Research Article

Evaluation of Otolithic Function in Patients with Unilateral Ménière's Disease Using Video Ocular Counter-Roll Test

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Abstract

Background: There is a need for more laboratory tests in the diagnosis of Ménière's disease (MD).

Purpose: The adequacy of the findings of the video ocular counter-roll reflex (OCR) test to support the diagnosis of patients with unilateral MD in the nonattack period was investigated.

Research Design: Hearing tests, ocular and cervical vestibular evoked myogenic potential (VEMP), Dizziness Handicap Inventory, and video OCR tests were performed on 31 patients with unilateral MD and 30 healthy controls, and the findings were compared.

Study Sample: There were 10 males and 21 females (51.22 ± 12.76 years) in the MD group and 12 males and 18 females (46.43 ± 9.98) in the control group.

Data Collection and Analysis: The significance of the difference between groups was analyzed using the Mann–Whitney *U* test for continuous data and the chi-squared test for categorical data. OCR degrees in the MD group were analyzed using the Wilcoxon test. A correlation matrix and intraclass correlation coefficients were also calculated to analyze the test–retest reliability of OCR degrees with the participant's head tilted at 15, 30, and 40°.

Results: In the ocular VEMP test, the N1–P1 amplitudes of both ipsilesional ($p < 0.001$) and contralesional ears ($p = 0.015$) were significantly lower in the MD group than in the control group. In the cervical VEMP test, the P1–N1 amplitudes of the ipsilesional ($p < 0.001$) and the contralesional sides ($p = 0.006$) were significantly lower in the MD group than in the control group. The OCR degrees did not show a significant difference between the MD and control groups, except for the 30th-second OCR degree of the right eye when the head was tilted 30° to the ipsilesional side ($p = 0.031$) and the 20th-second OCR degree of the right eye when the head was tilted 40° to the ipsilesional side ($p = 0.036$).

Conclusions: The video OCR (vOCR) test did not discriminate between the pathological and nonpathological ears in patients with unilateral MD during a nonattack period. Furthermore, the vOCR results did

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not discriminate between the patients with unilateral MD and the healthy controls. To obtain consistent vOCR degrees a head tilt of at least 30° and a recording time of at least 40 seconds may be required.

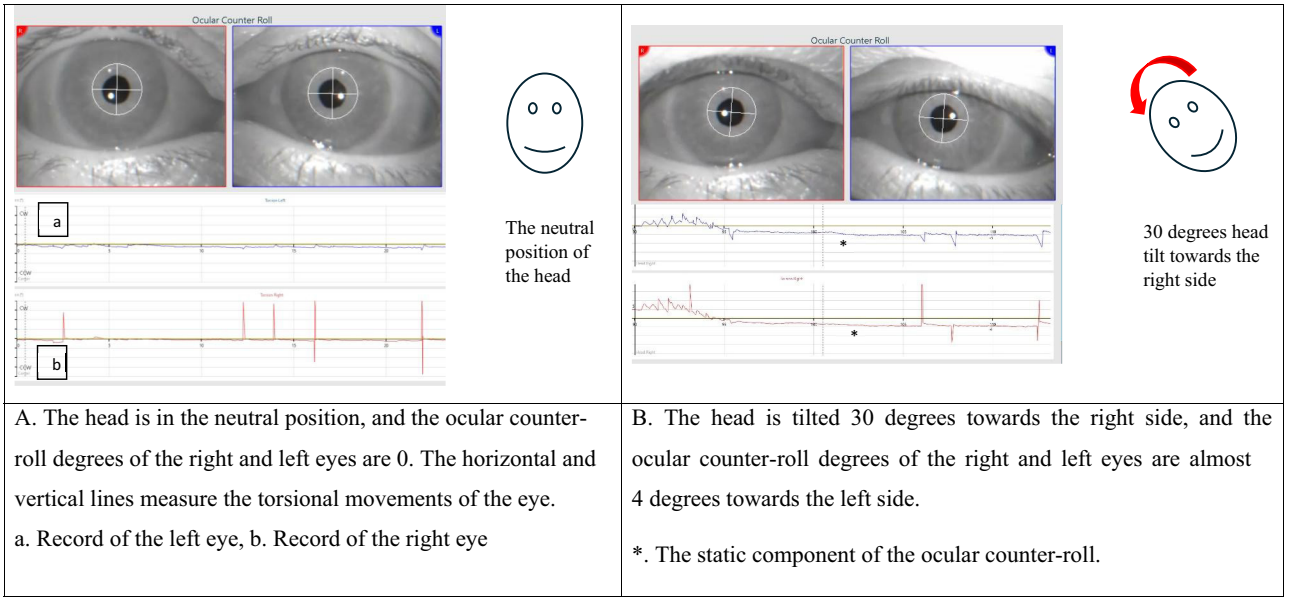
Key Words: Ménière's disease, ocular counter-roll, ocular vestibular evoked myogenic potentials, cervical vestibular evoked myogenic potentials

Abbreviations: cVEMP = cervical vestibular evoked myogenic potential; DHI = Dizziness Handicap Inventory; MD = Ménière's disease; OCR = ocular counter-roll reflex; oVEMP = ocular vestibular evoked myogenic potential; VEMP = vestibular evoked myogenic potential; vHIT = video head impulse test; VN = vestibular neuronitis; vOCR = video ocular counter-roll reflex; VOR = vestibulo-ocular reflex

INTRODUCTION

Ménière's disease (MD) affects the saccule, cochlea, utricle, and semicircular canals and is characterized by fluctuating hearing loss, vertigo with neurovegetative symptoms, tinnitus, and a sensation of fullness in the ear (Oku et al, 2003). These fluctuating and progressive symptoms may decrease the patient's quality of life.

