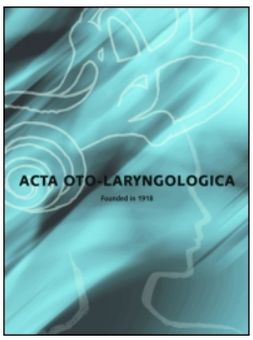

Acta Oto-Laryngologica

ISSN: (Print) (Online) Journal homepage: https://www.tandfonline.com/loi/ioto20

Normal values for cervical and ocular vestibular-evoked myogenic potentials using EMG scaling: effect of body position and electrode montage

Navid Shahnaz & Eytan A. David

To cite this article: Navid Shahnaz & Eytan A. David (2021): Normal values for cervical and ocular vestibular-evoked myogenic potentials using EMG scaling: effect of body position and electrode montage, Acta Oto-Laryngologica, DOI: 10.1080/00016489.2021.1887517

To link to this article: https://doi.org/10.1080/00016489.2021.1887517

Published online: 27 Feb 2021.

ACTA OTO-LARYNGOLOGICA
https://doi.org/10.1080/00016489.2021.1887517

Taylor & Francis
Taylor & Francis Group

RESEARCH ARTICLE

Normal values for cervical and ocular vestibular-evoked myogenic potentials using EMG scaling: effect of body position and electrode montage

Navid Shahnaz[a] and Eytan A. David[b]

[a]School of Audiology and Speech Sciences, University of British Columbia, Vancouver, Canada; [b]Department of Surgery, University of British Columbia, Vancouver, Canada

ABSTRACT

Background: The clinical utility of cervical and ocular vestibular-evoked myogenic potential (cVEMP and oVEMP) is limited by variability of testing protocols and a dearth of normative data using contemporary methods for amplitude scaling.

Aims/objectives: To investigate the effect of body position and electrode montage on VEMP responses and to establish normative values.

Material and Methods: This is a repeated measures study of 44 healthy young adult subjects (22 men and 22 women).

Results: The highest response rate (99%) for cVEMP was achieved in the supine position with the head elevated and turned. For oVEMP, the highest response rate (90%) was achieved using nasal alar electrode montage with the subject in a sitting position. Scaled peak-to-peak amplitude was higher in males than in females for both cVEMP and oVEMP.

Conclusion: Normative data for 44 young healthy adults was successfully collected for two body positions for cVEMP and two head positions and two electrode montages for oVEMP.

Significance: Our findings describe VEMP protocols that efficiently detect VEMP responses, and we provide normative VEMP response data for young healthy subjects. We describe a potential difference in response between males and females, which may be clinically important.

ARTICLE HISTORY
Received 12 December 2020
Revised 27 January 2021
Accepted 31 January 2021

KEYWORDS
cVEMP; oVEMP; vestibular; electrode; position; otolith; supine

Introduction

The vestibular sensing system provides information regarding orientation and acceleration of the head. This system comprises the utricle, the saccule, and three semicircular canals within each ear. The semicircular canals detect rotational acceleration, while the utricle and saccule detect linear acceleration and function as the gravity sensors. Afferent signals from these sensing organs elicit reflexes of ocular, spinal, and peripheral muscles, which produce coordinated movements of the skeletal and ocular muscles and allow for a coherent sense of balance [1].

A conventional vestibular assessment test battery involves caloric testing *via* videonystagmography (VNG) and video head impulse test (VHIT). These tests primarily measure function of the semicircular canals [2] and do not effectively assess the utricle and saccule; thus, vestibular disorders involving the otolithic organs can be incompletely diagnosed leading to underestimation of their prevalence.

Vestibular-evoked myogenic potential (VEMP) testing is a vestibular assessment procedure for otolith function that was approved in 2015 by the US Food and Drug Administration for use in clinical settings. VEMP responses are elicited by air- or bone-conducted stimulus and, after detection by the otolithic organs, produce downstream vestibular reflexes of the sternocleidomastoid muscle (SCM) or the inferior oblique muscle of the eye [3]. Tests to detect the former are referred to as cervical (cVEMP) while the latter is termed ocular (oVEMP). VEMP tests complement other vestibular assessment techniques such as caloric testing and VHIT [3].

VEMP has been proposed as a diagnostic tool for superior canal dehiscence syndrome, vestibular neuritis, benign paroxysmal positional vertigo (BPPV), and Menière's disease [3]; however, there are several barriers to its widespread adoption in the clinical setting. VEMP responses are known to decrease with age [4–7] and may vary with race or gender [5]. Variability concerning how the test is administered may limit the reliability and repeatability and may compromise comparison to published norms. For instance, VEMP assessments reported in the literature vary in terms of subject body position, the mounting locations of electrodes, characteristics of the sound stimulus, and method of normalizing background EMG activity [8].

In order to detect a cVEMP response, sufficient muscle tone of the SCM is required and many normative datasets

CONTACT Eytan A. David dr.david@shaw.ca School of Audiology and Speech Sciences, University of British Columbia, 11th Floor - 2775 Laurel Street, Vancouver V5Z 1M9, Canada

in the literature have relied on a biofeedback approach relying on subjects to actively maintain consistent SCM tone throughout the test [9–11]; However, this procedure may not be feasible in infants or in patients with neck injuries and subjects may have difficulty maintaining consistent muscle tone as they fatigue. EMG scaling has become a commonly accepted method for amplitude normalization for cVEMP that reduces the need to strictly control muscle tone; however, little normative data is available using this approach. For oVEMP studies, the normalization method was frequently not reported [12,13].

Procedural differences can lead to inter-test variability between individuals and even between the ears of the same individual. The latter case can be particularly challenging in the clinic—the difference in response amplitude between ears, knows as interaural asymmetry (IAA), can indicate otolith dysfunction.

In this study, we systematically evaluated the effects of body positioning and electrode montage on cVEMP and oVEMP response rates, latencies, EMG-scaled amplitudes, and asymmetry for 44 subjects with no history of vestibular or balance deficits. For cVEMP, we sought to compare response rates between two positions: lying supine with the head raised in the center (head center) and lying supine with the head raised and turned (head turned). For oVEMP, we sought to compare measurements collected with two electrode montages: placement of the inverting (reference) electrode infraorbitally beneath the active electrodes or on the fleshy part of the nose on the same side as the active electrode. We also compared response rates between two body positions, supine and sitting.

