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Original Article

Relationship Between Motion Sickness Susceptibility and Vestibular Test Results

Hareket Hastalığı Duyarlılığı ve Vestibüler Test Sonuçları Arasındaki İlişki

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ABSTRACT

Objective: There is no test parameter with high sensitivity and specificity for the diagnosis of motion sickness. The aim of this study was to demonstrate a correlation between vestibular function tests and motion sickness. In addition, our secondary aim is to evaluate the sensitivity of the skull vibration-induced nystagmus test (SVINT) in the diagnosis of motion sickness.

Methods: A total of 44 young adults aged 19-25 who had no hearing loss, complaints of dizziness/vertigo, or any diagnosed neurological disease were included. According to the motion sickness susceptibility questionnaire-short form (MSSQ-SF), participants were divided into the motion sickness group (21±1.38 years) and control group (20.5±1.18 years). Mean MSSQ-SF score for the motion sickness group is 78.18±12.2 and for control group 19.09±17.08. Ocular and cervical vestibular evoked myogenic potential tests, SVINT, video head impulse test, and oculomotor tests were performed.

Results: The only significant difference between the groups was in n1-p1 amplitudes in the left ocular vestibular evoked myogenic potential test (p=0.014). None of the other parameters differed between the two groups (p>0.05).

Conclusions: There was no significant relationship between motion sickness susceptibility and the results of any vestibular function test. Performing diagnostic tests for motion sickness in an environment that creates significant sensory conflict may yield different results. This study contributes to the literature in terms of evaluating the vestibular system using a comprehensive test battery and is the first to use the SVINT test in motion sickness.

Keywords: Motion sickness, oculomotor tests, skull vibration induced nystagmus test, vestibular evoked myogenic potentials, video head impulse test

ÖZ

Amaç: Hareket hastalığının tanısı için sensitivite ve spesifitesi yüksek bir test parametresi bulunmamaktadır. Bu çalışmadaki amaç, vestibüler fonksiyon testleri ile hareket hastalığı arasındaki ilişkiyi ortaya koymaktır. Ayrıca, ikincil amacımız kafatası vibrasyonu ile uyarılmış nistagmus testinin (KVUNT) hareket hastalığı tanısındaki duyarlılığını değerlendirmektir.

Yöntemler: Çalışmaya işitme kaybı, dizziness/vertigo şikayeti olmayan ve herhangi bir nörolojik hastalığı bulunmayan, yaşları 19-25 arasında değişen toplam 44 genç yetişkin dahil edildi. Hareket hastalığı duyarlılık ölçeği-kısa formuna (HHDÖ-KF) göre katılımcılar hareket hastalığı grubu (21±1,38 yaş) ve kontrol grubu (20,5±1,18 yaş) olarak ikiye ayrıldı. Ortalama HHDÖ-KF puanı, hareket hastalığı grubu için 78,18±12,2 ve kontrol grubu için 19,09±17,08. Bütün katılımcılar oküler ve servikal vestibüler uyarılmış miyojenik potansiyeller, KVUNT, video baş itme testi ve okülomotor testler ile değerlendirildi.

Bulgular: Gruplar arasındaki tek anlamlı fark sol oküler vestibüler uyarılmış miyojenik potansiyel testinde n1-p1 amplitüdünde gözlenmiştir (p=0,014). Diğer parametrelerin hiçbirinde iki grup arasında farklılık gözlenmemiştir (p>0,05).

Sonuçlar: Hareket hastalığına yatkınlık ile vestibüler fonksiyon test sonuçları arasında anlamlı bir ilişki saptanmamıştır. Önemli duyusal çatışma yaratan bir ortamda hareket hastalığına yönelik tanısal testlerin yapılması farklı sonuçlar doğurabilmektedir. Bu çalışma vestibüler sistemin kapsamlı bir test bataryası ile değerlendirilmesi açısından literatüre katkı sağlamakta olup, KVUNT testinin hareket hastalığında kullanıldığı ilk çalışmadır.

Anahtar kelimeler: Hareket hastalığı, okülomotor testler, kafatası vibrasyonu ile uyarılmış nistagmus, vestibüler uyarılmış miyojenik potansiyeller, video baş itme testi

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INTRODUCTION

Motion sickness is characterized by symptoms of autonomic and physiological discomfort that usually occur while traveling by vehicles such as cars, buses, trains, aircraft, and boats or during other types of movement such as swinging, spinning, and rolling[1,2]. It typically presents with dizziness, unsteadiness, nausea, and sometimes vomiting. Motion sickness can also be caused by perceived motion, such as when watching a moving scene or experiencing virtual reality[3]. Depending on the environment in which it occurs, motion sickness is also called travel sickness, sea sickness, car sickness, space sickness, and simulator sickness/movie sickness/cybersickness[4]. Although the incidence of motion sickness varies depending on the intensity of the stimulus and the individual's sensitivity, its general prevalence has been reported to be 13.4% in the healthy adult population[5]. Motion sickness is more common in the pediatric population. Children aged 6-12 years are highly susceptible to motion sickness, with a peak in susceptibility between 9 and 10 years of age[2]. One study reported the prevalence of motion sickness in school-age children to be 43.4% in cars and 43.2% on buses[6].

