Original Article

Cervical Vestibular-evoked Myogenic Potential in Healthy Adults: A Cross-sectional Study Investigating the Impact of Various Stimuli and Recording Conditions

Abstract

Background: Cervical vestibular-evoked myogenic potentials (c-VEMPs) is a noninvasive procedure that captures the electrical activity of sternocleidomastoid (SCM) muscles in response to auditory stimuli. The clinical value of VEMP, however, is affected by the use of appropriate stimuli and correct testing techniques. This study investigates the effects of different stimuli and recording conditions on c-VEMP recordings. **Materials and Methods:** Sixty healthy participants, aged 18–60 years, underwent c-VEMP recordings. Air-conducted sound stimuli (tone bursts and clicks) in sitting, supine neck torsion, and supine head lift and neck torsion positions along with the variation in the active electrode positions were employed to obtain the c-VEMP records. The c-VEMP parameters were compared by paired *t*-test, Wilcoxon signed-rank test and one-way ANOVA. $P < 0.05$ was considered statistically significant. **Results:** Tone burst and click-evoked c-VEMP varied with statistically significant differences in terms of amplitudes, corrected amplitudes, and thresholds ($P = 0.0000$). Tone burst stimuli produced larger amplitudes and lower thresholds in both ears. No significant difference was found in c-VEMP parameters tested for differences in active electrode placement except for threshold asymmetry ($P = 0.0123$) (Wilcoxon signed-rank test). c-VEMP recordings in the sitting position produced significantly larger corrected amplitudes compared to the supine head lift and neck torsion positions, for both sides (one-way ANOVA). **Conclusion:** The results of the current study revealed a greater response rates and larger amplitudes for tone burst-evoked c-VEMP responses as compared to those with click stimuli. A seated, head-turned position with the active electrode placed in the middle of the SCM muscle yielded larger tone burst-evoked c-VEMP responses. The variation in the VEMP data obtained owing to different stimuli and recording conditions should be considered when evaluating patients in clinical practice to optimize the clinical applicability of the VEMP examination.

Keywords: *Amplitudes, cervical vestibular-evoked myogenic potential, click stimuli, latencies, otolith organs, sternocleidomastoid, tone burst stimuli, vestibular function tests, vestibular-evoked myogenic potential*

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Introduction

Vestibular-evoked myogenic potentials (VEMPs) have garnered considerable interest as a method of assessing the function of the otolith organs in response to sound and vibration. The body of knowledge regarding VEMPs, their physiological basis, and their diagnostic implications has expanded at an unprecedented pace over the past decade. Cervical VEMPs (c-VEMPs) are short-latency, vestibular-dependent reflexes that are recorded from the sternocleidomastoid (SCM) muscles in the anterior neck.[1] The c-VEMP consists of a short latency (13 ms from onset to peak) positive (i.e., inhibitory) electromyography (EMG) potential in response to high-intensity air-conducted (AC) sound or bone-conducted (BC) vibration.[2]

The standard procedure to record c-VEMPs was first developed by Colebatch *et al.* in 1994.[1] They reported a click-induced muscle response in the ipsilateral SCM. By placing the electrodes over the tonically contracted SCM muscle, they recorded c-VEMP which elicited a biphasic wave (p13–n23), consisting of an initial positive peak followed by consecutive negative and positive peaks. This response was absent after the vestibular neurectomy but was present in patients with sensorineural hearing loss. This confirmed that c-VEMP has

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vestibular origins since the patient with sensorineural hearing loss has an intact vestibular function.[1] The c-VEMP test assesses the functioning of the saccule via the vestibulocollic reflex (VCR). The VCR arc comprises three components: The receptor (saccule), the afferent pathway (the inferior vestibular nerve), and the efferent pathway (the lateral vestibulospinal tract, the medial vestibulospinal tract, and the effector muscle).[3]

VEMPs can be elicited by a variety of stimuli which include AC clicks or tone bursts, BC vibrations induced by a bone-conduction vibrator, manual tapping, or galvanic electrical stimulation.[4,5] Todd *et al*., in 2003, elicited vestibular-evoked potentials using bone-conducted sound throughout the scalp.[5] In contrast to BC stimulation, AC sound has stimulus specificity, which leads to the activation of otolith organs in a differential manner. The threshold of the saccule to AC sound is approximately 15–20 dB lower than the utricle and considerably lower than the semicircular canals.[6-8] Based on the aforementioned, AC sound is often considered the optimal stimulus for c-VEMPs due to its relative selectivity for the saccule.

To stimulate the SCM muscle in c-VEMPs, a variety of maneuvers are performed such as sitting with head turned, supine, recumbent, and prone positions with head lift or head turned. Maintaining the SCM muscle's tonic contraction throughout the test is essential for eliciting c-VEMP responses, therefore EMG is used as a visual cue to manage the patient's effort during SCM muscle contraction. Absent c-VEMP responses might occur if the muscle is not contracted enough.[9-13]

Since VEMPs indicate the functioning of the otolith organs, which could not be assessed by the many other vestibular tests (vector-electronystagmography, rotating chair test, and platform test), interest in VEMPs has increased recently. Although the caloric test is the most commonly utilized in assessing vestibular function, its applicability is restricted to the upper vestibular nerve and the lateral semicircular canals.[14] In contrast to ENG testing, VEMP testing is more patient-friendly, simpler to conduct, less difficult to interpret, causes less nausea or dizziness, and is easier to perform.[15]

The clinical value of VEMP, however, is affected by the use of appropriate stimuli, correct testing techniques. In this regard, VEMP studies ought to have normative data that take into consideration the stimulus and recording conditions and the position of the subject during the procedure. Literature search for studies from the Indian population, reveals a scarcity of researches including varied testing techniques and methodologies in the control population.[16]

Considering the substantial disparity between the type of acoustic stimuli delivered, optimum active electrode location, and the important role of the position of the subject while the procedure is being performed, optimization of the VEMP studies becomes crucial. Moreover, with regard to the studies highlighting the crucial role of some less frequently employed stimuli, for example, click stimuli in specific groups/clinical conditions, it becomes imperative further to obtain a normative data including the same to contribute to the clinical evaluation. The current study, hence, attempts to record c-VEMP with different stimuli and recording conditions including tone-burst and click stimulus types, variation in active electrode placement sites, and with different body positions. The goal of the current study is to bridge the disparity caused by the lack of normative VEMP data in the Indian population. We attempted to obtain standardized normative data on cervical vestibular myogenic potentials (VEMPs) in healthy adults by investigating the effect of different stimuli and recording conditions and the effect of body posture on VEMP.