These data serve to establish normative data for absolute latencies, peak-to-peak amplitudes, and interaural amplitude differences for cVEMP waves (N1 (n23) and P1 (p13)) and oVEMP waves N1 ((n11) and P1 (p15)) using amplitude scaling.

Methods

Approval from the University Clinical Research Ethics Board was obtained prior to distribution of participant recruitment material and prior to contact with potential participants. Participants attended one test session about ninety minutes in duration.

Inclusion and exclusion criteria

To be included in this study, subjects had to meet the following criteria: (1) present pure-tone audiometric thresholds better than 25 dB HL at octave bands between 250 and 8000 Hz; (2) report no history of head trauma, middle-ear disease, excessive noise exposure or use of ototoxic drugs; (3) present no gross eardrum abnormalities or excessive cerumen as documented by otoscopic examination; (4) pass a distortion-product otoacoustic emission (DPOAE) screening (DPOAE testing was performed to further verify the condition of the cochlea and the middle ear); (5) have normal tympanometric parameters for the probe-tone frequency of 226 Hz and wideband acoustic immittance (WAI); (6) present ipsilateral middle ear muscle reflex using BBN stimulus (<85 dB HL). This was done to ascertain the normal middle ear condition as both cVEMP and oVEMP are absent in the presence of conductive component when being tested using air conduction signal.

Instrumentation and procedure

An Eclipse system equipped with VEMP module (Interacoustics, Denmark) was used to test the participants. In order to control for potential differences in background tonic EMG activity between sides, EMG scaling, also known as amplitude normalization, was implemented in the current study for both cVEMP and oVEMP. EMG scaling involves dividing the root mean square (RMS) value of each sample in the final signal-averaged waveform by the mean RMS value of the tonic EMG activity preceding stimulus onset. Electrode impedances were maintained below 3 kΩ. The stimulus for both cVEMP and oVEMP was air-conducted tone bursts (500 Hz, with 2 ms rise/fall time and 2 ms plateau, presented at a rate of 5.1/second at 118.5 dB peSPL).

For cVEMP, the skin was cleaned and abraded before the active surface electrode was placed just above the midpoint of the SCMs and the reference electrode was placed over the upper sternum. The ground electrode was placed on the forehead. Stimuli were presented initially at 95 dB nHL ipsilaterally to the contracted SCM muscle *via* an ER3A-insert earphone (Etymotic Research, Elk Grove Village, IL) while the participant was in one of two positions: (1) Supine position with head elevated and turned toward the contralateral shoulder and (2) Supine position with head elevated in the center.

For oVEMP, after skin preparation, the following electrode montage and positions were used: (1) Sitting position, active electrode below the eye, inverting electrode below active and ground on the forehead (infraorbital montage); (2) Supine position, active beneath the lateral canthus of the eye, inverting on the fleshy part of the nose at the same side as an active electrode and ground on the forehead (nasal alar montage); and (3) Sitting position, active shifted to the side, inverting on the fleshy part of the nose at the same side as an active electrode and ground on the forehead (nasal alar montage). Alar montage is represented in Figure 1. A target marker was placed on the ceiling (for the supine position) and on the wall (for sitting position) to obtain a gaze 30° above a neutral gaze. Tone bursts, initially at 95 dB nHL, were presented *via* an ER3A-insert earphone contralaterally to the active electrode while participants maintained a focus on the target marker.

For both cVEMP and oVEMP, a minimum of two VEMP responses from 200 stimuli were averaged and calculated within −20 to 80 ms time window (Figure 2). A minimum wave reproducibility of 75% was required to judge whether the response was present or absent.

The dependent variables were response rate, absolute latencies for N1 and P1, EMG scaled peak-to-peak amplitude, and IAA. The latter was calculated by dividing the

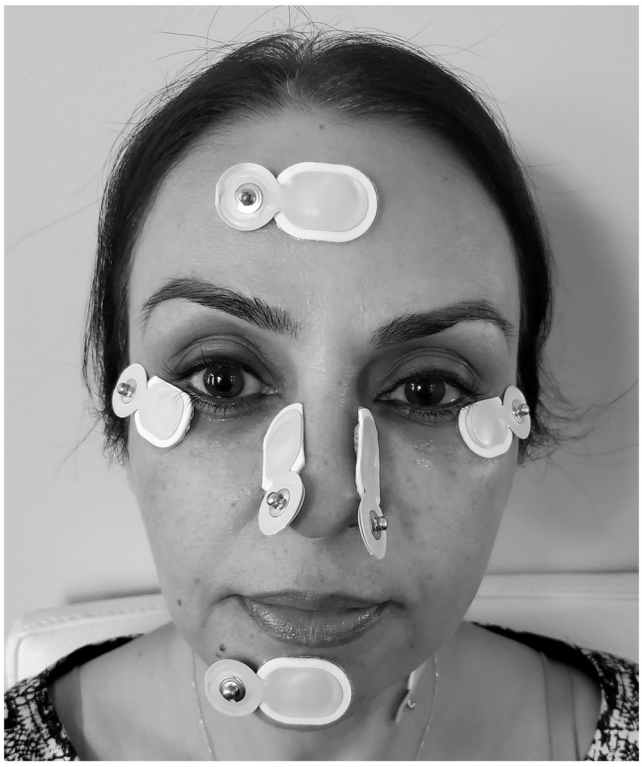

Figure 1. Example of alar montage for oVEMP recording. Active electrode below the eye in line with the lateral canthus, inverting electrode on the fleshy part of the nose, and ground electrode on the forehead. Electrodes on the neck and chin were not used for the oVEMP test. Picture used with permission.

inter-ear difference of P1-N1 interamplitude by the sum of the P1-N1 amplitudes of both ears.

