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Original article

Evaluation of bone-conducted oVEMPs using frontal medial and mastoid stimulations

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INFO ARTICLE

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ABSTRACT

Aims. – To determine the optimal stimulation intensity for frontal stimulation with a modified slit lamp holder and to compare the reliability and symmetry of bone-conducted ocular vestibular evoked myogenic potentials (oVEMPs) using two stimulation sites: frontal medial and mastoid.
Methods. – This observational study included 33 healthy volunteers (15 women, 18 men; mean age 24.5 years) at the University Hospital of Lausanne. Participants underwent otoneurological assessments, and those with normal results were included. Bone-conducted oVEMPs were recorded using a Brüel and Kjaer mini-shaker type 4810. A modified slit lamp holder was used for frontal stimulation to ensure consistent application pressure, freeing the examiner's hands. Mastoid stimulation was performed manually.
Results. – The best reproducibility of oVEMP recordings was observed at 70 dB nHL. Frontal stimulation demonstrated lower dispersion of data and lower asymmetry ratios of latencies (up to 7%) and amplitudes (up to 50%) compared to mastoid stimulation (up to 40% for latencies). Single stimulations at both frontal and mastoid sites were sufficient to obtain reliable measurements of both utricles.
Conclusion. – Frontal stimulation at 70 dB nHL using a modified slit lamp holder is recommended for bone-conducted oVEMP recordings due to its superior reproducibility, comfort, and reliability. This study establishes a new standard for optimal stimulation intensity and supports the use of frontal stimulation in clinical practice.

1. Introduction

Recording the activity of the otolith organ in the inner ear has always been challenging for clinicians due to the need to generate linear acceleration that selectively activates these organs. Vestibular evoked myogenic potentials (VEMPs) were developed in the early 1990s to assess otolith function [1,2]. Acoustic stimulation – sound, vibration, or galvanic – is used to produce linear acceleration in the utricular and saccular organs, resulting in short-latency myogenic responses [3]. Initially, these responses were recorded from the sternocleidomastoid muscle (cVEMPs) to evaluate saccular function via the inferior vestibular nerve. More recently, infra-ocular muscle recordings (oVEMPs) have been developed to selectively assess utricular function mediated by the superior vestibular nerve [4].

The current literature focuses primarily on the wave results and clinical applications of VEMPs [5]. While these studies provide valuable insights, there is limited emphasis on the reliability and symmetry of these recordings, which are critical for consistent clinical assessment. Furthermore, the optimal conditions for bone-conducted oVEMP recordings, particularly in terms of the ideal intensity and stimulation site, are not well established [6].

The main objective of the study was to evaluate the bone-conducted oVEMPs responses using a calibrated and optimized frontal stimulation, aiming in particular to determine the ideal stimulation intensity. The secondary objectives were to compare the results of the frontal stimulations to those obtained with mastoid stimulation.

2. Material and methods

This study followed the STROBE guidelines [7]. It was a single-center observational study and was conducted at the University Hospital of Lausanne, Switzerland (CHUV). The inclusion period was from June 2017 to December 2019. Ethical approval was obtai-

