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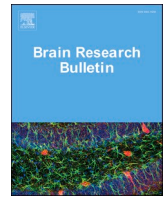
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Research report

Motion sickness and visual impairment

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ABSTRACT

Motion sickness (MS) is caused by exposure to unfamiliar movements. The theory is that MS is due to a conflict between information perceived by the vestibular, visual, and somatosensory systems. This study examines the role of vision in MS by comparing MS susceptibility among individuals with varying degrees of visual impairments to sighted individuals. We hypothesized that subjects with no perception of light would be less susceptible to MS than less impaired subjects, who would themselves be less susceptible than sighted subjects. To address these, the Motion Sickness Susceptibility Questionnaire (MSSQ¹) was administered to 340 subjects (170 visually impaired paired with 170 sighted subjects) to assess their susceptibility to various modes of transport under real conditions. Visually impaired subjects were divided into subgroups according to the presence (partially sighted) or absence (totally blind) of light perception, as well as the period of onset of impairment (congenital or acquired). Totally blind individuals are significantly less susceptible to MS than partially sighted ($p = 0.001$), and sighted ($p < 0.001$) subjects, with no difference between partially sighted and sighted subjects ($p = 0.526$). Additionally, acquired totally blind subjects are less susceptible to MS than congenitally blind subjects ($p = 0.038$). Thus, despite a lower susceptibility totally blind subjects may still be susceptible to MS. The absence of vision reduces MS susceptibility but does not completely prevent it. This suggests that vision is more a mediator, than an essential condition for MS appearance.

1. Introduction

Motion sickness (MS) is a discomfort caused by physical (e.g., car, boat, etc) or visual motion (Visually Induced Motion Sickness, VIMS, e.g., virtual reality, IMAX film, etc.), simulating sensory systems (visual, somatosensory, vestibular) (Golding, 2016). MS symptoms fall into four categories: gastrointestinal disorders, thermoregulatory disorders, dizziness/headaches, and decreased arousal (Sopite syndrome) (Cha et al., 2021). Susceptibility varies by environment, transportation type, and individual characteristics. For instance, age influences susceptibility: very young children are generally unaffected, but it appears around ages 6–7, peaks at 10, and decreases from adolescence into adulthood (Golding, 2006). Some authors suggest susceptibility continues to decline throughout life, but it might be due to avoiding modes of transportation that cause MS (Golding, 2006; Lamb and Kwok, 2015; Paillard et al., 2013). Sex is also important, with females generally more susceptible than males (Mittelstaedt, 2020).

The main explanation for MS is the sensory conflict theory (Reason, 1978; Reason and Brand, 1975). MS occurs when the brain receives conflicting information about body movements from different sensory

systems (visual, vestibular, and somatosensory). Sensory information forms a perceived movement model, which the central nervous system compares to an internal model based on past experiences and multi-sensory expectations. If the perceived and internal models match, the motion is perceived correctly. If they diverge, MS symptoms occur. Thus, according to the sensory conflict model, MS is related to the coherence of information from different sensory systems.

Studies on patients with vestibular system dysfunctions highlight the inner ear's prominent role in MS susceptibility. Individuals with complete bilateral vestibulopathy are less susceptible to MS, while those with unilateral vestibulopathy are more susceptible than the control population (Paillard et al., 2013; Johnson et al., 1999; Murdin et al., 2015). Conversely, the visual system is generally regarded as a modulator (Golding, 2017; Graybiel, 1970). Yet, the visual system contributes to the visual-vestibular conflict (Reason, 1978), and visual stimulation alone can induce MS (VIMS) (Chen et al., 2016). Furthermore, gaze orientation is crucial in reducing MS, such as looking outward during travel or being on deck to observe ship movements relative to the horizon (Turner and Griffin, 1999). Providing additional visual information about motion can also help reduce MS (de Thierry de Faletans et al.,

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2024; Emond et al., 2023). Thus, consistent visual and vestibular can reduce MS, while discordance can exacerbate it.

Several studies have examined the effect of vision absence on MS in sighted individuals by comparing symptoms in different conditions: eyes open with an outside view, eyes open with an inside vehicle view, and blindfolded. Some authors found that removing visual information reduces MS compared to an inside vehicle view (Bos et al., 2005; Ishak et al., 2018; Probst et al., 1982), while others found no difference (Butler and Griffin, 2006; Griffin and Newman, 2004; Mills and Griffin, 2000). Most studies concluded that subjects experienced more symptoms with eyes closed than with an outside view (Probst et al., 1982; Griffin and Newman, 2004; Mills and Griffin, 2000; Butler and Griffin, 2009). According to Bos et al. (Bos et al., 2005), MS intensity increases when visual and vestibular information diverges (eyes open indoors), and decreases when they converge (eyes open outdoors). When only vestibular information is available (blindfold), MS may reach an intermediate level.