Statistical analysis

Descriptive statistics were used to define mean, median, SD, and 90% range (5th to 95th percentile) for absolute latencies, interaural latency differences, and IAA for both cVEMP and oVEMP. The response rate was determined for each position and electrode montage. Wilcoxon signed rank test was used to test for differences of matched pairs for each body position and electrode montage. A mixed model analysis of variance was used to explore whether the differences were statistically significant between positions, electrode montage, and genders.

Results

Subjects

Forty-four adults (22 males and 22 females) with normal hearing and a mean age of 23.6 years (range 18–29) participated in this study. Testing was performed on both ears for a total of 88 normal ears tested.

cVEMP

cVEMP responses were observed in 87 of 88 ears (99%) in the head center position and in 86 or 88 ears (98%) ears in the head turned position (Table 1). There was no significant effect of head position on response rate. There was no difference in P1 latency between the two head positions; however, N1 latency was 24.6 ms [standard deviation (SD) = 1.98] for the head turned position, which was significantly shorter than the mean of 25.6 ms (SD = 2.48) for the head center position ($p < 0.0001$) (Table 1; Figure 3(A)).

EMG scaled peak-to-peak amplitude (ppAmp) was 1.44 ($SD = 0.68$) for the head turned position compared with 1.27 (SD = 0.59) for the head center position ($p < 0.0001$) (Table 1, Figure 3(B)). There was no significant effect of head position on IAA (Table 1; Figure 3(C)).

While **ppAmp** for the entire cohort was slightly greater in the head turned position, mixed-model ANOVA showed that this effect was specific to male subjects and males in general had larger **ppAmp** than females ($p = 0.0416$). IAA was less symmetric in males than females in the head center position (23% SD = 15.2 for males, 12% SD = 11.5 for females; $p = 0.0347$), but no difference was apparent in the head turned position ($p = 0.9973$).

oVEMP

In an unpublished pilot study, we determined that an electrode montage whereby the active electrode was placed below the eye and the inverting electrode on the fleshy part of the nose at the same side as the active electrode allowed for robust detection of oVEMP responses. We compared this montage, which we termed nasal alar montage, to a widely used method in which the active electrode is fixed below the eye and the inverting electrode is below the active (infraorbital montage).

oVEMP response rates, measured with the subject sitting upright, were 85% for infraorbital montage and 90% for nasal alar montage (Table 2). Alar montage was associated with shorter latencies than infraorbital montage for both the N1 (12.0 ms SD = 1.67 vs. 12.6 ms SD = 1.52; $p = 0.0171$) and P1 (16.0 ms SD = 1.72 vs. 17.5 ms $SD = 1.63$; $p < 0.0001$) peaks (Table 2; Figure 4(A)). **ppAmp** was greater for alar montage than for infraorbital (1.11 SD = 0.93 vs. 0.97 SD = 0.87; $p = 0.0016$) (Figure 4(B)). IAA was more symmetrical with alar montage (24% SD = 17.4) than conventional montage (31% SD = 17.5) in the sitting position ($p = 0.0408$) (Figure 4(C)).

oVEMP responses using alar montage with subjects in a supine, rather than sitting, position had a response rate of 88.6%. There were no significant differences between sitting and supine positions in either N1 or P1 latency (Table 2). ppAmp was greater for the sitting position than the supine position (1.11 SD = 0.93 vs. 0.85 SD = 0.67; $p < 0.0001$) (Table 2), but there was no difference in the IAA between positions.

oVEMP ppAmp was larger in males than females in both montages and both body positions ($p = 0.0003$) (Table 2). IAA was not significantly associated with gender for oVEMP.