The vestibular system generates vestibular reflexes that are critical for maintaining balance by sensing angular and linear head movements and gravity. One of these reflexes, the vestibulo-ocular reflex (VOR), which allows one to see the environment as the head moves, occurs through the reflex arcs between the vestibular sensors and the oculomotor muscles (Dalmaijer, 2018). The semicircular canals are responsible for forming the angular VOR, and the otolith organs (mainly the utricle) are responsible for forming the linear and torsional VOR (Oh et al, 2021). The linear VOR stabilizes horizontal eye movements during lateral translational movements of the head or body. The torsion of the eyes in the opposite direction of lateral head tilt is the ocular counter-roll reflex (OCR), and the gain of this reflex (static component) is approximately 10–25 percent of the angle of head tilt (Otero-Millan et al, 2017). The OCR has dynamic and static components. The dynamic component (approximately the first 5 seconds) occurs during head tilt, and the semicircular canals are responsible for this part. After the dynamic component, the static component (after the first 5 seconds) of the OCR occurs when the head reaches the target degree and is stable (Figure 1). The otolith organs (mainly the utricle) are responsible for this part. Previous studies have reported that the gains of the static component of OCR in patients with unilateral and bilateral peripheral vestibular loss or motion sickness were significantly affected by pathology, reliably confirming vestibular involvement (Schmid-Priscoveanu et al, 1999; Oliva Dominguez et al, 2010; Otero-Millan et al, 2017; Kitajima and Sugita-Kitajima, 2021; Sugawara et al, 2021). In addition, a decrease in ipsilateral OCR gain was found immediately after deafferentation in astronauts exposed to a nongravitational environment (Clément et al, 2007). OCR testing is performed with various devices such as a scleral search coil, video-oculography, and video head impulse



A. The head is in the neutral position, and the ocular counter-roll degrees of the right and left eyes are 0. The horizontal and vertical lines measure the torsional movements of the eye.
a. Record of the left eye, b. Record of the right eye

B. The head is tilted 30 degrees towards the right side, and the ocular counter-roll degrees of the right and left eyes are almost 4 degrees towards the left side.

*. The static component of the ocular counter-roll.

Figure 1. The video ocular counter-roll test screen of a patient with right unilateral Ménière's disease.

camera or observation without equipment. There is no standard protocol, and OCR is recorded at different degrees of head tilt and recording times. Currently, no OCR results have been reported in patients with unilateral MD. The search coil technique is defined as the gold standard in recording horizontal and vertical movements; however, this definition is not valid for torsional movements of the eye. Measurement deficiencies due to slippage of the contact lens or search coil were previously reported as a disadvantage in torsional motion recording with the search coil. The video OCR (vOCR) technique is included in the videonystagmography and is easy, practical, quick, and reliable (Otero-Millan et al, 2015).

This study had three objectives. The first was to compare the OCR functions of patients with unilateral MD to those of healthy subjects. The second was to define the optimal conditions for using the vOCR test. The third was to analyze the relationship between vOCR and vestibular evoked myogenic potential (VEMP) tests.

MATERIALS AND METHODS

After obtaining ethics committee approval (Istanbul Göztepe Training and Research Hospital Local Ethics Committee, No. 2022/0095; date February 23, 2022), 31 patients with unilateral MD (Lopez-Escamez et al, 2015) and 30 healthy controls without vestibular symptoms were evaluated by vOCR (Interacoustics, Visual Eyes™, Micromedical Videonystagmography, Denmark), ocular and cervical VEMP (oVEMP and cVEMP, respectively) (Chartr EP 200, Otometrics Natus Medical, Denmark), and pure tone and speech audiometry (Madsen Astera 2, Clinical Audiometer, Natus Medical, Denmark) after otoscopic examination. The Turkish version of the Dizziness Handicap Inventory (DHI) was used for the subjective assessment of vestibular symptoms (Karapolat et al, 2010). Written informed consent was obtained from all participants. All vestibular tests were performed by the same audiologist (BM). For vOCR and VEMP tests, an ear-nose-throat exam chair (the height of the chair was adjustable and the head support was removed) was used. The vOCR tests were performed using the OCR module of a videonystagmography device. During the vOCR test, the participant sat upright at a distance of 135 cm from the plasma display, and the height of the patient's head was adjusted to approximately 145 cm (so the clinician could more easily control the head movements of participants). The room was well-lit, and the lid of the goggles was open. Before the vOCR test, participants were informed about the test and told to keep their trunks upright and necks relaxed. The video goggles and headband were fixed to the participant's face and head. The clinician stood behind the chair. Eye movement calibrations were performed in the horizontal, vertical, and torsional planes. Because the device did not have a head movement measurement module, the level tool of the measurement app of the iPhone™ (Apple®, California, USA) was used to measure the head tilt degrees (Tousignant-Laflamme et al, 2013; Rodríguez-Sanz et al, 2019). During the OCR test, the iPhone was placed vertically to the contralateral temporal part of the head at a level aligned with the headband of the goggles by the clinician. The screen of the iPhone faced the clinician. At the beginning of the vOCR test, the head was held in the neutral position for 30 seconds, the torsion angles of the right and left eyes were at 0°, and the iPhone level tool was also at 0°. After that, the clinician slowly and passively tilted the participant's head 15° toward the left shoulder avoiding head rotation, and the participants were asked to fixate on the white dot on the screen across them. When the head position was stable at 15° of left tilt, the degrees of the torsional movement of the eyes in the opposite direction were recorded for 60 seconds from the right and left eyes separately (the static component of OCR). At the end of the 60 seconds, the head slowly and passively returned to the neutral position. The same procedure was achieved with the right lateral head tilt, and at the end of the 60-second recording the head was returned to the neutral position. The vOCR test was also repeated while the participant's head was tilted 30 and 40°. Studies in the literature have reported that 30° passive head or head and torso *en bloc* lateral tilt is a comfortable and sustainable angle for the patient and sufficient to create a significant OCR movement (Otero-Millan et al, 2015; Yang et al, 2023).

