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Evaluation of ocular and cervical vestibular evoked myogenic potentials in a conductive hearing loss model

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Abstract

Objective: To investigate the effects of conductive hearing loss (CHL) on vestibular evoked myogenic potentials (VEMPs) using a simulated CHL model, and to provide the basis for future studies.

Methods: Twenty-one healthy subjects were recruited in this study. We measured ocular VEMPs (oVEMPs) and cervical VEMPs (cVEMPs) in these subjects by air-conduction sound (ACS) stimulation. CHL was simulated later by blocking the right external auditory canal with a soundproof earplug to evaluate its impacts on VEMPs. Subjects' responses before simulated CHL served as the control, and were compared to their responses following simulated CHL.

Results: oVEMPs following simulated CHL showed decreased response rate, elevated thresholds, attenuated amplitudes and prolonged N1 latencies compared with those before simulated CHL, and the differences were statistically significant. Similarly, cVEMPs following simulated CHL also showed decreased response rate, elevated thresholds and attenuated amplitudes, with prolonged P1 latencies compared with those before simulated CHL, although only differences in response rate, threshold and amplitude were significant.

Conclusions: Conductive hearing loss affects the response rate and other response parameters in oVEMPs and cVEMPs.

Keywords: Conductive hearing loss; Ocular vestibular evoked myogenic potentials (oVEMPs); Cervical vestibular evoked myogenic potentials (cVEMPs); Model; Vestibular function

1. Introduction

Vestibular evoked myogenic potentials (VEMPs) are neurophysiological assessment techniques to evaluate the patient's vestibular functions (Colebatch and Halmagyi, 1992; Halmagyi et al., 1994). Based on the location of recording electrodes as well as the response origin, VEMPs can be chiefly categorized into ocular VEMPs (oVEMPs) and cervical VEMPs (cVEMPs) (Zhang et al., 2014a). The cVEMPs can be recorded from the sternocleidomastoid muscle, and is considered to be generated via the inferior vestibular nerve (Papathanasiou et al., 2014). The oVEMPs can be recorded from the contralateral inferior oblique muscle and is elicited mainly through the superior vestibular nerve (Curthoys, 2010; Curthoys et al., 2011). Several stimuli are used to elicit VEMPs, such as air-conducted sound (ACS), bone-conducted sound (BCV), and galvanic vestibular stimulation (GVS), among which ACS is the major and widely-used stimulus (Miyamoto et al., 2006; Curthoys et al., 2011). Because waves of ACS-VEMPs require loud sound stimulation to be evoked,

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impairment of sound transmission by ear diseases may affect VEMPs measurement. These ear diseases may include chronic otitis media (Lee et al., 2014), otosclerosis (Zhou et al., 2012), sudden sensorineural hearing loss (Niu et al., 2015) and Meniere's disease (Sandhu et al., 2012).

Conductive hearing loss (CHL) is a common presentation in patients visiting ENT clinics, and typically includes abnormalities of the outer and middle ear. Primary causes of CHL include cerumen, infection, perforation of tympanic membrane, fluid in the middle ear and ossicular chain disarticulations (Yueh et al., 2003). Impaired sound transmission in CHL may affect VEMPs measurement in vestibular function assessment. For example, Halmagyi et al. reported that cVEMPs were absent when air-bone gap was greater than 20 dB (Halmagyi et al., 1994). In addition, Bath et al. showed that cVEMPs were successfully elicited in only two of the 23 tested ears in the presence of CHL (Bath et al., 1999). However, CHL's impacts on VEMPs response rate and other measured parameters, especially for oVEMPs, remain largely unknown. Therefore, it is crucial to determine specific impacts on VEMPs parameters by CHL. In this study, using a simulated CHL model with soundproof earplugs, we tested CHL's impacts on VEMPs responses rate, threshold, amplitude, as well as P1 and N1 latencies.

2. Materials and methods

2.1. Subjects

Twenty-one healthy subjects (mean age = 24.52 ± 3.33 years; range 19–35 years, 13 males and eight females) were recruited by the following criteria: no history of any ear disorders; no history of any vestibular disorders; passed otoscopy, acoustical impedance, and pure tone audiometry tests. This study was approved by the Institutional Review Board of the Second Affiliated Hospital of Xi'an Jiaotong University School of Medicine, and each subject signed an informed consent.

2.2. CHL simulation

The right external auditory canal in the 21 subjects was blocked using a plastic soundproof earplug of appropriate sizes (Fig. 1). Following the blockage, pure tone audiogram (PTA) showed an average hearing threshold across 500, 1000, 2000 and 4000 Hz in the blocked ear at 30.24 ± 5.53 dB HL, and an average air-bone gap (ABG) of 22.66 ± 4.28 dB (range 16.67–28.33 dB).

