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Original Article

The Efficiency of Simultaneous Binaural Ocular Vestibular Evoked Myogenic Potentials: A Comparative Study with Monaural Acoustic Stimulation in Healthy Subjects

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Objectives. To evaluate the test-retest reliability and convenience of simultaneous binaural acoustic-evoked ocular vestibular evoked myogenic potentials (oVEMP).

Methods. Thirteen healthy subjects with no history of ear diseases participated in this study. All subjects underwent oVEMP test with both separated monaural acoustic stimulation and simultaneous binaural acoustic stimulation. For evaluating test-retest reliability, three repetitive sessions were performed in each ear for calculating the intraclass correlation coefficient (ICC) for both monaural and binaural tests. We analyzed data from the biphasic n1-p1 complex, such as latency of peak, inter-peak amplitude, and asymmetric ratio of amplitude in both ears. Finally, we checked the total time required to complete each test for evaluating test convenience.

Results. No significant difference was observed in amplitude and asymmetric ratio in comparison between monaural and binaural oVEMP. However, latency was slightly delayed in binaural oVEMP. In test-retest reliability analysis, binaural oVEMP showed excellent ICC values ranging from 0.68 to 0.98 in latency, asymmetric ratio, and inter-peak amplitude. Additionally, the test time was shorter in binaural than monaural oVEMP.

Conclusion. oVEMP elicited from binaural acoustic stimulation yields similar satisfactory results as monaural stimulation. Further, excellent test-retest reliability and shorter test time were achieved in binaural than in monaural oVEMP.

Key Words. *Ocular vestibular evoked myogenic potentials, Reproducibility of results, Vestibular function tests, Saccule and utricle, Human*

INTRODUCTION

Among the several vestibular function tests, no test was available for evaluating otolith function prior to the 1990s. However, cervical vestibular evoked myogenic potential (cVEMP) [1-3] and ocular VEMP (oVEMP) [4-6] for evaluating otolith functions have been reported recently. To our knowledge, cVEMP is now widely used to assess the sacculocollic pathway and plays an important role in the diagnosis of vestibular diseases. Although there are some arguments on its origin, oVEMP, especially induced by vibration, is gradually used for diagnosis in utricular dysfunction because the otolithic input to the inferior oblique muscles appears to originate predominantly from the utricular macula [7-10].

The oVEMP is larger in the eye contralateral to the stimulus [4,11]. Because the inferior oblique muscle is the most superficial extraocular muscle that transverses to the electrode recording site, oVEMP can be obtained easily from the skin surface beneath the eye, contralateral to the acoustically stimulated ear. Additionally, to detect muscular potential easily, upward gazing

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is essential because belly of the inferior oblique muscle is brought to close to the recording electrode and relatively synchronous motor unit activation caused by the inferior oblique muscle contraction. Thus, the amplitude of oVEMP increases when subjects gaze upward. For this reason, a successful oVEMP test mostly relies on the patient's concentration, contractility of inferior oblique muscles, and the fatigability of muscles [11-13].

A recent study has reported that the binaural acoustic oVEMP test yields the same information as the monaural oVEMP test, and the duration of recording in binaural oVEMP is shorter than in monaural oVEMP [11]. Nguyen et al. [13] reported that monaural oVEMP in response to various stimuli yielded excellent test-retest reliability. However, to the best of our knowledge, the test-retest reliability of binaural simultaneous oVEMP was not clearly identified. The objective of our study is to evaluate the test-retest reliability of simultaneous binaural acoustic evoked oVEMP and to identify the convenience of binaural oVEMP in normal populations. Also, we evaluated the differences of separated monaural and simultaneous binaural oVEMP.

MATERIALS AND METHODS

Subjects

Thirteen healthy subjects participated in this study. They did not experience any hearing or vestibular disorders. In all participants, twelve subjects had bilateral oVEMP response to both monaural and binaural acoustic stimulation. Eight male and 4 female participants were included this study (aged 28 to 34 years; mean, 30 years). All subjects with bilateral positive oVEMP findings underwent repeated testing sessions in each ear for evaluation of test-retest reliability. All subjects gave informed consent for the oVEMP testing through a protocol approved by the institutional review board where testing was performed.

Testing sessions

A total of three testing sessions were performed. Since continuous upward gazing and repeated trials may cause muscle strain or involuntary eye blinks which could deteriorate the quality of the waveform, five minutes of rest was given at the end of each session. Especially in monaural stimulation, a rest period was also given between the tests in each ear. To avoid the effect of muscle strain due to testing order, it was determined in each subject by a random number table whether which test was first.

