CLINICAL STUDY

FREQUENCY SHIFT FROM 500 HZ TO 1000 HZ IN CERVICAL VESTIBULAR EVOKED MYOGENIC POTENTIALS IN MENIERE'S DISEASES

Arzu KIRBAÇ PhD;[1], Büşra KAYNAKOĞLU PhD;[2], Ercan KAYA MD;[3], Şaziye Armağan İNCESULU MD;[3], Hülya ÖZEN PhD;[4]

[1]Eskişehir Osmangazi Üniversitesi, Odyoloji Bölümü, Eskişehir, Türkiye [2]Selçuk Üniversitesi Sağlık Bilimleri Fakültesi, Odyoloji Bölümü, Konya, Türkiye [3]Eskişehir Osmangazi Üniversitesi Tıp Fakültesi, Kulak Burun Boğaz Anabilim Dalı, Eskişehir, Türkiye [4]Sağlık Bilimleri Üniversitesi Gülhane tıp Fakültesi, Tıp Bilişimi Anabilim Dalı, Ankara, Türkiye

SUMMARY

Introduction: Cervical vestibular evoked myogenic potentials (cVEMP) are important in evaluating saccular function and the inferior vestibular nerve. During this test, measurements are routinely performed using a 500 Hz tone burst (TB) stimulus. This study aimed to determine how different stimulus frequencies affect cVEMP responses in Meniere's disease (MD).

Materials and Methods: Twenty-five adults (18-60 years) with unilateral definite MD were included in the study. Individuals were evaluated by otological-examination, conventional-audiometry, and the cVEMP using 500 Hz and 1000 Hz TB stimuli. The presence and amplitudes of P1-N1 waves at 500 and 1000 Hz were compared between healthy and affected ears.

Results: In individuals with MD, 96% of affected ears had abnormal cVEMP responses at 500 Hz and 68% at 1000 Hz. 1000 Hz P1-N1 amplitude was significantly higher in affected ears, whereas 500 Hz P1-N1 amplitude was higher in healthy ears ($p<0.001$). According to ROC (receiver operating characteristic) analysis, wave amplitudes ≤ 61µV at 500 Hz and ≤ 44.5µV at 1000 Hz in the cVEMP test favour MD. The area under the ROC curve was 0.995 for 500 Hz cVEMP and 0.769 for 1000 Hz cVEMP ($p<0.001$).

Discussion and Conclusions: The higher P1-N1 amplitude at 1000 Hz compared to 500 Hz in the affected ears of individuals with MD showed that the cVEMP test in MD shifts towards high-frequency stimuli. According to these data, evaluating individuals with 1000 Hz stimulus in addition to 500 Hz stimulus in the cVEMP test is useful for the diagnosis and follow-up of MD.

Keywords: Meniere's disease, cVEMP, Frequency shift, Acoustic stimuli, 500 Hz, 1000 Hz

MENİERE HASTALIĞINDA SERVİKAL VESTİBÜLER UYARILMIŞ MİYOJENİK POTANSİYELLERDE 500 HZ'DEN 1000 HZ'E FREKANS KAYMASI

ÖZET

Giriş: Sternocleidomastoid kası üzerinden yüzey elektrotlarla kaydedilen servikal vestibüler uyarılmış miyojenik potansiyeller (cVEMP), sakküler fonksiyon ve inferior vestibüler sinirin değerlendirmesinde önemli bir yere sahiptir. Bu test sırasında rutinde 500 Hz tone burst (TB) uyaran kullanılarak ölçümler yapılmaktadır. Bu çalışmada Meniere hastalığında (MH) farklı uyaran frekanslarının cVEMP yanıtlarını nasıl etkilediğinin belirlenmesi amaçlanmıştır.

Yöntemler ve Gereçler: Çalışmaya tek taraflı kesin MH tanısı almış 25 yetişkin (18-60 yaş, ortalama 44,4 ± 10,1 yıl) dâhil edilmiştir. Her birey otolojik muayene, konvansiyonel odyometri, 500 Hz ve 1000 Hz TB uyaranların kullanıldığı hava iletim cVEMP testi ile değerlendirilmiştir. Sağlıklı ve etkilenmiş kulaklar arasında 500 ve 1000 Hz' de P1-N1 dalgalarının varlığı ve amplitüdleri karşılaştırılmıştır.