Although research on the pathophysiology of motion sickness continues, the most widely accepted theory is the sensory mismatch theory, which describes motion sickness as sensitivity to conflicting information received through the vestibular, visual, and somatosensory systems[7]. Sensory conflict impairs the homeostatic stability of vestibulo-autonomic pathways. Although individuals susceptible to motion sickness have healthy vestibular, visual, or somatosensory structures and associated reflex arcs, motion sickness can be triggered by direct or indirect stimuli due to mismatches in the visual-vestibular-autonomic pathways. Thus, unwanted vestibulo-autonomic responses may occur[8]. However, sensory mismatch theory cannot easily explain motion sickness induced by conditions such as passive low-frequency vertical acceleration. A theory proposed by Bos and Bles[9] suggests that uncertainty in perceived vertical orientation is the specific cause of motion sickness. This theory points to the importance of the otolith organs (saccule and utricle) responsible for linear acceleration and tilt sensation in the pathogenesis of motion sickness[9], which has been supported by observations that motion sickness does not occur in the absence of the motion-sensing vestibular organs of the inner ear[10].

According to the Barany society, motion sickness is diagnosed when the stimulus that causes the disease is physical movement. The presence of two or four attacks is required for a possible diagnosis of motion sickness. In the absence of other disorders affecting vestibular function, susceptibility to motion sickness peaks in adolescence and decreases with age. Defining whether symptoms refer to the age range ≤12 years or >12 years will help to accurately communicate the current situation and identify prognostic variables. Scales used in research are used to show overlap in symptoms. Multiple symptom checklists regarding severity, single-answer severity state questionnaires, and retrospective scales to measure personal sensitivity can be used. The Barany Society recommends that each measure be used according to its specific advantages for the research question or clinical practice[11].

Numerous attempts have been made to identify physiological parameters that predict motion sickness susceptibility. To date, however, no single physiological or functional parameter with high sensitivity and specificity has been identified that would serve as a diagnostic tool for individual susceptibility to motion sickness. Thus, there is no gold standard test for the diagnosis of motion sickness. Some studies have reported the results of the cervical vestibular evoked myogenic potential (cVEMP) test[12], ocular vestibular evoked myogenic potential (oVEMP) test[13], video head impulse test (vHIT)[14], videonystagmography (VNG) caloric testing[15], and posturography[16] in motion sickness. Although some of these studies demonstrated vestibular system involvement[12,14-16], others showed no effect on vestibular test results[5,13,17].

The skull vibration induced nystagmus test (SVINT), which has been frequently used by Dumas et al.[18] in the evaluation of the vestibular system in recent years, is a practical, simple, and well-tolerated test and is a useful method for detecting vestibular asymmetry. Although it is more sensitive in the detection of peripheral vestibular disorders, central disorders can also be affected[18]. Although there are studies on SVINT and various vestibular pathologies in the literature, there is no study showing SVINT findings in individuals with motion sickness sensitivity. This study is the first to use the SVINT test for motion sickness. Using these test methods, we analyzed the peripheral and central vestibular pathways in a holistic approach to the diagnosis of motion sickness.

In most studies, participants were evaluated using one or two test methods[13-15]. This does not allow the evaluation of the different regions of the vestibular system in individuals with motion sickness. Therefore, we aimed to examine the state of vestibular influence in different regions of the vestibular system in the same people with motion sickness, where research continues and various theories are put forward. In addition, our secondary aim

is to evaluate the sensitivity and specificity of the SVINT in the diagnosis of motion sickness and its relationship with other vestibular tests.

MATERIALS and METHODS

The study was conducted in the Audiology Clinic of Bezmialem Vakif University. Approval for the study was obtained from the Non-Interventional Ethics Committee of Bezmialem Vakif University on 08/02/2022 (no: 2022/2). An informed consent form was obtained from the individuals who volunteered to participate in the study, which was conducted in accordance with the ethical principles specified in the Declaration of Helsinki.

