Aud Vest Res (2015);24(3):120-127.

REVIEW ARTICLE

Vestibular findings in motion sickness

Mehrnaz Hosseini[1], Saeid Farahani[1*], Mansoureh Adel Ghahraman[1], Shohreh Jalaie[2], Aboulfazl Khademi[3]

[1]- Department of Audiology, School of Rehabilitation, Tehran University of Medical Sciences, Tehran, Iran

[2]- Biostatistics, School of Rehabilitation, Tehran University of Medical Sciences, Tehran, Iran

[3]- Department of Aerospace Medicine, AJA University of Medical Sciences, Tehran, Iran

Received: 8 Dec 2014, Revised: 27 Feb 2015, Accepted: 21 Apr 2015, Published: 22 Jun 2015

Abstract

Background and Aim: Motion sickness (MS) is usually generated when there is a mismatch between the senses which serve balance. One of these senses is related to vestibular system, so it is highly possible that MS reflects in vestibular test results. But there are some conflicts in correlation between vestibular findings and MS. Thus, the objective of this study was to provide an overview of vestibular tests findings in individuals with MS.

Recent Findings: It has been demonstrated that susceptible subjects to different types of MS have more pathologic results in vestibular tests, such as eye movement recordings and vestibular evoked myogenic potentials (VEMPs) results, asymmetry ratios and posturography results in particular.

Conclusion: Based on abnormalities in various vestibular tests related to MS, possible contribution of signals from any part of the vestibular organ is likely in sensory conflict and triggering MS. Vestibular test results apparently can separate subjects with different susceptibilities to MS, but it seems difficult to differentiate susceptibilities to various types of MS.

[*] **Corresponding author:** Department of Audiology, School of Rehabilitation, Tehran University of Medical Sciences, Piche-Shemiran, Enghelab Ave., Tehran, 1148965141, Iran. Tel: 009821-77530636, E-mail: s_farahani@tums.ac.ir

Keywords: Motion sickness; vestibular test; electronystagmography; vestibular evoked myogenic potentials

Introduction

Motion sickness (MS) typically occurs during unusual body movements and when there is a conflict between sensory-motor signals, such as messages from motion in environment, is not compatible with reality. It is possible that movement signals induced from various senses (visual, vestibular, and proprioceptive) and motor system (efferent copy), do not match with other signals and/or internal representation of acceptable motion variable factors [1,2]. Depending on the type of motion, various types of sickness, such as carsickness, seasickness, airsickness, space sickness, etc. may occur [3,4]. About 5 to 10% of people are very susceptible to MS, while others show moderate susceptibility [5]. The incidence of MS, depending on study condition and population, are in the range of 7% in sea travelers to 81% in aviation students [6-13]. Asians are more susceptible in comparison to Caucasians and Africans [14], and it is reported that women show more severe sickness and a higher occurrence of nausea than men [15-17]; women also show smaller improvement in their symptoms after treatment [16]. Children who are aged older than 2 years, are more susceptible than adults [4]; and incidents of MS peak between 3 and 12 years, and gradually decrease after that [18]. Reavley et al. has estimated that MS has a hereditary factor of 35 to 70% [19]. This sickness has been seen in nearly 50% of patients with migraine [20].

The primary symptoms of MS include nausea, vomiting, wanes, and cold sweating; all of which have an autonomic nature [21]. These symptoms come from visual, vestibular, and proprioceptive cues of motion and probably alert the body towards potential danger of homeostasis. Conflict sensory input, evokes physiologic disorders that are similar to venom effects and leads to nausea and vomiting [22,23].

Sensory conflict theory is a possible explanation for MS [1,24,25], it fundamentally asserts that a mismatch between various sensory dimensions is the origin of accession of the symptoms. Visual, vestibular, and proprioceptive organs repetitively send current body status and movements to the central nervous system (CNS); thus, if each of these channels shows conflict with another or even inside themselves, MS can be produced [cited in 26]. Also it has been proposed that, there is an interaction between eye movement, sensory conflict, and postural instability in the symptomatology of MS [27].

Motion sickness diagnosis is somehow based on subjective reports and vestibular test results in MS are different and sometimes inconsistent among studies. Furthermore, there are no publications in guidance to vestibular diagnosis test battery and authors have not reached an agreement on that. So, this article reviews and collects various vestibular test results separately, to predict susceptibility to different types of MS and to determine the relationship of each test findings and MS features.