The OCR degrees of both eyes were noted at the 20th, 30th, 40th, and 60th seconds of the recording. Each recording was taken twice. Lateral head tilts were performed passively and slowly, and the tilted position of the head was maintained passively by the clinician to minimize the tension of the neck muscles so that the static component of the OCR was not affected by the cervico-ocular reflex or semicircular canal activity. Compensatory eye movement during the lateral tilt of the head is driven by the dynamic OCR (created by vertical semicircular canals and utricle) and the cervico-ocular reflex. The gain of the cervico-ocular reflex has been reported to be only around 0.1 (Ooka et al, 2020). The cervico-ocular reflex is activated by cervical muscle tension and the weight of the head. It has been reported that the static phase of the OCR is created by the utricle, also affected by gravity, and the cervico-ocular reflex may contribute to this phase. It has been stated that cervico-ocular reflex contamination to the OCR angle can be eliminated with a lateral tilt of the head and torso *en bloc* until 60°. However, this requires special equipment and is difficult to adapt to extended clinical practice (Ooka et al, 2020; Yang et al, 2023). In the protocol of the device that we used in this study, the tilt of the head is suggested. To

measure utricular function and keep the contamination of the cervico-ocular reflex to the OCR at a minimum, we aimed to keep the participant's neck relaxed, to tilt the head passively and slowly, and to eliminate a sudden increase in cervical muscle tone. Similarly, we analyzed the OCR degrees after the 20th second of the head tilt to eliminate the effect of vertical semicircular canal activity on the OCR.

Participants with ptosis, corneal lens implantation, bilateral MD, or who were unable to cooperate with the tests were excluded from the study. During the test, the patient was allowed to blink without exaggeration and was asked to keep their eyes open as much as possible when fixed on the point on the screen (Figure 2).

The cVEMP and oVEMP tests used air conduction stimuli at 124 dB pSPL (peak sound pressure level) through an insert earphone and a 500-Hz tone burst stimulus. The contractions of the sternocleidomastoid muscle were monitored between 100 and 200 μV using the electromyography panel of the device. Mono channel cVEMP recordings were performed sequentially and separately for both ears in the sitting position. The ground electrode was placed on the forehead, the active electrode on the incisura jugularis of the sternum, and the reference electrode on the middle of the sternocleidomastoid muscle of the tested side. It was ensured that the skin impedances for all electrodes were less than 5 kOhm. The cVEMP tests were performed with the following trial settings: Polarity: Rarefaction, Envelope: Blackman, Ramp–Plateau–Ramp: 2–0–2 cycles, Gain:5 K, Filters (low–high): 10 Hz–1 kHz, Rate: 5.1/second, Sweep Time:100 milliseconds, Sweep:100. P1 and N1 wave latencies, P1–N1 peak-to-peak raw amplitudes, and amplitude asymmetry ratios were recorded.

The ocular VEMP test was performed as mono channel and sequential recordings. The ground electrode was placed on the forehead, the reference electrode was placed approximately 0.5 cm below the lower eyelash line, and the active electrode was placed approximately 1 cm below the reference electrode. Because contralateral recording was performed during the oVEMP test, the reference and active electrodes were placed on the contralateral side of the ear to be stimulated. The oVEMP test was also performed with the patient in a sitting position. During the test, the audiologist placed one hand on the back of the patient's head to prevent head extension. The audiologist held her other hand approximately 30° above the patient's face and asked the patient to look at her index finger during the test. Skin impedances were verified to be less than 5 kOhm at all electrodes. oVEMP tests were performed with the following trial settings: Polarity: Alternate, Envelope: Blackman, Ramp–Plateau–Ramp:1–0–1 cycles, Gain:100 K,

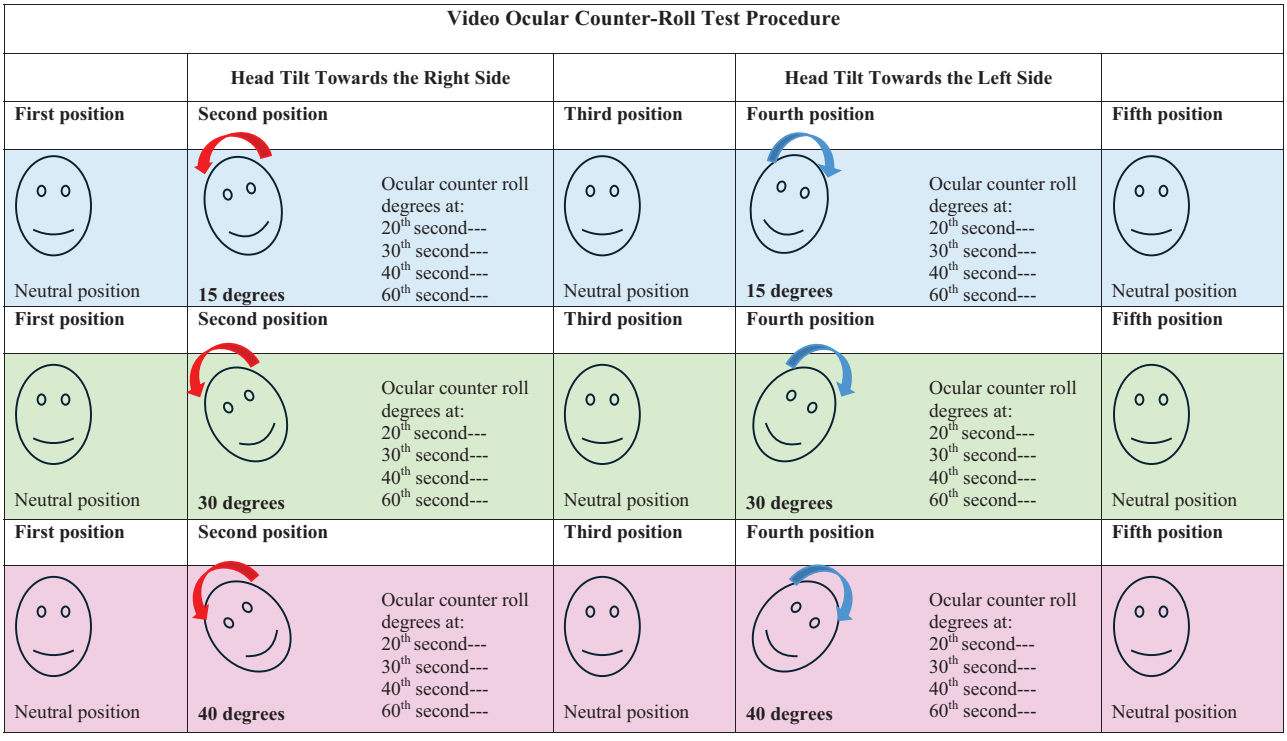


Figure 2. The flow diagram of the video ocular counter-roll test procedure. This procedure was repeated twice. At neutral positions, the ocular counter-roll records were done separately for 30 seconds from the right and left eyes. At the head tilt positions, ocular counter-roll degrees were recorded separately for 60 seconds from the right and left eyes. While the head was tilted, the ocular counter-roll degrees at 20, 30, 40, and 60 seconds were noted and analyzed.

