

Research Paper

Modulating Factors in the Development of Motion Sickness in Transportation Vehicles: Malaysia Case Study

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Abstract

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Motion sickness (MS) is a common issue for vehicle passengers, characterized by symptoms such as nausea, dizziness, and discomfort due to sensory conflicts between the visual and vestibular systems. This study aims to identify and quantify the modulating factors contributing to MS in vehicles within the Malaysian context. A systematic questionnaire was conducted, incorporating subjective feedback from 634 participants. The results highlight key factors like seating position, visual activities, and environmental conditions that influence MS susceptibility showing the most prominent factors are from Visual Activity with a mean of 3.44 among the others contributing most susceptibility from the activities of Reading (83.2%) and Writing (79.2%). Older people and females seemed to report greater susceptibility to motion sickness. This vulnerability is shown to increase with age as those 45+ years and above show the highest susceptibility, reporting a 69% rate on curvy roads and 66% during reading, in contrast with those between 18-29 who report a 52% and 50% susceptibility rate. Females again reported consistently higher rates than males, with the difference being larger in situations involving rear-facing seating or tasks requiring significant visual focus, such as reading (female 63% vs. male 46%) and driving on curvy roads (female 68% vs. male 50%). These factors of rear-facing seating and tasks involving intense visual focus, like reading or watching videos, were the strongest modulators identified, with a strong aggravating influence on symptoms across all groups. The findings provide crucial baselines for engineering future vehicle layouts, optimizing cabin climate systems, and designing targeted mitigation systems required to support human comfort and accelerate Automated Vehicle (AV) adoption in developing transport infrastructures.

Keywords: Motion sickness; Modulating factors; Sensory conflict, Susceptibility; Comfort

1. Introduction

AVs are emerging as a transformative technology to revolutionise transportation systems. By reducing the need for active driving, AVs provide the potential for safer roads, improved efficiency, and a reduction in the environmental footprint of commuting. These vehicles allow passengers to engage in Non-

Driving Related Tasks (NDRTs) such as working, reading, or entertainment during transit, enhancing productivity and the overall value of travel time. This shift from driver-centric to passenger-centric design is driving innovations in seat layouts and user interfaces. However, as AVs transition from concept to reality, they bring new challenges related to passenger experience,



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particularly motion sickness (MS), which could hinder their widespread adoption [1].

MS arises when a mismatch occurs between sensory inputs—primarily visual, vestibular, and proprioceptive systems—and the brain's expectations based on prior experiences. This phenomenon, explained by sensory conflict theory, is particularly prevalent among passengers in AVs due to their passive roles in anticipating motion [2]. Symptoms range from mild discomfort, such as drowsiness and pallor, to severe reactions like nausea and emesis. While drivers in traditional vehicles rarely experience MS due to their active engagement with vehicle dynamics, AV passengers are more susceptible, especially when exposed to horizontal accelerations during braking, cornering, or lane changes [3]. The unique nature of AV motion and environments demands a deeper understanding of factors affecting the MS development by investigating the current experience when using different transportation modes.

Several modulating factors are found to influence the onset and severity of MS, such as seating orientation, visual engagement, and individual characteristics. Rearward-facing seats, for example, prevent passengers from anticipating motion, leading to increased sensory conflict and higher rates of MS [1]. Similarly, visual tasks such as reading or using mobile devices exacerbate sensory mismatches, especially when coupled with restricted views of the external environment [4]. Environmental conditions, including lighting, temperature, and cabin vibration, also play significant roles in the occurrence of MS [5]. Effective mitigation strategies must account for these factors to improve passenger well-being inside a moving vehicle.

This study does not claim that the modulating factors of motion sickness are entirely new. Rather, its contribution lies in providing a Malaysia-specific quantification of these factors using an adapted factor grouping and a national respondent sample. Existing international studies provide important baseline knowledge, but their findings cannot be directly assumed to represent Malaysian passengers because travel behaviour, road environments, cabin climate exposure, transportation mode usage, and passenger activities may differ by region [6], [7]. In addition, the present study extends previous survey-based

work by including dietary conditions and structured onset-time categories for each modulating factor. Therefore, the study provides local evidence on which factors are most frequently associated with motion sickness, how quickly symptoms are perceived to occur, and how these patterns differ across gender and age groups.

Malaysia offers a unique context for advancing research on MS in terms of current and future AV transportation. As an emerging market with diverse road and traffic conditions, Malaysia provides a valuable environment for studying MS across varying scenarios. Its growing interest in transportation aligns with the need for region-specific data to guide vehicle design and policy decisions. Furthermore, understanding how cultural, climatic, and infrastructural factors influence MS for Malaysians [6] will contribute to global efforts in optimizing future AV designs and ensuring equitable technology adoption [8]. The novelty is not the discovery of entirely new motion sickness triggers, but the Malaysia-specific quantification of known and modified modulating factors, including their relative ranking, demographic patterns, and self-reported onset-time profiles.

2. Methods

The present study adopts a questionnaire-based approach to investigate factors that influence MS in different vehicles in Malaysia. This method analyses different habits passengers have when travelling and exposure to various environments, and preference for seating and activities in transportation.

2.1. Participants

Participants were recruited from various regions across Malaysia to ensure diversity in terms of driving dynamics, cultural habits, and exposure to various transportation modes. Special attention is given to capturing responses from frequent travellers and public transport users, as their exposure to motion makes them ideal candidates for assessing MS prevalence [9]. The study collected and analysed data from a total of 634 respondents. The sample comprised of 61.8% males and 38.2% females, with a mean age of 26.4 years (median = 24.0; Standard Deviation (SD) = 8.2). The age distribution was notably skewed

toward younger individuals, with the majority (84.7%, $n = 537$) falling within the 18-29 age range. Participants aged 30 to 45 accounted for 11.7% ($n = 74$) of the sample, while those aged 46 and above represented the smallest group at 3.6% ($n = 23$).

2.2. Data Collection

The data-gathering phase was done for eight (8) weeks to guarantee a suitable sample size and diversity in travel patterns and experiences. Respondents received a token of appreciation in the form of online credits to promote participation (RM5.00 ~ USD 1).