Electro/videonystagmographic findings

Semicircular-related tests

The angular vestibule-ocular reflex (aVOR), including its fast and slow pathways in MS has been extensively studied. Motion sickness has demonstrated that is generated through velocity storage (slow pathway) [28,29]. Some authors suggest that MS susceptibility can be reduced by decreasing the aVOR time constant. It has been demonstrated that saccades in a susceptible group showed increased latencies and velocities, and decreased accuracy, than a non-susceptible group [30].

The vestibular autorotation test (VAT) has also been used to determine MS and examines responses to active head oscillations at frequencies between 2 and 6Hz. At these frequencies, the vestibulo-ocular reflex (VOR) is the main source of eye movement for ocular stabilization. According to this fact, several authors reported that VAT may produce different findings in subjects at the two extremes of the seasickness susceptible scale [31,32]. Despite the statistical differences, VAT measurements could not be used for practical purposes to categorize individual MS susceptibility. Other researchers have reported the results of VOR parameters in seasickness susceptible subjects using sinusoidal harmonic acceleration (SHA) test and caloric test, which separately stimulated the horizontal semicircular canal. The present results support that a natural insusceptibility, or increased resistance to seasickness produced by adaptive responses to repeated sea exposure, may be reflected by lower VOR gain and higher phase lead (32,33); while Norfleet et al. reported more susceptibility when immersed in open water [34]. On the other hand, Cha et al. reported that most patients with mal de debarquement (MdD) showed normal neurological characteristics and normal electronystagmographic findings [35]. Also with post-rotatory and caloric nystagmus recordings, it has been demonstrated that visual fixation can reduce MS symptoms [36,37].

Otolith-related tests

In recent decades, eye torsion and its symmetry as a reflex governed by otolith organs, have been studied to investigate different types of MS, especially space MS. Markham and Diamond examined eye torsions during the hypo- and hypergravity of parabolic flights.

Subjects with a history of space MS (SMS) showed significantly higher scores of disconjugate eye torsion. The hypothesis of otolith asymmetry, compensated in 1 g, but being unmasked in novel gravitational states, is proposed to explain the torsional disconjugacy and ensuing SMS [38-41]. According to several studies in the case of relative roles of vestibular organs in weightlessness, it can be suggested that the vestibular organs and specially otolith receptors play major role, with extra-labyrinthine factors being contributory [42-46].

Off-vertical axis rotation (OVAR) test has also been used to assess ocular responses during otolith stimulation and its relationship with MS. Ventre-Dominey et al. quantified subject's susceptibility to MS, and then analyzed the angular eye velocity induced by the otolith stimulation [2]. They suggested that CNS, including velocity storage mechanism, reconstructs an eye velocity vector modulated by the head position in which length might predict MS occurrence during OVAR.

It is reported that some directions of head movement, such as moving the head back down to horizontal position, rotation velocity of about 105^{o}/s, and the frequency of 0.16Hz are the most provocative stimulations for MS [47-50]. Of course, Ji et al. indicated that as the velocity of the rotating pattern increased, the slow phase velocity of optokinetic nystagmus and the severity of MS increased [51]. Although women report more MS than men, a study by Park et al. determined they did not differ from men in the severity of symptoms of MS while looking at a rotating optokinetic drum [52].

Optokinetic tests

There are several conflicts in the relationship of nystagmus characteristics and MS. There is evidence that nystagmus parameters are not consistently correlated with susceptibility to MS [53,54]; but Gupta asserts that MS evokes jerk nystagmus with both optokinetic and vestibular stimulation [55]. Furthermore, Bukhtiiarov et al. reported that interocular nystagmus asymmetry was directly related to the severity of MS [56].

To reveal the effects of habituation in various kinds of motion stimulation and probably vestibular adaptation, there are some reports of shortened vestibular time, constant lower gain and advanced phase of VOR after habituation; with slower nystagmus decays and higher peak velocity in the susceptible group [57-59]. However, Matsnev et al. showed that subjects developed a vestibule-hemodynamic syndrome during prolonged otolith stimulation that included vestibular disorders and vestibular illusions [60].

Recent electrooculography findings are sumarized in Table 1.