Bulgular: MH olan bireylerde etkilenmiş kulakların % 96'sı 500 Hz'de, % 68'i 1000 Hz'de anormal cVEMP yanıtlarına sahipti. 1000 Hz P1-N1 dalga amplitüdü etkilenmiş kulaklarda anlamlı derecede yüksekken ($p<0,001$), 500 Hz P1-N1 dalga amplitüdü sağlıklı kulaklarda daha yüksek bulunmuştur. ROC analizine (receiver operating characteristic) göre cVEMP testinde dalga amplitüdünün 500 Hz' de ≤ 61µV ve 1000 Hz' de ≤ 44,5µV elde edilmesi, MH lehine bir bulgudur. ROC eğrisi altında kalan alan değeri 500 Hz cVEMP'de 0,995 ve 1000 Hz cVEMP'de 0,769 olarak belirlenmiştir ($p<0,001$).

Tartışma ve Sonuçlar: MH olan bireylerin etkilenmiş kulaklarında 1000 Hz ile elde ettiğimiz P1-N1 dalga amplitüdünün 500 Hz'e kıyasla daha yüksek olması, MH'de cVEMP testinde yüksek frekans uyaranlara doğru bir kaymanın olduğunu göstermiştir. Bu verilere göre, cVEMP testinde 500 Hz TB uyarana ek olarak, hastaların 1000 Hz TB uyaran ile değerlendirilmesi, MH'nin tanı ve takibi için fayda sağlamaktadır.

Anahtar Sözcükler: Meniere hastalığı, cVEMP, Frekans kayması, Akustik uyaran, 500 Hz, 1000 Hz

INTRODUCTION

Cervical vestibular evoked myogenic potential (cVEMP) is an electromyogram (EMG) recording. An electrical signal transmitted by the inferior vestibular nerve allows sternocleidomastoid (SCM) muscle to produce a substantial, short-latency inhibitory potential in response to high-intensity stimulation of the saccule (with stimuli such as a click or tone burst/TB). Biphasic waveforms have a positive peak at the beginning and a negative peak at the end of the cVEMP response, produced after stimulation[1]. Although cVEMP is the basic electrophysiological test that objectively evaluates saccular function, the best responses in healthy individuals are obtained using a 500 Hz

Corresponding Author: Arzu KIRBAÇ PhD. Eskişehir Osmangazi Üniversitesi, Odyoloji Bölümü, Eskişehir, Türkiye, E-mail: arzukirbac@gmail.com

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TB stimulus[2]. Dabbous et al. reported that in healthy adults, cVEMP responses were more frequently elicited at 500 Hz[3]. Furthermore, a study examining the effects of 250, 500, 1000, and 2000 Hz stimulus frequencies reported higher-amplitude cVEMP responses with a 500 Hz stimulus[4].

MD is a chronic inner ear illness[5]. Endolymphatic hydrops (EH) is the pathophysiology of disease[6]. Although post-mortem temporal bone studies have demonstrated saccular dysfunction due to EH in MD[7,8], it is difficult to perform such an evaluation in vivo. In addition, magnetic resonance imaging (MRI) studies have provided inconsistent findings concerning the percentage of EH in MD[9,10]. On the other hand, although there is no reliable oto-neurological test specific to MD that can measure saccular dysfunction, cVEMP has recently been used to assess individuals with MD in clinical practice[11].

Saccular function has been attempted to be evaluated with cVEMP in patients with MD; however, pathological results reported in the literature vary in an extensive range[12,13]. For example, the rate of abnormal results was reported to be 54% by De Waele et al.[14] and 96% by Seo et al.[15]. Studies with cVEMP have generally detected decreased amplitudes, prolonged latency, and absent responses in late-stage cases of MD[16]. Many factors, such as stimulus frequency, can cause inconsistent results[17]. In addition to authors recommending the use of a 500 Hz TB stimulus in MD[18,19], there are also those proposing that higher frequencies, such as 1000 Hz, should be used in this patient group, considering that hydrops-based saccular dilatation may increase the resonance frequency[20]. However, it remains unclear which frequency stimulus is more specific to MD.

This study aimed to compare cVEMP responses obtained with 500 and 1000 Hz TB stimuli in subjects with unilateral definite MD.

