Mini Review Article

Use of high-fidelity simulation technology in disasters: an integrative literature review

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New innovative high-fidelity simulation (HFS) technologies, including augmented reality and virtual reality, have begun being used for disaster response and preparedness. However, few studies have assessed the merit of these technologies in disaster simulation. This integrative literature review of 21 studies assesses the role of HFS technology in disaster. Most studies used a quantitative methodology (71.4%), followed by mixed (19%) or qualitative methods (9.6%). Nearly 60% covered only disaster preparedness phase, whereas 10% addressed disasters in middle-income countries without including low-income nations. The four most frequently mentioned technologies were immersive virtual reality simulation, computerized virtual reality simulation, full-scale simulation, and augmented reality wearable smart glasses simulation. Nearly 50% of the studies used technology for purposes other than disaster simulation education, including telemedicine (14.3%), risk planning (14.3%), high-risk map generation for preparedness purposes (9.5%), or rehabilitation medicine (4.8%). HFS technologies must be further evaluated outside of high-income countries and in different disaster phases to better understand their full potential in disaster simulation. Future research should consider different health professions and more robust protocols to assist disaster response professionals and agencies in the adoption of HFS technologies.

Key words: Augmented reality, disaster medicine, high-fidelity simulation training, public health, virtual reality

BACKGROUND

THE POTENTIAL FOR disasters has required health care and public health systems to identify and refine their disaster emergency preparedness protocols and constantly improve the quality of health-care provider disaster education and training.[1–3] Adequate disaster preparedness suffers from limited access to disaster training opportunities and costly and logistically challenging live disaster drills.[3] Alternatively, the increased use of technology in health care has increased patient education and expectations and the implementation of innovative modalities for health care education.[4] Simulation technology helps participants acquire, develop, and maintain the knowledge and skills necessary for safe and effective patient care.[5] High-fidelity simulation (HFS) is particularly adept at providing a high-quality environment for developing nontechnical management skills including communication, teamwork, leadership, and decision making, which are necessary when practicing a response to disaster situations.[4] Simulation fidelity is the similarity to reality achieved by the simulator. Simulations are considered high or low fidelity based on their similarity to reality (Table 1).[6] Despite the potential utility of HFS technologies, insufficient literature has evaluated its effectiveness in disaster response. This review seeks to describe the current ability of HFS technologies to simulate disasters and recommends areas for future study.[1]

METHODS

THIS STRUCTURED LITERATURE search identified works describing the use of HFS technologies in disaster response prior to October 1, 2019. All studies identified by selected search terms in the PubMed and Embase databases and published before the final search date were included. The earliest publication date included was September 30, 2014. Medical librarians and experts in simulation-based education and disasters determined the search terms. Search terms were ultimately adapted to meet the search criteria requirements for each included database (Table 2). Title/abstract and full-text reviews were performed. Only articles that used HFS technologies in real-life disaster or simulation scenarios were included. The following data were

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Table 1. A typology of fidelity within simulation adapted from Cant and Cooper[6]

Simulation tools in order of increasing fidelity	Description of simulation activity
Partial task trainers	Replica models or manikins used to learn, practice, and gain competence in simple techniques and/or procedures
Screen-based computer simulators	Programs used to acquire knowledge, to assess competency of knowledge attainment, and to provide feedback related to clinical knowledge and critical thinking skills
Virtual reality simulation	Combines a computer-generated environment with tactile, auditory, and visual stimuli provided through sophisticated partial trainers to promote increased authenticity
Augmented reality simulation	Combines real-world and virtual reality-like haptic systems
Standardized patients	Use case studies and role playing in the simulated learning experience, in which individuals are taught to portray a patient in a realistic and consistent manner
Full-scale simulation	Simulation that incorporates a computerized full-body manikin that can be programmed to provide realistic physiological response to student actions

extracted using a custom tool: first author and year, data type (qualitative, quantitative, or mixed method), disaster type, disaster setting (country), World Bank status,[7] disaster phase, responders involved, type of HFS technology, problems encountered, findings and significance, and additional comments. Because the primary focus was to characterize the contexts wherein HFS technologies were used rather than methodologic quality, quality assessment metrics were not used in our inclusion/exclusion criteria. Quantitative research deals with numbers and statistics, whereas qualitative research deals with words and meanings. Quantitative methods allow you to test a hypothesis by systematically collecting and analyzing data, while qualitative methods allow you to explore ideas and experiences in depth.