Testing protocol

The subjects were placed in the supine position. The recording electrode position was about 1 cm inferior to each eye. It was vertically located below the center of each pupil. Reference electrodes were located about 1.5 cm below the active electrode. Additionally, the ground electrode was positioned in the center of the forehead. The location of each electrode was cleansed with an alcohol swab before electrode placement. Before testing with stimulation, electrode impedance was checked for successful testing. All subjects were instructed to look upward at a small, fixed target 2 m above the eyes during the sound stimulation and electromyography (EMG) recording. Sound stimuli were delivered both separated monaurally (Mon-oVEMP) and simultaneous binaurally (Bin-oVEMP) via intraauricular speakers in each session. The data of Mon-oVEMP was obtained by contralateral recording from sound stimuli. But, Bin-oVEMP obtained the data from both ears at once. After a total of three sessions, the total time of each test such as Mon-oVEMP or Bin-oVEMP was recorded including rest periods. The type of air-conducted stimuli was 95 dB nHL of short tone bursts (500 Hz; rise/fall time, 1 ms; plateau time, 2 ms).

We analyzed the peak-to-peak amplitude of the initial negative to positive peak; n1 and p1. The n1 and p1 latencies were also measured. The asymmetric ratio (AR) of amplitude between the subject ears was calculated according to the following formula:

$$AR = \left|\frac{\text{Right amplitude} - \text{Left amplitude}}{\text{Right amplitude} + \text{Left amplitude}}\right| \times 100$$

Finally, we analyzed the intraclass correlation coefficient (ICC) between repetitions in each test according to the asymmetric ratio. ICC is commonly used statistical method for the assessment of consistency or reproducibility of quantitative measurements.

Statistical analysis

Peak to peak amplitude, the asymmetric ratio of n1-p1 complex, and latency of each n1 or p1 response in monaural and binaural stimulation were assessed using a paired *t*-test. Test-retest reliability was assessed with the ICC, calculated using a 2-way random effects and absolute agreement model. Similar to previous studies that examined VEMP test-retest reliability [14-16], we classified an ICC value of 1.00 as perfect reliability, ICC of 0.75 or greater as excellent reliability, ICC of 0.40 or greater but less than 0.75 as fair-to-good reliability, and ICC of less than 0.40 as poor reliability [13]. The level of significance was defined as a *P*-value of less than 0.05. Statistical analyses were performed using PASW ver. 17.0 (SPSS Inc., Chicago, IL, USA).

RESULTS

Of thirteen healthy volunteers, twelve participants had bilaterally positive oVEMP responses in monaural separated acoustic stimulation or binaural simultaneous stimulation. One participant had a unilateral absence of response in monaural and binaural stimulation. All Mon-oVEMP responses were elicited with contralateral sound stimulation in contrast to bilateral simultaneous response in Bin-oVEMP. Therefore, the average positive rate of oVEMP in these normal populations was 92.3% in both test methods, respectively.

Comparison of n1-p1 amplitude, asymmetric ratio, and latency between Mon-oVEMP and Bin-oVEMP

We compared each parameter of the n1-p1 complex, such as inter-peak amplitude, n1 latency, and p1 latency, between Mon-oVEMP and Bin-oVEMP. Table 1 shows the comparison of these parameters between the two tests. The mean n1-p1 amplitudes of Mon-oVEMP and Bin-oVEMP were 6.34±4.24 and 6.85±3.23 μV, respectively, indicating no statistical difference (P=0.34). Similarly, the asymmetric ratio of Mon-oVEMP was not different from that of Bin-oVEMP (P=0.42). However, n1 latency and p1 latency of both tests were statistically different. The mean n1 latencies of Mon-oVEMP and Bin-oVEMP were 10.54±0.45 and 10.95±0.64 ms, respectively (P<0.01). The mean p1 latencies of the two tests were 15.17±1.15 and 16.19±1.09 ms, respectively (P<0.01). But, the mean interlatency of Mon-oVEMP and Bin-oVEMP were 4.72±0.37 and 4.92±0.45, respectively (P=0.68). In other words, although the latency of initial negativity in Bin-oVEMPs could be delayed than Mon-oVEMP, interlatency was not changed (Table 1). Fig. 1 shows an example of the n1-p1 complex elicited from Mon-oVEMP and Bin-oVEMP.

