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Evaluation of the descriptive values and occlusion effects of air and bone conducted cervical vestibular evoked myogenic potentials in normal individuals

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Abstract

Objective: This study was aimed to establish the descriptive statistical values of cVEMPs's responses which are evoked by air and bone conducted stimuli and to examine the effects of occlusion on bone conducted (BC) cVEMPs test.

Methods: The study was carried out on 20 individuals ($n = 40$ ears), 11 women and 9 men, at the Medipol Mega University Hospital. cVEMPs tests were applied in five stages to the individuals who are volunteer to participate in this study. Firstly, the air conducted (AC) cVEMPs test was applied. Then, BC cVEMPs tests were applied in four different conditions with the aim of examining the occlusion effect.

Results: Latency values of the AC cVEMPs response were 15.17 ± 0.77 ms for P1 and 24.12 ± 1.38 ms for N1 and 8.95 ± 1.12 ms for interpeak latencies. P1N1 amplitude value was 149.73 ± 75.00 μ V. VEMPs asymmetry ratio (VAR) was 0.16 ± 0.16 . Latency measurements of the BC cVEMPs response were 14.38 ± 0.85 ms for P1 and 23.40 ± 1.50 ms for N1 and 9.05 ± 1.57 ms for interpeak latencies. P1N1 amplitude value was 107.58 ± 54.08 μ V. VAR was 0.15 ± 0.12 . Both AC cVEMPs and BC cVEMPs parameters were demonstrated that there are not any significant differences between female-male and left ear-right ear. When AC and BC cVEMPs responses were compared, the mean P1 and N1 latencies of BC cVEMPs were significantly shorter than those of AC cVEMPs ($p < 0.01$). The mean amplitudes of AC cVEMPs were significantly larger than those of BC cVEMPs ($p < 0.01$). When the impact of the occlusion effect on cVEMPs parameters was examined, no statistical significance was found.

Conclusion: As a result, it was thought that the BC cVEMPs, which is not widely used in clinics, might be used in the vestibular assessment of conductive hearing losses (CHL) in clinics, by obtaining descriptive values with this study. In addition, it was thought that it might be used as an auxiliary test to diagnose patients with hyperacusis who are disturbed by loud noises.

Keywords: Air conducted cVEMPs, Bone conducted cVEMPs, Occlusion effect, Vestibular system, Vestibular evoked myogenic potentials

Background

Vestibular evoked myogenic potentials (VEMPs) are electrophysiologic test methods widely used for assessing otolith organs and vestibular nerve [1–5]. There are two methods of measuring VEMPs, ocular VEMPs (oVEMPs) and cervical VEMPs (cVEMPs). cVEMPs to

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acoustic stimuli mainly reflects saccule and inferior vestibular nerve function [6–10]. cVEMPs responses can be obtained using air conducted loud sound, bone conducted sound, vibration, forehead taps, or galvanic stimulation [11].

VEMPs responses are not addicted to auditory sensitivity. VEMPs responses can be attained in individuals with sensorineural hearing loss whatever the degree [12, 13]. However, CHL can decrease or extinguish air conducted VEMPs responses due to decrease of the stimulus reaching the utricle and saccule [14–16]. Thus, the use of bone conducted stimuli can aid in evaluating the utricle and saccule function in people with middle ear problems. Several methods of bone conduction, including bone vibrators, mini-shakers, and reflex hammers have been indicated to effectually evoke VEMPs responses [16–18].

Sheykholslami et al. (2000) [19] firstly reported that 500 Hz tone-burst (TB) transmitted by a bone vibrator implemented over the mastoid of ipsilateral ear gives rise to short latency potentials in the sternocleidomastoid muscle (SCM), which were likely to be of vestibular origin. They also stated that the VEMPs responses obtained did not decrease with CHL [20].

Click and TB stimuli are used to evoke VEMPs responses. Five hundred hertz TB stimuli are more effective stimulus than click stimuli. The optimum frequency for evoking BC VEMPs is not known, but it has been reported that 500 Hz is effective [20–22].

The occlusion effect manifests as the enhanced loudness perception of bone conducted sound with an occluded external auditory canal (EAC) as compared with an open EAC [23]. It is most apparent with stimulation by low frequencies [24]. The occlusion effect is generally attributed to the osseotympanic conduction mechanism of bone conduction [24, 25]. Studies investigating the effect of occlusion effect on bone conducted cVEMPs test parameters are limited.

This study aims to specify descriptive statistical values of cVEMPs responses obtained as a result of air and bone conducted stimulation in healthy individuals without a history of hearing loss and dizziness/vertigo and to examine the effect of occlusion effect on cVEMPs test parameters. In addition, it is to enable the use of the cVEMPs test in the vestibular assessment of patients with CHL and to assist in the differential diagnosis.

Methods

Participants

The study was carried out on 20 individuals ($n = 40$ ears), 11 women and 9 men, at the Medipol Mega University Hospital. The approval for the research was obtained from the Ethics Committee of Istanbul Medipol University on October 9, 2019 (Approval number: 741). This

study was carried out in compliance with the principles of the Helsinki Declaration. An informed consent form was obtained from the participants.