Summary statistics on all the extracted data were calculated to better identify the use of HFS technology in the selected literature. This was followed by two steps. Simple descriptive statistics on the use of HFS technology in disaster research were calculated, which included methods, location, and so on. The second step required a review of the type of HFS technologies discussed in each article. The most commonly used HFS technologies in real-life or simulated

Table 2. Included databases, search terms, and search strategies

Included database, search terms, and search strategies		
Databases	PubMed, Embase	
Search terms	Disaster, mass casualty incident, high fidelity simulation, augmented reality, virtual reality	
Search strategy (PubMed)	((((disaster[MeSH Terms]) OR disaster*[Text Word]) OR mass casualty incident[MeSH Terms]) OR mass casualty incident*[Text Word]) AND ((((((high fidelity simulation[MeSH Terms]) OR high fidelity simulation*[Text Word]) OR augmented reality[MeSH Terms]) OR augmented realit*[Text Word]) OR virtual reality[MeSH Terms]) OR virtual realit*[Text Word]))	
Search strategy (Embase)	(‘disaster’ OR ‘mass casualty incident’) AND (‘high fidelity simulation’ OR ‘augmented reality’ OR ‘augmented realities’ OR ‘virtual reality’ OR ‘virtual realities’)	
Search counts	PubMed: 98 Embase: 96 Total = 194	
Field	Inclusion criteria	Exclusion criteria
Inclusion and exclusion criteria for review		
Language	English only	Non-English language
Study design	Original research	Gray literature, review papers, conference abstracts
Year	Within 5 years, 2014–2019	More than 5 years
Technology application	Real-world event	Research presents theoretical application of technology in disaster setting
Technology use	Augmented reality, virtual reality, high-fidelity simulation	Technology of interest is a survey, etc.

disasters were identified and their applications were recorded along with any unique or unexpected findings.

RESULTS

OF THE 98 abstracts identified in the final search, 41 were excluded following title/abstract screening. Fifty-seven full texts were screened, and 36 were excluded: 13 were inaccessible, 11 were published more than 5 years prior, 8 were not original research, 4 were not relevant, 2 were duplicates, and 1 was not in English. The preferred reporting items for systematic reviews and meta-analyses (PRISMA) diagram for this work[8] is shown in Figure 1.

Descriptive research statistics

Twenty-one articles were ultimately included (Table 3). More studies used quantitative methods (*n* = 15, 71.4%) than mixed (*n* = 4, 19%) or qualitative methods (*n* = 2, 9.6%). Of the included articles, 12 (57.1%) were published within the past 2 years, 14 (66.7%) covered only disaster preparedness. The articles originated from ten different countries, with only three being the source of more than two articles. The most cited countries were the United States (*n* = 10), Germany (*n* = 2), and Italy (*n* = 2). Most articles (*n* = 19, 90.5%) that reviewed HFS technologies were performed in high-income countries, two (9.5%) reviewed in middle-income countries, and none focused on low-income countries.[7] There were nine separate disaster types. Mass casualty incidents and facility fires were addressed in eight (38.1%) and five (23.8%) articles, respectively. All articles clearly specified their intended subjects: seven (33.3%) listed first responders (paramedics: 42.9%, *n* = 3; nurses: 28.6%, *n* = 2; physicians: 28.6%, *n* = 2) as their targets, while the same proportion targeted professional degree-seeking students (nursing students: 57.1%, *n* = 4; paramedic students: 28.6%, *n* = 2; medical students: 14.3%, *n* = 1). Almost

