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Vestibular evoked myogenic potentials using simultaneous binaural acoustic stimulation

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Abstract

The aim of this study is to investigate the feasibility of recording vestibular evoked myogenic potential (VEMP) using simultaneous binaural acoustic stimulation (B-VEMP), and compare it with that using monaural acoustic stimulation (M-VEMP). Seven healthy volunteers were evoked by initial B-VEMP test and subsequent M-VEMP test, whereas vice versa in another 7 volunteers. All 14 subjects demonstrated both B-VEMPs and M-VEMPs, without significant difference in the latencies of p13 and n23. When using interaural amplitude difference (IAD) ratio for interpreting amplitude, B-VEMPs did not differ significantly from that of M-VEMPs. Hence, B-VEMPs can produce information equivalent to M-VEMPs in terms of response rate, latencies, and IAD ratio in healthy subjects. Likewise, similar results were also shown in the patients with unilateral Meniere's disease. In conclusion, B-VEMPs provide neither different information nor less variability, as compared with M-VEMPs. In addition, B-VEMPs can offer information on unilateral inner ear (saccular) pathology similar to that by M-VEMPs. Furthermore, recording from binaural stimulation can be used as a possibly more convenient mode compared with two monaural recordings, especially when testing young or old or disabled patients, since a continuous muscular effort is required during recording.

Key words: Vestibular evoked myogenic potential; Binaural simultaneous acoustic stimulation; Monaural acoustic stimulation; Interaural amplitude difference

1. Introduction

By stimulating the ear with monaural loud sound and recording on tonically contracted neck muscles, the recently developed vestibular evoked myogenic potential (VEMP) testing has been validated to reflect inner ear function other than the cochlea and the semicircular canals (Colebatch et al., 1994; Murofushi et al., 1995). This expands the test battery for clinicians to explore saccular disease, adding a potential usefulness to the sacculo-collic reflex (Streubel et al., 2001; Chen et al., 2002; Young et al., 2002a,b). However, the VEMPs obtained by acoustic stimulation tended to vary markedly across subjects, and somewhat between trials. Even healthy subjects occasionally lack a VEMP response after repeated trials, possibly due to insufficient muscular effort (Lim et al., 1995). Although Colebatch et al. (1994) were the first to use binaural as well as monaural acoustic stimuli, VEMP has been elicited using monaural stimuli by most researchers. Recently, Brantberg and Fransson (2001) report that binaural acoustic stimulation leads to symmetric VEMPs. It was the authors' premise that if VEMPs could be elicited successfully by binaural acoustic stimulation, this would save time and muscular effort, since a continuous muscular effort is required during recording. The aim of this study is to

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Abbreviations: B-VEMP, vestibular evoked myogenic potential evoked by simultaneous binaural acoustic stimulation; EMG, electromyography; IAD, interaural amplitude difference; M-VEMP, vestibular evoked myogenic potential evoked by monaural acoustic stimulation; SCM, sternocleidomastoid; VEMP, vestibular evoked myogenic potential

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investigate the feasibility of VEMPs using simultaneous binaural acoustic stimulation in healthy subjects and Meniere's patients, and compare it with those using monaural acoustic stimulation.

2. Materials and methods

2.1. Subjects

Fourteen healthy volunteers from medical students and resident doctors (11 men and three women; ages ranged from 24 to 32 years, with a mean of 27 years), without previous ear disorders were subjected to the VEMP test. VEMP was evoked by simultaneous binaural acoustic stimulation (B-VEMP), recording bilaterally, and by monaural acoustic stimulation (M-VEMP) of each ear separately, recording ipsilaterally. Seven subjects (group I) underwent initial B-VEMP test, and subsequent M-VEMP test; while another seven subjects (group II) were performed by M-VEMP test first, and followed by B-VEMP test.

2.2. Patients

Another 12 patients (five men and seven women, age ranged from 24 to 80 years, mean = 44 years) with unilateral definite Meniere's disease according to the guideline of American Academy of Otolaryngology–Head and Neck Surgery's recommendation in 1995 were also enrolled in this study. Right side was affected in six patients, and left side also in six patients. Each patient underwent B-VEMP test initially, followed by M-VEMP test.