Materials and Methods

It was an analytical cross-sectional study involving 60 subjects from April 2023 to March 2024. The study was conducted at the Neurophysiology Laboratory, Department of Physiology at a tertiary care institute.

Since this was an exploratory study, to satisfy the central limit theorem, a total of 30 males and 30 female participants) were included by convenience sampling. The study protocol was approved by the Institute's Human Ethics Committee (IHEC ref no.: IHEC/AIIMS-GKP/BMR/123/2023).

Participants in the age group of 18–60 years, with normal otological and vestibular examination were included in the study. Participants with a history of otological, vestibular, neurological and neuromuscular disorders, a history of cerebral trauma, or those who could not perform neck movements were excluded from the study. The participants were healthy attendants of the patients visiting the hospital outpatient department (OPD) and Neurophysiology Laboratory, Department of Physiology, All India Institute of Medical Sciences (AIIMS) Gorakhpur. They were recruited while they were accompanying their patients in the OPD. The duration, type, and purpose of the study were explained to the participants in detail and informed written consent was obtained from each participant.

Cervical vestibular-evoked myogenic potential recording

The c-VEMP test was recorded on Neuro-MEP 8 (8-channel NCS, EMG, and multi-modality EP system). Surface EMG was recorded on Neuro-MEP. netω EMG software (M/S Neurosoft Ltd, Ivanovo, Russia).

c-VEMP was recorded in a quiet environment at a uniform temperature. Prior to the test, the participants were provided with information about the procedures to be conducted. Appropriate skin preparation was done before the application of surface electrodes. Cotton wool soaked with methylated spirit was used to clean the skin in order to remove oils/makeup/moisturizer/dead skin cells. In order to ensure good contact between the electrodes and the skin, and to achieve low impedances, a mild abrasive paste, i.e., Nuprep was also used to clean the skin. Gold-plated disc electrodes were used to record c-VEMP. The disc electrodes were applied on the prepared skin using Ten20 conductive paste. Micropore was used to secure the electrodes to the skin.

Study protocol

Participants were screened for their eligibility, based on the inclusion criteria and those fulfilling the same, were invited to participate in the VEMP testing conducted in the Neurophysiology laboratory, Department of Physiology, AIIMS Gorakhpur [Figure 1]. The duration, type, and purpose of the study were explained to the participants in detail and informed written consent was obtained. In order to exclude any otological disorder, participants of the study underwent auditory brainstem evoked responses in an appropriately sound-attenuated room prior to the study. A detailed history of any neuropathy, myopathy or previous cerebral trauma was taken with the help of a questionnaire.[17] Participants who did not fulfil our inclusion criteria were excluded from the study henceforth.

Procedure

Recording of vestibular-evoked myogenic potential

c-VEMP and surface EMG were recorded on Neuro-MEPω EMG software (M/S Neurosoft Ltd, Ivanovo, Russia) in a quiet environment at Neurophysiology Laboratory, AIIMS Gorakhpur. The acoustic stimulus was presented monoaurally by way of headphones (TA-01). Subjects were instructed to perform the appropriate movements for recording VEMP.

c-VEMP variables (for both the ears) were recorded and analysed. VEMP procedure for c-VEMP procedure was employed according to the guidelines reported by Papathanasiou *et al*. (International guidelines for the clinical application of c-VEMPs: An expert consensus report) [Table 1a-c].[18]

Figure 1: Cervical vestibular-evoked myogenic potential procedure

Cervical vestibular-evoked myogenic potential testing protocols

Prior to electrode placement, skin surfaces were cleaned to ensure a skin impedance of 5 kΩ (kiloohms) or lower. The response window was set within 50 msonds (ms) and averaged over 200 stimuli for each run. The signal was band-pass filtered between 30 Hz and 2000 Hz. The 500 Hz tone burst (rise/fall time 0 ms, plateau 2.67 ms, stimulation rate 5/s) and click acoustic stimuli (0.1 ms) were used. c-VEMPs stimuli were delivered monaurally at 95 dB nHL with rarefaction polarity, using headphones (TA-01).

Electromyography settings

Surface EMG was recorded during the VEMP. The gain was set to around 2000 for c-VEMPs, with a sampling rate of approximately 2–5 kHz. Filter setting was 1–5 Hz (high pass, low cut) to approximately 200 Hz to 1000 Hz (low pass, high cut).

Measurement of muscle contraction was done by viewing the EMG during muscle contraction as a visual guide to control the patient's effort. Furthermore, a background EMG estimate was used to calculate an amplitude ratio by dividing the amplitude by estimate of muscle contraction (corrected amplitude).

Cervical vestibular-evoked myogenic potential variables

- Latencies: P1 and N1 (P13 and N23)
- Threshold stimulus (the lowest amplitude sound stimulus that still elicits a reproducible c-VEMP response)

Table 1a: Recording conditions

Features	Settings
Number of channels	One
Filters (Hz)	
High pass filter	30
Low pass	2000
Amplifier gain	2500 and 5000
Number of sweeps	100–250

Table 1b: Stimulus conditions

Features	Settings
Type of stimulus	Tone burst and clicks
Frequency of stimulus	500 Hz
Polarity	Rarefaction
Intensity	95 dB nHL and below (for threshold)

dB nHL: Decibels normalized hearing level

Table 1c: Electrode Montage

Features	Settings
Reference (+)	SJ/midpoint of SCM
Active (−)	Midpoint of SCM muscle/SJ
Ground	Forehead (Fpz) (10–20 system)

SCM: Sternocleidomastoid; SJ: Sternoclavicular junction

- Threshold asymmetry
- Amplitude: P13-N23
- AR: Amplitude of VEMP recorded from the right side
- AL: Amplitude of VEMP recorded from the left side
- Amplitude asymmetry: The interaural asymmetry ratio (IAR) was calculated using the Jongkees' formula (right - left)/(right + left) s
- Amplitude asymmetry ratio = (AR-AL)/(AR + AL) × 100.

Participant positioning for recording cervical vestibular-evoked myogenic potential

a. The participants were first made to sit in the upright position with their head turned contralateral to the ear receiving the acoustic stimulus
b. Second recording was obtained in the supine position with neck torsion
c. Third recording was obtained in a supine position with head lift and neck torsion position.

Two hundred and fifty sweeps of the stimuli were presented. The recording was repeated to check the replica of the peaks [Figure 2]. Recordings from both the ears were obtained. The recording time for c-VEMP was 90 min.