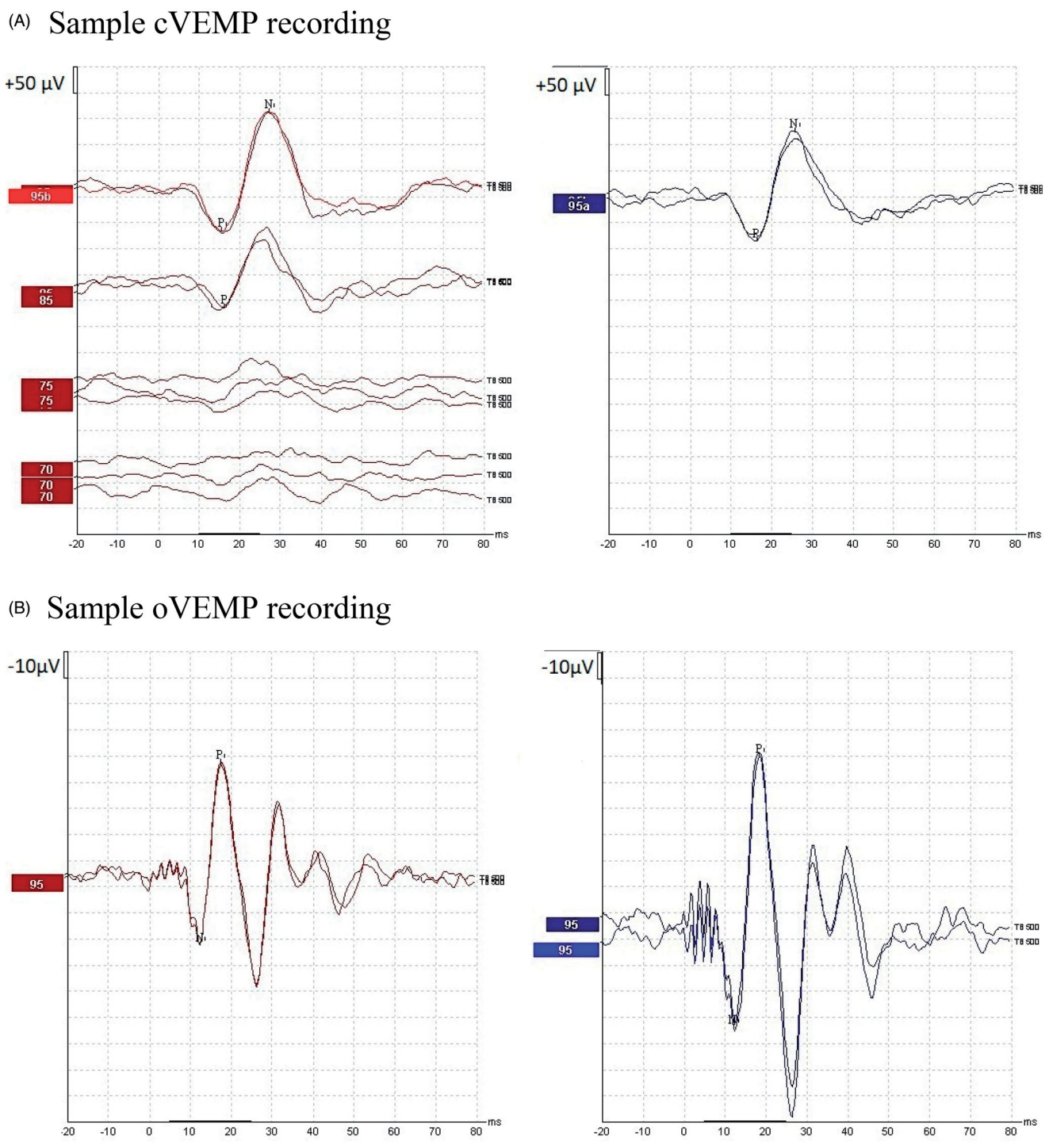

Figure 2. (A) Sample recording of the cVEMP using a 500 Hz tone burst and amplitude scaling for adjustment of the SCM electromyogenic EMG activity. Note that for the right ear the threshold for cVEMP was also established. (B) Sample recording of the oVEMP using a 500 Hz tone burst and amplitude scaling for adjustment of the electromyogenic EMG activity.

Discussion

VEMP holds promise as a clinical tool for evaluation of otolith dysfunction in patients with vestibular symptoms; however, variability around the test protocol and a lack of normative data have presented a barrier to widespread clinical use of the VEMP test to date. In order for VEMP assessment to be used successfully in the clinic to diagnose vestibular deficits, there is a need for robust protocols for subject position, electrode montage, sound stimulus, and data processing that provide a high response rate, replicable myogenic potential wave shape, and that is applicable to a wide diversity of patients.

In this study, we evaluated two body positions in cVEMP and two body positions and two electrode montages in oVEMP. We also provide normative cVEMP and oVEMP data for a large cohort of healthy subjects. Importantly, we

Table 1. cVEMP responses in normal healthy subjects.

Gender	Mean age (range)	*N*	Response rate %	P1 Latency ms ± SD	N1 latency (ms) ±SD	Scaled ppAmp ± SD	IAA ± SD
Current study							
Supine; head raised in center; EMG scaling; 118.5 dB peSPL; tone burst 500 Hz; 2-2-2							
22 F	23.5	44 ears	99%	16 ± 1.46	25.6 ± 2.48	1.27 ± 0.59	17 ± 14.4%
22 M	(20–29)						
22 F	23.8	22 ears	100%	15.9 ± 1.44	25.6 ± 2.80	1.22 ± 0.53	12 ± 11.5%
22 M	23.3	22 ears	98%	16.3 ± 1.48	25.6 ± 2.14	1.31 ± 0.64	23 ± 15.2%
Supine; head turned and raised; 118.5 dB peSPL; tone burst 500 Hz; 2-2-2							
22 F	23.5	44 ears	98%	16 ± 1.08	24.6 ± 1.98	1.44 ± 0.68	18.5 ± 11.3%
22 M	(20–29)						
22 F	23.8	22 ears	100%	16.3 ± 1.19	24.9 ± 2.24	1.29 ± 0.62	18 ± 11.6%
22 M	23.3	22 ears	95%	16.3 ± 0.98	24.4 ± 1.66	1.60 ± 0.71	20 ± 11.1%
Blakley and Wong [14]; Supine head raised; EMG monitoring; 100 dBHL; tone duration not given							
28 F	36.3	96 ears	98%	5^{th} pctl 13.9; 95^{th} pctl 19.2	5^{th} pctl 22.9; 95^{th} pctl 30.3	NR	1.7–41.4%
20 M	(23–64)						
Isaradisaikul et al. [11]; Sitting head turned; 30 − 75 μV visual feedback; 120 dB peSPL; tone duration not given							
38 F	44	100 ears	86%	15.99 ± 2.04	23.08 ± 1.05	28.36 ± 11.65	14.22 ± 9.42%
12 M	(22–57)						
Janky and Shepard [9]; Sitting head turned; 45 mmHg blood pressure cuff; 123 dB peSPL, tone burst 500 Hz; two cycle rise/fall, no plateau							
NR	20–76	46 subjects	97%	16.24 ± 2.42	22.97 ± 2.62	27.65 ± 11.13	NR
Maes [10]; Sitting, head turned; 40 mmHg blood pressure cuff; 130 dB peSPL; 1-2-1							
33 F	24	61 subjects	100%	14.97 ± 1.42	23.41 ± 1.66	147.34 ± 68.66	NR
28 M	(19–39)						
Rosengren et al. [7]; Reclined 30° head raised; EMG ratio to background; 105 dB L_{Aeq}; 2 ms unshaped							
28F,33M	18–80	122 ears	96%	14.9 ± 1.9	22.5 ± 2.2	1.41 ± 0.59	18 ± 17%
Su et al. [6]; Supine head raised; 50–200 μV visual feedback; 95 dB nHL; Group II only; 0.1 ms clicks							
NR	21–40	40 ears	98%	11.47 ± 0.86	19.05 ± 1.31	NR	19 ± 15%

Tone duration given as x–y–z in milliseconds where x is rise, y is plateau, z is fall, unless otherwise noted; data given as mean ± SD except age (given as mean and range) and data from Blakley et al. given as range. dB nHL: decibels above normal hearing level; dB peSPL: peak equivalent sound pressure level; F: female; M: male; IAA: interaural asymmetry; ms: millisecond; NR: data was not reported in the published article; pctl: percentile; Scaled ppAmp: EMG scaled peak-to-peak amplitude; SD: standard deviation.

use EMG scaling for amplitude normalization for both cVEMP and oVEMP, in contrast to the majority of published studies which have used biofeedback to normalize muscle tone.

