.687
P1–N1 interamplitude (μV)	7.98 ± 6.85	10.80 ± 10.44	0.204
Asymmetry ratio (%)	14.22 ± 9.42	15.48 ± 12.22	0.652

*In subjects with bilateral responses. VEMP = vestibular evoked myogenic potential; diff = difference; SD = standard deviation; grp = group; dBSPL = decibels sound pressure level; msec = milliseconds

increases with click and tone-burst intensity level but not with cervical VEMP latency. The largest tone-burst evoked cervical VEMP responses, and the lowest response thresholds, are obtained at 500 and 750 Hz.[26] In normal subjects, the best cervical VEMP response is evoked at 500 Hz.[27] Higher response rates are seen with low frequency stimuli (100 per cent at 250 and 500 Hz), compared with high frequency stimuli (97.5 per cent at 1000 Hz and 87 per cent at 2000 Hz).[12]

In normal subjects, tone-burst evoked cervical VEMP responses tend to exhibit lower stimulus thresholds, larger amplitude, and prolonged P1 and N1 latency, compared with responses evoked by clicks.[13,16,22,24] However, other studies comparing cervical VEMP responses to click and tone-burst stimuli in normal subjects have reported different results: Cheng *et al.*[22] reported response rates of 98 and 88 per cent, while Janky and Shepard[13] reported response rates of 33 and 97 per cent.

TABLE IV
PREVALENCE OF CERVICAL VEMP RESPONSE* IN NORMAL SUBJECTS: PUBLISHED FINDINGS

Study	Cases (*n*)	cVEMP (%)
Present	50	86
Chiarovano *et al.*[11]	32	100
De Oliveira Barreto *et al.*[12]	78	100
Janky & Shepard[13]	46	97
Maes *et al.*[14]	61	100
Isaradisaikul *et al.*[15]	20	87
Wu *et al.*[16]	22	100
Picciotti *et al.*[17]	40	100
Kelsch *et al.*[18]	30	100
Wang & Young[19]	20	100
Basta *et al.*[20]	64	100
Su *et al.*[21]	80	90
Cheng *et al.*[22]	29	88
Wang & Young[23]	14	100
Patko *et al.*[24]	95	100
Wu *et al.*[25]	16	100

*Evoked by 500-Hz, short tone-burst stimulus. cVEMP = cervical vestibular evoked myogenic potential

The cervical VEMP amplitude depends on the tonic EMG level: the higher the level, the larger the amplitude of the response waveform.[28] An absence of cervical VEMP response could result from the lack of muscle tone or from muscle fatigue due to over-contraction. Subjects should maintain sufficient tonicity of the muscle, although with minimum discomfort, throughout the test, with relaxation of the sternocleidomastoid muscle between tests.

Published protocols for evoking cervical VEMP responses differ in terms of: (1) the target EMG level maintained during testing, i.e. 50 μV,[16] 40–150 μV[15] or 50–200 μV;[19–21] (2) the number of stimuli, i.e. 50,[9] 128,[21,22,29] 200[13,16,19,23,25] or 256;[14,30] and (3) the positioning used to maintain muscle tonicity, i.e. sitting with head turned,[13,14] supine with head raised,[16,21–23,25,29] or recumbent with head raised or turned.[15,30,31] In healthy adults, the average cervical VEMP response amplitude decreases with age, with dramatic drops beyond 60 years.[20,30] All subjects in the present study were younger than 60 years. With reference to other published protocols, the cervical VEMP test protocol used in the present study, and the age of the study subjects, should not have been major causes of difference in response rate or other parameters.

To date, no evidence-based study has confirmed the most useful and reliable cervical VEMP parameter with which to evaluate vestibular disorders. In previous reports, the absence of a cervical VEMP response has been the most common feature identified when interpreting test results.[24,32–35] A good parameter should be reliable, sensitive and able to detect minor dysfunction in the vestibulo-collic reflex. The reliability of the cervical VEMP parameters in normal subjects has differed between reports. Parameters generally evaluated for reliability include response threshold, P1 and N1 latency, P1–N1 interamplitude, and asymmetry ratio. Isaradisaikul *et al.*[15] have previously assessed cervical VEMP response parameters in the presence of EMG monitoring, and found that P1–N1 interamplitude, asymmetry ratio, N1 latency and response threshold showed greater reliability than P1 latency. Nguyen *et al.*[31] studied cervical VEMP evoked by tone-burst stimulus, and found that N1 latency and P1–N1 peak-to-peak amplitude showed greater reliability than P1 latency and asymmetry ratio. Maes *et al.*[14] reported greater reliability for P1 and N1 latency, response threshold, and P1–N1 interamplitude than for asymmetry ratio. Versino *et al.*[36] reported that P1 and N1 latency were more reliable than P1–N1 interamplitude.

