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Virtual Reality for Disaster Response Training: Feasibility and Impact on Emergency Healthcare Professionals

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ABSTRACT

Disaster medicine training is essential for healthcare professionals and encompasses classroom-based education, tabletop exercises, drills, and field exercises. Advancements in technology, such as the development of extended reality modalities, have led to the emergence of virtual reality (VR) as an effective educational tool. This is particularly relevant with regard to disaster response medicine (DRM), enhancing experiential learning and preparedness. Accordingly, this study evaluates the feasibility of integrating VR into DRM training. As such, a cross-sectional study was conducted among emergency department doctors. Participants engaged in a VR-based scenario for emergency response training and provided feedback through a 5-point Likert scale questionnaire assessing usability, personal experience, and adverse events. Furthermore, a quantitative performance matrix was employed to evaluate participant performance levels. A total of 70 participants volunteered for the study, of whom 38 (54.3%) were male, and 32 (45.7%) were female, with a median age of 33. Notably, 49 participants (70%) had no prior VR experience. Over 80% reported the VR system was easy to use, relevant to real-life scenarios, and beneficial to their field, while more than 90% believed it could enhance professional performance. Meanwhile, the most common adverse event was visual discomfort (30%), followed by dizziness, with fewer reports of headaches, fatigue, nausea, stomach awareness, and postural instability. Despite these effects, 60% of participants exceeded the 80% performance benchmark. Moreover, VR-based training in DRM demonstrated high usability, realism, and effectiveness in skill enhancement. Nevertheless, with optimised exposure times and user-friendly interfaces, VR can serve as a viable, immersive tool to complement traditional DRM training while minimising adverse effects.

Keywords: *Disaster response medicine, Virtual reality, Healthcare training, Emergency medicine training, Simulation-based learning*

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INTRODUCTION

Disasters are unpredictable and infrequent events, making real-world exposure to such scenarios limited in everyday clinical practice (1). Nonetheless, for healthcare professionals, particularly those in the emergency department, being prepared to respond effectively to disasters is critical (2). Thus, comprehensive disaster education and training are essential to equip medical personnel with the necessary knowledge, decision-making skills, and hands-on proficiency required in high-pressure, mass-casualty situations (3).

Traditional training methods, such as classroom-based learning, tabletop exercises, and field training exercises, provide valuable theoretical and practical insights. However, they may not always replicate the dynamic, high-stakes environment of real disasters. According to Hsu et al. (4), traditional classroom teaching and web-based training often lack realism and excitement, leading to varying levels of engagement among participants. Furthermore, organising these exercises presents significant challenges, as they require extensive preparation, resource allocation, logistical coordination, and the involvement of a large number of participants (5, 6). In addition, implementing real-life drills can have the unintended consequence of disrupting regular local services. This, in turn, poses additional obstacles to coordinating training efforts (7).

Innovative training approaches such as virtual reality (VR) provide an immersive and interactive platform that bridges the gap between theoretical knowledge and practical application in disaster response preparedness (7, 8). In line with this, VR offers unique advantages in education and training by enabling realistic simulations, customisable scenarios, and performance tracking (9). Additionally, the utilisation of VR as a learning strategy has been observed to significantly enhance student engagement, attention, and interaction, resulting in a beneficial impact (10). Andonova et al. (11) demonstrated that VR significantly improves information retention and recall by engaging multiple senses, creating more memorable learning experiences. In essence, VR supports personalised learning, allowing users to train at their own pace on any modern laptop or desktop without specialised software.

The vast potential of VR in disaster response training is particularly noteworthy. Therefore, this study examines the feasibility of using a locally developed VR module to train emergency healthcare professionals in disaster response medicine (DRM). Specifically, the assessment focuses on usability, user experience, potential adverse events, and performance outcomes.

METHODOLOGY

Study Design and Participants

A cross-sectional study was conducted in the VR facility at the faculty of medicine between May 2022 and December 2023. Participants were emergency doctors with varying levels of clinical practice experience from a single university hospital's emergency department in the Klang Valley. Consent was obtained from all participants before the study commenced. Individuals with a history of significant motion sickness, anxiety disorders, or epilepsy were excluded. A convenience sampling method was employed to recruit participants.