Filters (low–high): 1 Hz–1 kHz, Rate: 5.1/second, Sweep Time: 50 milliseconds, Sweep: 200. N1 and P1 wave latencies, N1–P1 peak-to-peak amplitudes, and amplitude asymmetry ratios were recorded. Duplicate recordings were made for both ears for both cVEMP and oVEMP testing. Patients included in the study had their last attack at least 4 weeks before the vestibular tests (Angeli and Goncalves, 2019). Neither spontaneous nystagmus nor subjective vestibular complaints were present in patients with MD during the assessments.

The DHI was designed to assess self-perceived handicaps due to vestibular dysfunction. The DHI contains 25 questions. For each question, the patient received four points for a yes response, two points for a sometimes response, and 0 points for a no response. The total score ranges from 0 to 100, with higher scores indicating greater disability (Otero-Millan et al, 2015).

Statistical Analyses

The power analysis of the study was calculated using G*Power 3.1.9.4 (Faul et al, 2009). Because the data were not normally distributed (Shapiro–Wilks test, $p < 0.001$), nonparametric statistical methods were used. Means and ± two standard deviations of continuous data and frequencies of categorical data of the MD and control groups were calculated. The significance of the difference between groups was analyzed using the Mann–Whitney *U* test for continuous data and the chi-squared test for categorical data. OCR scores in the MD group were analyzed using the Wilcoxon test. A correlation matrix and intraclass correlation coefficients were also calculated to analyze the test–retest reliability of OCR scores with the participant's head tilted at 15, 30, and 40°. Spearman's correlation coefficients were calculated to analyze the relationship between VEMP and OCR scores. Statistical analyses were performed using SPSS version 22.0 (IBM, New York, USA). The significance level was 0.05, and the corresponding confidence level was 95 percent.

RESULTS

This study, with 61 participants, had an effect size of 0.7, an alpha value of 0.05, a critical *t*-value of 1.67, and a power of 83 percent with 56.25 degrees of freedom (post hoc power analysis). The demographic characteristics of the participants are presented in Table 1. The mean 500- to 4,000-Hz air conduction thresholds ($p < 0.001$) and speech audiometry results ($p < 0.001$) of the ipsilesional and contralesional ears ($p = 0.001$) of the MD group were significantly worse than those of the control group (Table 1).

In the healthy control group, all participants had oVEMPs. However, in the MD group, the presence of oVEMPs was 51.6 percent for the ipsilesional side and 77.4 percent for the contralesional side. The oVEMP presence rates of the ipsilesional ($p < 0.001$) and contralesional ($p = 0.011$) ears of patients with MD were significantly lower than those of healthy controls. The N1–P1 amplitudes of both ipsilesional ($p < 0.001$) and contralesional ears ($p = 0.015$) were significantly lower in the MD group than in the healthy control group. Similarly, the N1–P1 amplitudes of the oVEMP were found to be more asymmetrical between the ipsi- and contralesional ears in the MD group than in the healthy control group ($p = 0.003$). Furthermore, the N1 ($p = 0.734$) and P1 ($p = 0.651$) latencies of the ipsilesional side in the MD group were similar to those in the control group (Table 2).

In the healthy control group, all participants had cVEMPs. However, in the MD group, the presence of cVEMP responses was 48.4 percent for the ipsilesional and 83.9 percent for the contralesional side. The cVEMP presence rates of ipsilesional ($p < 0.001$) ears of patients with MD were significantly lower than those of healthy controls. The P1–N1 raw amplitudes of the ipsilesional side were significantly lower in the MD group than in the control group ($p < 0.001$). In addition, the P1–N1 raw amplitudes of the contralesional ears of the patients with MD were lower than those of the

Table 1. The Demographics, Subjective Vestibular Complaints, and Hearing Status of the Participants

	Controls	Unilateral MD Group	p
Sex	12 male (40%), 18 female (60%)	10 male (32.25%), 21 female (67.74%)	0.529
Age (years)	46.43 ± 9.98	51.22 ± 12.76	0.061
Dizziness Handicap Inventory	Total score: 0	Total score: 45.59 ± 26.16	**<0.001**
Ipsilesional side PTA averages* (0.5–4 kHz)	10.57 ± 6.31	52.26 ± 23.53	**<0.001**
Contralesional side PTA averages* (0.5–4 kHz)	10 ± 6.34	20.57 ± 21.33	**0.001**
Ipsilesional side speech detection* thresholds (dB)	17.33 ± 67.04	58.78 ± 28.92	**<0.001**
Contralesional side speech detection thresholds* (dB)	20.66 ± 19.11	22.67 ± 16.47	0.132
Ipsilesional side word recognition scores* (%)	96.13 ± 3.99	58.78 ± 28.92	**<0.001**
Contralesional side word recognition scores* (%)	95.33 ± 3.16	90.42 ± 9.63	0.071

* For the control group, the "ipsilesional side" means the right side, and the "contralesional side" means left side. The bold values are statistically significant. MD = Ménière's disease, PTA = Pure tone audiometry.

