Evaluating Object Collection in Emergency Simulations Using Virtual and Augmented Reality

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ABSTRACT

Virtual Reality (VR) and Augmented Reality (AR) have enormous potential in their implementation in various fields. Still, both have different ways for users to interact with the user's digital connection and physical environment. This study evaluated the interaction between participants and objects in VR and AR. To achieve this, a user study was conducted with 24 participants using Meta Quest 3 headsets to run simulations in both environments. The study focused on disaster preparedness and management activities using objective and subjective metrics to evaluate participants' interactions. Results showed that participants in Group 1 preferred AR while Group 2 preferred VR. Results of VRSQ showed that VR produced higher oculomotor and disorientation symptoms than AR, while AR showed a milder impact on virtual sickness symptoms. Data showed that more male participants experienced symptoms when using VR, while women only showed significant disorientation. In the context of AR, women experienced a higher frequency of oculomotor and disorientation symptoms than men. Based on these results, it is recommended that new users use AR first before switching to VR to reduce the percentage of virtual sickness and improve user experience. VR is more effective in accurately gathering objects in disaster preparedness scenarios. Participants focus more on small objects in AR, while VR participants often ignore these small objects. Although participants in VR experienced more human error related to collisions with real objects, the overall impact on immersion was not significant enough to support one technology over another.

Keywords: Augmented reality, virtual reality, virtual objects, user interaction, immersion, symptom rates

1. Introduction

The increase in virtual reality (VR) and augmented reality (AR) technology has resulted in a significant turnaround in many fields. One such example is its use in disaster management simulation. VR or AR provides a safer and more controlled environment for the community to practice evacuation procedures and decision-making skills compared to a real live simulation. By immersing participants in realistic scenarios, VR and AR enhance engagement and retention of critical information and allow for the repetition of training exercises without the logistical challenges and risks associated with live drills.

While VR and AR offer immersive experiences, they differ in their fundamental approaches. VR creates a truly immersive experience that can transport users into virtual environments and make them feel as if they are physically there. On the other hand, AR layers digital content on top of the real world, enhancing it with digital details that complement the environment. Additionally, VR requires a compatible device such as a headset, while AR can be used via mobile devices, displays, and cameras, making it more accessible.

With this difference in mind, the way users interact with objects in these environments is also fundamentally different. In AR, users interact with virtual objects superimposed onto a real-world environment. This means that users can view and interact with digital content while still paying attention to the physical environment around them. On the other hand, VR creates a fully immersive digital environment that replaces the real world. Users wear a VR headset that blocks out the physical world and presents them with a visual and audio simulation experience.

* Corresponding author.
Received: December 25th, 2024. Revised: January 11th, 2025. Accepted: January 31st, 2025.

Available online: February 25th, 2025.

DOI: 10.12962/j24068535.v23i1.a1252

This means that users can interact with digital objects more naturally and intuitively because the user is entirely in the virtual environment. The differences in user interaction between AR and VR have essential implications for the design and development of applications in each technology. AR apps must be designed to work seamlessly with real-world environments, while VR apps must create truly immersive experiences that feel natural and intuitive to the user.

Many research studies have explored the interaction between the user and AR, VR, or even both. Such research shows many results suggesting either the usage of VR and AR in many fields or investigating user behavior in VR or AR. One study investigated user interactions and error rates within AR and VR environments using a simulated dataset to analyze how these interactions impact system performance and overall user experience [1]. By analyzing the dataset, mainly containing about four actions in the environment, which are "Select," "Drag," "Resize," and "Rotate", this research gives insight into how to optimize the user experience and the system itself based on the result of the prediction of error from the certain actions. While the research before explored the dataset of user interaction using the action itself, another research explored how the users engage and communicate within hybrid virtual environments that combine AR and VR, which focuses on identifying the factors that facilitate interactions and conversations among multiple users when experiencing cultural heritage objects [2]. Another study explored the differences between VR and AR in terms of interactivity, sense of presence, sensory experience of brand apps, attitudes, and behavioral intent [3]. The experiment was conducted natively in a shopping environment at IKEA. It was found that although both VR and AR technologies utilize clarity and interactivity as key features, the effects on the user experience in VR and AR differ significantly due to their inherent characteristics. Another study examined the impact of an agent providing navigation aids in a virtual environment [4]. They designed a virtual agent to help users explore the virtual world of a museum and provide instructions from objects that users can interact with. In addition, different studies examined how social interaction can affect visitors from VR users of underwater seascape exploration [5]. The experiment was carried out by asking visitors to use VR to explore two scenes created about flora, fauna, and the underwater environment around the user in the virtual world. Another study applied AR and VR to preserve an element of ancient culture [6] digitally. The application was made on a smartphone, and it interacted with several objects. AR and VR systems were also applied to explore historical cityscape tours [7]. The scenery was displayed panoramically using uncrewed airborne vehicle (UAV) photography. A similar study developed a VR and AR-based display system for arts and crafts museums to create an immersive and interactive experience for museum visitors, allowing visitors to explore the exhibits more engagingly and informatively [8]. Particular research has used VR to maintain and operate hydropower plants [9].

A recent study integrated AR and VR into a single head-mounted display, providing firefighters with a safe and realistic training environment [10]. It was shown that integration improved knowledge retention and practical skills compared to traditional training methods. Similarly, AR and VR were integrated to create realistic training environments that simulate extreme emergencies to enhance preparedness and effectiveness among emergency responders [11]. Meanwhile, another research [12] emphasized how AR, VR, and haptic can improve the realism and effectiveness of training scenarios for soldiers. This resulted in safe, cost-effective, and realistic solutions enhancing soldiers and operational readiness. A different approach was used, using Internet of Things (IoT) based simulation and real-time feedback systems by integrating VR and AR [13].

Studies also research the use of digital twins inside virtual environments. A study used Extended Reality (XR) technologies, using digital twins, to enhance user interaction and exploration in virtual environments [14]. Similar research studied digital twin technology and metaverse within the context of innovative city development, which shows how digital twin and metaverse can reshape urban planning, management, and public services [15]. Different studies have explored digital twins with AR to create an architecture that represents sound in three-dimensional space [16].

Even so, this research investigating user behavior was mainly related to the user and the virtual interface surrounding the user or the virtual objects in VR or real objects in AR. A virtual object is defined as any item that exists within a digital environment and typically lacks specific shapes or textures. Generally, one can refer to any object within a virtual environment as a virtual object. This research focused on the interaction between the user and the virtual object inside a VR and AR simulation. By evaluating the interaction between participants and objects, the result may be used to determine how VR and AR affect participants' interaction in simulation or how this virtual object should be implemented to increase the overall simulation experience in VR or AR. The virtual object defined in this research was the object the user required to "collect" and "use." To describe it more, this research divided the object into three groups based on their size, which are "Small," "Medium," and "Large." To make it more engaging for the user, the simulation environment used in this research for each VR and AR is a virtual replica based on a concept of a digital twin of an informatics laboratory/computer lab for the VR and the use of passthrough in Meta Quest 3 for AR.