A total of 44 young adults aged 19-25 who had normal hearing (pure-tone average ≤20) and normal ear, nose, and throat examination findings, no complaints of dizziness/vertigo, or any diagnosed neurological disease were included. Participants were selected from patients and their relatives who applied to the Hospital Polyclinic of Bezmialem Vakif University. The motion sickness susceptibility questionnaire-short form (MSSQ-SF), recommended by the Barany Society to determine general motion sickness susceptibility, was used to identify participants in the study[11].

The MSSQ-SF, created by Reason and Brand[19] and revised by Golding[20], was administered. The Turkish validity and reliability study for the MSSQ-SF was conducted by Ugur et al.[21]. The Turkish version includes 20 questions in total, 10 about symptoms in childhood (before 12 years of age) and 10 about symptoms in the last 10 years. Total raw and percentile scores were determined according to the provided scoring guide. Participants with a motion sickness susceptibility of 60% or higher (n=22) were included in the motion sickness group (21±1.38 years; 20F, 2M) and those with a motion sickness susceptibility of 40% or lower (n=22) were included in the control group (20.5±1.18 years; 16F, 6M)[22].

Hearing was assessed using pure tone audiometry using a Madsen Astera® 2 audiometer. Air conduction hearing thresholds at octave frequencies of 125-8000 Hz were evaluated using Telephonics® TDH-39 headphones, and bone conduction hearing thresholds at frequencies of 250-4000 Hz were evaluated using a RadioEar™ B71 bone vibrator. Individuals with a pure tone average (for 0.5, 1, 2, and 4 kHz) ≤20 dB HL were included in the study. Individuals with middle ear pathology according to the immunometric evaluation performed using a GSI Tympstar were excluded from the study.

oVEMP and cVEMP tests were performed using an Interacoustics Eclipse EP25 (Middelfart, Denmark). Using inserted earphones, a 500 Hz tone burst stimulus at a 100 dB nHL intensity level, a repetition rate of 5.1 Hz, and 200 sweeps were recorded by double-trace recording. In the cVEMP test, the positive electrode was placed on the upper sternum, the ground electrode on the forehead, and the negative electrodes on the upper third of the right/left sternocleidomastoid muscle (SCM). It was ensured that the participant performed neck flexion and rotation to the contralateral side in a way that would cause the right and left SCM muscles to contract. For effective contraction of the SCM, electromyographic (EMG) activity was maintained between 50 and 200 μV with the EMG feedback system. An example of the cVEMP measurement is shown in Figure 1. In the oVEMP test, the negative electrodes were placed on the right/left inferior oblique muscle, the positive electrode was placed below the negative electrodes, and the ground electrode was placed on the forehead. The participant was asked to look at a fixation point 30°-40° above without moving his/her head throughout the test. An example of the oVEMP measurement is shown in Figure 2. In the oVEMP and cVEMP testing for both ears, p1 and n1 absolute latency; p1-n1 interwave latency; p1-n1 amplitude, and amplitude asymmetry ratio were determined. cVEMP and oVEMP thresholds were screened in all participants to rule out the possible presence of third window syndrome.

SVINT was performed at 100 Hz with a Synapsys® VVIB 3F (Marseilles, France) using VNG goggles with a cover and excluding fixation. The researcher performed the test, preferably standing in front of or behind the patient, holding the vibrator firmly with the dominant hand to ensure reproducibility. The test was performed by sequential stimulation of the two mastoid processes and vertex in three stimulation sequences, each lasting 5-10 seconds (s). In the mastoid application, a vibrator was applied behind the auricle at the level of the external auditory canal. The researcher used his free hand to hold the patient's head in the correct position[23].

Criteria for a positive result in SVINT:

• SVIN starts and stops with stimulation, does not recur after the stimulus is removed, does not change direction, and beats in the same direction after simulation of the left and right mastoid processes (e.g., beats right when the right mastoid process is stimulated and beats right when the left mastoid process is stimulated).

• SVIN should have a slow phase velocity ≥2.5°/s,

• The SVIN should be reproducible and identical or similar in two consecutive tests[23].

Oculomotor tests in the VNG test battery were evaluated with Micromedical VisualEyes™ VNG (Chatham, IL, USA) and VisualEyes™ EyeSeeCam model goggles.

