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What is This?
Comparison of Bone-Conducted Vibration for Eliciting Ocular Vestibular-Evoked Myogenic Potentials: Forehead versus Mastoid Tapping

Chia-Chen Tseng, MD¹, Shou-Jen Wang, MD², and Yi-Ho Young, MD¹

Abstract

Objective. This study compared bone-conducted vibration (BCV) stimuli at forehead (Fz) and mastoid sites for eliciting ocular vestibular-evoked myogenic potentials (oVEMPs).

Study Design. Prospective study.

Setting. University hospital.

Methods. Twenty healthy subjects underwent oVEMP testing via BCV stimuli at Fz and mastoid sites. Another 50 patients with unilateral Meniere’s disease also underwent oVEMP testing.

Results. All healthy subjects showed clear oVEMPs via BCV stimulation regardless of the tapping sites. The right oVEMPs stimulated by tapping at the right mastoid had earlier nl and pl latencies and a larger nl-pl amplitude compared with those stimulated by tapping at the Fz and left mastoid. Similar trends were also observed in left oVEMPs. However, the asymmetry ratio did not differ significantly between the ipsilateral mastoid and Fz sites. Clinically, tapping at the Fz revealed absent oVEMPs in 28% of Meniere’s ears, which decreased to 16% when tapping at the ipsilesional (hydropic) mastoid site, exhibiting a significant difference.

Conclusion. Tapping at the ipsilateral mastoid site elicits earlier oVEMP latencies and larger oVEMP amplitudes when compared with tapping at the Fz site. Thus, tapping at the Fz site is suggested to screen for the otothic function, whereas tapping at the ipsilesional mastoid site is suitable for evaluating residual otothic function.

Keywords

bone-conducted vibration, ocular vestibular evoked myogenic potential, Meniere’s disease, mastoid tapping

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enrollment in this study. All subjects denied previous ear disorders and were further checked by otoscopy. Then, each subject underwent oVEMP tests by BCV stimuli tapping at the forehead (Fz) and mastoid sites in a randomized order according to the registration number: odd (Fz site first) or even (mastoid site first).

Another 50 patients with unilateral definite Meniere’s disease were also enrolled in this study. Thirteen were men and 37 were women, with ages ranging from 23 to 66 years (mean, 51 years). Right and left ears were affected in 18 and 32 patients, respectively. The diagnosis of definite Meniere’s disease was based on the guidelines proposed by the American Academy of Otolaryngology—Head and Neck Surgery (1995). Accordingly, 50 patients were classified: 20 patients as stage I, 11 patients as stage II, and 19 patients as stage III. All patients were without vertiginous attack at the moment of oVEMP testing using the same method as the healthy subjects. The time lag between the last vertiginous attack and the testing time varied from 1 week to 2 months. This study was approved by the institutional review board of the College of Medicine, National Taiwan University Hospital, for stimulating and recording conditions of the oVEMP in humans, and each subject signed an informed consent to participate.

**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, Florida). Two active electrodes were placed about 1 cm below the center of the lower eyelids. The other 2 reference electrodes were positioned about 1 to 2 cm below the active ones, and one ground electrode was placed on the sternum. During recording, the subject was instructed to look upward at a small fixed target above the horizontal.

BCV stimuli were delivered using a handheld electromagnetic vibrator (V201 vibrator, Ling Dynamic Systems, Royston, England) fitted with a short M4 bolt (2 cm in length), which terminated in a Bakelite cap. The input signal was half a cycle of a condensation 500-Hz sine wave (1.0 milliseconds in duration), which was driven by a custom amplifier combination. The driving voltage was adjusted to 8.0 V and fixed to produce a peak force of 128-dB force level.

The operator held the vibrator by hand and supported most of its weight such that the axis of the connected Bakelite cap perpendicularly delivered a repeatable tap with little pressure on the subject’s skull at the Fz site (the midline forehead at the hairline) and right and left mastoid sites (2 cm behind the opening of external ear canal) in a randomized order.