2.3. VEMP test

The sternocleidomastoid (SCM) muscle was chosen as the target to record the VEMPs. Surface electromyographic (EMG) activity was recorded (Smart EP2, Intelligent hearing system, USA) in a supine subject with a 0.9 cm Ag/AgCl electrode on the upper half of the SCM muscle on both sides, and a reference electrode on the lateral end of the upper sternum. During the recording, the instructor kept an eye on the monitor and the subject was instructed to keep his or her head elevated while in a supine position throughout the entire test. EMG signals were amplified and bandpass filtered between 30 and 3000 Hz, and monitored to maintain muscle activity at a relatively constant level (50–200 μV). Once the biphasic waveform became dubious, the subject was aroused to strengthen his/her muscle activity. The acoustic stimuli were short tone bursts (500 Hz, 95 dB nHL, ramp = 2 ms, plateau = 2 ms) delivered through an earphone. The stimulation rate was 5 Hz and the analysis time for each response was 60 ms, and 200 responses were averaged for each run. Two consecutive runs were performed on the same ear to verify the reproducibility, and the results were averaged providing the final response.

The initial positive/negative polarity of waveform with peaks termed p13 and n23 based on their latencies was used to determine the presence or absence of the VEMP response. The latency of each peak (p13, n23) and p13–n23 amplitude were measured. Both relative amplitude and interaural amplitude difference (IAD) ratio were used to compare. Relative amplitude indicated the p13–n23 amplitude of B-VEMPs divided by that of M-VEMPs (Takegoshi and Murofushi, 2003). The IAD ratio was defined as the difference of p13–n23 amplitude in the right and left ears divided by the sum of p13–n23 amplitudes of both ears (R−L/R+L). In our laboratory, the mean IAD ratio was 0.13 ± 0.10 (mean ± S.D.). Hence, the condition of IAD ratio exceeding 0.33 (mean+2S.D.) was labeled, either augmented VEMP or depressed VEMP, depending on whether the amplitude of the lesioned side is greater or less than the opposite side (Young et al., 2002b, 2003).

2.4. Statistical methods

The latencies of p13 and n23 of B-VEMP were compared with those of M-VEMP using two-tailed paired *t*-test. The p13–n23 amplitude and IAD ratio between B-VEMP and M-VEMP were compared with Wilcoxon signed-rank test. The relative amplitudes between groups I and II were analyzed with Mann–Whitney test. A significant difference indicates $P < 0.05$.

This study was approved by an institutional review board, and each patient received the informed consent.

3. Results

3.1. Latency in healthy subjects

All 14 healthy volunteers displayed both normal biphasic B-VEMPs and M-VEMPs (Fig. 1). Group I underwent B-VEMP test first, followed by M-VEMP test. The mean latencies of p13 and n23 of the B-VEMPs in group I ($N = 14$ ears) were 14.23 ± 1.89 ms, and 21.42 ± 1.76 ms, respectively. Compared to those of the M-VEMPs: 14.43 ± 1.97 ms, and 21.82 ± 1.84 ms, respectively, there was no significant difference between these values (paired *t*-test, $P > 0.05$) (Table 1).

Group II underwent initial M-VEMP test, and subsequent B-VEMP test. The mean latencies of p13 and n23 of the B-VEMPs in group II ($N = 14$ ears) were