In this context, the susceptibility of visually impaired individuals to MS is a pertinent question due to differences in the central nervous system's anatomical and functional organization of the central nervous system between visually and non-visually impaired subjects. Visual deprivation induces neuronal circuit reorganization in intact sensory systems (intramodal plasticity), and in structures that normally process visual information (intermodal plasticity) (Röder et al., 2021). This compensates for the loss of visual functions needed for movement perception and postural control by other senses, like the somatosensory system (Parreira et al., 2017). Similarly, occipital areas, typically processing visual information, can be activated by tactile or auditory stimuli (Bedny et al., 2010; Ricciardi et al., 2007). Consequently, internal movement models based on past experiences may differ in visually impaired individuals due to disturbances or the absence of visual memory, which may lead to changes in sensory conflict.

To our knowledge, only one study has compared susceptibility to MS between visually impaired and sighted individuals using Coriolis stimulation, finding no difference between the groups (Graybiel, 1970). The authors concluded that vision is secondary in MS onset. However, this study included subjects with varying degrees of visual impairments, from partial sight to total congenital blindness, and had a small sample size (12 subjects), preventing grouping by severity (low vision or blindness) or onset of impairment (congenital or acquired). Nevertheless, the variety of visual impairments may impact the formation of perceived and internal movement patterns differently, which may affect the resulting sensory conflict.

This study aimed to examine the role of vision in MS by comparing the susceptibility among individuals with varying degrees of visual impairments to sighted individuals. This study addressed two main questions: (i) Is there a difference in MS susceptibility between visually impaired and sighted individuals?; (ii) Is there a difference between congenital and acquired total blindness regarding MS susceptibility? The hypotheses were: (1) Individuals with total blindness will be less susceptible to MS than partially sighted subjects, who are themselves less susceptible than sighted subjects, due to less visual information conflicting with other sensory systems; (2) Individuals with congenital total blindness will be less susceptible to MS than those who become blind later in life, as they lack visual memory that could create conflicts with other senses.

2. Methods

2.1. Study design

An online questionnaire was created using LimeSurvey (Engard, N.C. LimeSurvey. Available online: <http://limesurvey.org>, accessed on 15 May 2015). It is a secure online survey tool for research institutes. All the data were collected prospectively during 2023 (between March and December) in French and French-speaking countries. The entire

questionnaire was anonymous and required approximately 15 minutes to complete. It was e-mailed to representatives of various French-speaking organizations and associations for the visually impaired, who were free to distribute it to their members. Due to the participants' disabilities, special attention was given to the accessibility of the questionnaire. Particular attention was paid to the choice of typeface, color, contrast, and character size. The questionnaire was compatible with the use of zoom tools, screen reader software, and keyboard navigation was also possible. The accessibility of the questionnaire was tested by two visually impaired people using different assistive tools and by a company that develops assistive technology for people with visual impairments. If participants encountered difficulties completing the questionnaire, they could also contact one of the experimenters to complete it by phone.

The first part of the questionnaire included questions about the participants' characteristics (age, sex, height, weight, etc). The second part addressed questions related to their visual impairment (severity, onset, progression, etc). Finally, the last part focused on evaluating susceptibility to MS using the Motion Sickness Susceptibility Questionnaire (MSSQ (Golding, 2006)). The MSSQ is a reliable tool for predicting individual differences in susceptibility to MS. This questionnaire assesses participants' susceptibility to MS by considering susceptibility during childhood (MSA score, <12 years) and susceptibility in adulthood (MSB score, over the past 10 years) based on various modes of transportation and entertainment experienced (car, bus, train, airplane, small boat, ships, swings in playgrounds, roundabouts in playgrounds, big dippers/funfair rides). For all modes of transport and entertainment, subjects were asked how often they felt sick or nauseous. Subjects can answer on a 5-point scale: not applicable/ never traveled, never felt sick, rarely felt sick, sometimes felt sick, frequently felt sick. Responses were evaluated as follows: 0 = never felt sick, 1 = rarely felt sick, 2 = sometimes felt sick, 3 = frequently felt sick. MSA and MSB scores were calculated using the formula given by Golding, 2006a. A total MSSQ score is also calculated by summing the MSA and MSB scores. Regarding the psychometric properties of the MSSQ in the general population, the MSA score is significantly higher than the MSB score, and the two sub-scores are significantly correlated (Lamb and Kwok, 2015; Golding, 2006).