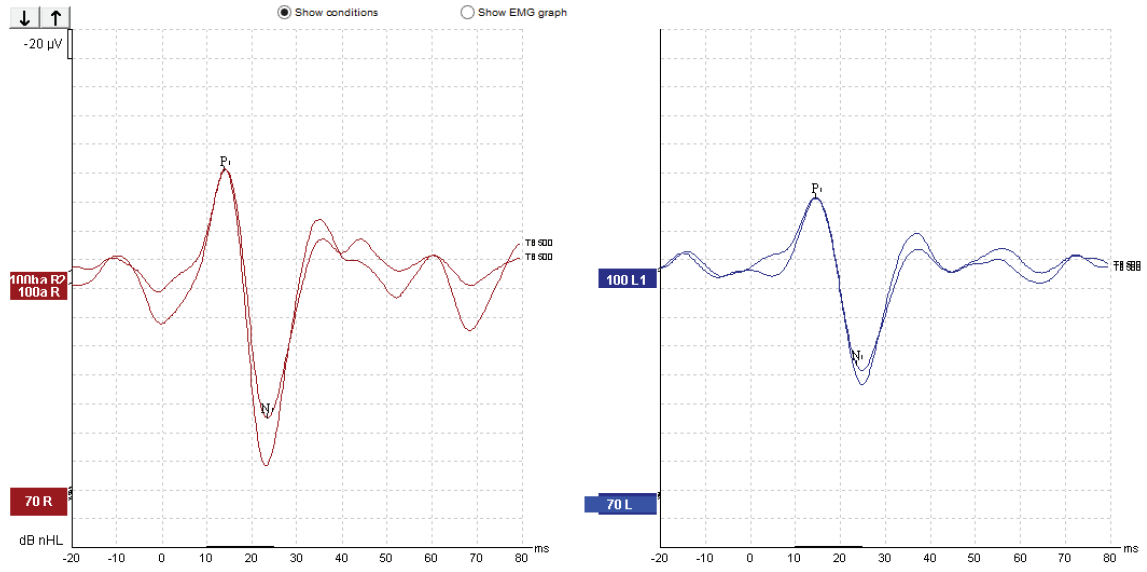

Figure 1. Example of cVEMP measurement.

EMG: Electromyogram, cVEMP: Cervical vestibular evoked myogenic potential

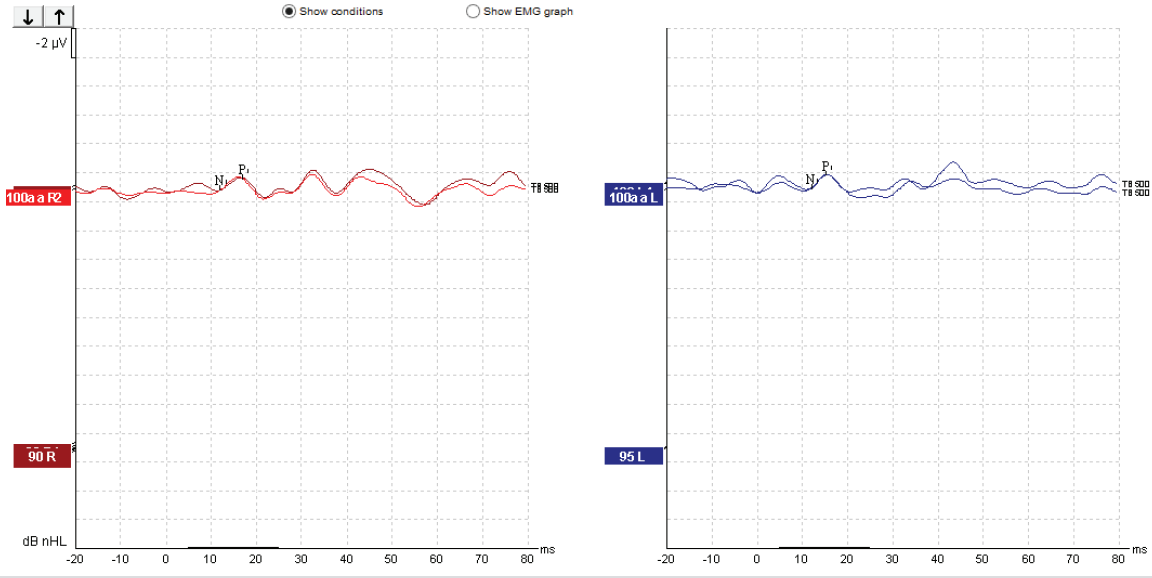

Figure 2. Example of oVEMP measurement.

EMG: Electromyogram, oVEMP: Ocular vestibular evoked myogenic potential

The test was conducted in a dark environment, and the distance between the participant and the light bar was 100-105 cm. The participant was seated directly opposite the light bar, which was adjusted to the eye height. Calibration was performed before the test, and the participants were asked to keep their heads steady and follow the target with their eyes during the test. Gaze, spontaneous nystagmus, smooth pursuit, saccade, and optokinetic tests were evaluated.