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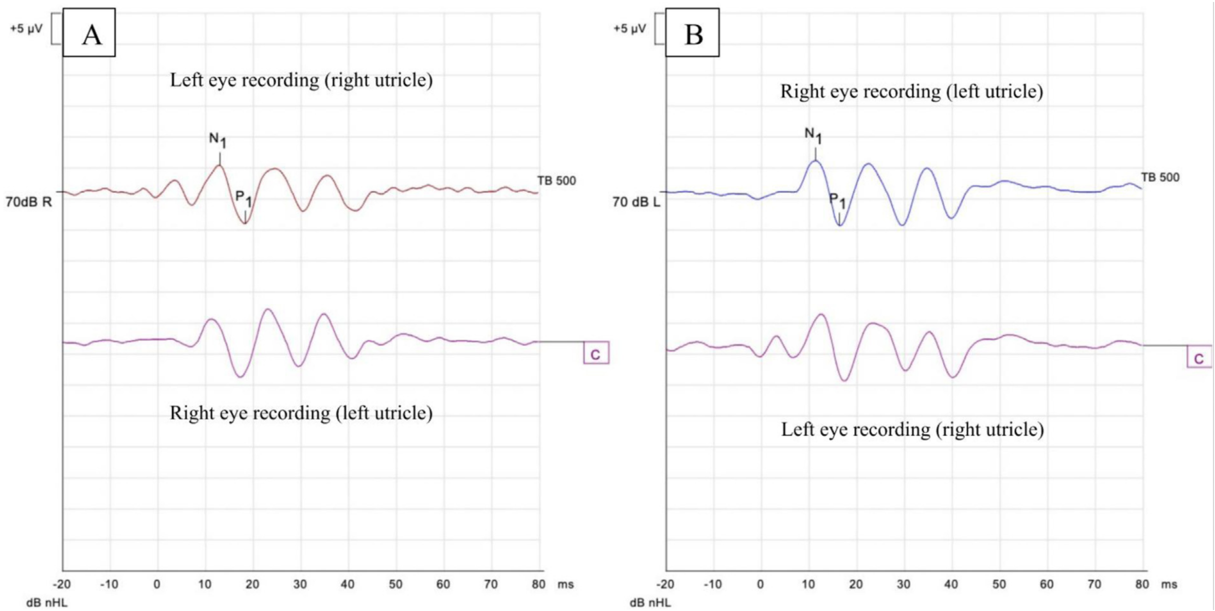

Fig. 1. Display of ocular vestibular evoked myogenic potentials (oVEMPs) recordings. A typical oVEMPs waves is displayed with N1 as the beginning of the excitation phase of the muscle and P1 as the beginning of the repolarization phase. On the left side (A), the upper wave represented the response of the right utricle measured below the left eye and the bottom wave represents the recording of the left utricle below the right eye at the same acquisition time. The right side (B) showed a second acquisition time where the left utricle was measured in the upper wave and the right utricle in the bottom wave. The Eclipse software allowed the data to be measured only in the superior waves of both sides (A and B), so two separate acquisitions were required to analyze both utricles.

ned from the État de Vaud ethics committee (approval number: 2017-04-24). The inclusion criteria were: age > 18 years; normal audio-vestibular examinations, including pure tone audiogram, video head impulse test, and videonystagmography. The exclusion criteria included any history of vestibular disease or otological surgery as well as pathological audio-vestibular examinations. All participants signed an informed consent form.

The primary outcome of the study was to evaluate the oVEMP recordings obtained through frontal medial stimulations using a modified slit lamp holder. The goal was to determine the optimal stimulation intensity and to assess the precision and reliability of the results. The secondary outcome was to compare the frontal stimulation with the mastoid stimulation at 70 dB nHL.

The bone stimuli were performed using the Brüel and Kjaer bone vibrator (mini-shaker) type 4810. The device specifications included a weight of 1.1 kg, a diameter of 76 mm, a height of 75 mm, a maximum current of 1.8 A, and an impedance of 3.5 Ohms at 500 Hz. The device was CE marked for medical use. VEMPs recordings were made using the Eclipse EP15 from Interacoustics, with stimulation levels ranging from 0 to 100 dB nHL. The Brüel and Kjær amplifier type 2718 was used to interface the acoustic signal from the Eclipse to the bone vibrator, providing an additional gain of up to 40 dB nHL. For this study, a 500 Hz tone burst was used as the stimulus in accordance with previous clinical guidelines [8].

The utriculo-ocular reflex pathway was activated, transmitting signals from the stimulated utricle via the superior vestibular nerve to the contralateral oculomotor nuclei, thus activating the inferior ocular muscles [9]. EMG surface electrodes recorded these muscle responses under the contralateral lower eyelid, with the reference electrode on the chin and the ground electrode on the forehead [10].