Test-retest reliability of oVEMP response in Mon-oVEMP and Bin-oVEMP

Table 2 showed the ICC values for Mon-oVEMP and Bin-oVEMP which indicate test-retest reliability between the two tests. In the present study, the ICC is the ratio of the variance of a VEMP parameter due to subject differences divided by the sum of variances due to subject differences and measurement errors. For a VEMP test to be clinically useful, variance over repeated measures should be minimized in the same patient. The more measurement errors were eliminated, the more ICC values were close to one. All parameters of oVEMP were shown as having better test-retest reliability in Bin-oVEMP than in Mon-oVEMP. Additionally, all of these results had statistical significance (P<0.05). Fig. 2 shows the dot plot of the dataset with intraclass correlation in asymmetric ratio. According to Table 2 and Fig. 2, the asymmetric ratio of Bin-oVEMP tended to be similar in same subject than Mon-oVEMP. As we mentioned above, an ICC value of 0.75 or greater meant excellent reliability. Therefore, we could determine that Bin-oVEMP had greater reliability than Mon-oVEMP.

Testing time of oVEMP in Mon-oVEMP and Bin-oVEMP

Table 3 shows the testing time of Mon-oVEMP and Bin-oVEMP

Table 1. Comparison of parameters in the n1-p1 complex between Mon-oVEMP and Bin-oVEMP

Parameter	Mon-oVEMP	Bin-oVEMP	P-value*	Spearman correlation	
				Correlation coefficient (r)	P-value
n1-p1 amplitude (μV)	6.85	6.34	0.34	0.48	<0.01
n1 latency (ms)	10.55	11.02	<0.01	0.38	0.04
p1 latency (ms)	15.18	16.19	<0.01	0.52	<0.01
n1-p1 interlatency	4.72	4.92	0.68	0.76	<0.01
AR (%)	19.06	17.50	0.42	0.42	0.03

oVEMP, ocular vestibular evoked myogenic potential; Mon-oVEMP, oVEMP response using monaural separated acoustic stimulation; Bin-oVEMP, oVEMP response using binaural simultaneous acoustic stimulation; AR, asymmetric ratio of amplitude between both ears.
*Paired t-test.

Table 2. Comparison of ICC values in Mon-oVEMP and Bin-oVEMP

Parameter	Mon-oVEMP	Bin-oVEMP
n1-p1 amplitude (μV)	0.95	0.97
n1 latency (ms)	0.44	0.68
p1 latency (ms)	0.76	0.94
AR (%)	0.61	0.98

All parameters are P<0.05. ICC>0.75, excellent reliability; 0.4≤ICC≤0.75, fair to good reliability; ICC<0.4, poor reliability.
ICC, intraclass correlation coefficient; oVEMP, ocular vestibular evoked myogenic potential; Mon-oVEMP, oVEMP response using monaural separated acoustic stimulation; Bin-oVEMP, oVEMP response using binaural simultaneous acoustic stimulation; AR, asymmetric ratio of amplitude between both ears.

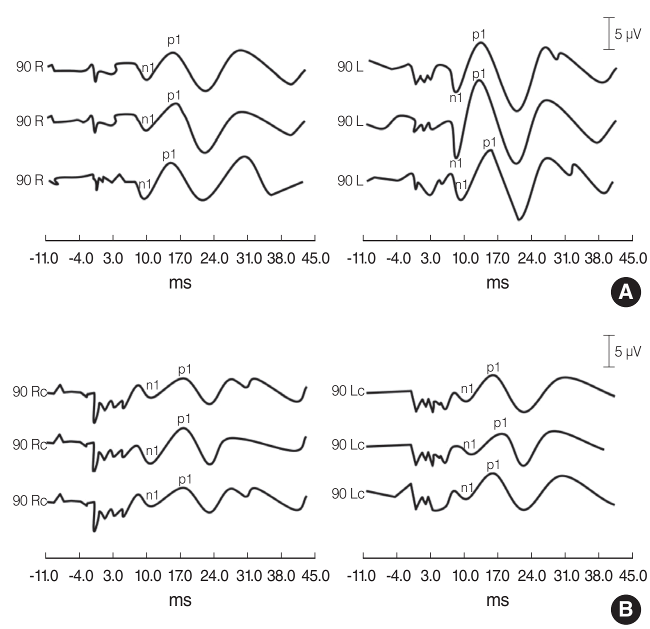

Fig. 1. Examples of n1-p1 complexes elicited from (A) Mon-oVEMP and (B) Bin-oVEMP. Left column means right side three repetitive session results and right column means left side repetitive test results. Compare with (B), (A) shows more different interpeak amplitude between right and left side oVEMP response. oVEMP, ocular vestibular evoked myogenic potential; Mon-oVEMP, oVEMP response using monaural separated acoustic stimulation; Bin-oVEMP, oVEMP response using binaural simultaneous acoustic stimulation.