In studies assessing the use of cervical VEMP responses to discriminate between patients with and without vestibular dysfunction, the absence of a cervical VEMP response has been the only parameter which differed between these groups. Table V shows

https://doi.org/10.1017/S0022215113001655 Published online by Cambridge University Press

TABLE V
PREVALENCE OF ABSENT CERVICAL VEMP RESPONSE* IN PATIENTS WITH VARIOUS VESTIBULAR DISORDERS: PUBLISHED FINDINGS

Vestibular disorder	Study	Cases (*n*)	cVEMP (%)
Acoustic neuroma	Present	4	75
	Chiarovano *et al.*[11]	12	50
	Ushio *et al.*[37]	78	80.8
	Patko *et al.*[24]	170	45.9
	Ushio *et al.*[35]	87	67
Ménière's disease	Present	23	48
	Chiarovano *et al.*[11]	26	50
	Akkuzu *et al.*[38]	20	20
	Chen & Young[39]	14	57
	Rauch *et al.*[27]	34	15
	Young *et al.*[40]	40	8
Idiopathic sudden deafness	Present	4	25
	Chen & Young[39]	14	14
	Wu & Young[41]	20	0
Vestibular neuritis	Present	2	0
	Chiarovano *et al.*[11]	12	66
	Govender *et al.*[42]	23	0
Superior canal dehiscence	Present	1	0
	Chiarovano *et al.*[11]	5	80
	Roditi *et al.*[43]	17	0
BPV in childhood	Chang & Young[44]	20	10
Acute vestibulopathy	Faralli *et al.*[45]	20	100
Basilar artery migraine	Liao & Young[46]	20	35
Herpes zoster oticus	Present	1	0
	Lu & Young[47]	8	62

*Evoked by 500-Hz, short tone-burst stimulus. cVEMP = cervical vestibular evoked myogenic potential

published studies reporting the prevalence of absence of cervical VEMP response evoked by 500-Hz, short tone-burst stimulus in different vestibular disorders.

- **The cervical vestibular evoked myogenic potential (VEMP) assesses vestibular function via the vestibulo-collic reflex**
- **To date, there is no strong evidence linking cervical VEMP parameters with specific pathology sites or disease characteristics**
- **This study analysed cervical VEMP responses in normal and vertiginous subjects**
- **Absence of cervical VEMP response was the only parameter differentiating these groups**
- **Cervical VEMP responses should be confirmed with a comprehensive vestibular test battery**

The diagnostic utility of cervical VEMP has been documented in a variety of vestibular disorders. However, there is no strong evidence to support the concept that any particular cervical VEMP parameter can precisely define a specific site of pathology or characteristic of disease.

Conclusion

In this study, the absence of cervical VEMP response was more common in ears with established vestibular pathology than normal ears. However, this finding fails to identify the site of vestibular dysfunction along the vestibulo-collic reflex arc, and provides no evidence of utility in defining a specific disorder. In cases in which a cervical VEMP response is present, other cervical VEMP abnormalities may provide clues in the diagnosis of vestibular disorders. In order to interpret these parameters, clinicians should establish their own protocols and normal reference ranges.

Although the stages of cervical VEMP testing and interpretation are less complicated, and the test is less uncomfortable for the patient than other vestibular function tests, the prevalence of response absence in vestibular disorder ears was only 46 per cent in the present study. Cervical VEMP testing is not a good method with which to exclude vestibular dysfunction. Thus, patients should undergo a comprehensive battery of other vestibular tests in order to confirm their cervical VEMP responses.

Acknowledgement

The authors would like to thank Professor Herman A Jenkins for his kind editorial assistance, and Dr Rommanee Chaiwarit for statistical consultation and analysis. This research was supported by funds from the Faculty of Medicine, Chiang Mai University.