The questionnaire used in this study was adapted from [9], with modifications to reflect the Malaysian transport context and include additional dietary-related conditions (e.g., full vs. empty stomach). Unlike the original, this version categorized MS onset time (time taken for MS to take effect) into structured options to reduce recall bias and standardize responses. Since English is widely used in Malaysia, no additional translations were necessary. A clear explanation of MS was included in the questionnaire to guarantee that the respondents understood the mentioned symptoms. It was divided into four (4) parts, each targeting specific dimensions of the condition to ensure a comprehensive understanding of the phenomenon (see [Figure 1](#)).

The first part of the questionnaire focuses on gathering general information about the participants. This demographic includes details such as age and gender as well as their prior experiences with MS. Collecting this data is crucial for identifying trends and correlations between personal characteristics and susceptibility to motion sickness. For example, it may reveal whether certain age groups or genders are more prone to experiencing symptoms, providing a foundational understanding of how individual factors influence MS [10], [11].

The second part examines the connection between participants' primary modes of transportation and the incidence of MS. Respondents are asked to report their experiences with different travel methods, such as cars, buses, trains, or airplanes, including the frequency and severity of their symptoms. This section aims to determine which transportation modes are most likely to trigger MS and whether regular exposure to certain modes affects tolerance levels. By

analysing these responses, the study can identify high-risk travel scenarios and contribute to recommendations for reducing discomfort during transit.

The third part delves into specific factors that may contribute to MS, such as reading while traveling, sitting in the back seat, or exposure to poor ventilation. Participants are presented with statements to evaluate how these variables influence their MS symptoms. This section helps pinpoint common triggers and assess their relative impact, offering insights into potential mitigation strategies. Understanding these factors is essential for developing practical solutions to minimize MS, particularly for individuals who frequently travel. In total, 21 modulating factors were evaluated in the survey. To facilitate interpretation and statistical analysis, these factors were categorized based on the type of stimulus they represent. The categories include: (1) Driving Dynamics, which captures movement such as curvy roads and stop-and-go traffic; (2) Visual Activities, encompassing actions like reading, watching screens, and observing surroundings; (3) Smell and Air Quality, referring to environmental stimuli such as cigarette smoke and cabin temperature; (4) Auditory Inputs, such as music and conversations [9]; and (5) Dietary Conditions, which examine the impact of stomach fullness on MS incidence [12], [13].

The fourth and final part explores the temporal aspects of MS, including the onset time and duration of symptoms. Participants are asked to describe how quickly their symptoms appear after travel begins and how long they typically last as a passenger while doing the modulating factors introduced in the third part. This information is valuable for understanding the progression of motion sickness and identifying critical periods for intervention. By analysing the timing of symptoms, the study can contribute to strategies for preventing or alleviating MS before it becomes severe [14]. To explore how quickly MS symptoms emerge under different conditions, the questionnaire included a structured measure of onset time for each modulating factor. Participants were asked to indicate the duration it took for them to experience symptoms after exposure to each factor. To improve consistency and reduce subjectivity, five fixed time categories were provided: "Immediate" (within 5 minutes),

Part 1 (General Information)	Part 2 (Mode of Transportation and Motion Sickness Incidence)	Part 3 (Modulating Factors Causing Carsickness)	Part 4 (Onset Time of Motion Sickness Incidence)
• Age • Gender	• Types of Transportation and Frequency of usage • Incidence of Motion Sickness in Different Types of Transportation	• Questions about incidents of Carsickness (as Passenger) during: ◦ Driving Dynamics ◦ Visual Activities ◦ Auditory Activities ◦ Air and Smell ◦ Dietary Condition	• Questions of Onset Time for Carsickness Incidence with Modulating Factors.

Figure 1. Questionnaire of modulating factors on motion sickness incidence

“Short-term” (5–10 minutes), “Long-term” (20–30 minutes), “Extended exposure” (more than 30 minutes), and “Not applicable” (no symptoms experienced). This format allowed for a standardized comparison of symptom latency across a wide range of experiences.

2.3. Statistical Analysis

Chi Square analysis was applied to explore the relationship between demographic factors and MS moderating factors. This technique allowed for the examination of how variables such as age, gender, and transportation influenced the likelihood of experiencing MS. Prior research suggests that younger individuals and females tend to report higher motion sickness incidence, possibly due to differences in vestibular sensitivity and postural stability [9]. The logistic regression model quantified the extent to which these demographic factors contributed to MS, providing insights into high-risk populations and their susceptibility.

A one-way analysis of variance (ANOVA) was conducted to assess how motion sickness onset times differed across travel conditions. The test compared symptom onset across seating orientations (forward-facing, rearward-facing, reclined), visual engagement levels (reading, using mobile devices, watching screens), and environmental conditions (air quality, temperature, vehicle motion). Previous studies have shown that rearward-facing seating exacerbates sensory conflicts, leading to faster symptom onset and increased discomfort [1][15]. By applying ANOVA, the study aimed to identify statistically significant differences in MS development across these key factors.

By analysing the distribution patterns of MS experiences, the study can identify trends in passenger susceptibility and how it varies across different travel conditions. Frequency analysis is

also essential in determining the percentage of participants affected by modulating factors such as air quality, temperature, and visual engagement, providing valuable insight into environmental contributors to motion sickness [16].

The Friedman test was used to determine whether the likelihood of motion sickness differed across the 21 modulating factors and the five main categories (Visual Activities, Driving Dynamics, Air and Smell, Auditory Inputs, and Dietary Conditions). This non-parametric test was chosen because the same respondents rated multiple related conditions and the data were ordinal. Mean ranks were used to identify stronger and weaker contributors, with higher mean ranks indicating a greater likelihood of motion sickness. When significant differences were found among the five categories, post-hoc pairwise comparisons were performed using the Wilcoxon signed-rank test with Bonferroni correction to account for multiple comparisons, resulting in an adjusted significance level of $p < 0.005$.

All inferential statistical tests were conducted with a p-value threshold of 0.05, ensuring that results met statistical significance criteria and were not due to random variation. This structured analytical approach provided empirical evidence on how MS develops in transportation, helping identify key modulating factors that could be addressed in future vehicle designs to enhance passenger comfort and usability.