Development of a Disaster Response VR Module

A disaster response VR module was developed in collaboration with three emergency physician consultants, a healthcare simulation specialist, and a VR technology team. The module simulates a mass casualty incident involving a bus crash into a ravine, requiring participants to resume the role of prehospital care provider to manage the scene. Key tasks include reporting to the incident commander, organising a Casualty Clearing Station (CCS), placing medical resources, and constructing a medical facility. Participants use a VR controller to navigate the scenario, respond to embedded multiple-choice questions, and make critical decisions. They are required to establish a CCS by selecting an appropriate location and choosing the necessary equipment using the controller. These activities assess participants' knowledge, decision-making, and clinical reasoning skills. The scenario includes 18 virtual patients with variable injuries, triaged into four categories: critical (red), semicritical (yellow), non-critical (green), and deceased (black). Treatment is administered at the CCS prior to hospital transport. During each segment of the disaster response VR simulation, participants were required to attempt the questions presented. Upon selecting the correct answer, the VR system provided explanations to enhance self-directed learning (Figure 1). Content and construct validation of the VR disaster response training module were conducted by two senior consultant emergency physicians with expertise in disaster response management. They reviewed and evaluated the module, offering feedback on its technical aspects. The research team subsequently refined the module based on their recommendations. Face validity was assessed by a group of 10 medical officers who were not involved in the study.

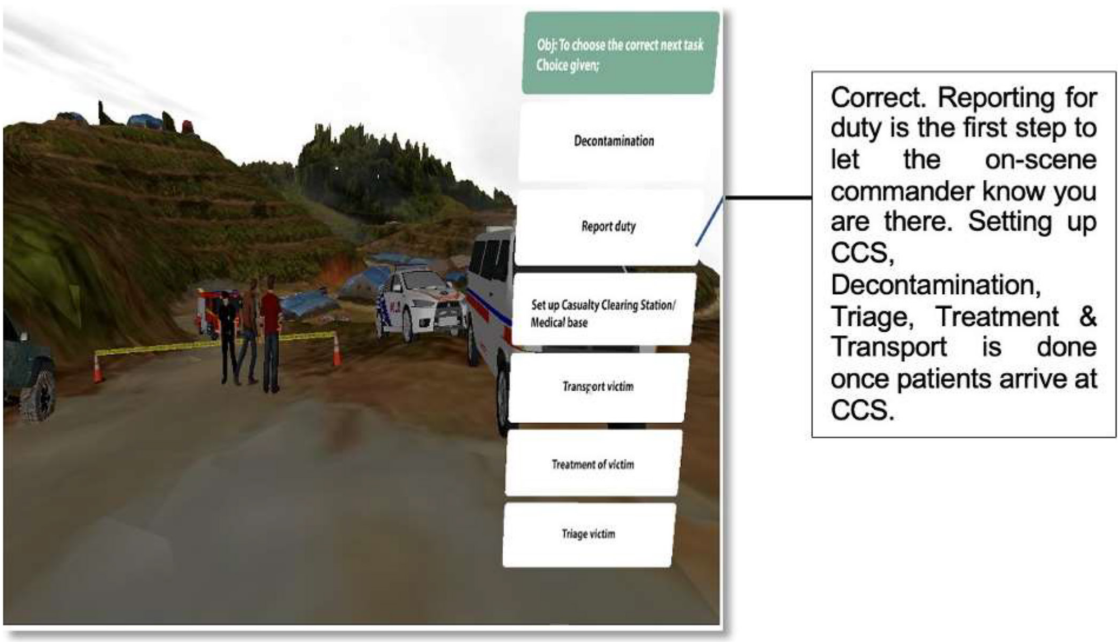

Figure 1: VR simulation interface displaying multiple-choice questions with feedback.

