Motion sickness in children: An update from its origins to nowadays

A narrative review

Melissa Castillo-Bustamante MD, 2Patricia Sommervogel MD, 3Jorge Madrigal MD, 4Claudia del Cid MD, 5Licelott Bello MD, 6Magalí Vázquez Aud, 7Mirtha Baez MD

1Universidad Pontificia Bolivariana, Medellín Colombia, 2Hospital Juan P Garrahan, Buenos Aires Argentina, 3Centro de Vértigo y Mareo, Mexico City Mexico, 4Hospital Militar, Guatemala City Guatemala, 5Otoclinic, Dominican Republic, 6Private practice, Asunción Paraguay, 7Universidad Nacional de Asunción, Asunción Paraguay

Abstract— Motion sickness is presented during air, ground and sea transportation. This is usually seen during childhood, mainly at ages between 2 to 12 years old. Nausea, pallor, sweating and vomiting are often presented during episodes, but other symptoms have been described over the last decades, affecting the quality of life of this patient’s population. Symptom description, adequate, available treatments and, vestibular rehabilitation during childhood, are some of the challenges for healthcare providers. In this review, we aimed to describe the latest findings in literature about motion sickness, with an overview on diagnosis, treatment and rehabilitation.

Index Terms—motion sickness; vertigo; childhood

I. INTRODUCTION

Motion sickness is defined as the increased sensibility to movement during ground, air and sea transportation (Spinks, 2011). The current pathophysiology of motion sickness includes host and genetic factors, and the ability of the vestibular system to adapt to continuous exposure to movement (Spinks, 2011; Rine, 1999). Motion sickness susceptibility in children leads to relevant restriction of mobility, daily activities and quality of life (Spinks, 2011; Rine, 1999). Travel sickness is a condition in which a discrepancy exists between visually felt movement and the sense of movement in the middle ear. Sensory conflict theory is one of the most established theories for explaining the circumstances in which motion sickness arises. This theory assumes that motion sickness originates from a sensory conflict between real versus expected invariant patterns of vestibular, visual and somato-sensory inputs. This sensory mismatch leads to an activation of vestibular autonomic pathways, which have been shown to also be involved in producing nausea and vomiting. Motion sickness episodes may be triggered by traveling on ground transportation; in trains, airplanes and boats; or by riding on swings and carousels (Spinks, 2011; Rine, 1999). During those activities, nausea, vomiting, pallor, sweating, hypersalivation, hyperventilation and headaches are the most common symptoms reported by patients and parents (Spinks, 2011; Rine, 1999).

Girls 6–12 years old are affected more often than boys; however, after 12 years of age, the presentation becomes equal between females and males (Zhang, 2016; Dizzio, 2000). This disorder is commonly associated with a reduction in cognitive, social and intellectual activities at school, on playgrounds and at home (Hüppe, 2019). Even though several articles are found in the literature regarding motion sickness in adults, little is known about motion sickness in children and the challenges of their diagnosis, treatment and rehabilitation (Buyuklu, 2009; Chang, 2012). The aim of this narrative review is to perform an update of the existing literature about children affected by motion sickness and its clinical implications, alternative treatments and targeted items in rehabilitation and prevention.

MATERIALS AND METHODS

This narrative review was conducted between July and October 2021. The search strategy included the following MeSH terms: “vertigo”, “vestibular disorder”, “motion sickness”, “child”, and “motion”. To search PubMed, Embase, Scielo, Bvsalud and Google Scholar databases for relevant articles. The search was limited to articles between 2001 and the year 2021, where most of the research publications were released.

Papers were initially screened by their titles only. However, to better define their status according to the inclusion criteria, the abstract and/or manuscript was read to clarify ambiguities. We included complete manuscripts published in English and Spanish, meeting the aims of the review. Studies outside the field of Otolaryngology and Pediatrics were excluded. Duplicates were removed manually by the authors. Review articles, letters of opinion, comments to the editor and case reports were excluded. Articles in other language than English were also excluded.

Further, for the purpose of the review, relevant papers were read and mined for relevant content. Results were cross-checked among all the authors. All articles were evaluated for quality and fit the research aims for titles seemed worthy of inclusion. If the article was applicable, qualitative, and quantitative data was extracted, and then the content was analyzed and categorized.

In total, 214 indexed papers were obtained in the initial search. From these, only 15 indexed articles were selected because they reported motion sickness in children. Data were manually extracted as profiles of manuscripts with major findings relevant to the
review were added to an excel spreadsheet. The quality of evidence in the published articles was reviewed according to the 2009 Levels of Evidence of the Oxford Centre for Evidence-Based Medicine.