MATERIAL and METHODS

Twenty-five adults diagnosed with unilateral definite MD, according to the Barany Society[21] were included in the study. Written informed consent was obtained from all the patients.

Healthy (asymptomatic) ears were used as the control group, while the ears with MD (symptomatic ears) were used as the case group. Patients with systemic diseases (diabetes, hypertension, etc.), ototoxic drug use (loop diuretics, etc.), a history of ear surgery, and medical (diuretics, vestibule-suppressants, etc.) and intratympanic treatment were excluded from the study. Further excluded were individuals with air bone gaps in the audiogram, considering the effect of cVEMP amplitudes on middle ear pathologies[22], as well as those with hearing loss, tinnitus, or aural fullness symptoms in healthy ears.

Otological examination, conventional audiometry, and cVEMP testing were used to assess each patient. The active period in MD was accepted as seven days after a vertigo attack occurs. We applied the tests during the inactive period.

Air conduction thresholds at 0.25-8.0 kHz, followed by bone conduction hearing thresholds at 0.5-4 kHz, were determined by an audiometer. Average pure tone average (PTA) was calculated at the 0.5, 1, 2, and 3 kHz AC thresholds. Based on the PTAs, the cases were staged according to the MD classification of the AAO-HNS as follows: stage I, PTA of less than 26 dB; stage II, 26-40 dB; stage III, 41-70 dB; and stage IV, more than 70 dB. The presence of a type A tympanogram and the absence of an air-bone gap in the audiogram were accepted to indicate normal middle ear function. All patients had sensorineural-type hearing loss only in the affected ears.

In the cVEMP test, the reference electrode was positioned on the middle 1/3 of the SCM, the active electrode was positioned near the sternum of the SCM tendons, and the ground electrode is positioned on the patient's forehead. Before placing the electrodes, the skin tissue was cleaned with a skin cleansing gel. The electrode impedance did not exceed 5 kOhm and that the resistance difference between the electrodes did not exceed 3 kOhm. During cVEMP testing, the patient was asked to turn his/her head to the opposite side of the stimulated ear in the sitting position to activate the SCM muscle. EMG monitoring was performed to ensure equal contraction activity in each patient. The tonic EMG level was evaluated with a VEMP monitor,

and the intensity of muscle contraction was equalized bilaterally. During the test, the EMG monitor was kept in a position visible to the patient, and the amount of contraction was confirmed to be within the desired range. This procedure was repeated for both ears while cVEMP responses were recorded. At the frequencies of 500 and 1000 Hz, a TB stimulus with negative (rarefaction) polarity and the Blackman envelope (rise/fall time = 2 cycles, plateau time = 0 cycles) at an intensity level of 100 dB nHL was sent through an insert earphone to obtain a monaural response. The responses were amplified with band-pass filtering in the range of 10 Hz -750 Hz and recorded 200 times by averaging. The stimulus rate was taken as 5.1 s. cVEMP responses were obtained after monaural stimulation. The first potentials were a positive peak (P1) and a negative peak (N1). The presence of P1-N1 waves at 500 and 1000 Hz and the amplitudes of the waves, if present, were compared between the healthy and affected ears.

Statistical Methods

Data analysis was employed with SPSS 25.0 and R Studio (version: 2023.09.1+494). Descriptive statistics of quantitative variables were shown as mean ± standard deviation, while qualitative variables were presented as count and percentages. Normality of quantitative variables was evaluated with Shapiro Wilk test. Comparisons of P1-N1 wave amplitudes values between and within symptomatic and asymptomatic ears were performed with paired samples t test. Association between quantitative variables was evaluated with Spearman correlation analysis. Mc Nemar analysis was conducted to assess differences on dichotomous dependent variables between two related methods. The receiver operating characteristic (ROC) curve was used to evaluate the predictive performance of the stimulus values. The area under the ROC curve (AUC) was used to assess the overall discriminatory ability of the stimulus values. The optimal cut-off values for the methods were determined using the Youden index. The sensitivity and specificity values with respect to the proposed cut-off values were reported. Comparison of the predictive performance of two ROC curves was conducted with DeLong test using R package "pROC". P values less than 0.05 were considered significant.