Cervical vestibular-evoked myogenic potential study protocol

Participants who underwent c-VEMP, received both short tone burst (STB) and click stimuli in different sets of experiments [Table 1d]. Initially, the active electrode was placed in the middle of the SCM, the reference electrode on the sternoclavicular junction (SJ), and the ground electrode on the forehead. In the second set of recordings, the active electrode was placed on the SJ, the reference electrode in the middle of the SCM, and the ground electrode remained on the forehead. Under these conditions, c-VEMP recordings were taken in sitting, supine with neck torsion, and supine with head lift and neck torsion positions. The ipsilateral recording was employed, where subjects were asked to turn their head opposite to the contracted SCM muscle.

Table 1d: Sets of experiments for c-VEMP (cervical vestibular-evoked myogenic potentials) recording

Recording set	Type of AC stimulus	Active electrode placement	Position of the subject
Set 1	Tone burst	SCM	Sitting
Set 2	Tone burst	SCM	Supine NT
Set 3	Tone burst	SCM	Sitting HLNT
Set 4	Tone burst	SJ	Sitting
Set 5	Tone burst	SJ	Supine NT
Set 6	Tone burst	SJ	Sitting HLNT
Set 7	Click	SCM	Sitting
Set 8	Click	SCM	Supine NT
Set 9	Click	SCM	Sitting HLNT
Set 10	Click	SJ	Sitting
Set 11	Click	SJ	Supine NT
Set 12	Click	SJ	Sitting HLNT

SCM: Sternocleidomastoid; SJ: Sternoclavicular junction; AC: Air conducted; NT: Neck torsion; HLNT: Head lift-NT

c-VEMP was recorded with the above-mentioned sets of experiments in each participant. All the c-VEMP parameters were noted and analysis was performed for finding the effect of variation in stimulus and recording conditions.

Statistical analysis

All the data was tested for normality of distribution using Shapiro–Wilk test. Summary statistics of normally distributed data were expressed as mean ± standard deviation (SD) and the ones not falling in the normal distribution, as median (25^{th} percentile–75^{th} percentile). Paired *t*-test and Wilcoxon signed-rank test were employed to identify differences between different stimulus and recording conditions for c-VEMP parameters. One-way ANOVA test was employed to analyze the effect of different recording positions on c-VEMP parameters. Further comparison among the three groups with different positions was analysed by the Tukey HSD (honestly significant difference) *post hoc* test. Age-stratified analysis was performed for all the above-mentioned comparisons (among the subjects ≤40 years and those >40 years). The level of statistical significance was set at 0.05. All the analyses and graphical visualizations were performed using the statistical software, Stata: version 12 (StataCorp LLC 4905 Lakeway Drive College Station, Texas 77845-4512 USA).

Results

Sixty participants aged between 18 years and 60 years (mean age in years ± SD: 36.25 ± 12.07) were recruited for

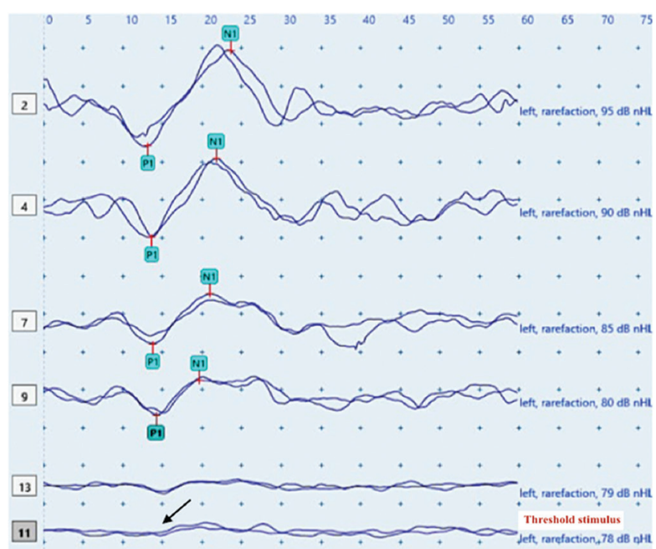

Figure 2: Cervical vestibular-evoked myogenic potential response waves (left ear) recorded from a healthy participant. The figure depicts the stimulus threshold, obtained as 78 dB nHL). [(Electrode placement: Active-sternocleidomastoid muscle, reference-sternoclavicular junction and Ground-Fpz; Position of the subject: Sitting; type of stimuli: Tone burst acoustic stimuli) (delivered to left ear with decreasing intensity to detect the threshold)]

c-VEMP recording. Out of 60 participants who underwent c-VEMP recording, 30 (50%) were males and 30 (50%) were females. c-VEMPs were bilaterally present in all the participants. All the subjects received tone burst and click stimuli with two different electrode montages. In the first montage, active electrode was placed on SCM and then in the next trial, placement was done on SJ. With the above-mentioned stimulus and recording conditions, c-VEMP was recorded in the following different positions: Sitting, supine neck torsion and supine head-lift and neck torsion position.

Effect of stimulus variations (tone burst vs. click stimuli) on cervical vestibular-evoked myogenic potential

The analyses for studying the variation in c-VEMP measures with the type of stimulus (STB and click) were performed with the active electrode placement as SCM and the position of the subject during the procedure as sitting for the above-mentioned comparisons.

The mean, median, SD and interquartile range (IQR) values of c-VEMP parameters and their comparison with stimulus variations (tone burst vs. click stimuli) are shown in Table 2.

For the comparison of right and left ear p13 latency, n23 latency and threshold asymmetry between the c-VEMP parameters for tone burst and click stimuli, paired *t*-test was employed, while for right and left ear amplitude, corrected amplitude, and threshold comparisons, Wilcoxon signed-rank test was employed.

When the c-VEMP parameters were compared between the groups with stimulus variation (tone burst and click), it was observed that there was no significant difference for p13 and n23 latency, amplitude asymmetry and threshold asymmetry (in both right and left ear) ($P > 0.05$). On the contrary, comparisons for right ear amplitude (z = 6.316, $P = 0.0000$), left ear amplitude (z = 5.801, $P = 0.0000$), right ear corrected amplitude (z = 6.294, $P = 0.0000$), left ear corrected amplitude (z = 6.103, $P = 0.0000$), right ear threshold (z = −6.769, $P = 0.0000$), and left ear threshold (z = −6.707, $P = 0.0000$) revealed significant differences between the c-VEMP responses for tone burst and click stimuli [Figures 3-8]. Similar results were obtained on age-stratified analysis as well [Table 2].