cVEMP

For this study, we compared two supine positions that differ with respect to the position of the subject's head. In the first, the subject lies supine with their head elevated to the center and in the second, the head is turned away from the stimulated ear. Elevating and turning the head is intended to induce baseline muscle tone in the SCM, which is required to measure the cVEMP response. Some individuals exhibit significant asymmetries in the amount of SCM contraction they are able to generate, particularly as the SCM fatigues over the course of the test. This asymmetry can be corrected one of two ways: patient self-monitoring or EMG scaling. In the self-monitoring approach, the subject is provided with feedback, such as a display of the current SCM electrical potential or display of the pressure they are creating against a blood pressure cuff, in order to maintain target muscle tone [10]. However, this method is subject to variability as the subject fatigues or loses motivation. EMG scaling does not require the subject to maintain consistent muscle tone and instead corrects for asymmetry mathematically [16]. EMG scaling is more comfortable for subjects and is feasible in those that cannot maintain strong muscle contraction.

There was no significant difference in the response rate between the two positions. In the head center position, all but one ear for the 44 subjects (88 ears) tested had a positive response. For the head turned position, two ears had an absent response—one of which was the same ear of the same subject that had an absent response for the head center position.

The latencies recorded in our cohort were longer than in the normative studies we have cited in Table 1. Interestingly, the studies with the shortest latencies used shorter tone durations than we did [6,7,10], which may have contributed to the difference in P1 and N1 latencies. However, VEMP latencies have been reported to vary by age, race, and sex [5] and a survey of published normal latencies were highly variable between studies [14].

There was no difference in mean IAA between the two positions; however, the head turned position had a smaller standard deviation (mean 18.5% SD = 11.3) compared to the head center position (17.3% SD = 14.5). Blakley and Wong reviewed the literature for IAA in order to establish a cut off for abnormal IAA findings, which they set at +2 standard deviations (+2 SD) from the mean for healthy subjects. For the eight studies they included in their survey, the lowest +2 SD cut-off value was 32% while the +2 SD value in their own cohort was 41.4%.[14] At 41.1% and 46.3% for head turned and head center, respectively, our +2 SD values are broadly in agreement with the published literature.

oVEMP

Body position is known to influence oVEMP responses [12]. The orientation of the utricle is not horizontal but rather tilted downward and back and its baseline condition due to gravity is different in sitting and supine positions. Some studies have shown that oVEMP amplitudes are greater in

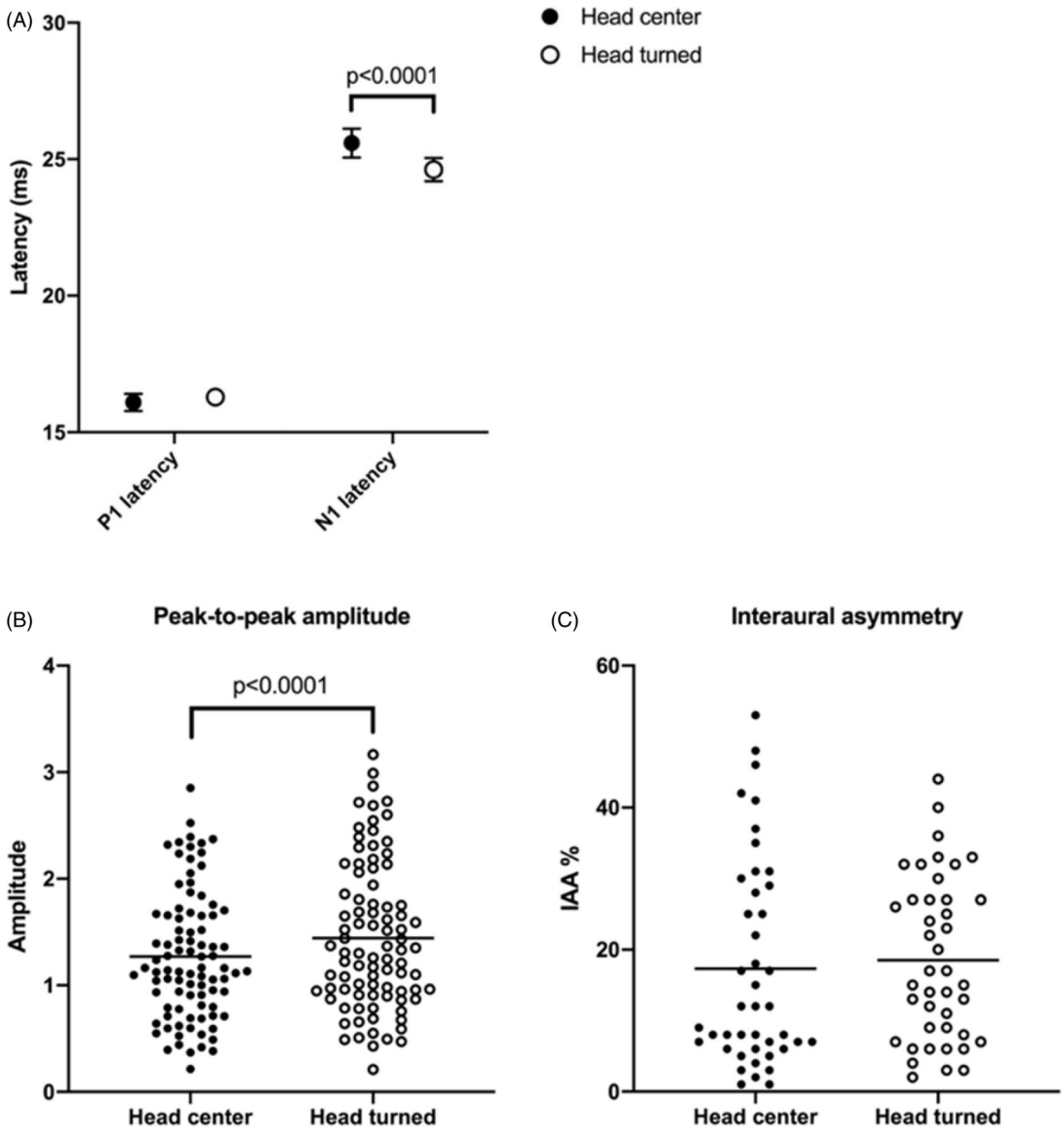

Figure 3. (A) Head position has no effect on cVEMP P1 latency; however, N1 latency is significantly shorter in the head turned position. (B) The head turned position is associated with larger corrected EMG scaled peak-to-peak amplitude. (C) There was no difference in IAA between head positions.

the sitting position [12]; however, though others found no difference [17]. Our protocol compared sitting and supine positions while subjects gazed approximately 30° above neutral gaze, as this has been demonstrated to improve oVEMP response [8]. Our study is concordant with the literature in that the oVEMP response rate was greater, and the amplitude larger, in the sitting position than when the subject was supine.

