Is There a Safe Level for Recording Vestibular Evoked Myogenic Potential? Evidence From Cochlear and Hearing Function Tests

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Objective: There is a growing concern among the scientific community about the possible detrimental effects of signal levels used for eliciting vestibular evoked myogenic potentials (VEMPs) on hearing. A few recent studies showed temporary reduction in amplitude of otoacoustic emissions (OAE) after VEMP administration. Nonetheless, these studies used higher stimulus levels (133 and 130 dB peak equivalent sound pressure level [pe SPL]) than the ones often used (120 to 125 dB pe SPL) for clinical recording of VEMP. Therefore, it is not known whether these lower levels also have similar detrimental impact on hearing function. Hence, the present study aimed at investigating the effect of 500 Hz tone burst presented at 125 dB pe SPL on hearing functions.

Design: True experimental design, with an experimental and a control group, was used in this study. The study included 60 individuals with normal auditory and vestibular system. Of them, 30 underwent unilateral VEMP recording (group I) while the remaining 30 did not undergo VEMP testing (group II). Selection of participants to the groups was random. Pre- and post-VEMP assessments included pure-tone audiometry (250 to 16,000 Hz), distortion product OAE, and subjective symptoms. To simulate the time taken for VEMP testing in group I, participants in group II underwent these tests twice with a gap of 15 minutes.

Results: No participant experienced any subjective symptom after VEMP testing. There was no significant interear and intergroup difference in pure-tone thresholds and distortion product OAE amplitude before and after VEMP recording ($p > 0.05$). Furthermore, the response rate of cervical VEMP was 100% at stimulus intensity of 125 dB pe SPL.

Conclusions: Use of 500 Hz tone burst at 125 dB pe SPL does not cause any temporary or permanent changes in cochlear function and hearing, yet produces 100% response rate of cervical VEMP in normal-hearing young adults. Therefore, 125 dB pe SPL of 500 Hz tone burst is recommended as safe level for obtaining cervical VEMP without significantly losing out on its response rate, at least in normal-hearing young adults.

Key words: Hearing, Stimulus level.

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INTRODUCTION

Vestibular evoked myogenic potential (VEMP) reflects vestibular system's sensitivity to acoustic vibrations. It is elicited by loud sounds and detected as a change in the muscle potentials (Colebatch et al. 1994). VEMPs can be recorded from several muscles of the body. When recorded from the sternocleidomastoid muscle, these ipsilateral potentials are called cervical VEMP (cVEMP) (Colebatch et al. 1994); and when recorded from the extraocular muscles, specifically inferior oblique muscle, they are referred as ocular VEMP (Rosengren et al. 2005).

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VEMP plays an important part in the test battery of clinics and medical centers worldwide, offering an evaluation of the functional integrity of the otolith organs (Young 2006; Kantner & Gürkov 2012). These organs were previously not accessible to testing, especially in patients with balance and vestibular disorders. While cVEMP provides information pertaining to functional integrity of the saccule and its afferents (Colebatch et al. 1994), ocular VEMP primarily unveils the functional status of the utricle and its afferents (Valko et al. 2011; Curthoys et al. 2012). However, there seems increasing concern regarding the effect of sound levels used for eliciting VEMP on cochlear function (Krause et al. 2013; Mattingly et al. 2015; Strömberg et al. 2016; Rodriguez et al. 2017).

After the findings of Mhatre et al. (2010), who reported transient reduction of the distortion product otoacoustic emissions (DPOAE) after auditory brainstem response (ABR) recordings in rats, Soni et al. (2017) reported similar reduction of DPOAE amplitudes after ABR recording in human subjects. Most often, ABR recordings make use of stimuli exceeding 80 dB nHL or 115 to 120 dB SPL, whereas VEMP recordings utilize much higher levels, usually in excess of 125 dB peak equivalent sound pressure level (pe SPL) or 95 dB nHL. On the other hand, ABR recording requires the use of 1500 to 2000 stimuli to be presented to an ear, whereas VEMP requires only 64 to 200 averages. However, it is not known whether the reduction in number of stimuli can offset the increase in the intensity in case of VEMP recording.

Recently, Krause et al. (2013) evaluated the impact of acoustic stimuli used for recording cVEMP on pure-tone thresholds and DPOAE amplitude in 30 young adults between 20 and 35 years of age. The tone burst level used for recording cVEMP was 133 dB pe SPL. They reported significant post-VEMP reduction of DPOAE amplitudes at 6 and 8 kHz but no significant change in pure-tone thresholds after cVEMP testing. More recently, Strömberg et al. (2016) showed significant reduction in DPOAE amplitude at 0.75 and 3 kHz in response to the use of 500 Hz tone bursts presented at 130 dB pe SPL (stimulus duration = 6 ms, rise/fall time = 2 ms, plateau time = 2 ms), but no significant changes in auditory thresholds assessed using Bekesy audiometry. However, the tone burst levels used in these studies were about 5 to 18 dB higher than most of the studies on cVEMP and ocular VEMP (Todd et al. 2009; Murnane et al. 2011; Sandhu et al. 2012; Singh & Barman 2013, 2014, 2015, 2016a, 2016b). Therefore, it is not known if these lower levels (120 or 125 dB pe SPL) would also produce similar deleterious effect on DPOAEs as 130 and 133 dB pe SPL. Further, both these studies restricted the frequency range of DPOAE to 8 kHz or lower frequencies which deprived the assessment of the more sensitive high-frequency regions that could potentially show even a stronger effect. Therefore, there is a need to further study