RESULTS

Twenty-five subjects with unilateral definite MD (17 women, eight men; mean age, 44.4 ± 10.1 years, range, 23-60 years) were evaluated. The mean age was 42.05 ± 9.6 years among women and 49.3 ± 10 years among men. There was no difference in the mean age according to gender ($p = 0.094$). The mean duration of MD was 39 (range, 5-180) months.

P1-N1 waves were obtained in eight of the 25 MD ears with the 500 Hz TB stimulus (normal amplitude in one and low amplitudes in seven) and in twenty-two ears with the 1000 Hz TB stimulus (normal amplitudes in eight and low amplitudes in 14), while no response was obtained in three ears with MD with either stimulus (Table 1). Ninety-six percent (24/25) of the 25 ears with definite MD had abnormal cVEMP responses (no or low-amplitude P1-N1 waves) at 500 Hz, while 68% had abnormal responses at 1000 Hz (17/25).

The asymptomatic (healthy) ears showed normal PTA levels, while the ears with MD had a 44.8-decibel hearing level. The difference in hearing thresholds between the healthy and MD groups was significant ($p < 0.05$). According to the audiometric examination, none of the ears with MD had air-bone gaps, and all these ears had sensorineural-type hearing loss. Concerning the severity of hearing loss, 13 cases of MD were stage II (26-40 dB), and 12 were stage III (41-70 dB). Among the ears with stage II MD, there were abnormal P1-N1 responses at 500 Hz in 12/13 (92.3%) and at 1000 Hz in 7/13 (58.3%). In the stage III MD group, abnormal P1-N1 responses were obtained at 500 Hz in 12/12 (100%) and 1000 Hz in 10/12 (83.3%) of the ears. All healthy ears had a P1-N1 response to both stimuli (Figure 1).

On the symptomatic side, there was no relationship between PTA and 500 Hz wave amplitude, while there was a moderate, negative, significant relationship at 1000 Hz. In other words, as hearing loss increased, only the 1000 Hz P1-N1 wave amplitude decreased. Hearing loss was not associated with disease duration ($p = 0.693$). There was a moderate, negative, significant correlation between the duration of MD and the amplitude of P1-N1 waves obtained with both stimuli. As the duration of the disease

increased, the wave amplitude decreased (Table 2).

Although the P1-N1 wave amplitudes were significantly higher at 1000 Hz than at 500 Hz in ears with MD ($p < 0.001$), lower amplitudes were found in this group for both stimuli ($p < 0.05$). On the other hand, the P1-N1 wave amplitude at 500 Hz was higher among the healthy ears (Table 3 and Figure 2).

There was a moderate, negative correlation between age and P1-N1 wave amplitudes at 500 Hz ($r = -0.525$, $p = 0.007$) and 1000 Hz ($r = -0.427$, $p = 0.033$). The wave amplitudes decreased with increasing age.

ROC curves were constructed to assess the accuracy of the two stimuli and confirm the best cut-off point for MD. According to the results of this analysis, the cut-off value was 61 µV at 500 Hz and 44.5 µV at 1000 Hz. In other words, the cVEMP test successfully predicted MD when the amplitude was ≤ 61 µV at 500 Hz and ≤ 44.5 µV at 1000 Hz (Table 4 and Figure 3).

The area under the ROC curve value was 0.995 at 500 Hz cVEMP and 0.769 at 1000 Hz cVEMP ($p < 0.001$) (Table 5).

Table 1. cVEMP responses (P1-N1 waves) obtained with 500 Hz and 1000 Hz stimuli in ears with MD