2.2. Participants

Three hundred and forty subjects took part in this study: 170 visually impaired (103 females, mean age: 46.2 ± 18, Body Mass Index (BMI): 25.8 ± 6.0) and 170 sighted subjects (group S, 103 females, mean age: 45.8 ± 17.7, BMI: 24.5 ± 4.2) matched for sex, age, and BMI. They were recruited from the university community, associations, or federations comprising individuals with visual impairments in various French-speaking countries. Subjects had to be over 18 years old, not diagnosed with vestibular disorders, or consume antihistamines. Sighted subjects had to have normal or corrected-to-normal vision whereas visually impaired subjects needed to have a visual impairment as defined by the World Health Organization (2022) and diagnosed by a medical doctor. In this study, we separated the visually impaired subjects into groups of totally blind (total absence of light perception) and partially sighted (including low vision and near-total blindness), because we aimed to evaluate the effect of the total lack of light perception compared to the presence of some visual information and normal vision (Fig. 1). 130 subjects were Partially sighted (P group, 88 females, mean age: 44.2 ± 17.8, BMI: 25.4 ± 5.8), and 40 subjects had total Blindness (group B, 15 females, mean age: 52.4 ± 16.9, BMI: 27.1 ± 6.9). Among the subjects with total blindness, 23 had Congenital total Blindness (group CB, 10 females, mean age: 48.9 ± 16.7, BMI: 27.3 ± 7.6), and 17 had Acquired total Blindness (group AB, 5 females, mean age: 57.3 ± 16.3, BMI: 26.6 ± 6.4). All subjects provided voluntary and informed consent to participate in the questionnaire and were free to withdraw at any time. This study was conducted in accordance with the

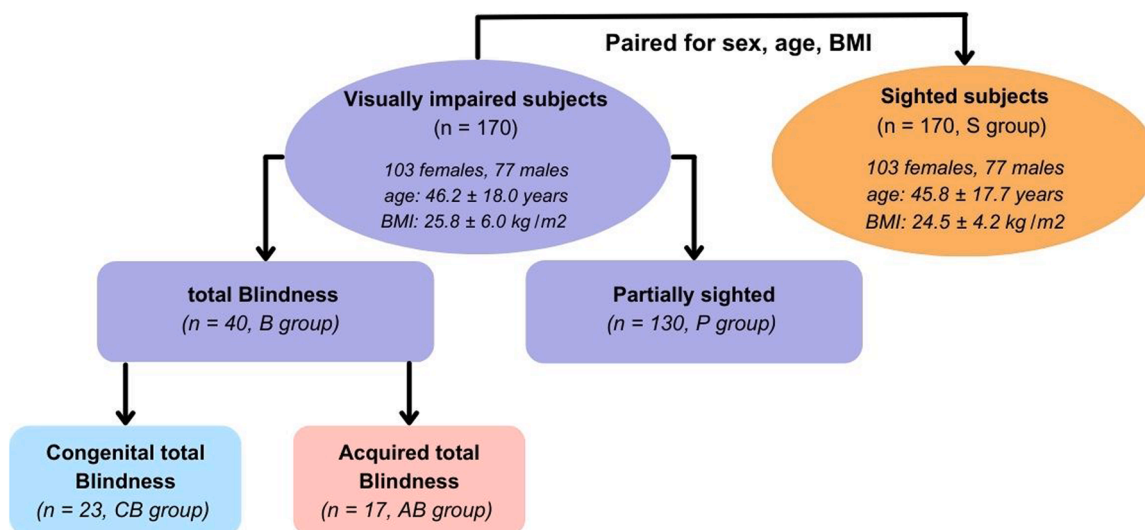


Fig. 1. Distribution of subjects in the different subgroups according to their visual impairment. *n* = number of subjects in the group, BMI = body mass index. Age and BMI are presented as mean ± standard deviation.

Declaration of Helsinki and approved by a National Ethics Committee (IRB 00012476–2023–17–02–231) before commencement.

2.3. Statistical analysis

Analyses were performed on JAMOVI (version 2.0.0.0). Shapiro-Wilk test showed that the data did not meet the conditions for normality. So, the relationships between MSA and MSB within each group were assessed by Spearman correlations and Wilcoxon tests. A Kruskal Wallis followed by Dwass-Steel-Critchlow-Fligner post hoc was performed to compare susceptibility between the 3 groups (S, B, P). Mann-Whitney test was used to compare susceptibility between CB and AB. The significance level was set at $p < 0.05$ ($* < 0.05$, $** < 0.01$, $*** < 0.001$). Effect sizes (ES) based on standardized differences between mean scores were calculated to examine the magnitude of such differences. ES were calculated using epsilon squared for Kruskal Wallis and interpreted as follows: $ES < 0.01$ [trivial], 0.01–0.06 [small effect], 0.06–0.14 [medium effect], and > 0.14 [large effect]; and rank-biserial correlation for Mann-Whitney and Wilcoxon’s test interpreted as $ES < 0.1$ [trivial], 0.1–0.3 [small effect], 0.3–0.5 [medium effect], and > 0.5 [large effect].