The electromyographic wave was derived from the average of 200 tone bursts and consisted of N1 (onset of muscle excitation) and P1 (onset of repolarisation), both measured in milliseconds (ms). The amplitude (amp) was calculated as the difference in electrical potential (microvolts, μV) between N1 and P1. In this study, N1 right and P1 right represented the latencies of the right utricle stimulation recorded under the left lower eyelid, while N1 left and P1 left represented those of the left utricle recorded under the right lower eyelid. Amp right corresponded to the amplitude of the right utricle response, and Amp left to the amplitude of the left utricle response. These measurements are shown in Fig. 1.

In our study, the first acquisition corresponded to the right utricle stimulation and the second to left utricle stimulation. The electrodynamic properties of the bone vibrator were assessed at the Swiss Federal Institute of Technology in Lausanne (EPFL) using a voltmeter and a sinusoidal function generator. The electrical signal flattened progressively as pressure on the bone vibrator increased and stabilized at 500 grams of pressure and above, indicating the optimal pressure condition. Mechanical properties were assessed using a Brüel and Kjær type 4930 artificial mastoid, which showed that the mechanical force stabilized at 0.775 Newton (N) at 300 grams and above.

Frontal stimulation was performed with the bone shaker attached to a modified slit lamp, designed by the authors and built by the CHUV technical department (Fig. 2). The slit lamp allowed the bone vibrator to be held and adjusted in height, depth, and angle, freeing the examiner's hands. This device optimized the pressure applied to the forehead by ensuring consistent and controlled pressure application during stimulation minimizing variability due to patient morphology. The Brüel and Kjær type 2718 amplifier had a built-in ammeter that monitored changes in electrical current according to the pressure applied on the forehead via a small digital display. Stabilization of the electrical signal indicated the optimal pressure.

Mastoid recordings were acquired subsequently. For this test, the patient's head was placed on a pillow, turned to the right for left mastoid stimulation and to the left for right mastoid stimulation. The shaker was held manually by the examiner, with a maximum pressure of 500 grams, half the weight of the shaker. The pressure conditions were more variable compared to the frontal recordings. The stimulus intensity used was 70 dB nHL, which was the optimal intensity found for frontal stimulation.

Fig. 2. Frontal stimulation. Modified slit lamp holding the bone vibrator and allowing a three-dimensional adjustment of the position of the bone vibrator on the patient's forehead. The small digital display on the Brüel and Kjaer amplifier type 2718 (red arrow) showed the electrical current delivered by the device according to the pressure applied, allowing the optimal pressure on the forehead to be adjusted.

Efforts to minimize bias included using the same equipment and procedures for all participants.

The correlation of the measurements was evaluated to determine the dispersion of the data for each stimulation intensity. On the x-axis, the subjects were ranked from the lowest to the highest value of N1 right latency. The value of the latencies (ms) or amplitudes (μV) for each participant was then displayed on the y-axis (Fig. 3).

The distribution of the results was analyzed to determine whether the latency and amplitude values followed a Gaussian distribution. The data were plotted with the latency time (ms) or the amplitude value (μV) on the x-axis and the number of participants on the y-axis.

As shown in Fig. 1, the Eclipse software did not allow direct measurement of the contralateral wave corresponding to the contralateral utricle results during the same acquisition. Therefore, the contralateral wave was measured manually using a ruler and the scale on the graphs by the main author alone as this action is an objective graphical evaluation. These measurements were then compared with the results of the second acquisition for the same utricle side.

The symmetry of the results and the analysis of the contralateral wave were assessed using the paired Student's *t*-test with a significance threshold of $P < 0.005$ [11]. A QQ-plot and a Shapiro-Wilk test were performed to assess if the data distribution followed a Gaussian distribution. The analysis was performed using IBM SPSS statistics software. A post-hoc power analysis was conducted using G*power software.

Table 1
Mean value, standard deviation and asymmetry ratio of latencies and amplitudes at 70 dB nHL frontal stimulation for both utricles.