2. Literature Review

This section discusses the literature used as a reference in this research, including related research, VR and AR, digital twin, passthrough, and the Go-Bag concept.

2.1. Related Research

This paper used four primary research sources for its references. One research source utilized subjective and objective measures to assess AR applications' usability and User Experience (UX) tested within VR environments [17]. Objective measures included quantifiable performance metrics such as task completion times, accuracy, and error rates. On the other hand, subjective measures involved gathering users' feedback through surveys and questionnaires.

A study introduced the Immersion Questionnaire (IQ), which serves as a tool to assess players' immersive experiences [18]. This study, which presented IQ, served as a basis for the questionnaire used in this research. Meanwhile, research introduced the Virtual Reality Sickness Questionnaire (VRSQ) as a specialized tool for assessing motion sickness experienced in VR, which created this set of questionnaires to address the limitation of the previous questionnaire set, Simulator Sickness Questionnaire (SSQ) [19]. The research introduced an adapted version of the VRSQ that aims to capture better the nuances of cybersickness symptoms, which can vary significantly among users due to other factors [20].

2.2. Basic of VR, AR, Digital Twin, and Passthrough

VR technology allows users to interact with the environment resulting from computer simulations. VR enables users to explore and interact with virtual environments that resemble the real world. VR technology leverages VR headsets or glasses to create immersive user experiences. One example of a VR headset is the Meta Quest 3 in Fig. 1. Meanwhile, AR can be defined as a system that enhances the real world by superimposing computer-generated information on it [21]. AR is usually in images or graphics inserted into the real world through digital devices such as smartphones.

Fig. 1: Meta Quest 3

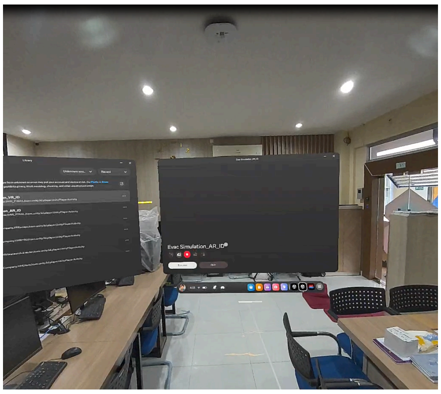

Fig. 2: Meta Quest 3 Passthrough Feature

Fig. 3: Go-Bags Content [27]

This research used the concept of digital twins and the passthrough feature to create VR and AR applications. A digital twin is a virtual replica of a physical object, system, or process that can be used to simulate and analyze the behavior and performance of its physical partner [22]. A study states that one of the main aspects of the definition collected by this researcher is that a digital twin must be associated with an object that exists [23]. Digital twins are created using Computer-Aided Design (CAD) or other 3D modeling tools to create 3D models of physical objects.

Meanwhile, passthrough is a feature on Meta Quest headsets that allows users to step out of an immersive display to see the user's environment in real-time [24]. Fig. 2 shows an example of Meta Quest 3′s Passthrough feature. By using passthrough, fully immersive VR can be enhanced in several ways. Through technology, we can create a mixed-reality experience where the virtual and real world coexist perfectly.

2.3. Go-Bags

A Go-Bag, or some call it a Grab-Bag, is a bag used during an emergency that contains essential items and is used in times of emergency. A literature review recommends that Grab-Bags continue to be promoted as a household preparedness measure, but also by following the recommendations of two other authors to improve the evidence and develop good practices in line with their current use [25]. The contents of the Go-Bag can generally be adjusted to personal needs. Items from a Go-Bag can range from money, medical items, personal items, food and water, and documentation [26]. Based on [27], emergency kits at least contain food, water, tools for warmth, first aid kits, medicines, medical equipment, and protection from environmental elements. The content can still be added with alternatives for lighting and materials for cooking, sanitation, and waste management. An example of a Go-Bag and its contents based on the research [27] can be seen in Fig. 3.

3. Methodology

This section discusses the design of the user study in this research, which consists of the experiment apparatus, variables, and procedure.

3.1. Apparatus

An application was developed to simulate the environment used in this research. The application was divided into three scenarios, each for VR and AR. The first scenario was based on a concept called Go-Bag, and the second and third scenarios simulated disaster events, specifically a sudden fire and a toxic gas leak. By referencing a concept called digital twin, a replica of a computer lab was made to increase the immersive feel for the user when using the VR simulation. The AR system used the Meta Quest 3 Passthrough feature.

Taking a reference from a concept called Go-Bag, the first scenario simulated the preparation of a bag for an emergency, which the player did by collecting items spawned inside the computer lab. The items referenced in this scenario were taken from the basic need of what a Go-Bag is supposed to have, with the addition of a few items that are not supposed to go inside it. Items were separated into three categories, which were "Small," "Medium," and "Large." By collecting these items, the user gained specific points based on the categories of the items to show the

Fig. 4: Item Size Categorized as Small, Medium, and Large (Left to Right)

limitation of the Go-Bag content. After the user had gathered the items, the system moved the user into the second scenario, part one. An example of the object collected based on size can be seen in Fig. 4.

The second scenario simulates managing a sudden fire disaster inside the computer lab. In this part, the user must escape the room by extinguishing the fire using a fire extinguisher. Before the user can use the fire extinguisher, the user must find a hammer to access the fire extinguisher from a locked glass fire extinguisher box. The third scenario contained the management of a gas leak inside a room. Users were notified that there was a gas leak inside the lab, and the user must find a gas mask and use it before the time limit. After that, the user must find a key inside the lab to unlock the door and escape. With the gas addition, the gas mask itself had a damaged filter, so the user must find and use another air filter to add to their time limit for using the gas mask.

3.2. Variables

This research evaluated AR applications' usability and user experience using subjective and objective criteria, similar to previous research that assessed AR applications' usability and user experience through VR simulations [17].

The objective criteria searched in this research were divided into each scenario, with the outline of the parameters as the following:

- Duration: The duration of time. For each scenario, the duration was precisely defined as a time (number) variable for the scenario's duration, with one exception for scenario 2 part 2, which was divided into 2-time parameters.
- Movement/Non-Movement Duration: The duration for each user while having movement or standing still. Defined as a time (number) variable for each of the scenarios.
- Collected Items: A collection of objects that the user collects in the first scenario. This is specific to the first scenario only. Define the objects as object names, size categories, and the user's memorization capability.
- Error: Define as an "unwanted" accident that happened to (or by) the player or system while the experiment is running.