Table 1
Mean values and standard deviations of MSA, MSB, and MSSQ scores for each group.

Groups	MSA mean (SD)	MSB mean (SD)	p-value (ES)	MSSQ mean (SD)	MSA/MSB correlations
S (n=170)	8.79 (6.9)	6.99 (6.9)	$<0.001^{***}$ (0.502)	15.77 (13.0)	$r = 0.736$ ($p < 0.001$) ***
P (n=130)	8.20 (8.4)	7.48 (7.6)	0.054 (0.227)	15.68 (15.4)	$r = 0.803$ ($p < 0.001$) ***
B (n=40)	3.84 (5.3)	2.54 (4.0)	0.032^* (0.503)	6.38 (8.5)	$r = 0.594$ ($p < 0.001$) ***
CB (n=23)	4.08 (4.8)	3.76 (4.4)	0.507 (0.190)	7.84 (8.7)	$r = 0.694$ ($p < 0.001$) ***
AB (n=17)	3.51 (6.1)	0.88 (2.8)	0.022^* (1.0)	4.40 (8.1)	$r = 0.505$ ($p = 0.037$) *

* $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$. S: Sighted subject group; P: Partially sighted; B: total Blindness; CB: Congenital total Blindness; AB: Acquired total Blindness. MSA: Motion sickness Susceptibility child, MSB: Motion sickness Susceptibility Adult, MSSQ: Motion Sickness Susceptibility Questionnaire, SD: Standard Deviation, ES: Effect Size.

3. Results

3.1. Psychometric proprieties of the MSSQ and intra-group comparison

MSA and MSB scores were positively correlated for all groups (Table 1) and the MSA score was significantly higher than the MSB score (Table 1), except for the CB group which did not show a significant difference between MSA and MSB scores (a strong tendency for the P group).

MSSQ score was weakly negatively correlated with age in sighted subjects ($r = -0.188$, $p = 0.014$) and visually impaired subjects ($r = -0.163$, $p = 0.034$; Fig. 2A). MSSQ score was significantly higher for females than for males in the sighted group ($U = 2012$, $p < 0.001$, $ES = 0.417$ [medium effect], females: 19.5 ± 13.7 , males: 10.1 ± 9.40) and in the visually impaired group ($U = 2185$, $p < 0.001$, $ES = 0.367$ [medium effect], females: 16.9 ± 15.4 , males: 8.23 ± 11.7 ; Fig. 2B).

3.2. Susceptibility to MS according to the level of visual information available (hypothesis 1)

MSSQ score was significantly different according to the level of visual information available (groups S, P, and B) ($H(2) = 21.9$, $p < 0.001$, $\epsilon^2 = 0.064$ [medium effect]). Post hoc analysis showed that B group was significantly less susceptible to MS than S group ($p < 0.001$), and P group ($p = 0.001$), but there was no difference between P and S groups ($p = 0.526$, Fig. 3A). Similar results were observed when comparing MSA (H