2.3. oVEMPs and cVEMPs recording

All tests were performed in a sound-proofed examination room. For VEMPs testing. ACS (500 Hz tone bursts) was presented through a calibrated headphone. oVEMPs and cVEMPs recording techniques have been described previously (Sheykholeslami et al., 2001; Zhang et al., 2014b). Namely, for oVEMPs testing, two active electrodes were placed below the lower margin of each eyelid, while the reference electrodes were placed 1–2 cm below each active electrode. A ground electrode was placed on the median line of the forehead. The subject lay down in a supine position and was asked to look upwards when hearing the sound. For cVEMPs testing, an active electrode was placed at the mid point of each sternocleidomastoid muscle, the reference electrode was placed on the surface of sternoclavicular joint on each side, and a ground electrode on the median line of the forehead. The subject was asked to raise his/her head to increase tension of the SCM muscle.

2.4. oVEMPs and cVEMPs measurement

Both oVEMPs and cVEMPs were recorded before and after the simulated CHL. The response rate, threshold (dB nHL), P1 and N1 latencies (ms), interpeak intervals (ms), and amplitudes (μV) were measured. Repeatable biphasic waveforms were regarded as a positive response, whereas unrepeatable or unrecognizable waveforms were regarded as non-responses. The positive (P1) and negative (N1) peaks in the recorded biphasic waveform were marked for both cVEMPs and oVEMPs. The threshold was the lowest stimulus intensity to elicit a recognizable and repeatable biphasic waveform. The length of time between 0 ms and the peak of P1 or N1 was recorded as P1 or N1 latency, respectively, and the period between the peaks of P1 and N1 was determined as the interpeak interval. Amplitude was determined as the vertical distance of voltage between the peaks of P1 and N1.

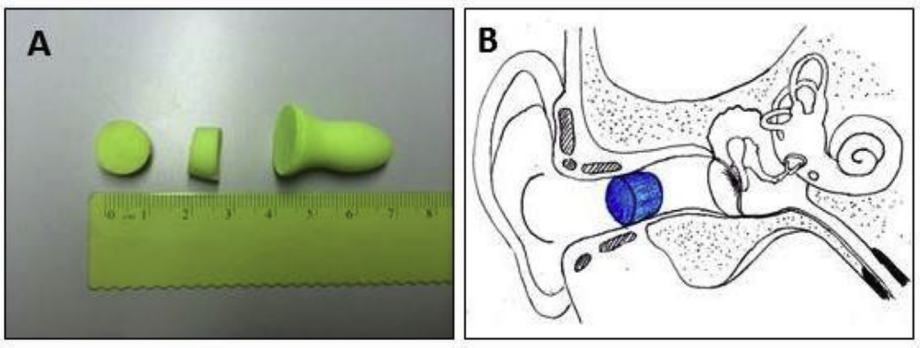

Fig. 1. (A) Plastic soundproof earplugs (B) Sketches showing right external auditory canal blockage.

2.5. Data analysis

Categorical variables, such as response rates, were compared between the two groups using the X^2-square test, and continuous variables such as latencies, amplitudes and thresholds, were compared using the Student *t*-tests. The X^2-square test was also used for correlation analysis of response rates between oVEMPs and cVEMPs. The Statistical Package for the Social Sciences (SPSS) Windows Release 13 (SPSS Inc., Chicago, IL, US) was used for statistical analyses. All data were expressed as mean ± SD (SD = standard deviation). A P value of less than 0.05 was considered statistically significant.

3. Results

3.1. CHL impacts on VEMPs response rate

Before CHL simulation, the response rate was 100% (21/21) for both oVEMPs and cVEMPs. With simulated CHL resulting in an air-bone gap of 22.66 ± 4.28 dB, the response rate decreased to 38.1% (8/21) for oVEMPs, and to 69.1% (13/21) for cVEMPs. The differences in the response rate before and after CHL simulation were statistically significant for both oVEMPs and cVEMPs ($P < 0.01$, Table 1). The correlation in response rate between oVEMPs and cVEMPs was statistically insignificant ($r^2 = 0.232$, $P = 0.123$, Table 1).