Effect of different active electrode positions (sternocleidomastoid vs. sternoclavicular junction) on cervical vestibular-evoked myogenic potential findings

The analyses for studying the variation in c-VEMP measures with the active electrode positions (SCM vs. SJ) were performed with tone burst stimuli and the position of the subject as sitting, for the above-mentioned comparisons.

Table 2: Comparison of c-VEMP findings with stimulus variations (tone burst vs click stimuli) (age-stratified and total)

c-VEMP parameters	Stimulus	Total		Age ≤40 years		Age >40 years	
		Mean±SD/median (IQR)	*P*	Mean±SD/median (IQR)	*P*	Mean±SD/median (IQR)	*P*
Right ear p13 latency (ms)	Tone burst	13.82±1.39[a]	0.1011	13.9±1.3[a]	0.2053	13.78±1.47[a]	0.10
	Click	13.48±1.32[a]		13.7±1.3[a]		13.25±1.35[a]	
Right ear n23 latency (ms)	Tone burst	22.79±1.51[a]	0.6147	22.5±1.2[a]	0.5028	23.2±1.7[a]	0.64
	Click	22.93±1.68[a]		22.9±1.5[a]		22.9±1.9[a]	
Left ear p13 latency (ms)	Tone burst	13.66±1.21[a]	0.1898	14.0±1.1[a]	0.3672	13.23±1.24[a]	0.42
	Click	13.37±1.42[a]		13.3±1.4[a]		13.48±1.48[a]	
Left ear n23 latency (ms)	Tone burst	22.34±1.44[a]	0.8865	22.3±1.2[a]	0.7735	22.38±1.68[a]	0.26
	Click	22.38±1.62[a]		22.0±1.5[a]		22.87±1.63[a]	
Right ear amplitude (µv)	Tone burst	81.5 (93.6)[b]	0.0000*	123 (72.9)[b]	0.0000*	36.5 (22.9)[b]	0.0001*
	Click	38.75 (38.38)[b]		63.1 (48.2)[b]		28.7 (12.3)[b]	
Left ear amplitude (µv)	Tone burst	66.5 (112.13)[b]	0.0000*	134 (92.5)[b]	0.0000*	35.6 (17.5)[b]	0.0004*
	Click	44.9 (42.1)[b]		62.3 (44.7)[b]		24.7 (20.9)[b]	
Right ear corrected amplitude	Tone burst	0.38 (0.3)[b]	0.0000*	0.51 (0.31)[b]	0.0000*	0.23 (0.14)[b]	0.0005
	Click	0.21 (0.14)[b]		0.29 (0.17)[b]		0.16 (0.07)[b]	
Left ear corrected amplitude	Tone burst	0.41 (0.23)[b]	0.0000*	0.51 (0.32)[b]	0.0000*	0.23 (0.09)[b]	0.00032
	Click	0.21 (0.14)[b]		0.24 (0.13)[b]		0.14 (0.08)[b]	
Amplitude asymmetry (µv)	Tone burst	−2.8 (18.9)[b]	0.3239	−2.65 (16.27)[b]	0.85	−3.03 (26.35)[b]	0.18
	Click	−2.98 (18.3)[b]		−2.4 (23.5)[b]		−4.66 (17.93)[b]	
Right ear threshold (dB nHL)	Tone burst	81.5 (4.25)[b]	0.0000*	80 (3.5)[b]	0.0000*	84 (1)[b]	0.0000*
	Click	85 (4)[b]		83 (2)[b]		87 (2)[b]	
Left ear threshold (dB nHL)	Tone burst	82.5 (4)[b]	0.0000*	80 (2)[b]	0.0000*	84 (1)[b]	0.0000*
	Click	85 (4)[b]		83 (2)[b]		87 (2)[b]	
Threshold asymmetry (dB nHL)	Tone burst	−0.53±1.78[a]	0.0593	−0.75±2.18[a]	0.085	−0.26±1.10[a]	0.43
	Click	0.13±1.55[a]		0.30±1.83[a]		−0.07±1.11[a]	

*$P<0.05$; [a]Mean±SD; [b]Median (IQR). SD: Standard deviation; IQR: Interquartile range; c-VEMP: Cervical vestibular-evoked myogenic potentials, dB nHL: Decibels normalized hearing level

The mean, median, SD, and IQR values of c-VEMP parameters and their comparisons with different active electrode positions (SCM vs. SJ) are shown in Table 3.

To evaluate the effect of different active electrode positions (SCM vs. SJ) on different c-VEMP parameters, paired *t*-test was employed for right and left ear p13 latency, n23 latency, while the Wilcoxon signed-rank test was employed for right and left ear amplitude, corrected amplitude, threshold and threshold asymmetry.

On comparing c-VEMP parameters between SCM and SJ active electrode positions, no significant difference was observed for p13 and n23 latency, amplitude, corrected amplitude, amplitude asymmetry and thresholds of both right and left ears ($P > 0.05$). Significant differences were only observed between SCM and SJ active electrode placement for threshold asymmetry ($z = -2.504$, $P = 0.0123$), which further, were found to be insignificant in the older age group (>40 years) [Table 3].

Effect of different recording positions (sitting, supine neck torsion and supine head lift-neck torsion positions on cervical vestibular-evoked myogenic potential parameters)

The analysis for studying the variation in c-VEMP measures with different recording positions of the subjects (sitting, supine neck torsion, and supine head lift-neck torsion) was performed with tone burst stimuli and the active electrode positions as SCM, for the above-mentioned comparisons.

The mean, median, SD and IQR values of c-VEMP parameters and their comparisons with different recording positions (sitting, supine neck torsion, and supine head lift-neck torsion) are shown in Table 4.

A one-way ANOVA test was employed for the comparison of c-VEMP parameters between sitting, supine neck torsion and supine head lift with neck torsion positions.

