Evaluating Motion Sickness Responses to the Virtual Horizon in VR-HMDs: A Real-World Marine Study

Kartika Kusuma Wardani
Department of Marine Engineering, Institut Teknologi Sepuluh Nopember, Surabaya, Indonesia | Department of Visual Communication Design, Institut Teknologi Sepuluh Nopember, Surabaya, Indonesia
kartikawardani@its.ac.id

Ketut Buda Artana
Department of Marine Engineering, Institut Teknologi Sepuluh Nopember, Surabaya, Indonesia
ketutbuda@its.ac.id (corresponding author)

Ellya Zulaikha
Department of Product Design, Institut Teknologi Sepuluh Nopember, Surabaya, Indonesia
ellya.zulaikha@its.ac.id

Semin
Department of Marine Engineering, Institut Teknologi Sepuluh Nopember, Surabaya, Indonesia
semin@its.ac.id

Anak Agung Bagus Dinariyana
Department of Marine Engineering, Institut Teknologi Sepuluh Nopember, Surabaya, Indonesia
kojex@its.ac.id

Emmy Pratiwi
Department of Marine Engineering, Institut Teknologi Sepuluh Nopember, Surabaya, Indonesia
emmy.p@its.ac.id

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ABSTRACT

Motion sickness continues to be a significant issue for ferry passengers, especially in fluctuating marine conditions, where immediate visual stability is absent. Despite the growing utilization of Virtual Reality (VR) systems, there is a limited understanding of the ideal visual configurations to alleviate Visually Induced Motion Sickness (VIMS) in maritime environments. This study examines how varying the horizon-deviation angles shown through a VR Head-Mounted Display (VR-HMD) affects the intensity of motion sickness during real boat trips. During a three-day field test, 15 participants encountered five virtual horizon deviations (0–25°) while experiencing pitching and rolling motions on a Lembar–Padang Bai ferry. The responses on the Simulator Sickness Questionnaire (SSQ) satisfied the assumptions for linear regression, indicating that each 1° deviation increased the SSQ ratings by 1.311 points ($p = 0.002$), while the moderate sea states contributed an additional 23.281 points ($p = 0.030$). The Motion Illness Symptom Classification (MISC) scale identified symptom exacerbation only at 20 to 25° ($H = 13.14$; $p = 0.011$). The substantial SSQ–MISC correlation ($\rho = 0.818$) validates the reliability of both instruments. The resultant prediction model provides an inaugural field-based guideline for enhancing virtual horizon configurations in adaptive VR designs for marine applications.

Keywords-motion sickness symptoms; virtual reality; marine field experiment; simulator sickness questionnaire; motion deviation

I. INTRODUCTION

Research has shown that VR-HMDs reduce Visually Induced Motion Sickness (VIMS) symptoms in lab and simulator studies [1]. Most of the research has focused on controlled situations and has not yet proven efficacy at sea. Initial predictions of ship physical movements were tested only on the dock [2]. Visual field configurations, including segmentation and masking areas, greatly impact VIMS levels, emphasizing the importance of visual design in VR [3]. According to [4], age and user experience significantly impact VIMS vulnerability, especially in VR-illiterate groups. Few practical commercial ships use virtual horizons. VR is not feasible for ship passengers without field data. Simulator research shows that 0–20° horizon variations reduce sensory conflicts [5]. Recent neuro-digital studies focus on interface optimization without addressing angles greater than 20° [6], while in [7], it was revealed that specific head movement patterns are substantially connected with vection and motion sickness levels, stressing the importance of sensory design in VR studies. In [8], the dynamics of lighting angles in VR content were highlighted. However, the 25° horizon deviation has never been verified. Thus, the optimal deviation dose for ferry passengers is uncertain.

The Simulator Sickness Questionnaire (SSQ) is recognized as sensitive to VIMS, and its correlation with physiological indicators such as EKG has been demonstrated when subjects walk in VR [9]. On the other hand, the Motion Illness Symptoms Classification (MISC) is widely used in maritime studies due to its ability to capture the dynamics of symptoms in real-time [10]. In [11], a VR user ergonomics evaluation tool was presented, which has strong validity in assessing physical weariness and cybersickness, thus complementing the SSQ and MISC in field research. However, SSQ has never been directly compared with MISC under real wave conditions, but multisensory synchronization can affect the sensitivity of subjective reports [12]. The current quantitative VIMS model uses ground simulators [13] or uses cross-domain machine learning, such as reservoir computing for trajectory prediction [14] or brain connectivity-based classification with CNN-LSTM [15]. According to [16], motion sickness alters the temporal brain dynamics that underlie postural control in VR. The feasibility study of fast boat ride-control systems [17] and the review of VR/AR in transportation engineering [18] stress the need for field datasets for adaptive designs. Without regression equations from actual travels, the VR material for interleaved scenarios relies on laboratory assumptions.