Inclusion criteria

Inclusion criteria of the study were as follows:

- A chronological age ranging from 20 to 30 years
- Normal otoscopic examination
- Normal hearing (< 25 dB HL, Pure Tone Average (PTA); (500 Hz, 1 kHz, 2 kHz, and 4 kHz)
- $\geq 88\%$ Speech Discrimination Score (SDS)
- type A tympanogram and the presence of bilateral acoustic reflexes

Exclusion criteria

Exclusion criteria of the study were as follows:

- The presence of systemic, neurological or psychiatric disease,
- A history of otological disease and/or ear surgery,
- The presence of neck problems and/or complaints,
- A history of vertigo or dizziness,
- Absence of air and/or bone conducted cVEMPs responses

cVEMPs test

In the study, Interacoustics® Eclipse EP25 (Assens, Denmark) device was used to record myogenic activities. Surface Ag/AgCl electrodes were attached at the middle third of the SCM muscle (active electrodes), the sternoclavicular junction (reference electrode), and the center of the forehead (ground electrode). During the test, the electrode impedance was less than 5 k Ω , with interelectrode impedance less than 3 k Ω . VEMPs were recorded while subjects were seated on a revolving chair and rotated to face the contralateral side to provide adequate tension of the SCM muscle. The range of the visual reference feedback was between 70 and 120 μ V RMS EMG. Thus, a more symmetrical contraction of the SCM muscles was achieved.

cVEMPs tests were applied in five stages to the individuals who are volunteer to participate in this study. Firstly, the air conducted cVEMPs test was applied. Then, bone conducted cVEMPs tests were applied in four different conditions with the aim of examining the occlusion effect.

In the present study, a direct comparison of the cVEMPs in response to AC and BC 500 Hz TB stimuli was made in the same subjects, using the same recording methods. AC stimuli were presented through insert earphones,

Table 1 Descriptive statistical values of AC cVEMP parameters (mean ± SD)

PARAMETER	N	95 dB nHL	N	90 dB nHL	N	85 dB nHL	N	80 dB nHL	N	75 dB nHL
P1 Latency (ms)	40	15,17±0,77	39	15,58±0,77	30	15,63±0,97	20	15,40±1,05	11	15,67±1,03
N1 Latency (ms)	40	24,12±1,38	39	24,50±1,20	30	24,47±0,92	20	24,30±1,09	11	24,06±1,14
Interpeak latency (ms)	40	8,95±1,12	39	8,92±1,26	30	8,84±0,98	20	8,90±1,05	11	8,39±0,92
P1N1 Amplitude(µV)	40	149,73±75,00	39	115,64±71,15	30	86,10±55,05	20	66,00±43,08	11	48,59±25,78
VEMP Asymmetry Ratio	20	0,16±0,16	19	0,10±0,09	13	0,17±0,13	9	0,20±0,12	4	0,31±0,14

Table 2 Comparison of BC cVEMP parameters applied at 50 dB nHL intensity according to the occlusion conditions

Parameter	Condition	N	Mean	SD	χ^2	p values
P1 latency (ms)	Condition 1	40	14.343	0.8278	0.537	0.911
	Condition 2	40	14.451	1.0475		
	Condition 3	40	14.360	0.8682		
	Condition 4	40	14.376	0.6497		
	Total	160	14.382	0.8528		
N1 latency (ms)	Condition 1	40	22.993	1.3130	6.214	0.102
	Condition 2	40	23.225	1.5477		
	Condition 3	40	23.676	1.5191		
	Condition 4	40	23.691	1.5665		
	Total	160	23.396	1.5061		
Interpeak latency (ms)	Condition 1	40	8.800	1.8755	7.429	0.059
	Condition 2	40	8.775	1.4932		
	Condition 3	40	9.317	1.4281		
	Condition 4	40	9.317	1.4104		
	Total	160	9.052	1.5711		
P1N1 amplitude (μ V)	Condition 1	40	103.948	54.8940	0.700	0.873
	Condition 2	40	107.624	56.6696		
	Condition 3	40	110.604	49.9248		
	Condition 4	40	108.152	56.4436		
	Total	160	107.582	54.0865		
VEMP asymmetry ratio	Condition 1	20	0.138	0.1135	1.875	0.599
	Condition 2	20	0.164	0.1304		
	Condition 3	20	0.128	0.1229		
	Condition 4	20	0.162	0.1038		
	Total	80	0.148	0.1168		

Condition 1 bilateral ears occluded, Condition 2 contralateral ear occluded, Condition 3 ipsilateral ear occluded, Condition 4 bilateral ears open

Table 3 Descriptive statistical values of BC cVEMP parameters (mean \pm SD)

Parameter	N	50 dB nHL	N	45 dB nHL	N	40 dB nHL
P1 latency (ms)	160	14.38 \pm 0.85	129	14.65 \pm 0.96	79	14.78 \pm 1.07
N1 latency (ms)	160	23.40 \pm 1.50	129	23.45 \pm 1.39	79	23.39 \pm 1.55
Interpeak latency (ms)	160	9.05 \pm 1.57	129	8.80 \pm 1.36	79	8.62 \pm 1.48
P1N1 amplitude (μ V)	160	107.58 \pm 54.08	129	77.40 \pm 43.35	79	58.09 \pm 30.35
VEMP asymmetry ratio	80	0.15 \pm 0.12	58	0.15 \pm 0.12	31	0.21 \pm 0.13

