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Identification and Evaluation of Cybersickness Impact of Mixed Reality Simulator (MRSi) System

Mohamad Jamil[1,2*], Hadiyanto Hadiyanto[1], Ridwan Sanjaya[3]

[1] Department of Information Systems Doctorate, Diponegoro University, Semarang 50241, Indonesia
[2] Department of Informatics Engineering, Khairun University, Ternate 97718, Indonesia
[3] Department of Information System, Soegijapranata Catholic University, Semarang 50234, Indonesia

Corresponding Author Email: jamil@unkhair.ac.id

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ABSTRACT

Although Mixed Reality (MR) technology offers many advantages, users can experience cybersickness, like motion sickness, with symptoms such as dizziness, nausea, headaches, and eye strain. This phenomenon is a significant challenge, especially in applications that require continuous and immersive interaction. This paper aims to identify and evaluate the impact of cybersickness experienced by users in the process of disaster mitigation simulation using the Mixed Reality Simulator (MRSi) system. The results show that age, duration of use, and content design have a significant impact on user comfort. Older users tend to experience disorientation more quickly, while long duration of use and inappropriate content design can increase nausea. Although some factors do not show statistically significant effects, such as duration on oculomotor scores, they still have potential indirect impacts. In addition, the cause of discomfort may also be influenced by low refresh rates, non-ergonomic physical design of the device, and visual stimuli from the Head Mounted Display (HMD).

1. INTRODUCTION

In recent years, the development of Mixed Reality (MR) technology has had a significant impact on various sectors, including education, training, health, and disaster simulation [1-3]. MR combines elements of the virtual world with the real world and enables a deep immersive experience for users [4]. One potential application of this technology is a disaster mitigation simulation, where users can practice and plan responses to emergencies more interactively and realistically. This simulation can involve visual, auditory, and haptic elements working together to create a near-realistic experience.

Even though MR technology offers many advantages, users can experience a phenomenon known as cybersickness or virtual motion sickness. Cybersickness refers to physical discomfort like motion sickness, which can include symptoms such as dizziness, nausea, headaches, and eye strain [5, 6].

The phenomenon of cybersickness or virtual motion sickness is a main challenge in the use of MR technology, especially in applications that require continuous and immersive interaction. Cybersickness occurs when there is a mismatch between the visual input received by the eyes and the sensation of movement felt by the body, which usually occurs when using virtual reality (VR) or augmented reality (AR) devices [7, 8]. When users interact with a virtual environment that moves or changes without being proportional to their body movements, the human body's sensory system receives conflicting information, causing symptoms such as dizziness, nausea, headaches, and eye strain [9].

Cybersickness is an obstacle that needs to be overcome for the sustainability of immersive technology in the future. Salgado et al. [10] emphasize that in immersive systems with a high degree of spatial presence, such as those found in the use of high-quality VR or AR devices, users tend to feel as if they are in the virtual environment they are viewing.

However, the difference between what they see and the body movements they experience in the real world can cause sensory conflict, which then triggers cybersickness. In other words, although this technology offers a more immersive experience, its users become more susceptible to physical discomfort due to the increasing immersion felt.

Breves and Dodel [11] also support this finding by comparing high-quality devices with simpler devices, such as Head-Mounted Display (HMD) cardboards. They found that high-quality devices, although increasing spatial presence (sense of presence) more effectively, can increase the likelihood of cybersickness. This is due to several factors, including screen resolution, refresh rate, and high latency on low-quality devices, which can reduce the level of user discomfort. In other words, better devices in terms of image quality and immersive experience do not always mean a more comfortable experience, especially if other technical issues, such as latency or low frame rates, still need to be properly addressed.

Thus, although immersive technology has great potential in various fields, including entertainment, education, and training, the biggest challenge still faced is how to reduce or even eliminate the symptoms of cybersickness that can interfere with user comfort and reduce the technology's effectiveness in the long term [12, 13].

This study aims to evaluate the level of cybersickness experienced by users in the disaster mitigation simulation process using the Mixed Reality Simulator (MRSi) system. With a better understanding of the factors causing cybersickness, it is hoped that solutions or system designs can be found that can reduce these negative impacts while increasing the effectiveness and comfort of users in undergoing training. This research is also expected to contribute to the development of more optimal and user-friendly simulation technology, especially in the context of disaster management training applications that are increasingly relevant in the future

2. RELATED WORK

The simulation training system for natural disaster management provides a new way for educators, scientists, and emergency personnel to master their job responsibilities and improve their ability to respond to emergencies. Li et al. [14] found an increasing demand for simulation training systems that utilize visualization technologies such as VR, AR, and MR to simulate major natural disasters. In the context of disaster mitigation simulation, aspects such as visual latency, synchronization between participant movement and the virtual environment, and the quality of real-world representation in the MR system need to be carefully considered to minimize the possibility of cybersickness.