Study Protocol

Participants were assigned to small groups, and they were provided with a 30-minute instructional video covering key principles of DRM. Prior to the intervention, an orientation session familiarised participants with the VR controller and VR Stereo 3D Glass (Figure 2) and guided appropriate positioning for the duration of the VR study. The intervention consisted of a single immersive VR simulation training session. Participants were equipped with VR headsets and interacted with the virtual environment using motion-tracked controllers, selecting the correct answers from options displayed on the screen. They were assessed across five specific areas: (a) Scene assessment and team reporting for duty; (b) Selection of an appropriate CCS; (c) Triage based on injury severity; (d) Selection of appropriate treatments;

(e) Prioritisation of victim transport based on injury severity. To ensure participants' safety, the VR simulation was limited to 30 minutes. Participants were continuously monitored to prevent accidental collisions with surrounding objects. They were given the option to pause the VR simulation if they experienced any undesirable outcomes. The entire session was recorded using a Sony ZV-1 camera, and performance data were analysed using an unbiased evaluation matrix. Upon completing the module, participants completed the questionnaire for further analysis.

Figure 2: VR stereo 3D glasses and controllers.

Assessment Tools

Questionnaire

The questionnaire assessed participants' sociodemographic characteristics, usability, and experience with VR simulation training in DRM, and any adverse events encountered. Usability and user experience were evaluated using a 5-point Likert scale, ranging from 1 (strongly disagree) to 5 (strongly agree). Responses of 'strongly agree' and 'agree' were categorised as positive, while 'disagree' and 'strongly disagree' were classified as negative. 'Neutral' was considered an absence of strong preference. Moreover, to evaluate adverse events associated with VR training, a rating scale was used to assess symptoms such as headaches, dizziness, visual discomfort, fatigue, nausea, vomiting, and postural instability. Responses were scored from −2 (strongly disagree) to +2 (strongly agree), with lower (more negative) scores indicating fewer side effects and fewer adverse events. The questionnaire was validated through a two-step process. Face validation was performed with feedback from 10 independent emergency department medical officers, while content validation was conducted by 6 experienced emergency physicians from different institutions. They evaluated and scored the questionnaire to ensure it effectively measured the intended constructs. The face validation index (FVI) and content validation index (CVI) were calculated, yielding high agreement scores of 0.97 and 0.98, respectively.

Objective Performance Matrix

Participants' performance was assessed using an objective scoring system. They were required to demonstrate key competencies. This includes reporting to the incident commander, identifying their team, assessing the situation, selecting an appropriate location for CCS, establishing a CCS by accurately placing medical icons, and conducting triage evaluations. Additionally, they were evaluated on their selection of appropriate treatment and transportation options. Each correct action was awarded one point, with a maximum possible score of 62. Scores were then converted into percentages and categorised into three performance levels: high (≥ 80%), moderate (61% to 79%), and low (< 60%). The objective performance matrix was validated by two emergency physicians with expertise in disaster management from an independent institution. A group of medical officers further assessed face validity.

Statistical Analysis

All statistical analyses were conducted using the Statistical Package for the Social Sciences (SPSS) version 27.0. Descriptive statistics were applied to summarise all data, including demographic data, Likert scale questionnaire responses, and a performance matrix. Notably, age was reported as the median with interquartile ranges (IQR), while categorical demographic variables were presented as frequencies and percentages. Adverse events were assessed using a rating scale ranging from –2 (strongly disagree) to +2 (strongly agree), where lower scores indicated a lower likelihood of experiencing a specific adverse effect. Performance assessments were categorised into three levels based on Bloom's cutoff points: high, moderate, and low. The results were summarised using frequency and percentage distributions.

RESULTS

A total of 70 participants were involved in the study. Among them, 38 (54.3%) were male, and 32 (45.7%) were female. The median age of the participants was 33 years. Notably, 49 participants (70%) had no prior experience with VR. Similarly, 69 participants (98.6%) had never used VR simulation for disaster training (Table 1).