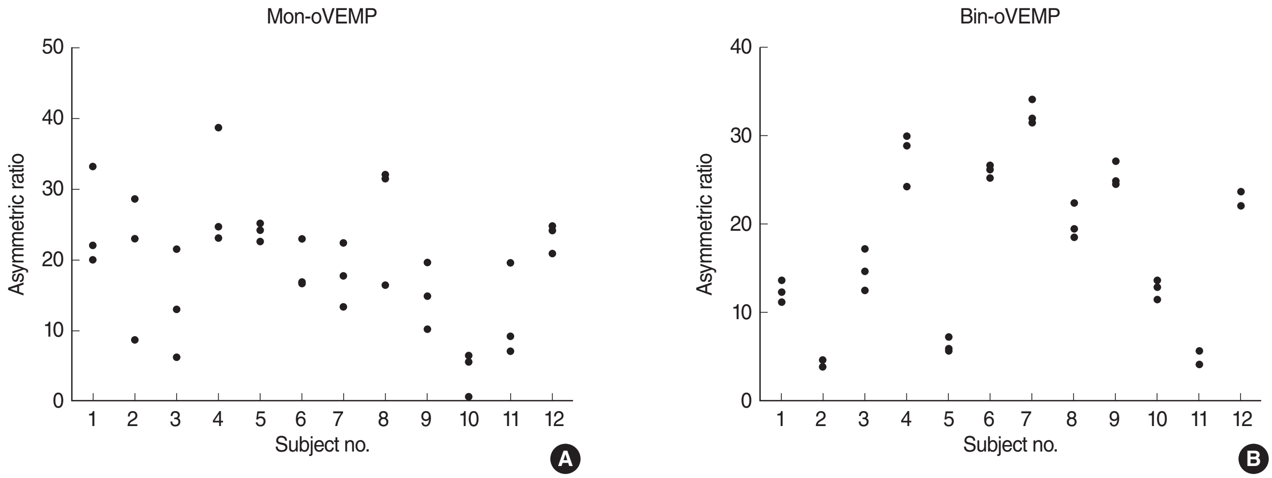

Fig. 2. (A) Mon-oVEMP and (B) Bin-oVEMP. The dot plot of the dataset with intraclass correlation in asymmetric ratio of interpeak amplitude. The values of asymmetric ratio from same subject tend to be more similar in Bin-oVEMP than in Mon-oVEMP. oVEMP, ocular vestibular evoked myogenic potential; Mon-oVEMP, oVEMP response using monaural separated acoustic stimulation; Bin-oVEMP, oVEMP response using binaural simultaneous acoustic stimulation.

Table 3. Testing time of Mon-oVEMP and Bin-oVEMP

Testing time (minute)	Mon-oVEMP	Bin-oVEMP
One session including rest period*	7	1
Three sessions including rest period*	31	13

oVEMP, ocular vestibular evoked myogenic potential; Mon-oVEMP, oVEMP response using monaural separated acoustic stimulation; Bin-oVEMP, oVEMP response using binaural simultaneous acoustic stimulation.
*Rest period, 5 minutes of rest period were given to participants in each test for avoiding muscle fatigue.

in the study population. The testing time except for the rest period of each session was 1 minute irrespective of whether the stimulation type was monaural or binaural. However, because a monaural test in one participant should be performed separately with each ear, resting periods must be necessary for avoiding muscle fatigue. Considering 5 minutes of resting time, the total testing time of one session in Mon-oVEMP and Bin-oVEMP were 7 minutes and 1 minute, respectively. As we performed three sessions of oVEMP in each participant, total testing time in Mon-oVEMP was 31 minutes, and in Bin-oVEMP, it was 13 minutes. Therefore, Bin-oVEMP could be finished more quickly than Mon-oVEMP.

DISCUSSION

Among VEMP studies in normal subjects, a variety of protocol parameters have been used in not only oVEMP but also cVEMP [12,17,18]. Stimuli that have been used to evoke VEMP responses include air sound, bone-conduction, forehead taps, and vibration. Additionally, many variable methods can be utilized, such as testing position, the location of the electrode, and so on [13]. In other words, no standard protocol or methods for VEMP response have been established up to the present time. Nevertheless, the VEMP test was widely used in various vestibular disorders using various protocols [19]. For the VEMP test to be more clinically useful, reliability and convenience of the test might be some of the most important factors [13,14]. Probably, the test with greater reliability could not have greater accuracy. However, in VEMP test, relative value or difference between two ears was more important than absolute value. Besides, comparing another research, our amplitude or latency of Mon-oVEMP and Bin-oVEMP were not different from another study [11,13,20].