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the impact of VEMP evoking stimulus on not only the frequencies below 8 kHz but also in the extended high-frequency range. Furthermore, when studying the effect of VEMP evoking air conduction stimuli on hearing, Krause et al. used frequencies up to 10,000 Hz for pure-tone audiometry and showed no significant effect of VEMP eliciting stimulus on pure-tone thresholds, whereas Strömberg et al. used frequencies up to 8000 Hz to show no significant changes in hearing acuity. It is well known that extended frequencies around 8,000 to 16,000 Hz are more sensitive to early damage due to noise exposure (Somma et al. 2008; Mehrparvar et al. 2011, 2014) and hence it is imperative to investigate the effect of VEMP eliciting stimuli on thresholds in this frequency region before drawing conclusions regarding lack of threshold shift.

Most recently, a publication using 10 young adults and 15 children reported no significant change in audiometric thresholds and DPOAE amplitudes after cVEMP and ocular VEMP testing using 500 Hz tone bursts presented at 125 and 120 dB pe SPL to young adults and children, respectively (Rodriguez et al. 2017). None of the subjects in their study reported symptoms consistent with otologic or auditory changes after VEMP stimulus exposure. Because the actual peak equivalent sound pressure levels for 125 dB pe SPL in some of the children's ears were found to exceed 132 dB pe SPL, the level beyond which various sources consider risk for unsafe sound levels (European Union 2003; Colebatch & Rosengren 1994), the authors recommended 120 dB pe SPL with 4 ms stimulus duration (2 ms rise/fall time and 0 ms plateau time) as the safe level for recording VEMP. However, this study deviated from the optimum values of the stimulus-related parameters, and therefore, the outcomes would be difficult to generalize. This makes the case for further investigating the effect of VEMP stimuli on cochlear function while ensuring the use of optimum parameters.

Several previous studies have reported on the normative data of cVEMP (Bath et al. 1998; Welgampola & Colebatch 2001a, 2001b; Cheng et al. 2003; Zapala & Brey 2004; Basta et al. 2005; Wang et al. 2008; Janky & Shepard 2009; Isaradisaikul et al. 2012). However, issues remain with using the available normative data due to the following: (1) These studies have used stimulus levels >125 dB pe SPL, which has already been deemed unsafe by the investigations discussed above (Krause et al. 2013; Strömberg et al. 2016; Rodriguez et al. 2017). (2) Although some of the studies have used 125 dB pe SPL or lower stimulus levels and provided normative values for cVEMP for these stimulus intensities, they have deviated on the use of optimum parameters for vital stimulus factors such as rise/fall time, plateau time, and stimulus duration which have been shown to affect the cVEMP responses significantly. (3) A number of these studies have used unrectified cVEMPs, which is largely believed to be less reliable for clinical applications (McCaslin et al. 2013, 2014). Therefore, there is a need to provide the normative data for the safe stimulus levels while ensuring the use of optimum stimulus parameters.

The above discussion brings to the fore two vital points—need for investigating the safe stimulus level for obtaining cVEMP and need for reporting normative data of cVEMP for the safe stimulus level. Therefore, the present study aimed at (1) evaluating the effect of VEMP eliciting stimulus on cochlear function evaluated using conventional and high-frequency audiometry and DPOAE to find whether or not the 125 dB pe SPL is safe for obtaining cVEMP and (2) obtaining normative data of cVEMP for the stimulus parameters used in the present study, if found safe.

MATERIALS AND METHODS

The study adheres to global guidelines for protection of human subjects used for research. The method used in the study was approved by ethical committee for bio-behavioral research of the institute as a part of an ongoing research project. The participants were not paid in any kind for their participation in the present study.

Participants

The study was conducted in two separate phases. Phase I was dedicated to finding whether or not the tone burst of 500 Hz delivered to the ear using an intensity of 125 dB pe SPL was safe for cochlea and hearing function. Phase II of the study was a conditional phase. This was to be taken up only after finding that the above-mentioned stimulus level had no significant detrimental effect on cochlea and hearing. This was designed to obtain the normative data of cVEMP for the thus proved safe stimulus intensity.