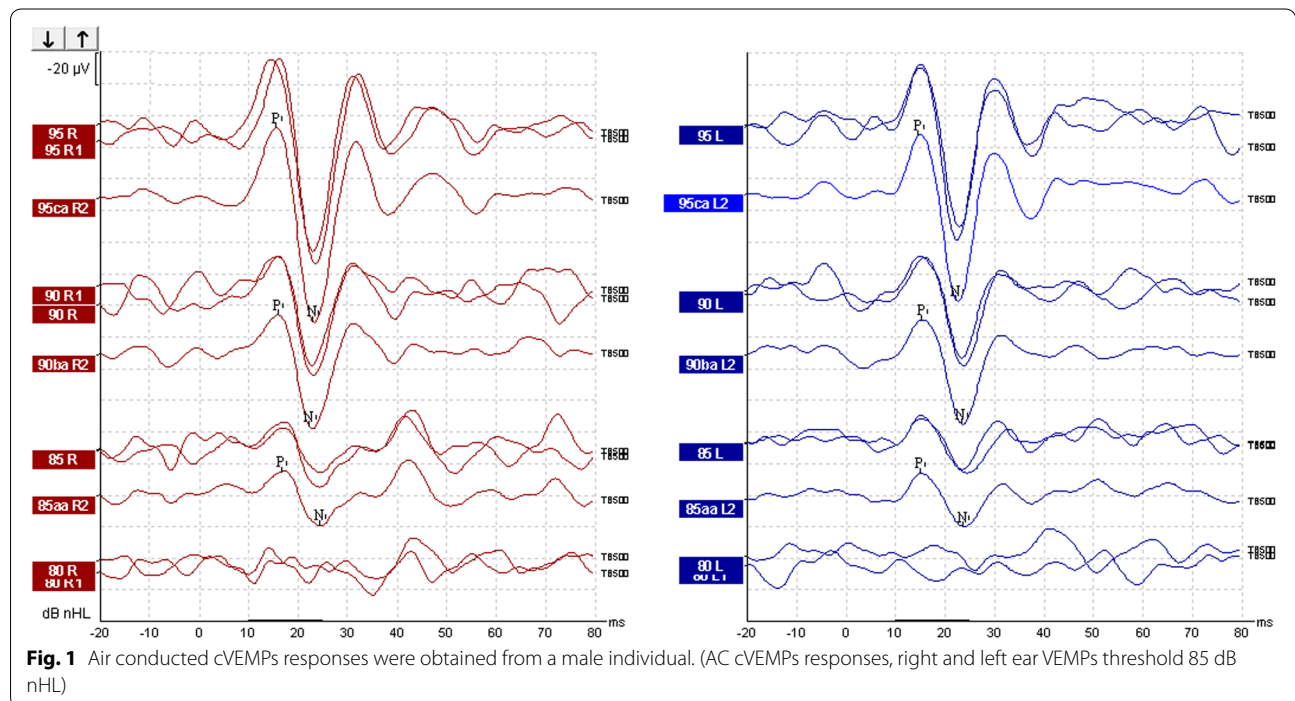
whereas BC stimuli were presented through a B-71 bone vibrator positioned on the mastoid. Since B81 bone vibrator is not available in our country, B71 bone vibrator was used. cVEMPs were recorded at a sampling rate of 5.1 Hz and averaged over 200 individual trials using OtoAccess[®] software. The band-pass filter was 10 Hz–1 kHz. The initial intensity was 95 dB nHL for air-conducted stimulation adjusted by 5 dB nHL per step to elicit the threshold. The P1 latency (ms), N1 latency (ms), P1-N1 interpeak latency (ms), P1-N1 interpeak amplitude (μ V), and VEMPs asymmetry ratio (VAR) were recorded.