This research aimed to:

- Validate the efficacy of the VR-HMD virtual horizon on commercial ferries.
- Evaluate the influence of five horizon angle deviations (0, 10, 15, 20, and 25°) on VIMS intensity.
- Compare the sensitivity of SSQ and MISC in actual sailing conditions.
- Create a predictive model for SSQ derived from field data to enhance adaptive VR design.

This approach yields original contributions through real-world validation, examination of untested deviation parameters, comparison of marine equipment, and the inaugural predictive equation developed from ferry data.

II. RESEARCH METHODOLOGY

This section describes the field experiment design, devices, protocols, measuring instruments, and data processing methods. Horizontal movement, angular deviation, sea conditions, gender, and age are independent variables. The dependent variables are ΔSSQ and $\Delta MISC$, indicating changes in pre-post scores on each measure. Beaufort sea state was recorded in the captain's log and approved by BMKG-Maritim Lombok every 30 minutes. Moderate circumstances (Beaufort 3–4) have 11–21 knots and 0.5–1.5 m waves, whereas calm conditions (Beaufort 1–2) have 10 knots or less. Seasickness symptoms are linked to standardized ocean physical parameters by this periodic verification of Beaufort values for all experimental sessions on data collection day.

The method involves tool design, participant characteristics, experimental protocols, measuring tools, and data analysis. Static and dynamic horizon stimuli were projected on VR Glasses Pro HMDs (120° FOV) from two Redmi Note 9 Pro cellphones running a Unity 3D sea-horizon application. The virtual horizon concept uses 3D animation to regulate movement without an active gyroscope. The horizon angle deviation was designed to stay at 0, 10, 15, 20, and 25° to isolate visual variables from ship motion fluctuations for experimental control. Minimizing bias drift across sensors made two alternating HMDs consistent. An external IMU on the open deck is impossible on commercial ferries due to its unstable power supply and line-of-sight RF connection. This groundbreaking study maps the link between visual deviation and VIMS symptoms and then adds IMU-to-VR motion synchronization after determining key parameters. Table I summarizes the complete experimental design.

TABLE I. SUMMARY OF EXPERIMENTAL DESIGN

Factor	Level	Description	Number of tests per participant
Type of horizon motion (F1)	2	Pitching (±10°, ±20°) and Rolling (±15°, ±25°)	5 pitching sessions and 5 rolling sessions
Angle deviation (F2)	5	0, 10, 15, 20, and 25°	One session per angle per type of movement
Sea conditions (Covariate)	2	Calm = Beaufort 1–2 (0–0.5 m), Moderate = Beaufort 3–4 (0.5–1.5 m)	Determined based on the Indonesian Meteorology, Climatology, and Geophysical Agency log every 30 minutes
Experimental structure	–	10 sessions × 10 minutes (total 100 minutes per participant, with a 5-minute break in between)	10

The experiment was conducted over three days on two ferries (Ferry 1: L = 73.3 m, Vs = 13 knots, cap. 400 pax; Ferry 2: L = 71.8 m, Vs = 14 knots, cap. 513 pax) on the Lembar–Padangbai route (4–5 hours travel). Out of the 15 participants (10 men and 5 women, aged 15–55 years, average 31.4±13.7 years), two women stopped early due to seasickness, but their data were still analyzed. Inclusion criteria: healthy, limited VR experience, free from alcohol/anti-nausea medication, and no history of vertigo or hearing/visual impairments. Before attending the three 10-minute experimental sessions (Table II), participants had health tests and gave informed consent. Feedback was collected in a brief post-session interview.

The MISC scale subjectively rates seasickness on a 0–10 Likert scale before, during, and after sessions. The SSQ comprises 16 symptoms (0–4) in three dimensions: Nausea, Oculomotor, and Disorientation, plus a Total Score. Recent field-based VR testing indicated that SSQ has higher dimensional sensitivity than MISC [9]. The SSQ was only given before and after the trial due to its duration. All data were analyzed with SPSS 25, and 15 people provided 40 samples. Independent factors were pitching/rolling, angle deviation (0, 10, 15, 20, and 25°), gender, age (5 categories), and sea state (calm/moderate). The dependent variables are ΔSSQ and $\Delta MISC$ score changes.