The EMG signals were amplified and bandpass filtered between 1 and 1000 Hz. The stimulation rate was 5 Hz, and 30 responses were averaged for each run. The initial negative-positive biphasic waveform comprised peaks nI and pl. Consecutive runs were performed to confirm the reproducibility of peaks nl and pl, and oVEMPs were then deemed to be present. Conversely, oVEMPs were absent when the biphasic waveform was not reproducible. The latencies of peaks nl and pl, nl-pl amplitude, and asymmetry ratio of amplitude were measured. The latter (%) was defined as the difference of the amplitude nl-pl on each ear divided by the sum of amplitude nl-pl of both ears, that is (larger amplitude – smaller amplitude/larger amplitude + smaller amplitude) × 100. Those with an asymmetry ratio >40% were interpreted as reduced or augmented responses.

**Triaxial Accelerometry**

One miniature (10 mm³, 5 gm) triaxial accelerometer (Endevco model 65-100, San Juan Capistrano, California) was fixed, using a tight elastic bandage, to each subject’s right/left mastoid area just behind the auricle during oVEMP testing (**Figure 1**). The accelerometer was used to measure the 3-dimensional linear acceleration along the x-axis (anterior-posterior), y-axis (inter-aural), and z-axis (rostro-caudal) simultaneously. Forward, outward, and upward were defined as the positive x, y, and z directions, respectively. The voltage sensitivity was typically 100 mV/g, and the frequency response was 1.5 to 6000 Hz (±1 dB). The triaxial accelerometer signals were digitalized at 10 kHz using a dynamic signal analyzer (NI USB-4431, National Instruments, Austin, Texas), which provided signal conditioning and constant current supply (2.1 mA) to the accelerometer. The initial peak magnitudes of linear acceleration were analyzed using a customized program (LabVIEW 8.5, National Instruments) during oVEMP testing.

**Statistical Methods**

The latencies and amplitudes of oVEMPs among the 3 sites were compared by 1-way repeated-measures analysis of variance (ANOVA) test and Bonferroni-adjusted t test. The prevalence of oVEMP in Meniere’s ears between the 2 methods was compared by McNemar test. A difference of P < .05 was considered significant.

Reproducibility of the nl-pl amplitude in 2 test sessions was further quantified by the intraclass correlation coefficient (ICC) of reliability for each stimulus location. An ICC...
value of 0.75 or greater was considered to represent excellent reliability, while an ICC <0.40 indicated poor reliability. ICC values between 0.40 and 0.75 were considered as fair to good reliability.\textsuperscript{15}

### Results

#### Comparison of the nl and pl Latencies

In all healthy subjects, BCV stimulation at either the Fz or mastoid site produced clear oVEMPs (Figure 2). The right oVEMPs (recorded from left eye) stimulated by tapping at the right (ipsilateral side) mastoid had mean nl and pl latencies of 7.7 ± 0.3 (mean ± SD) and 12.3 ± 0.6 milliseconds, respectively, which showed significantly earlier than 8.4 ± 0.5 and 13.3 ± 1.1 milliseconds when tapping at Fz and 11.7 ± 1.6 and 16.5 ± 1.8 milliseconds when tapping at the left mastoid (contralateral side; Table 1). The oVEMP latencies differed significantly among the 3 sites (P < .01, repeated-measures 1-way ANOVA test and Bonferroni-adjusted \( t \) test). Of them, the right oVEMPs stimulated by right (ipsilateral) mastoid tapping had earlier nl and pl latencies compared with those stimulated by tapping at the Fz and left (contralateral) mastoid sites.

Similar trends were also observed in left oVEMPs (Table 1).