REVIEW

BACKGROUND

Motion sickness was described for the first time by Hippocrates, as an associated event to sea navigation (Chan, 2006). In his first description, he indicated that “navigating in the sea promotes health disorders in the body” (Leung, 2019). Many centuries passed before Irwin described motion sickness in 1881 as the discomfort occurring because of the oscillatory and repeated movements during ground, air and sea transportation (Chan, 2006). To this day, motion sickness is considered an abnormal response to movement stimuli and to contradictory spatial and sensorial information (Leung, 2019). However, this not only happens during transportation, but it may also occur while using videogames or at the playground (Drugs Ther. Pers, 2001). Depending on the cause, it can also be referred to as seasickness, simulation sickness, car sickness or airsickness.

An altered neural response and sensorial involvement have been postulated as associated events involving vestibular nuclei, archicerebellum, hypotalamus and limbic system (Drugs Ther. Pers, 2001). In addition, proprioceptive and vestibular pathways may be affected by the autonomic, sensorial, and contradictory information coming from the brain and vision (Drugs Ther. Pers, 2001). Nowadays, the Barany Society, presented the diagnostic criteria for motion sickness, which are listed in Table 1 (Gordon, 1999). An acute episode of motion sickness is induced by physical motion/visual motion that meets Criteria A through D (Cha, 2021).

Table 1. Barany Society Diagnostic Criteria for Motion Sickness

<table>
<thead>
<tr>
<th>A. Physical motion of the person1 or visual motion elicits sign(s) and/or symptom(s) in at least one of the following categories, experienced at greater-than-minimal severity:</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Nausea and/or gastrointestinal disturbance</td>
</tr>
<tr>
<td>2. Thermoregulatory disruption</td>
</tr>
<tr>
<td>3. Alterations in arousal</td>
</tr>
<tr>
<td>4. Dizziness and/or vertigo</td>
</tr>
<tr>
<td>5. Headache and/or ocular strain</td>
</tr>
<tr>
<td>B. Sign(s) and/or symptom(s) appear during motion and build as exposure is prolonged</td>
</tr>
<tr>
<td>C. Sign(s) and/or symptom(s) eventually stop after cessation of motion</td>
</tr>
<tr>
<td>D. Sign(s) and/or symptom(s) are not better accounted for by another disease or disorder</td>
</tr>
</tbody>
</table>

Epidemiology and Pathophysiologic Facts

Motion sickness is described in children 2–12 years old and is frequently observed in females close to menarche and puberty (Schmal, 2013). After this age range, this disorder usually declines but sometimes may be extended until 18 years of age (Schmal, 2013; Shupak, 2006). Rates are higher among females than males across all age groups and increase during menstruation and pregnancy. Aerobic physical fitness is associated with higher susceptibility to motion sickness. This might be explained by a suggested link between aerobic capacity and increased vasomotor activity (Jahn, 2016). Ninety percent of individuals report that they have experienced motion sickness at least once in their lifetime. Indeed, motion sickness has been described as a normal response to an abnormal situation; it is never a disease per se. When patients under the age of 1 present motion sickness, they often have more severe episodes between the ages of 6 and 9 (Schmal, 2013). This early onset usually happens in children with a family history of motion sickness (Schmal, 2013). At 5 to 10 years of age, with the maturation of the visual and vestibular systems and the hormonal peaks oscillatory and fluctuating, there is an increased susceptibility to presenting with this disorder (Schmal, 2013). At least 40% of pediatric patients with motion sickness indicate increased disturbances while riding a bicycle or in a car or bus, while 7% usually described increased episodes when riding on a carousel (Jahn, 2016). For airplanes and swings, the incidence of episodes is not well specified in the literature reviewed. Patients between 2 and 3 years of age diagnosed with motion sickness, usually get sick on ground transportation, while adolescents experience motion sickness during air and sea transportation (Bakwin, 1949).

Motion sickness results from discordant information between body movement and the information received by the visual, vestibular, and proprioceptive systems (Chan, 2006; Cha, 2021). The vestibular system, the vestibule-cochlear nerve, the uvulae at the cerebellum, the medulla oblongata, the vomiting center in the reticular formation and the hypothalamus are mainly involved (Cha, 2021).