The subjective criteria in this research were determined using the Immersive Experience Questionnaire (IEQ) and VRSQ. IEQ is a set of questions used to measure the degree to which the user is fully engaged and immersed in the virtual environment. Typically, IEQ consists of 33 questions, 32 of which use a five-point scale and one of which uses a 10-point scale to gauge the user's immersion inside the virtual environment. However, these 32 standard questions in IEQ are not used entirely. These questions were selected and categorized based on the needs of this research.

The VRSQ is a derived form of questionnaire from the SSQ [28]. SSQ is a set of questions designed to evaluate the level of sickness symptoms experienced in simulator environments. In contrast, the VRSQ was developed to address specific limitations of the SSQ, particularly its applicability to VR environments [19]. One key reason for this improvement is that the SSQ was designed initially for simulator sickness and may not fully capture the unique aspects of cybersickness in VR. The VRSQ simplifies the assessment by focusing on two primary factors, oculomotor and disorientation, compared to the more complex structure of the SSQ, which includes additional factors. Furthermore, the VRSQ consists of nine items, while the SSQ contains 16. This reduction aims to facilitate easier completion for users while ensuring that important aspects of cybersickness are still accurately measured. However, it is worth noting that the VRSQ does not include nausea symptoms, which are often associated with other forms of motion sickness. The oculomotor factors consist of headache, fullness of the head, blurred vision, dizzy eyes closed, and vertigo, while disorientation factors consist of eyestrain, difficulty focusing, general discomfort, and fatigue.

This research focused on finding the mean from the result. To make it easier, a formula was created based on the nature of the IEQ and VRSQ. For IEQ, each of the five answers available for each question, except for the last question in the VR version of IEQ, was given a value of 1 to 5, where 1 indicates no immersion, and 5 indicates total immersion. Meanwhile, VRSQ was given a value of 0 to 3, where 0 indicates no symptoms, and 3 indicates severe symptoms. The calculation for IEQ was given the following formula:

$$A_n = \frac{\sum_{i=1}^{n} Q_i}{n} \tag{1}$$

Where A_n is the mean score, n is the total of questions, and Q_i is the individual score per question.

Meanwhile, the calculation for VRSQ is given the following formula:

$$P_O = \frac{\sum_{i=1}^{n} \times S_i^O}{M_O} \times 100\% \tag{2}$$

$$P_D = \frac{\sum_{i=1}^{n} \times S_i^D}{M_D} \times 100\% \tag{3}$$

$$T_S = \frac{P_O + P_D}{2} \tag{4}$$

Where P_O is the percentage of oculomotor, P_D is the percentage of disorientation, n is the total items in the category, S_i^O is the total score for each oculomotor symptom, S_i^D is the total score for each disorientation symptom, M_O is the maximum possible score for oculomotor, M_D is the maximum possible score for disorientation and is the total score.

In addition to the average calculation, IEQ and VRSQ will be tested using the Binomial and Kruskall-Wallis tests. The purpose of the test using this Binomial Test is to find out if there is a difference in the number of participants from the initial hypothesis that has been determined. Meanwhile, the Kruskall-Wallis test was conducted to assess whether there was a significant difference in the participants' experience between VR and AR environments. Meanwhile, for IEQ, tests will be carried out using the Shapiro-Wilk Test to test whether the sample data obtained is distributed normally.

The calculation in the Binomial Test in this study will be based on the gender division of the participants who took this test and the total score of the score calculation on the 5-point scale question. This study set the probability level at 20% (0.02). For the Null Hypothesis (H0) set in this study, it was stated that the number of participants in the man/woman gender who got a score below 3 was equal to or less than the probability. Meanwhile, the Alternative Hypothesis (Ha) states that the number of participants in the man/woman gender who get a score below 3 exceeds the probability. Based on literature research [29], significant levels follow generally accepted levels, with substantial levels $\alpha = 0.05$. Meanwhile, the H0 used for VRSQ measurement is the number of participants in the man/woman gender who get an oculomotor/disorientation percentage below 10% equal to or less than the probability. Meanwhile, for Ha, it was determined that the number of participants in the man/woman gender who got a percentage of oculomotor/disorientation below 10% was more than the probability.

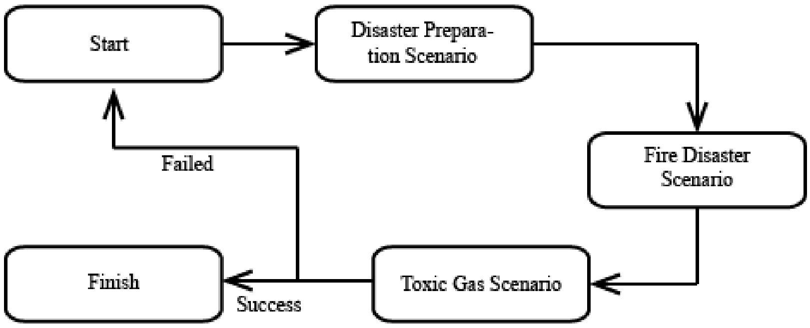

Fig. 5: Experiment Procedure

3.3. Procedure

The procedure of this experiment was divided into three scenarios: disaster preparation, fire disaster, and toxic gas. A more detailed procedure is in Fig. 5. While instruction exists inside the simulation, participants were instructed on the scene on how to do the simulation. Participants were divided into two groups: one group started with VR and then continued to AR, while the other group did otherwise. After each participant finished either VR or AR, the participant was asked to fill the IEQ and the VRSQ, with an addition of a single question to ask the user to recall the name of the items that they had collected in the first scenario.

The disaster preparation scenario consists of collecting items for the Go-Bag (Fig. 6). Participants were instructed to gather items spread throughout the lab on the table. The participants were briefed on Go-Bags and the kinds of items that usually go inside them. Once the participants were ready, the system instantiated all the objects and started the first scenario. Participants were then asked to collect the objects selected by the user into a Go-Bag located on a chair in the lab. The participant is not provided with information about the important objects, so they must determine what is essential based on their awareness of the previous explanation of the Go-Bag function. For each object size, a specific point is shown to the participant. Once the user has collected the object within a specific point limit, the system will save the necessary data and proceed to the next scenario, the fire disaster scenario.

The fire disaster scenario consists of fire disaster management (Fig. 7). In this scenario, participants will see a fire on the way out of the room. In this scenario, participants are given orders to successfully overcome the fire and exit the room. The system will direct participants to get a fire extinguisher in the room to deal with the fire. After the briefing on how to use the fire extinguisher, the participants will be given directions. If the box door is damaged, they must find a hammer to break the glass from the box. The system will instantiate the hammer required to break the glass of the fire extinguisher in one of the four pre-installed places. After the participants get the fire extinguisher, they are directed to approach and use the fire. The system will declare the scenario complete if the participants successfully apply the fire extinguisher to the fire and then proceed to the next scenario.