References

1 Wuyts FL, Furman J, Vanspauwen R, Van De Heyning P. Vestibular function testing. *Curr Opin Neurol* 2007;**20**:19–24
2 Zhou G, Cox LC. Vestibular evoked myogenic potentials: history and overview. *Am J Audiol* 2004;**13**:135–43
3 Bickford RG, Jacobson JL, Cody DT. Nature of average evoked potentials to sound and other stimuli in man. *Ann N Y Acad Sci* 1964;**112**:204–23

https://doi.org/10.1017/S0022215113001655 Published online by Cambridge University Press

4 Townsend GL, Cody DT. The averaged inion response evoked by acoustic stimulation: its relation to the saccule. *Ann Otol Rhinol Laryngol* 1971;**80**:121–31
5 Colebatch JG, Halmagyi GM, Skuse NF. Myogenic potentials generated by a click-evoked vestibulocollic reflex. *J Neurol Neurosurg Psychiatry* 1994;**57**:190–7
6 Welgampola MS, Colebatch JG. Characteristics and clinical applications of vestibular-evoked myogenic potentials. *Neurology* 2005;**64**:1682–8
7 Eleftheriadou A, Koudounarakis E. Vestibular-evoked myogenic potentials eliciting: an overview. *Eur Arch Otorhinolaryngol* 2011;**268**:331–9
8 Park HJ, Lee IS, Shin JE, Lee YJ, Park MS. Frequency-tuning characteristics of cervical and ocular vestibular evoked myogenic potentials induced by air-conducted tone bursts. *Clin Neurophysiol* 2010;**121**:85–9
9 Ochi K, Ohashi T, Nishino H. Variance of vestibular-evoked myogenic potentials. *Laryngoscope* 2001;**111**:522–7
10 Young YH. Vestibular evoked myogenic potentials: optimal stimulation and clinical application. *J Biomed Sci* 2006;**13**: 745–51
11 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**:1650–9
12 De Oliveira Barreto AC, Colafamina JF, De Lemos Menezes P. Saccular sensitivity function measured by vestibular evoked myogenic potential. *Acta Otolaryngol* 2011;**131**:618–23
13 Janky KL, Shepard N. Vestibular evoked myogenic potential (VEMP) testing: normative threshold response curves and effects of age. *J Am Acad Audiol* 2009;**20**:514–22
14 Maes L, Vinck BM, De Vel E, D'haenens W, Bockstael A, Keppler H *et al*. The vestibular evoked myogenic potential: a test-retest reliability study. *Clin Neurophysiol* 2009;**120**: 594–600
15 Isaradisaikul S, Strong DA, Moushey JM, Gabbard SA, Ackley SR, Jenkins HA. Reliability of vestibular evoked myogenic potentials in healthy subjects. *Otol Neurotol* 2008;**29**:542–44
16 Wu HJ, Shiao AS, Yang YL, Lee GS. Comparison of short tone burst-evoked and click-evoked vestibular myogenic potentials in healthy individuals. *J Chin Med Assoc* 2007;**70**:159–63
17 Picciotti PM, Fiorita A, Di Nardo W, Calo L, Scarano E, Paludetti G. Vestibular evoked myogenic potentials in children. *Int J Pediatr Otorhinolaryngol* 2007;**71**:29–33
18 Kelsch TA, Schaefer LA, Esquivel CR. Vestibular evoked myogenic potentials in young children: test parameters and normative data. *Laryngoscope* 2006;**116**:895–900
19 Wang CT, Young YH. Comparison of the head elevation versus rotation methods in eliciting vestibular evoked myogenic potentials. *Ear Hear* 2006;**27**:376–81
20 Basta D, Todt I, Ernst A. Normative data for P1/N1-latencies of vestibular evoked myogenic potentials induced by air- or bone-conducted tone bursts. *Clin Neurophysiol* 2005;**116**:2216–19
21 Su HC, Huang TW, Young YH, Cheng PW. Aging effect on vestibular evoked myogenic potential. *Otol Neurotol* 2004;**25**: 977–80
22 Cheng PW, Huang TW, Young YH. The influence of clicks versus short tone bursts on the vestibular evoked myogenic potentials. *Ear Hear* 2003;**24**:195–7
23 Wang SJ, Young YH. Vestibular evoked myogenic potentials using simultaneous binaural acoustic stimulation. *Hear Res* 2003;**185**:43–8
24 Patko T, Vidal PP, Vibert N, Tran Ba Huy P, De Waele C. Vestibular evoked myogenic potentials in patients suffering from a unilateral acoustic neuroma: a study of 170 patients. *Clin Neurophysiol* 2003;**114**:1344–50