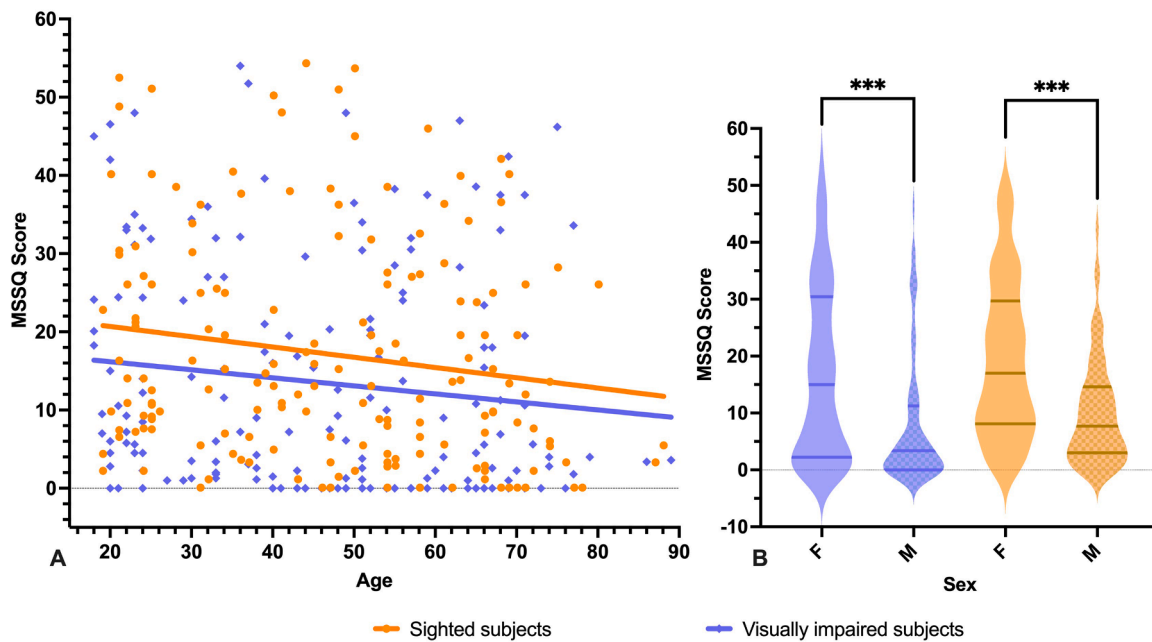


Fig. 2. : Graph A shows the correlations between age and MSSQ score for sighted (orange circles) and visually impaired subjects (purple diamonds). Graph B shows a plot with median and quartiles 1 and 3 for MSSQ scores as a function of sex for sighted subjects (orange) and visually impaired subjects (purple). *** $p < 0.001$; MSSQ: Motion Sickness Susceptibility Questionnaire, F: Females, M: Males.

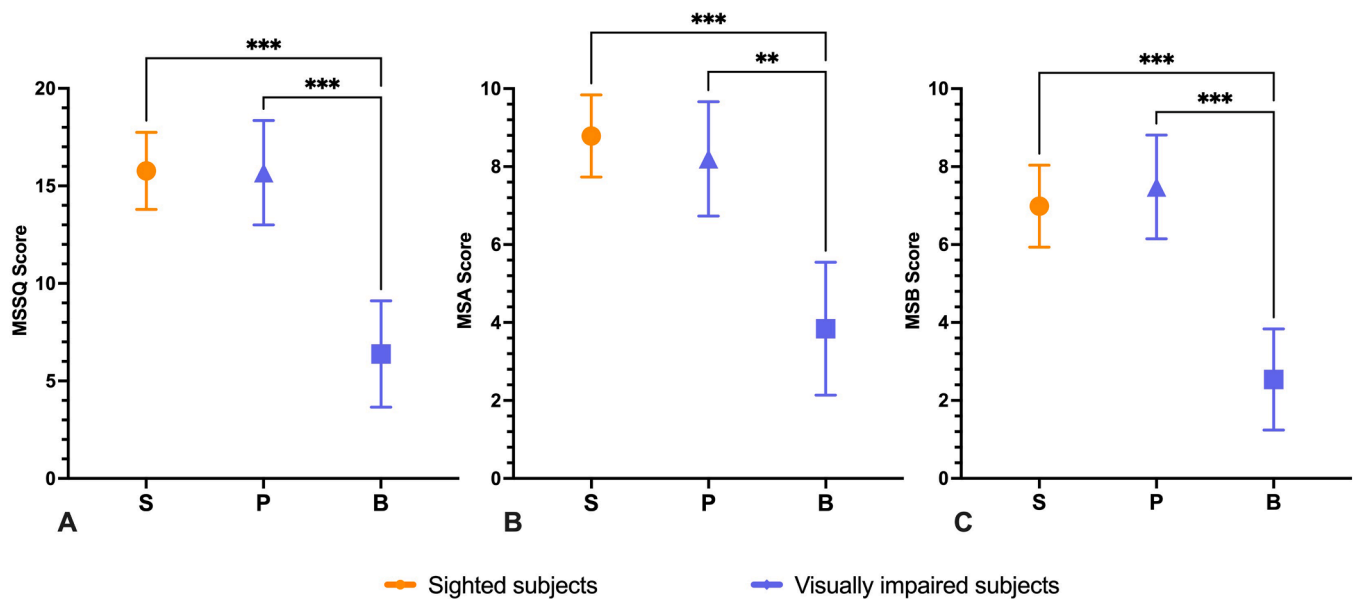


Fig. 3. : Means and error bars of 95 % CIs for MSSQ (graph A), MSA (graph B), and MSB (graph C) scores, according to groups. S: Sighted subjects (orange circles), P: Partially sighted subjects (purple triangles), and B: total Blindness subjects (purple squares). * $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$; MSA: Motion sickness Susceptibility child, MSB: Motion sickness Susceptibility adult, MSSQ: Motion Sickness Susceptibility Questionnaire.