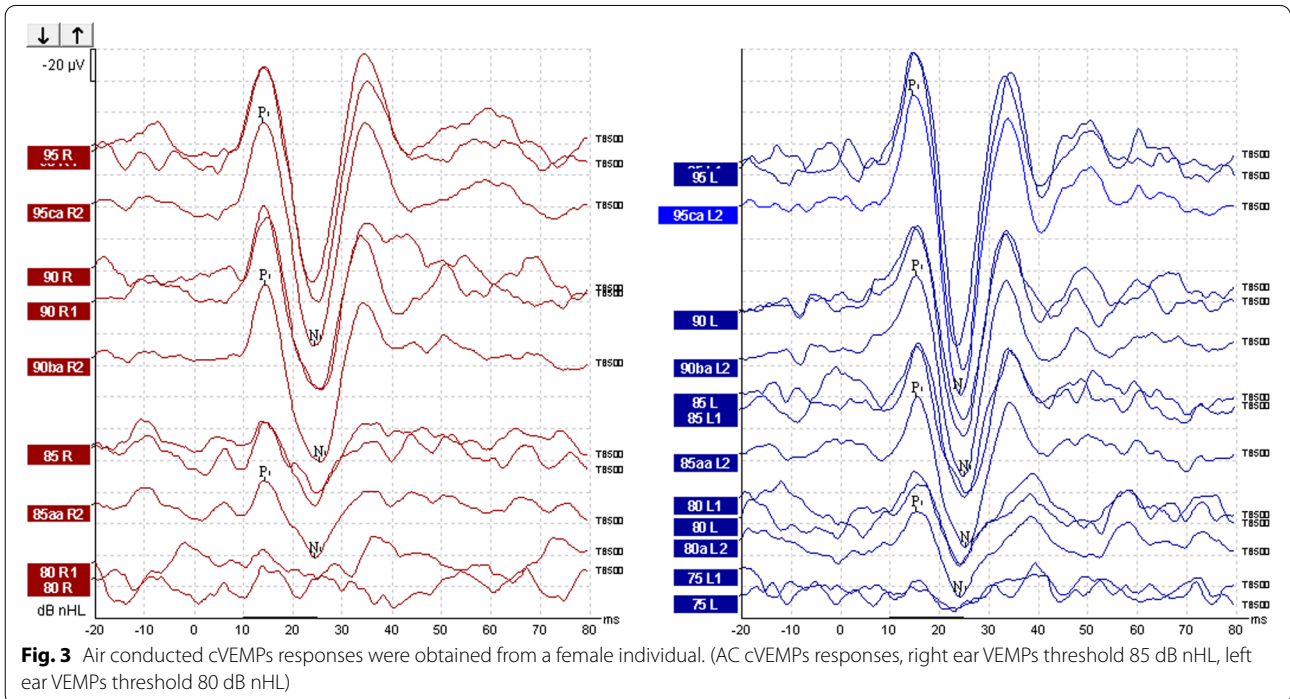
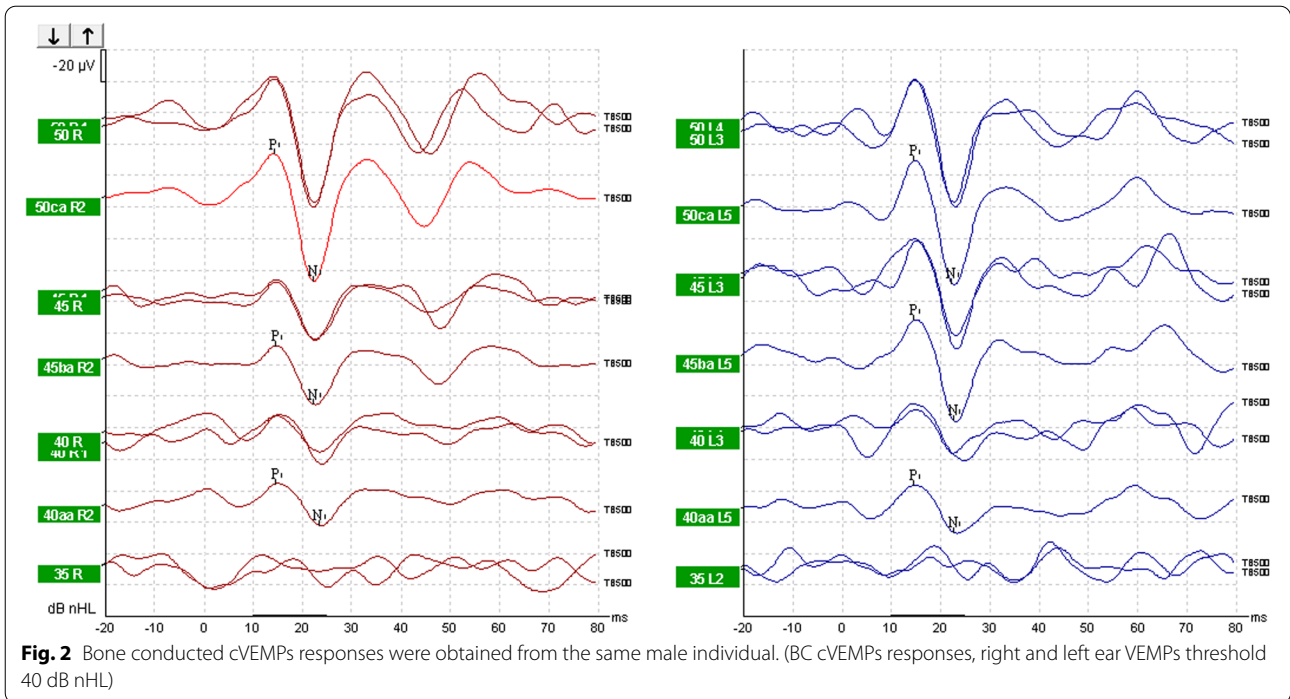
Bone conducted cVEMPs measurements were made in four different conditions to examine the occlusion effect. Ear/ears were occluded during testing to create an occlusion effect. Disposable foam eartip was used to occlude the ear. Bone conducted cVEMPs measurements were named according to the ear stimulated with a bone vibrator. Accordingly, BC cVEMPs measurements were applied, respectively; bilateral ears were occluded with the foam eartip, only the contralateral ear foam eartip was occluded, only the ipsilateral ear foam eartip was occluded, and finally, the bilateral ears were open.