Table 2. The 500-Hz Tone Burst, Air Conduction Ocular and Cervical VEMP Raw Findings of Participants

	Controls	Unilateral MD Group	p
Ocular VEMP			
Ipsilesional side N1 latencies*	10.94 ± 0.92	11.15 ± 1.18	0.734
Contralesional side N1 latencies*	11.07 ± 0.87	11.31 ± 2.42	0.484
Ipsilesional side P1 latencies*	15.37 ± 1.16	15.23 ± 1.72	0.651
Contralesional side P1 latencies*	15.53 ± 1.1	15.36 ± 1.53	0.678
Ipsilesional side N1–P1 amplitudes*	3.72 ± 1.71	0.94 ± 1.13	**<0.001**
Contralesional side N1–P1 amplitudes*	3.67 ± 2.33	2.51 ± 2.31	**0.015**
Amplitude asymmetry ratio (%)	14.94 ± 17.81	50.76 ± 41.04	**0.003**
Cervical VEMP			
Ipsilesional side P1 latencies*	11.68 ± 2.04	13.97 ± 3.19	**0.033**
Contralesional side P1 latencies*	11.87 ± 1.95	13.57 ± 0.64	0.064
Ipsilesional side N1 latencies*	17.19 ± 1.91	19.32 ± 4.1	0.212
Contralesional side N1 latencies*	17.38 ± 1.49	18.46 ± 3.52	0.901
Ipsilesional side P1–N1 amplitudes*	49.98 ± 31.03	27.91 ± 19.55	**<0.001**
Contralesional side P1–N1 amplitudes*	45.25 ± 29.3	23.01 ± 14.85	**0.006**
Amplitude asymmetry ratio (%)	12.49 ± 12.29	59.77 ± 39.44	**<0.001**

* For the control group, the "ipsilesional side" means the right side, and the "contralesional side" means the left side. The bold values are statistically significant. MD = Ménière's disease, VEMP = vestibular evoked myogenic potentials.

control group ($p = 0.006$). The P1–N1 raw amplitudes of the cVEMP in the MD group showed more asymmetry between the ipsi- and contralesional ears compared to the healthy control group results ($p < 0.001$). In the MD group, the P1 latencies of the patients' ipsilesional ear were longer than in the healthy control group ($p = 0.033$).

Table 3 shows a comparison of the vOCR results of the MD and healthy control groups. From these comparisons, it can be seen that when the head was tilted to one side the OCR angles did not show a significant difference between the MD and control groups, except for the 30th-second OCR degree of the right eye when the head was tilted 30° to the ipsilesional side ($p = 0.031$) and the 20th-second OCR degree of the right eye when the head was tilted 40° to the ipsilesional side ($p = 0.036$).

Table 4 shows the difference in OCR degrees in the MD group when the head was tilted to the ipsi- and contralesional side. Significant differences between ipsi- and contralesional side head tilt were observed only at the 20th second of the 30° head tilt (left eye: $p = 0.032$; right eye: $p = 0.043$) and at the 40th second of the 40° head tilt (left eye: $p = 0.025$).

Table 5 shows the reliability and internal consistency analyses of the OCR results in the control group. From these analyses, the correlation matrix and intraclass correlation coefficients were higher than the other parameters, especially at the 20th- (Cronbach's alpha = 0.895 and 0.912), 30th- (Cronbach's alpha = 0.904 and 0.866), and 40th-second (Cronbach's alpha = 0.883 and 0.904) values when the head was tilted 30° toward the right side.

In the MD group, N1–P1 amplitudes of the oVEMP of the ipsi- and contralesional sides showed a positively weak correlation with OCR degrees during 30° of head tilt toward the contralesional side ($p = 0.038$, 0.04, 0.041, 0.026, and 0.043, respectively). Additionally, OCR degrees that were recorded during 30° of head tilt toward the contralesional side showed a positively weak correlation with N1 and P1 latencies of cVEMP ($p = 0.039$, 0.049, and 0.019, respectively) (Table 6).

DISCUSSION

The vOCR test is a quick and convenient method for both the patient and the clinician. The vOCR results in this study showed no significant difference when the head was tilted to the ipsilesional and contralesional sides in the unilateral MD group. We also found that the vOCR results for the unilateral MD group did not show a significant difference from the control group, unlike the cervical and ocular VEMP tests. On the other hand, in the vOCR protocol the degrees of OCR recorded during the 30° of head tilt showed more consistency and reliability than the other degrees of head tilt. Considering the other studies in the literature related to OCR results, this seems to be the first cross-sectional study to evaluate patients with unilateral MD using vOCR. Sadeghpour et al (2021) investigated the OCR evoked by 30° of head tilt in patients with unilateral peripheral vestibular loss after vestibular schwannoma resection. Sadeghpour et al, in their study, followed the patients with vestibular schwannoma resection after the surgery and analyzed their OCR during their acute (first 4 weeks after the surgery), subacute (between 4 weeks and 6 months after the surgery), and chronic (over 6 months after the surgery) periods postoperatively and compared them with 15 healthy controls. In the acute and subacute phases of unilateral vestibular loss, they observed a decrease in OCR gains when the head was tilted to the ipsilesional side. They did not find the same results in

Table 3. The Ocular Counter-Roll Degrees Recorded Separately from Right and Left Eyes at 20th, 30th, 40th, and 60th Seconds of 15, 30, and 40° Head Tilt in MD and Control Groups

