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Ocular vestibular-evoked myogenic potentials elicited from monaural versus binaural acoustic stimulations

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ABSTRACT

Objective: This study compared the ocular vestibular-evoked myogenic potentials (oVEMPs) that are elicited (recorded) in response to monaural and separately, simultaneous binaural acoustic stimulations. The optimal stimulation mode for oVEMPs was also determined.

Methods: Twenty healthy volunteers (14 men and 6 women, aged from 22 to 33 years, mean 28 years) without any previous ear disorders were enrolled in this study. Each subject underwent oVEMP testing using monaural acoustic stimulation (Mon-oVEMP) with different stimulus intensities, and with bilateral recording. On another day, the same volunteers underwent oVEMP testing using simultaneous binaural acoustic stimulation and bilateral recording (Bin-oVEMP).

Results: With 95 dB nHL tone burst stimulation, the biphasic nI–pI waveforms were recorded with maximal amplitudes from the electrodes located below the eyes contralateral to the side of acoustic stimulation while the subject was gazing upward. Significant correlations were identified between Mon-oVEMPs and Bin-oVEMPs with respect to threshold, latencies and amplitude. However, no significant difference existed between Mon-oVEMPs and Bin-oVEMPs in terms of the response rate, threshold, latency or amplitude.

Conclusions: The Bin-oVEMP test yields the same information as the Mon-oVEMP test, but the duration of recording in the former is shorter than the latter.

Significance: The Bin-oVEMP test may be a more convenient screening tool for evaluating the crossed vestibulo-ocular reflex.

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1. Introduction

Vestibular-evoked myogenic potential (VEMP) has been successfully recorded from tonically contracted neck muscles by acoustic stimulation; it is referred to as cervical VEMP (cVEMP) (Welgampola and Colebatch, 2005). Recent investigations have revealed that VEMP can also be recorded from extraocular muscle in response to air-conducted sound, bone-conducted sound or head taps. Such VEMP has been termed ocular VEMPs (oVEMPs) (Rosengren et al., 2005; Todd et al., 2007). Unlike the cVEMP test, which assesses the descending vestibular pathway as ipsilateral sacculo-ocollic reflex, the oVEMP test has been validated to evaluate the ascending vestibular pathway as crossed vestibulo-ocular reflex (Iwasaki et al., 2007).

Previously, the authors studied the feasibility of recording cVEMPs using simultaneous binaural acoustic stimulation, which provides neither different information nor less variability than monaural acoustic stimulation (Wang and Young, 2003). The authors' premise was that binaural acoustic stimulation can elicit oVEMPs as effectively as monaural acoustic stimulation does. Hence, the former method may require less muscular effort than the latter, since continuous upward gazing is necessary during oVEMP testing. Further, adding oVEMP tests into the test battery of vestibular function in one patient definitely prolongs the testing session. Thus, binaural acoustic stimulation may help to reduce the testing time of oVEMP. The aim of this study was to compare the oVEMPs in response to monaural and separately, simultaneous binaural acoustic stimulations, and to determine the optimal stimulation mode for oVEMPs.

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2. Materials and methods

2.1. Subjects

Twenty healthy volunteers (medical students and resident doctors, 14 men and 6 women, aged from 22 to 33 years, mean 28 years) without any previous ear disorders were enrolled in this study. Each subject underwent oVEMP testing using monaural acoustic stimulation (Mon-oVEMP) with various stimulus intensities, and with bilateral recording. On another day, the same volunteers underwent oVEMP testing using simultaneous binaural acoustic stimulation (Bin-oVEMP) with various stimulus intensities and bilateral recording.

2.2. oVEMP test

The subject was in a sitting position. Surface potentials, predominantly electromyographic (EMG) activities, were recorded (Smart EP 3.90, Intelligent Hearing Systems, Miami, FL, USA) with five Ag/AgCl electrodes. Because the largest oVEMP responses occurred in the electrodes below the eyes, each active electrode was placed on the face just inferior to each eye, around 1 cm vertically oriented below the center of the lower eyelid. The reference electrodes were about 1.5 cm below the active ones on the cheek. One ground electrode was sited over the sternum, based on the montage suggested by Todd et al. (2007). The electrode impedance was kept under 7 kΩ. During recording, the subject was instructed to look upward at a small fixed target >2 m from the eyes, with a vertical visual angle of approximately 30–35° above horizontal. Each subject's eyes remained fixed on the target throughout the test.