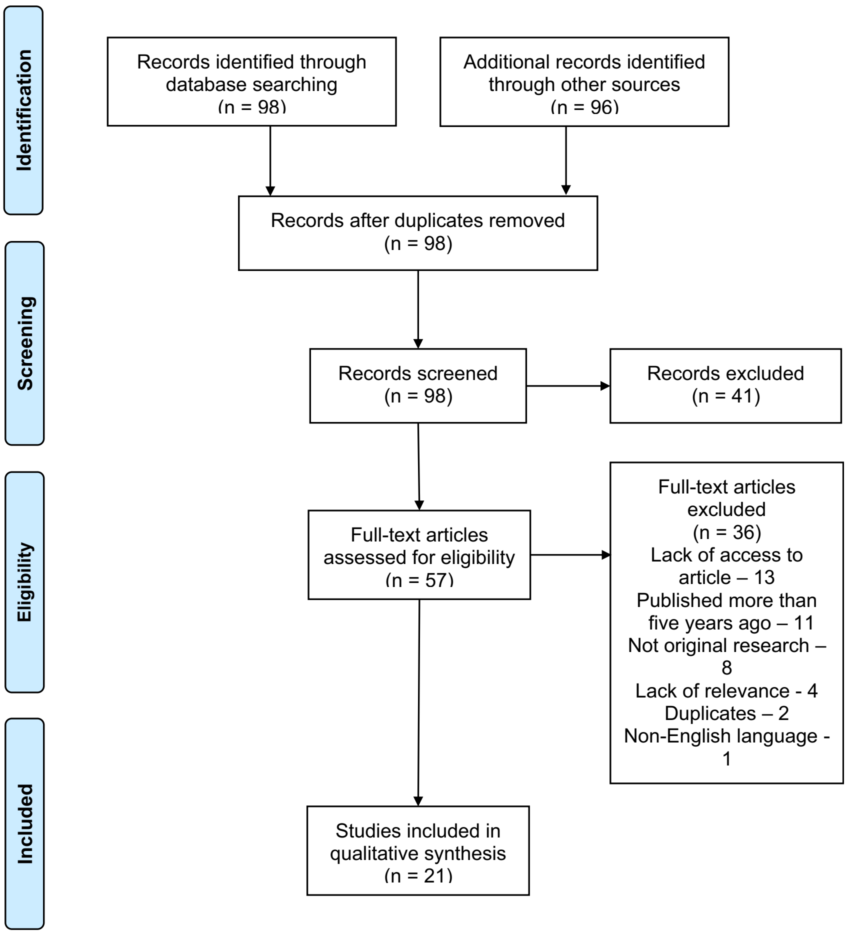

Fig. 1. PRISMA diagram

Table 3. Characteristics of the studies included in the review ($n = 21$)

	Study	Year	Data type	Disaster phase	Country	World Bank status	Disaster type	Technologies	Purposes for technologies	Intended users	Challenges described?
1	Broach *et al.*[22]	2018	Mixed method	Preparedness response	United States of America	High income	Mass casualty incident drills	Augmented reality with wearable smart glasses	Telemedicine Damage assessment: Triage	First responders paramedics	Yes
2	Cao *et al.*[13]	2017	Quantitative	Preparedness	China	Middle income	Virtual facility fires	Immersive virtual reality	Real-time stressful environment Evacuation route decision-making environment	All	Yes
3	Carenzo *et al.*[23]	2015	Qualitative	Preparedness response	Italy	High income	Mass casualty incident drills	Augmented reality with wearable smart glasses	Telemedicine Damage assessment: Triage	First responders paramedics	Yes
4	Dorozhkin *et al.*[10]	2017	Quantitative	Preparedness	United States of America	High income	Virtual facility fires: OR	Immersive virtual reality simulation	First responder training: OR fire response	First responders surgeon, nurses,	
				anesthesiologist	Yes						
5	Dubovsky *et al.*[15]	2017	Quantitative	Preparedness	United States of America	High income	Virtual mass casualty incidents: ED	Computerized virtual reality simulation	First responder training: ED triage	First responders ED nurses	Yes
6	Farra *et al.*[11]	2019	Mixed methods	Preparedness	United States of America	High income	Virtual miscellaneous disasters: NICU	Immersive virtual reality simulation	First responder training: NICU evacuation	First responders NICU workers	Yes
7	Farra *et al.*[16]	2015	Quantitative	Preparedness	United States of America	High income	Virtual radiation-related disaster	Computerized virtual reality simulation	First responder training: Decontamination	Students nurse students	Yes
8	Ferrandini Price *et al.*[12]	2018	Quantitative	Preparedness	Spain	High income	Virtual mass casualty incidents	Immersive virtual reality simulation Full-scale simulation	First responder training: Triage	Students nurse students	Yes
9	Follmann *et al.*[24]	2019	Quantitative	Preparedness response	Germany	High income	Mass casualty incident drills	Augmented reality with wearable smart glasses	Telemedicine Damage assessment: Triage	First responders paramedics	Yes
10	Jain *et al.*[17]	2016	Quantitative	Preparedness	Canada	High income	Virtual mass casualty incidents	Computerized virtual reality simulation	First responder training: Triage	Students/ paramedical students	Yes
11	Kinateder *et al.*[14]	2019	Quantitative	Preparedness	Germany	High income	Virtual facility fires	Immersive virtual reality environment	Evacuation route decision making	All	Yes

Table 3. (Continued)