In the gaze test, the participants were asked to keep their gaze fixed for 15 s on a visual stimulus 15° below and above in the vertical plane and 20° to the right and left in the horizontal plane. The presence of saccadic oscillation and nystagmus was also checked. In the saccade test, the patient was requested to follow a light randomly moving 7°-24° right and left. Recordings were taken for 30 targets (15 right, 15 left). Accuracy, velocity, and latency were evaluated for both gaze directions. In the smooth

pursuit test, a target that moved at frequencies of 0.1, 0.2, and 0.4 Hz on the horizontal plane was used, and a 10 s recording was taken at each frequency. The gain and asymmetry values of the tested frequencies were evaluated for both viewing directions. In the optokinetic test, the target speed was set as 30°/s to the right and 30°/s to the left while the light bar was in the horizontal position, and the gain values were calculated for both gaze directions. In the spontaneous nystagmus test, the VNG goggles were covered, and the participants were asked to fixate on a fixation light. The fixation light was then removed, and another recording was obtained in the same way. Nystagmus was assessed in the presence and absence of fixation.

vHIT was performed using a Synapsys® vHIT Ulmer II (Marseilles, France). Both horizontal and vertical semicircular canals were evaluated during the test. The participants were asked to fixate on a target point at 0° to evaluate the horizontal semicircular canals. While the participant's head was at 30° flexion, the researcher performed a high-acceleration head impulse with 10-20° excursion applied at a speed of 120-150°/s. Then participants were asked to fixate on target points 20° to the right for the right anterior-left posterior semicircular canals and 20° to the left for the left anterior-right posterior semicircular canals. With the head in these positions, the clinician rotated the head 30°-45° right and left, respectively, and pulsed the head up and down at a velocity of 120°-150°/s. Vestibulo-ocular reflex (VOR) gain and asymmetry values were measured for each semicircular canal.

Statistical Analysis

The descriptive statistics of the evaluated parameters were calculated using IBM SPSS version 22.0. Normality testing of continuous numerical variables was performed using the Shapiro-Wilk test. Variables with normal distribution (bilateral anterior, posterior, and lateral vHIT gains, bilateral saccade velocity and latency, right saccade accuracy, left optokinetic gain, bilateral cVEMP n1 latency, and left cVEMP p1-n1 interpeak latency oVEMP amplitude asymmetry) were compared between the motion sickness and control groups using the independent samples t-test, and those with non-normal distribution (bilateral 0.1, 0.2, and 0.4 Hz smooth pursuit gain, right optokinetic gain, right saccade accuracy, and posterior, anterior, lateral vHIT asymmetry, bilateral cVEMP p1 latency, right cVEMP p1-n1 interpeak latency, bilateral cVEMP p1n1 amplitude, and cVEMP amplitude asymmetry, bilateral oVEMP n1 and p1 latency, bilateral oVEMP n1-p1 amplitude and interpeak latency) were compared using the Mann-Whitney U test. For the categorical variables (SVINT), statistical analysis was performed using the chi-square test. All analyses were performed at a 95% confidence interval, and the significance level was determined as $p<0.05$. G-Power analysis was performed to determine the sample size, and the required sample size was calculated to be 16 per group with α of 0.05 and power of 0.80.

RESULTS

A total of 44 participants, including 22 participants in the control group (16 females, 6 males) and 22 participants in the motion sickness group (20 females, 2 males), participated in the study. The mean age of the study participants was 21±1.38 years (range, 19-25 years) in the control group and 20.5±1.18 years (range, 19-25 years) in the motion sickness group. There was no statistical difference between the motion sickness group and the control group's age ($p=0.124$). Control and MS the mean MSSQ-SF score was 19.09±17.08 (range, 0-40) in the control group and 78.18±12.2 (range, 60-100) in the MS group. The motion sickness group's scores were significantly higher ($p<0.001$). The demographic features of the participants are reviewed in Table 1.

In the cVEMP test, all participants in both groups had p1-n1 responses. In the oVEMP test, no response was obtained from five people in each group. Although the motion sickness group had shorter latency values and larger amplitude values than the control group in both the cVEMP and oVEMP, the only significant difference between the groups was in the n1-p1 amplitudes in the left oVEMP (Table 2).

In the SVINT, positive results were obtained in three participants in the control group (13.6%) and one participant in the motion sickness group (4.5%). Fisher's Exact test showed no association between the motion sickness and control groups ($p=0.607$) for SVINT results. In the oculomotor evaluation, no significant difference was observed between the two groups in saccade, pursuit, or optokinetic tests (Table 3). In both groups, there were no abnormal results in the gaze test. In the spontaneous nystagmus test with fixation, abnormal results (nystagmus and saccadic oscillation) were

Table 1. Demographic features of participants.