TABLE II. EXPERIMENTAL ACTIVITIES AND DURATION

Experimental activities and duration				
No.	**Activities**	**Duration (minutes)**		
		I	**II**	**III**
1	Ask a passenger to join the experiment	5	-	-
2	Fill in informed consent and personal data	5	-	-
3	Fill the pre-MISC and SSQ	3	3	3
4	Install HMD	2	5	1
5	Experiment	10	10	10
6	MISC (mid of experiment)	1	1	1
7	Fill the post MISC and SSQ	3	3	3
8	Break until participants feel well	5	5	5
9	Interview and thanks	-	-	5
	Total	79		

The standard assumption tests (VIF<10; DW=1.854; KS p=0.174; BP p>0.05) are satisfied for SSQ, although MISC is evaluated nonparametrically. Since Wilcoxon Signed-Rank compares paired pre- and post-scores from the same subjects, it requires (i) paired data, (ii) at least an ordinal scale, (iii) a roughly symmetric distribution of the paired differences, and (iv) no strict normality assumption. If MISC data is abnormal (Kolmogorov-Smirnov - KS: p = 0.00), nonparametric testing is performed. The stepwise Multiple Linear Regression (MLR) analysis identified angle deviation and sea conditions as significant predictors for ΔSSQ (F = 8.441; p = 0.001). SSQ changes are positively connected with those parameters, per one-tailed Pearson correlation. For $\Delta MISC$, non-parametric tests include Mann-Whitney for binary variables (horizon movement, gender, sea conditions), Kruskal-Wallis for multi-category variables (angle deviation, age), and Wilcoxon for SSQ symptom details. This test measures pre–post symptom scores in moving and static horizon stimulation and SSQ-MISC associations using Spearman correlation. Figure 1 shows this experiment's statistical workflow.

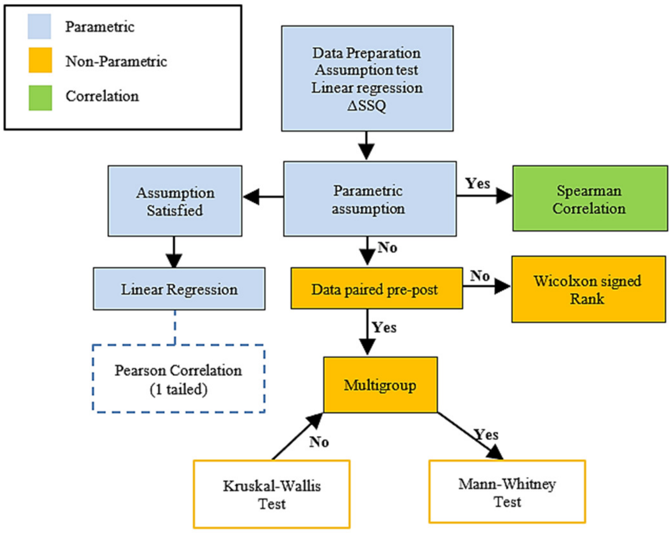

Fig. 1. Flowchart of the statistical analysis pipeline.

III. RESULTS AND DISCUSSION

The multicollinearity test shows if independent variables are highly related in MLR. The experiment's MLR utilizing SSQ data revealed no significant correlation between independent variables, with a VIF score of 1.003 (< 10). Autocorrelation tests the correlation of linear regression residuals. According to Durbin-Watson tests, MLR models must have no significant residual association. A Durbin-Watson score of 1.854 between dU of 1.6 and 2.4 indicates no autocorrelation in the SSQ regression model. Normal MLR residuals were determined using this test. If a bell-shaped residual histogram or a K-S test with a p-value larger than 0.05 shows a normal distribution, the MLR model is normal. The K-S test on SSQ data showed regularly distributed unstandardized residuals with a p-value of 0.174. In the MLR model, the Breusch-Pagan-Godfrey test needs homoscedasticity and a p-value above 0.05. Significant residual squared regression values suggest non-homoscedastic SSQ data. Normal assumption tests for SSQ data passed, and linear regression showed the independent-dependent relationship. The conventional assumption test used MISC data, but the unstandardized residuals were not normally distributed. A nonparametric MISC test determined the independent-dependent relationship.