An existing theory called visual misadjustment indicates that motion sickness may progress in three phases: Phase I, also called the high resistance phase, occurs at age 1 (Cha, 2021; Schmal, 2013). During this phase, newborn patients are subject to a vestibular-visual disturbance, but they do not use visual help for acquiring the self-perception of movement. In phase II, there is a peak before puberty when a hormonal hypersensitivity presented and a sensory-motor disarrangement occurs, generating a visual and vestibular disturbance (Cha, 2021; Schmal, 2013). Phase III includes a post-puberty decline, consistent in visual and vestibular breakdowns.
due to the habituation to repetitive stimuli on transportation (Cha, 2021; Schmal, 2013). This sensory conflict hypothesis is the most widely accepted theory for the pathogenesis of motion sickness. Children under the age of 1 might be highly resistant to the susceptibility of motion sickness because they use the visual system only to a limited extent for self-motion perception and therefore are less subject to visual-vestibular conflicts. The prepubertal high frequency of susceptibility may indicate an oversensitivity to the visual-vestibular mismatch of motion stimulation. Motion sickness occurs because of low-frequency stimuli that could be vertical, lateral, angular or rotary on non-adapted individuals (Chan, 2006). The severity and duration of symptoms are determined by the grade of incoordination between the stimuli received by the vestibular and central nervous systems and the ability of the individual to adapt to their normal environment (Chan, 2006).

In addition, there are two conflict categories that comprise the pathways of motion sickness (Chan, 2006; Cha, 2021). The first conflict is between the visual-vestibular and proprioceptive signals, and the second one comes from conflicts between canalicular signals (those including the vertical and horizontal accelerations) and the otolithic (including accelerations and linear decelerations in the three spatial axes) (Chan, 2006; Cha, 2021). These conflicts are described as the labyrinth conflict (Chan, 2006; Cha, 2021). This conflict may be prolonged even years after puberty, and a neural and sensorial disarrangement is usually seen associated with a hypersensitivity to movements (Chan, 2006; Cha, 2021).

Shupak and Gordon (Shupak, 2006) affirm that a functional vestibular system is a prerequisite for motion sickness to occur. Subjects with non-functioning labyrinths were immune to motion sickness under all test conditions, even after prolonged exposure to stormy seas. A bilateral vestibular neurectomy and labyrinthine ablation rendered susceptible laboratory animals immune to motion sickness (Shupak, 2006). Vision is not essential to motion sickness; blind subjects are also susceptible to it. Bilaterally labyrinthine defective subjects would develop only mild symptoms of visually induced sickness, although no direct stimulus of the semicircular canals or otoliths is practiced during the provoking stimulus. This suggests that visual inputs normally associated with a vestibular stimulus would give rise to a central vestibular activity, even in the absence of a vestibular stimulus. Indeed, optokinetic stimulation has been found to induce direction-specific modulations of resting discharge in the vestibular nuclei in several species, including the rhesus monkey. If tonic activation of the vestibular nuclei neurons is not maintained by the primary vestibular afferents, no central vestibular response to optokinetic stimulus would take place (Shupak, 2006).

**Triggers and Symptoms**

Sea (10.4%), ground (74.3%) and air (7.5%) transportation are commonly known as triggers of motion sickness in children (D'Zio, 2000). Less frequently, riding carousels (24.4%), virtual reality use (8.3%) and video gaming (2.6%) also induce motion sickness (D'Zio, 2000; Buyuklu, 2009). In regard to oculus use or goggles for virtual reality, children over 10 years old using these devices for more than 50 minutes have an increased risk of presenting motion sickness (Buyuklu, 2009). The body postures adopted while gaming also increase the risk (Buyuklu, 2009). Non-vertiginous dizziness, pallor, malaise, nausea, vomiting, profuse sweating and discomfort are commonly known symptoms. Depending on each individual and their sensibility to movement, the severity and intensity of symptoms vary (Chan, 2006). Other known clinical manifestations include headache, blurry vision, hyperventilation, diminished ability to concentrate and perform daily tasks, somnolence, and lethargy (Chan, 2006). One of the most common clinical symptoms seen in most patients is nausea associated with epigastric pain and vomiting (Shupak, 2006) This may be associated with fear, snappishness, intense odors, closed rooms, poor ventilation and excitement (Shupak, 2006; Henriques, 2014).

There are two clinical forms of manifestations. The vagotonic form, usually seen in males, is characterized by headaches, malaise and bradycardia (Bawkin, 1949). Vomiting is infrequent and is not preceded by nausea (Lamb, 2015; Henriques, 2014). The sympathicotonic form, more frequent in females, is characterized by nausea and vomiting associated with tachycardia and headaches (Lamb, 2015; Henriques, 2014). Both forms are seen mainly during puberty (Lamb, 2015; Henriques, 2014).