Phase I • This phase of the present study included 60 young adults with normal audiovestibular system in the age range of 18 to 35 years after obtaining informed written consents for their participation in the study. The audiological well-being of the participants was ensured through normal results on a test battery consisting of pure-tone audiometry (air conduction and bone conduction thresholds ≤15 dB HL at octave and mid-octave frequencies from 250 to 16,000 Hz), immittance evaluation ("A" type tympanogram with presence of ipsilateral and contralateral acoustic reflexes at 100 dB HL), and OAE (presence of transient evoked oto-acoustic emissions with global signal-to-noise ratio ≥+6 dB along with response reproducibility of ≥80% and DPOAE with signal-to-noise ratio ≥+6 dB along with response reproducibility of ≥80% across frequencies from 500 to 16,000 Hz). The vestibular well-being was assured by the normal results on behavioral screening tests consisting of the Romberg test (no noticeable sway), Fukuda stepping test (deviation of <45° in either direction and distance of <1 m from the starting point), tandem gait test (heel-to-toe walking—no imbalance or stretching of arms), and past pointing test (finger-to-nose test showing no evidence of tremors and under/overshooting of targets). In addition, normal results (vestibulo-ocular reflex gain >0.8 and 0.7 from horizontal and vertical canals, respectively, and absence of refixation saccades) were also obtained on video head impulse test in all of them. Further, the participants had no complaint or history of vestibular and neurological deficits which was assessed by a detailed structured case history. The participants were randomly divided into two equal groups of 30 individuals each. The participants in group I underwent cVEMP testing in one ear, whereas those in group II did not undergo cVEMP testing.

Phase II • After the results of phase I showed that there was no detrimental effect of the VEMP stimulus levels used in the present study, phase II of the study was conducted. In this phase, all 60 participants underwent cVEMP testing to obtain the normative values of cVEMP evoked using the thus found safe stimulus level, keeping the other stimulus parameters same as in phase I.

Calibration of Equipments

The calibration of stimulus outputs from Grason-Stadler Incorporated 61 (GSI-61, Eden Prairie, MN) clinical audiometer and Biologic Navigator Pro evoked potential system version 7.2.1 (Natus Medical Incorporated, Mundelein) was done

using a sound level meter (SLM) type 824 (Larson Davis, Incorporated, Provo) with a 1-inch condenser pressure microphone connected to it. The SLM was not required for calibration of stimulus output from Starkey DP2000 OAE system (Mimosa Acoustics Incorporated, Champaign). The DPOAE stimulus output calibration was done using the manufacturer's specifications using the "Cut-off 2-cc syringe."

The transducers used for air conduction were TDH-50 supra-aural headphones and HDA-200 circumaural headphones for conventional (250 to 8000 Hz) and extended high-frequency (>8000 Hz) audiometry, respectively. For output calibration of TDH-50 and HAD-200 transducers, one headphone at a time was placed over a 6-ml coupler NBS-9A and a weight of 500 gm was applied over the headphone. The output of the coupler was routed to the SLM via a 1-inch pressure microphone. A low-frequency tone of 250 Hz was introduced, and the headphone was reseated on the coupler until the highest SPL value was read. This helped to assure optimal headphone placement over coupler. This was followed by recording the output sound pressure levels for various octave and mid-octave frequencies corresponding to an output intensity selection of 70 dB HL in the audiometer. In absence of any other standard specification for reference equivalent threshold sound pressure level values for the extended high-frequency audiometry, the manufacturer's specifications were used to ensure audiometric calibration. For the conventional audiometric calibration, the manufacturer's specifications were same as those recommended by American National Standards Institute standards for TDH50 supra-aural headphones [(American National Standards Institute S3.6-1996, cited in Jiang 1998) and, therefore, these values were used. In case of a discrepancy of >1 dB between the SLM reading and the manufacturer's specification, the knob inside the audiometer was adjusted to ascertain accurate outputs. Accuracy in stimulus outputs was checked once every week using SLM whereas daily listening check was performed using a human subject (who was not a part of the study) with known air conduction thresholds. Frequency calibration was performed using the frequency counter which is built-in in the above-mentioned SLM.

Etymotic ER-3A insert earphones of the Biologic Navigator Pro evoked potential system was used for stimulus delivery to the ear canal for recording cVEMP. The output of the insert earphones was checked by connecting it with 2-ml coupler namely AEC 203 (Larson Davis, Incorporated, Provo) which was further connected via the 1-inch pressure microphone to the SLM. The output sound pressure levels were noted for the tone burst stimuli used in the present study (details of tone burst stimuli are mentioned in procedure section), and the outputs were within 0.5 dB of that selected in the instrument. The SPL equivalent to long duration pure tone was also noted which was 105.3 dB SPL which was also within 0.5 dB of the manufacturer's specification for the tone burst. The schedule for calibration of the tone burst stimuli was same as that for the audiometric calibration.

The objective calibration for stimulus output from Etymotic RE-10C probe-tip of the Starkey DP2000 DPOAE system was performed at the beginning of the study and rechecked every week during the study and at the end of the study to ensure appropriate stimulus outputs. Before beginning the recording of DPOAEs in each session, the "Cut-off 2-ml syringe" was used for quick calibration followed by in-the-ear calibration in each test session. The linearity check for the stimulus output from was performed once every week during the entire course of the study to guard against false-negative measurements of cochlear problems arising out of nonlinear elements in the system. The challenge of preventing the standing waves in the ear canal from affecting the DPOAE measurements was addressed using the manufacturer's recommendation in this regard. The standing waves can be identified as a sharp dip in the frequency response in the calibration curve during the in-the-ear calibration of the probe tones. When there was evidence for a standing wave, a deeper probe insertion was used as per the manufacturer's recommendation. Calibration procedures were repeated after reinsertion to confirm the elimination of the standing waves. The maneuver to eliminate the effects of standing waves was required for only one participant in the present study.