A. *Regression Analysis of SSQ Scores*

SPSS MLR incorporates variable correlation, which measures the link between variables, but not causation. A one-tailed Pearson correlation was used to analyze the correlation between the independent factors and the dependent variable (ΔSSQ). There was a strong positive correlation between SSQ and sea conditions [r(38) = 0.332, p = .018], motion deviation (0.467, p =.001), and rolling motion (0.353, p = 0.013). Pitching motion, gender, and age did not contribute to the increase in SSQ. Sea condition, motion deviation, and rolling motion are strongly linked, but this does not necessarily improve SSQ scores. The causal relationship between independent and dependent variables needs further research.

In Table III, angle deviation (β = 1.311, p = 0.002) and sea conditions (β = 23.281, p = 0.030) are significant predictors of ΔSSQ using stepwise MLR analysis. Statistics show that model variables affect motion sickness ratings simultaneously. Table IV lists model variables that significantly affected the SSQ score. Sea state and motion deviation had t(38) = 3.306, p = 0.002, and 2.261, 0.030, respectively. The SSQ score increases 52.36 points with a 25° horizon deviation, more than five times from a static 0° horizon (10.22 points). The regression model indicates that a 1° deviation raises SSQ points by 1.311 (β = 1.311; p = 0.002), whereas moderate sea conditions add 23.281 (β = 23.281; p = 0.030). A 25° deviation with moderate sea conditions should result in 62 points of moderate to severe seasickness. This shows that visual-vestibular conflict greatly impairs VIMS in VR sailing simulations. The unstandardized B formula in Table IV can predict the dependent variable, according to linear regression. SSQ increase is projected using 6.309 + 1.311 × (motion deviation) + 23.281 × (sea condition), with calm sea conditions of 0 and moderate sea conditions of 1. By 1.311 per degree of deviation, participant motion sickness scores climb, and moderate sea conditions are 23.281 higher than calm sea conditions. The Wilcoxon test was used to evaluate SSQ (16 symptoms) and MISC symptom differences after identifying non-normal data (K-S: $p<0.05$).

TABLE III. ANOVA RESULTS

	Modela	Sum of squares	df	Mean square	F	Sig.
1	Regression	9099.772	2	5449.886	8.441	.001[b]
	Residual	19944.081	37	539.029		
	Total	29043.853	39			

a: Dependent variable SSQ increased
Predictors: (Constant), motion deviation, sea condition

TABLE IV. COEFFICIENT SSQ

	Unstandardized coefficient		Standardized coefficient		
Model[a]	B	Std. Error	Beta	t	Sig.
(Constant)	6.309	5.701		1.107	.276
Motion Deviation	1.311	.396	.451	3.306	.002
Sea Condition	23.281	10.295	.309	2.261	.030

a: Dependent variable SSQ increased

Figure 2 illustrates the average SSQ scores before and after the experiment by motion deviation, which strongly affects motion sickness intensity. The difference between pre- and post-SSQ scores grows with motion deviation: 0° generates 10.22, 10° 22.91, 15° 27.68, 20° 29.39, and 25° 52.36. Sea state is another variable in Figure 3. The mean SSQ scores pre- and post-experiment showed that calm sea conditions increased scores less than moderate sea conditions. This demonstrates that sea conditions and motion deviation affect motion sickness intensity. Table V shows how sea conditions and motion deviation affect the increase in the SSQ score. Adjusted R² of 0.276 indicates that variations and sea conditions explain 27.6% of the variance in ΔSSQ, while R² = 0.313 reveals that they explain 31.3%.

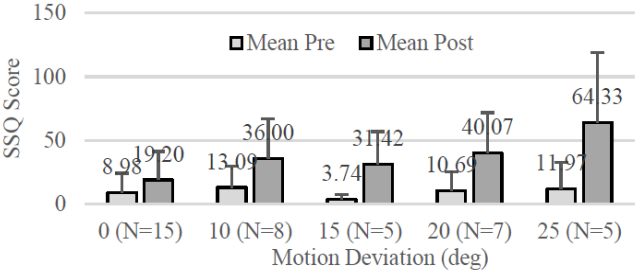

Fig. 2. SSQ score classified by motion deviation.

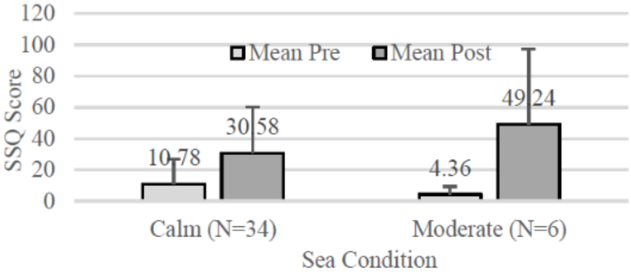

Fig. 3. SSQ score classified by sea condition.