	Latency (ms)		Amplitude (μV)
	N1	P1	
Right utricle			
Mean value	11.06	15.98	8.48
Standard deviation	2.57	2.91	6.39
Left utricle			
Mean value	11.09	16.26	8.50
Standard deviation	2.34	2.85	5.80
R-L assymmetry ratio			
Min. assymmetry ratio (%)	0	0	0.79
Max. assymmetry ratio (%)	6.43	4.79	50.4

Table 2
Mean value, standard deviation and asymmetry ratio of latencies and amplitudes at 70 dB nHL left mastoid stimulation for both utricles. Similar results for right mastoid stimulation (not shown).

	Latency (ms)		Amplitude (μV)
	N1	P1	
Right utricle			
Mean value	11.34	16.75	19.26
Standard deviation	2.62	3.05	15.76
Left utricle			
Mean value	10.24	15.71	24.27
Standard deviation	1.83	1.60	23.94
R-L assymmetry ratio			
Min. assymmetry ratio (%)	0	0	3.13
Max. assymmetry ratio (%)	20.20	40.51	57.09

3. Results

3.1. Participants

A total of 37 patients were selected for the study. Thirty-three were included and 4 were excluded due to pathological otoneurological examinations. None of them had history of rhinosinusal disease. The participants included were 15 women and 18 men, with a mean age of 24.5 years.

Primary and secondary outcomes were assessed for all participants.

3.2. Primary outcome: stimulation intensity (frontal stimulation)

Above 75 dB nHL, saturation of the device was observed. Below 60 dB nHL of stimulation, no bone-conducted vestibular response was detected. The stimulations were applied at intensities of 60, 65, 70, and 75 dB nHL.

The latency results (N1; P1) showed consistent intra-individual data for each subject with a low variability of the response between both ears. The best consistency of measurements was found at 70 dB nHL of stimulation, as shown in Fig. 3A. Similar results were obtained for the amplitude results (not shown). Tables 1 and 2 show the mean value, standard deviation and asymmetry ratio of the responses obtained at 70 dB nHL. The asymmetry ratio between the two utricles was about 7% for the latencies but could reach up to 50% for the amplitudes. No significant statistical difference ($P > 0.005$) was found when comparing the results of the right and left utricles at all stimulus intensities. The results displayed a Gaussian distribution of latencies and amplitudes for both utricles. The G* power analysis revealed a power of 0.87.