Postural evaluation

It is believed that sensory inputs of visual-vestibulosomatosensory conflict, such as induced by virtual reality, result in MS, and subjective dizziness and postural instability [61]; while Stoffregen and Smart proposed that postural instability precedes the onset of MS [62]. Therefore, Takada et al. suggested using stabilometry (sway measurement in the body's center of gravity) while subjects stood in Romberg's posture to detect MS [63].

The sharpened Romberg test (SRT) is commonly used by diving and hyperbaric physicians as an indicator of neurological decompression illness (DCI) and mal de debarquement (sea legs); while Gibbs et al. reported that there is no significant impact on SRT performance of divers resulting from "sea legs" [64].

Computerized dynamic posturography

Computerized dynamic posturography (CDP) examines the response pattern to simultaneous, multimodal sensory stimulation, and several studies reported abnormalities in CDP findings in subjects with MS [65,66]. The results of CDP test demonstrated that susceptible subjects might be more dependent on somatosensory and visual inputs and less on vestibular inputs for maintenance of balance compared with non-susceptible subjects, and reweighting of sensory modalities can be seen during habituation to motion conditions [67,68].

Table 1. Recent electrooculography findings in motion sickness

Author(s)	Test	Population	Results
Markham and Diamond (1992)	Eye torsion recording	Astronauts on KC-135 shuttle	These results support previous findings on disconjugacy of otolith-induced eye torsion on orbit with different gravity from the earth.
Quarck et al. (2000)	Horizontal eye movement measurement during EVAR and OVAR	27 subjects with and without motion sickness symptoms	Eye movements is not correlated to motion sickness
Nachum et al. (2002)	VOR recording by VAT	35 healthy male volunteers with different susceptibility to seasickness	The lag of only vertical phase is significantly higher in the susceptible group, but there is a significant interaction between group and frequency, in the horizontal phase.
Bos et al. (2002)	Eye movement recording	14 low- and 10 high-susceptible subjects to motion sickness	Susceptible subjects have slower nystagmus decay and higher peak velocity.
Dornhoffer et al. (2004)	Rotary chair	Healthy volunteers 18 years and older aged	Scopolamine significantly increases tolerable rotation time.
Dai et al. (2007)	videooculography	10 leasioned-labyrinthine	Motion sickness susceptibility can be reduces by reducing the aVOR time constant.
Cha et al. (2008)	Electronystagmography and different neurological tests	64 patients with mal de debarquement	One patient with torsional positional downbeat nystagmus, but most of them had normal ENG.
Ji et al. (2009)	OKN recording during rotating optokinetic drum	60 female students and 14 other subjects	Severity of vision induced motion sickness increases by increment the velocity of rotating pattern.
Bukhtiiarov et al. (2010)	Intermittent rotator acceleration and binocular recording with closed eye, during and after rotating	135 medically accepted subjects for pilotage course	Binocular nystagmus asymmetry is directly related to motion sickness.
Jeong et al. (2010)	Videooculography, bithermal caloric test, rotary chair, and MSSQ	131 patients with migraine and 50 healthy subjects	Motion sickness is independent of increased time constant.
Dai et al. (2011)	OKN recording during sinusoidal rotation and after OVAR exposure	29 subjects with different susceptibility to motion sickness	Habituation via OVAR reduces the vestibular time constant and OVAR induced-motion sickness.
Murdin et al. (2014)	OVAR	12 healthy and 44 subjects with different types of migraine and neuritis	Vestibular migraine and migraine similarly enhances motion sickness susceptibility.

EVAR; earth vertical axis rotation, OVAR; off vertical axis rotation, VOR; vestibule-ocular reflex, VAT; vestibular autorotation test, aVOR; angular vestibulo-ocular reflex, ENG; electronystagmography, OKN; optokineticnystagmus, MSSQ; motion sickness susceptibility questionairre.

Galvanic vestibular stimulation

Although Balter et al. study implied that carsick subjects show a similar ability to healthy subjects after galvanic vestibular stimulation (GVS) [69], other researchers used GVS and could induce sensory conflict triggering MS-like symptoms [70] and suggested a method of oculo-vestibular recoupling to reduce MS [71].