TABLE V. MODEL SUMMARY

Model summary					
Model[a]	R	R square	Adjusted R-squared	Std. error of the estimate	DW
1	.560[b]	.313	.276	23.21700	1.854

a: Dependent variable SSQ increased
Predictors: (Constant), motion deviation, sea condition

B. Non-Parametric Analysis of MISC Scores

The Mann-Whitney test for horizon motion demonstrates no statistically significant difference in MISC score increases between pitching 2.00 and rolling 3.00. For $N_{pitching}$ = 15 and $N_{rolling}$ = 10, U is 64.50 with z = -0.589 and p =.556. Pitch and roll motions on the virtual horizon do not influence the MISC score. According to the Mann-Whitney test for sea condition, calm (Mdn = 1.00) and moderate (Mdn = 5.50) MISC scores are not significantly different, showing that sea conditions do not affect the MISC score. Age is categorized into five categories, from 1 to 5 for 15-19, 20-29, 30-39, 40-49, and 50-59. The Kruskal-Wallis test was performed with more than two levels to investigate if age affects the MISC score. The results showed no significant difference between categories 1 (Mdn = 2.00), 2 (Mdn = 1.00), 3 (Mdn = 1.00), 4 (Mdn = 1.00), and 5 (Mdn not available) [H(4) = 2.437, p =.656]. In Table VI, the motion deviation variable was classified as 0, 10, 15, 20, and 25° and tested using the Kruskal-Wallis test. H(4) = 13.142 with p =.011 showed a significant difference across the five categories: 0° (Mdn = 0.00), 10° (Mdn = 1.50), 15° (Mdn = 3.00), 20° (Mdn = 2.00), and 25° (Mdn = 3.00). The results show that motion variation increases MISC. As shown in Table VII, pitching, rolling, gender, and age did not significantly affect motion sickness intensity.

TABLE VI. KRUSKAL WALLIS TEST

	Motion deviation	N	Mean Rank
MISC increase	0	15	12.43
	10	8	23.94
	15	5	23.20
	20	7	26.43
	25	5	28.20
Kruskal-Wallis H	13.142		
df	4		
Asymp. Sig.	.011		

TABLE VII. EXCLUDED VARIABLES

Excluded Variables						
					Collinearity statistic	
	Model^{a}	Beta in	t	Sig.	Tolerance	VIF
1	Pitching	-.089^{c}	-.604	.549	.876	1.142
	Rolling	.094^{c}	.550	.586	.648	1.544
	Gender	.194^{c}	1.367	.180	.896	1.116
	Age	-.064^{c}	-.464	.645	.993	1.007

a: Dependent variable SSQ increased

Table VIII shows that only four symptoms did not significantly change ($p > 0.05$) during virtual horizon pitching and rolling. Sweating, attention difficulties, dizziness, and burping (p = .763–.317) occurred. The experiment with a stationary virtual horizon only showed significant findings for eye strain ($p = 0.025$) and blurred vision ($p = 0.023 < 0.05$). The Wilcoxon test was utilized to see if the motion virtual horizon significantly impacted the overall SSQ score and motion sickness dimensions compared to the no-motion virtual horizon.

TABLE VIII. WILCOXON-TEST OF MOTION SICKNESS SYMPTOMS

Wilcoxon-Test of Motion Sickness Symptoms			
No.	Symptoms	Wilcoxon-test (Motion)	Wilcoxon-test (No motion)
1	General Discomfort*	z=-3.640, p=0.000	z=-1.633, p=0.102
2	Fatique*	z=-1.964, p=0.005	z=-1.000, p=0.317
3	Headache*	z=-2.530, p=0.011	z=-1.342, p=0.108
4	Eye Strain*#	z=-4.234, p=0.000	z=-2.236, p=0.025
5	Difficulty Focusing*	z=-2.919, p=0.004	z=0.000, p=1.000
6	Increased Salivation*	z=-2.640, p=0.008	z=0.000, p=1.000
7	Nausea*	z=-2.812, p=0.005	z=-1.000, p=0.317
8	Fullness of the Head*	z=-2.972, p=0.003	z=-1.000, p=0.317
9	Blurred Vision*#	z=-2.333, p=0.020	z=-2.271, p=0.023
10	Dizzy (Eyes Open) *	z=-2.714, p=0.007	z=-1.342, p=0.180
11	Dizzy (Eyes Closed) *	z=-2.530, p=0.011	z=0.000, p=1.000
12	Stomach Awareness*	z=-2.460, p=0.014	z=0.000, p=1.000
13	Sweating	z=-0.302, p=0.763	z=-1.633, p=0.102
14	Difficulty Concentrating	z=-1.633, p=0.102	z=-1.000, p=0.317
15	Vertigo	z=-1.414, p=0.157	z=0.000, p=1.000
16	Burrping	z=-1.000, p=0.317	z=-1.000, p=0.317