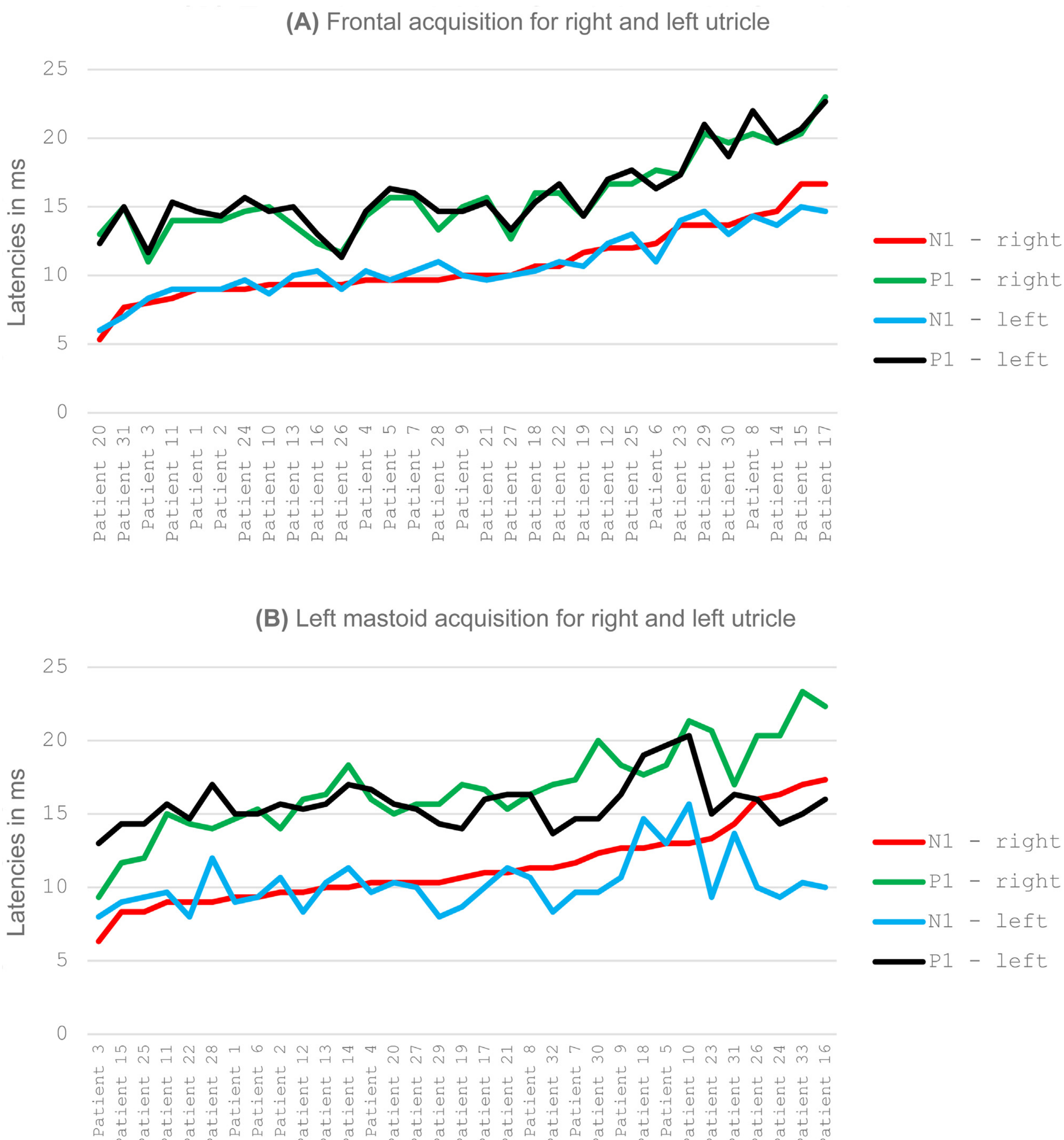

Fig. 3. Data dispersion. Comparison of right utricle and left utricle acquisitions using a frontal medial (A) and left mastoid (B) stimulation at 70 dB nHL. Each parameter was attributed to a different color (N1 right in red; N1 left in blue; P1 right in green; P1 left in black). The abscissa corresponded to the subjects ranked from the lowest to the highest value of N1 right. The ordinate corresponded to the latencies in ms for each subject. For the mastoid stimulation, no contralateral conduction delay was noticed when N1 right and N1 left as well as P1 right and P1 left were compared.

3.3. *Secondary outcomes*

3.3.1. *Frontal and mastoid stimulation comparison*

In the mastoid stimulation, the asymmetry ratio could reach up to 40% for the latencies and up to 57% for the amplitudes. In the right mastoid stimulation, the latency and amplitude results were similar to the left side. No significant statistical difference ($P > 0.005$) was found when comparing the results of the right and left utricles. Mastoid stimulation showed better consistency of latency measurements with left mastoid stimulation (Fig. 3B, right mastoid not shown). During a unilateral mastoid stimulation, no conduction delay was found for the response of the contralateral utricle. However, the dispersion of the results was higher compared to the frontal stimulation at 70 dB nHL for both latencies and amplitudes (amplitudes not shown).

3.3.2. *Comparison of unilateral utricle response (right or left) obtained in the two acquision times (see Fig. 1 and Material and methods)*

The results showed no significant statistical difference ($P > 0.005$) for both frontal and mastoid stimulations.