The recorded activity was amplified and bandpass filtered between 1 and 1000 Hz. Acoustic stimuli were 95 dB nHL (equal to 117 dB peak SPL) short-tone bursts (500 Hz, rise/fall time = 1 ms, plateau time = 2 ms) with rarefaction polarity and were delivered through an insert earphone. Either monaural or binaural acoustic stimulation with bilateral recordings was employed. The stimulation rate was 5 Hz, the analysis time for each response was 50 ms, and 100 responses were averaged for each run. An online automatic artifact rejection system was utilized to eliminate the effect of eye blinks.

The initial negative–positive biphasic waveform comprised peaks nI and pI. Consecutive runs were performed to confirm the reproducibility of peaks nI and pI, which were interpreted by two independent observers, and oVEMPs were then deemed to be present. Conversely, oVEMPs were deemed to be absent when the biphasic waveform was not reproducible.

Each subject then underwent a series of oVEMP tests. The initial stimulus intensity was 95 dB nHL; then intensity was decreased in 10-dB steps until the waveform was absent. The stimulus intensity was then increased in steps of 5 dB until the oVEMP response reappeared, and the threshold was thus determined. Thereafter, the latencies of peaks nI and pI, amplitude nI–pI, and interaural amplitude difference (IAD) ratio were measured. The latter was defined as the difference of the amplitude nI–pI on the right and left ears divided by the sum of amplitude nI–pI of both ears (R − L/R + L) (Young et al., 2003).

2.3. Statistical methods

The response rate, defined as the percentage of subjects in which a clear response was identified, in Mon-oVEMP was compared with that in Bin-oVEMP, using the exact McNemar test. The relationship between the response rates at 95 and 85 dB nHL under either monaural or binaural oVEMP testing was also analyzed using the exact McNemar test. The thresholds, latencies, amplitudes and IAD ratios between Mon-oVEMP and Bin-oVEMP were compared using the paired *t*-test. A difference was regarded as significant at $p < 0.05$. The correlation between Mon-oVEMP and Bin-oVEMP response parameters with respect to thresholds, latencies, amplitudes and IAD ratios was calculated by obtaining the Spearman rank-correlation coefficient (Spearman's ρ). This