3.2. CHL impacts on VEMPs parameters

For the 21 subjects, the oVEMPs response rate was 100% without simulated CHL, with a mean threshold at 88.33 ± 6.95 dB nHL, mean N1 latency of 10.85 ± 1.18 ms, mean P1 latency of 15.41 ± 1.87 ms, mean N1–P1 interval of 4.61 ± 0.98 ms, and a mean amplitude of 6.28 ± 4.75 μV. For cVEMPs, the mean threshold was 83.85 ± 8.93 dB nHL, mean P1 latency was 17.78 ± 3.52 ms, mean N1 latency was 24.33 ± 3.77 ms, mean P1–N1 interval was 8.03 ± 1.52 ms, and the mean amplitude was 210.67 ± 82.19 μV.

Only some subjects showed positive VEMPs with CHL. In the eight subjects showing positive oVEMPs following simulated CHL, the mean threshold was 95.63 ± 4.96 dB nHL, mean N1 latency was 12.78 ± 1.57 ms, mean P1 latency was 16.83 ± 1.84 ms, mean N1–P1 interval was 4.05 ± 0.91 ms and mean amplitude was 2.67 ± 0.93 μV, compared to the mean threshold of 85.00 ± 8.02 dB nHL, mean N1 latency of 11.28 ± 1.19 ms, mean P1 latency of 16.31 ± 1.93 ms, mean N1–P1 interval of 5.03 ± 0.89 ms and a mean amplitude of 8.18 ± 4.72 μV in their oVEMPs before simulated CHL (Fig. 2). In the 13 subjects showing positive cVEMPs with simulated CHL, the mean threshold was 96.15 ± 5.83 dB nHL, mean P1 latency was 18.63 ± 3.12 ms, mean N1 latency was 24.66 ± 3.45 ms, mean P1–N1 interval was 6.89 ± 1.62 ms, and mean amplitude was 143.29 ± 58.40 μV, compared to the mean threshold of 83.85 ± 8.93 dB nHL, mean P1 latency of 17.78 ± 3.52 ms, mean N1 latency of 24.33 ± 3.77 ms, mean P1–N1 interval of 8.03 ± 1.52 ms and mean amplitude of 210.67 ± 82.19 μV in their cVEMPs without simulated CHL (Fig. 3, Table 2).

Table 1
Comparison of response rates with/without CHL simulation and between VEMPs.

	CHL	Control	*P*	Elicited	Unelicited	*P*
oVEMP	38.1% (8/21)	100% (21/21)	<0.01	8	13	0.123
cVEMP	61.9% (13/21)	100% (21/21)	<0.01	13	8	

3.3. Comparison of hearing losses between oVEMPs and cVEMPs following simulated CHL

Following CHL simulation, the average PTA was 18.33 ± 3.33 dB HL in the eight subjects in whom oVEMPs were successfully elicited, and 21.28 ± 4.52 dB HL in the 13 subjects in whom oVEMPs were not elicited. The difference was statistically insignificant ($P = 0.13$). Likewise, the average PTA was 20.38 ± 4.04 dB nHL in the 13 subjects in whom cVEMPs were successfully elicited, and 19.79 ± 4.91 dB HL in the eight subjects in whom cVEMPs were not elicited. Again, the difference was statistically insignificant ($P = 0.77$, Table 3).

4. Discussion

We first established a CHL model using soundproof earplugs to block the subjects' right external ear canals causing a mean ABG of 22.66 ± 4.28 dB. Following simulated CHL, oVEMPs response rates decreased from 100% to 38.1%, and cVEMPs response rates from 100% to 61.9%. In addition, our results show that CHL significantly impacts oVEMPs and cVEMPs parameters, including elevated thresholds, prolonged latencies, and attenuated amplitudes.

Our previous study showed that as the acoustic stimulus intensity decreased, response rates and amplitudes also decreased in both oVEMPs and cVEMPs among Chinese subjects under the age of 40 years (Zhang et al., 2014c). Moreover, a study showed that the VEMPs response rate in CHL patients (mean ABG of 26.8 ± 11.3 dB) was 64%, but increased to 86% after a paper patch was applied to the perforation tympanic membrane (Lee et al., 2014). Others found that patients with CHL whose ABG was greater than 20 dB typically showed no cVEMPs responses (Halmagyi et al., 1994). However, few studies reported CHL impacts on the response rate of oVEMPs. Wang et al. reported that oVEMPs were present in 18 of 24 healthy ears by ACS, but absent in patients with chronic otitis media (COM) (Wang et al., 2010). In the current study, oVEMPs and cVEMPs response rates decreased significantly due to decreased sound intensity transmission caused by soundproof earplug blockage. The cVEMPs response rates were consistent with Lee's results, although differed from Halmagyi's and Wang's. Moreover, the oVEMPs response rates were different from Wang's results. The reason for these discrepancies is probably the chronic