4. Discussion

In this study, we aimed to analyze the reliability and symmetry of bone-conducted oVEMPs recordings using two stimulation sites. We found that the maximum stimulation intensity was 75 dB nHL. The frontal stimulations showed a good correlation of the results with the best reproducibility at 70 dB nHL. The current literature lacks precise recommendation for the stimulation level, with several intensities being used [6]. As reported by Rosengren et al., the characteristics of bone-conducted stimulation are less known compared to air-conducted stimulation, with no clear consensus [6]. Bhagat described the properties of oVEMPs using a 70 dB nHL bone-conducted stimulation but did not report why this intensity was chosen [12]. Therefore, our study is the first to establish 70 dB nHL as the optimal intensity for bone-conducted oVEMPs recordings using the Brüel and Kjaer mini-shaker type 4810. In the frontal stimulation, we found that the asymmetry ratio of the latencies was low (up to 7%) but could reach up to 50% for the amplitudes. These values are higher than those reported in the current literature. Curthoys et al. showed a normal amplitude asymmetry ratio of up to 40% [4]; more recent studies have reported a pathological amplitude asymmetry ratio of 31% [13,14]. Our results could be explained by the small number of our subjects, but our sample size was adequate to reliably detect significant differences (post-hoc study power of 0.87).

In order to optimize the frontal stimulation, we have designed a modified slit lamp holder that allowed the examiner's hands to be free. The idea of having a fixed support was already proposed by Todd et al. in 2008 [15]. These authors tested 4 healthy subjects on the mastoid using the shaker attached to a pulley system. In our study, the slit lamp holder not only fixed the patient's head, reducing muscle tension but also allowed the shaker to be positioned correctly on the patient's forehead in order to adjust the optimal pressure. In our clinic, we now routinely use the modified slit lamp holder that provides reliable results and makes the examination more comfortable.

Compared to frontal stimulation, mastoid stimulation displayed higher data dispersion and greater asymmetry ratios (up to 40% for latencies). This means that when the oVEMPs were elicited through mastoid stimulation, the latencies and amplitude data exhibited a wider range of values within each individual and a higher degree of asymmetry between the responses from the left and right utricles. In contrast, the frontal stimulation showed more consistent results with lower dispersion and asymmetry, making it a potentially more reliable method for recording oVEMPs. Although both stimulation sites yielded good results, we recommend using frontal stimulation for evaluating bone-conducted oVEMPs. The disadvantages of mastoid acquisition include the lack of optimal calibration for bone stimulation and the necessity for the examiner to hold the shaker manually.

With the current device, two separate acquisitions are required to measure the responses of both utricles. In this study, we observed that the contralateral wave of the first acquisition showed no statistical difference compared to the same utricle side measured by the Eclipse in the second acquisition. Our results support that a single stimulation in the frontal and mastoid sites would be sufficient to obtain reliable measurements of both utricles and would significantly reduce the examination time. This would require the use of software that could measure both utricles in the same acquisition time.

In terms of limitation, our study provides valuable insights into the optimal stimulation parameters for bone-conducted oVEMPs in normal subjects, but further research is needed to determine the efficacy and reliability of the proposed methods in patients with vestibular pathologies such as Menière's disease, vestibular neuritis, vestibular schwannoma and others. The absence of an artificial face system specifically designed for calibrating frontal stimulation rises a significant challenge. While there is an artificial mastoid device used for calibration, the lack of a dedicated calibration system for frontal stimulation could introduce variability in the results due to differences in patient morphology and frontal sinus anatomy. Lin et al. showed that larger frontal sinuses (> 1.91 mL) enhance oVEMP amplitudes, while sinus inflammation may reduce them [16]. Iwasaki et al. confirmed that despite anatomical differences, mastoid BCV reliably stimulates the utricle [17]. In our study, none of our participants had a history of rhinosinusitis. Although energy loss through soft tissues is likely in bone-conducted stimulation, the consistent application method used in our study, in particular the modified slit lamp holder, helped to minimize these effects. Finally, the mastoid stimulation required the examiner to hold the shaker in their hands, potentially introducing variability in the application of pressure and calibration of bone stimulation. This examiner-dependent factor could impact the reliability of the data.

5. Conclusion

Our study introduced a modified slit lamp holder that allowed the examiner to keep their hands free while using the bone vibrator for frontal stimulation. The recordings demonstrated the best reproducibility at 70 dB nHL. Both frontal and mastoid stimulations could be used to record bone-conducted oVEMPs, but frontal stimulation provided a more comfortable examination with lower data dispersion and a lower asymmetry ratio of latencies and amplitudes compared to mastoid stimulation. For both stimulation sites, a single stimulation appeared to be sufficient to obtain reliable measurements of both utricles. These findings suggest that frontal stimulation, with its improved comfort and reliability, may be preferable in clinical practice. Future research should focus on validating these findings in patients with vestibular disorders.