Electrode montage is known to effect latency, amplitude, and IAA [12,18] and must balance lateral specificity against signal amplitude [8]. For oVEMP, infraorbital montage is the most common [7,13,15]. During the planning phase of this study, we determined that mounting the active electrode below the eye and the reference electrode on the fleshy part of the nose on the same side as the active electrode, which we refer to as nasal alar montage in this paper, gave the highest response rates. In this study, we indeed found robust responses for nasal alar montage, detecting responses in 90% of ears tested compared with 85% for infraorbital montage, when both were assessed in the sitting position, though this difference was not statistically significant. We observed no apparent cross-stimulation from the contra-lateral eye. The response rate for oVEMP in our cohort is similar to that reported by Rosengren et al., which detected responses in 99 or 122 ears (81%) using infraorbital electrode montage [7].

For our analysis, we treated each ear tested as an independent data point; however, of the eight absent responses for the nasal alar montage, six ears corresponded to three subjects who had an absent responses bilaterally. Similarly, of the 13 absent responses in the infraorbital test, 8 corresponded to ears of 4 subjects that had bilateral absent responses. Bilateral absence of VEMP responses has been reported previously, but this has

Table 2. oVEMP responses in normal healthy subjects.

Gender	Mean age (range)	*N*	Response rate	N1 latency (ms) ±SD	P1 latency (ms) ±SD	Scaled ppAmp ± SD	IAA ± SD
Current study							
Supine; gazing 30° backward; alar montage; EMG scaling; 118.5 dB peSPL; tone burst 500 Hz; 2-2-2							
22F, 22M	23.5 (20–29)	88 ears	88.6%	11.9 ± 0.93	16.4 ± 1.15	0.85 ± 0.67	26 ± 17.1%
22 F	23.8	44 ears	98%	11.9 ± 1.05	16.2 ± 1.25	0.64 ± 0.58	25 ± 17.5%
22 M	23.3	44 ears	80%	11.9 ± 0.78	16.6 ± 0.99	1.11 ± 0.71	26 ± 16.7%
Sitting upright; gazing 30° up; alar montage; EMG scaling; 118.5 dB peSPL; tone burst 500 Hz; 2-2-2							
22F,22M	23.5 (20–29)	88 ears	90%	12.0 ± 1.67	16 ± 1.72	1.11 ± 0.93	24 ± 17.4%
22 F	23.8	44 ears	91%	11.9 ± 2.17	16.2 ± 2.17	0.92 ± 0.79	21 ± 17.8%
22 M	23.3	44 ears	91%	12.1 ± 0.95	16.5 ± 1.10	1.29 ± 1.03	27 ± 16.7%
Sitting upright; gazing 30° up; infraorbital montage; EMG scaling; 118.5 dB peSPL; tone burst 500 Hz; 2-2-2							
22F,22M	23.5 (20–29)	88 ears	85%	12.6 ± 1.52	17.5 ± 1.63	0.97 ± 0.87	31 ± 17.5%
22 F	23.8	44 ears	92%	12.5 ± 1.60	17.5 ± 1.90	0.79 ± 0.77	31 ± 17.9%
22 M	23.3	44 ears	89%	12.7 ± 1.47	17.5 ± 1.37	1.13 ± 0.94	30 ± 17.3%
Makowiec et al. [12]							
Sitting upright; gazing 30° up; belly-tendon montage; unknown EMG normalization method; 122 dB peSPL; tone burst 500 Hz; 2-0-2							
14F, 3M	24.16	17 subjects	100%	11.4 + 2SD 12.18	NR	15.72 + 2SD 32.7	15.84% +2SD 40.50
Sitting upright; gazing 30° up; infraorbital montage; unknown EMG normalization method; 122 dB peSPL; tone burst 500 Hz; 2-0-2							
14F, 3M	24.16	17 subjects	47%	12.05 + 2SD 14.29	NR	8.26 + 2SD 21.05	22.40% +2SD 47.49
Supine; gazing 30° backward; belly-tendon montage; unknown EMG normalization method; 122 dB peSPL; tone burst 500 Hz; 2-0-2							
14F, 3M	24.16	17 subjects	47%	11.49 + 2SD 12.39	NR	12.42 + 2SD 27.7	16.85%+2SD 39.13
Wang et al. [15]; sitting upright, gazing up 30-35°; infraorbital montage; EMG recording; 117 dB peSPL; tone burst 500 Hz; 1-2-1							
6F,14M	28 (22–33)	20 subjects	95%	11.1 ± 0.7	15.9 ± 1.0	6.5 ± 2.9	1.0 ± 23%
Rosengren et al. [7]; sitting upright, gazing up 20°; infraorbital montage; unknown EMG normalization method; 105 dB L_{Aeq}; tone burst 500 Hz; 2 ms unshaped							
28F,33M	18–80	122 ears	81%	9.9 ± 1.0	15.4 ± 1.3	3.78 μV ± 3.06	45%
Piker et al. [13] (18–49-year age group only); Sitting upright, gazing up 20–30°; infraorbital montage; unknown EMG normalization method; 95 dB nHL; tone burst 500 Hz; 2-0-2							
NR	33.9 (18–49)	58 ears	NR	12.5 ± 0.88	17.1 ± 1.3	5.1 ± 3.1	13 ± 1 0%

Tone duration given as x–y–z in milliseconds where x is rise, y is plateau, z is fall; data given as mean ± SD except age (given as mean and range) escept Makowiec et al. given as mean (+2 SD). dB nHL: decibels above normal hearing level; dB peSPL: peak equivalent sound pressure level; dB L_{Aeq}: A-weighted equivalent continuous sound level; F: female; M: male; IAA: interaural asymmetry; ms: millisecond; NR: data was not reported in the published article; Scaled ppAmp: EMG scaled peak-to-peak amplitude; SD: standard deviation.

often been attributed to loss with age [5]. It is unclear why young, otherwise healthy, individuals should have absent oVEMP responses.