Group	Control	Motion sickness
Gender (n)	Female: 16	Female: 20
	Male: 6	Male: 2
Age (mean ± SD)	20.5±1.18	21±1.38
MSSQ-SF (mean ± SD)	19.09±17.08	78.18±12.2

SD: Standard deviation, MSSQ-SF: Motion Sickness Susceptibility Questionnaire–Short Form

Table 2. Intergroup comparison of cVEMP and oVEMP results.

	cVEMP					oVEMP			
	Group	**Mean**	**SD**	**p-value**		**Group**	**Mean**	**SD**	**p-value**
P1 latency-right	Control	17.478	2.501	0.071	N1 latency-right	Control	11.906	1.285	0.560
	MS	16.173	1.484			MS	11.666	1.334	
P1 latency-left	Control	17.677	2.639	0.093	N1 latency-left	Control	12.387	1.430	0.229
	MS	16.280	1.297			MS	11.905	1.155	
N1 latency-right	Control	26.211	2.563	0.237	P1 latency-right	Control	17.186	2.005	0.478
	MS	25.440	2.143			MS	16.840	1.280	
N1 latency-left	Control	26.640	1.900	0.110	P1 latency-left	Control	17.440	1.766	0.723
	MS	25.746	2.183			MS	17.047	1.371	
P1-N1 amplitude-right	Control	117.855	49.900	0.624	N1-P1 amplitude-right	Control	4.912	3.709	0.326
	MS	129.743	60.314			MS	5.866	4.092	
P1-N1 amplitude-left	Control	117.279	44.626	0.660	N1-P1 amplitude-left	Control	4.614	3.549	0.014*
	MS	128.638	63.732			MS	7.287	4.800	
Asymmetry ratio	Control	0.131	0.088	0.264	Asymmetry ratio	Control	0.257	0.159	0.565
	MS	0.176	0.130			MS	0.226	0.206	

*p<0.05. MS: Motion sickness, SD: Standard deviation, cVEMP: Cervical vestibular evoked myogenic potential, oVEMP: Ocular vestibular evoked myogenic potential

Table 3. Intergroup comparison of oculomotor tests results.

		Group	**Mean**	**SD**	**p-value**
Saccade test	Saccade velocity left moving	Control	339.73	21.03	0.468
		MS	334.35	33.21	
	Saccade velocity right moving	Control	278.76	20.50	0.240
		MS	283.85	23.31	
	Saccade latency left moving	Control	214.37	20.14	0.430
		MS	216.44	25.83	
	Saccade latency right moving	Control	217.24	22.46	0.746
		MS	216.90	22.94	
	Saccade accuracy left moving	Control	96.92	3.21	0.199
		MS	92.51	15.59	
	Saccade accuracy right moving	Control	98.99	8.06	0.274
		MS	98.95	5.59	
Optokinetic test	Optokinetic gain right	Control	0.93	0.13	0.397
		MS	0.91	0.12	
	Optokinetic gain left	Control	0.93	0.09	0.184
		MS	0.92	0.11	
Smooth pursuit test	0.1 Hz left	Control	0.97	0.04	0.625
		MS	0.97	0.04	
	0.1 Hz right	Control	0.97	0.04	0.540
		MS	0.96	0.04	
	0.2 Hz left	Control	0.98	0.04	0.818
		MS	0.99	0.02	
	0.2 Hz right	Control	0.98	0.58	0.689
		MS	0.98	0.04	
	0.4 Hz left	Control	0.97	0.54	0.591
		MS	0.98	0.03	
	0.4 Hz right	Control	0.97	0.68	0.054
		MS	0.97	0.03	

MS: Motion sickness, SD: Standard deviation

observed in three participants in the control group and four participants in the motion sickness group, whereas in the spontaneous nystagmus test without fixation, abnormal results were observed in five participants in the control group and four participants in the motion sickness group.

In the vHIT, no significant difference was observed between the groups in bilateral horizontal, posterior, and anterior canal gains or asymmetry values (Table 4). In addition, no covert or overt saccades were observed in either group.

DISCUSSION

In this study, we aimed to evaluate peripheral and central vestibular system function using VNG-oculomotor tests[15]; saccule function using cVEMP[12]; crossed vestibuloocular pathway and utricle function using oVEMP[13]; VOR and six semicircular canal gains using vHIT[14]; and asymmetry in otolith function and vestibular receptors using SVINT[18]. These tests include different stimulation frequency characteristics and evaluate various the vestibular frequency spectrum. To the best of our knowledge, no previous study has examined the relationship between motion sickness susceptibility and a comprehensive range of vestibular function test results. Our study revealed no significant difference in the results of the oculomotor test, vHIT, SVINT, or cVEMP evaluations between young adults with motion sickness and the control group. Only the n1-p1 amplitude in oVEMP testing of the left ear was significantly greater in the motion sickness group.