25 Wu CH, Young YH, Murofushi T. Tone burst-evoked myogenic potentials in human neck flexor and extensor. *Acta Otolaryngol* 1999;**119**:741–4
26 Akin FW, Murnane OD, Proffitt TM. The effects of click and tone-burst stimulus parameters on the vestibular evoked myogenic potential (VEMP). *J Am Acad Audiol* 2003;**14**:500–9
27 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**:333–8
28 Akin FW, Murnane OD, Panus PC, Caruthers SK, Wilkinson AE, Proffitt TM. The influence of voluntary tonic EMG level on the vestibular-evoked myogenic potential. *J Rehabil Res Dev* 2004;**41**:473–80
29 Brantberg K, Fransson PA. Symmetry measures of vestibular evoked myogenic potentials using objective detection criteria. *Scand Audiol* 2001;**30**:189–96
30 Welgampola MS, Colebatch JG. Vestibulocollic reflexes: normal values and the effect of age. *Clin Neurophysiol* 2001; **112**:1971–9
31 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
32 De Waele C, Tran Ba Huy P, Diard JP, Freyss G, Vidal PP. Saccular dysfunction in Meniere's disease. *Am J Otol* 1999; **20**:223–32
33 Iwasaki S, Takai Y, Ozeki H, Ito K, Karino S, Murofushi T. Extent of lesions in idiopathic sudden hearing loss with vertigo: study using click and galvanic vestibular evoked myogenic potentials. *Arch Otolaryngol Head Neck Surg* 2005;**131**:857–62
34 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**:1069–72
35 Ushio M, Matsuzaki M, Takegoshi H, Murofushi T. Click- and short tone burst-evoked myogenic potentials in cerebellopontine angle tumors. *Acta Otolaryngol Suppl* 2001;**545**:133–5
36 Versino M, Colnaghi S, Callieco R, Cosi V. Vestibular evoked myogenic potentials: Test-retest reliability. *Funct Neurol* 2001; **16**:299–309
37 Ushio M, Iwasaki S, Murofushi T, Sugasawa K, Chihara Y, Fujimoto C *et al*. The diagnostic value of vestibular-evoked myogenic potential in patients with vestibular schwannoma. *Clin Neurophysiol* 2009;**120**:1149–53
38 Akkuzu G, Akkuzu B, Ozluoglu LN. Vestibular evoked myogenic potentials in benign paroxysmal positional vertigo and Meniere's disease. *Eur Arch Otorhinolaryngol* 2006;**263**:510–17
39 Chen CN, Young YH. Differentiating the cause of acute sensorineural hearing loss between Meniere's disease and sudden deafness. *Acta Otolaryngol* 2006;**126**:25–31
40 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**:815–18
41 Wu CC, Young YH. Vestibular evoked myogenic potentials are intact after sudden deafness. *Ear Hear* 2002;**23**:235–8
42 Govender S, Rosengren SM, Colebatch JG. Vestibular neuritis has selective effects on air- and bone-conducted cervical and ocular vestibular evoked myogenic potentials. *Clin Neurophysiol* 2011;**122**:1246–55
43 Roditi RE, Eppsteiner RW, Sauter TB, Lee DJ. Cervical vestibular evoked myogenic potentials (cVEMPs) in patients with superior canal dehiscence syndrome (SCDS). *Otolaryngol Head Neck Surg* 2009;**141**:24–8
44 Chang CH, Young YH. Caloric and vestibular evoked myogenic potential tests in evaluating children with benign paroxysmal vertigo. *Int J Pediatr Otorhinolaryngol* 2007;**71**:495–9
45 Faralli M, Molini E, Ricci G, Scardazza R, Trabalzini F, Altissimi G *et al*. Study of vestibular evoked myogenic potentials in unilateral vestibulopathy: otolithic versus canal function testing. *Otol Neurotol* 2006;**27**:1115–19
46 Liao LJ, Young YH. Vestibular evoked myogenic potentials in basilar artery migraine. *Laryngoscope* 2004;**114**:1305–9
47 Lu YC, Young YH. Vertigo from herpes zoster oticus: superior or inferior vestibular nerve origin? *Laryngoscope* 2003;**113**:307–11

Address for correspondence:
Dr Suwicha Isaradisaikul,
Department of Otolaryngology,
Faculty of Medicine,
Chiang Mai University,
110 Intawaroros Rd,
Sriphum, Mueang,
Chiang Mai 50200, Thailand

Fax: +66 53 945564
E-mail: sisaradi@mail.med.cmu.ac.th

Dr S Isaradisaikul takes responsibility for the integrity of the content of the paper
Competing interests: None declared