Table 1: Sociodemographic characteristics of the participants (N = 70)

Variable	n (%)
Age	33 (32–36)*
Gender	
Male	38 (54.3)
Female	32 (45.7)
Wearing glasses	
Yes	40 (57.1)
No	30 (42.9)
VR games experience	
Yes	21 (30.0)
No	49 (70.0)
VR simulation experience in disaster training	
Yes	1 (1.4)
No	69 (98.6)

Note: *Median (IQR)

Usability of VR in DRM Training

Figure 3 presents participants' responses regarding the usability of VR in DRM training. The majority (81.4%) agreed that the VR simulation user interface was user-friendly. Most participants (92.9%) perceived the VR scenarios as realistic and potentially occurring in real life. Moreover, 91.4% indicated they would act in a similar manner during a real-life situation. In contrast, the visual portrayal received relatively lower positive feedback, with 64.3% agreeing it was realistic, 21.4% responding neutrally, and 14.3% expressing negative perceptions.

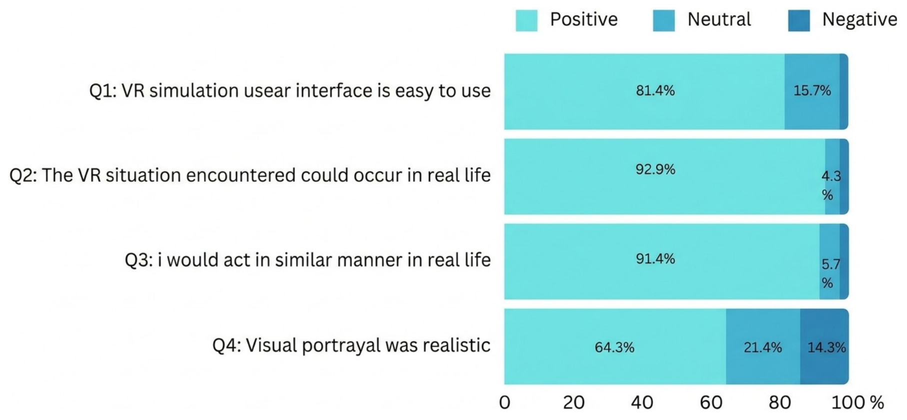

Figure 3: Response of participants on usability of VR in training DRM.

VR Experience in DRM Training

Figure 4 summarises participants' responses regarding their VR experience in DRM training. A substantial proportion (80.0%) agreed that VR simulation was effective, and 71.4% agreed that it was realistic, in DRM teaching. More than half (55.7%) believed VR addressed training needs not covered by the usual curriculum, though 32.9% were neutral. Most participants reported VR to be applicable to their practice (84.3%) and helpful for improving it (92.9%). Enjoyment of VR during disaster training was high (92.9%), and 90.0% recommended its use in future training. Additionally, 71.4% perceived VR as more cost-effective than traditional methods.

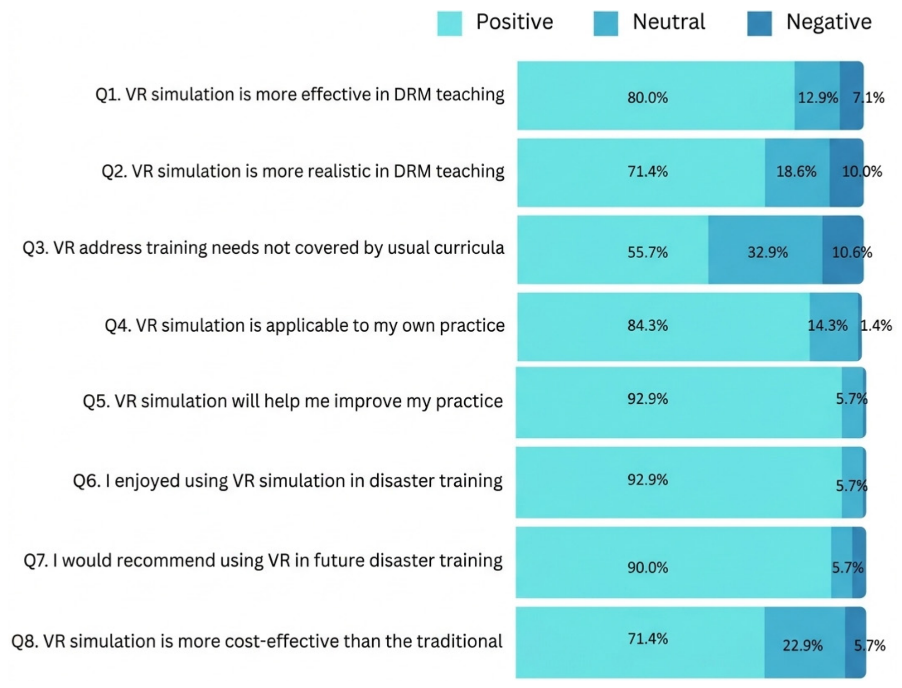

Figure 4: Participants' responses on VR experience in DRM training.