Stauffer et al. [15] stated that high latency could reduce the application's graphic performance and trigger cybersickness. Their research found that latency in a system is not always constant but can show complex timing patterns with various varying behaviors.

Brunnström et al. [16] also highlighted the importance of managing latency in VR simulators because significant delays can reduce the quality of the experience and even cause uncomfortable symptoms for users. The findings presented from the research conducted, namely a delay lower than about 500 ms (half a second), may not be too disturbing or significant for the trainees. However, once the delay reaches 800 ms, the impact becomes very clear and disturbing and affects task performance and user comfort substantially.

Kirollos and Merchant [17] in their study explored whether the use of HMD MR causes different levels of cybersickness compared to HMD VR, and how the quantity of graphics in the display affects the severity. This study was conducted by modulating the number of graphics displayed in three different conditions, namely two MR conditions where the first condition with only foreground objects displayed graphically and at the same time the background remains visible, the second MR condition is where the entire scene (both foreground and background) is displayed graphically in MR, then one VR condition where all graphics (foreground and background) are displayed entirely in virtual reality which means that the user only sees the virtual world. Participants were asked to observe the scenes in these three conditions for 30 minutes while reporting the level of cybersickness. The findings obtained are that the use of HMD MR can trigger cybersickness, especially if the number of graphics displayed is very high.

The exact cause or triggering factors for cybersickness are still not fully understood. Petri et al. [18] highlighted the influence of age, content familiarity, and gender on the impact of cybersickness in their study. The findings from this study indicate that older adults and those who are not familiar with certain types of content are more susceptible to cybersickness, especially when the duration of exposure is longer. In addition, women tend to report symptoms of cybersickness more than men [19].

In addition, Li et al. [20] state that user characteristics, as well as the software and hardware used in the system, can affect the level of cybersickness.

Furthermore, Zaidi et al. [21] developed a cybersickness potential prediction system using a machine learning algorithm in their study. The findings presented are that artificial intelligence, especially machine learning algorithms, can provide a more effective solution to predict and overcome cybersickness in the development of VR technology. Further evaluation can add additional attributes in the form of the Simulator Sickness Questionnaire (SSQ).

Huygelier et al. [22] convey a different point, namely that cybersickness is not a big problem for the older adult group. This could be because they are more open and interested in using VR technology for health applications after trying the first experience.

Based on a literature review of several studies that have been conducted by previous researchers, the main focus of our proposed research is to explore the impact of cybersickness in a more specific context, especially the use of MR in the disaster mitigation simulation training process. Therefore, our research questions are:

(RQ1): Is there a significant influence between cybersickness symptoms (Nausea, Occulomotor, and Disorientation) on user comfort using the Mixed Reality Simulator (MRSi) system?

(RQ2): Do factors such as duration of use, age, and content design moderate the relationship between cybersickness symptoms and user comfort using the Mixed Reality Simulator (MRSi) system?

3. METHODOLOGY

This research methodology is designed to identify and evaluate the impact of cybersickness caused by the MRSi system in a disaster mitigation training simulation. Figure 1 shows the stages of this research.

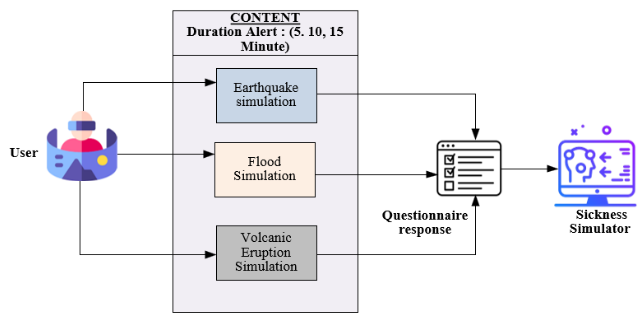

Figure 1. Research stages

This study involved 100 users, consisting of 53% male and 47% female, as research subjects who would undergo simulations with three main disaster scenarios: earthquake, flood, and volcanic eruption. Each simulation was designed to create a realistic experience through visual and sensory elements, with varying durations (5, 10, and 15 minutes) to observe the effect of length of exposure on the level of cybersickness. Figure 2 presents various MRSi system simulation content.