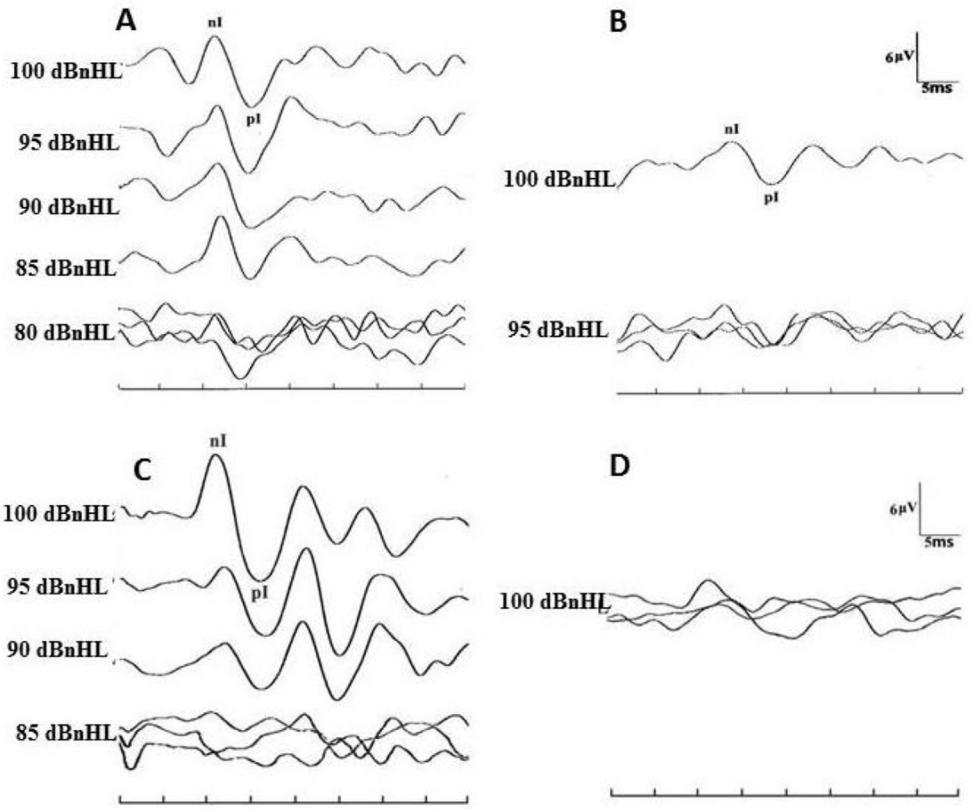

Fig. 2. Ocular VEMPs (oVEMPs) recorded with and without CHL simulation. (A) oVEMPs waveforms without CHL simulation; (B) oVEMPs following CHL simulation; (C) oVEMPs waveforms before CHL simulation; (D) No oVEMPs response after CHL simulation.