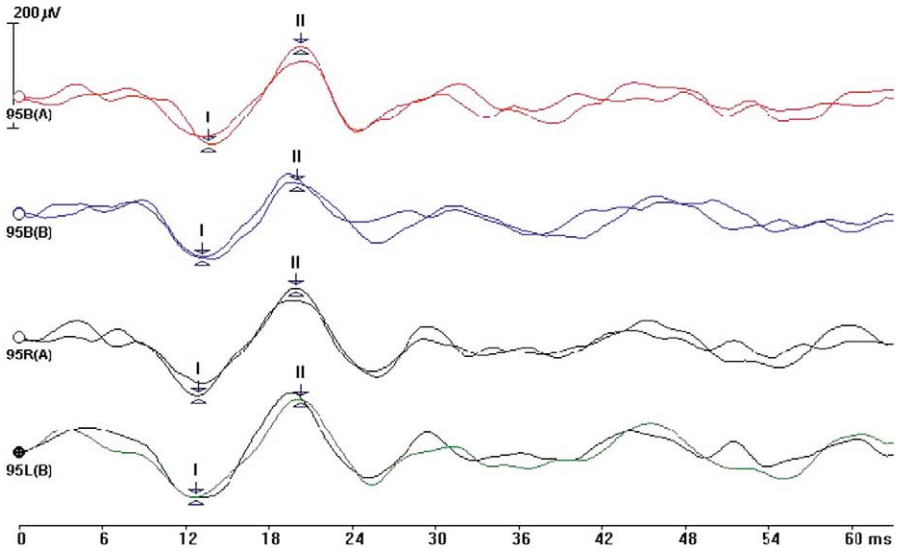

Fig. 1. VEMPs evoked by simultaneous binaural acoustic stimulation (the upper two tracings) and monaural acoustic stimulation (the lower two tracings) in a 24-year-old healthy volunteer demonstrating symmetric VEMP responses (I:p13, II:n23; 95B(A): 95 dB tone burst, binaural, right side recording; 95B(B): 95 dB tone burst, binaural, left side recording; 95R(A): 95 dB tone burst, monaural, right side recording; 95L(B): 95 dB tone burst, monaural, left side recording).

14.55 ± 1.64 ms and 21.48 ± 1.64 ms, respectively. In contrast, those of M-VEMPs in group II revealed 14.49 ± 1.28 ms and 21.83 ± 1.65 ms, respectively, exhibiting no significant difference (paired t-test, $P > 0.05$, Table 1).

3.2. Amplitude in healthy subjects

The median relative amplitudes (amplitude of B-VEMP divided by that of M-VEMP) in group I were 0.85 (0.27 ~ 1.19) [median (minimum ~ maximum)], including six ears (43%) without reduction and eight ears with reduction in relative amplitude. Compared to those in group II, 0.81 (0.50 ~ 1.20) [median (minimum ~ maximum)], including six ears (43%) without reduction and eight ears with reduction in relative amplitude, both groups did not differ significantly (Table 2, $P > 0.05$, Mann–Whitney test). In group I, B-VEMPs disclosed 15% reduction in the median relative amplitudes. Similarly, the amplitudes of B-VEMPs in group II also decreased significantly (19% reduction). Restated, B-VEMPs displayed significant reduction of amplitude when compared to M-VEMPs ($P < 0.05$, Wilcoxon signed-ranks test).

However, when using the IAD ratio for comparison between B-VEMPs and M-VEMPS, 0.00 (−0.38 ~ 0.33) [median (minimum ~ maximum)] and 0.03 (−0.24 ~ 0.21), respectively, both stimulation modes did not differ significantly (Table 3, $P > 0.05$, Wilcoxon signed-ranks test).

3.3. VEMPs in Meniere's disease patients

Another 12 patients with unilateral definite Meniere's disease were also enrolled in this study. When using binaural stimulation, normal symmetric VEMPs were disclosed in nine patients (75%), whereas asymmetric VEMPs were shown in three patients, including absent VEMPs one, augmented VEMPs one, and depressed VEMPs one on the lesioned ears. In contrast, using

Table 1
Comparison of latencies in VEMPs between binaural (B-VEMP) and monaural (M-VEMP) acoustic stimulation in two groups

	N	Latency p13 (ms)	Latency n23 (ms)
Group I			
Initial B-VEMP	14	14.23 ± 1.89	21.42 ± 1.76
Subsequent M-VEMP	14	14.43 ± 1.97	21.82 ± 1.84
		NS	NS
Group II			
Initial M-VEMP	14	14.49 ± 1.28	21.83 ± 1.65
Subsequent B-VEMP	14	14.55 ± 1.64	21.48 ± 1.64
		NS	NS

Data are expressed as mean ± S.D.
NS: not statistically significant ($P > 0.05$, two-tailed paired t-test).