The widely accepted sensory mismatch theory explains the clinical symptoms of motion sickness. Movement estimation depends on inputs from the visual and somatosensory systems, mainly the vestibular system. Sensory mismatch occurs when these inputs differ from patterns learned from previous experiences, resulting in the development of motion sickness symptoms[24]. Studies have stated that motion sickness is not observed in individuals without peripheral vestibular system function. Therefore, the vestibular system plays a critical role in the development of motion sickness[10]. Maladaptive vestibular system responses to vertical stimuli and asymmetric otolith function between the two labyrinths are possible causes of motion sickness[9]. These findings have led researchers to use vestibular test batteries to evaluate vestibular disorders that may cause motion sickness.

Various studies have used the oVEMP and cVEMP tests to assess otolith function in people with motion sickness, with evaluations made in terms of amplitude, threshold, and asymmetry. In several studies involving cVEMP, evaluation of the saccule (which responds

Table 4. Intergroup comparison of vHIT results.

	Group	Mean	SD	p-value
Right anterior SCC gain	Control	1.029	0.067	0.424
	MS	1.016	0.053	
Left anterior SCC gain	Control	1.018	0.075	0.620
	MS	1.009	0.057	
Anterior SCCs asymmetry	Control	2.533	1.925	0.139
	MS	1.800	1.554	
Right posterior SCC gain	Control	0.997	0.053	0.734
	MS	0.991	0.064	
Left posterior SCC gain	Control	1.003	0.060	0.682
	MS	0.997	0.062	
Posterior SCCs asymmetry	Control	1.733	1.460	0.674
	MS	1.760	1.164	
Right lateral SCC gain	Control	0.997	0.039	0.396
	MS	1.006	0.038	
Left lateral SCC gain	Control	0.991	0.041	0.340
	MS	1.002	0.043	
Lateral SCCs asymmetry	Control	1.466	1.008	0.584
	MS	1.280	1.021	

MS: Motion sickness, SCC: Semicircular canal, SD: Standard deviation, vHIT: Video head impulse test

to vertical acceleration) showed that amplitude and asymmetry were greater in the motion sickness group[12,25,26]. The magnitude of the amplitude values obtained in the motion sickness group is associated with the otolith in the vestibular system and/or its relationship with its neural pathways and hypersensitivity in these pathways/systems[9,26]. The differences in asymmetry obtained in cVEMP responses are based on the theory that the response produced by bilateral otolith organs is asymmetrical and that motion sickness symptoms occur because of the transmission of this asymmetrical response to the central structures. However, numerous studies have reported the absence of any difference in asymmetry[5,15,27–29], amplitude, and latency[5,12,25,27-29] in people with motion sickness on the cVEMP test. Similarly, we observed no difference in latency, amplitude, or asymmetry in the cVEMP results of the motion sickness group. This is consistent with the idea that there may not be a neural influence in the saccule and vestibulocolic reflex pathways in motion sickness that would affect cVEMP test results[12].

Studies have reported that asymmetry, latency, and amplitude differences were not observed in oVEMP tests evaluating utricle function[13,25,28]. We also observed no significant difference in the latency or asymmetry values in the oVEMP tests. Amplitudes were higher in the motion sickness group, but a significant difference was observed only in left n1-p1 amplitude. This result differs from those of a few other studies in the literature[13,25,28]. The differences in cVEMP and oVEMP test results reported in the literature may be due to the differences in the questionnaires used in the studies, the inclusion of people who feel less motion sickness symptoms due to continuous exposure to stimuli such as sea travel[28,29], and the difference in the test methods applied. Based on the differences between studies, VEMP tests lack the specificity to identify the possible otolith organ dysfunction that causes motion sickness.

Unlike other studies in the literature, we applied SVINT to both groups in our study. Because this test has been reported to give a differential result in unilateral vestibular weakness[30], we investigated whether it would support the theory of otolith asymmetry causing motion sickness. However, we observed no significant difference in SVINT, with positive results in 4.5% of the motion sickness group and 13.6% of the control group. Two studies reported that in normal individuals without auditory and vestibular complaints, 20-27% of participants had vibration-evoked nystagmus[31,32]. Additionally, Zamora et al.[32] reported that the number of positive results with repeated SVINT varied in normal individuals, with none of the participants having positive results in all six repetitions. Based on this information and the positive results obtained in both groups, we believe that SVINT should be repeated for a more accurate evaluation and should be included in motion sickness studies to determine its specificity, as in VEMP studies in future.