The toxic gas disaster scenario involves the management of toxic gas (Fig. 8). At the beginning of this scenario, the system will pop up a notification in the participant's view that warns that a gas leak is dangerous to the participant's body. In this scenario, the system will direct the participants to immediately find a gas mask and use it before the deadline is exceeded. Suppose the participants fail to use the gas mask before the deadline. In that case, the simulation will end, and the participant is asked to repeat the scenario from the beginning. Afterward, the participants were directed to the door and found that the exit was locked. Participants were then given instructions on how to exit the lab. In this part of the scenario, the user must find a key that can be used to open the door and exit the lab. The system will provide additional briefings that the gas masks used by participants have time limitations because the air filters used are of low quality, so participants must pay attention to the time limit of the gas masks used. The system will inform the participants that the gas mask used by the participants has a replaceable gas filter. So that participants can add time by discovering and using new air filters. After the participant exits the room, the system will provide information if the participant completes the simulation and saves the participant's data into a file. Suppose the participants exit the lab before the air filter time runs out. In that case, the system will record

Fig. 6: Disaster Preparation Scenario (VR)

Fig. 7: Fire Disaster Scenario (VR)

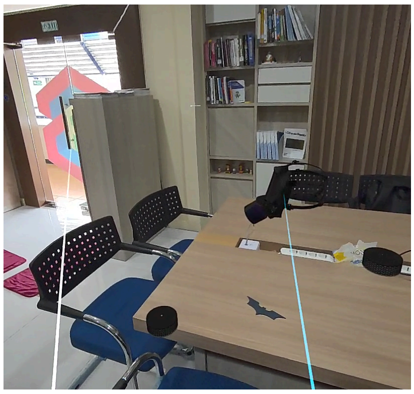

Fig. 8: Toxic Gas Scenario (AR)

the data from the toxic gas scenario as null, and the participants will be asked to repeat the simulation from the beginning.

After each VR and AR session (and the other with the second group), the participants were asked to fill out the IEQ and VRSQ forms. After the participants filled out both forms, they were asked to write down the items they had collected in the disaster preparation scenario.

4. Results and Discussion

This section discusses the results gained from the experiment conducted in this research. The results are divided into two sections, which discuss the objective and subjective results. It is to be noted that no participant managed to fail in a toxic disaster scenario.

4.1. Objective Results

In this section, the results taken objectively are discussed further. The results are explained in five parameters: duration of moving and standing still condition, completion duration, objects collected, objects forgotten, and human error. It is to be noted that the data collected related to the duration of the participants' movement and standing pose on the objective results may be affected by the performance of the Meta Quest 3 headset.

Fig. 9 and Fig. 10 show the graphs of the average calculation results of all participants in moving conditions in group 1 and group 2. Meanwhile, Fig. 11 and 12 are graphs of the average calculation results of all participants in standing still conditions in group 1 and group 2. From the data, group 1 showed higher engagement with VR on the participants' moving conditions in the disaster preparation scenario (Duration = 31.50, SD = 14.1) compared to Group 2 (Duration = 23.88, SD = 8.69). However, in a fire disaster scenario, the duration of group 2 AR (Duration = 12.40, SD = 10.56) exceeds the duration of group 1 AR (Duration = 9.01, SD = 3.43). Both groups showed a very high VR duration in the disaster preparation scenario for the standing still condition. Still, group 1 had a much higher duration (Duration = 436.81, SD = 72.11) than group 2 (Duration = 186.96, SD = 59.19). The duration of VR for both groups while moving is generally higher than AR, especially in disaster preparation scenarios. This shows that VR can provide a more immersive experience that encourages longer interaction times. Although AR showed lower engagement in most simulated scenarios, AR had a significant duration in the toxic gas scenario for group 2 when standing still (Duration = 72.97, SD = 87.61), thus suggesting that AR can also effectively attract participants' attention under certain conditions.

Fig. 13 shows the results obtained for the participants' time to complete the simulation scenarios. In terms of duration, the average participants are more likely to stand still than move in simulations in both VR and AR. Comparing first-time use, participants spend more time on disaster preparation scenarios in VR than in AR. However, in fire disaster scenarios and toxic gas disaster scenarios, participants require more time in AR than VR. The higher duration of group 1 in VR suggests that VR can provide a more engaging immersive environment for practicing disaster preparation, especially in disaster preparation scenarios. Meanwhile, the higher engagement rate