	Study	Year	Data type	Disaster phase	Country	World Bank status	Disaster type	Technologies	Purposes for technologies	Intended users	Challenges described?
12	Ko *et al.*[25]	2014	Qualitative	Prevention/Mitigation preparedness Response resilience	United States of America	High income	Simulated hurricane/ food poisoning/ power shortage/ traffics	Computational visual analytics simulation platform	Damage assessment Improve various disaster management/ decision making Early warning system coverage/high-risk maps for preparedness Risk planning	National government (nonmilitary) Community	Yes
13	Lugi Ingrassia *et al.*[20]	2015	Quantitative	Preparedness	Italy	High income	Virtual mass casualty incidents	Computerized virtual reality simulation Full-scale simulation	First responder training: Triage	Students/medical students	Yes
14	Mills *et al.*[18]	2019	Quantitative	Preparedness	Australia	High income	Virtual mass casualty incidents	Computerized virtual reality simulation	First responder training: Triage	Students (paramedical students)	Yes
15	Ngo *et al.*[19]	2016	Mixed method	Preparedness	United States of America	High income	Virtual earthquake/ hazmat/dirty bomb mass casualty incidents	Computerized virtual reality simulation Full-scale simulation	First responder training Improve various disaster management/ decision making	First responders EM residents	Yes
16	Smith *et al.*[9]	2018	Mixed method	Preparedness	United States of America	High income	Virtual radiation-related disaster	Immersive virtual reality simulation	First responder training Decontamination	Students/nurse students	Yes
17	So *et al.*[30]	2019	Mixed method	Preparedness	United States of America	High income	Virtual smallpox outbreak	Virtual tabletop exercise simulation	Improve various disaster management/ decision making Risk planning	National government (nonmilitary)	Yes
18	Unver *et al.*[21]	2018	Quantitative	Preparedness	Turkey	Middle income	Earthquake drills	Full-scale simulation	First responder training triage/first aid	Students/nurse students	Yes
19	Weichelt *et al.*[31]	2018	Quantitative	Preparedness response	United States of America	High income	Facility fire drills	Augmented reality with hazard analysis Visual mapping display	Coverage/high-risk maps for preparedness Improve various disaster management/ decision making	National government (nonmilitary) Community First responders	Yes

Table 3. (Continued)

	Study	Year	Data type	Disaster phase	Country	World Bank status	Disaster type	Technologies	Purposes for technologies	Intended users	Challenges described?
20	Winkler *et al.*[26]	2018	Quantitative	Prevention/Mitigation preparedness Response Resilience	Austria	High income	Simulated flooding	Computational virtual reality analytics simulation	Coverage/high-risk maps for preparedness Improve various disaster management/decision making Risk planning	National government (nonmilitary) Community	No
21	Wu *et al.*[27]	2019	Quantitative	Resilience	Taiwan	High income	Explosion	Virtual reality leap motion control	Rehabilitation for hand burn Biofeedback and training of fine motor function	Patients/survivor	Yes

every article mentioned the challenges they faced during HFS technology implementation.

Descriptive high-fidelity simulation technology statistics

The HFS technologies evaluated can be divided into nine categories. Table 4 displays all the HFS technology categories with further details.

Immersive virtual reality simulation uses a motion-tracked stereoscopic 3D head-mounted display with motion-tracked hand controls.[9] All articles covered only the preparedness phase of a disaster, and most assessed the effectiveness of immersive virtual reality simulation on training professional degree-seeking students (n = 2, 33.3%) and first responders (n = 2, 33.3%) for mass casualty incident triage, fire response, and chemical/radiological decontamination.[9–12] However, some articles analyzed the capacity of immersive virtual reality simulation for evacuation route decision making.[13,14] Immersive virtual reality simulation was shown to be a cost-effective, accessible, and viable method of both learning and retention in disaster preparedness and evacuation that required disaster-specific low-volume/high-risk skills.[11]

Computerized virtual reality simulation uses a three-dimensional desktop computer environment and mouse-and-keyboard controls.[9] All articles only covered a disaster's preparedness phase and analyzed computerized virtual reality simulation with the intent of assessing its effectiveness for professional degree-seeking student (n = 4, 66.6%) and first responder (n = 2, 33.3%) training for natural disaster/mass casualty incident triage or chemical/radiological decontamination.[15–19] Computerized virtual reality simulation was shown to be safe and cost-effective for preparing for mass casualty incidents or epidemics given its minimal resource utilization, training site flexibility, and ease of reconfiguring for training disaster-specific low-volume/high-risk skills that must be performed with accuracy.[15,16,18]