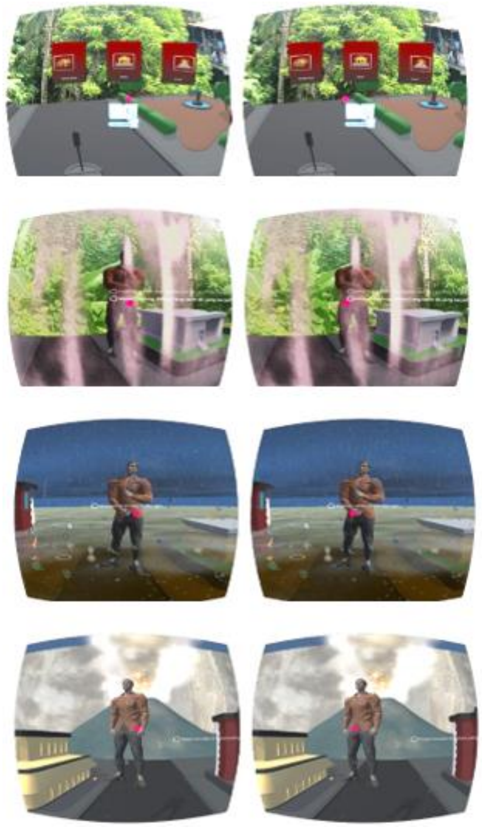

Figure 2. MRSi simulation content

Furthermore, Table 1 below shows the distribution of respondents by gender.

Table 1. Distribution of respondents by gender

No	Gender	Frequency	Percentage
1	Male	53	53%
2	Female	47	47%
Total		100	100%

Table 1 above shows that the composition of respondents consisted of 53% male and 47% female, with a total of 100 respondents. This distribution aims to ensure a balanced gender representation. These data show that both gender groups are relatively evenly distributed, with a slight dominance of male respondents. Detailed interpretation shows that the dominance of men as simulation participants is likely due to several factors. First, in the social and cultural context, men are often considered to have a greater role in dealing with emergency or disaster situations. This can lead to more active involvement of men in disaster mitigation simulations, both in leadership roles and direct responses in the field. In some environments, men may also be more accustomed to being involved in technical activities, which may explain their higher representation in technology-based simulations. However, the almost equal participation of women (47%) indicates an increase in their awareness and involvement in activities related to disaster mitigation. This is very positive, considering that the role of women in disaster situations is often critical, especially in the context of family planning, health, and broader community response. Furthermore, respondent data based on age is shown in Table 2.

Table 2. Distribution of respondents by age

No.	Age Group	Frequency	Percentage
1	10-14	11	11.0%
2	15-19	11	11.0%
3	20-24	11	11.0%
4	25-29	12	12.0%
5	30-34	11	11.0%
6	35-39	8	8.0%
7	40-44	11	11.0%
8	45-49	10	10.0%
9	50-54	8	8.0%
10	55-59	5	5.0%
11	60-64	2	2.0%
	Total	100	100.0%

After undergoing the simulation, users were directed to fill out a user response questionnaire online at http://mrsi.my.id/motion-sickness and also continued by filling out a questionnaire measuring cybersickness symptoms using SSQ at http://mrsi.my.id/ssq to assess the level of discomfort or symptoms experienced by a person after being exposed to virtual simulation devices. The data obtained from the test results would then be statistically analyzed using SEM-PLS to determine the relationship and influence of each variable, including Nausea, Oculomotor, and Disorientation, on the level of comfort and user experience in using MRSi. Figure 3 shows the model of the cybersickness evaluation hypothesis.

Based on Figure 2, the next process was to determine the variables and indicators of the hypothesis model created.

Table 3 describes the relationship between variables from the hypothesis model.

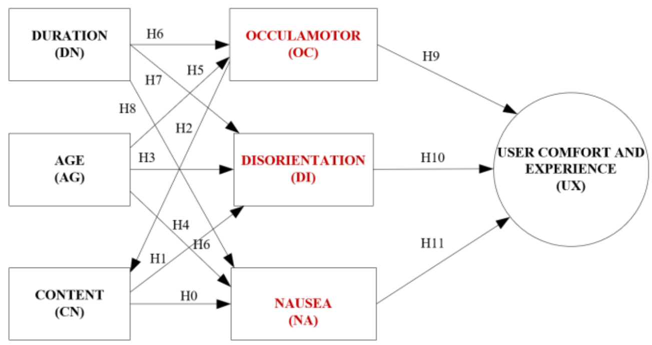

Figure 3. Hypothesis model

In Table 3, 12 variables will be used in the cybersickness evaluation process. Based on the existing variables, the questionnaire material containing six main questions was compiled to evaluate the impact and symptoms of cybersickness related to the use of the MRSi system. Table 4 below shows the questionnaire items for cybersickness evaluation.