Alar montage resulted in shorter latency for both the N1 and P1 peaks, larger ppAmp, and was more symmetric between ears of the same subject. Coupled with the greater response rate, alar montage may have advantages over the commonly employed infraorbital montage; however, the generalizability of this finding to a more representative population, and in those with vestibular dysfunction, is unknown.

The shorter latencies we observed with alar montage are consistent with two other studies that mounted reference electrodes on the nose [12,18]. This was also consistent with the observation by Sandhu et al. that the latency of the N1 peak to become shorter as the active electrode was placed further laterally [19].

Gender differences

Few studies have investigated whether males and females differed in their VEMP responses and most studies have not reported data for males and females separately. A study of pilots found higher oVEMP amplitudes in men [20] and a similar trend was reported in another study, though this difference was not statistically significant [5]; however, others have reported no differences in VEMP responses between men and women [13,14]. We enrolled equal numbers of males and females of similar age in order to evaluate any differences in VEMP responses. We found that males had larger ppAmp than females for both cVEMP and oVEMP ($p = 0.0416$ and $p = 0.0003$, respectively). While the male and female groups in our study were well-matched for age, there were poorly matched in terms of ethnicity. 50% of female subjects identified as Caucasian, 23% as Asian, 5% as South Asian, and 23% as mixed or other. In contrast, 32% of males identified as Asian, 23% as South Asian, 14% as Caucasian, and 32% as other. Li et al. reported that subjects in the Baltimore Longitudinal Study of Aging that identified as Black or African had shorter latencies, higher amplitudes, and higher rates of VEMP responses [5]. Li et al. only compared Caucasian and Black subjects, and our study included no Black subjects, but this disparity of the distribution of races between the male and female subgroups may contribute to the apparent gender differences we observed.

Conclusions

Choosing optimal electrode montage and positioning will help the clinician to maximize VEMP responses in the clinic. For cVEMP testing, the supine head turned position resulted in a 99% response rate and, interestingly, was less variable between genders than the supine head center position. For oVEMP testing, the sitting position using a nasal alar electrode montage resulted in the highest response rate of 90%. We observed a difference in VEMP responses between males and females; however, we acknowledge the potential confounding factor of ethnicity.