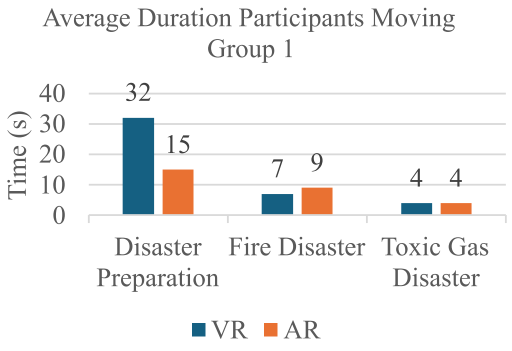

Fig. 9: Average Duration of Movement in Group 1

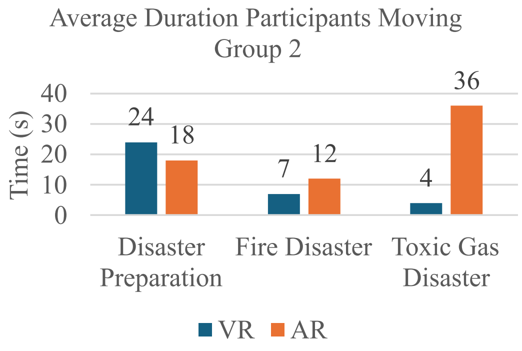

Fig. 10: Average Duration of Movement in Group 2

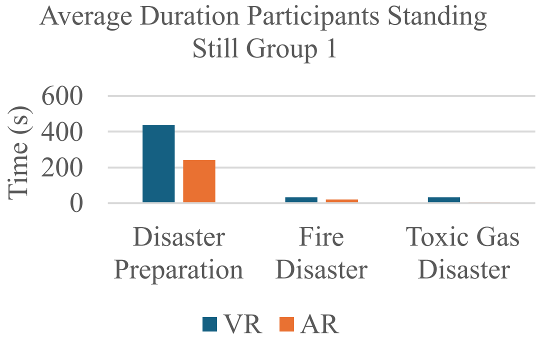

Fig. 11: Average Duration of Standing Still in Group 1

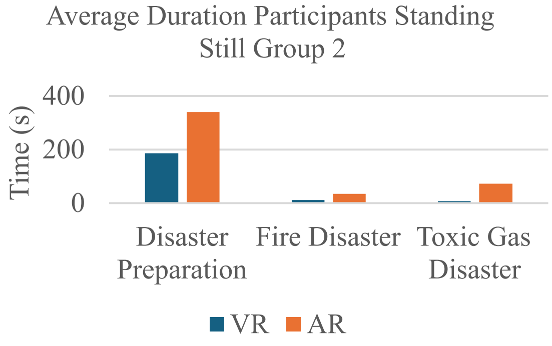

Fig. 12: Average Duration of Standing Still in Group 2

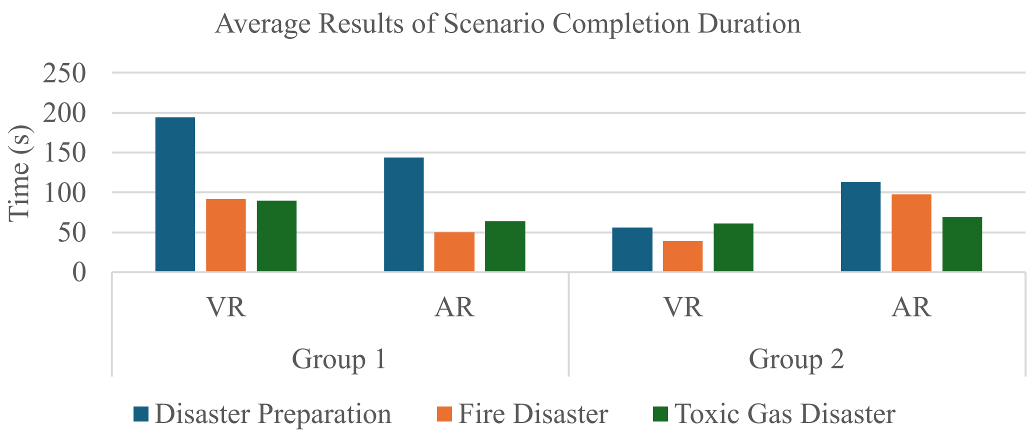

Fig. 13: All Scenario Average Completion Duration

of group 2 with AR in fire scenarios suggests that AR can be useful for training related to rapid response situations with an interest in rapid decision-making.

To see the results of the participant's level of awareness in knowing the important objects in the disaster preparation scenario, Fig. 14 and Fig. 15 contain the comparison of the objects collected correctly and incorrectly based on the definition of Go-Bags. The data showed that more participants in the VR simulation collected more correct objects than incorrect ones. Thus, VR can provide a more effective platform to learn or practice simulations. While the number of AR participants who collect the correct objects is also higher, AR has more participants who collect more incorrect objects. Both VR and AR had participants achieving the same number of true and false responses (2 in VR and 3 in AR), suggesting that participants in both environments had difficulty with the simulation.

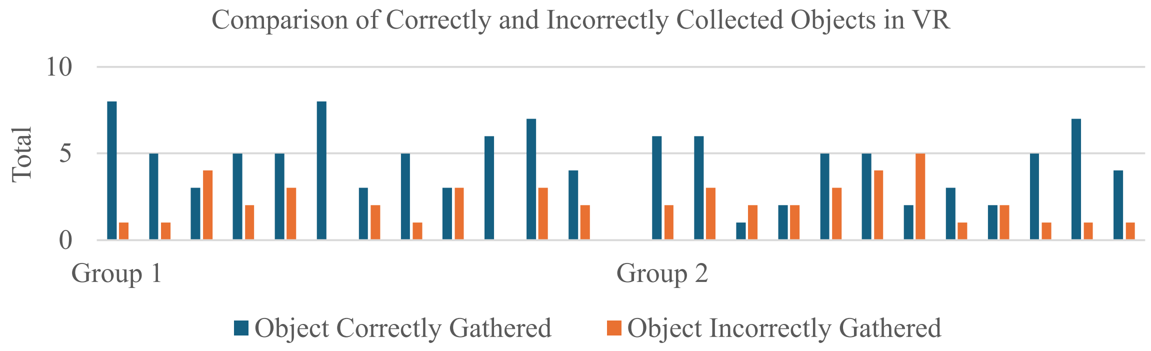

Fig. 14: Object Collected Correct and Incorrect in VR

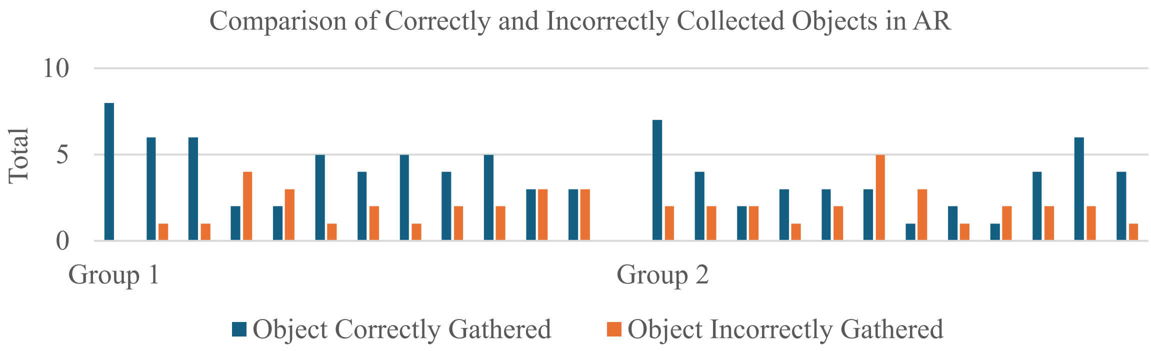

Fig. 15: Object Collected Correct and Incorrect in AR

Table 1 shows the results of the most collected objects, while Fig. 16 shows the total number of collected objects by size category. Both groups showed a strong preference for small-sized objects, especially in VR. Group 1 had the highest number of small object collections in VR (53), indicating more significant attention to small objects. The medium-sized category shows a moderate collection of balanced attention but less than small-sized objects. The collection of large-sized objects is very low in both groups, especially in VR. In all group cases and simulation modes, the average participants chose water bottles as the important objects to collect based on the simulation theme in the disaster preparation scenario.