After completing the simulation process, the questionnaires were disseminated online to users at http://mrsi.my.id/motion-sickness/.

Table 3. Variables and indicators

Variable	Indicator	Hypothesis
H0	Content (CN)	Whether Content Design (CN) affects (NA)
H1	Content (CN)	Whether Content Design (CN) affects (DI)
H2	Content (CN)	Whether Content Design (CN) affects (OC)
H3	Age (AG)	Whether Age (AG) affects (DI)
H4	Age (AG)	Whether Age (AG) affects (NA)
H5	Age (AG)	Whether Age (AG) affects (OC)
H6	Duration (DN)	Whether Duration (DN) affects (OC)
H7	Duration (DN)	Whether Duration (DN) affects (DI)
H8	Duration (DN)	Whether Duration (DN) affects (NA)
H9	Oculomotor (OC)	Whether a high score of Oculomotor (OC) can affect the comfort and user experience of the MRSi System
H10	Disorientation (DI)	Whether a high score of Disorientation (DI) can affect the comfort and user experience of the MRSi System
H11	Nausea (NA)	Whether a high score of Nausea (NA) can affect the comfort and user experience of the MRSi System

Table 4. Questionnaire items for cybersickness evaluation

No.	Questions
1	Do you have a history of certain diseases?
2	How do you feel when using the Mixed Reality Simulator device for 5 minutes?
3	How do you feel when using the Mixed Reality Simulator device for 10 minutes?
4	How do you feel when using the Mixed Reality Simulator device for 15 minutes?
5	Which simulation rooms are likely to cause discomfort effects?
6	Which features caused you to experience certain symptoms (discomfort, fatigue, dizziness, difficulty concentrating, nausea, etc.)?

4. RESULTS AND DISCUSSION

The Simulation Process was conducted by asking participants to use the technology for varying durations, such as 5 minutes, 10 minutes, and 15 minutes, to observe the development of cybersickness symptoms they experienced. Data from respondents were then collected through a questionnaire designed to assess various symptoms, such as nausea, dizziness, fatigue, headaches, and eye strain, as well as the duration and severity of these symptoms.

The results of the data collection obtained were then arranged in Table 5, which shows the number of respondents who reported certain symptoms at each simulation duration. This table provides information on the frequency of symptoms that occurred in the first 5 minutes, 10 minutes, and 15 minutes, as well as the percentage of respondents who experienced each symptom.

Furthermore, this data was analyzed to identify patterns or relationships between the duration of technology use and the intensity of symptoms experienced by participants. This analysis aims to provide further insight into the factors that influence cybersickness, as well as to evaluate how much influence the duration of exposure has on user comfort and health.

Summary data of cybersickness evaluation questionnaire results in Table 5 shows that the number of respondents was 100. However, 97 suitable respondent samples for further analysis were obtained after filtering and validation. The data show that Fatigue is the most frequently reported symptom at a duration of 5 minutes with 61.9% (60 of 97 participants), decreasing drastically at 10 minutes (27.8%) and remaining the same at 15 minutes (27.8%). This shows that although fatigue is dominant initially, many participants may adapt or get used to MRSi over time. The next dominant symptom is Sweating, showing a consistent increase from 5 minutes (8.2%) to 15 minutes (33.0%), and it tends to increase along with the duration of MRSA use.

Symptoms that tend to be stable are Difficulty Focusing and Nausea, showing a relatively stable percentage at various durations, around 3.1% and 4.1%, respectively. This shows that these symptoms are not greatly affected by the duration of MRSi use. The fluctuating symptom Eye Strain had a significant increase from 5 minutes (11.3%) to 10 minutes (37.1%) but decreased again at 15 minutes (15.5%).

This may indicate that eye strain may peak in the middle period and then decrease. Furthermore, the Dizziness (Eyes Open) symptom increased gradually from 5 minutes (5.2%) to 15 minutes (12.4%), indicating that dizziness may take a longer time to continue to increase. The low-frequency symptom of Discomfort was only reported at the beginning (2.1%) and did not appear again after 10 and 15 minutes, indicating that this symptom may disappear quickly or be insignificant after a short time. Furthermore, the symptom Headache slightly increased at 10 minutes (6.2%) and decreased again at 15 minutes (4.1%). After obtaining the data from the questionnaire filling process, the next step was to evaluate the severity level.