*Significant value of the motion experiment
Significant value of the no motion experiment

Table IX shows a Wilcoxon test ($p < 0.05$) for all motion sickness components in the virtual horizon experiment. The key parameters were nausea, oculomotor function, and disorientation (p = 000). Oculomotor and disorientation were significant in the stationary virtual horizon trial, but nausea was not. The SSQ score varied greatly with and without motion stimulation.

TABLE IX. WILCOXON TEST OF MOTION DIMENSIONS

Dimentions	Wilcoxon-test (Motion)	Wilcoxon-test (No motion)
Nausea*	z=-3.780, p=0.000	z=-0.954, p=0.340
Aculomotor*#	z=-4.212, p=0.000	z=-2.399, p=0.016
Disorientasion*#	z=-3.807, p=0.000	z=-2.209, p=0.027
Total score*#	z=-4.288, p=0.000	z=-2.155, p=0.031

C. Symptom Sensitivity and Instrument Comparison

MISC scores were taken before, five minutes into, and after the trial. A Spearman correlation test (Table X) showed a substantial positive connection between MISC and SSQ scores [Rs(38) = 0.818, p =.000). A nonparametric test was performed since MISC data unstandardized residuals were not normally distributed according to the K-S test (p =.000). Gender, pitching and rolling horizon motion, and calm and moderate sea state were compared using Mann-Whitney tests. For age and motion differences, Kruskal-Wallis was used.

TABLE X. CORRELATION SSQ AND MISC

		SSQ increased	MISC increased
SSQ Increased	Correlation Coef.	1.000	.818**
	Sig. (2-tailed)	.	.000
	N	40	40
MISC Increased	Correlation Coef.	.818**	1.000
	Sig. (2-tailed)	.000	.
	N	40	40

**Correlation is significant at the 0.01 level (2-tailed).

The results revealed a substantial association between SSQ and MISC. MISC measures motion sickness intensity more than SSQ, but it is less motion sickness-sensitive than SSQ. The MLR of the SSQ scores demonstrated that sea conditions and motion deviation greatly affected motion sickness intensity. The only significant MISC score variable was motion deviation. The sea condition had the highest significance, but was not statistically significant. SSQ is more sensitive than MISC in assessing the severity of motion sickness.

Recent EEG signal classification tests reveal that CNN-LSTM can separate VIMS symptom clusters better than self-report. [15]. In addition, recent reservoir computing trajectory prediction research showed highly accurate motion estimation and responsiveness for dynamic simulation platforms [14]. This study corroborates the finding that FIS improved cinematic shadow quality in VR simulations [8]. This ferry simulation boosted SSQ-MISC sensitivity by 31.3%, while in [8], a 42% increase in experimental group post-test scores was observed.

Due to commercial ferry safety and logistical constraints, this pilot study included 15 passengers (10 men, 5 women). Although the within-subject approach increases statistical power, male dominance may restrict generalizability. This study found no gender effect on ΔSSQ ($p > 0.18$), but a larger, gender/age-balanced sample is needed for replication.

IV. CONCLUSION

This field study addresses a key research gap by quantifying the influence of virtual horizon deviation on motion sickness during actual ferry travel using VR-HMDs. Stepwise MLR identified two significant predictors for ΔSSQ:

the angular deviation of the virtual horizon [t(38) = 3.306, p = 0.002] and sea state conditions [t(38) = 2.261, p = 0.030], together explaining 31.3% of SSQ variance. While MISC scores reflected symptom increases only at higher deviations (more than 20°), SSQ captured a more continuous sensitivity to both visual and environmental parameters.

This study provides a prediction equation that quantifies how angular deviation affects symptoms, laying the groundwork for future adaptive VR systems, such as real-time synchronization between virtual horizons and vessel movements using IMU or gyroscopic input to improve user comfort in marine VR applications.

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