In the present study, we analyzed the test-retest reliability of both monaural and binaural oVEMP. To the best of our knowledge, this is the first study that has examined test-retest reliability of binaural simultaneous acoustic evoked oVEMP compared with monaural separated oVEMP. Although oVEMP response with acoustic stimulation is widely used in clinics, it is mostly relies on various factors, such as the patient's concentration or blink reflex and the degree of inferior oblique muscle fatigability. For these reasons, conventionally used Mon-oVEMP with acoustic stimulation could be different even in the same patient. However, Bin-oVEMP could have greater test-retest reliability than Mon-oVEMP because it is easier with Bin-oVEMP to maintain bilateral inferior oblique muscle contraction, similarly. When we test monaurally, we have to perform the test by two times due to evaluation of both ears. But, it is difficult to maintain muscle contraction at same level between two times of tests. That is to say, it is possible to alter oVEMP responses between both ears even in same subject. Nguyen et al. [13] reported oVEMP response parameters demonstrated better test-retest reliability than cVEMP response parameters in a large healthy population. In their study, sound stimuli were delivered monaurally. The ICC values of amplitude and asymmetric ratio using tone burst stimuli were 0.79 and 0.50, respectively, in Mon-oVEMP. Compared with our Mon-oVEMP results, their results were similar to ours. However, the Bin-oVEMP results of our study were much better than those of Mon-oVEMP. ICC values of amplitude and asymmetric ratio in Bin-oVEMP were 0.97 and 0.98, respectively. As it was very close to one, binaural simultaneous oVEMP with acoustic stimulation had almost perfect test-retest reliability. In other words, Bin-oVEMP was more suitable for clinical usage than monaural separated oVEMP because the test had higher reproducibility in the same patient.

Another important point was the test convenience. Testing time is recognized as an important factor, especially in clinical testing. In this study, the difference in testing time in Mon-oVEMP and Bin-oVEMP during the three sessions was 18 minutes. As the testing time of Bin-oVEMP was 13 minutes, two patients can be tested within 31 minutes of the time for Mon-oVEMP in only one patient. From a viewpoint of cost-effectiveness, Bin-oVEMP is more attractive than Mon-oVEMP.

In the comparison of parameters between Mon-oVEMP and Bin-oVEMP, n1-p1 amplitude and asymmetric ratio were not different between the two tests. Wang et al. [11] also reported that the Bin-oVEMP test provides the same information as the Mon-oVEMP test. However, in our study, n1 latency and p1 latency were slightly longer in Bin-oVEMP. We thought this latency delay was due to the ipsilateral cross-over effect. Generally, many studies reported a small number of subjects showed apparently biphasic responses beneath the eyes ipsilateral to the stimulation [4]. Chihara et al. [20] reported ipsilateral n1-p1 response was delayed in ten healthy subjects. According to their results, contralateral n1 and p1 latency were 10.5 ± 0.1 and 15.9 ± 0.3, respectively. Ipsilateral n1 and p1 latency were 12.8 ± 0.6 and 17.7 ± 0.9, respectively. Therefore, about 2 ms of delay was existed between contralateral and ipsilateral response. But, interlatency between contralateral response and ipsilateral response was relatively consistent and the difference was about 5 ms [20]. Although our participants did not show apparent oVEMP response in the ipsilateral stimulation side, unclear weak responses seem to be affected on latency in binaural simultaneous stimulation. However, in our interlatency analysis, the mean interlatency of Mon-oVEMP and Bin-oVEMP were not different each other. Therefore, we thought it was a negligible effect on the graph shape of response and reading a result because all parameters of the n1-p1 complex were well-correlated between Mon-oVEMP and Bin-oVEMP by Spearman correlation test.

In the present study, we analyzed binaural simultaneous oVEMP compared with Mon-oVEMP. Although this research was performed in a relatively small healthy population, Bin-oVEMP has many advantages in applications of clinical usage. Therefore, additional research is needed to further explore in various vestibular disease with large populations and should seek to clarify the potential limitations in disease populations.

In the present study, we analyzed binaural simultaneous oVEMP compared with Mon-oVEMP in healthy populations. Bin-oVEMP provides almost the same information as the Mon-oVEMP, and additionally, the testing time can be shorter. Futhermore, Bin-oVEMP has excellent test-retest reliability. Therefore, it may be a more convenient clinical test for evaluating vestibular functions.

CONFLICT OF INTEREST

No potential conflict of interest relevant to this article was reported.

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