Table 5. Summary of cybersickness evaluation questionnaire results

No.	Cybersickness Symptoms	Duration					
		5 Minutes		10 Minutes		15 Minutes	
		F	%	F	%	F	%
1	Sweating	8	8.2%	16	16.5%	32	33.0%
2	Difficulty Focusing	3	3.1%	3	3.1%	3	3.1%
3	Discomfort	2	2.1%	0	0.0%	0	0.0%
4	Fatigue	60	61.9%	27	27.8%	27	27.8%
5	Eye Strain	11	11.3%	36	37.1%	15	15.5%
6	Nausea	3	3.1%	4	4.1%	4	4.1%
7	Dizziness (Eyes Open)	5	5.2%	5	5.2%	12	12.4%
8	Headache	5	5.2%	6	6.2%	4	4.1%
	Total	97	100%	97	100%	97	100%

Table 6 shows the results of evaluating the distribution of the severity level.

Based on the severity distribution evaluation data, most participants (53.6%) reported Oculomotor symptoms with mild severity, while 21.6% experienced moderate severity and 4.1% experienced severe severity; 20.6% of participants did not experience this symptom at all. Furthermore, more than half of the participants (51.5%) did not experience Nausea symptoms. A total of 42.3% experienced mild nausea, and 6.2% experienced severe nausea; no participants reported moderate nausea. While in the Disorientation symptoms, similar to the oculomotor, most participants (53.6%) reported disorientation with mild severity, 21.6% experienced moderate severity, and 4.1% experienced severe severity; 20.6% of participants did not experience this symptom at all. After obtaining data from the evaluation of the severity distribution, the next process is to describe the data from the evaluation of symptom-causing features. Table 7 shows the results of the descriptive analysis of symptom-causing features.

Table 6. Results of evaluating the distribution of the severity level

No.	Severity Level	Based on					
		Oculomotor		Nausea		Disorientation	
		F	%	F	%	F	%
1	Severe	4	4.1%	6	6.2%	4	4.1%
2	Moderate	21	21.6%	0	0.0%	21	21.6%
3	Mild	52	53.6%	41	42.3%	52	53.6%
4	None	20	20.6%	50	51.5%	20	20.6%
	Total	97	100%	97	100%	97	100%

Table 7. Results of evaluating the symptom-causing features

No	Symptom-Causing Features	F	%
1	Hand Tracking	73	75.3%
2	Eye Tracking	21	21.6%
3	Hand Tracking, Eye Tracking	3	3.1%
	Total	97	100%

Table 7 presents the frequency (F) and percentage (%) of features in the MRSi system that are believed to cause cybersickness symptoms experienced by users. The Hand Tracking feature is the most dominant cause of symptoms, with 73 participants (75.3%) reporting it as the cause of cybersickness symptoms. Furthermore, although the Eye Tracking feature is less dominant than hand tracking, the eye tracking feature also has a significant impact, with 21 participants (21.6%) reporting it as a cause of symptoms. In the Hand Tracking and Eye Tracking features, the combination of these two features was reported by 3 participants (3.1%) as the cause of cybersickness symptoms. After knowing the features that cause symptoms, the next process is to observe the simulation space that causes the impact of discomfort. The results of the descriptive analysis related to the simulation space that caused the discomfort effect are shown in Table 8.

The appearance of discomfort symptoms in most participants indicates that the Earthquake Mitigation Simulation has the potential to cause unwanted reactions in users. Possible causes of discomfort effects in earthquake mitigation simulations can come from factors such as realistic visualization of earthquakes, sharp camera movements, or sudden audio shocks. As for the Earthquake & Flood Mitigation Simulation Combination, although only a few participants reported discomfort effects from this combination, it should be noted that the presence of this effect indicates the possibility of factors contributing to discomfort in earthquake mitigation simulations when combined with flood mitigation simulations.

After knowing the various factors that cause cybersickness symptoms and the distribution of severity, the next step is to evaluate the symptom factors and SSQ scores, as shown in Table 9.

Table 8. Result of evaluating the simulation space that causes the discomfort effect

No.	Simulation Space that Causes the Discomfort Effect	F	%
1	Earthquake Mitigation Simulation	95	97.9%
2	Earthquake Mitigation Simulation & Flood Mitigation Simulation	2	2.1%
	Total	97	100%

Table 9. Results of evaluating the symptom factors and SSQ scores

Distribution	Nausea	Oculomotor	Disorientation	Total Score
Mean	5.34	8.19	3.76	6.40
Median	0.00	7.58	0.00	3.74
STD	6.37	5.74	7.84	4.31