	Recording Time (seconds)	Recording Eyes	Controls	Unilateral MD Group	p		Recording Time (seconds)	Recording Eyes	Controls	Unilateral MD Group	p
15° Head tilt to contra lesional side	20	Left	2.53 ± 1.35	2.51 ± 1.54	0.941	15° Head tilt to ipsilesional side	20	Left	3.2 ± 1.39	2.9 ± 1.71	0.376
		Right	2.96 ± 1.44	2.45 ± 1.52	0.248			Right	2.66 ± 1.34	3.16 ± 1.71	0.362
	30	Left	2.5 ± 1.38	2.67 ± 1.57	0.657		30	Left	3.4 ± 1.19	3.03 ± 1.88	0.341
		Right	2.9 ± 1.21	2.83 ± 1.52	0.819			Right	3 ± 1.11	3.09 ± 1.77	0.912
	40	Left	2.46 ± 1.35	2.74 ± 1.45	0.553		40	Left	3.43 ± 1.19	3.09 ± 1.7	0.3
		Right	3.03 ± 1.4	2.81 ± 1.53	0.541			Right	3 ± 1.31	3.09 ± 1.77	0.959
	60	Left	2.3 ± 1.29	2.64 ± 1.4	0.408		60	Left	3.26 ± 1.28	3.19 ± 1.85	0.654
		Right	3 ± 1.36	2.64 ± 1.49	0.289			Right	2.83 ± 1.36	3.19 ± 1.88	0.624
30° Head tilt to contra lesional side	20	Left	4.63 ± 2.12	4.25 ± 1.93	0.737	30° Head tilt to ipsilesional side	20	Left	4.53 ± 1.73	5.22 ± 2.09	0.222
		Right	5 ± 2	4.32 ± 1.98	0.323			Right	4.3 ± 1.63	5.29 ± 2	0.061
	30	Left	4.8 ± 2.24	4.58 ± 1.78	0.924		30	Left	4.7 ± 1.87	5.54 ± 2.23	0.2
		Right	5.23 ± 2.23	4.87 ± 1.82	0.786			Right	4.53 ± 1.73	5.74 ± 2.06	**0.031**
	40	Left	4.5 ± 2.21	4.54 ± 1.87	0.564		40	Left	4.93 ± 1.57	5.54 ± 2.2	0.329
		Right	5.13 ± 2.23	4.93 ± 1.93	0.948			Right	4.66 ± 1.56	5.51 ± 2.36	0.136
	60	Left	4.6 ± 2.06	4.29 ± 1.86	0.93		60	Left	4.6 ± 1.9	5.32 ± 2.24	0.31
		Right	5.3 ± 2.11	4.64 ± 1.79	0.326			Right	4.36 ± 1.71	5.48 ± 2.31	0.06
40° Head tilt to contra lesional side	20	Left	5.63 ± 2.14	5.03 ± 2.07	0.47	40° Head tilt to ipsilesional side	20	Left	5.2 ± 2.35	5.87 ± 2.47	0.298
		Right	6.23 ± 2.12	5.67 ± 1.98	0.516			Right	4.9 ± 2.15	6.35 ± 2.56	**0.036**
	30	Left	5.86 ± 2.17	5.29 ± 2.31	0.497		30	Left	5.56 ± 2.08	6.22 ± 2.37	0.28
		Right	6.5 ± 2.34	5.67 ± 2.18	0.384			Right	5.5 ± 2.02	6.35 ± 2.1	0.137
	40	Left	5.8 ± 2.18	5.25 ± 2.06	0.38		40	Left	5.33 ± 1.93	6.32 ± 2.28	0.067
		Right	6.36 ± 2.48	5.77 ± 2.12	0.427			Right	5.46 ± 2.19	6.12 ± 2.44	0.301
	60	Left	5.7 ± 2.13	5.22 ± 2.27	0.362		60	Left	5.3 ± 2.08	6.12 ± 2.43	0.164
		Right	6.36 ± 2.48	5.77 ± 2.29	0.432			Right	5.43 ± 2.06	6.32 ± 2.45	0.149

* For the control group, the "ipsilesional side" means the right side, and the "contralesional side" means the left side. The bold values are statistically significant. MD = Ménière's disease.

Table 4. The Ocular Counter-Roll Degrees of MD Group Recorded Separately from the Right and Left Eyes, at 20, 30, 40, and 60 Seconds of 15, 30, and 40° Head Tilt to the Ipsilesional and Contralesional Side and Their Comparisons with Each Other

	Recording Time (seconds)	Recording Eyes	Ipsilesional Side	Contralesional Side	p
15° Head tilt	20	Left	2.9 ± 1.71	2.51 ± 1.54	0.368
		Right	3.16 ± 1.71	2.45 ± 1.52	0.116
	30	Left	3.03 ± 1.88	2.67 ± 1.57	0.594
		Right	3.09 ± 1.77	2.83 ± 1.52	0.531
	40	Left	3.09 ± 1.7	2.74 ± 1.45	0.467
		Right	3.09 ± 1.77	2.81 ± 1.53	0.504
	60	Left	3.19 ± 1.85	2.64 ± 1.4	0.289
		Right	3.19 ± 1.88	2.64 ± 1.49	0.328
30° Head tilt	20	Left	5.22 ± 2.09	4.25 ± 1.93	**0.032**
		Right	5.29 ± 2	4.32 ± 1.98	**0.043**
	30	Left	5.54 ± 2.23	4.58 ± 1.78	0.057
		Right	5.74 ± 2.06	4.87 ± 1.82	0.067
	40	Left	5.54 ± 2.2	4.54 ± 1.87	0.054
		Right	5.51 ± 2.36	4.93 ± 1.93	0.311
	60	Left	5.32 ± 2.24	4.29 ± 1.86	0.062
		Right	5.48 ± 2.31	4.64 ± 1.79	0.061
40° Head tilt	20	Left	5.87 ± 2.47	5.03 ± 2.07	0.139
		Right	6.35 ± 2.56	5.67 ± 1.98	0.16
	30	Left	6.22 ± 2.37	5.29 ± 2.31	0.08
		Right	6.35 ± 2.1	5.67 ± 2.18	0.178
	40	Left	6.32 ± 2.28	5.25 ± 2.06	**0.025**
		Right	6.12 ± 2.44	5.77 ± 2.12	0.533
	60	Left	6.12 ± 2.43	5.22 ± 2.27	0.106
		Right	6.32 ± 2.45	5.77 ± 2.29	0.284

The bold values are statistically significant.

patients in the chronic phase or in healthy controls. In addition, the asymmetries of OCR values between the ipsilesional and contralesional sides were significantly higher in the acute-phase patients than in the postoperative chronic-phase patients and healthy controls. They reported that the OCR findings of the patients in their chronic phase may be a result of long-term central compensation and a recovery process. Sadeghpour et al (2021) found the performance of vOCR in discriminating patients with unilateral vestibular loss from healthy controls to be high in the acute phase of the disease. They found that an OCR angle of 4.5° at a head tilt of 30° was the threshold for vestibular loss, with a sensitivity of 80 percent and a specificity of 82 percent. They also argued that the vOCR test is reliable for detecting and monitoring otolith dysfunction and following the central compensation after unilateral vestibular loss (Sadeghpour et al, 2021). In our study, the OCR values of the MD group were 5.2° or more when the head was tilted 30° ipsilesionally. However, the OCR values were over 4.5° when the head was tilted 30° contralesionally.