Adverse Events in DRM Training Using VR

Among the reported symptoms, visual discomfort was the most common, affecting 30.0% of participants. Dizziness or spinning sensations were reported by 14.3%, while fatigue was noted by 8.6%. Headache and postural instability were each experienced by 7.1% of participants, and nausea-related symptoms, including vomiting and stomach discomfort, were the least frequently reported (2.9%). The scoring system reflected this trend, with more negative values corresponding to lower symptom frequency. Nausea-related symptoms had the lowest score (–99), followed by postural instability (–89) and headache (–73) (Table 2).

Table 2: Adverse events using VR in DRM training

Variables	Positive symptoms n (%)	Scoring system
I experienced headache during VR training	5 (7.1)	−73
I had dizziness/spinning sensation during VR training	10 (14.3)	−58
I had visual discomfort during VR training	21 (30)	−29
I had fatigue and tiredness during VR training	6 (8.6)	−71
I had nausea/vomiting/stomach awareness due to VR training	2 (2.9)	−99
I had postural instability during VR training	5 (7.1)	−89

VR Performance in DRM Training

The performance level among participants in the VR DRM training is presented in Figure 5. The majority of participants (60%, n = 42) achieved a high level of performance, while 40% (n = 28) demonstrated moderate performance. Notably, no participants were categorised as having a low level of performance.

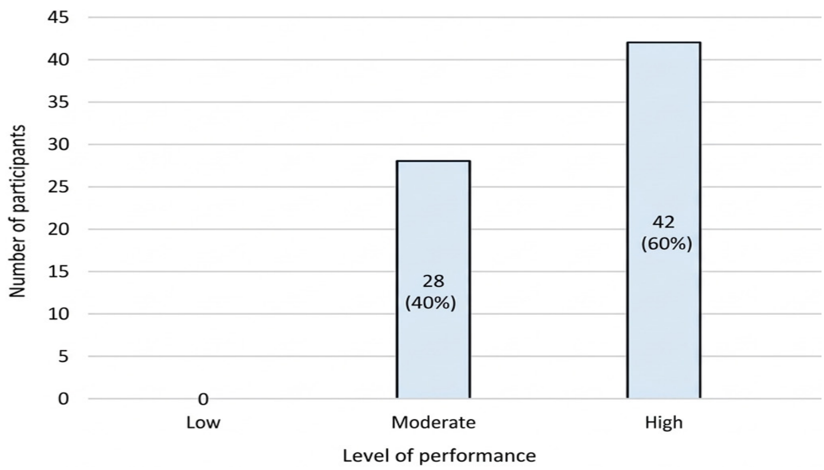

Figure 5: VR performance in DRM training.

DISCUSSION

This study evaluated the feasibility of VR-based training in DRM and demonstrated promising results. The findings indicate that VR simulation was well received by participants, with high usability ratings and a strong perception of realism. The effectiveness of the usability was attributed to the precise replication of disaster situations that aligned with the participants' educational requirements. VR offers an unparalleled degree of realism and immersion (12), enabling trainees to interact with a realistic environment that nearly replicates actual disaster scenarios. Additionally, this VR system offered feedback mechanisms to help users discover areas for growth, implement necessary changes, and continuously better their skills. Numerous studies highlight the crucial role of feedback in guiding student progress and optimizing performance (13, 14). This positive reaction emphasises the need for having an instinctive and easily understandable interface for efficient learning in a digital environment. In addition, these findings are consistent with previous studies, which support the effectiveness of VR in disaster preparedness training (15–18).