Table 9 shows that there are three SSQ components: nausea (N), oculomotor (O), and disorientation (D) [23]. The overall SSQ score (total of SSQ components) is obtained by combining the severity scale scores and component weights. The mean score is obtained from the sum of SSQ calculations containing 16 cybersickness symptoms assessed by simulation officers against participants with a severity scale for each symptom of 0, 1, 2, and 3. The scale score is multiplied by the nausea, oculomotor, and disorientation components with weights of 0 and 1. For the nausea component, $\alpha N = 9.54$, the oculomotor component, $\alpha O = 7.58$, and the disorientation component, $\alpha D = 3.74$. Based on the evaluation results, visual disorder (oculomotor) has the highest average (8.19), which indicates the most significant impact of the three disorders. This indicates that the symptoms of visual disorder tend to be more significant in general in the given data sample. After obtaining the SSQ score of each component, the following process is to conduct hypothesis testing (path analysis), as shown in Table 10. This section evaluates coefficients or parameters that indicate one latent variable's causal relationship or influence on another. A causal relationship is declared insignificant if the t-statistics/critical ratio (C.R.) score is between -1.96 and 1.96, with a significance level of 0.05 [24].

From the results of the analysis, it can be seen that several symptoms have a tendency to increase and reach their peak due to several factors, including:

- Visual and audio factors: In earthquake mitigation simulations, sudden camera movements or sounds can cause more direct symptoms such as nausea or confusion, which can quickly reach their peak (for example, oculomotor symptoms or disorientation). More visual symptoms (such as visual disturbances) may be felt more quickly than more internal or less visible symptoms such as nausea.
- Combination of simulations: When earthquake and flood mitigation simulations are combined, there may be more

complex interactions between symptoms. Symptoms of discomfort may not appear immediately, but over time and interactions between simulations, certain symptoms will begin to appear or develop. This could explain why some symptoms appear more slowly in the combination of simulations.

Table 10. Results of hypothesis testing of cybersickness variables

The Effect Between Latent Variables			Coefficient of Path	t-Statistics	P-Score	Conclusion
Causal Variable (Exogen)	**-->**	**Effect Variable (Endogen)**				
Duration (DN)	-->	Oculomotor Score (OC)	-0.099	0.809	0.419	Insignificant
Age (AG)	-->	Oculomotor Score (OC)	0.223	1.783	0.075	Insignificant
Content Design (CN)	-->	Oculomotor Score (OC)	-0.218	1.472	0.142	Insignificant
Duration (DN)	-->	Disorientation (DI)	0.104	0.984	0.325	Insignificant
Age (AG)	-->	Disorientation (DI)	0.375	2.719	0.007	Significant
Content Design (CN)	-->	Disorientation (DI)	0.203	1.123	0.262	Insignificant
Duration (DN)	-->	Nausea (NA)	-0.359	3.578	0.000	Significant
Age (AG)	-->	Nausea (NA)	0.359	3.552	0.000	Significant
Content Design (CN)	-->	Nausea (NA)	-0.407	4.984	0.000	Significant
Oculomotor Score (OC)	-->	Comfort and User Experience on MRSi System (UX)	-0.655	14.647	0.000	Significant
Disorientation (DI)	-->	Comfort and User Experience on MRSi System (UX)	-0.212	3.573	0.000	Significant
Nausea (NA)	-->	Comfort and User Experience on MRSi System (UX)	-0.385	7.651	0.000	Significant

The results of the hypothesis testing of cybersickness variables can be summarized as follows:

1. Age (AG) to Disorientation (DI): Age significantly affects users' disorientation. The older the user, the more likely they will experience disorientation when using the MRSi simulator.
2. Duration (DN) to Nausea (NA): The duration of MRSi use significantly affects the occurrence of gastrointestinal disorders (nausea). The longer the user uses the simulator, the more likely they will experience nausea.
3. Age (AG) to Nausea (NA): Age also significantly affects the occurrence of nausea. Older users tend to have a higher risk of experiencing nausea when using the simulator.
4. Content Design (CN) to Nausea (NA): Content design significantly affects users' nausea. Well-designed content can reduce the likelihood of nausea when using the simulator.
5. Oculomotor Score (OC) to Comfort and User Experience (UX): Oculomotor score significantly affects the simulator's comfort level and overall user experience. The higher the oculomotor score, the more comfortable and satisfying the user experience.
6. Disorientation (DI) to Comfort and User Experience (UX): The level of disorientation the user feels significantly affects comfort and user experience. The higher the level of disorientation, the lower the comfort level and user experience.
7. Nausea (NA) to Comfort and User Experience (UX): Nausea also significantly affects comfort and user experience. The higher the level of nausea, the lower the comfort level and user experience.