#### Comparison of the nl-pl Amplitude

The mean nl-pl amplitudes of right oVEMPs was 28.1 ± 11.5 \( \mu \)V when tapping at the right (ipsilateral) mastoid, exhibiting significantly larger responses than tapping at the Fz and left (contralateral) mastoid. The opposite was true for the left oVEMPs (P < .05; Table 1). However, tapping at the Fz and contralateral mastoid sites did not produce significant differences in the mean amplitude (P > .05). The mean asymmetry ratios of nl-pl amplitude obtained by ipsilateral mastoid tapping and Fz tapping were 9% ± 7% and 8% ± 6%, respectively, revealing a nonsignificant difference (P > .05, paired \( t \) test).

Test-retest reliability was assessed by the ICC of the nl-pl amplitudes for each stimulus location. All demonstrated excellent reliability (ICC > 0.75) regardless of diverse stimulus locations (Table 1).

#### Comparison of the Acceleration Magnitude: Fz versus Mastoid Tapping

To measure the acceleration magnitude during right oVEMP trials, the triaxial accelerometer was fixed on the left mastoid and vice versa (Figure 3). The mean acceleration magnitudes from right mastoid tapping were 0.06 ± 0.03 g (mean ± SD; g-force) along the x-axis, 0.84 ± 0.23 g along the y-axis, and 0.11 ± 0.07 g along the z-axis (Table 2). These 3 components of acceleration differed significantly, with the acceleration magnitude higher along the y-axis than along the x- or z-axis (P < .01; Table 2). Likewise, the mean acceleration magnitudes produced by Fz tapping were higher along the y-axis than along the x- and z-axes (P < .01; Table 2). Compared with Fz tapping (0.26 ± 0.13 g), the mastoid tapping (0.84 ± 0.23 g) obtained a significantly higher acceleration magnitude (P < .01), but only along the y-axis and not along the x- and z-axes (P > .05; Table 2).

The triaxial accelerometer was then fixed on the right mastoid during left oVEMP trials (Figure 3). Similarly, mastoid tapping produced higher interaural acceleration magnitude than Fz tapping did (Table 2).

The mean interaural acceleration magnitudes obtained by right and left mastoid tapping were 0.84 ± 0.23 g and 0.93 ± 0.20 g, respectively, which was not significantly different (P > .05, paired \( t \) test; Table 2). Likewise, no significant side-difference was observed in the interaural acceleration magnitudes (0.26 ± 0.13 g vs 0.28 ± 0.12 g) when tapping at Fz (Table 2). With regard to the acceleration magnitude along the x- or z-axis, a significant side-difference was not shown whether tapping at the Fz or mastoid site (Table 2).
Comparison of oVEMPs in Patients with Meniere’s Disease

Since ipsilateral mastoid tapping produced dominant oVEMP responses, 50 patients with unilateral definite Meniere’s disease underwent oVEMP tests via tapping at the Fz site and ipsilesional mastoid site of the hydropic ear.

At Fz, BCV stimuli obtained normal oVEMPs in 29 Meniere’s ears and abnormal oVEMPs in 21 Meniere’s ears, including augmented responses in 3 ears, reduced responses in 4 ears, and absent responses in 14 ears (28%). However, when BCV stimuli were applied at the ipsilesional mastoid site, 6 of 14 Meniere’s ears with absent oVEMPs from Fz tapping turned out to be clear oVEMPs (Figure 4), while the other 8 ears remained absent responses. Restated, using ipsilesional mastoid tapping, 35 Meniere’s ears showed normal oVEMPs and 15 Meniere’s ears had abnormal oVEMPs, consisting of augmented responses in 3 ears, reduced responses in 4 ears, and absent responses in 8 ears (16%). Thus, the prevalence of absent oVEMPs decreased from 28% to 16%, exhibiting a significant difference ($P < .05$, McNemar test).