3. Results and Discussion

3.1. Effect of Transportation Modes on MS Incidence

Among respondents who used cars as a mode of transportation, 46.3% reported experiencing MS symptoms within the past five years. Notably, the back seat of the car showed the highest incidence (46.4%), followed by the front seat

(36.7%) and driver position (17.2%). The result supports existing literature that drivers are significantly less likely to experience motion sickness due to increased control and visual stability [17] (see Figure 2). Interestingly, while the driver seat shows low overall incidence [18], 3.9% of drivers still reported experiencing motion sickness “almost always”.

Across other transportation types, the highest incidence of MS was reported in boat or ship travel (62.1%), significantly exceeding all other modes (see Figure 2). While using the train has the lowest incidence (30.6%). This aligns with expectations given the unpredictable and multidirectional motion typically associated with waterborne transport [11], [19]. Malaysia has mixed transport exposure and diverse road environments, so MS should be interpreted within local travel behaviour (citation). Also, analysing which transportation can be improved for MS.

3.2. Demographic as Predictors

Chi-Square analysis from Table 1 revealed significant gender-related differences in MS susceptibility. When compared by gender, significant differences were mainly observed for car passenger positions: females reported 48% MS while being in the front passenger seat compared to 36% for males ($\chi^2(1) = 12.67$, $p < 0.001$); and in the back seat 52% of females suffered from motion sickness compared with 40% of males ($\chi^2(1) = 11.45$, $p = 0.001$). No significant gender differences were found for the driver position or other transport modes such as ships or planes. These results concur with the findings of [9] and earlier research by [20], which observed higher incidences of motion sickness among females than among males. [20] directly correlated such gender differences with hormonal influences and those related to the function of the vestibular apparatus. These results collectively support the proposition that gender does influence the occurrence of motion sickness, but mostly under high-risk conditions like sitting as a car passenger.

These results collectively support the proposition that gender does influence the occurrence of motion sickness [21], but mostly under high-risk conditions like sitting as a car passenger. These consistent patterns of results across several studies underscore the importance of considering demographic differences in motion

sickness research, vehicle design, and public health recommendations.

The age-related findings may reflect developmental differences in sensory integration, with younger adults' nervous systems being more reactive to motion conflicts [22] (see Figure 3). The occurrence of motion sickness across age groups varied by transportation type. Some age-related differences were found in passengers driving a car and sitting at the front or rear; no meaningful differences appeared in other modes of transport, such as buses, trains, ships, or airplanes. For front seat passengers in the car, 46% of motion sickness was reported among participants aged 18–29, while 39% was reported among those 30–45 years old, and only 32% was reported among participants aged 46 and above ($\chi^2(2) = 15.84$, $p < 0.001$). The distinction among the back seat passengers indicated even more disparity: 51% for the 18–29 group, 43% for the 30–45 group, and 34% for the 46+ group ($\chi^2(2) = 18.30$, $p < 0.001$). Alternatively, the results could indicate behavioural factors, as younger participants likely engage more frequently with digital devices during travel. While not statistically conclusive in this study, they contribute to ongoing discussions about potential biological, hormonal, or sociocultural influences on MS susceptibility [11], [22].

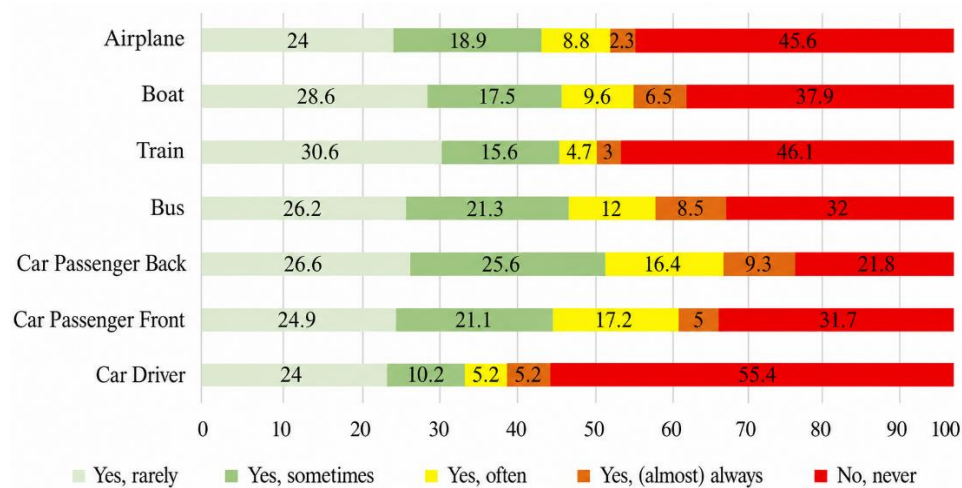
Pairwise comparisons confirmed that when tested between the age groups, the largest effects would have been between the youngest and the oldest groups, under the Bonferroni-corrected threshold for presence. This does affirm what [9] reported—that younger adults are more susceptible to motion sickness as car passengers. According to [9], the discriminating effect of visual conditions, such as navigating through curvy roads and rearing, was greater. This was further supported by [23], who stated that this pattern might be due to higher vestibular sensitivity and sensory dependence of younger subjects [20].

Table 1. Gender Chi-Square result

Mode	Chi-Square Test
Driver	$\chi^2(1) = 1.35$, $p = 0.245$
Passenger Front	$\chi^2(1) = 12.67$, $p < 0.001^*$
Passenger Back	$\chi^2(1) = 11.45$, $p = 0.001^*$
Bus	$\chi^2(1) = 4.92$, $p = 0.027$
Train	$\chi^2(1) = 3.78$, $p = 0.052$
Boat	$\chi^2(1) = 2.60$, $p = 0.107$
Airplane	$\chi^2(1) = 1.89$, $p = 0.169$
*Indicates significant difference	