Table 4 Comparison of AC and BC cVEMP responses

	Parametre	N	Mean	SD	p value
Condition 1	P1 latency of BC cVEMP (ms)	40	14.343	0.8278	0.000**
	P1 latency of AC cVEMP (ms)	40	15.175	0.7657	
	N1 latency of BC cVEMP (ms)	40	22.993	1.3130	
	N1 latency of AC cVEMP (ms)	40	24.124	1.3840	
	P1N1 amplitude of BC cVEMP (µV)	40	103.948	54.8940	
	P1N1 amplitude of AC cVEMP (µV)	40	149.734	74.9975	
Condition 2	P1 latency of BC cVEMP (ms)	40	14.451	1.0475	0.000**
	P1 latency of AC cVEMP (ms)	40	15.175	0.7657	
	N1 latency of BC cVEMP (ms)	40	23.225	1.5477	
	N1 latency of AC cVEMP (ms)	40	24.124	1.3840	
	P1N1 amplitude of BC cVEMP (µV)	40	107.624	56.6696	
	P1N1 amplitude of AC cVEMP (µV)	40	149.734	74.9975	
Condition 3	P1 latency of BC cVEMP (ms)	40	14.360	0.8682	0.000**
	P1 latency of AC cVEMP (ms)	40	15.175	0.7657	
	N1 latency of BC cVEMP (ms)	40	23.676	1.5191	
	N1 latency of AC cVEMP (ms)	40	24.124	1.3840	
	P1N1 amplitude of BC cVEMP (µV)	40	110.604	49.9248	
	P1N1 amplitude of AC cVEMP (µV)	40	149.734	74.9975	
Condition 4	P1 latency of BC cVEMP (ms)	40	14.376	0.6497	0.000**
	P1 latency of AC cVEMP (ms)	40	15.175	0.7657	
	N1 latency of BC cVEMP (ms)	40	23.691	1.5665	
	N1 latency of AC cVEMP (ms)	40	24.124	1.3840	
	P1N1 amplitude of BC cVEMP (µV)	40	108.152	56.4436	
	P1N1 amplitude of AC cVEMP (µV)	40	149.734	74.9975	

Condition 1 bilateral ears occluded, Condition 2 contralateral ear occluded, Condition 3 ipsilateral ear occluded, Condition 4 bilateral ears open, **p < 0.01

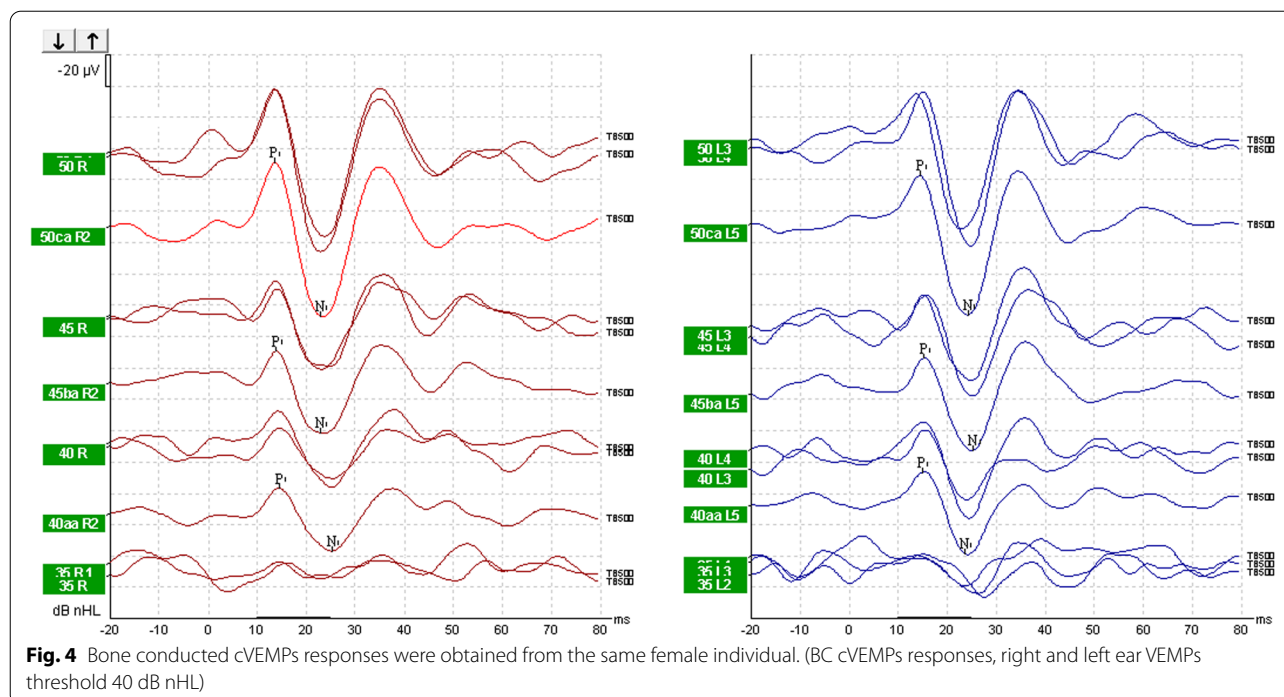




The initial intensity was 50 dB nHL for bone-conducted stimulation adjusted by 5 dB nHL per step to elicit the threshold. The P1 latency (ms), N1 latency (ms), P1-N1 interpeak latency (ms), P1-N1 interpeak amplitude (μV), and VEMPs asymmetry ratio (VAR) were registered.

Statistical analysis

Statistical Package for the Social Sciences version 20.0 (IBM Corp.; Chicago, IL, USA) software was used. Data were tested for normal distribution using the Shapiro-Wilk test and expressed as mean \pm SD. Non-parametric (Mann-Whitney



U test for non-paired data and Wilcoxon test for paired data) tests were used to compare different values. Kruskal-Wallis variance analysis was used in the comparisons made for four different conditions in BC cVEMPs measurements. A *p* value less than 0.05 was considered significant for all comparisons.