In our study, the vOCR degrees did not define the pathological side of the patients with unilateral MD and did not discriminate the patients from the healthy controls. Conducting the study during the nonattack period may have caused no otolithic deficiencies to be detected in the measurements. In other words, negative findings of OCR may result from the central compensation process. In future studies, assessing vOCR during the attack period may eliminate the dominance of central compensation and monitor the effect of MD on OCR. On the other hand, in our study, cVEMP or oVEMP results in patients with unilateral MD were not affected by the central compensation as much as the OCR.

All vOCR tests were performed in a well-lit room in our study. The plasma screen was across from the patient and the natural visual input was not interfered with. It is conceivable that neural pathways activated by visual input during OCR may reduce the utricular effect and may also cause the similarity in OCR findings in patients with MD and healthy controls. In this study, we aimed to evaluate the findings in patients with MD using the current protocol of the device that we use in our clinic. To eliminate the visual input during the vOCR test, recordings may be performed in a dark room just as with the electronystagmography test. One other reason for the inability of the OCR to discriminate the pathological ears of patients with MD or a healthy person from a patient with MD is that the gain of the OCR is almost 10–25 percent of the head tilt. For instance, when the head is tilted 30°, the OCR degree will be approximately 5°. However, VEMP or video head impulse tests measure more obvious

Table 5. Results of the Test–Retest Reliability Analysis of Ocular Counter-Roll Degrees in the Control Group

	Recording Time (seconds)	Recording Eyes	Test	Retest	Correlation Matrix	Intraclass Correlation Coefficient (Cronbach's alpha)
15° Head tilt toward right side	20	Left	2.53 ± 1.35	2.4 ± 1.22	0.533	0.693
		Right	2.96 ± 1.44	2.83 ± 1.39	0.698	0.822
	30	Left	2.5 ± 1.38	2.33 ± 1.12	0.554	0.703
		Right	2.9 ± 1.21	2.76 ± 1.43	0.642	0.775
	40	Left	2.46 ± 1.35	2.36 ± 1.27	0.436	0.607
		Right	3.03 ± 1.4	2.9 ± 1.34	0.604	0.753
	60	Left	2.3 ± 1.29	2.23 ± 1.41	0.155	0.268
		Right	3 ± 1.36	2.83 ± 1.44	0.649	0.787
30° Head tilt toward right side	20	Left	4.63 ± 2.12	4.53 ± 1.99	0.812	0.895
		Right	5 ± 2	5.36 ± 1.86	0.841	0.912
	30	Left	4.8 ± 2.24	4.63 ± 1.9	0.836	0.904
		Right	5.23 ± 2.23	5.43 ± 1.95	0.77	0.866
	40	Left	4.5 ± 2.21	4.7 ± 1.95	0.796	0.883
		Right	5.13 ± 2.23	5.23 ± 1.94	0.833	0.904
	60	Left	4.6 ± 2.06	4.63 ± 1.97	0.793	0.884
		Right	5.3 ± 2.11	5.16 ± 1.87	0.81	0.892
40° Head tilt toward right side	20	Left	5.63 ± 2.14	5.8 ± 2.36	0.848	0.915
		Right	6.23 ± 2.12	6.46 ± 2.44	0.707	0.824
	30	Left	5.86 ± 2.17	5.9 ± 2.26	0.704	0.826
		Right	6.5 ± 2.34	6.56 ± 2.32	0.773	0.872
	40	Left	5.8 ± 2.18	6 ± 2.31	0.789	0.881
		Right	6.36 ± 2.48	6.63 ± 2.12	0.745	0.848
	60	Left	5.7 ± 2.13	6.06 ± 2.5	0.774	0.864
		Right	6.36 ± 2.48	6.56 ± 2.28	0.825	0.902

reflexes of the vestibular system. We may state that during the nonattack period in patients with unilateral MD the vOCR test cannot take the place of the VEMP tests.

In one study, patients with chronic unilateral (14 patients) and chronic bilateral vestibular loss (6 patients) were evaluated using vOCR, oVEMP, and cVEMP tests (Otero-Millan et al, 2017). The researchers obtained OCR angles of 4.6° in healthy controls, 2.7° in patients with unilateral vestibular loss, and 1.6° in patients with bilateral vestibular loss when the head was tilted 30°. They also reported that the vOCR angle threshold for detecting vestibular loss was 3° for a 30° head tilt (sensitivity and specificity values were 80 and 81 percent, respectively). They found that the vOCR results of patients were significantly lower than those of healthy controls; however, they could not distinguish

Table 6. Correlation Coefficients of Ocular and Cervical VEMP and Video Ocular Counter-Roll Findings

		Recording Parameters	r	p
Ocular VEMP	Controls			
Amplitude asymmetry ratio (%)	30° Head tilt toward the right side	20th-second, right-eye recording	**0.546**	**0.003**
		20th-second, left-eye recording	**0.387**	**0.046**
		40th-second, right-eye recording	**0.491**	**0.009**
Ocular VEMP	Unilateral MD Group			
Ipsilesional side N1–P1 amplitudes	30° Head tilt toward the contralesional side	60th-second, right-eye recording	**0.394**	**0.038**
Contralesional side N1–P1 amplitudes	30° Head tilt toward the contralesional side	20th-second, right-eye recording	**0.391**	**0.04**
		30th-second, right-eye recording	**0.389**	**0.041**
		40th-second, right-eye recording	**0.421**	**0.026**
		60th-second, right-eye recording	**0.385**	**0.043**
Cervical VEMP	Unilateral MD Group			
Ipsilesional side N1 latencies	30° Head tilt toward the contralesional side	30th-second, left-eye recording	**0.537**	**0.039**
Contralesional side P1 latencies			**0.39**	**0.049**
Contralesional side N1 latencies			**0.458**	**0.019**

The bold values are statistically significant. MD = Ménière's disease, VEMP = vestibular evoked myogenic potentials.