Vestibular evoked myogenic potentials

Table 2. Recent VEMP findings in motion sickness

Author(s)	Tests	Population	Results
Tal et al. (2006)	cVEMP	30 naval crew members (15 susceptible-seasickness and 15 non-susceptible-seasickness)	Susceptible group has significantly higher VEMP thresholds and lower p13-n23 peak-to-peak interval than non-susceptible group
Gilbey et al. (2007)	cVEMP	10 susceptible-seasickness and 14 non-susceptible-seasickness male naval crew members	There is no difference in p13-n23 amplitude or latency, but susceptible subjects have asymmetry ratios > 35%.
Buyuklu et al. (2009)	Caloric and cVEMP	20 susceptible and 20 non-susceptible to motion sickness	There is no correlation between cVEMP and caloric test. caloric and VEMP findings is not involved in motion sickness.
Boldingh et al. (2011)	cVEMP and MSSQ	37 subjects with vestibular migraine, 32 migraineurs, and 30 healthy subjects	Patients with migraine show more susceptibility to motion sickness than controls. cVEMP findings shows more pathology in Migraineurs.
Noiij et al. (2011)	Ocular counter-rolling recording, oVEMP, bithermal caloric test	15 healthy subjects	Susceptible subjects have marginally higher degree of utricular asymmetry and semicircular canal sensitivity. Both the utricular and semicircular canals system are involved in motion sickness.
Xie et al. (2012)	oVEMP and MSSQ	54 (31 with and 23 without susceptibility to motion sickness)	There is no significant difference in p10-n15 amplitude or latency, but it has seen a trend to greater asymmetry in susceptible subjects.
Fowler (2014)	cVEMP, MSSQ	24 healthy young adults	Greater susceptibility to motion sickness correlates with larger amplitude and lower interaural asymmetry in cVEMP.

cVEMP; cervical vestibular evoked myogenic potential, MSSQ; motion sickness, OVEMP; ocular vestibular evoked myogenic potential

One theory proposes that MS arises from a mismatch between reality and past experience in vertical motions, reflecting in cervical vestibular evoked myogenic potential (cVEMP) characteristics, such as larger amplitudes and lower interaural asymmetries of cVEMP; while there are reports that cVEMP results are not affected by individual susceptibility to MS. Abnormalities may be seen in other types of VEMP tests, including VEMP asymmetry ratios>35%, and higher oVEMP thresholds and lower p13-n23 peak- to peak amplitudes in susceptible groups [72-76].

Recent VEMP findings are summarized in Table 2.

Subjective vertical test

Describing a model using explicit knowledge of the vestibular system, Firstly, the conflict theory was restated in terms of a conflict between a vertical as perceived by the vestibular organ and the subjective vertical. Secondly, this concept was integrated with optimal estimation theory by the use of an internal model. It is demonstrated that after vestibular training, MS repeatedly reduced with each session but subjects showed greater error in subjective visual vertical after habituation, which reflected that spatial orientation is also affected by vestibular training [77,78].

Anti-motion sickness drugs efficiency evaluation using vestibular tests

Some medications are reported to be effective as an anti-MS drug, including scopolamine, phenytoin (dilantin), rizatriptan, cinnarizine, and the combination promethazine+d-amphetamine, based on rotary chair, OVAR, VOR recording, and VEMP tests, respectively [79-83].

Motion sickness and migraine

It is reported that vestibular migraine and migraine similarly enhance MS susceptibility, and patients with migraine reported MS more than others and had more pathology of VEMP [84,85]. On the other hand, Jeong et al. asserted that MS was independent of prolonged time constant factor in patients with migraine. Increased suppression may be an adaptive cerebellar mechanism for suppressing the hyper-active vestibular system in patients with mig-raine [86].

Conclusion

Nowadays MS is a progressive concern in relation to various types of transport and may disturb some special personnel performance like crew members. Thus, it is beneficial to deter-mine the severity or predict the susceptibility to MS. Vestibular tests, such as eye movement recordings and VEMP results, particularly asymmetry ratios, and posturegraphy results can reflect MS dimensions; indicating that the involvement of all semicircular canals, and utricular and saccular receptors. Also, patients with migraine have more susceptibility to MS. Vestibular tests results apparently can separate subjects with different susceptibility to MS, but it seems difficult to differentiate susceptibility to various types of MS. Since MS severity and susceptibility are reported by individual sub-jective sensation, there are some difficulties in categorizing subjects and allocating vestibular test results to different extremes of the susceptibility spectrum. Because of some conflicts in vestibular test findings related to MS, further researches with a larger study population are needed to prove the best test battery to diagnose MS.

Acknowledgments

Current review article is extracted from M. Hosseini MSc. dissertation in Audiology submitted in Tehran University of Medical Sciences.

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