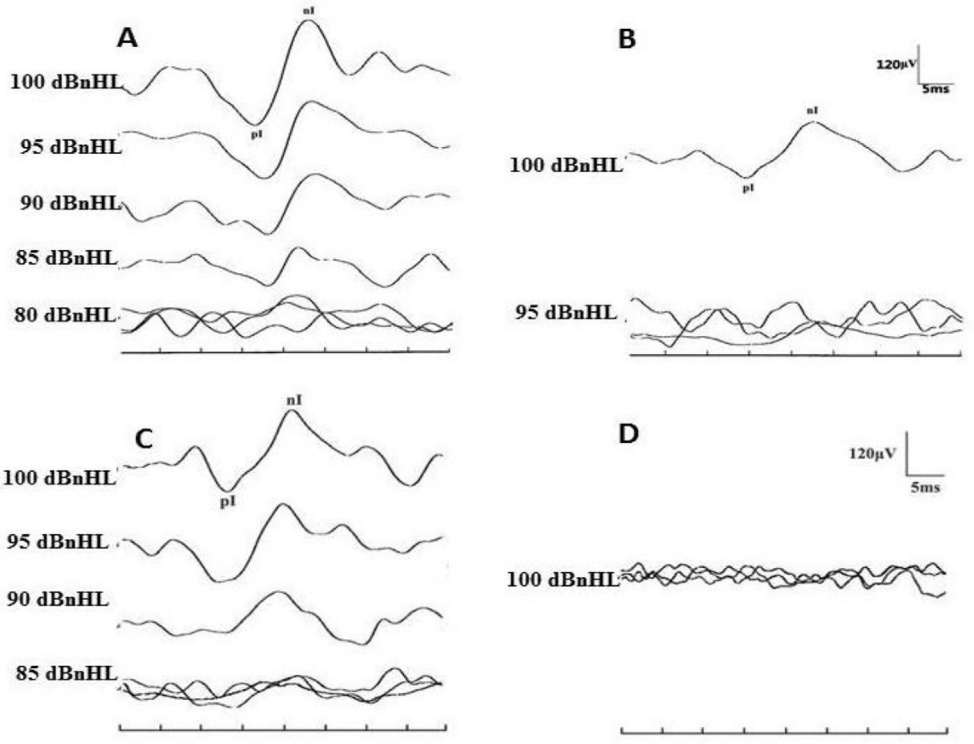

Fig. 3. Cervical VEMPs (cVEMPs) recorded with and without CHL simulation. (A) cVEMPs waveforms without CHL; (B) cVEMPs waveforms following CHL simulation; (C) cVEMPs waveforms before CHL simulation; (D) No cVEMPs response after CHL simulation.

Table 2
Characteristic parameters of VEMPs.

Parameters	oVEMPs		P	cVEMPs		P
	CHL (n = 8)	Control (n = 8)		CHL (n = 13)	Control (n = 13)	
Threshold	95.63 ± 4.96	85.00 ± 8.02	0.04	96.15 ± 5.83	83.85 ± 8.93	0.01
N1 latency	12.78 ± 1.57	11.28 ± 1.19	0.01	24.66 ± 3.45	24.33 ± 3.77	0.76
P1 latency	16.83 ± 1.84	16.31 ± 1.93	0.42	18.63 ± 3.12	17.78 ± 3.52	0.45
N1−P1 interval	4.05 ± 0.91	5.03 ± 0.89	0.06	6.89 ± 1.62	8.03 ± 1.52	0.08
Amplitude	2.67 ± 0.93	8.18 ± 4.72	0.01	143.29 ± 58.40	210.67 ± 82.19	0.01

Values are expressed as Mean ± SD.

Table 3
Comparison of hearing losses between responding and non-responding subjects following CHL simulation.

	Elicited	Unelicited	*t* value	*P*
oVEMP	18.33 ± 3.33	21.28 ± 4.52	1.59	0.13
cVEMP	20.38 ± 4.04	19.79 ± 4.91	0.30	0.77

Values are expressed as Mean ± SD.

inflammation caused by COM which impairs the function of utricle and saccule, leading to the decreased response rate.

Furthermore, Lee et al. showed that the P1 and N1 latencies of cVEMPs were delayed in COM patients, and the P1 latency was shortened after paper patching the tympanic membrane (Lee et al., 2014). In addition, Wang et al. demonstrated that the P1 and N1 latencies of cVEMPs were prolonged significantly in patients with middle ear effusion, which were shortened to within normal range after tympanic aspiration (Wang et al., 2009). However, there have been no reported studies showing impacts of CHL on oVEMPs. Our results show that in CHL, if cVEMPs can be elicited, P1 and N1 latencies are prolonged, which is consistent with Lee's results. Moreover, we also found that response thresholds were elevated, amplitudes attenuated, P1−N1 intervals was shortened at a marginal value. oVEMPs also showed elevated thresholds, decreased amplitudes, prolonged P1 and N1 latencies, as well as shortened P1−N1 intervals. Taken together, our results support the notion that CHL has significantly impacts on both oVEMPs and cVEMPs.

An intact conductive system in the middle ear is crucial for ACS-VEMPs, through which sound stimulus travels from middle ear to the inner ear. If sound energy transmission attenuates, as caused by conductive malfunction, including tympanic membrane perforation, middle ear effusion, otosclerosis, the saccule and utricle may receive insufficient energy for VEMPs to be successfully elicited. In the current study, oVEMPs were elicited in eight of the 21 ears with simulated CHL, which might be attribute to variation of sensitivity in otolithic functions among individuals. In addition, our results show no statistically insignificant correlation in response rates between oVEMPs and cVEMPs, which further support that oVEMPs and cVEMPs may have different origins. Interestingly, recent studies showed that bone conduct vibration (BCV), as a new stimulus for VEMPs, could stimulate otolithic end organs through the temporal bone directly. Herein, for patients with CHL, BCV may be used as a substitute stimulus to elicit VEMPs.

In conclusion, CHL can have impacts on VEMPs response rate and other parameters, leading to decreased response rates, prolonged latencies, elevated thresholds and decreased amplitudes.

Conflicts of interest

The authors declare no conflict of interest.

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