		1000 Hz		p
		Absent	Present	
500 Hz	Absent	3	14	**<0.001[a]**
	Present	0	8	

a: Mc Nemar test

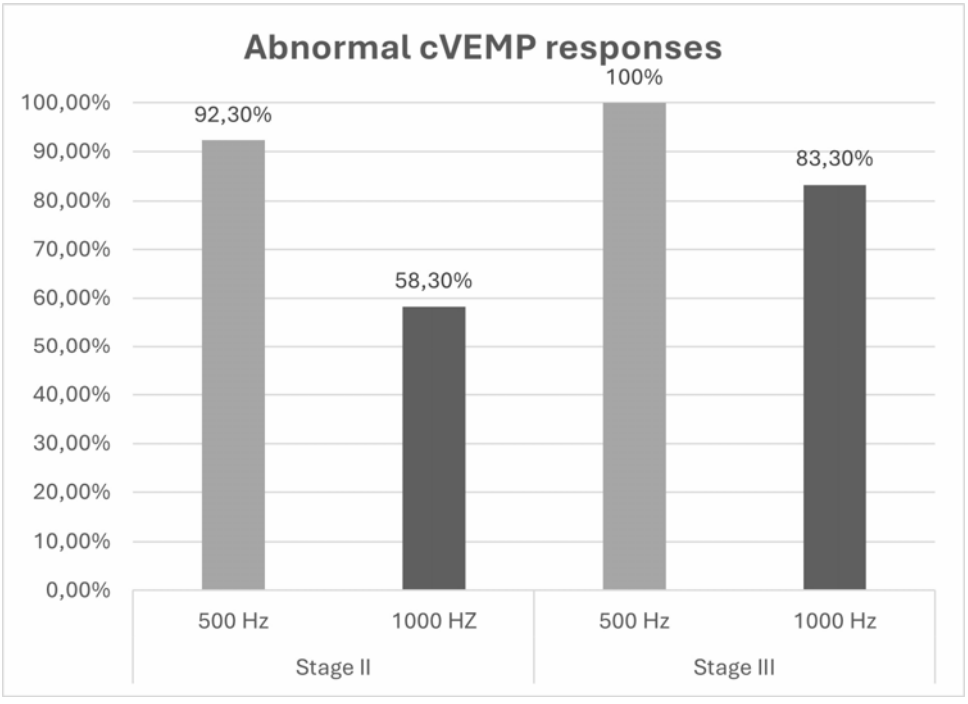

Figure 1: *Abnormal cervical vestibular evoked myogenic potential (cVEMP) responses according to Meniere's disease stage (P1-N1 waves)*

Table 2. Correlation analysis of disease duration and PTAs with P1-N1 amplitudes in ears with MD*

		PTA	500 Hz amplitude	1000 Hz amplitude
Disease duration (month)	r	0.083	-0.498	-0.654
	p	0.693	**0.011**	**<0.001**
PTA (dBHL)	r		-0.183	-0.504
	p		0.382	**0.010**

** Spearman correlation analysis*

PTA: pure tone average, MD: Meniere's disease, dBHL: decibel hearing level

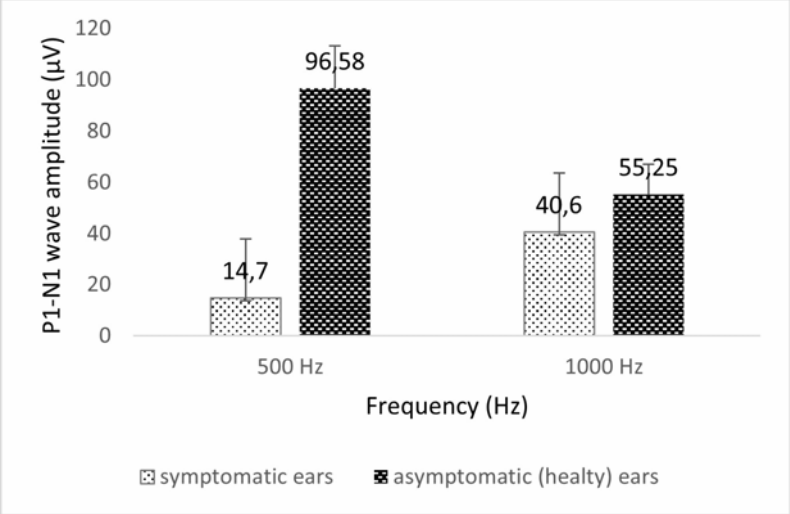

Figure 2: *P1-N1 wave amplitudes of symptomatic and asymptomatic ears*

Table 3. Comparison of P1-N1 wave amplitudes obtained with 500 Hz and 1000 Hz stimuli within and between symptomatic and asymptomatic ears

	Frequency	Symptomatic Ears	Asymptomatic Ears	P
P1-N1 wave amplitude	500 Hz	14. 70 ± 23. 31	96. 58 ± 16. 68	**<0.001**
(µV)	1000 Hz	40. 60 ± 22. 94	55. 25 ± 11. 73	**0.010**
P		**<0.001**	**<0.001**	