Table 2. Age group Chi-Square results

Mode	Chi-Square Test	Pairwise comparison with Bonferroni correction
Driver	10.359	18–29 vs. 30–45: $\chi^2 = 0.91$, $p = 0.341$ 18–29 vs. 46+: $\chi^2 = 1.55$, $p = 0.213$ 30–45 vs. 46+: $\chi^2 = 0.79$, $p = 0.374$
Passenger Front	14.030	18–29 vs. 30–45: $\chi^2 = 3.17$, $p = 0.075$ 18–29 vs. 46+: $\chi^2 = 8.42$, $p = 0.004^*$ 30–45 vs. 46+: $\chi^2 = 5.38$, $p = 0.021$
Passenger Back	13.496	18–29 vs. 30–45: $\chi^2 = 4.65$, $p = 0.031$ 18–29 vs. 46+: $\chi^2 = 10.12$, $p = 0.001^*$ 30–45 vs. 46+: $\chi^2 = 7.84$, $p = 0.005^*$
Bus	14.355	18–29 vs. 30–45: $\chi^2 = 1.65$, $p = 0.198$ 18–29 vs. 46+: $\chi^2 = 3.12$, $p = 0.077$ 30–45 vs. 46+: $\chi^2 = 2.32$, $p = 0.128$
Train	25.752	18–29 vs. 30–45: $\chi^2 = 1.48$, $p = 0.224$ 18–29 vs. 46+: $\chi^2 = 2.61$, $p = 0.106$ 30–45 vs. 46+: $\chi^2 = 1.74$, $p = 0.187$
Boat	16.793	18–29 vs. 30–45: $\chi^2 = 2.42$, $p = 0.120$ 18–29 vs. 46+: $\chi^2 = 3.90$, $p = 0.048$ 30–45 vs. 46+: $\chi^2 = 1.79$, $p = 0.180$
Airplane	27.348	18–29 vs. 30–45: $\chi^2 = 1.21$, $p = 0.271$ 18–29 vs. 46+: $\chi^2 = 2.03$, $p = 0.154$ 30–45 vs. 46+: $\chi^2 = 0.89$, $p = 0.346$
* Indicates significant difference		

**Figure 2.** Motion sickness incidence in transportation modes

One of the main factors influencing a person's susceptibility to MS is their age. Young individuals (18 to 29 years old) were the most afflicted group and were far more likely to report symptoms than older adults (46+) [22], [23]. This could be the result of increased vestibular sensitivity and more active participation in visual activities while travelling, such as reading or using a smartphone. Despite a tendency towards greater sensitivity than the older group, middle-aged people (30–45) did not demonstrate a statistically significant difference after

adjustment. These results provide credibility to the use of age-specific design factors in car interiors and travel advice for future planning and transport recommendations.

Based on these results, transportation designers should consider age-specific mitigation strategies, such as optimised seating for younger passengers who show greater susceptibility. The gender trends, while still under verification, suggest that female passengers may benefit from additional preventive measures during high-risk activities, such as reading while in motion. Future

research with larger, balanced samples should investigate whether these gender trends achieve statistical significance in broader populations [24].

3.3. Modulating Factors Lead to Motion Sickness

From the descriptive statistics (see Figure 3), susceptibility that is (Likely + Very Likely) shows that the most provocative category emerged as “Driving Dynamics”, where the physics of motion itself proved fundamentally disruptive. Roads with many turns (71.8% susceptibility) and curvy roads (76%) stood out as particularly challenging, creating what vestibular experts describe as “sensory mismatch” the disagreement between what the eyes see and what the inner ear feels. These complex motion patterns generate sensory conflict, with multiple acceleration vectors simultaneously challenging the body's equilibrium systems [25]. Even the start-stop pattern of traffic congestion triggered noticeable symptoms in 56.8% of participants, though less severely than winding and curvy roads. The data suggest that while all vehicular motion carries some risk, it is the unpredictable, multidirectional movements that most aggressively provoke the nausea response. These findings demonstrate that irregular, unpredictable motion patterns create substantially more sensory conflict than maintained velocities, supporting classical motion sickness theories [26], [27]. The abrupt directional changes and acceleration variations associated with winding routes appear particularly challenging for the vestibular system [2]. Curvy roads, many turns, stop-and-go traffic, and speed changes are relevant in Malaysia because local studies show road geometry, speed behaviour, travel direction, and time of day affect vehicle movement [7].

“Visual Activities” presented a paradox of modern travel; the behaviours one engages in to pass time often aggravate discomfort. Reading (83.2%) and Writing (79.2%) topped this category, their danger lying in the cognitive-visual double threat they pose. When focusing on a book or screen, the body essentially tells the brain that the body is stationary or not moving to read, while our vestibular system screams otherwise [13]. This explains why looking at the road ahead (34.7%) or outside the window (36.6%) proved significantly less provocative. These activities allow visual and vestibular inputs to reconcile. Electronic devices (84%) presented a particularly modern dilemma, combining the focus demands of reading with the added sensory disruption of screen flicker and motion feels, making this factor a bit more like the two factors that topped this category. Device use is locally important because Malaysian young drivers/passengers are highly exposed to mobile phone use in [28]. The clear hierarchy from high-focus activities to passive visual behaviours supports the sensory conflict hypothesis, with near-field visual fixation creating particularly pronounced mismatches with peripheral motion cues [2], [25].

The “Air and Smell” category revealed this stimulus as an unexpectedly potent trigger, with cigarette and exhaust fumes (71.3%) outperforming even certain visual factors. This suggests smell may influence motion sickness through multiple pathways, both as a direct nausea trigger and by amplifying existing sensory conflicts. Warm Air (57.8%) showed moderate effects, likely through its impact on circulation and comfort, while Cold Air (40.7%) proved least disruptive in this category. The dominance of smell triggers over temperature effects suggests

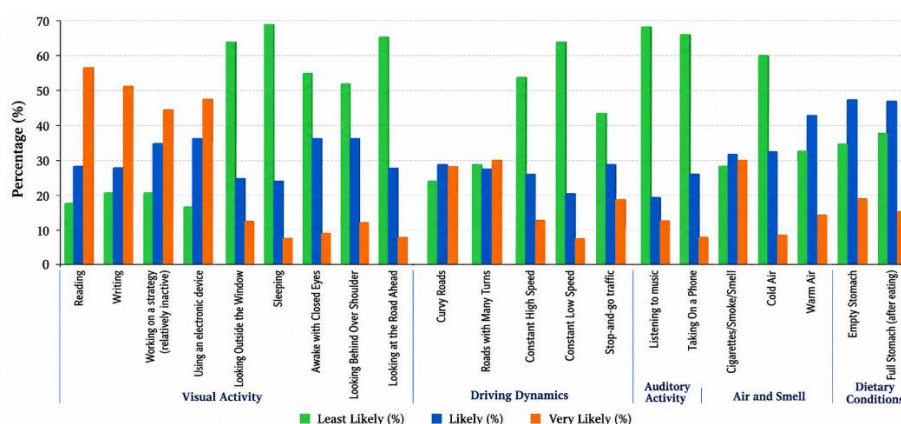


Figure 3. Modulating factors of motion sickness incidence (%)

that smell may have direct neurological pathways influencing nausea perception [13], beyond simple comfort factors.