Procedure

In phase I, the participants of group I underwent a baseline recording of DPOAE from both ears before undergoing cVEMP testing in one ear. While half of the subjects underwent cVEMP in right ear, the other half had cVEMPs recorded from left ears. DPOAE was again recorded from both ears after a gap of 5 minutes after cVEMP testing. Participants of group II also underwent DPOAE recording on two occasions, separated by 15 minutes, to simulate the time gap that was caused by cVEMP testing in group I. Phase II commenced after finding that 125 dB pe SPL was safe for cochlear and hearing function when used in conjunction with the other stimulus and acquisition parameters of the present study. In this phase, cVEMPs were recorded from both ears of all 60 participants to provide the normative data for this safe stimulus. However, the stimulus parameters were kept same in both phases.

Recording of cVEMP • The participants were seated in a comfortable chair in an upright position. The recording sites were cleaned with a commercially available abrasive gel to obtain acceptable electrode impedances (absolute electrode impedance <5 kΩ, interelectrode impedance <2 kΩ). Gold-plated electrodes were placed using adequate amount of commercially available conductive paste and secured in place with surgical tape. The inverting (negative) electrode was placed at the sternoclavicular junction, the noninverting (positive) electrode at the upper one third of the sternocleidomastoid muscle and the ground electrode on the forehead. Participants were instructed to turn their heads away from the side of stimulation to tense the sternocleidomastoid muscle for ipsilateral recording of cVEMP. Tone bursts of 500 Hz were presented at 125 dB pe SPL using a repetition rate of 5.1 Hz through Etymotic ER-3A insert earphones of the Biologic Navigator Pro evoked potential system. The ramps and plateau time used were 2 and 1 ms, respectively, as these ramping and plateau times were found to be best suited for cVEMP recording (Singh et al. 2014). Analysis window was set to 74 ms which included a 20 ms prestimulus (baseline) recording. The responses were averaged across 200 sweeps after being band-pass filtered between 10 and 1500 Hz and multiplied by a factor of 5000. To control for the effect of variable electromyography between the sides, prestimulus rectification was applied to the recordings which resulted in corrected amplitude for the response. The parameters noted were response rate (percentage of ears with presence of biphasic cVEMP waveform), individual peak latencies, and peak to peak amplitude in phase I. Phase II additionally included computation of interaural amplitude ratio (also called asymmetry ratio).

Conventional and Extended High-Frequency Pure-Tone Audiometry • Air conduction audiometry was carried out at octave and mid-octave frequencies from 250 to 16,000 Hz using a calibrated clinical audiometer GSI-61 with TDH-50 supra-aural headphones and HDA-200 circumaural headphones for conventional (250 to 8000 Hz) and extended high-frequency (>8000 Hz) audiometry, respectively. For obtaining pure-tone thresholds at each frequency, participants were instructed to press the response switch upon hearing the tone which was presented for 1 to 2 seconds at each intensity. The threshold (level associated with minimum 50% detection) at each frequency was obtained using modified Hughson-Westlake procedure (Carhart & Jerger 1959). The order of frequency was randomly changed between the subjects to avoid order effect.

Recording of DPOAE • For obtaining DPOAEs, a calibrated Starkey DP-2000 otoacoustic system with Etymotic ER10C probe tip, which consists of 2 miniature transducers for emitting acoustic stimuli and a low-noise microphone to record sound in the ear canal, was used. An appropriate size expandable foam tip was selected out of the three available sizes (ER10C-14A, ER10C-14B, and ER10C-14C) and secured over the probe to ensure good probe fit in the ear canal. Intersession variations in the insertion depth of the probe tip were controlled by marking a point on the tip to indicate the extent of insertion, and this point was used to ensure same insertion depth during the subsequent recording session. For eliciting DPOAEs, two frequencies (f1 and f2) were used in such a way that the ratio between them (f2/f1) was maintained constant at 1.22. The stimulus intensity levels for the two frequencies were 65 and 55 dB SPL, respectively, for f1 and f2. The response level associated with second-order intermodulation distortion product (2f1–f2) was depicted as a function of frequency in the DPgram at octave and interoctave frequencies from 500 to 16,000 Hz. The criterion of ≥+6 dB for signal-to-noise ratio was considered for the presence of DPOAEs. The amplitude of DPOAE was noted at the above-mentioned octave and mid-octave frequencies.

Subjective Symptoms After cVEMP Recording • Each participant was asked questions regarding the feeling of muffled hearing, ear pressure, otalgia, tinnitus, or any other aural symptoms immediately after undergoing cVEMP recording (after 5 minutes). The questions were framed in such a way that the answer required was "yes"/"no." This (enquiring about subjective symptoms) was done to find if the subjective symptoms felt by the participants were vindicated by the outcomes of DPOAEs and audiometry.