Fig. 17 shows the total number of participants-forgotten objects by size category. Most forgotten objects in both groups are small, especially in VR, where Group 1 has the highest number (23). Thus, smaller items are easier to forget during the simulation. Medium-sized objects are also significantly forgotten, especially in AR for group 1 (10). Large objects are almost entirely forgotten in both groups, with only a few recorded data corresponding to

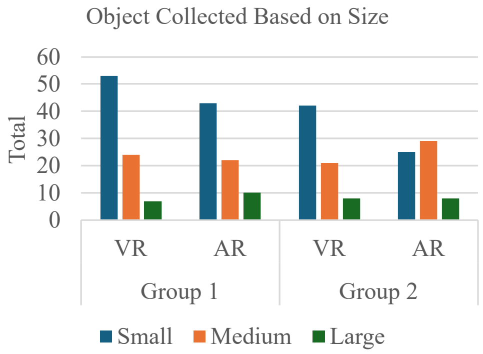

Fig. 16: Total Object Collected by Size Category

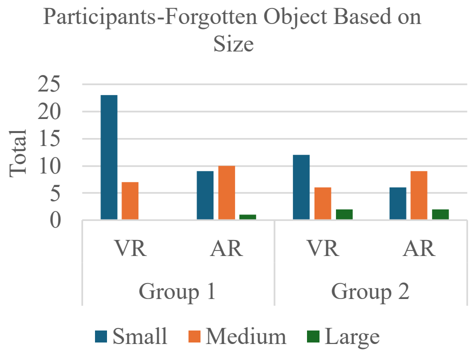

Fig. 17: Total User-Forgotten Object by Size Category

Table 1: Most Collected object

Group 1		Group 2	
VR (n)	**AR (n)**	**VR (n)**	**AR (n)**
Water Bottle (10)	Water Bottle + ID Card (8)	Water Bottle (10)	Water Bottle (8)
Smartphone (8)	Case + Laptop (6)	Healthkit (9)	Healthkit (7)
ID Card (7)	Flashlight (5)	Case (6)	Case (6)

Table 2: Human Error

	VR		AR	
	Collision	**Fallen Object**	**Collision**	**Fallen Object**
Group 1	16	3	1	1
Group 2	10	0	1	7

object collection data where large objects are not collected frequently. Group 1 generally has more forgotten objects than Group 2 in VR and AR simulations.

Table 2 shows the total results of human error that occurred during the experiment. Human error, defined during testing, is either a collision between participants and real objects or virtual objects detached from the participant's hand (controller). Human error occurred more in participants when running VR than in AR, which is 9 out of 12 participants in group 1 (VR), 7 out of 12 participants in group 2 (VR), and 1 out of 12 participants in groups 1 and 2 (AR). The total human errors in the collision were counted as 16 in VR and 1 in AR for Group 1, and 10 in VR and 1 in AR for Group 2. Although not numerous, objects detached from the participant's controller were likelier to be in Group 2 when running AR and Group 1 when running VR.

4.2. Subjective Results

This section explains the results obtained subjectively. The results listed in this section are from IEQ and VRSQ. In IEQ, 29 questions were used for VR and 21 for AR.

For these two data sets in Fig. 18 and Fig. 19, tests were carried out using the Shapiro-Wilk Test to test the data distribution normality. In group 1, statistical results of 0.94 and a p-value of 0.51 were obtained for VR, while for AR, statistical results were obtained at 0.89 and a p-value of 0.15. In group 2, statistical results of 0.89 and a p-value of 0.14 were obtained for VR, while for AR, statistical results were obtained at 0.94 and a p-value of 0.51. Based on these results, both groups for VR and AR showed that there was no significant evidence to reject H0 to normality based on the results of the Shapiro-Wilk test, so for both data, the data distribution was normally distributed. After that, tests were carried out using the Binomial Test to assess the range of participants' proportions. In the context of VR, male participants showed a p-value of 0.205, while female participants showed a p-value of 0.441. These results show the absence of significant evidence to reject the null hypothesis. Meanwhile, in the context of AR, male participants showed a p-value of 0.072, while no female participants were recorded in this range. This result shows that for male participants, there was no significant evidence to reject the null hypothesis, but for female participants, there was not enough evidence to support either hypothesis due to a lack of data.

Based on the data obtained in the IEQ results in Fig. 18 and Fig. 19, it can be assumed that several things are related to VR and AR. Based on the data of each participant for group 1, in total, 7 participants preferred AR compared to 5 participants who preferred VR with the highest score for AR in Participant 2 with a score of 3.48 (SD = 2.76) and Participant 5 with a score of 3.48 (SD = 3.18). Meanwhile, for group 2, 3 participants preferred AR, 7 participants preferred VR, and 2 participants had the same score for both VR and AR, with the highest score for VR in participant 22 with a score of 3.43 (SD = 2.78). Fig. 20 compares first-time use, where group 1 is in VR and group 2 is in AR, and there are different implications. Based on the graph, 7 participants had more AR than 5 participants who chose VR, with the highest participants in VR, namely participant 10 with a score of 3.32 (SD = 2.85), and in AR, namely participant 16 with a score of 3.67 (SD = 2.76). After that, the overall test results can be

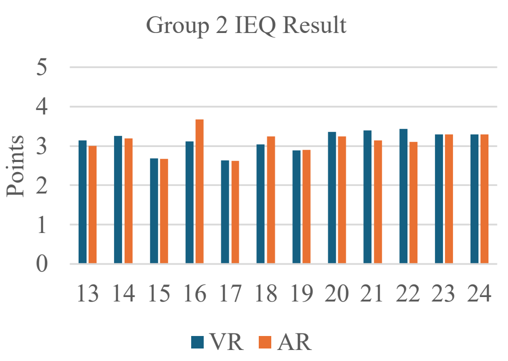

Fig. 18: IEQ Result for Group 1

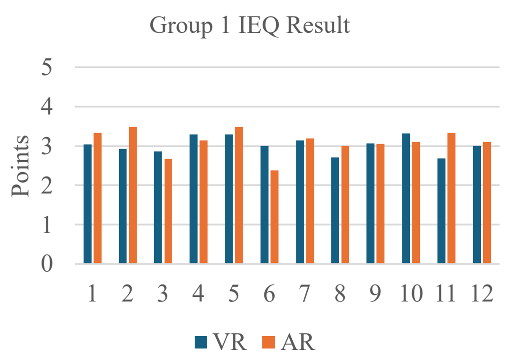

Fig. 19: IEQ Result for Group 2

compared, as seen in Fig. 21. In group 1, the value of VR ranged from 3.027 (SD = 0.21), while in AR, it was 3.103 (SD = 0.31), and in group 2, the value of VR ranged from 3.125 (SD = 0.26), and in AR it was 3.111 (SD = 0.28).

To see the level of immersion obtained from VR, a comparison graph is made in Fig. 22. Based on the data obtained from the last question from IEQ on VR, several things can be concluded about this result. Group 1 experienced the highest level of immersion at a value of 8, indicating that this value may represent an optimal point for engagement within this group. In contrast, group 2 maintained a consistent immersion rate at a lower value but increased at 10. This data showed that although both groups had participants who felt immersion, the participants' experiences were not uniform. Thus, it points to potential areas for further investigation into the factors contributing to the differences in such immersion.