“Auditory” inputs stood apart as the least provocative category, with music (32.2%) and phone conversations (36.8%) showing minimal direct impact. This challenges common assumptions about auditory influences, suggesting that while sound may modulate symptom perception, it does not appear to fundamentally drive the sensory conflict at motion sickness's core. These results indicate auditory inputs may have minimal direct impact on sensory conflict mechanisms, though they may influence symptom perception through distraction or stress pathways [29].

“Dietary Conditions” presented rather surprising information to common wisdom. Both empty (65.9%) and full stomachs (62.5%) showed similar susceptibility rates, challenging the standard advice of years to not travel on an empty stomach [12], [30]. This may indicate that gastric state influences motion sickness through mechanisms beyond simple stomach volume, possibly involving metabolic or blood sugar factors. The similar susceptibility between empty and full stomach conditions challenges conventional wisdom about fasting prevention, suggesting metabolic factors may play complex roles in motion sickness pathophysiology [31].

A Friedman test (see Figure 4) showed a statistically significant difference across the 21 individual modulating factors, $\chi^2(20, n = 634) = 3040.835$, $p < 0.001$, indicating that the factors did not contribute equally to motion sickness likelihood. Based on the mean ranks, the highest-ranked factors were Reading, Using Electronic Devices, Writing, and Watching Screens, suggesting that visually demanding activities were among the strongest contributors. In contrast, Sleeping, Talking on the Phone, Looking at the Road Ahead, and Listening to Music produced lower mean ranks, indicating weaker associations with motion sickness.

At the category level (see Table 3), the Friedman test also showed a significant difference among the five modulating-factor categories, $\chi^2(4, n = 634) = 365.941$, $p < 0.001$. Visual Activities produced the highest mean rank, followed by Dietary Conditions, Driving Dynamics, Air and Smell, and Auditory Inputs. Post-hoc Wilcoxon signed-rank tests with Bonferroni correction

showed that Visual Activities were significantly higher than Driving Dynamics, Air and Smell, and Auditory Inputs. However, the difference between Visual Activities and Dietary Conditions was not significant after correction. Auditory Inputs were significantly lower than all other categories, confirming that auditory-related factors were the weakest contributors among the five categories.

3.4. Modulating Factors vs Age and Gender

This study also reveals striking demographic patterns in MS susceptibility that align with both vestibular neuroscience research and previous epidemiological findings. In line with previous findings, females demonstrated consistently higher vulnerability across all measured factors, with particularly pronounced differences in situations involving complex sensory integration [22], [32]. Gender disparity peaked in scenarios combining visual-vestibular conflict with environmental stressors, notably on roads with many turns (68% female vs. 50% male susceptibility), during reading activities (63% vs. 46%), and in warm air conditions (67% vs. 50%) (see Figure 4). These results are consistent with findings reported by [9], who observed that female participants across multiple countries reported higher motion sickness rates, especially in conditions involving complex sensory conflict, such as curvy roads and rear seat positioning in vehicles. Similarly, [20] also highlighted gender differences in motion sickness, linking these differences to possibilities in hormonal influences and heightened vestibular sensitivity.

The gender gap narrowed for less complex stimuli, such as phone conversations (39% female vs. 26% male) and cold air exposure (38% vs. 27%), suggesting that as sensory demands decrease, biological differences become less pronounced. This susceptibility aligns with the “sensory integration threshold” hypothesis proposed by vestibular researchers, which suggests that female neurology may process conflicting sensory inputs with greater sensitivity due to evolutionary adaptations for enhanced environmental monitoring [11], [20]. Taken together, the present study and prior research underscore that gender-related differences in motion sickness are most pronounced under conditions that require high sensory processing demands, reinforcing the need for demographic considerations in both vehicle design and motion sickness mitigation strategies.

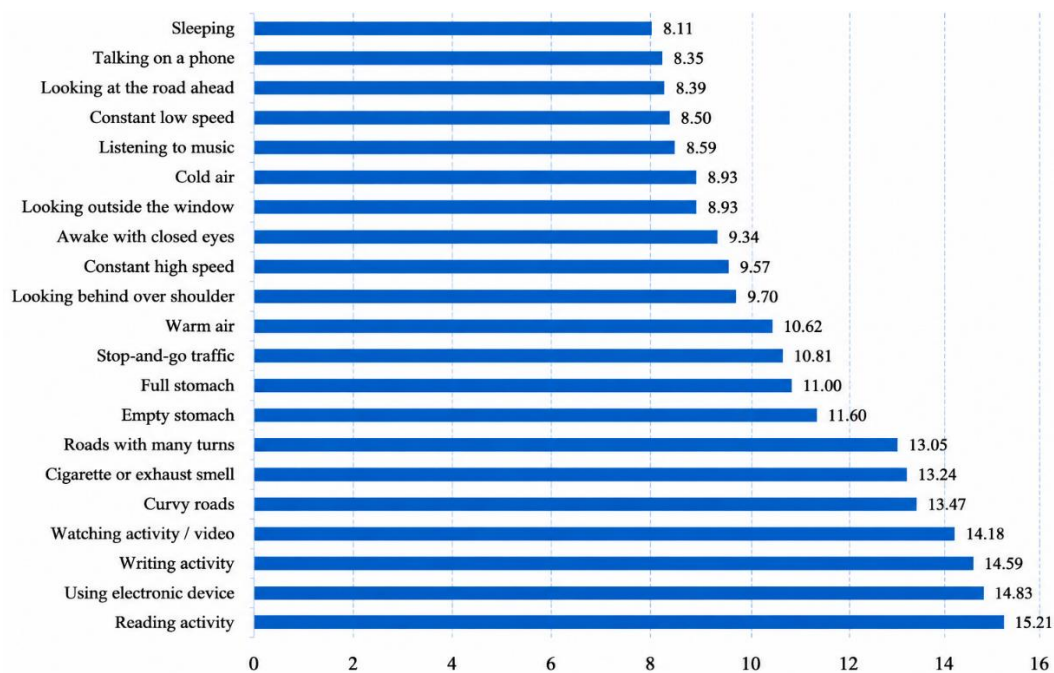
Table 3. Category-level friedman mean ranks with bonferroni-corrected post-hoc grouping