the side of the lesion (for unilateral pathologies). oVEMP amplitudes showed moderate, cVEMP amplitudes showed poor, and asymmetry ratios of all VEMPs showed no correlation with the static component of OCR. They stated that these results might be related to the binaural stimulation of OCR and the process of central compensation. In our study, both the cVEMP and oVEMP tests discriminated between the ipsilesional and contralesional ears of patients with MD and between the MD group and the healthy group. The oVEMP test stimulates type I hair cells and irregular afferents in the utriculus (Zalewski et al, 2018). By contrast, OCR movement created by lateral head tilt stimulates type II hair cells and regular afferent fibers. Because these two tests stimulate two different types of hair cells in the utricle, we may not have been able to obtain a correlation between the responses of these two tests in our study. The OCR is driven by the inputs from right and left utricles simultaneously with ipsilateral dominancy. Another possibility is that the stimulation is monoaural in the oVEMP test and the push–pull interaction with the nonlesional side utricle is passive. However, a response may be obtained via the ipsi- and contralateral excitation–inhibition mechanism in the OCR. The central compensation process during the nonattack period of patients with MD may have enhanced the OCR response via the nonlesional ear's utricle interaction.

The discrepancy of oVEMP-OCR tests in patients with MD may be similar to the discrepancy of the video head impulse test (vHIT) and caloric test. In the nonattack period of the patients with unilateral MD, a canal paresis of the ipsilesional ear was reported in the caloric test; in contrast, the vHIT did not detect the corrective saccades (Cordero-Yanza et al, 2017; Rubin et al, 2018; Limviriyakul et al, 2020; Hannigan et al, 2021; Oliveira et al, 2021). In the literature, three possible reasons for this finding were stated. First, in the vHIT test, high-acceleration head impulses stimulate the type I hair cells of the ampulla, and caloric stimulation stimulates type II hair cells. Because different hair cells were stimulated, the responses were also different (Rubin et al, 2018; Limviriyakul et al, 2020). Second, due to the binaural push–pull effect, the velocities of eyes and head movements were almost equal in vHIT. Third, the endolymphatic hydrops made dilatation of the membranous labyrinth reducing the caloric response in the ipsilesional ear (Cordero-Yanza et al, 2017; Limviriyakul et al, 2020; Hannigan et al, 2021; Oliveira et al, 2021). Taken together, we can say that MD has different characteristics than other peripheral vestibulopathies due to the responses obtained in different vestibular tests. Some authors have suggested discrepancies between vestibular tests could be a biomarker in the diagnosis of MD (Rubin et al, 2018). For this purpose, we believe that there is a need for more studies to be carried out during the attack and the nonattack periods.

In this study, we found a few eye-specific differences. This may be related to the ocular alignment at the fixation point. During the head tilt, the eyes may have had to move vertically or laterally to maintain the fixation relative to the straight-up condition. Such a situation can provoke false torsion factors. In our study, all tests were performed twice by the same clinician. During the vOCR, the clinician avoided any rotation movement during the lateral tilt of the head, and the OCR degrees of both eyes were simultaneously checked by the clinician on the computer screen during the test. In another study, three separate white dots that were at the same degrees with the head movements were used (for the neutral position, one dot was in the middle; for the right-side head tilt one dot was 30° on the right side; for the left side head tilt one dot was 30° on the left side) during the vOCR recordings (Yang et al, 2023). Their method may help to decrease the problem of ocular alignment during head movement in future research.

The average age of healthy people who agreed to participate in this study was lower than the average age of the patient group, though it was not statistically significant. This difference may have contributed to worse VEMP amplitudes and amplitude asymmetry ratios in the MD group compared to the control group.

Schmid-Priscoveanu et al (1999) evaluated the OCR gains of 10 patients with acute (1 day to 2 weeks) and 14 patients with chronic (6 months to 6 years) vestibular neuronitis (VN) using a scleral coil. They found that OCR gains decreased when the head was tilted to the ipsilesional side in patients with acute VN. In the group of patients with chronic VN, OCR gains of ipsi- and contralesional side were symmetric. They measured OCR when the head was tilted 20°, and the OCR gains did not reveal the localization of the lesion in the chronic VN group. They stated that the result of their study could be a result of central compensation and cervico-ocular reflex regulations in the chronic phase of VN. In our study, the OCR degrees did not reveal the localization of unilateral MD. According to our results, unilateral MD acted as a chronic vestibular loss in terms of OCR function.

Oliva Dominguez et al (2010) stated that OCR could not be measured in patients with bilateral vestibular loss and that the OCR test could differentiate the presence of bilateral vestibulopathy. In their study, the dynamic component of OCR was observed without equipment and the degree of head tilt was not reported. It was reported that the patient's torsional eye movements were carefully observed by the clinician, who used a metronome while tilting the patient's head left and right at a frequency of 0.25 Hz. Thus, the focus was on the presence or absence of ocular counter-rolling, not on the static OCR degrees or gains. They concluded that the dynamic component of OCR is a function of the canalicular mechanism, and the absence of this ocular

movement is related to bilateral vestibulopathy. In that study, they compared the results of dynamic OCR with the caloric test and found a statistically significant correlation. The dynamic component of OCR is driven by both utricle and vertical semicircular canals. In future research, there is a need for the comparison of oVEMP and dynamic components of OCR.

Limitations

The main limitation is that we could not evaluate patients during the attack period. Comparing the OCR findings of the attack period and the nonattack period may be more effective in monitoring otolith involvement in MD. On the other hand, the device used in this study does not have an internal module that measures head movements, which may be described as another limitation. In our study, the average age of the control group was lower than the average age of the patient group, though it was not statistically significant. This difference may have contributed to worse cVEMP and oVEMP amplitudes and amplitude asymmetry ratios in the MD group compared with the control group.

CONCLUSIONS

This study showed that the OCR degrees of the patients with unilateral MD during the nonattack period were similar when the head was tilted to the ipsilesional and contralesional sides. Thus, the vOCR test did not discriminate between the pathologic and nonpathological ears in these patients. Furthermore, the vOCR results did not discriminate between the patients with unilateral MD and the healthy controls. To obtain consistent vOCR results, a head tilt of at least 30° and a recording time of at least 40 seconds may be required. However, further studies are needed to evaluate otolith function in patients with vestibulopathy using vOCR.

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