The majority of participants noted the VR interface to be user-friendly and felt that the scenarios realistically simulated real-life disaster situations. A well-designed, user-friendly interface plays a crucial role in enhancing learning by fostering active engagement and improving knowledge retention (19). Furthermore, investing in user-friendly VR interfaces can enhance immersion and satisfaction in learning experiences, ultimately improving training effectiveness (20). Consistent with this, most participants reported that their actions in the VR environment would translate to real-world responses. Participants' feedback from DRM VR simulations provides valuable insights into their perceived effectiveness and acceptance. In a study evaluating VR as a training tool for public health Rapid Response Teams, participants reported high usability and excitement, indicating a positive reception of VR-based training methods (21).

Our study challenges the common belief that VR experiences in disaster response medical education led to a high incidence of cybersickness, despite previous research reporting discomfort rates ranging from 20% to 80% among users (8, 22, 23). Our findings indicate a more favorable level of acceptance. Only 30% of participants reported visual discomfort, and just 14.3% experienced dizziness following VR training. Several factors may explain these lower rates of cybersickness. One key factor is age. Kim et al. (22) reported a higher prevalence of cybersickness in individuals aged 40 to 59 compared to those aged 19 to 39. Similarly, Keshavarz et al. (24) stated that older adults (65 and above) are more susceptible than younger individuals (18 years old to 39 years old). Another critical factor is exposure time. To minimise adverse effects, we limited VR sessions to 30 minutes. This is particularly relevant, as a significant incidence of cybersickness has been observed in participants after a 30-minute VR session (25). Moreover, our study incorporated VR stereo 3D glasses, which are recognised for being less disorienting and isolating (26). This feature may have contributed to the lower incidence of discomfort reported by our participants.

Performance assessments further demonstrated the effectiveness of VR training, with 60% of participants achieving a high level of proficiency. VR simulations surpass traditional training methods by providing a fully immersive and realistic learning environment (27). In contrast to conventional tabletop exercises, VR-based training immerses participants in authentic disaster scenarios, enhancing the development of preparation plans (28). Apart from that, in conventional field disaster training, students are typically assigned specific roles, such as triaging patients or delivering treatment at the CCS (29). As a result, they have limited exposure to the broader disaster management process, restricting their understanding of how various components function together. To address this gap, our module was designed as a structured, step-by-step simulation of an out-of-hospital disaster response. The scenario begins with reporting to the on-scene commander, identifying an appropriate location for the CCS, and setting it up with the necessary equipment for both indoor and outdoor operations. Participants then triage victims based on injury severity, provide appropriate on-site management, and make transport decisions based on patient acuity. By fully immersing participants in this structured simulation, VR enhances their understanding of disaster response coordination, decision-making, and interprofessional collaboration (30). This comprehensive training approach likely contributed to the strong performance observed among participants in this study. By creating carefully designed and realistic scenarios, participants demonstrated strong proficiency, with an additional 40% achieving a moderate score.

LIMITATIONS

This study has several limitations. First, the use of written closed-ended questionnaires, while structured and practical, may have limited the immersive experience of the VR DRM training. To enhance fidelity in future research, incorporating voice prompts powered by large language models could offer a more interactive and engaging assessment, providing deeper insights without compromising the current study's validity. Second, the study population varied in terms of working experience and exposure to disaster situations. Considering their differing levels of prior training, establishing a uniform baseline of experience was challenging, which may have influenced their perceptions of the VR training. Lastly, the VR stereo 3D glasses were not well-fitted for participants who wore spectacles, potentially reducing their sense of immersion and making it harder for them to fully engage in the simulated disaster scenarios. Thus, future studies should consider optimising VR equipment to enhance user comfort and immersion.

CONCLUSION

This study highlights VR's growing role in DRM education, emphasising its usability, realism, and ability to enhance skills. With continued refinement, VR can bridge gaps in traditional training, offering an immersive approach to better prepare healthcare professionals. While concerns about cybersickness persist, by optimising VR exposure time and using less disorienting hardware, the incidence of adverse effects can be minimised, making VR a viable and effective DRM training tool.

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ETHICAL APPROVAL

This study was approved by the Medical Research and Ethics Committee (JEP2022-333).

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