Pairwise Comparison	Z	Bonferroni-correction p-value
Visual Activity vs. Driving Dynamics	-3.643	0.003*
Visual Activity vs Air and Smell	-4.104	< .001*
Visual Activity vs Auditory	-15.726	< .001*
Visual Activity vs Dietary	-2.747	0.060
Driving Dynamics vs Air and Smell	-1.16	1.000
Driving Dynamics vs Auditory	-13.706	< .001*
Driving Dynamics vs Dietary	-0.128	1.000
Air and Smell vs Auditory	-12.533	< .001*
Air and Smell vs Dietary	-0.967	1.000
Auditory vs Dietary	-12.346	< .001*

* Indicates significant difference

This study also reveals striking demographic patterns in MS susceptibility that align with emerging research in vestibular neuroscience. Females reported consistently higher vulnerability across all measured factors, with particularly pronounced differences in scenarios involving complex sensory integration. The gender disparity between females and males reached its peak in situations combining visual-vestibular conflict with environmental stressors, notably on roads with many turns (68% (F) vs 50% (M) susceptibility), during reading activities (63% vs 46%), and in warm air conditions (67% vs 50%) (see [Figure 4](#)). These findings support recent studies showing heightened interoceptive awareness in female brains, particularly in the insular cortex regions responsible for nausea perception [10].

The gender gap narrowed for less complex stimuli like phone conversations (39% vs 26%) and cold air exposure (38% vs 27%), suggesting that as sensory demands decrease, biological differences become less pronounced. This spectrum of susceptibility aligns with the "sensory integration threshold" hypothesis proposed by vestibular researchers [11], [19], which shows that female neurology may process conflicting sensory inputs with greater sensitivity due to evolutionary adaptations for enhanced environmental monitoring. The analysis revealed that there were definite age-related differences in motion sickness susceptibility via the 21 factors for modulation. Under almost all conditions in the study, the 46+ group rated the highest likelihood of motion sickness, followed by the 30–45 group, while the 18-29 group always rated the least (see [Figure 5](#)).

**Figure 4.** Mean rank of motion sickness likelihood across modulating factors

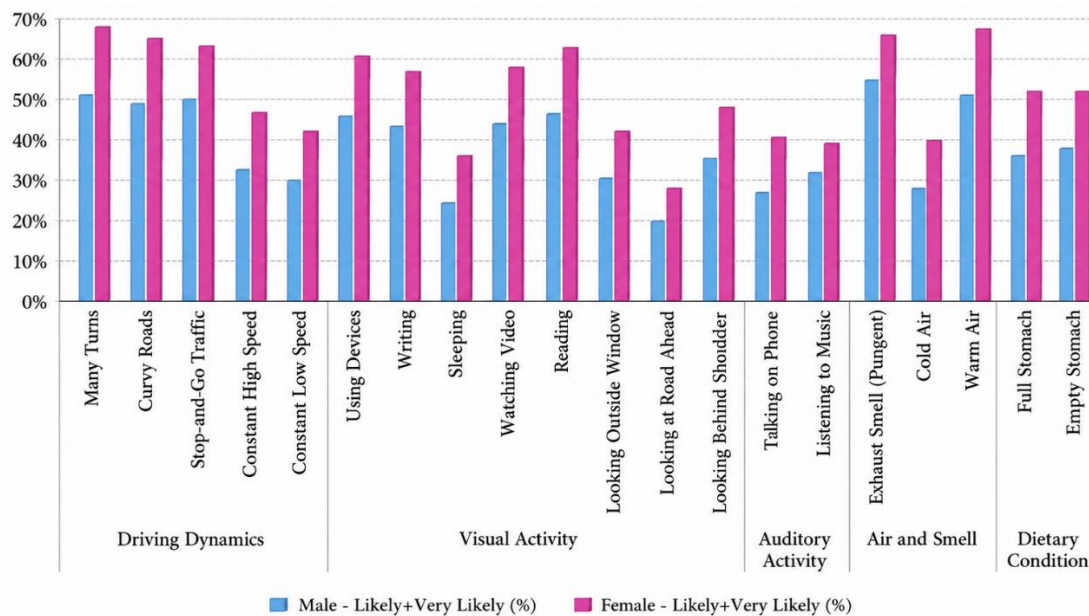


Figure 5. Gender comparison on modulating factors

The biggest age-related differences occurred in visually demanding activities. In contrast, reading had 66% of the older people reporting being likely or very likely to experience motion sickness, as compared to 56% amongst the middle-aged group and only 50% of young adults. Similarly, older people reported 69% motion sickness incidence along curvy road routes when the rate in the middle and youngest groups was 57% and 52%, respectively. These trends were also present for exhaust smell (71% vs. 60% vs. 58%) and watching video (59% vs. 51% vs. 46%).

The repeated patterns across visual, vestibular, and environmental triggers suggest a progressive rate of susceptibility that could affect sensory or neurological changes occurring with age. In even lesser stimuli, such as talking on the phone or looking back, discomfort is reported to be higher in older generations [22]. Overall, the results imply that older adults are more prone to motion. These recurrent trends with visual, vestibular, and environmental triggers show that susceptibility potentially sets in at late ages, maybe because of alterations in sensory integration or vestibular function with aging. Thus, this corresponds with [13], who have emphasized the fact that multisensory integration with increasing age can lead to an increased likelihood of motion-induced discomfort. Malaysian driving studies also show age and gender affect driving behaviour [33], where drivers range from young adults, working

middle age drivers and even old people that go around different types of roads in Malaysia.