**Diagnosis and Differential Diagnosis**

Clinical diagnosis is based on the Bárány Society’s criteria (Cha, 2021). There are some questionnaires, such as the Motion Sickness Susceptibility Questionnaire and the Motion Sickness Susceptibility Questionnaire Short, that may help to evaluate the susceptibility to motion sickness in diverse scenarios (Lamb, 2015). They evaluate the predisposition of an individual to having or developing this condition during their lifetime. The Motion Sickness Susceptibility Questionnaire Short has been used on pediatric populations and consists of 11 items focused on triggers for motion sickness such as riding in vehicles, playing on the playground, using elevators and electric stairs, and others (Henriques, 2014; Golding, 1998). For each item, there are five options for the answer: non-applicable, never gets sick, barely sick, sometimes gets sick and frequently sick. The maximum score obtained for sick patients is 33 (Henriques, 2014).

Migraines, pregnancy in teenagers, concussions, ethanol intoxication, basilar artery occlusion, strokes, peripheral vestibulopathy, hypoglycemia, depression and anxiety are some of the most common differential diagnoses (Chan, 2006).

**Challenges of Motion Sickness**

Motion sickness may be associated with other vestibular disorders, such as orthostatic dizziness (38%), benign paroxysmal positional vertigo (40%) and vestibular migraine (57%) (D'Zio, 2000). The association of vestibular migraine with motion sickness has been studied over the years, as they share several pathologic features that may predispose both disorders at any given time of life (Abouzari, 2020). Motion sickness can be provoked by active head movements in the presence of vestibular motion during ground, air or sea transportation and in visually induced stimulation such as video games on large screens, three-dimensional movies and...
virtual reality (Abouzari, 2020). One specific event called vection, or sensory-spatial illusion, may create false sensations of self-motion, leading to visual motion sickness and postural status (Abouzari, 2020; Krueger, 2017). Also, in patients with vestibular migraine complaining of motion sickness during childhood and puberty, a large reduction in perceptual motion thresholds, abnormalities in the perception of head motion and an increased susceptibility to visual motions have been found (Lewis, 2011).

One special situation to consider in patients with motion sickness and vestibular migraine is that individuals presenting both conditions have severe and more intense episodes compared to patients only diagnosed with motion sickness (Lipson, 2020). In addition to this clinical finding, testing abnormalities, mainly in abnormal rotatory testing and ocular vestibular evoked myogenic potentials (oVEMP) testing, indicate an increased risk of utricular impairment and horizontal plane disturbances leading to more visual and sensorial mismatch (Lipson, 2020; Strupp, 2018). Other vestibular testing abnormalities in children with motion sickness are seen in the subjective visual, mainly in younger children 2–7 years old (Schnabel, 2022). These results seem to improve when these individuals approach puberty (Schnabel, 2022). In patients with motion sickness, there is a limitation attributed to parallel receptive feedback about the true earth vertical sensed by the otoliths and somatosensors that counteracts the misleading visual information given by motion (Dichgans, 1998).

Other common clinical situations that may lead to increased episodes of severe motion sickness include benign paroxysmal torticollis of infancy, benign paroxysmal vertigo of childhood, otitis media and motor delay (Strupp, 2018). Other less common situations include Eustachian tube dysfunction, a history of global developmental delay, sensory processing disorder, sensorineural hearing loss, congenital cochlear vestibulopathy, central vestibulopathy, cerebral palsy and epilepsy (Strupp, 2018). Even though they are described, further studies with clinical, neurologic and audio-vestibular testing are needed.

The treatment presents several challenges, as different approaches have been released and tested over the last years. Pharmacologic treatments such as ondansetron, cyproheptadine and meclizine have been described in the United States, only demonstrating increased symptom relief and improvement during travel with cyproheptadine, followed by meclizine and less improvement with ondansetron use (Strupp, 2018). Other strategies with described improvement are vestibular rehabilitation and, in a few patients, tympanostomy tubes (Strupp, 2018). For other strategies, such as acupressure wristbands and car seat position, the evidence is controversial (Strupp, 2018). Next, some of the pharmacologic and vestibular rehabilitation strategies currently used will be described.

**Considerations in Treatment and Prevention**

Motion sickness may be prevented and treated using some specific strategies such as nonpharmacologic treatment, pharmacologic treatment and adaptation therapies (Chan, 2006).