Statistical Analyses

Statistical analyses were performed using a commercially available statistical tool Statistical Package for Social Sciences version 17.0. The within- and between-group comparisons were done using Wilcoxon signed rank test and Mann-Whitney U test respectively, as the results of Shapiro-Wilk test of normality revealed non-normal distribution of the data ($p < 0.05$). In addition, descriptive statistics was used to report mean, SD, and median.

RESULTS

Phase I

Distortion Product Otoacoustic Emissions • The study had two groups of otologically and neurologically healthy individuals. Individuals in group I underwent cVEMP recording from one ear, whereas individuals in group II did not undergo cVEMP recording in the first phase of the study. While DPOAEs were obtained before and after cVEMP recording (after 5 minutes of cVEMP) in group I, individuals in group II underwent DPOAE testing twice while maintaining the same gap between the two recordings as in group I (15 minutes). Table 1 shows the mean and SD of DPOAE absolute amplitude for both recordings across frequencies in both groups.

Wilcoxon signed rank test revealed no significant difference in DPOAE amplitude between the ears at any frequency in both test sessions ($p > 0.05$). Further, there was no significant difference between pre-VEMP and post-VEMP DPOAE amplitude in both ears at any frequency in group I as well as group II ($p > 0.05$). Mann-Whitney U test was done for investigating the group difference. The results revealed no significant difference in DPOAE amplitude at any frequency between the groups ($p > 0.05$) in any of the two sessions of DPOAE recording.

Subjective Symptoms • A total of 30 individuals underwent cVEMP testing. Of them, 3 individuals reported perception of object movement (slight vibration) at the time of receiving cVEMP stimuli and cessation of vibration perception as soon as the stimulus stopped. Reduced or muffled hearing, tinnitus, otalgia, ear pressure, or any other audiological complaint soon after cVEMP testing or at any other time during the 24 hr that followed was not reported by any participant.

Conventional and Extended High-Frequency Pure-Tone Audiometry • All the individuals of both the groups underwent air conduction pure-tone audiometry. The median in both ears of both groups was 5 or 0 dB HL at most frequencies, and the median value ranged between −5 and +5 dB HL across frequencies (Table 2). In terms of the individual differences, none of the participants in any of their ears showed a difference of more than 5 dB HL between the two test sessions. The Wilcoxon signed rank test showed no significant difference in pre- and post-VEMP pure-tone thresholds between the ears in both groups ($p > 0.05$). The outcome of Mann-Whitney U test revealed no significant group difference in the audiometric threshold at any frequency in both groups ($p > 0.05$).

Phase II

After the results of the present study which showed no significant difference between pre- and post-VEMP recording DPOAE amplitude and air conduction pure-tone thresholds, cVEMPs were obtained from both ears of all 60 participants. This was done to report the normative data of cVEMP at 125 dB pe SPL when using 500 Hz air conduction tone bursts. All individuals had bilateral presence of cVEMP at this intensity, thereby yielding a response rate of 100%. The mean P1 and N1 latency were found to be 14.54 ms (SD = 0.93) and 23.59 ms (SD = 1.02). The mean peak to peak amplitude was found to be 6.47 μV (SD = 3.53), whereas the mean interaural amplitude ratio (also called asymmetry ratio) was 21.38% (SD = 6.16).

DISCUSSION

Results of the present investigation showed that there was no significant difference in DPOAE amplitude between baseline recording and after VEMP testing at any of the frequencies. This is not consistent with the findings of the published studies in

TABLE 1. Mean and SD (Within Parenthesis) of DPOAE Absolute Amplitude and SNR for Both Recordings in Group I (Group That Underwent Unilateral VEMP Testing) and Group II (Group That Did Not Undergo VEMP Testing)