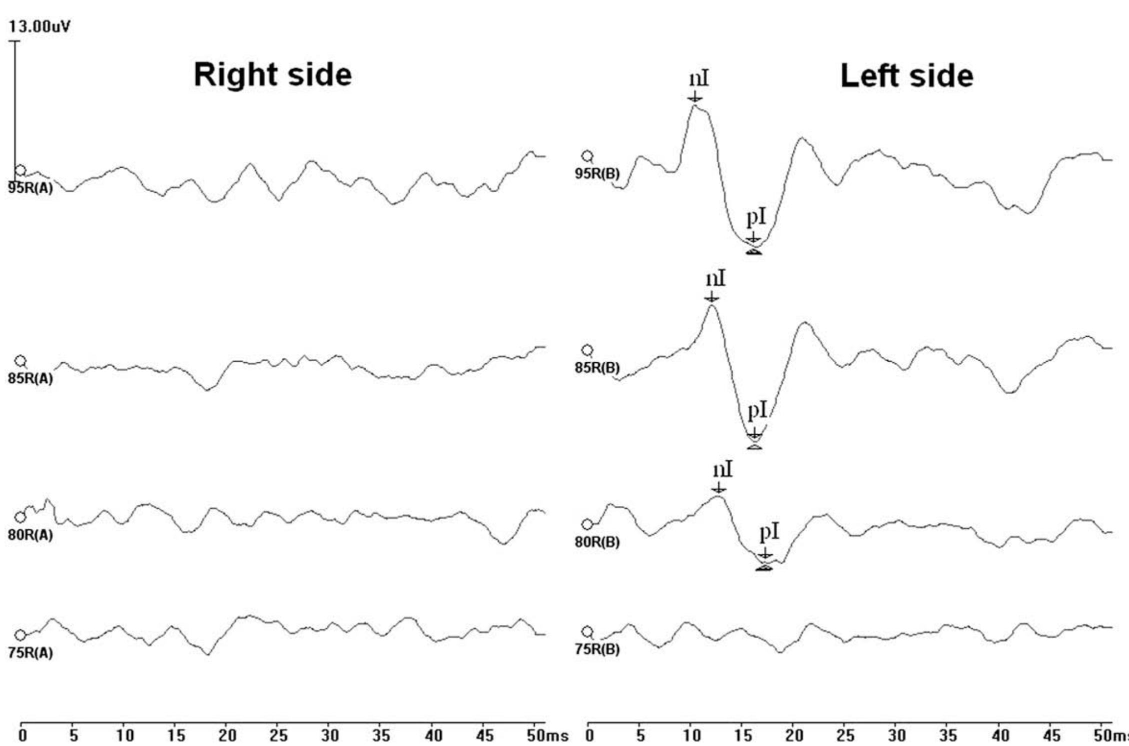

Fig. 1. Mon-oVEMPs elicited by right monaural acoustic stimulation. nI–pI biphasic responses are shown on the left, but not on the right side. The threshold is 80 dB nHL.

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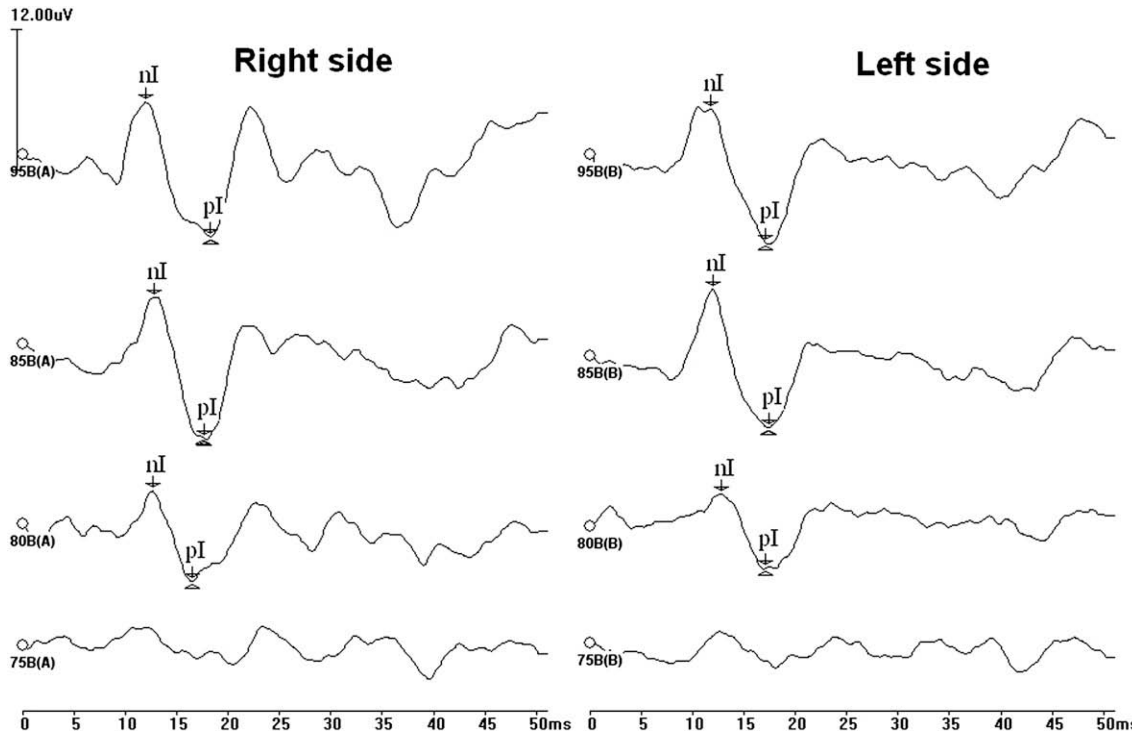

Fig. 2. Bin-oVEMPs elicited by simultaneous binaural acoustic stimulation. nI–pI biphasic responses are shown on both sides. The threshold is 80 dB nHL on each side.

study was approved by the Institutional Review Board, and each subject signed the informed consent.

3. Results

3.1. Comparison of response rates and thresholds between Mon-oVEMP and Bin-oVEMP

Using monaural 95 dB nHL acoustic stimulation, Mon-oVEMPs were elicited in 19 (95%) of 20 healthy subjects. The negative–positive biphasic waveforms with short latency were recorded with maximal amplitudes from the electrodes located below the eyes contralateral to the side of acoustic stimulation while the subject was gazing upward. For example, right acoustic stimulation results in prominent Mon-oVEMPs recorded on the left side (Fig. 1), and vice versa. Conversely, only 5 (10 ears, 25%) of the 20 subjects showed negative–positive Mon-oVEMPs ipsilaterally recorded on the stimulated side.