Results

The 20 individuals in this study included 11 (55%) females and 9 (45%) males (*n* = 40 ears), and their mean age was 23.65 ± 2.08 (range 20–30) years.

AC cVEMPs

The AC cVEMPs thresholds were obtained at average of 81.63 dB nHL (SD = 7.37, range 65–95 dB nHL). There were no statistically significant differences concerning gender or ear side in AC cVEMPs thresholds (*p* = 0.79 for gender and *p* = 0.51 for ear side).

The AC cVEMPs parameters (latencies of P1 and N1, interpeak latency, P1N1 amplitude, and VEMPs asymmetry ratio) did not demonstrate any statistically significant differences between male-female and right ear-left ear (*p* > 0.05). Table 1. shows the mean and standard deviation of the AC cVEMPs parameters.

BC cVEMPs

The BC cVEMPs thresholds were obtained at average of 42.79 dB nHL (SD = 4.94, range 30–50 dB nHL). There

Table 5 Comparison of AC cVEMPs and BC cVEMPs thresholds

Parameter	N	AO	SS	P
AC cVEMPs thresholds	40	81.625	7.372	0.000**
BC cVEMPs thresholds, Condition 1	40	43.250	4.606	
AC cVEMPs thresholds	40	81.625	7.372	0.000**
BC cVEMPs thresholds, Condition 2	40	42.375	4.802	
AC cVEMPs thresholds	40	81.625	7.372	0.000**
BC cVEMPs thresholds, Condition 3	40	42.125	5.175	
AC cVEMPs thresholds	40	81.625	7.372	0.000**
BC cVEMPs thresholds, Condition 4	40	43.375	5.236	

Condition 1 bilateral ears occluded, Condition 2 contralateral ear occluded, Condition 3 ipsilateral ear occluded, Condition 4 bilateral ears open, ***p* < 0.01

were no statistically significant differences concerning the gender and ear side in BC cVEMPs thresholds (*p* > 0.05). Also, there were no statistically significant differences concerning occlusion conditions in BC cVEMPs thresholds ($\chi^2 = 1.691, p = 0.639$). The BC cVEMPs parameters (latencies of P1 and N1, interpeak latency, P1N1 amplitude, and VEMPs asymmetry ratio) did not demonstrate any statistically significant differences between male-female, right ear-left ear, and all occlusion conditions (*p* > 0.05). The comparison of BC cVEMPs measurement parameters applied at 50 dB nHL according to occlusion conditions is shown in Table 2. Table 3 shows the mean and standard deviation of the BC cVEMPs parameters.

Comparison of AC and BC cVEMPs responses

Ninety-five decibels nHL AC cVEMPs responses and 50 dB nHL BC cVEMPs responses were compared. These intensities were the highest sound intensities applied. In general, the latencies of both P1 and N1 were statistically significantly shorter in response to BC as compared with AC stimuli ($p < 0.01$). Mean P1N1 amplitudes were statistically significantly larger to AC stimuli as compared with cVEMPs elicited by BC stimuli ($p < 0.01$) (Table 4) (see Figs. 1, 2, 3, and 4). The mean interpeak latencies and VARs did not differ statistically significantly between the AC and BC cVEMPs responses ($p > 0.05$). The stimulus threshold for AC cVEMPs was 81.62 dB nHL, and that for BC cVEMPs 42.78 dB nHL. BC cVEMPs thresholds are statistically significantly lower than AC cVEMPs thresholds ($p = 0.000$).

Discussion

This study evaluated the cVEMPs in response to AC and BC 500 Hz TB that can be used to elicit the cVEMPs. Besides, this study examined the effects of occlusion on the BC cVEMPs test.

In our study, the results of the AC cVEMPs test performed with a 500 Hz TB stimulus at 95 dB nHL; mean P1 latency 15.17 ± 0.77 ms, N1 latency 24.12 ± 1.38 ms, interpeak latency 8.95 ± 1.12 ms, P1N1 amplitude value 149.73 ± 75.00 μ V, and VEMPs asymmetry ratio was found to be 0.16 ± 0.16 . No statistically significant results were obtained in male-female and right ear-left ear comparisons in all applied intensities. The results of our study were found to be similar to the literature [26–29]. Small differences are thought to be due to methodological or hardware differences. Since measurement parameters and application conditions in the cVEMPs test may differ in each clinic, each clinic should determine its normative data.

Vanspauwen et al. [26] applied 500 Hz TB stimulus with an intensity of 95 dB nHL, and the average P1 latency was 15.4 ± 1.5 ms, N1 latency was 24.1 ± 2.0 ms, interpeak latency was 8.6 ms, P1N1 amplitude value was 280 μ V, and obtained the VEMPs asymmetry ratio as 0.14. They also found the AC cVEMPs threshold to be an average of 80 dB nHL. They found no statistically significant difference in all parameters based on gender and ear side. Akin et al. [27] in their study with 500 Hz TB stimulus at 100 dB nHL, found P1 latency as 14.3 ms, N1 latency as 20.3 ms, and P1N1 amplitude as 150.2 μ V. Driscoll et al. [28] in their study with a 500 Hz TB stimulus of 110 dB nHL, found P1 latency as 14.80 ms, N1 latency as 24.22 ms, and interpeak latency as 9.41 ms. Wu et al. [29] in their study with a 95 dB nHL 500 Hz TB stimulus, found P1 latency 14.83 ± 0.81 ms, N1 latency 22.54 ± 1.30 ms, P1N1 amplitude value 198.53 ± 64.64 μ V, and VEMPs

asymmetry ratio 0.13 ± 0.12 . Basta et al. [30] showed that gender did not affect latency and amplitude parameters of P1 and N1. Derinsu et al. [31] obtained VEMPs responses from 105 dB nHL to 85 dB nHL in their study, and when they analyzed the latency and amplitude values at all intensity levels they applied in terms of gender and ear side, they did not detect a statistically significant difference.