			16 kHz		12 kHz		8 kHz		6 kHz		4 kHz		3 kHz		2 kHz		1.5 kHz		1 kHz		0.75 kHz		0.5 kHz	
Group	Ear	Session	Amp	SNR	Amp	SNR	Amp	SNR	Amp	SNR	Amp	SNR	Amp	SNR	Amp	SNR	Amp	SNR	Amp	SNR	Amp	SNR	Amp	SNR
I	NV	1	−9.71	7.51	9.24	14.17	8.52	14.62	12.88	22.70	8.99	26.31	7.04	23.63	10.10	24.53	10.05	24.19	5.76	21.28	2.83	8.01	1.89	6.45
			(10.72)	(7.31)	(9.05)	(6.96)	(8.42)	(5.35)	(5.29)	(5.84)	(5.88)	(8.29)	(5.98)	(7.46)	(4.57)	(6.15)	(6.57)	(6.10)	(6.58)	(7.69)	(5.73)	(5.19)	(6.85)	(6.10)
		2	−8.49	8.30	9.48	13.41	8.39	14.42	12.19	21.76	8.15	26.09	7.26	21.20	10.23	22.02	10.69	23.81	6.34	18.34	3.05	7.96	1.92	7.31
			(11.06)	(7.56)	(9.26)	(5.90)	(7.71)	(6.08)	(5.55)	(7.04)	(6.17)	(6.64)	(6.04)	(6.93)	(4.91)	(6.50)	(6.29)	(7.25)	(6.81)	(7.78)	(5.75)	(6.20)	(7.19)	(4.21)
	V	1	−9.43	6.95	10.94	12.71	7.46	13.82	13.10	22.48	7.34	26.85	6.45	24.29	9.20	23.15	9.79	23.47	5.03	18.95	2.30	8.13	1.28	5.76
			(10.04)	(10.90)	(10.70)	(4.57)	(6.93)	(5.89)	(5.05)	(5.45)	(6.78)	(7.65)	(5.61)	(6.99)	(5.84)	(6.14)	(6.32)	(6.17)	(6.30)	(6.40)	(5.96)	(7.19)	(7.03)	(7.88)
		2	−8.36	10.20	8.47	12.01	7.63	15.20	12.62	23.62	7.60	27.10	6.62	25.30	8.42	24.65	9.54	23.61	5.17	19.01	3.66	9.84	1.32	5.72
			(9.22)	(9.81)	(9.81)	(5.24)	(7.52)	(4.59)	(6.53)	(4.85)	(5.63)	(7.80)	(4.75)	(7.57)	(6.54)	(6.70)	(6.52)	(6.07)	(6.16)	(6.05)	(5.58)	(4.39)	(7.24)	(8.17)
II	L	1	−9.36	8.05	8.54	12.95	7.88	14.35	11.11	21.90	7.29	27.12	6.71	23.33	7.48	25.34	8.49	23.97	6.31	22.86	3.07	9.76	4.81	7.33
			(11.45)	(7.13)	(9.12)	(7.60)	(7.36)	(5.07)	(5.56)	(5.23)	(5.27)	(8.92)	(4.96)	(7.62)	(5.96)	(6.57)	(5.55)	(6.74)	(6.85)	(7.69)	(6.88)	(5.02)	(9.36)	(6.23)
		2	−11.01	9.70	6.75	12.40	7.83	13.72	9.73	21.21	7.07	27.09	6.51	22.35	7.40	23.35	8.94	24.02	5.39	22.30	2.76	8.91	5.05	7.45
			(10.69)	(7.25)	(12.34)	(6.11)	(6.80)	(6.08)	(6.12)	(7.04)	(5.21)	(6.37)	(4.94)	(6.56)	(6.06)	(6.73)	(5.24)	(7.01)	(6.65)	(7.29)	(6.26)	(6.44)	(7.97)	(4.67)
	R	1	−10.10	10.85	8.73	12.71	8.75	12.70	10.28	22.04	6.33	26.42	6.83	23.89	6.98	24.47	7.30	25.90	5.53	20.59	3.21	9.33	1.73	6.71
			(10.99)	(10.01)	(9.83)	(4.75)	(6.44)	(5.93)	(6.94)	(5.53)	(4.86)	(7.72)	(4.03)	(7.02)	(5.13)	(6.87)	(6.58)	(6.59)	(5.09)	(6.81)	(5.93)	(7.76)	(10.22)	(7.02)
		2	−12.47	8.47	8.91	12.81	8.43	12.90	9.68	22.13	6.57	26.15	6.04	26.34	6.59	25.10	7.33	22.37	4.75	21.37	2.88	8.99	2.39	7.47
			(9.82)	(8.80)	(8.35)	(5.84)	(6.04)	(4.21)	(6.76)	(4.59)	(4.70)	(7.75)	(4.09)	(7.03)	(4.95)	(6.83)	(6.62)	(6.68)	(5.19)	(6.56)	(5.67)	(5.63)	(8.27)	(6.95)

Amp, amplitude; DPOAE, distortion product otoacoustic emissions; NV, non-VEMP ear; SNR, signal-to-noise ratio; V, VEMP ear; VEMP, vestibular evoked myogenic potential.