Prevention includes some practices that can be used during short and long transportation. Those include the use of pediatric adaptable and movable chairs; focusing on an object on the horizon while riding in a car, bus or on a bicycle; avoiding reading or participating in games that require visual fixation; avoiding night travel; using sunglasses during the day (to reduce visual stimulation); sleeping while traveling; leaning in the direction of curves while riding in a car; avoiding disgusting odors; allowing adequate ventilation; making stops during long trips; playing music during long road trips; avoiding smoking; maintaining hydration by drinking water; and eating small meals frequently (Drugs Ther. Pers., 2001).

Pharmacologic treatment includes suppressive medications targeted to the functioning of the vestibular pathway, diminishing the sensory input, and resolving conflicts between the vestibular, visual, and other proprioceptive systems (Gordon, 1999). Antihistamines, anticholinergics and antidopaminergics are the most common pharmacologic treatments used (Drugs Ther. Pers., 2001).

Anticholinergics are some of the most common medications used in children and in adults for motion sickness. Scopolamine is the most effective medication for motion sickness. Its use is not recommended for children under 12 years old (Drugs Ther. Pers., 2001). This medication can be used with Transderm Scop, which is an adhesive patch that is placed behind the ear. Its prophylactic use usually takes 6–8 hours after its placement, and its medication can be released over a three-day period. It is recommended during ship and airplane trips (Schnabel, 2022; Gil, 2005).

Antihistamines are frequently used for motion sickness in the pediatric population. These include cyclizine, dimenhydrinate, meclizine and promethazine (Lewis, 2011). Dimenhydrinate is the most common medication used for children (Lewis, 2011). Cyclizine and dimenhydrinate are two major ones. Although using antihistamines to treat motion sickness in children is considered off-label, for children 2–12 years old, dimenhydrinate (Dramamine), 1–1.5 mg/kg per dose, or diphenhydramine (Benadryl), 0.5–1 mg/kg per dose up to 25 mg, can be given once before travel and every six hours during the trip (Dichgans, 1972).

Diphenhydramine is an antihistaminic used for respiratory and skin allergies. It is commonly used for motion sickness 30 minutes before traveling. Recommended doses are 5 mg/kg/day (2.5 mg/ml) every 6–8 hours. For children 3–5 years old: 5 ml every 8 hours (maximum dose 37.5 mg/day). For children 6–12 years old: 5 ml every 6 hours (maximum dose 150 mg/day) (Schnabel, 2022).

Cinnarizine is commonly used for teenagers. For children 5–12 years old, 2.5 drops every hour is recommended (Drugs Ther. Pers., 2001).

**Adaptation Therapy**

Adaptation over time to sickness-inducing stimuli has been reported to be one of the most effective methods for the long-term prevention of motion sickness. Repetitive exposure to stimuli results in a diminished response toward them. This is called habituation. It is the most effective strategy used in vestibular rehabilitation in the pediatric population with motion sickness, and it presents better long-term results with continued follow-up; however, at least 5% of children do not present any improvement with this therapy (Drugs Ther. Pers., 2001). Habituation strategies, cognitive behavioral therapy and mindfulness are used in motion sickness treatment for symptom relief (Drugs Ther. Pers., 2001). Vestibular rehabilitation is commonly used to achieve self-confidence in short and long periods (Abouzari, 2020).
trips, preserve the vestibulo-ocular reflex and maintain adequate movements on the horizontal plane (Drugs Ther. Pers, 2001). To achieve this goal, optokinetic exercises are commonly used (Drugs Ther. Pers, 2001). Nowadays, there are several developments with adapted devices for children that are being researched. One of them is goggles composed of bores containing free liquid that moves along with head movements [10,12]. Their development and use are still being researched.

Limitations of this narrative review include the lack of available studies focused on motion sickness in children. Prospective and cohort studies are needed to evaluate the progression over the time of this disorder, the implications on adulthood and the relationship with other vestibular disorders after puberty. Further studies in animal models are needed to support some clinical findings on the vestibular and central nervous systems perceived in children and teenagers.

CONCLUSION

Motion sickness is one of the most common vestibular disorders seen in pediatric populations, but it still poses a challenge for clinicians regarding diagnosis, therapeutics, and rehabilitation. The involvement of central nervous and vestibular systems seems to be critical in the development of symptoms from the first years of life. Vestibular rehabilitation and pharmacologic strategies are still being researched and are focused on symptom relief. Further experimental and prospective studies are in need to get a better understanding of motion sickness in children.

REFERENCES