On comparing the c-VEMP variables for sitting, supine neck torsion and supine head lift-neck torsion recording positions, no significant difference was observed for p13, n23 latency, amplitudes, thresholds of right and left ears, amplitude asymmetry, and threshold asymmetry ($P > 0.05$) (one-way ANOVA). However, right ear corrected amplitude ($f = 20.33$, $P = 0.0000$) and left ear corrected amplitude ($f = 30.71$, $P = 0.0000$) showed significant differences between the different positions [Figures 9 and 10]. The Tukey HSD *post hoc* pairwise comparisons revealed that c-VEMP recordings in the sitting position produced significantly larger corrected amplitudes compared to the supine head lift and neck torsion positions, for both the sides [right side ($P = 0.01$)

Table 3: Comparison of c-VEMP parameters with different active electrode positions (SCM vs SJ) (age-stratified and total)

c-VEMP parameters	Active electrode position	Total: Mean±SD/ median (IQR)	Total: *P*	Age ≤40 years: Mean±SD/ median (IQR)	Age ≤40 years: *P*	Age >40 years: Mean±SD/ median (IQR)	Age >40 years: *P*
Right ear p13 latency (ms)	SCM	13.82±1.39[a]	0.4897	13.8±1.34[a]	0.44	13.8±1.5[a]	0.5735
	SJ	13.98±1.37[a]		14.0±1.28[a]		13.9±1.5[a]	
Right ear n23 latency (ms)	SCM	22.80±1.52[a]	0.0575	22.63±1.28[a]	0.7	22.94±1.7[a]	0.0532
	SJ	22.31±1.30[a]		22.55±1.07[a]		22.04±1.5[a]	
Left ear p13 latency (ms)	SCM	13.66±1.21[a]	0.1091	14.0±1.1[a]	0.9885	13.2±1.2[a]	0.0126
	SJ	13.81±1.3[a]		13.5±1.1[a]		14.2±1.4[a]	
Left ear n23 latency (ms)	SCM	22.34±1.44[a]	0.7414	22.3±1.2[a]	0.0530	22.4±1.7[a]	0.0512
	SJ	22.45±2.22[a]		22.0±1.3[a]		23.0±2.9[a]	
Right ear amplitude (µv)	SCM	81.5 (93.6)[b]	0.7572	123 (72.9)[b]	0.873	36.5 (22.9)[b]	0.97
	SJ	64.85 (96.9)[b]		127 (80.05)[b]		38.2 (15.1)[b]	
Left ear amplitude (µv)	SCM	66.5 (112.13)[b]	0.8626	134 (92.5)[b]	0.14	35.6 (17.5)[b]	0.07
	SJ	72.2 (88.1)[b]		114 (81)[b]		39.5 (14.4)[b]	
Right ear corrected amplitude	SCM	0.38 (0.3)[b]	0.3972	0.51 (0.33)[b]	0.52	0.23 (0.14)[b]	0.55
	SJ	0.32 (0.27)[b]		0.49 (0.26)[b]		0.23 (0.09)[b]	
Left ear corrected amplitude	SCM	0.36 (0.39)[b]	0.3239	0.58 (0.3)[b]	0.31	0.23 (0.09)[b]	0.73
	SJ	0.33 (0.28)[b]		0.48 (0.32)[b]		0.24 (0.11)[b]	
Amplitude asymmetry (µv)	SCM	−2.77 (18.87)[b]	0.7572	−2.85 (20.35)[b]	0.95	−3.03 (26.35)[b]	0.89
	SJ	−1.36 (16.19)[b]		−1.54 (21.88)[b]		−0.06 (13.5)[b]	
Right ear threshold (dB nHL)	SCM	81.5 (4.25)[b]	0.1932	80 (3)[b]	0.06	85 (0)[b]	0.08
	SJ	83 (4)[b]		80 (2)[b]		84 (1)[b]	
Left ear threshold (dB nHL)	SCM	82.5 (4)[b]	0.1024	80 (2)[b]	0.08	84 (2)[b]	0.09
	SJ	82 (4)[b]		80 (2)[b]		84 (1)[b]	
Threshold asymmetry (dB nHL)	SCM	0 (3)[b]	0.0123*	−1 (3)[b]	0.0089*	0 (2)[b]	0.5
	SJ	0 (2)[b]		0 (2)[b]		0 (2)[b]	

*P<0.05; [a]Mean±SD; [b]Median (IQR). SCM: Sternocleidomastoid; SJ: Sternoclavicular junction; SD: Standard deviation; IQR: Interquartile range; c-VEMP: Cervical vestibular-evoked myogenic potentials; dB nHL: Decibels normalized hearing level

Table 4: Comparison of c-VEMP findings with different positions of the subject (Sitting vs Supine neck torsion versus Supine head lift and neck torsion) (age-stratified and total)

c-VEMP parameters	Position of the subject	Total		Age ≤40 years		Age >40 years	
		Mean±SD	*P*	Mean±SD	*P*	Mean±SD	*P*
Right ear p13 latency (ms)	Sitting	13.82±1.39	0.0993	13.85±1.34	0.3914	13.78±1.47	0.2350
	Supine NT	13.3±1.25		13.51±1.12		13.05±1.37	
	Supine HLNT	13.34±1.1		13.50±1.12		13.19±1.14	
Right ear n23 latency (ms)	Sitting	22.8±1.52	0.2986	22.50±1.26	0.1620	23.15±1.74	0.8477
	Supine NT	22.7±1.49		22.32±1.25		23.16±1.64	
	Supine HLNT	22.47±1.34		22.03±1.06		23.01±1.47	
Left ear p13 latency (ms)	Sitting	13.66±1.21	0.1627	14.00±1.08	0.0560	13.23±1.24	0.3082
	Supine NT	13.72±1.35		13.60±1.12		13.79±1.60	
	Supine HLNT	13.33±1.1		13.36±1.09		13.29±1.05	
Left ear n23 latency (ms)	Sitting	22.34±1.44	0.3191	22.31±1.24	0.2565	22.38±1.67	0.3722
	Supine NT	22.49±1.55		22.09±1.09		22.97±1.87	
	Supine HLNT	22.65±1.35		22.46±1.45		22.86±1.21	
Right ear amplitude (µv)	Sitting	91.35±62.84	0.3695	127.78±60.12	0.6315	46.82±27.7	0.0548
	Supine NT	97.31±75.05		133.81±79.60		52.7±34.97	
	Supine HLNT	101.8±80.9		140.16±88.32		54.90±32.96	
Left ear amplitude (µv)	Sitting	90.85±63.19	0.3743	127.44±58.13	0.5085	46.12±33.52	0.1079
	Supine NT	91.94±63.04		124.80±64.15		51.77±30.16	
	Supine HLNT	99.11±78.21		136.98±84.61		52.82±31.96	
Right ear corrected amplitude	Sitting	0.41±0.23	0.0000*	0.54±0.22	0.0002*	0.26±0.12	0.0000*
	Supine NT	0.37±0.25		0.49±0.26		0.22±0.11	
	Supine HLNT	0.29±0.21		0.39±0.23		0.17±0.09	
Left ear corrected amplitude	Sitting	0.41±0.23	0.0000*	0.54±0.21	0.0000*	0.25±0.12	0.0000*
	Supine NT	0.35±0.22		0.46±0.23		0.22±0.09	
	Supine HLNT	0.28±0.22		0.37±0.25		0.16±0.08	
Amplitude asymmetry (µv)	Sitting	−0.38±12.07	0.3708	−0.32±11.26	0.4325	−0.45±13.20	0.7253
	Supine NT	−1.34±11.18		−1.97±10.96		−0.56±11.06	
	Supine HLNT	−2.67±10.37		−3.05±10.39		−2.21±10.52	
Right ear threshold (dB nHL)	Sitting	81.1±3.43	0.3220	79.18±3.54	0.3362	83.44±1.31	0.7216
	Supine NT	81.35±2.87		79.57±2.60		83.51±1.25	
	Supine HLNT	81.5±2.59		79.88±2.23		83.48±1.28	
Left ear threshold (dB nHL)	Sitting	81.65±2.78	0.9703	79.93±2.53	0.8839	83.74±1.16	0.4740
	Supine NT	81.68±2.43		80.12±2.11		83.59±1.00	
	Supine HLNT	81.7±2.37		80.09±1.87		83.67±1.07	
Threshold asymmetry (dB nHL)	Sitting	−0.53±1.78	0.3725	−0.75±2.17	0.4593	−0.26±1.09	0.3990
	Supine NT	−0.33±1.43		−0.54±1.78		−0.07±0.78	
	Supine HLNT	−0.2±1.45		−0.21±1.83		−0.18±0.78	