All comparisons were performed with paired t test

Table 4. Predictive performance of the applied stimuli for Meniere's disease

Stimulus	Cut-off point (µV)	Sensitivity	Sensitivity 95% CI	Specificity	Specificity CI
500 Hz	≤61	0.96	0.79-0.99	1.00	0.86-1.00
1000 Hz	≤44.5	0.68	0.46-0.85	0.88	0.68-0.97

CI: confidence interval, *Cut-off points were proposed using Youden index*

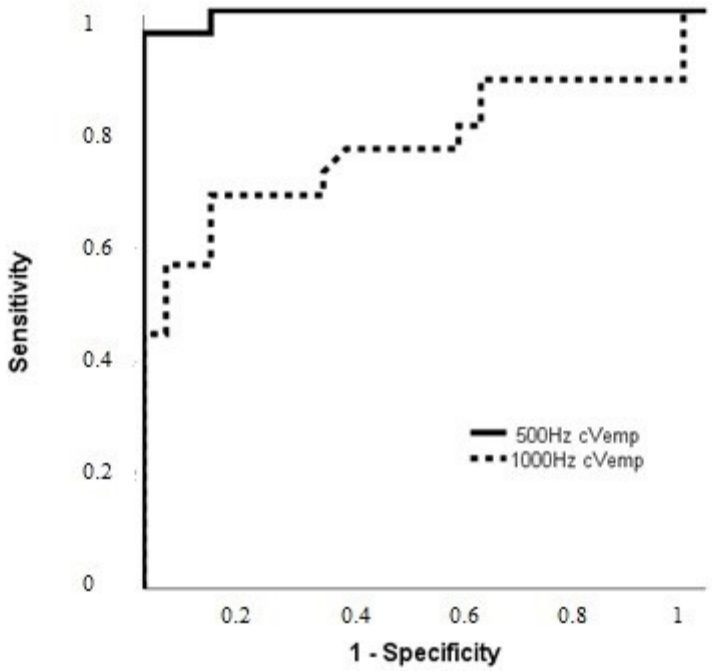

Figure 3: *Receiver operating characteristic (ROC) curves of cervical vestibular evoked myogenic potentials (cVEMP) at 500 Hz and 1,000 Hz*

Table 5. Differentiation between symptomatic and asymptomatic ears at 500 Hz and 1000 Hz in cervical vestibular evoked myogenic potential testing

	AUC	**Standard error**	**p**
500 Hz	0.995	0.010	**<0.001[a]**
1000 Hz	0.769	0.067	

AUC: area under the ROC curve; *a: DeLong test*

DISCUSSION

MD is a common inner ear disease, but its diagnosis has always been confusing due to non-specific symptoms in the early stages, the fluctuating course of the disease, difficulty distinguishing it from other inner ear diseases, and a lack of specific tests[23]. Although postmortem histological studies have proven that the cochlea and vestibular organs are affected by EH in MD, it is not easy to detect these effects in routine examinations[7,24]. In other words, the most important reason why individuals with hearing and balance loss are often diagnosed with MD is the lack of diagnostic tests for this disease[23]. Although the use of cVEMP in MD has recently become widespread, more specific stimuli have not been fully determined[2,25,26]. This study aimed to compare cVEMP responses obtained with 500 and 1000 Hz TB stimuli in individuals with unilateral definite MD.