The path diagram of measurement and structural models in Figure 4 describes the path coefficients in the structural model and the factor weight scores of the manifest variables in the measurement model

Based on the path diagram above, the Comfort and User Experience variables on the MRSi System (UX) are more dominantly influenced by the Oculomotor Score (OC) of -0.655, where the dominant variable in measuring the Oculomotor Score (OC) construct is the Age factor (AG) with the highest path coefficient of 0.223. This indicates that the higher the age of the participants, the more impact on increasing the Oculomotor Score (OC), which in turn will reduce the score of Comfort and User Experience on the MRSi System (UX). This indicates that the higher the age of the participants, the more impact on increasing the Oculomotor Score (OC), which in turn will reduce the score of Comfort and User Experience in the MRSi (UX) System. After the estimated model meets the construct validity test criteria, the next stage is to test the model fit (Goodness of Fit) using the coefficient of total determination, where the test results can explain how much the path model formed is able to represent the observed data. The coefficient of total determination ranges from 0.0 to 100.0%, where the higher the coefficient of total determination, the higher the path model can represent the observed data [25]. Table 11 shows the coefficient of determination **(**R-squared).

In detail, the results of measuring the standard inner model testing criteria based on the total coefficient of determination are shown in Table 12. Table 12 shows global optimization information to test how strong the confirmation of the theory is based on the constructed model. It is known that the total coefficient of determination is 0.967, where the score is in the range of 0.700 – 1.000. After testing the coefficient of determination (R-Square), the next process is to analyze the mediation variable (indirect effect) through two approaches, namely the difference in coefficients and multiplication of coefficients. The coefficient difference approach uses an examination method by conducting an analysis with and without involving mediating variables. In contrast, the multiplication method is done using the Sobel method [26]. In this case, the detection is carried out with the coefficient multiplication approach and the Sobel test [27]. The results of the coefficient multiplication are shown in Table 13.

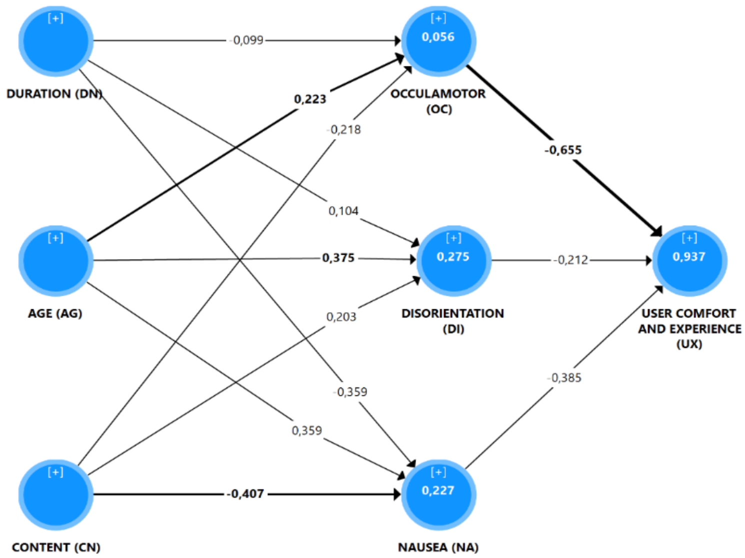

Figure 4. Path diagram of measurement and structural models (overall)

Table 11. Coefficient of determination (R-squared)

Influence			R-Square
Duration (DN)	-->	Oculomotor Score (OC)	
Age (AG)	-->	Oculomotor Score (OC)	0.056
Content Design (CN)	-->	Oculomotor Score (OC)	
Duration (DN)	-->	Disorientation (DI)	
Age (AG)	-->	Disorientation (DI)	0.275
Content Design (CN)	-->	Disorientation (DI)	
Duration (DN)	-->	Nausea (NA)	
Age (AG)	-->	Nausea (NA)	0.227
Content Design (CN)	-->	Nausea (NA)	
Oculomotor Score (OC)	-->	Comfort and User Experience on MRSi System (UX)	
Disorientation (DI)	-->	Comfort and User Experience on MRSi System (UX)	0.937
Nausea (NA)	-->	Comfort and User Experience on MRSi System (UX)	

Table 12. Coefficient of determination (R-squared)

No.	R-Square Criterion Standard		R-Square Total	Information
	Interval	Category		
1	0.000 – 0.299	Very Weak		
2	0.300 – 0.499	Weak	0.967	Strong
3	0.500 – 0.699	Moderate		
4	0.700 – 1.000	Strong		