(2) = 19.9, $p < 0.001$, $\epsilon^2 = 0.058$) and MSB ($H(2) = 20.3$, $p < 0.001$, $\epsilon^2 = 0.060$) scores between groups. The results of post hoc analyses for MSA and MSB scores are shown in Figs. 3B and 3C.

3.3. Susceptibility to MS according to the period of total vision loss (hypothesis 2)

The average age of total vision loss in the AB group was 26 ± 18 years. MSA score was not significantly different according to the period of total vision loss (groups AB and CB) ($U = 158$, $p = 0.288$, $ES = 0.192$ [small effect], Fig. 4B). However, MSSQ score was significantly higher in

CB group than on AB group ($U = 121$, $p = 0.038$, $ES = 0.381$ [medium effect], Fig. 4A). Similarly, the MSB scores was significantly higher in CB group than in AB group ($U = 96.0$, $p = 0.003$, $ES = 0.509$ [large effect]). So, CB subjects had a greater susceptibility to MS in adulthood than AB subjects (Fig. 3C). Of the 17 subjects in group AB, 88 % had an MSB score of 0 (only 2 subjects had a higher score), whereas, of the 23 subjects in group CB, 35 % had an MSB score of 0. The chi-square test revealed that this difference in frequency was significant ($\chi^2(1, n = 40) = 11.4$, $p < 0.001$).

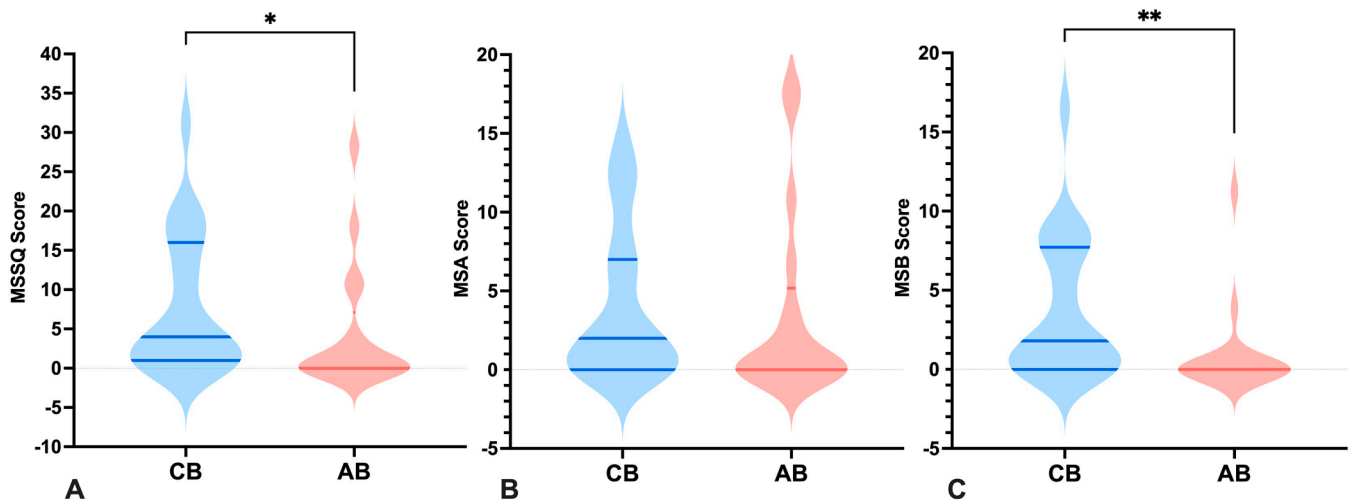


Fig. 4. Plot with median and quartiles 1 and 3 for MSSQ (graph A), MSA (graph B), and MSB (graph C) scores, according to groups. CB: Congenital total Blindness (blue), AB: Acquired total Blindness (red). * $p < 0.05$, ** $p < 0.01$; MSA: Motion sickness Susceptibility child, MSB: Motion sickness Susceptibility Adult, MSSQ: Motion Sickness Susceptibility Questionnaire.

4. Discussion

The major findings of this study show that subjects with total blindness are less susceptible to MS than partially sighted and sighted subjects. However, there is no difference in susceptibility between partially sighted and sighted subjects. The results also show that the onset period of total blindness (congenital or acquired) influences MS susceptibility. These raise the question of the possible role of vision as a modulator in MS susceptibility.