*$P<0.05$. NT: Neck torsion; HLNT: Head lift-NT; SD: Standard deviation; c-VEMP: Cervical vestibular-evoked myogenic potentials; dB nHL: Decibels normalized hearing level

and the left side ($P = 0.004$)]. Similar results were obtained when age-stratified analysis was performed for the above comparisons [Table 4].

Discussion

VEMP testing is an efficient method for assessing the integrity of the superior and inferior vestibular nerves as well as the otolith functions. There have been inconsistencies in the methods employed to record the VEMPs related to the stimuli used (clicks or tone bursts), electrode montages, patient position at the time of recording, and others. The optimal way to record VEMPs has not been widely agreed upon in the literature, despite the large number of studies conducted in this area. As the VEMP procedure is strongly influenced by the settings under which the testing is conducted and technological challenges that may arise, this study used a variety of protocols (stimulation type, testing position, and different electrode montages) in order to determine the normative values of VEMP testing.

c-VEMPs were 100% detectable (response rates) to both short tone-burst (STB) and click stimuli. However, in the present study, it has been observed that the ideal stimulus for evoking the c-VEMP responses was STBs. Tone burst-evoked responses produced higher amplitudes and lower thresholds than click-evoked

Figure 3: Comparison of right ear p13-n23 amplitude between cervical vestibular-evoked myogenic potential recordings by tone burst and click stimuli. µv: Microvolts

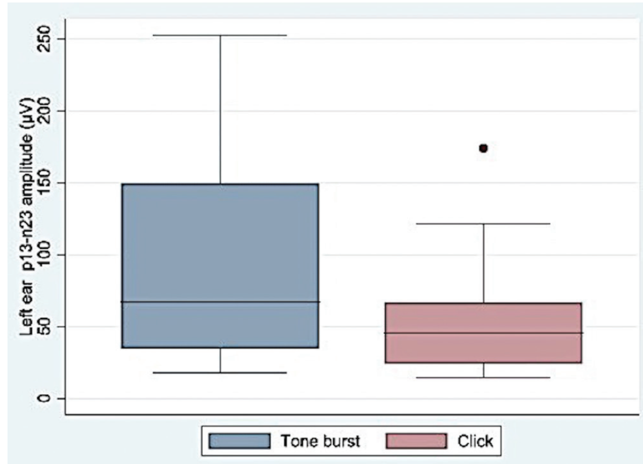

Figure 4: Comparison of left ear p13-n23 amplitude between cervical vestibular-evoked myogenic potential recordings by tone burst and click stimuli. µv: Microvolts

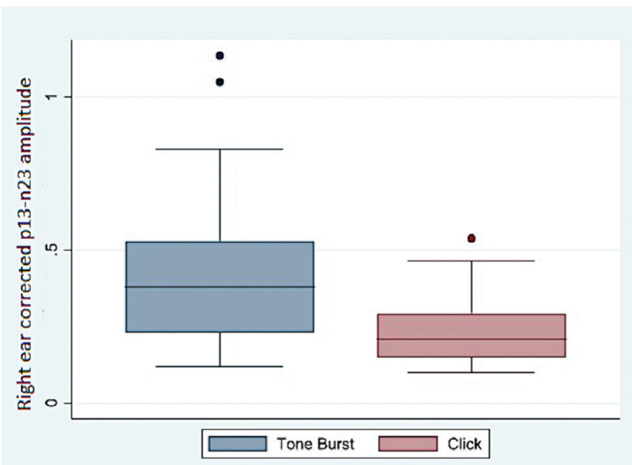

Figure 5: Comparison of right ear corrected p13-n23 amplitude between cervical vestibular-evoked myogenic potential recordings by tone burst and click stimuli

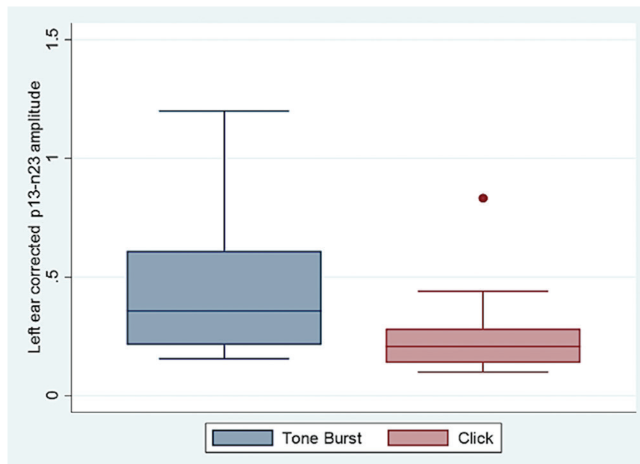

Figure 6: Comparison of left ear corrected p13-n23 amplitude between cervical vestibular-evoked myogenic potential recordings by tone burst and click stimuli