this regard (Krause et al. 2013; Strömberg et al. 2016). Krause et al. (2013) reported significant reduction in DPOAE amplitude at 6 and 8 kHz after undergoing VEMP testing, whereas Strömberg et al. (2016) observed reduction in DPOAE amplitude at 0.75 and 3 kHz. The discrepancy in findings between the studies could be attributed to three major differences in the methods used between the present study and those reported earlier. These differences are as follows: (1) difference in the use of gating function (window) for stimulus generation (Hanning window versus Blackman window), (2) differences in stimulus duration (10 and 6 versus 5 ms), and (3) difference in intensity of tone bursts used to elicit VEMP (133 and 130 versus 125 dB pe SPL). While energy in the central main lobe for Hanning as well as Blackman window remains the same, energy in the side lobes is higher for the former than the later (Podder et al. 2014; Naidu 2015). This could result in exposure to high effective energy and thereby prove more deleterious when using a stimulus passed through Hanning window than Blackman window. Therefore, use of Hanning window in the study by Krause et al. could have been one of the contributing factors to decreased DPOAE amplitude at 6 and 8 kHz which differentiated the findings of present study from that by Krause et al. The information regarding gating window is not provided in Strömberg et al. Second, the present study used 5 ms stimulus duration as against 10 ms used in the study by Krause et al. and 6 ms in the study by Strömberg et al. This would have further resulted in more exposure duration in Strömberg et al. and double exposure durations in Krause et al. than the present study. One of the measures used to assess the impact of repetitive sound impulses in a closed area is B-duration. It (B-duration) refers to the sum of periods in a quasi-oscillating waveform during which the pressure envelope exceeds 10% of the peak pressure value (Ward 1968). Replicating the stimulus parameters (stimulus gating, stimulus duration, and stimulus intensity) of the present study and those by Strömberg et al. and Krause et al., we found that the B-duration of each stimuli was 0.8 ms for the stimuli used in the present study as against 2.7 ms for stimuli used in Strömberg et al. and 4.8 ms for stimuli used in Krause et al. All these B-durations fall under safe levels as per most standards as these standards consider sounds of peak levels <135 to 140 dB pe SPL and B-durations <20 ms as safe with no temporary or permanent threshold shifts associated with them (European Union Directive [86/188/EEC] 1986; CHABA 1992; ISO 1999 1990). Nonetheless, these values were arrived at using studies that used pure-tone thresholds to validate the effects of various levels of impulse noise. These levels need not necessarily be considered safe when using OAEs, as OAE amplitudes have been found to diminish as a result of noise exposure despite no significant change in hearing thresholds for the same levels of noise (Bhatiya 2015). In fact, Bhatiya (2015) showed that an impulse noise produced by gun shots causes significant reduction in DPOAE amplitude in the high-frequency region (>4 kHz) despite showing no significant change in pure-tone thresholds. Further, while levels <135 dB pe SPL are considered safe by most regulatory agencies world over, a few sporadic studies have shown higher susceptibility to impulse noise by showing deleterious impact of sounds around 132 dB pe SPL (Price 1981). Because 133 dB pe SPL was used by Krause et al. and 130 dB pe SPL by Strömberg et al., there might have been the effect of lowered individual susceptibility in some individuals which produced the results that they found. However, there are no studies to the best of our knowledge that

TABLE 2. Mean, Median, and SD of Air Conduction Pure-Tone Thresholds (in dB HL) for Both Sessions in Group I (Group That Underwent Unilateral VEMP Testing) and Group II (Group That Did Not Undergo VEMP Testing)

Group	Ear	Session	Parameter	0.25 kHz	0.5 kHz	0.75 kHz	1 kHz	1.5 kHz	2 kHz	3 kHz	4 kHz	6 kHz	8 kHz	12.5 kHz	16 kHz
I	V	1	Mean	2.16	0.50	2.83	4.00	4.00	4.16	4.83	2.16	0.66	3.50	2.16	0.66
			SD	6.78	7.91	7.03	5.93	6.74	5.88	5.33	6.11	6.78	7.67	5.97	8.58
			Median	5.00	–5.00	5.00	5.00	5.00	5.00	0.00	0.00	0.00	5.00	5.00	0.00
		2	Mean	2.00	0.83	3.50	4.16	5.00	5.66	4.33	2.33	1.16	3.50	3.66	1.66
			SD	6.89	8.20	6.17	5.42	6.29	4.68	5.52	6.53	6.52	5.89	6.14	7.35
			Median	5.00	0.00	5.00	5.00	5.00	5.00	5.00	5.00	0.00	5.00	5.00	0.00
	NV	1	Mean	–1.16	–2.16	1.16	3.16	2.66	3.00	2.83	2.00	1.00	2.33	0.16	–0.83
			SD	5.82	6.39	6.25	5.79	5.20	7.49	7.50	6.24	6.35	6.78	6.49	7.43
			Median	–2.50	–5.00	5.00	5.00	2.50	5.00	0.00	0.00	0.00	5.00	0.00	0.00
		2	Mean	–1.00	–1.16	1.83	3.16	3.33	3.33	2.50	0.83	1.00	2.66	1.66	–0.33
			SD	5.78	6.65	5.94	5.49	4.97	6.86	5.04	6.30	5.31	6.26	5.77	6.42
			Median	0.00	0.00	5.00	5.00	5.00	5.00	0.00	0.00	0.00	5.00	5.00	0.00
II	R	1	Mean	1.16	0.50	2.83	4.16	4.16	4.16	4.83	2.16	0.66	3.50	2.66	0.33
			SD	7.84	7.91	7.03	6.30	7.08	5.88	5.33	6.11	6.78	7.67	7.15	9.09
			Median	0.00	–0.50	5.00	5.00	5.00	5.00	5.00	0.00	0.00	5.00	5.00	0.00
		2	Mean	–0.33	–2.16	1.50	3.50	2.66	3.00	2.83	2.00	1.00	2.33	–0.16	–1.50
			SD	6.81	6.96	6.96	6.45	5.20	7.49	7.50	6.24	6.35	6.78	6.22	8.52
			Median	2.50	5.00	5.00	5.00	2.50	5.00	0.00	0.00	0.00	5.00	5.00	0.00
	L	1	Mean	1.16	1.50	4.66	4.66	4.00	4.00	4.66	2.16	0.50	3.00	3.33	0.83
			SD	7.03	6.17	6.28	4.53	4.23	5.31	5.07	6.52	6.34	7.72	5.46	8.41
			Median	0.00	0.00	5.00	5.00	5.00	5.00	5.00	2.50	0.00	5.00	5.00	0.00
		2	Mean	–0.33	–2.66	1.33	3.16	3.33	3.00	3.66	2.16	1.00	2.00	0.33	0.50
			SD	6.68	5.20	6.14	5.16	4.79	6.77	6.42	6.11	5.78	6.24	6.68	7.69
			Median	0.00	–5.00	0.00	5.00	5.00	5.00	5.00	2.50	0.00	0.00	0.00	0.00