Table 13. Indirect effect between latent variables

Indirect Effect	Calculation	Result	t-Count	P-Score	Information
Duration (DN) on the Comfort and User Experience on MRSi System (UX) through Oculomotor Score (OC)	-0.099 × -0.655	0.065	0.819	0.413	Insignificant
Age (AG) on the Comfort and User Experience on MRSi System (UX) through Oculomotor Score (OC)	0.223 × -0.655	-0.146	1.828	0.068	Insignificant
Content Design (CN) on the Comfort and User Experience on MRSi System (UX) through Oculomotor Score (OC)	-0.218 × -0.655	0.143	1.505	0.133	Insignificant
Duration (DN) on the Comfort and User Experience on MRSi System (UX) through Disorientation (DI)	0.104 × -0.212	-0.022	0.928	0.354	Insignificant
Age (AG) on the Comfort and User Experience on MRSi System (UX) through Disorientation (DI)	0.375 × -0.212	-0.080	2.866	0.004	Significant
Content Design (CN) on the Comfort and User Experience on MRSi System (UX) through Disorientation (DI)	0.203 × -0.212	-0.043	0.895	0.371	Insignificant
Duration (DN) on the Comfort and User Experience on MRSi System (UX) through Nausea (NA)	-0.359 × -0.385	0.138	3.093	0.002	Significant
Age (AG) on the Comfort and User Experience on MRSi System (UX) through Nausea (NA)	0.359 × -0.385	-0.138	3.230	0.001	Significant
Content Design (CN) on the Comfort and User Experience on MRSi System (UX) through Nausea (NA)	-0.407 × -0.385	0.157	4.385	0.000	Significant

Based on the results of the tests carried out, the impact of significant and insignificant findings related to the indirect effect of independent variables on user comfort and experience in using the MRSi System (UX) is as follows:

Significant impacts:

Age (AG) on Disorientation (DI): The finding that age significantly affects the level of disorientation in the use of Mixed Reality Simulator (UX) systems suggests that older users may experience greater difficulty adapting to the simulation environment. In system development, this requires special attention to provide a more intuitive and understandable experience for older users.

Duration (DN), Age (AG), and Content Design (CN) on Nausea (NA): The significant effect of these variables on nausea suggests that these factors may directly affect user comfort. Longer duration of use, older users, and less appropriate content design may increase the risk of users experiencing nausea symptoms. In development, this suggests the need to pay attention to these aspects to reduce the risk of users feeling uncomfortable.

Age (AG) and Content Design (CN) on Nausea (NA): The findings also highlight that factors such as user age and content design quality have a direct impact on user comfort level. Therefore, in system development, it is important to consider the appropriateness of users of different age groups as well as the quality of content design that may affect the comfort level and user experience.

Insignificant impacts:

Duration (DN), Age (AG), and Content Design (CN) on Oculomotor Score (OC): Although statistically insignificant, these findings suggest that these factors may have an indirect effect on the oculomotor, which may affect users' comfort and experience in using the MRSi System (UX). Although statistically insignificant, it is still necessary to consider these factors in system development.

Duration (DN) on Disorientation (DI) and Nausea (NA): Although insignificant, the indirect effect of Duration (DN) on Disorientation (DI) and Nausea (NA) suggests the potential that longer duration of use may contribute to an increased risk of users experiencing disorientation and nausea. Although statistically insignificant, this still needs to be a concern in development to minimize the risk of users experiencing discomfort.

The cause of discomfort in some previously reported studies can be due to several factors, namely:

Low refresh rate: Low refresh rates often cause dizziness when using VR headsets, necessitating an increase in refresh rates to at least above 60 Hz [28].

Device physical design: Device ergonomics factors such as uneven weight distribution on the head can cause users to feel dizzy [29].

Visual stimuli of a head-mounted display (HMD): This refers to the stimulation or visual input received by the eye or brain through the HMD device, which may cause disorientation [17, 30].

5. CONCLUSIONS

Evaluation of the level of cybersickness experienced by users in the process of disaster mitigation simulation using the Mixed Reality Simulator (MRSi) system is affected by several factors, such as age, duration of use, and content design, that have a significant impact on user comfort and experience in using the MRSi system. Older users tend to experience higher levels of disorientation, while long duration of use and inappropriate content design can increase the risk of nausea. Although some factors, such as duration to disorientation and nausea, do not show statistically significant effects, it is still important to consider these factors in system development. The causes of discomfort can also be influenced by low refresh rates, unergonomic physical design of the device, and visual stimuli from the Head Mounted Display (HMD). Therefore, to reduce the negative impact of cybersickness and improve user comfort, it is necessary to improve these aspects.

In the future, our work will focus on using AI and machine learning to make MR systems more intelligent and responsive to user reactions, and to increase their comfort. By customizing the experience based on factors such as gender and expanding the use of smartphones to make MR technology more inclusive and accessible to a wider range of people, we will address the limitations of previous simulations using HMD devices.

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