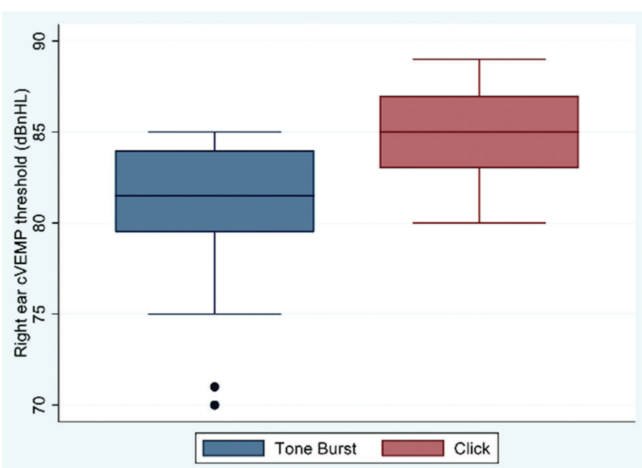

Figure 7: Comparison of right ear cervical vestibular-evoked myogenic potential threshold between cervical vestibular-evoked myogenic potential recordings by tone burst and click stimuli

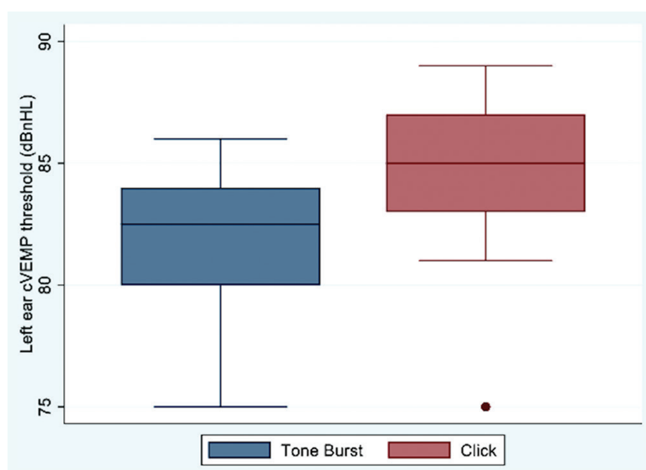

Figure 8: Comparison of left ear cervical vestibular-evoked myogenic potential thresholds between cervical vestibular-evoked myogenic potential recordings by tone burst and click stimuli

c-VEMP response ($P < 0.001$) (Wilcoxon signed-rank test) [Table 2 and Figures 3-8]. The increased threshold associated with click stimuli, has been attributed to the fact that the brief duration of the stimuli results in a lower total sound energy, which is dispersed across a variety of frequencies.[19] In line with the previous similar studies, click stimulation requires higher sound intensity (more than 95 dB nHL) to evoke c-VEMP responses than that with tone burst stimulation.[9,11,20] Studies have also reported that sound intensity above 95 dB nHL relatively causes discomfort to the subjects.[19,21] A clinical study showed that the response amplitude of the 500 Hz tone bursts was more robust than those with click stimuli, and the c-VEMP latencies (p13 and n23) were not influenced by the stimulus level.[19,22] Similar results have been observed in this study. The present study did not find significant differences in p13 and n23 latency, amplitude asymmetry and threshold asymmetry with the stimulus variation among the subjects. Age-stratified analysis also revealed similar findings suggesting that the differences in the c-VEMP parameters with stimulus variations were not significantly influenced by age [Table 2]. There are literature which have reported that the latency of tone burst stimulation is longer compared to that of click stimulus.[23] It is hypothesized that this is due to the comparably longer rise/fall time and therefore, the late peak of a tone burst stimulation response wave results. Conversely, the click stimulation response wave, with a shorter rise/fall time, results in a VEMP response before it stimulates the stapes reflex.[23] The rise and fall time for STB stimuli in our study was 0 msonds. This, to a great extent, explains the absence of latency prolongation in our study with tone burst stimulation. The longer latencies produced by tone burst stimuli have also been attributed to different excitation patterns of vestibular neurons with the stimuli. It has been reported that primary vestibular neurons respond to tone burst stimulus by double or triple firing.[24]

In the current study, active electrode placement on the middle arm of the SCM compared to that on SJ did not reveal any significant differences in c-VEMP parameters except for the presence of threshold asymmetry variation (P = 0.0123) (Wilcoxon signed-rank test) [Table 3]. However, there are studies which have reported significant variation in the amplitudes with respect to active electrode positions. According to Sheykholeslami *et al*., c-VEMP responses recorded from the upper part of the SCM muscle showed the largest amplitude compared to the locations at the level of mandibular angle, the middle part of the muscle, and immediately above the sternal and clavicular origins of the SCM muscle.[25] However, Colebatch 2012 and Rosengren *et al*., in 2016, concluded that the placement of the active electrode on the midpoint of SCM muscle produced larger amplitudes and shorter latencies.[26,27] Rosengren *et al*. have recommended the continued use of the traditional belly (SCM midpoint)-sternum/clavicle c-VEMP montage.[27] Contrary to the above findings, no such variations in the majority of c-VEMP parameters were obtained in the current study. Placement of active electrodes on the SCM muscle has been widely accepted montage, yet as the results of the current study obtained no significant variation in the amplitudes and the other parameters, both the locations/montages (midpoint of SCM-SJ and SJ-midpoint of SCM) can be employed to produce c-VEMP responses. However, polarity inversion should be borne in mind, that invariably occurs with the interchange of active and reference electrode positions.

The present study compared the effect of different testing positions (sitting, supine neck torsion, and supine head lift with neck torsion) on c-VEMP parameters to produce a sufficient level of SCM muscle contraction. The strength of the SCM muscle contraction is an important factor to consider in c-VEMP recording and measurement, as c-VEMP amplitude is generally found to be greater during strong contractions. Optimum and bilaterally uniform levels of SCM contraction are crucial. The position of the subject, to a great extent, influences the effort and the strength of muscle contraction. The result of the present study revealed larger corrected amplitudes for both right and left ear in sitting position ([right ear and the left ear (P = 0.0000)] (one-way ANOVA) [Table 4, Figures 9 and 10]. Rosengren *et al.* has reported that a simple axial head rotation away from the stimulated ear in an upright position is sufficient to produce a c-VEMP response.[28] In case of an absent c-VEMP response, head turned against resistance, can be performed to increase the SCM muscle contraction by the examiner.[4] In general, in small laboratory setups, lack of space for a bed is a common reason for using the sitting position to record c-VEMP. According to a previous study, lifting the head from a supine position results in greater SCM muscle activity and can produce larger amplitudes.[29] Yet, the difficulty of enduring the posture during the test can result in fatigue of SCM muscles, which can affect the test results of the opposite side.[30] Kim *et al.* reported that the supine neck torsion position causes difficulty in maintaining a constant