Bin-oVEMPs (Fig. 2) were elicited in 17 (85%) of 20 healthy subjects by binaural 95 dB nHL acoustic stimulation, and the difference between the response and the 95% response rate of Mon-oVEMPs was not significant ($p > 0.05$, exact McNemar test).

When the acoustic stimulation declined to 85 dB nHL, the 50% and 40% response rates of the Mon-oVEMP and Bin-oVEMP groups, respectively, were significantly lower than those associated with 95 dB nHL stimulation ($p < 0.01$, exact McNemar test). However, no significant difference existed between the rate of response to monaural 85 dB nHL stimulations and that to binaural 85 dB nHL stimulation ($p > 0.05$, exact McNemar test).

With respect to the threshold, all but two subjects with positive Bin-oVEMPs had the same thresholds for the right and left eyes. Additionally, the mean thresholds were 88 ± 7 dB nHL (means ± SD) for the Mon-oVEMP and 89 ± 6 dB nHL for the Bin-oVEMP, revealing non-significant difference ($p > 0.05$, paired t-test, Table 1).

3.2. Comparison of latencies and amplitudes between Mon-oVEMP and Bin-oVEMP

Under 95 dB nHL acoustic stimulation, the mean latencies of nI and pI for Mon-oVEMP were 11.1 ± 0.7 and 15.9 ± 1.0 ms, respectively. These values did not differ significantly from the respective 11.1 ± 0.6 and 15.8 ± 0.9 ms for Bin-oVEMP ($p > 0.05$, paired t-test, Table 1).

The mean amplitudes nI–pI of Mon-oVEMP and Bin-oVEMP in response to 95 dB nHL acoustic stimulations were 6.5 ± 2.9 and 6.1 ± 2.2 μV, respectively, revealing a non-significant difference ($p > 0.05$, paired t-test). The largest discrepancy between the

Table 1
Comparison and correlations between Mon-oVEMP and Bin-oVEMP under 95-dB nHL acoustic stimulations.

	N	Mon-oVEMP	Bin-oVEMP	p value[a]	Spearman's ρ	p value[b]
Threshold	34 ears	88 ± 7 dB nHL	89 ± 6 dB nHL	0.16	0.95	<0.01
nI latency	34 ears	11.1 ± 0.7 ms	11.1 ± 0.6 ms	0.76	0.50	<0.01
pI latency	34 ears	15.9 ± 1.0 ms	15.8 ± 0.9 ms	0.32	0.72	<0.01
nI–pI amplitude	34 ears	6.5 ± 2.9 μV	6.1 ± 2.2 μV	0.13	0.76	<0.01
IAD ratio	17 subjects	−0.01 ± 0.23	0.04 ± 0.18	0.14	0.86	<0.01

IAD, interaural amplitude difference.
[a] Paired t-test.
[b] Spearman rank-correlation analysis.

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amplitude with bilateral compared to unilateral stimulation was 1.8 μV. For those five subjects with ipsilateral Mon-oVEMP responses, the nI latency, pI latency and nI–pI amplitude were 13.1 ± 1.2 ms, 18.1 ± 1.6 ms, and 2.3 ± 0.6 μV, respectively.

Since the amplitude of the oVEMP varies considerably among subjects and in each subject between trials, the IAD ratio was used to specify the side difference rather than the absolute amplitude. Accordingly, the means ± SD of IAD ratio was −0.01 ± 0.23 versus 0.04 ± 0.18, demonstrating no significant difference between the IAD ratios of oVEMP associated with monaural and binaural 95 dB nHL acoustic stimulation ($p > 0.05$, paired t-test, Table 1).

3.3. Correlation between Mon-oVEMP and Bin-oVEMP

Seventeen subjects (34 ears) with present Mon-oVEMPs and Bin-oVEMPs under 95 dB nHL acoustic stimulation were recruited to investigate the correlation. As regard to the thresholds, the Mon-oVEMP group was significantly consistent with the Bin-oVEMP group (Spearman's $\rho = 0.95$, $p < 0.01$, Table 1).