Table 2
Comparison of relative amplitudes in VEMPs between group I (initial B-VEMP+subsequent M-VEMP) and group II (initial M-VEMP+subsequent B-VEMP)

	N	Minimum	Maximum	Median	IQR
Group I	14	0.27	1.19	0.85*	0.43
Group II	14	0.50	1.20	0.81*	0.25

*$P > 0.05$ (Mann–Whitney test). IQR: inter-quartile range.

Table 3
Comparison of the IAD ratio between simultaneous binaural (B-VEMP) and monaural (M-VEMP) acoustic stimulation in 14 healthy subjects

	N	Minimum	Maximum	Median	IQR
B-VEMP	14	−0.38	0.33	0.00*	0.16
M-VEMP	14	−0.24	0.21	0.03*	0.13

*$P > 0.05$ (Wilcoxon signed-ranks test). IQR: inter-quartile range.

monaural acoustic stimulation, similar results were obtained (Fig. 2). Restated, the response rate for normal VEMPs in unilateral definite Meniere's disease is 75%, despite using either binaural or monaural acoustic stimulation.

In 11 patients with positive VEMP response, the mean latencies of p13 and n23 of B-VEMPs recorded on the lesioned side were 14.84 ± 2.41 ms and 20.88 ± 3.54 ms, respectively. Compared to M-VEMPs recorded on the lesioned side, 14.91 ± 1.72 ms and 21.25 ± 4.35 ms, respectively, each exhibited a non-significant difference (Table 4, $P > 0.05$, paired *t*-test). Furthermore, there was also no significant difference in the mean latencies of p13 and n23, recorded on the contralateral healthy side between B-VEMPs and M-VEMPs (Table 4, $P > 0.05$, paired *t*-test).

In comparison of the IAD ratio in Meniere's ears versus contralateral healthy ears between B-VEMPs and M-VEMPs, −0.02 (−1.00 ~ 0.33) [median (minimum ~ maximum)] and −0.03 (−1.00 ~ 0.34), respectively, both stimulation modes did not differ significantly (Table 5, $P > 0.05$, Wilcoxon signed-ranks test).

Table 4
Comparison of latencies in VEMPs initiated by binaural (B-VEMP) and monaural (M-VEMP) acoustic stimulation recorded on 11 patients with unilateral Meniere's disease

	N	Latency p13 (ms)	Latency n23 (ms)
Lesioned side			
B-VEMP	11	14.84 ± 2.41	20.88 ± 3.54
M-VEMP	11	14.91 ± 1.72	21.25 ± 14.91
		NS	NS
Contralateral side			
B-VEMP	11	14.32 ± 2.64	20.74 ± 3.79
M-VEMP	11	14.91 ± 1.72	21.25 ± 4.35
		NS	NS

Data are expressed as mean ± S.D.
NS: not statistically significant ($P > 0.05$, two-tailed paired *t*-test).

4. Discussion

The effectiveness of a neuromuscular reflex, either excitatory or inhibitory, has been found to be correlated with the voluntary task undertaken by the muscle (Matthews, 1986). VEMP amplitude has been shown to be linearly related to the level of background activity of the target muscle. Lim et al. (1995) suggested that the amplitude of VEMP was related to both the intensity of acoustic stimulus and voluntary EMG activity. Therefore, calibrated sound sources as well as appropriate intensities must always be used, and 95 dB HL is now accepted as the optimal acoustic stimulus for VEMP (Murofushi et al., 1999; Cheng and Murofushi, 2001). Subsequently, how to maintain steady SCM muscle contraction challenges the researchers, especially in some elderly patients or young children (Chen et al.,