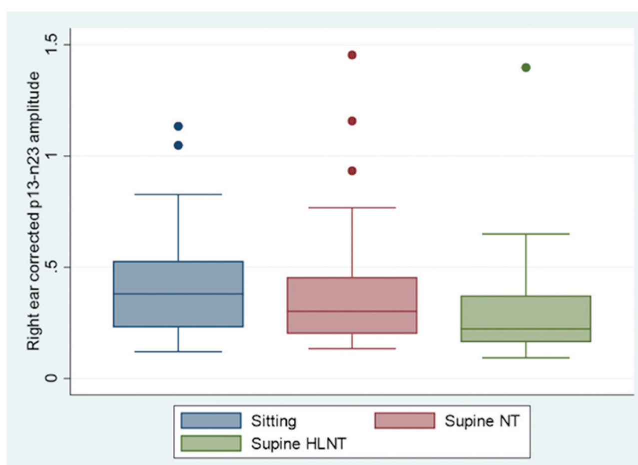

Figure 9: Comparison of right ear corrected p13-n23 amplitude between cervical vestibular-evoked myogenic potential recordings in sitting, supine neck torsion and supine head lift-neck torsion position. Supine NT: Supine neck torsion, Supine HLNT: Supine head lift-neck tors

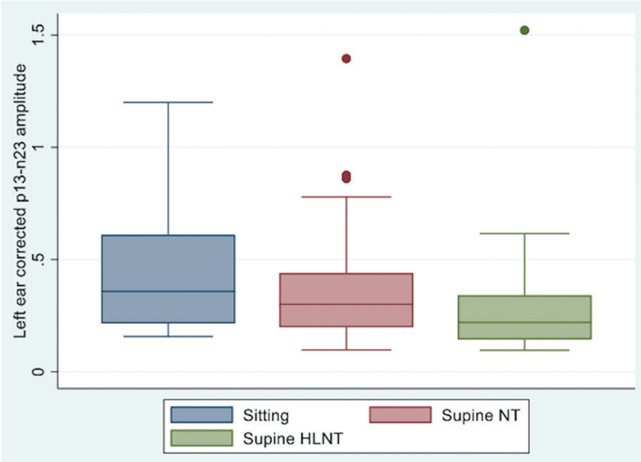

Figure 10: Comparison of left ear corrected p13-n23 amplitude between cervical vestibular-evoked myogenic potential recordings in sitting, supine neck torsion and supine head lift-neck torsion position. Supine NT: Supine neck torsion, Supine HLNT: Supine head lift-neck torsion

contraction of the SCM muscle compared to the seated position.[31] Therefore, supine neck torsion and supine head lift-neck torsion position are generally not recommended in c-VEMP testing. Larger c-VEMP responses in our study with the sitting position of the subject during testing, suggest the same to be the appropriate testing position for recording c-VEMP, which also has the advantage of lesser muscle fatigue and can be employed for smaller laboratory setups.

Amplitude asymmetry which is another important c-VEMP parameter to evaluate the function of the saccule and the inferior vestibular nerve integrity has been found to be a valuable tool for the detection of many unilateral vestibular pathologies. The upper limit of the corrected amplitude asymmetry for tone burst-evoked responses (maximum percentage of amplitude asymmetry) was found to be 21.68% and that for the clicks to be 28.4%, in the current study. Our values are slightly lower than those in the previous studies. Welgampola and Colebatch *et al.* found the upper limit of corrected amplitude asymmetry for click-evoked c-VEMPs to be 35%, while McCaslin *et al.* reported the upper limit of corrected amplitude asymmetry for tone-burst-evoked c-VEMPs to be 37%.[32,33]

Limitations

In the current study, BC stimulation was not employed to elicit VEMP responses. It is known that BC stimulation potentially can yield c-VEMP responses, particularly in cases where bilateral responses are absent, especially among the elderly population. This study employed a 500 Hz stimulus frequency to elicit c-VEMP responses. Normally, the preferred range for AC stimulation in VEMP testing spans from 300 to 1000 Hz. Future research could explore the effects of different stimulus frequencies within the 300–1000 Hz range to assess frequency sensitivity in vestibular function assessment.

Conclusion

The results of the current investigation demonstrate that c-VEMP responses can be elicited in normal healthy adults, by both tone burst and click stimuli albeit with greater response rates for tone burst-evoked responses. The tone-burst-evoked responses (500 Hz) are larger, and exhibit clearer morphology (with standard electrode montage and patient position). These differences highlight the importance of selecting the appropriate stimulus type and that the clinical evaluation should be intricately done, taking into account the type of AC stimuli that are employed to elicit VEMP responses. Furthermore, by identifying the optimal positions for eliciting muscle contractions in each test, our study enhances the reliability and accuracy of vestibular function assessments. Specifically, a seated, head-turned position for c-VEMP testing ensures consistent SCM contractions, which are essential for evaluating the saccule and the inferior vestibular nerve pathway. This tailored approach to positioning enhances the diagnostic utility of c-VEMP tests, ultimately improving the detection and management of vestibular disorders.

VEMP test, a relatively novel neurological tool with the potential to aid in the diagnosis of a wide variety of vestibular illnesses, is, however, contingent upon the use of appropriate stimuli, accurate testing methodologies, and the comparison of results with control data. The shortcomings of the tests in terms of a relative lack of standardized normative values can be improved by attaining sufficient data with different stimuli and recording conditions in healthy participants. A consensus in the literature as to the best recording method for VEMPs is still necessitated. The prevalent predominance of VEMP testing as a clinical otolith function test suggests a higher likelihood of success for VEMP in future. Further research and advancement are required to strengthen the normative values obtained and to enhance the reliability and repeatability of VEMP as a diagnostic test. Furthermore, the documentation of the characteristic VEMP findings in common vestibular disorders would be needed to improve the diagnostic utility of the technique.

Ethical statement

The study was undertaken after prior approval by the Institutional Human Ethics Committee of All India Institute of Medical Sciences (AIIMS), Gorakhpur, UP (IHEC ref no.: IHEC/AIIMS-GKP/BMR/123/2023).

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Nil.

Conflicts of interest

There are no conflicts of interest.

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