3.5. Onset Time and Identification

A comprehensive investigation into motion sickness onset times reveals striking temporal patterns across different trigger categories, with visual activities and environmental factors provoking significantly faster symptom development than physical motion characteristics alone. The ANOVA results ($F(2,925) = 6.39$, $p = 0.002$) confirm these categorical differences are statistically robust, suggesting distinct physiological pathways mediate symptom onset for different trigger types [14]. Five selections are given to participants to describe at which point they start to feel motion sickness symptoms, that is, immediate (<5mins), short term (5-10 mins), long term (10-20 mins), extended (>30 mins), and not applicable. These can be referred to as Figure 6, showing the different categories and their onset times.

“Visual Activities” contribute faster to the discomfort of motion sickness. Reading with the fastest onset 30.1% of participants experienced symptoms during the first 5 minutes, followed by an additional 25.6% after 5-10 minutes, resulting in more than half of individuals being affected within the first 10 minutes. Similar patterns were found in Watching Videos (26.7% quick beginning), Using Devices (22.3%), and Writing (28.2%). This form of

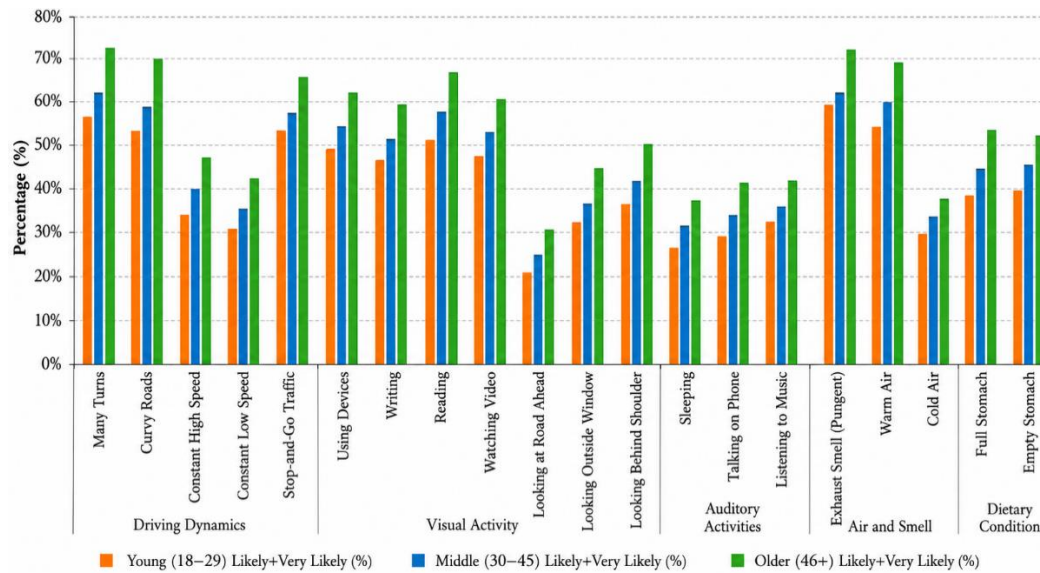


Figure 6. Age group comparisons on modulating factors

conflict supports neuroimaging evidence that focused visual attention amplifies vestibular cortex activity [5],[34]. This may explain why passengers absorbed in books or devices often report sudden, intense nausea compared to those watching the horizon in this study. Interestingly, visually passive situations such as "Awake with Eyes Closed" had slower effects, reporting symptoms after more than 30 minutes, indicating that a lack of visual reference may promote motion sickness in a more gradual, cumulative way.

"Air and Smell" as a rapid environmental trigger, with Cigarette or Exhaust Smell producing a significant 22.5% immediate onset and 24.6% short-term onset (within 5–10 minutes). Similarly, Warm Air and Cold Air also induced fast responses, with over 35% of participants affected within the first 10 minutes. These findings suggest that air quality changes, especially unpleasant or sharp smells, can provoke nausea very quickly, challenging conventional views of environmental factors as slow-acting contributors [35].

"Driving Dynamics" is a delayed but potent factor. Activities such as Curvy Roads and Roads with Many Turns had lower immediate onset rates (16.2% and 17.9%, respectively), but significantly higher proportions in the long-term and extended categories, with 26.2% and 25.9% reporting symptoms only after more than 30 minutes. This temporal pattern implies that initial motion exposure may trigger adaptive

mechanisms, slowing down the effects of the vestibular system getting confused, and the mismatch happens later at a period where the body cannot compute the speed in the car [18].

"Auditory Activities" such as talking on the phone and listening to music were the least provocative motion sickness stimuli. As shown in the Figure 7, only around 10% of participants reported an immediate onset (≤ 5 minutes) for both activities, while most responses fell under "Not Applicable" (around 50%), indicating many participants did not experience motion sickness at all in these conditions. A combined total of just under 20% reported any symptoms within 30 minutes. This finding is in line with previous studies [20], which suggest that passive auditory engagement may even help distract from motion cues, thereby reducing discomfort [9], [21]. These activities showed little difference across age or gender groups, supporting the claim as generally non-provocative triggers.

"Dietary Conditions", for both empty stomach and full stomach circumstances, 15% of participants experienced symptoms immediately, while 20% to 25% fell into the short-term and long-term groups (within 30 minutes) [30]. More than 30%, however, selected "Not Applicable," which shows the absence of symptoms under these circumstances. Dietary elements fall somewhere between visual and dynamic triggers: they aren't the most severe, but they may cause discomfort.