L, left ear; R, right ear; NV, non-VEMP ear; V, VEMP ear; VEMP, vestibular evoked myogenic potential.

show impulse noise of 125 dB pe SPL and B-duration of <1 ms to have deleterious impact on hearing or OAE.

On conventional and extended high-frequency pure-tone audiometry, all participants in both groups showed no change or change in thresholds by 5 dB HL during post-VEMP measurement compared with the pre-VEMP condition. There was no significant difference between the test sessions. The difference of 5 dB or less was not considered a significant change due to VEMP eliciting stimulus. This is because it is well established that up to 5 dB change could occur in pure-tone thresholds between two test sessions despite keeping all other variables constant (Schmuziger et al. 2004; Swanepoel et al. 2010; de Mello et al. 2015). The findings of pure-tone audiometry (0.25 to 16 kHz) in the present study are similar to those reported by Krause et al. (2013) and Strömberg et al. (2016), although they used frequencies up to 8 kHz. However, Mattingly et al. (2015) reported sudden permanent increase in pure-tone thresholds by 25 to 30 dB across the frequencies, similar increase in speech reception thresholds and drop in word recognition scores by 44 to 65% in two ears. It is well known that noise-induced damage is primarily cochlear in nature (Bohne et al. 1987; Bohne & Harding 2000); however, unless steeply sloping audiograms are encountered (Bess 1983), the disproportionately poor speech identification scores to pure-tone average thresholds, as observed in Mattingly et al., are generally indicator of a retrocochlear lesion (Olsen et al. 1975; Bess 1983; Yellin et al. 1989). Noise levels in excess of 140 dB SPL usually can cause tearing off of the organ of Corti from the basilar membrane (Lurie 1942; Bohne 1976) which might also show such results. However, the levels used in the study by Mattingly et al. were ≤135 dB pe SPL and therefore are not likely to result in such aberrations of the organ of Corti. Hence, the findings in Mattingly et al. could possibly be a coincidental sudden idiopathic sensorineural hearing, not necessarily associated to VEMP testing. The levels used in the present study were still lower, and therefore, VEMP stimuli used in the present study had no significant effect on pure-tone thresholds for octave and mid-octave frequencies from 0.25 to 16 kHz.

All participants of the present study, similar to the study by Krause et al. (2013) and Strömberg et al. (2016), were asked questions related to subjective symptoms related to hearing after undergoing VEMP recording. No participant reported complaint of hearing-related symptoms like reduced or muffled hearing, tinnitus, otalgia, ear pressure, or any other audiological complaint soon after VEMP recording or at any time within 24 hr of it. Strömberg et al. also reported no such complaints from all their participants. In all, 10 (30%) participants in Krause et al. had some temporary subjective symptoms with slightly muffled hearing in eight, slight ear pressure in three, noise-like tinnitus in one, and otalgia in one. Therefore, the findings of the present study are in agreement with those of Strömberg et al. but did not corroborate with those of Krause et al. The differences in level of stimulus, duration of each stimulus, and stimulus gating function, as explained above, could be the reasons behind the differences in the findings between the present study and that by Krause et al.

Last, it is worth noting that a recent report of VEMP stimulus measurement in children's and adults' ear canal showed ≥3 dB difference between the measurements of dB pe SPL between children and adults (Rodriguez et al. 2017; Thomas et al. 2017). In fact, Rodriguez et al. (2017) reported that the actual stimulus intensity measured in the ear canals of some children was as high as 132 dB pe SPL despite the stimulus intensity selected in the equipment being 125 dB pe SPL. Going by these findings,

it worth cautioning the readers of the present study that 125 dB pe SPL was found safe only for adults in the age range of 18 to 35 years and therefore should not be generalized to children or any other population beyond the age range used in the present study. This also means that there is a scope of future research in this area by including older adults and also individuals with cochlear hearing losses.

CONCLUSIONS

The findings from the present study show no significant change in pure-tone thresholds and DPOAE amplitude and no subjective symptoms after VEMP testing when using 500 Hz tone bursts of 125 dB pe SPL for its elicitation. Further, the response rate of cVEMP was 100% for the use of these stimulus parameters. Therefore, use of 125 dB pe SPL for 500 Hz tone burst is recommended as safe level for clinical recording of cVEMP in normal-hearing young adults.

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