In our study, 500 Hz and 1000 Hz cVEMP responses were obtained from all healthy ears, and the 500 Hz wave amplitude was higher in these ears. Fu et al. investigated four different frequencies (250, 500, 1000, and 1,500 Hz) and reported that the highest amplitude from TB stimuli was obtained at 500 Hz in healthy adults[17]. Other studies presented similar results[19,27]. There is a consensus in the literature that the largest amplitude response is obtained at 500 Hz in healthy ears, which is also supported by our findings. On the symptomatic side, we obtained significantly lower amplitudes than healthy ears with both stimuli. However, in contrast to the healthy side, the ears with MD had the largest amplitudes at 1000 Hz in cVEMP. Sandhu et al. reported a shift in frequency sensitivity from 500 Hz to higher frequencies in the cVEMP test only in subjects with definite MD but not in those with probable MD or healthy controls[28]. The high amplitudes we obtained at 1000 Hz are in agreement with previous studies reporting a shift toward higher frequencies in MD in cVEMP testing[19,20,29]. Jerin et al. suggested that EH might increase stiffness, thus reducing low-frequency conduction in the inner ear[30]. This can help to explain the larger amplitudes are observed at higher frequencies in individuals with MD. In addition, these tuning shifts from 500 to 1000 Hz reflect mechanical adjustments caused by EH and can be measured using various amplitude slope/ratio calculations[31]. Maxwell et al. reported that the 500 Hz/1000 Hz cVEMP amplitude ratio was a consistent indicator of MD[32]. This amplitude rate, known as the tuning property test (TPT), was determined by discovering that the optimal cVEMP frequency changes in MD patients[19]. Murosfoni et al. also examined the relationship between the cVEMP TPT results and MRI findings in patients with unilateral definite or probable MD. The authors reported that the cVEMP TPT test results were significantly correlated with gadolinium-enhanced inner ear MRI findings. They also suggested that the cVEMP TPT was useful for EH screening and follow-up[33]. However, cVEMP responses are generally not obtained from ears with MD using 500 Hz TB stimuli[15]. It is not possible to apply this formula without measuring the 500 Hz response amplitude. In our study, we did not obtain cVEMP responses at 500 Hz in 17 (68%) of the 25 ears with MD and at 1000 Hz in three (12%) ears. Due to the absence of a 500 Hz cVEMP response in most ears with MD, we were not able to calculate the amplitude rate. The TPT can only be performed when both 500 and 1000 Hz responses are obtained; therefore, this evaluation is not feasible in all cases of MD.

MD is described as having vertigo, fluctuating hearing loss, ear fullness and tinnitus. Mild and sensorineural hearing loss affects low frequencies in the early stages, while the degree of loss increases in the late stages and affects all frequencies, resulting in a flat hearing curve. Tinnitus is initially in the form of a humming sound and low tones. Tinnitus increases with worsening hearing, and it fluctuates in MD[34]. Symptoms in the early stages of MD may disappear for a while or even permanently, but symptoms in the late stages of MD are permanent. Significantly, permanent damage to the inner ear is associated with hearing loss due to the degree of complete loss of labyrinthine function, but not with vertigo attacks[23]. The physiopathological process explaining the clinical findings of MD is associated with damage to the membranous labyrinth. The two parts of the membranous labyrinth that are

vulnerable to EH are the saccule and Reissner's membrane, and expansion is especially observed in these two structures[25,34,35]. EH is usually located in the pars inferior (cochlea and saccule). The saccule is the most common location for EH to occur after the cochlea in MD[11,24]. Responses on the VEMP test are related to the MD stage. Normal, augmented or slightly decreased cVEMP amplitude due to a dilated saccule (depending on the degree of dilatation) in the early stage of MD[36] and the complete disappearance of the cVEMP response as a result of saccular membrane rupture with increasing hydrops in the later period reflect a permanently affected saccule response[37,38]. In studies, abnormal (decreased or absent waveform) cVEMP responses vary widely in patients with MD. While De Waele et al. reported 54% abnormal responses in MD[14], Seo et al. reported this rate to be much higher at 96%[15]. Predictably, the altered mechanics of a swollen saccule due to hydrops would lead to an altered cVEMP result in MD. cVEMP measurements after and during MD episodes may be an important reason for the discrepancies between studies. Kharkheli et al. reported different cVEMP responses to the 500 Hz TB stimulus at different stages of MD[39]. Kuo et al. found no response in 67% of the ears with MD in 500 Hz TB cVEMP recordings taken during the active period of the disease[40]. Kırbaç et al. evaluated 16 ears with unilateral definite MD during the inactive period using 500 Hz TB stimulus and detected abnormal responses at a rate of 81.3% (13/16 ears)[41]. In our study, the cVEMP response was abnormal in 96% (24/25 ears) of the ears with MD at 500 Hz and in 68% of the ears at 1000 Hz during the inactive period of MD. The duration of MD ranged from five to 180 months, and there was a significant decrease in 500 Hz and 1000 Hz cVEMP amplitudes with increasing disease duration. In contrast, disease duration was not correlated with hearing loss. These data (especially 500 Hz cVEMP responses) confirm that MD's saccular function is significantly affected.