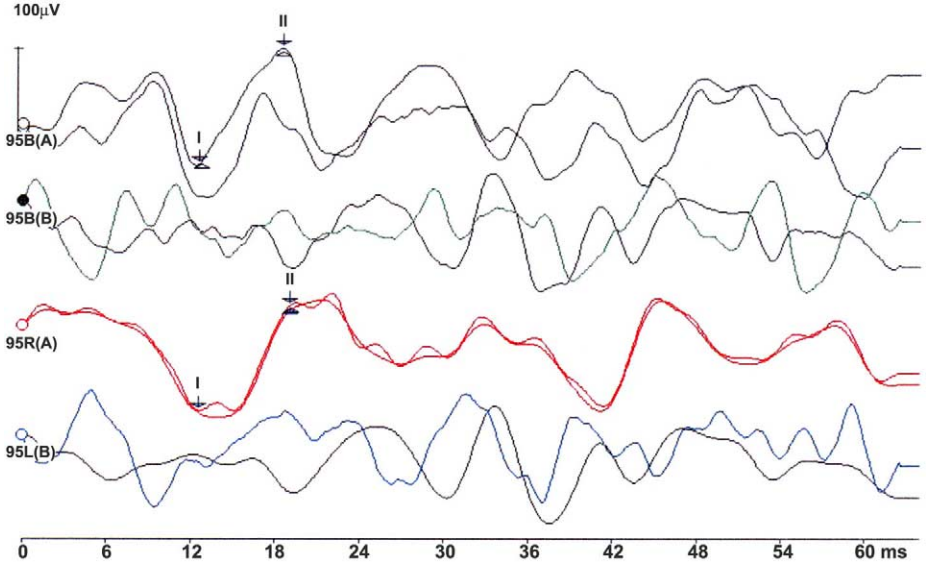

Fig. 2. VEMPs initiated by binaural simultaneous acoustic stimulation (the upper two tracings) and monaural acoustic stimulation (the lower two tracings) in a 22-year-old man with left Meniere's disease demonstrating absent VEMPs on the left side, and normal VEMPs on the right side (I:p13, II:n23; 95B(A): 95 dB tone burst, binaural, right side recording; 95B(B): 95 dB tone burst, binaural, left side recording; 95R(A): 95 dB tone burst, monaural, right side recording; 95L(B): 95 dB tone burst, monaural, left side recording).

Table 5
Comparison of the IAD ratio initiated by binaural (B-VEMP) and monaural (M-VEMP) acoustic stimulation recorded on 12 patients with unilateral Meniere's disease

IAD	*N*	Minimum	Maximum	Median	IQR
B-VEMP	12	−1.00	0.33	−0.02*	0.18
M-VEMP	12	−1.00	0.34	−0.03*	0.37

*$P > 0.05$ (Wilcoxon signed-ranks test). IQR: inter-quartile range.

2000), who display absent VEMPs frequently, due to insufficient muscular effort following repeated trials. Hence, in this study, we attempt to elicit VEMPs using binaural acoustic stimulation in order to save muscular effort.

Since the vestibulocollic reflex pathway descends through predominantly ipsilateral and minor contralateral vestibulospinal tracts, and terminates in the upper cervical segments (Sato et al., 1997), 'crossover' in VEMP response is anticipated. The contralateral VEMP is manifested as a small, inverted and delayed first peak, with a latency of approximately 3 ms later than that of ipsilateral VEMP in response to monaural click stimulation. Hence, the amplitude of ipsilateral B-VEMPs can be contaminated by 'crossover' inverted VEMPs, leading to reduction of the p13–n23 amplitude of B-VEMPs, after subtraction from the contralateral VEMPs (Table 2). In our previous report (Wu et al., 1999), an acoustic stimulus of 95 dB HL short tone burst was used to test 16 healthy young adults, all 32 stimulated ears demonstrated p13–n23 VEMPs of ipsilateral SCM muscle successfully; however, contralateral VEMPs were present on only about 50% of the recordings. In this study, the relative amplitudes (amplitude of B-VEMP divided by that of M-VEMP) in healthy subjects range from 0.27 to 1.19 and from 0.50 to 1.20 in groups I and II, respectively (Table 2). There are six (43%) out of 14 recordings without reduction in the relative amplitude in either group I or II, indicating that the amplitude of B-VEMPs is not always less than that of M-VEMPs, possibly due to lack of the 'crossover' response in some subjects. Because of inconsistent 'crossover' response, contralateral VEMPs are not always present whether using monaural or binaural stimulation. Therefore, the difference between the sum of two monaural stimulations (one on each side) and binaural stimulation is not analyzed.