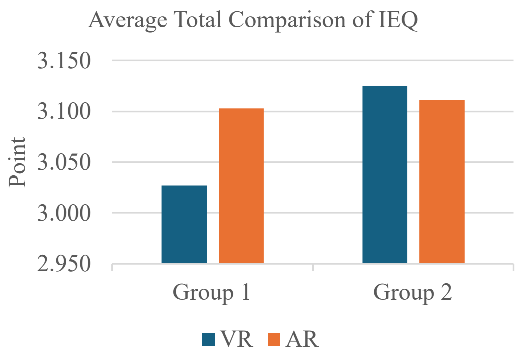

Fig. 20: IEQ Result by First-Time Application Use

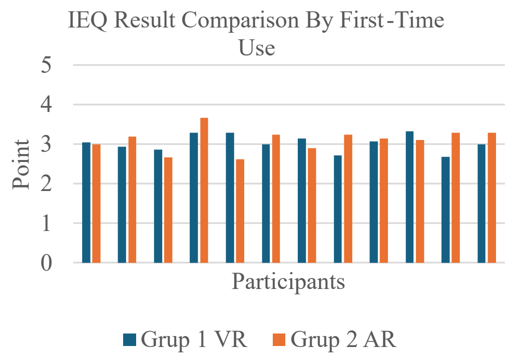

Fig. 21: IEQ Average Comparison

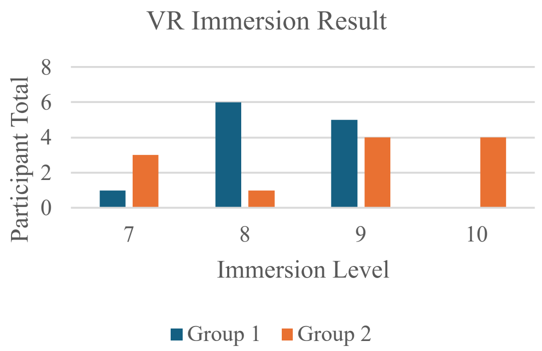

Fig. 22: Result of Immersion from IEQ

Meanwhile, for the results of VRSQ, a comparison graph was made between oculomotor symptoms and disorientation in both groups of participants. Fig. 23 and Fig. 24 are the results of the VRSQ in group 1 for VR and AR. In VR, the percentage of oculomotor symptoms varied from 0% to 26.67%, suggesting that some participants experienced significant oculomotor symptoms while others reported no. Meanwhile, the percentage of disorientation symptoms ranged from 0% to 50%, implying that disorientation was common and affected some participants significantly. The highest percentage of disorientation at 50% was recorded for Participant 8, while Participant 1 reported no symptoms in either category. This variability suggests that an individual's susceptibility to the percentage of symptoms that appear while running VR can differ from one to another. In contrast, the highest percentage of oculomotor symptoms in AR was 20%, which was lower than the highest percentage recorded in VR. Thus, AR shows a smaller percentage of oculomotor symptoms than VR. Meanwhile, the highest percentage of disorientation was also lower than the percentage in VR, which was highest at 41.67% for participants 5 and 6. It should be noted that some participants reported no symptoms at all in the oculomotor category, which could indicate that the experience of using AR has the potential to put less strain on the visual system (oculomotor) compared to VR.

Fig. 25 and Fig. 26 are the VRSQ results for group 2. In VR, oculomotor symptoms ranged from 0% to 40%, suggesting that while some participants did not experience oculomotor symptoms, others reported high oculomotor symptoms, especially participants 16 and 22. Meanwhile, in disorientation symptoms, the percentage of symptoms ranges from 0% to 58.33%. Participant 18 reported the highest level of disorientation, showing a significant percentage of disorientation symptoms, while some participants (Participants 13, 19, and 23) reported no symptoms. In AR simulations, the percentage of symptoms showed different results. The percentage of oculomotor symptoms ranges from 0% to 40%. Like VR, participant 22 showed the highest percentage of oculomotor symptoms at 40%, showing consistent experience of oculomotor symptoms in both VR and AR. The percentage of disorientation symptoms was generally lower than in VR, with a maximum of 25% for 16 participants. Some participants showed the absence of a percentage of disorientation symptoms at all (Participants 13, 19, 21, and 23).