When we classified the ears with MD according to the severity of hearing loss, 500 Hz responses were abnormal in 92.3% of the ears with stage II (26-40 dB) MD, representing milder hearing loss, and in 100% of those with stage III (41-70 dB) MD, where there is increased hearing loss. At 1000 Hz, 58.3% of the ears with stage II MD and 83.3% of those with stage III MD had abnormal responses. While there was no significant difference in 500 Hz cVEMP test results according to the MD stages evaluated based on the severity of hearing loss, the abnormality rate of 1000 Hz cVEMP responses increased significantly as hearing loss, i.e., the MD stage, progressed. In other words, the severity of hearing loss and MD stage were important parameters for 1000 Hz responses. Similar to our study, Rauch et al. showed that a reduction in amplitude or the absence of cVEMP response at 500 Hz TB stimulus was unrelated to ipsilateral audiometric thresholds[19]. On the contrary, Young et al., who examined 500 Hz cVEMP responses in unilateral MD, reported a positive correlation between MD stages and abnormal responses[42].

The current study revealed decreased cVEMP amplitudes with both stimuli with increasing age. Consistently, Jankly and Shepard reported that VEMP test response decreased with increasing age[43]. This may be due to muscle atrophy and decreased muscle strength in older adults. cVEMP amplitudes begin to decline at the age of 60 years[3,44]. In the current study, to exclude the effect of age on cVEMP amplitudes, the maximum age limit of the participants was set at 60.

In our study, the optimal cut-off value of the P1-N1 wave amplitude was determined to be ?61 uV for the 500 Hz stimulus and ?44.5 for the 1000 Hz stimulus. Results below these values strengthen the possibility that the evaluated ear has MD. cVEMP amplitudes at 500 Hz were very good at distinguishing the ears with MD from healthy ears, with an area under the curve value of 0.995 and sensitivity and specificity values of at least 96% and 100%, respectively. However, 1000 Hz amplitudes were less effective in this differentiation. Similarly, Noij et al. reported higher AUC values at 500 Hz than at 1000 Hz. In that study, 500 Hz was determined to be the best frequency to distinguish between the amplitude groups (area under the curve: 0.846 for 500 Hz and 0.762 for 1000 Hz)[22].

Although cVEMP is among the methods frequently used in MD, the stimuli employed during this test show differences among studies. Considering factors such as the ability of cVEMP to distinguish ears with MD from healthy ears (99.5% at 500 Hz, and 76.9% at1000 Hz), the abnormality rate we obtained from symptomatic ears (96% at 500 Hz and 68% at 1000 Hz), and the relationship between MD stage and cVEMP responses (abnormal responses at 500 Hz even in the early disease stage), it can be stated that the 500 Hz TB stimulus in the AC cVEMP test reveals saccular involvement more reliably in the current study. On the other hand, we obtained the highest P1-N1 wave amplitudes at 1000 Hz in ears diagnosed with definite MD.

In conclusion, our study findings have shown that there is a shift towards high frequency stimuli in the cVEMP test in MD. In light of the findings of the study, we recommend the combined use of low-frequency (500 Hz) and high-frequency (1000 Hz) TB stimuli in cVEMP testing in the diagnosis and follow-up of MD. There is no specific test for Meniere's disease, but in MD, which is diagnosed by clinical findings, there are tests to assist in the diagnosis and follow-up. In addition to the 500 Hz TB stimulus in the cVEMP test, evaluating patients with suspected MD with the 1000 Hz TB stimulus will be beneficial in clinical use for diagnosing and following MD. 1000 Hz cVEMP testing alone is not considered sufficient for MD's diagnosis and follow-up, but it can be used as an important component of a test battery.

The main limitation of this study concerns the use of asymptomatic ears as a control group. Including a control group of healthy individuals in future studies may provide more useful findings.

Ethical approval

Ethical approval for this study was obtained from the Non-Pharmaceutical and Non-Medical Device Research Ethics Committee (approval number: 12) and completed in conformity with the standards set by the Declaration of Helsinki.

Conflict of interest

There are no conflicts of interest, financial or otherwise.

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Author's Note:

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