Our study population aligns with existing literature on the psychometric properties of the MSSQ. Consistent with previous findings, MSA and MSB scores were significantly correlated, susceptibility to MS was higher in females than in males, and higher in childhood (MSA) than adulthood (MSB) (Lamb and Kwok, 2015; Golding, 2006) in both sighted and visually impaired subjects. Similar to Paillard et al., we found a weak correlation between increasing age in adults and reduced MS in both groups (Paillard et al., 2013). Interestingly, totally blind subjects showed no correlation between age and MS susceptibility ($r = -0.016$, $p = 0.921$), suggesting a role of the visual system in the age-related decrease. Notably, only subjects with congenital total blindness showed no significant difference between childhood and adulthood scores, indicating stable MS susceptibility across these periods. These results suggest vision influences MS susceptibility in adulthood, but also between childhood and adulthood.

4.1. Susceptibility to MS according to the level of visual information available

Our first hypothesis, based on sensory conflict theory, expected that MS susceptibility would be linked to the amount of available visual information, with sighted subjects being more susceptible than partially sighted who would be more susceptible than totally blind subjects. Our results did not show a difference in MS susceptibility between sighted and partially sighted groups, aligning with Graybiel (1970) findings that visually impaired and sighted individuals did not differ in MS susceptibility when exposed to Coriolis accelerations. However, we observe a significant reduction in MS susceptibility in total blind subjects compared to partially sighted and sighted subjects. The small number of subjects (12 visually impaired including only 2 with total blindness), coupled with the interindividual variability related to MS, is likely one of the reasons that these authors did not highlight this difference. In our study, the MSSQ score for totally blind subjects was half that of partially sighted and sighted groups. These findings support sensory conflict

theory, suggesting that MS arises from conflicts between different sensory inputs during movement, particularly the visual-vestibular conflict (Reason, 1978; Reason and Brand, 1975). Without visual information during transportation, visual conflict with other sensory systems is weaker or absent.

However, some subjects with total blindness still reported MS symptoms, as 62 % of them had a susceptibility score greater than 0. Despite a reduction, symptoms in this group *can be explained* by a reduced, but still present, visual-vestibular conflict between the lack of visual input and the presence of vestibular information related to movement. Indeed, a sensory conflict can occur in three situations: (1) receptors A and B both indicate movement, but it is perceived differently (e.g. looking out the rear window of a moving vehicle); (2) receptor A detects movement, but receptor B does not (e.g., VIMS); (3) receptor B detects a movement, but receptor A does not (e.g., reading a book in a moving vehicle) (Reason, 1978). Another explanation might be a sensory conflict unrelated to vision, such as an intra-sensory conflict between different structures of the inner ear. Intra-vestibular conflict can occur when inputs from the semicircular canals, which provide information about head rotation, do not align with changes in the gravito-inertial force detected by the otolithic organs. This occurs, for instance, when turning the head around a non-vertical axis during rotation around the Earth's vertical axis (known as the Coriolis effect (Reason, 1978; Bertolini and Straumann, 2016)). Graybiel (Graybiel, 1970) may not have found a difference in susceptibility between groups because they used Coriolis stimulations, which create intra-vestibular conflict rather than a visual-vestibular conflict. This approach might not have captured the effect of the absence of vision on sensory conflicts. Finally, "blindsight" might still be present in subjects from our total blindness group. Defined by Weiskrantz et al., blindsight is the ability of some blind individuals to respond to motion stimuli presented in their blind field without consciously perceiving them (Weiskrantz et al., 1974). This phenomenon could influence posture, orientation, and locomotion, potentially causing visual-vestibular conflict even in those who do not report conscious vision.

4.2. Susceptibility to MS according to the period of total vision loss

Regarding the second hypothesis, we proposed that individuals with congenital total blindness would be less susceptible to MS than those who become totally blind later in life due to the absence of visual memory that could contribute to sensory conflict. Contrary to this, the results show lower susceptibility to MS in adulthood (MSB) among those