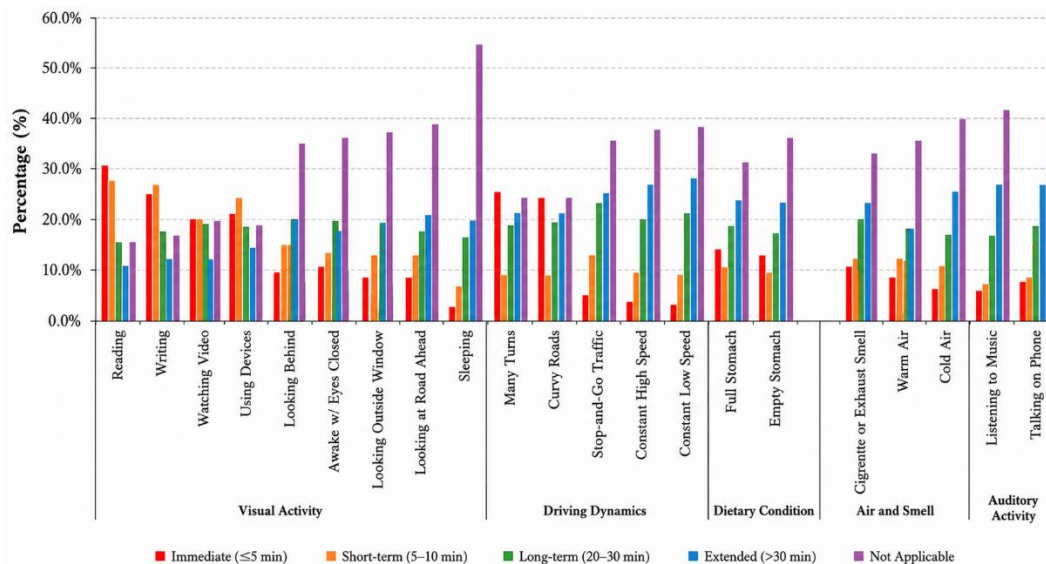


Figure 7. Onset time for motion sickness

4. Conclusion

Motion sickness (MS) remains a significant challenge for passengers in various modes of transportation, activities, and factors, particularly in Malaysia's diverse and dynamic transportation environment. This study highlights the critical role of sensory conflicts, environmental conditions, and individual susceptibility in exacerbating motion sickness symptoms. Key findings reveal that younger individuals and females are more prone to motion sickness, while activities like reading and rearward seating significantly increase discomfort. Environmental factors such as poor ventilation, strong odours, and erratic vehicle motion further contribute to symptom severity. The insights from this research underscore the need for targeted mitigation strategies, including optimized seating arrangements, improved cabin ventilation, and passenger education on reducing sensory conflicts. For future successful adoption of automated vehicles, manufacturers must prioritise designs that minimize motion sickness triggers, ensuring passenger comfort and acceptance. Future studies should also expand on these findings with longitudinal data and physiological measurements to refine predictive models and intervention approaches.

For future automated vehicle development, greater attention should be given to factors that are most likely to affect passengers during non-driving travel. These findings suggest that visually demanding activities, particularly

reading, using electronic devices, writing, and watching screens, should be prioritised because these activities showed the strongest association with motion sickness. Driving dynamics such as curvy roads, many turns, and stop-and-go traffic should also be considered, as automated vehicle passengers may have less control and anticipation of vehicle movement. In addition, cabin-related conditions such as cigarette or exhaust smell, warm air, and passenger dietary state should not be overlooked, as these factors may further increase discomfort during travel. Therefore, future AV interior design and passenger comfort strategies should focus on reducing visual-vestibular conflict, improving external visual reference, optimising motion control, and maintaining good cabin air quality to minimise motion sickness risk. By addressing these factors, stakeholders can enhance travel experiences, reduce MS prevalence, and support the transition toward safer and more comfortable automated transportation systems. This study not only contributes to the growing body of MS research but also provides actionable recommendations tailored to Malaysia's unique road conditions and passenger behaviors.

The findings have practical significance for vehicle designers, particularly in Malaysia, where infrastructural and environmental factors vary. Seat position, access to external views, and cabin air quality should all be prioritised. The Malaysian perspective strengthens the interpretation of the present findings in three ways: first, local road

geometry and speed variation provide context for the high susceptibility reported during curvy roads and roads with many turns; second, mobile-device use among Malaysian road users supports the relevance of visually demanding in-vehicle activities; and third, local studies showing age and gender differences in driving behaviour support the need to consider demographic variation when developing passenger comfort strategies. Therefore, while the modulating factors identified in this study are broadly consistent with international motion sickness literature, their ranking, onset-time patterns, and demographic variation provide Malaysia-specific evidence that is useful for transport design, passenger education, and future automated vehicle planning. Furthermore, vehicle systems might have personalised settings depending on age and gender to lessen the risk of illness. These findings not only promote passenger comfort design but also help to define universal comfort criteria for the future of automated vehicle platforms.

5. Limitation

Although this study provides novel insight into the modulating factors and perceived onset time of motion sickness within the Malaysian transportation context, several limitations should be acknowledged. First, the sample's age distribution was skewed toward younger respondents, with the majority in the 18–29 age group. As a result, the findings may primarily reflect the motion sickness experiences, travel behaviours, and activity patterns of younger passengers, particularly those who may be more frequently exposed to visually demanding in-vehicle activities such as reading or using digital devices. This demographic imbalance may limit the generalisability of the findings to older populations, whose vestibular function, sensory integration, and travel habits may differ.

The onset time data were based on participants' retrospective self-reports. Although fixed onset-time categories were introduced to standardise responses and reduce variability, recall bias may still have influenced participants' ability to accurately estimate when symptoms first occurred during past travel experiences. The options may also limit the range the participants may want to express. Motion sickness onset can also be affected by contextual factors such as road

condition, trip duration, seating position, activity type, and individual susceptibility, which may not be fully captured through questionnaire responses alone. These findings may be interpreted within the Malaysian transport context, where local driving behaviour, road geometry, and in-vehicle mobile-device exposure can shape passenger experience.

Despite these limitations, the study systematically examines modulating factors of motion sickness and symptom onset patterns in a Malaysian transport setting. Future research should consider a more balanced age distribution, prospective symptom tracking, and objective measurements of vehicle motion, environmental conditions, and physiological responses to further validate and extend the present findings.

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Author's declaration

Authors' contributions and responsibilities

Conceived and designed the experiments (M.I.A.M.I, J.K, M.Z.H); Performed the experiments (M.I.A.M.I, J.K); Analysed and interpreted the data (M.I.A.M.I, J.K); Wrote the original paper (M.I.A.M.I, J.K); and Wrote the revised manuscript (M.I.A.M.I, J.K, M.Z.H, F.A, A.F.H.Z, S.S, Z.M.J, M.R).

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Availability of data and materials

All data are available from the authors.

Competing interests

The authors declare no competing interest.

Generative AI statement

The author(s) declare that no generative AI or AI-assisted technologies were used in the preparation of this manuscript.

Additional information

No additional information from the authors.

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