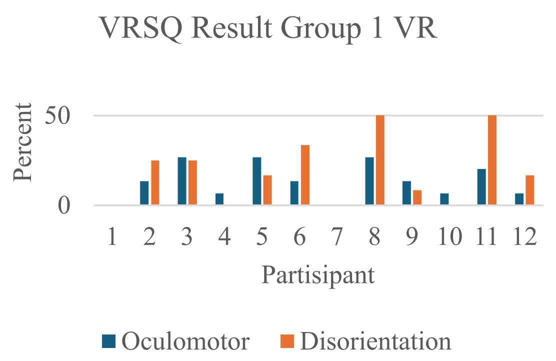

Fig. 23: Result for VRSQ Group 1 in VR

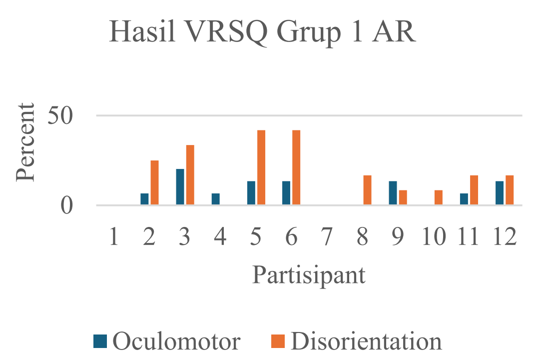

Fig. 24: Result for VRSQ Group 1 in AR

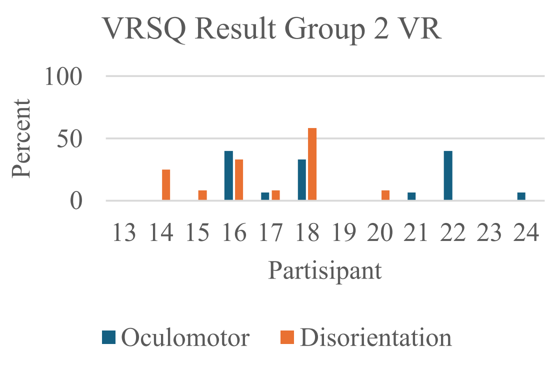

Fig. 25: Result for VRSQ Group 2 in VR

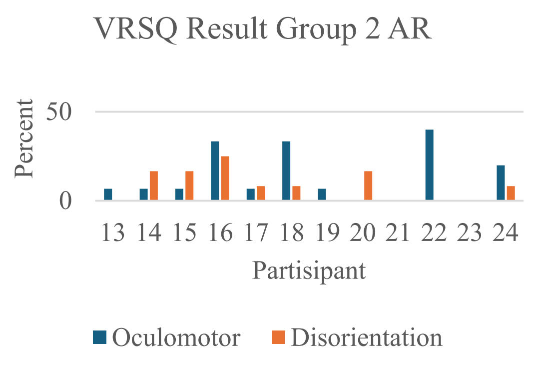

Fig. 26: Result for VRSQ Group 2 in AR

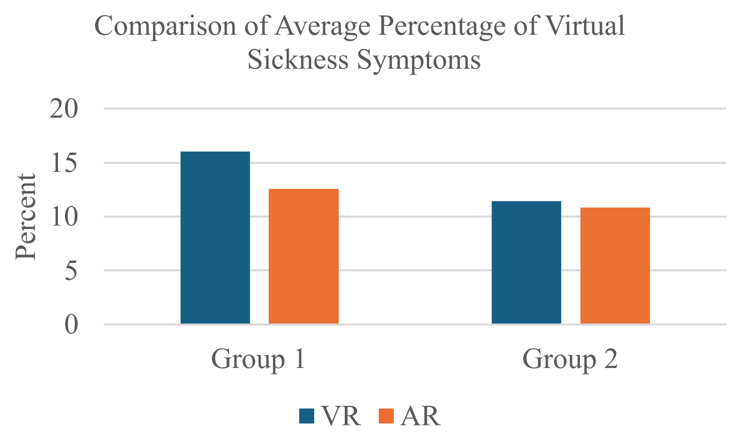

Fig. 27: Average Percentage of Virtual Sickness Symptoms

Fig. 27 was created to clarify the results, which show the average percentage comparison of the entire group of participants for VRSQ. Overall, the percentage of symptoms that appeared was lower when running simulations on AR, with 12.56% (SD = 10.24) in group 1 and 10.83% (SD = 9.03) in group 2. If compared for the first time of use, AR is still superior in the low number of symptoms that appear, with a difference of 5.21%.

For the VRSQ data that has been collected, a Binomial Test is also carried out to evaluate based on the predetermined H0 and Ha. In VR, the p-value for male participants in the oculomotor was < 0.001, and the p-value was 0.003 for disorientation, while for female participants in the oculomotor was obtained a p-value of 0.072 and a p-value of 0.003 was obtained for disorientation. Meanwhile, in AR, p-values were obtained for male participants at oculomotor 0.019 and 0.205 for disorientation, while for female participants, p-values were < 0.001 for both oculomotor and disorientation. For VR, both p-values for oculomotor and disorientation in men indicate that H0 is rejected so that more male participants experience a percentage of symptoms for oculomotor and disorientation above the 10% level. Meanwhile, for women, the p-value for oculomotor did not have enough evidence to reject H0, but there was enough evidence to reject H0 at disorientation. As for AR, the p-value for the oculomotor H0 is accepted, so there is more than a probability, but there is not enough p-value to disorient to reject H0. Meanwhile, for women in AR, both p-values for oculomotor and disorientation had strong values for rejecting H0, indicating a higher percentage occurrence of symptoms than the expected outcome.

For both the IEQ and VRSQ data, a Kruskal-Wallis test was conducted using all participant's data from both groups to assess whether there was a significant difference in participants' experience between VR and AR environments. The results showed no significant difference for the two questionnaires, with an H statistic of 0.188, a p-value of 0.664 for IEQ, and an H statistic of 0.0 with a p-value of 1.0 for VRSQ. These values suggest that participants did not report varying symptoms or experiences when using VR compared to AR, suggesting that both VR and AR may resulted in similar participant responses regarding the measured construct. Due to this lack of significant differences, it can be concluded that the design and implementation of VR and AR applications do not need to differ substantially in user experience, at least as assessed by this questionnaire.

5. Conclusions

From the subjective standpoint, the analysis of immersive experiences revealed that in group 1, more participants preferred AR over VR, while in group 2, VR was favored. Notably, group 1 also reported the highest level of immersion, indicating that immersive experiences can vary significantly among users. This variability suggests a need for further research into the factors influencing user experience in both VR and AR. The results from VRSQ indicated that symptoms related to oculomotor and disorientation varied among participants, with VR generally producing a higher percentage of symptoms than AR. Thus suggesting that AR has a milder impact on users' well-being than VR. Further statistical analysis highlighted gender differences in symptom occurrence; male participants in VR reported more oculomotor and disorientation symptoms, while significant evidence of disorientation was noted among female participants in VR. Conversely, women using AR experienced oculomotor and disorientation symptoms more frequently than their male counterparts. Based on these findings, it is recommended that new users initially engage with AR before transitioning to VR, as this approach may help mitigate virtual sickness symptoms and enhance the overall user experience.

From the objective standpoint, results from object collection tasks revealed that VR proved more effective for participants in accurately gathering objects during disaster preparation scenarios, as evidenced by more participants achieving better results in disaster preparedness tasks. Participants in the VR simulation collected more objects correctly than those who did not perform as well in the AR setting, demonstrating that VR can serve as a more effective platform for learning and practicing disaster preparedness scenarios. Participants utilizing AR tended to focus more on collecting small objects, whereas those in VR often overlooked these items. Despite VR users experiencing more human errors related to real-world collisions, this did not significantly affect immersion levels during simulations, indicating no clear advantage between VR and AR.

This study evaluating users' interactions has limitations due to hardware and software issues, unforeseen incidents, and technical constraints. For example, the application was not developed to adjust to real-time environmental changes, which caused participants to experience sudden shifts during simulations. Additionally, discrepancies in the number of gas filters collected versus those taken by participants during VR simulations rendered some results unusable, an error not observed in the AR application despite having an identical program.

Future studies should broaden the definition of user-collected objects by considering their unique geometric shapes, which can significantly affect interaction dynamics and enhance simulation conditions, particularly in critical user states. Additionally, research should focus on refining the understanding of user behaviors in both standing still and moving conditions to capture a more extensive range of interactions and decision-making processes influenced by diverse object geometries and environmental contexts.

While this study researches the interaction between users and objects inside VR and AR in a simulation environment, the result is not limited to being used in a simulation environment. The results concerning virtual sickness that occurred inside VR and AR can be used as a basis for other studies in both VR and AR or even the integration between both technologies. It is to be noted that while the result may be used for other studies, the methodology used in this research, particularly in the program, might not be suitable for other studies.

CRediT Authorship Contribution Statement

Matthew V. Suriawan: Conceptualization, Methodology, Software, Formal analysis, Data Curation, Writing – Original Draft, Visualization. **Hadziq Fabroyir:** Conceptualization, Methodology, Software, Validation, Formal analysis, Resources, Writing – Review & Editing, Supervision, Project Administration, Funding Acquisition. **Darlis Herumurti:** Conceptualization, Methodology, Software, Validation, Formal analysis, Resources, Writing – Review & Editing, Supervision, Project Administration, Funding Acquisition.

Declaration of Competing Interest

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

Data Availability

The data supporting this study are not publicly available due to confidentiality, ethical concerns, or proprietary restrictions.

Declaration of Generative AI and AI-assisted Technologies in The Writing Process

The authors used generative AI to improve the writing clarity of this paper. They reviewed and edited the AI-assisted content and take full responsibility for the final publication.

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