In this study, all 14 healthy volunteers displayed both B-VEMPs and M-VEMPs, without significant difference in the latencies of p13 and n23, indicating a bilateral symmetric innervation for the VEMPs, with its connection to both SCM motor neuron pools on both sides. Although the relative amplitude of B-VEMPs is less than that of M-VEMPs, there is no significant difference when using the IAD ratio in interpreting the result of amplitude (Table 3). One may ask if rejecting absolute or relative amplitude information is available for evaluating the unilateral inner ear (saccular) pathology? Hence, VEMP test was applied to those with unilateral Meniere's disease using both binaural and monaural acoustic stimulation.

Since the amplitude of the VEMP varies substantially between subjects and in one subject between trials, the IAD ratio instead of absolute peak-to-peak amplitude has been applied for evaluating VEMPs in cases of Meniere's disease (Young et al., 2002a). In our recent report (Young et al., 2003), the IAD ratio of VEMPs correlates with the stage of Meniere's disease, and can be served as another aid to assess the stage of Meniere's disease. Variations in the IAD ratio of VEMPs can be explained by different stages of Meniere's patients. Thus, nine (75%) out of 12 Meniere's patients have normal symmetric VEMPs, whereas three patients (25%) showing asymmetric VEMPs, e.g. absent VEMPs one, augmented VEMPs one, and depressed VEMPs one, despite using either binaural or monaural acoustic stimulation. Likewise, there is also no significant difference in the mean latencies of p13 and n23 recorded on the Meniere's ears between B-VEMPs and M-VEMPs (Table 4). Hence, binaural VEMPs can produce information equivalent to monaural VEMPs. Restated, bilateral simultaneous acoustic stimulation can also provide information on the unilateral inner ear (saccular) pathology similar to that by monaural stimulation. This is truly an advantage in some elderly patients or young children, with the benefits of saving time and muscular effort from repeated SCM muscle contractions.

Indeed recording with binaural stimulation would allow twice less time than two monaural recordings, e.g. at least two runs for both ears when using binaural stimulation, compared to four runs more if using monaural stimulation, since the IAD ratio must be derived from bilateral p13–n23 amplitudes. As regards the disabled patients, e.g. irradiated nasopharyngeal carcinoma patients with neck fibrosis (Wu et al., 2003), they can only tolerate SCM muscle contraction two or three times, thus sometimes it is hard to verify the reproducibility of p13–n23 waveform if using monaural stimulation. Restated, binaural stimulation is a convenient mode especially when testing disabled patients since a continuous muscular effort is required during recordings.

Apart from muscular weakness from repeated trials, the second cause for absent VEMPs in the elderly may be attributed to an aging effect. Welgampola and Colebatch (2001) recently reported that in subjects beyond the age of 60 years, click evoked VEMP amplitudes decrease rapidly, probably due to morphological changes in the vestibular system occurring with aging, leading to a decreased magnitude of bilateral VEMPs,

symmetrically. Hence, asymmetric B-VEMPs in the elderly may be helpful in the differentiating pathological change from physiological aging effect. Furthermore, elderly patients undergoing B-VEMP test may verify this assumption.

5. Conclusion

B-VEMPs provide neither different information nor less variability, as compared with M-VEMPs. In addition, B-VEMPs can offer information on unilateral inner ear (saccular) pathology similar to that by M-VEMPs. Furthermore, recording from binaural stimulation can be used as a possibly more convenient mode compared with two monaural recordings, especially when testing young or old or disabled patients, since a continuous muscular effort is required during recording.

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