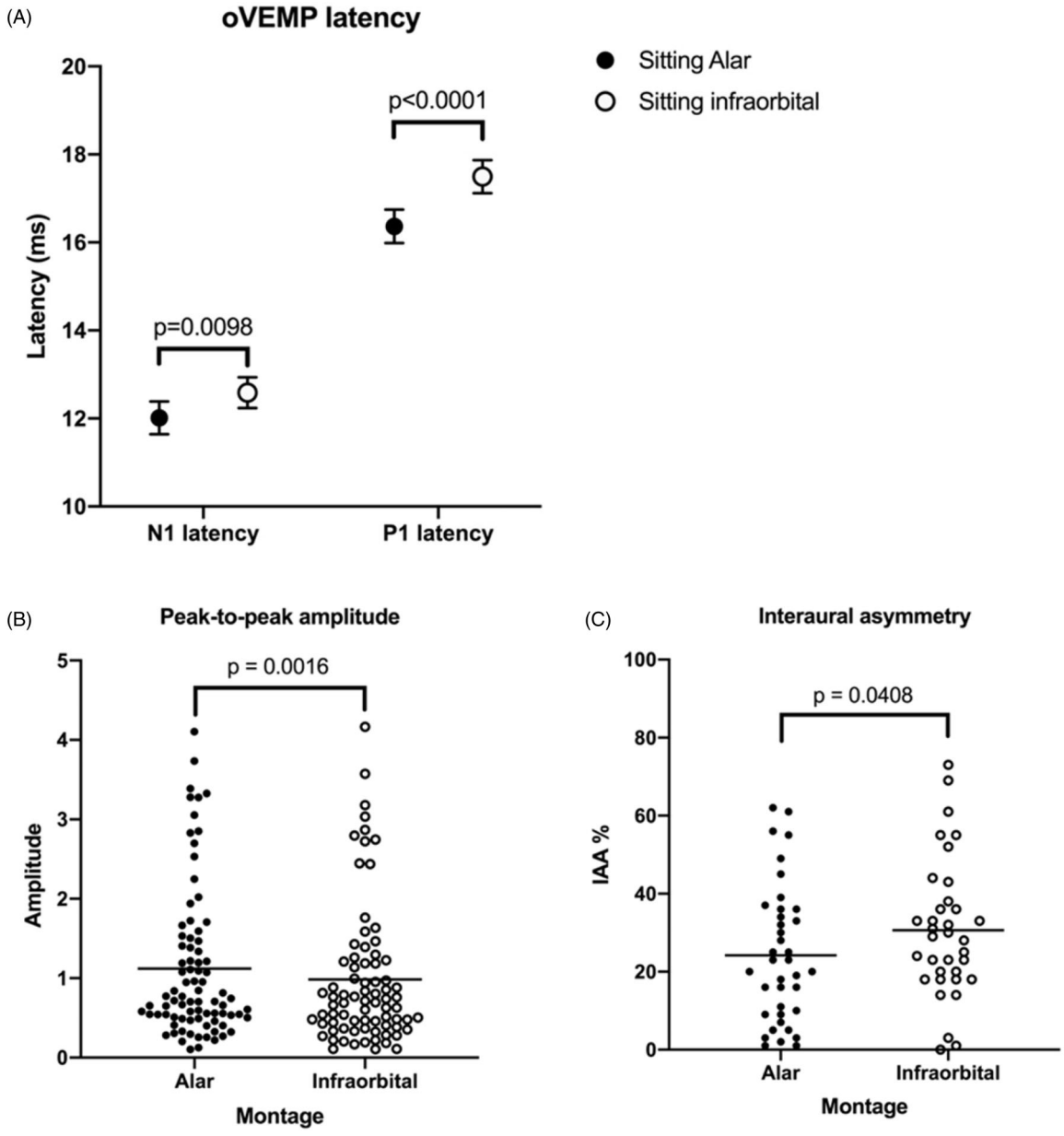

Figure 4. (A) Alar montage is associated with shorter N1 and P1 latencies than infraorbital montage for oVEMP. (B) Alar montage is associated with larger corrected EMG scaled peak-to-peak amplitudes than infraorbital montage. (C) Alar montage is associated with lower IAA (i.e. greater symmetry) than infraorbital montage for oVEMP.

Methodological considerations/limitations

We enrolled a cohort of young, healthy adults, aged 20–29 to our study, which facilitated our data collection as these individuals tend to have robust VEMP responses. However, many of those with vestibular symptoms seen in the clinic are older and it remains to be determined whether our findings are generalizable to older populations. Our observation of a gender difference in VEMP response merits further study; however, our male and female groups were poorly matched for ethnicity, which may be a confounding factor. We did not directly compare EMG scaling with patient self-monitoring using biofeedback, which limits the comparisons that can be made to studies that used the latter method for regulating SCM tone. We did not collect VEMP threshold data for all subjects so cannot compare threshold responses between testing conditions, nor can we rule out deficits, such as superior canal dehiscence syndrome, that are associated with abnormal VEMP thresholds.

Acknowledgements

The authors are grateful to the members of the Middle Ear Lab, Ainsley Ma, and Shahab Ravanparast for their hard work on participant recruitment, data collection, and establishing the database. Special thanks to the DiaTec Canada, and Interacoustics Denmark, and the U.S.A. team for their timely and essential technical assistance.

Disclosure statement

No potential conflict of interest was reported by the author(s).

ORCID

Eytan A. David http://orcid.org/0000-0001-5669-1961

References

[1] Casale J, Gupta G. Physiology, vestibular system. StatPearls. StatPearls Publishing: Treasure Island (FL); 2020.
[2] Cohen HS. A review on screening tests for vestibular disorders. J Neurophysiol. 2019;122(1):81–92.
[3] Murofushi T. Clinical application of vestibular evoked myogenic potential (VEMP). Auris Nasus Larynx. 2016;43(4):367–376.
[4] Welgampola MS, Colebatch JG. Vestibulocollic reflexes: normal values and the effect of age. Clin Neurophysiol. 2001;112(11):1971–1979.
[5] Li C, Layman AJ, Carey JP, et al. Epidemiology of vestibular evoked myogenic potentials: data from the baltimore longitudinal study of aging. Clin Neurophysiol. 2015;126(11):2207–2215.
[6] Su H-C, Huang T-W, Young Y-H, et al. Aging effect on vestibular evoked myogenic potential. Otol Neurotol. 2004;25:977–980.
[7] Rosengren SM, Govender S, Colebatch JG. Ocular and cervical vestibular evoked myogenic potentials produced by air- and bone-conducted stimuli: comparative properties and effects of age. Clin Neurophysiol. 2011;122(11):2282–2289.
[8] Rosengren SM, Colebatch JG, Young AS, et al. Vestibular evoked myogenic potentials in practice: methods, pitfalls and clinical applications. Clin Neurophysiol Pract. 2019;4:47–68.
[9] Janky KL, Shepard N. Vestibular evoked myogenic potential (VEMP) testing: normative threshold response curves and effects of age. J Am Acad Audiol. 2009;20(8):514–522.
[10] Maes L, Vinck BM, Vel ED, et al. The vestibular evoked myogenic potential: a test-retest reliability study. Clin Neurophysiol. 2009;120(3):594–600.
[11] Isaradisaikul S, Navacharoen N, Hanprasertpong C, et al. Cervical vestibular-evoked myogenic potentials: norms and protocols. Int J Otolaryngol. 2012;2012:913515.
[12] Makowiec K, McCaslin DL, Jacobson GP, et al. Effect of electrode montage and head position on air-conducted ocular vestibular evoked myogenic potential. Am J Audiol. 2017;26(2):180–188.
[13] Piker EG, Jacobson GP, McCaslin DL, et al. Normal characteristics of the ocular vestibular evoked myogenic potential. J Am Acad Audiol. 2011;22(4):222–230.
[14] Blakley BW, Wong V. Normal values for cervical vestibular-evoked myogenic potentials. Otology Neurotol. 2015;36:1069–1073.
[15] Wang S-J, Jaw F-S, Young Y-H. Ocular vestibular-evoked myogenic potentials elicited from monaural versus binaural acoustic stimulations. Clin Neurophysiol. 2009;120(2):420–423.
[16] Noij KS, Herrmann BS, Rauch SD, et al. Toward optimizing vestibular evoked myogenic potentials: normalization reduces the need for strong neck muscle contraction. Audiol Neurootol. 2017;22(4-5):282–291.
[17] Iwasaki S, Chihara Y, Smulders YE, et al. The role of the superior vestibular nerve in generating ocular vestibular-evoked myogenic potentials to bone conducted vibration at Fz. Clin Neurophysiol. 2009;120(3):588–593.
[18] Leyssens L, Heinze B, Vinck B, et al. Standard' versus 'nose reference' electrode placement for measuring oVEMPs with air-conducted sound: Test–retest reliability and preliminary patient results. Clin Neurophysiol. 2017;128(2):312–322.
[19] Lee KJ, Kim MS, Son EJ, et al. The usefulness of rectified VEMP. Clin Exp Otorhinolaryngol. 2008;1(3):143–147.
[20] Xie S-J, Xu Y, Bi H-Z, et al. Ocular vestibular-evoked myogenic potentials in healthy pilots and student pilots. Aviat Space Environ Med. 2011;82(7):729–733.