Disclosure of interest

The authors declare that they have no competing interest.

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Références

[1] Colebatch JG, Halmagyi GM. Vestibular evoked potentials in human neck muscles before and after unilateral vestibular deafferentation. Neurology 1992;42:1635–6.
[2] Colebatch JG, Halmagyi GM, Skuse NF. Myogenic potentials generated by a click-evoked vestibulocollic reflex. J Neurol Neurosurg Psychiatry 1994;57:190–7.
[3] Rosengren SM, Welgampola MS, Colebatch JG. Vestibular evoked myogenic potentials: past, present and future. Clin Neurophysiol 2010;121:636–51.
[4] Curthoys IS, Manzari L, Smulders YE, Burgess AM. A review of the scientific basis and practical application of a new test of utricular function – ocular vestibular-evoked myogenic potentials to bone-conducted vibration. Acta Otorhinolaryngol 2009;29:179–86.
[5] Rosengren SM, Aw ST, Halmagyi GM, Todd NP, Colebatch JG. Ocular vestibular evoked myogenic potentials in superior canal dehiscence. J Neurol Neurosurg Psychiatry 2008;79:559–68.
[6] Rosengren SM, Colebatch JG, Young AS, Govender S, Welgampola MS. Vestibular evoked myogenic potentials in practice: methods, pitfalls and clinical applications. Clin Neurophysiol Pract 2019;4:47–68.
[7] von Elm E, Altman DG, Egger M, Pocock SJ, Gøtzsche PC, Vandenbroucke JP. STROBE Initiative. Strengthening the Reporting of Observational Studies in Epi-

demiology (STROBE) statement: guidelines for reporting observational studies. BMJ 2007;335(7624):806–8.
[8] Driscoll C, Bekessy A, Bui V, Fox D, McCoy H, Mackenzie D. Vestibular evoked myogenic potentials: clinical implications of a normative investigation. Aust N Z J Audiol 2007;29:98–112.
[9] Shin BS, Oh SY, Kim JS, Kim TW, Seo MW, Lee H, et al. Cervical and ocular vestibular-evoked myogenic potentials in acute vestibular neuritis. Clin Neurophysiol 2012;123:369–75.
[10] Kantner C, Gürkov R. The effects of commonly used upward gaze angles on ocular vestibular evoked myogenic potentials. Otol Neurotol 2014;35:289–93.
[11] Ioannidis JPA. The proposal to lower P value thresholds to.005. JAMA 2018;319(14):1429–30.
[12] Bhagat SP. Properties of binaural vestibular evoked myogenic potentials elicited with air-conducted and bone-conducted tone bursts. Int J Audiol 2006;45:609–16.
[13] Wang MX, Su J, Zhang J, Xu Y, Guo Y, Zhou HF. The features of c/oVEMP in patient with unilateral Menière's disease. Lin Chuang Er Bi Yan Hou Tou Jing Wai Ke Za Zhi 2017;31:1504–7.
[14] Maheu M, Elblidi A, Saliba I. Investigating performance of cVEMP and oVEMP in the identification of superior canal dehiscence in relation to dehiscence location and size. Audiol Res 2021;11:452–62.
[15] Todd NP, Rosengren SM, Colebatch JG. Tuning and sensitivity of the human vestibular system to low-frequency vibration. Neurosci Lett 2008;444:36–41.
[16] Lin KY, Jaw FS, Young YH. Resonance effect of the frontal sinus on ocular vestibular-evoked myogenic potential recordings. Ear Hear 2021;42(5):1321–7.
[17] Iwasaki S, Smulders YE, Burgess AM, McGarvie LA, Macdougall HG, Halmagyi GM, et al. Ocular vestibular evoked myogenic potentials to bone conducted vibration of the midline forehead at Fz in healthy subjects. Clin Neurophysiol 2008;119:2135–47.