Sheykholeslami et al. [19] first reported cVEMPs in response to 500 Hz TB delivered via a bone vibrator over the mastoid process. This technique bypasses the middle ear and also stimulates both sides. In a similar study, Welgampola et al reported that response to bone conduction stimulation was often bilateral, with the largest VEMPs recorded from the ipsilateral SCM. They reported that VEMPs could be elicited at lower sound levels for stimuli delivered by bone conduction [18]. In this study, BC cVEMPs thresholds were statistically significantly lower than the AC cVEMPs thresholds ($p = 0.000$) (Table 5) (see Figs. 1, 2, 3, and 4). Bone conducted sound or vibration at a given perceptual intensity is therefore a more effective vestibular stimulus than air conducted sound [18].

The occlusion effect is the enhanced perception of bone-conducted sounds originating from occluding the meatus of an open external auditory canal. The occlusion effect causes lower hearing thresholds. Only two studies examined the effect of occlusion effect on bone conducted cVEMPs test. These studies examined the change in only BC-cVEMPs thresholds and BC-cVEMPs amplitudes. In our study, we examined the effects of occlusion on P1 and N1 latencies, interpeak latencies, and VEMPs asymmetry ratios apart from these two parameters. In this context, our study is the first in the literature. When we examined the effects of the occlusion effect on P1 and N1 latencies, interpeak latencies, P1N1 amplitude, VEMPs threshold, and VEMPs asymmetry ratio, we found no statistically significant difference (see Table 2). In two other studies in the literature, the amplitude of the occluded condition was significantly larger than that for the nonoccluded condition. We thought that reason might be the use of 55 dB nHL intensity, which was higher than in our study, or the type of earplugs used. Also, bone-conducted stimuli were delivered using a B81 bone vibrator in the previously two studies. B81 bone vibrator has a higher force output and lower distortion. However, considering that the occlusion effect was examined in four different situations in our study and we reached more data, we concluded that the occlusion effect was not an effective phenomenon in the BC cVEMPs test as in the auditory system. When the bone conduction sound stimulus is applied, the sound stimulus is

transmitted directly to the bone and affects the saccular. For this reason, we think that the sound pressure changes transmitted through the air column resulting from EAC occlusion do not affect the BC cVEMPs test.

Basta et al. [30] in their study in which they gave 500 Hz TB stimulation with the B70B bone vibrator, obtained P1 latency as 16.3 ± 2.2 ms, N1 latency as 24.1 ± 2.1 ms, and P1N1 amplitude as 60.2 ± 33.2 μ V. Govender et al. [32] in their study in which they gave 500 Hz TB stimulation with the Minishaker 4810, obtained P1 latency as 13.9 ± 0.6 ms and N1 latency as 23.3 ± 1.8 ms.

Mahdi et al. [33] obtained the mean P1 and N1 latencies as 13.68 ± 1.43 ms and 21.95 ± 3.70 ms, respectively, in the BC cVEMPs measurements performed by B81 bone vibrator at an intensity of 70 dB nHL in healthy individuals. They obtained P1 and N1 latencies as 14.57 ± 2.31 ms and 23.65 ± 4.11 ms, respectively, in the AC cVEMPs measurements performed at TDH 39 and 95 dB nHL. When they examined the AC and BC cVEMPs measurements in terms of latency, they found no statistically significant difference. The mean BC cVEMPs amplitude was 83.64 ± 39.13 , while the AC cVEMPs amplitude was 75.45 ± 21.17 and the BC cVEMPs amplitude was statistically significantly greater ($p = 0.025$). They obtained VEMPs asymmetry ratios as 0.24 ± 0.21 in the BC and 0.17 ± 0.13 in the AC, and they did not determine a significant difference.

In the study conducted by McNerney and Burkard [34], a 500-Hz TB stimulus was applied with a TDH39 earphone in the AC and a B71 bone vibrator in the BC. As the stimulus intensity, measurements were made from 120 dB SPL in the AC and 120 dB FL in the BC. While the average AC P1 latency was 13.85 ms, N1 latency was 21.80 ms and, the P1N1 amplitude was 53.79 μ V, the mean P1 latency of the BC was 13.14 ms, the N1 latency was 20.82 ms and, the P1N1 amplitude was 86.54 μ V. As a result of this study, while P1 and N1 latencies obtained through bone conduction were observed to be shorter than those obtained by air conduction, only N1 latencies were statistically significantly shorter ($p = 0.043$). Bone conducted cVEMPs amplitudes were found to be greater than those obtained from the air conduction ($p = 0.002$).