Although rotational chair and caloric tests are frequently used in studies of motion sickness[5,33,34], few studies have evaluated oculomotor test results. However, Fowler et al.[15] compared the VNG results of people with low, moderate, and high suspicion of motion sickness and observed no statistically significant difference in oculomotor findings between the groups, similar to our study. Similarly, Bilgen and Kirazlı[35] reported no significant difference between the control and motion sickness groups in oculomotor evaluation using electronystagmography. They interpreted this as indicating the absence of pathology in the central vestibular pathways in motion sickness[35]. In addition, in a study in which saccade assessment was performed on participants with space sickness before, during, and after flight, it was observed that saccade latency increased significantly while saccade velocity decreased significantly during flight. However, no significant differences in saccade velocity, accuracy, or latency were observed between the groups with and without space sickness[36]. This suggests that the system is disrupted during movement in people with motion sickness.

The fact that VORs are affected in vestibular pathologies has led researchers to investigate the results of vHIT in the evaluation of motion perception[37,38]. VOR stabilizes the image in the fovea during head movements. Under certain conditions, such as visual tracking of objects moving in sync with the head, VOR must be suppressed to maintain foveal fixation. However, when this suppression is insufficient, retinal image movement results in oscillopsia, the persistence of which can lead to motion sickness-like symptoms[39]. Kılınç et al.[14] reported that a significant decrease was observed in all semicircular canal gains in the motion sickness group and a significant increase was observed only in anterior canal asymmetry. However, Neupane et al.[12] reported that asymmetry rates were statistically more significant in the motion sickness group and that semicircular canal gains were lower in the right anterior-left posterior plane. They stated that this can be explained by intersensory conflict in the semicircular canals in motion sickness and concluded that the asymmetry ratio is a more valuable parameter than the VOR gain[40]. Our study revealed no significant difference between the groups in terms of VOR gains or asymmetry rates.

Similarly, Kumar et al. observed no significant difference between individuals with and without motion sickness in terms of VOR gain and VOR gain asymmetry in the head impulse paradigm and suppression head impulse tests[17]. In individuals with motion sickness, VOR and vestibulocollic reflex dysfunction occur in the presence of a provocative stimulus that elicits symptoms. In our study, none of the participants reported any motion sickness symptoms during or after the vHIT, although Karababa et al.[40] reported that some motion sickness symptoms were observed after a rotational stimulus. These differences between studies were likely due to differences in sensitivity between individuals and whether conditions provoked symptoms during the tests. Greater susceptibility to motion sickness is associated with a more pronounced deterioration of the VOR[12,40].

Because there is no cut-off value for MSSQ-SF scores, we used 0-40 and 60-100 percentile scores to determine the control and patient groups, respectively. One of the study's major limitations is that because motion sickness susceptibility is scored according to self-report, there is a possibility of intertwining data rising during grouping. Another limitation is that tests that include a condition that will trigger motion sickness were not included in our test battery, and smooth pursuit and saccade tests were not performed in the vertical plane during the evaluation of vertical visual perception. In addition, the narrow age range of the participants included in the study is another limitation of our study.

CONCLUSION

There is currently no gold standard test for diagnosing motion sickness; the pathophysiology still needs to be fully elucidated, and the search for appropriate test batteries for diagnosis continues to determine possible effects. In our study, a large vestibular test battery including VNG-oculomotor tests, vHIT, cVEMP, and SVINT evaluations revealed no significant effect on the vestibular test results in motion sickness. The observation of a significant difference only in oVEMP n1-p1 amplitude in our study suggested that the utricular function in the motion sickness group should be emphasized in further studies. Our study contributes to the literature on vestibular test results in motion sickness, which remains a subject of controversy. In addition, our study reports the first use of SVINT to evaluate motion sickness. On the basis of our findings, we believe that tests for the diagnosis of motion sickness should be performed under conditions that will create a significant sensory conflict.

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Ethics

Ethics Committee Approval: Approval for the study was obtained from the Non-Interventional Ethics Committee of Bezmialem Vakif University on 08/02/2022 (no: 2022/2).

Informed Consent: An informed consent form was obtained from the individuals who volunteered to participate in the study.

Author Contributions

Concept: O.G.T., Design: O.G.T., M.B.B., N.B., F.A., Data Collection and/or Processing: E.K., S.O., B.R., E.T., S.A., Analysis and/or Interpretation: O.G.T., E.K., S.O., M.B.B., N.B., F.A., Literature Search: O.G.T., E.K., S.O., Writing: O.G.T., E.K., S.O.

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