Likewise, the relationship between Mon-oVEMP and Bin-oVEMP revealed significant positive correlation in terms of nI latency (Spearman's $\rho = 0.50$, $p < 0.01$) and pI latency (Spearman's $\rho = 0.72$, $p < 0.01$). Significant positive correlation also existed between the Mon-oVEMP and Bin-oVEMP groups with respect to the nI–pI amplitudes and IAD ratios ($p < 0.01$, Table 1).

4. Discussion

During the past decade, VEMP research has advanced markedly. In addition to cVEMPs, which have widespread clinical application in evaluating otolithic function (Welgampola and Colebatch, 2005; Young, 2006), the recently developed oVEMP test provides another diagnostic tool for assessing vestibulo-ocular reflex integrity. The characteristic of the biphasic waveform (Fig. 1) implies that oVEMP is a crossed excitatory vestibulo-ocular response, which is consistent with the literature (Iwasaki et al., 2007). Since the inferior oblique muscle is the most superficial extraocular muscle which transverses to the electrode recording site, oVEMP may be easily obtained from the skin surface beneath the eye contralateral to the acoustically stimulating ear. Thereby, the amplitude of oVEMP becomes more prominent with upward gazing, in which the belly of the inferior oblique muscle is brought close to the recording electrode. An additional possible explanation is that when this muscle is contracted with upward gazing, its motor units (motor neurons and/or muscle fibers) are activated more synchronously, producing larger amplitude of compound action potentials. However, continuous upward gazing and repeated trials may cause eye strain and involuntary eye blinks, deteriorating the quality of waveform. Therefore, binaural acoustic stimulation with bilateral recordings helps to reduce the duration of the recording session. Nevertheless, a question is raised regarding whether bone-conducted vibration should be adopted rather than binaural air-conducted acoustic stimulation in eliciting oVEMP.

First, vestibular activation by air-conducted sound in healthy adults is highly reproducible between experiments and more symmetrical than activation by head taps or bone-conducted vibration (Welgampola et al., 2003). Second, binaural air-conducted sound selectively stimulates the saccular macula, while bone-conducted vibration stimulates both the utricular and saccular macula (Curthoys et al., 2006). Third, a conventional instrument for evoked potentials is generally equipped with a maximum level of 70 dB nHL (107 dB force level) for bone-conducted sound, which is lower than the normal threshold of 130 ± 1 dB force level for eliciting oVEMPs (Welgampola et al., 2008). Thus, eliciting oVEMPs by bone-conducted stimulation requires the extra cost of adding an amplifier to the original instrument. Consequently, binaural air-conducted acoustic stimulation is plausibly more specific, reliable and practicable than bone-conducted vibration in eliciting oVEMPs to investigate the function of the saccule and inferior vestibular nerve in subjects without conductive hearing loss, which could be excluded by conventional audiometry.

Since recording oVEMP is more effortless than recording cVEMP, will the oVEMP test replace cVEMP test in people who cannot maintain adequate cervical muscle activity during testing? Unfortunately, the answer is negative, because the assessment of the reflex pathways differs between oVEMPs and cVEMPs. Restated, the oVEMP test may complement the cVEMP test in obtaining the information about a lesion in the brainstem.

Five (25%) of the 20 subjects herein exhibited ipsilateral negative–positive oVEMP responses under monaural 95 dB nHL acoustic stimulation. The lack of ipsilateral responses may be due to using a weak stimulus. The presence of the ipsilateral effect means that it will sum with the crossed effect but, more profoundly, given the expected origin from the saccule, and the latter's physiology, there was the possibility of finding facilitation with bilateral excitation. On the other hand, the response rate under 95 dB nHL stimulation mode was significantly higher than that under 85 dB nHL stimulation mode, compatible with the properties of cVEMPs that higher acoustic stimulation intensity induces larger cVEMP amplitudes (Colebatch et al., 1994).

The latencies and amplitudes of Mon-oVEMP or Bin-oVEMP in this work (Table 1) were similar to those in a recent investigation (Chihara et al., 2007). In addition, significant correlations without difference between Mon-oVEMP and Bin-oVEMP were demonstrated with respect to threshold, latencies and amplitude (Table 1), indicating that the Bin-oVEMP test provides the same information as the Mon-oVEMP test, but that the recording duration of the former is shorter than that of the latter. Thus, the Bin-oVEMP test may be a more convenient screening tool for assessing the crossed vestibulo-ocular reflex.

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