Wang et al. [35] compared the air and bone conducted cVEMPs responses in their study. While giving the AC stimulus with insert earphones, they applied the BC stimulus from the middle of the forehead using a mini-shaker. The mean P1 and N1 latencies of AC cVEMPs were 15.6 ± 1.7 and 23.3 ± 1.5 ms, respectively. Bone conducted were 14.4 ± 1.5 and 21.9 ± 1.3 ms for cVEMPs. Bone conducted cVEMPs latencies were significantly shorter than AC cVEMPs latencies ($p = 0.01$). Interpeak latencies were obtained as 7.7 ± 1.0 ms in the air conduction

and 7.5 ± 1.4 ms in the bone conduction. Amplitudes were found as 179.5 ± 114.7 μ V in the air conduction and 171.9 ± 117.0 μ V in the bone conduction. No significant difference was found between air and bone conduction interpeak latencies and amplitudes.

Sheykholeslami et al. [19] 500 Hz TB stimulus, 95 dB nHL were given from the AC with a TDH-351 earphone, and 70 dB NHL was given from the mastoid bone with a BR41 bone vibrator in the bone conduction. In AC cVEMPs responses, mean P1 latency was 14.74 ± 2.6 ms and, N1 latency was 23.41 ± 4.00 ms. In bone conducted cVEMPs response, the mean P1 latency was 12.98 ± 1.34 ms and, the N1 latency was 20.00 ± 2.36 ms. Bone conducted cVEMPs latencies were significantly shorter than AC cVEMPs latencies. The mean bone-conducted cVEMPs P1N1 amplitude was 158.48 ± 63 μ V.

Our findings at 50 dB nHL in BC cVEMPs were consistent with most studies in the literature [32, 33, 35]. When we compared the air and bone conducted cVEMPs responses, we found that P1 and N1 latencies obtained with BC cVEMPs were statistically significantly shorter than those obtained from the AC cVEMPs ($p < 0.01$). This result was consistent with other studies in the literature [19, 34, 35]. The amplitudes were statistically significantly smaller than those obtained from the air conduction ($p < 0.01$). This finding was not compatible with the literature. While the stimulus intensity used in other studies in the literature was at least 55 dB nHL, in our study the highest stimulus intensity was 50 dB nHL. We thought that the reason why the amplitude finding was not compatible with the literature was the difference in stimulus intensity. When we compared the interpeak latencies and VEMPs asymmetry ratios obtained from the air and bone conduction, we have not found statistically significant difference in line with the literature [33, 35].

There are few studies in the literature which investigated all parameters of bone conducted cVEMPs test performed with a bone vibrator. Also, there are only two studies which examined the effect of the occlusion effect on the BC cVEMPs test. It was observed that the number of ears in these two studies was less than the number of ears in our study. It is seen that there are minor differences in the studies which created descriptive statistical values. The reason why it is different is the population in which the test is applied, the type of stimulus used, the way the stimulus is delivered, and the application of different recording parameters. It is thought that by obtaining descriptive statistical data of the BC cVEMPs, which is not widely used in clinics, with this study, it can be used as a diagnostic test in clinics, especially in the vestibular assessment of CHL and in patients with hyperacusis who are disturbed by loud noises.

Limitations

RadioEar[®] mark B71 bone vibrator was used in our study. The maximum output power of this vibrator is 50 dB nHL at 500 Hz tone burst stimulus, in Interacoustics[®] mark Eclipse EP25 device, with OtoAccess[®] program. Therefore, 50 dB nHL intensity could be applied as the maximum intensity level when performing the bone conducted cVEMPs test. By using vibrators with higher output power, such as the B81 bone vibrator, bone conducted cVEMPs testing can be performed at higher intensities and normative data can be generated at these intensities.

Since the occlusion effect in BC cVEMPs tests was also examined in addition to the AC cVEMPs test in our study, the test period was very long and therefore the patients had difficulty in keeping the SCM muscle contracted. Therefore, the study was only applied to the 20–30 age group with strong cooperation. By applying BC cVEMPs test to wider age groups, normative data of these age groups can be obtained and comparisons can be made according to age groups.

Conclusions

The BC cVEMPs, which is not widely used in clinics, might be used in the vestibular assessment of conductive hearing losses (CHL) in clinics, by obtaining descriptive values with this study. It was thought that it might be used as an auxiliary test to diagnose patients with hyperacusis who are disturbed by loud noises. In addition, it was concluded that the occlusion effect was not an effective phenomenon in the BC cVEMPs test as in the auditory system.

Abbreviations

dB: Decibel; HL: Hearing level; cVEMP: Cervical vestibular evoked myogenic potentials; BC: Bone conducted; AC: Air conducted; VAR: VEMP asymmetry ratio; CHL: Conductive hearing losses; TB: Tone-burst; SCM: Sternocleidomastoid muscle.

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Authors' contributions

BT: data collection and article writing. EG: data collection. MBS: design of the work. The authors read and approved the final manuscript.

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Availability of data and materials

The datasets used and analyzed during the current study are available from the corresponding author on reasonable request.

Declarations

Ethics approval and consent to participate

Written informed consent was obtained from the study participants, and Ethics Committee of Istanbul Medipol University approved the study proposal (Approval number: 741).

Consent for publication

Not applicable.

Competing interests

The authors declare that they have no competing interests.

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