who acquired total blindness compared to those with congenital total blindness. The average age of total vision loss in the acquired total blindness group is 26 ± 18 years, which aligns with observing effects in the MSB score but not in MSA score. This suggests that vision loss occurring later in life may lead to less susceptibility to MS compared to congenital total blindness. Differences in the neuroplasticity mechanisms between congenitally blind and late blind individuals have been noted (Röder et al., 2021; Voss, 2013) and can explain this result. For example, Schwesig et al., found that the somatosensory and vestibular systems can compensate for the loss of vision, but these compensatory mechanisms are more effective in congenitally blind individuals than in those with late blindness (Schwesig et al., 2011). Bedny et al., demonstrated that the middle temporal cortex, which perceives visual motion, can respond to auditory stimuli in congenitally blind individuals but not in those with late blindness or sighted individuals (Bedny et al., 2010). This indicates a sensitive period for neural network development, where early visual experiences are crucial for the specialization of some visual areas (Röder et al., 2021; Bedny et al., 2010; Voss, 2013). Once specialized, these areas remain unchanged even after prolonged blindness. Thus, in congenitally blind individuals, early development of intramodal and intermodal plasticity leads to an atypical neural network organization (Röder et al., 2021) and the specialization of some visual areas for processing other sensory information. Consequently, movement perception and MS in congenitally blind individuals may primarily involve conflicts between intact sensory systems, such as somatosensory and vestibular systems. In contrast, individuals with late blindness rely on compensatory plasticity through the reorganization of existing visual connections (Röder et al., 2021). Studies show that late-blind individuals continue to use visual-spatial concepts (Röder et al., 2004), suggesting that they still incorporate previously acquired visual information into their internal movement models. Thus, after losing their vision, they find themselves in a sensory conflict situation similar to that of sighted individuals who are blindfolded (Bos et al., 2005; Ishak et al., 2018).

Another explanation is that individuals with congenital total blindness lack vestibulo-ocular reflexes, whereas this reflex is altered but still present in those with acquired blindness (Kömpf and Piper, 1987; Leigh and Zee, 1980; Sherman and Keller, 1986). Thus, congenital blindness individuals cannot initiate voluntary eye saccades and experience the nystagmus phase (Kömpf and Piper, 1987; Leigh and Zee, 1980). Ebenholtz et al., proposed that MS could be induced by inappropriate eye movements that stimulate the vagus nerve through extraocular muscle afferents (Ebenholtz et al., 1994). Authors have shown that reducing nystagmus might alleviate MS symptoms (Flanagan et al., 2002; Krueger, 2017). Unfortunately, this remains hypotheses, as our questionnaire did not inquire about nystagmus or the presence of blindsight.

4.3. Limitations and perspectives

Since this study is based on questionnaires, there is a potential for selection bias among respondents. Those with high MS symptoms might have been more likely to respond to the questionnaire, potentially artificially increasing the scores. Nevertheless, observed group differences suggest a genuine variation in susceptibility, which could be confirmed with a larger sample. The median MSSQ score for the sighted group was 12.4, with a 25th percentile at 5.1 and a 75th percentile at 24.0. These scores are close to those reported by Lamb and Kwok (2015), who presented new MSSQ norms on a sample of 1711 subjects from the general population averaging 40.4 years old. This indicates that our sample is representative of MS susceptibility in sighted individuals. Finally, despite medium to large effect sizes, the small sample sizes and sex disparities within the congenital and acquired total blindness subgroups should be considered when interpreting the results. Similarly, it's important to keep in mind that other elements can influence participants' experiences with MS (Mittelstaedt, 2020). These include

psychological factors such as anxiety and a person's expectations regarding their susceptibility, which can exacerbate the occurrence of symptoms. Fatigue or food intake before and during exposure to movement, as do environmental factors, such as the type of movement also plays a role in the onset of symptoms. For example, considering their disability, visually impaired subjects may have been less exposed to various modes of transport compared to sighted subjects, which may have influenced their susceptibility.

For future research, directly assessing MS susceptibility in partially sighted and totally blind individuals through controlled motion tests in a laboratory setting would be valuable. This should include precise visual impairment assessments by a medical doctor to evaluate effects across different subgroups of visual deficiencies. Correlating these results with the presence of nystagmus would also be beneficial. Additionally, electroencephalography measurements in completely blind subjects could help to evaluate electrical activity in the occipital areas during visual stimulation, assess plasticity mechanisms, and test for blindsight. The aim would be to identify any links between MS and blindsight.

5. Conclusion

This study examines the role of vision in MS by comparing the susceptibility among blind, partially sighted, and sighted subjects. The complete absence of vision significantly reduced susceptibility to MS, confirming the important role of vision in the genesis of MS, in line with the sensory conflict theory. However, some totally blind subjects still reported non-zero susceptibility, suggesting that vision is a key factor but it not essential for MS to occur. This indicates that other sensory conflicts could also be involved and highlights the potential for developing non-visual MS reduction devices.

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CRediT authorship contribution statement

Camille de Thierry de Faletans: Writing – original draft, Methodology, Investigation, Formal analysis, Data curation, Conceptualization. **Pascale Duché:** Writing – review & editing, Supervision, Resources, Project administration. **Eric Watelain:** Writing – review & editing, Supervision, Methodology, Funding acquisition, Conceptualization.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Data Availability

Data will be made available on request.

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