Discussion

Using a vibrator for tapping at the skull may sufficiently stimulate both utricular and saccular macula. However, whether tapping at the forehead or mastoid is better for generating oVEMPs remains undetermined. The forehead tapping has the advantage of stimulating bilateral otolithic receptors simultaneously, while the lateral impulse obtains an acceleration effect primarily in the horizontal plane, which is likely to activate utricular receptors. Thus, this study compared different tapping sites to see what oVEMPs are elicited in healthy subjects and Meniere’s patients.
Healthy Subjects

In response to BCV stimuli, the skull moves away from the stimulation site and then back again. These movements can generate inertial effects on labyrinthine fluid and vestibular end organs. For example, the BC hearing threshold was measured with the transducer applied on one mastoid. When the stimulation is close to one ear, the sound is lateralized to the other ear. This lateralization arises when the stimulation of one cochlea is earlier or at a slightly higher level than that at the opposite cochlea.

As the skull motion in response to a tap is a complex interaction of stimuli at the level of the sensors in the temporal bone, triaxial accelerometry combined with BCV stimuli was performed to elucidate the mechanism. In this study, ipsilateral mastoid tapping produced significantly higher interaural acceleration magnitude than Fz tapping did. Thus, the earlier oVEMP latencies and larger oVEMP waveforms (Figure 2) obtained by tapping at the ipsilateral mastoid compared with those obtained by tapping at Fz (Table 1) indicate that delivery of the stimuli to the otolithic end organs is relatively more efficient or that the stimulation is more purely utricular and a larger population of afferents is activated via tapping at the ipsilateral mastoid site than the Fz site. Conversely, BCV to the contralateral mastoid elicits an nl-pl amplitude similar to that obtained by tapping at the Fz site. In addition, equally excellent reliability (ICC of nl-pl amplitude >0.75) of the 3 tapping sites (Table 1) further confirms that ipsilateral mastoid tapping elicits dominant large oVEMPs.

Regarding the right-left difference, both forehead and mastoid tapping had no significant difference in the asymmetry ratio of nl-pl amplitude (Table 1). Furthermore, no significant side-difference was noted in the mean acceleration magnitude regardless of whether the forehead or mastoid was tapped (Table 2). Thus, like Fz tapping, ipsilateral mastoid tapping can generate symmetrical oVEMPs in healthy subjects.
Meniere’s Patients

A test battery comprising audiometry, eVEMP test via ACS mode, oVEMP test via BCV mode, and caloric test has been used for assessing the function of the cochlea, saccule, utricle, and semicircular canals, respectively. The decreasing order of abnormal physiological percentages in patients with Meniere’s disease mimics the declining sequence of hydrops formation in temporal bone studies, indicating that this test battery may provide information about the localization and prevalence of hydrops formation in Meniere’s disease.7

In this study, oVEMPs were absent in 14 Meniere’s ears (28%) when applying BCV stimulation to the Fz. However, 8 ears remained with absent responses, and the other 6 ears turned out to be clear oVEMPs when tapping at the ipsilesional mastoid site (Figure 4), indicating that Meniere’s ears require a stronger stimulus to elicit the oVEMP than healthy ears.

Applying BCV stimulation to the Fz failed to elicit a clear oVEMP in some Meniere’s ears and would have been diagnosed as having absent otolithic function, when in fact they do have otolithic function, as demonstrated by the presence of oVEMPs via tapping at the ipsilesional mastoid site. While the vestibulo-ocular reflex pathway may still be intact, it may not be functioning normally. Thus, BCV stimulation via ipsilesional mastoid tapping is suitable for confirming oVEMP areflexia in Meniere’s ears.

Conclusion

Tapping at the ipsilateral mastoid site elicits relatively higher stimulus magnitude, leading to earlier oVEMP latencies and larger oVEMP amplitudes when compared with tapping at the Fz site. Thus, tapping at the Fz site is suggested for screening for the otolithic function, whereas tapping at the ipsilesional mastoid site is suitable for evaluating residual otolithic function.

Author Contributions

Chia-Chen Tseng, performed VEMP and wrote article; Shou-Jen Wang, performed VEMP; Yi-Ho Young, corresponding author, supervised study.

Disclosures

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