Full-scale simulation combines mock injured high-fidelity manikins in a high-fidelity environment with digital video-recording and wireless communication to create realistic disaster conditions.[19] All articles covered only the preparedness phase, and analyzed full-scale simulation with the intent for professional degree-seeking student (n = 3, 75%) and first responder (n = 1, 25%) training on various disaster management/decision-making skills for natural disaster/mass casualty incident triage or chemical/radiological decontamination.[12,19–21] High-fidelity hybrid simulation using both full-scale simulation and standardized patients had clinical superiority in teaching complex clinical skills.[19] Furthermore, full-scale simulation created a superior clinical training environment and provided the ability to repetitively train critical skills and actions in both patient care and disaster management, including teamwork, interpersonal communications, and coordination of care.[19]

Augmented reality wearable smart glasses simulation displays clinical algorithm and telemedicine assistance with augmented reality displaying a triage algorithm within the glasses and using its integrated camera to connect with a senior physician. All three articles covered both preparedness and response phases and analyzed augmented reality wearable glasses with the intent of assessing their usability and reliability for first responder training on mass casualty incident triage with telemedical assistance.[22–24] This simulation technology was promising as both a telemedicine and an augmented-reality disaster response support system.[23]

Simulation technology use in the prevention/mitigation phase

Only two articles explored HFS technology use in the prevention/mitigation phase.[25,26] One analyzed the computational virtual reality analytics simulation, wherein a computer graphics three-dimensional visual display simulates flooding dynamics for the assessment and management to plan disaster prevention measures and rescue interventions for national governments and communities.[26] The other analyzed the computational visual analytics simulation—a visual analytics platform that consists of a desktop computer application, a component model, and a host of simulation components for modeling different societal threats to plan optimal mitigation measures for national governments and communities.[25] These HFS technologies enabled prevention/mitigation planning, increased preparedness and response to a situation, and improved community resilience.[25]

Simulation technology use in the resilience phase

Only three articles explored HFS technology use in the resilience phase.[25–27] Two studies on computational virtual reality analytics simulation and computational visual analytics simulation were previously discussed.[25,26] The third analyzed the virtual reality leap motion control simulation, and includes virtual reality games used in neurorehabilitation and provides the user with biofeedback to permit the training of fine motor tasks to improve hand function.[27]

DISCUSSION

TODAY 's world is troubled with devastating natural disasters, terrorist attacks, and the pandemic viral infection. Disasters are complex and cause a level of confusion for those involved. Developing a simulation technology to effectively manage the situation is inherently challenging. It is significant that a simulated environment with a high level of detail and organization has been successfully implemented.[19] HFS technology has been developed in recent decades. Simulation technology allows interactive and immersive activity by recreating all or part of a disaster experience without associated risks for those involved. The range of available technologies used in simulation is growing exponentially. These range from simple partial task trainers to highly sophisticated computer-driven HFS models, depending on fidelity (Table 1).[6]

This integrative literature review of HFS technologies in disaster preparations revealed several important deficiencies that should be evaluated in future studies. More validated studies on the use of HFS in all disaster types and phases are required, and additional experimental design considerations to strengthen the scientific rigor and quality of HFS research are recommended.

Almost all articles included in this review discussed the use of HFS technologies to prepare for mass casualty incidents, facility fire, natural disasters of earthquake, hurricane, and flooding, or CBRNE (chemical, biological, radiological, nuclear, explosive disaster). These were motivated by the high number of articles that discussed the ability for simulation education to cover various types of disasters in the preparedness phases by creating safe realistic clinical learning experiences meticulously for professional degree-seeking students and first responders including paramedics, nurses, and physicians. However, according to an epidemiology report in 2015, 40% of all natural disaster-related deaths worldwide were caused by storms, 27% from extreme temperatures, and 26% from flooding.[28] Therefore, further research could be needed to determine the use of HFS technologies more for these additional disaster types. Further, nearly all of articles that were identified in the review originated from high-income nations. However, 59% of global deaths from weather-related disasters occur in low- or middle-income countries (LMICs).[28] Nearly 70% of the articles reporting on the use of HFS technology focused on the preparedness phase of the disaster cycle. Minimal work attempted to simulate the prevention/mitigation, response, and recovery phases. Literature reviews can suffer from reporting bias. This was minimized by using the best practice guidelines (PRISMA) to form the methodology of this review and its reporting.[8] Included articles came from five disciplines: paramedical, nursing, medicine, rehabilitation, and disaster management. Most of the articles discussed the challenges of their protocol, citing limitations such as a small sample size and nonrandom allocation. The gold standard for scientific intervention research is the randomized

Table 4. Disaster research summary (nine high-fidelity simulation technology categories)

Technology	Number of articles	Purpose for technology (Top 3)	Disaster type for technology (Top 3)	Disaster phase of technology	Intended user	Location of technology
Immersive virtual reality simulation	6	1. First responder/ student training 2. Evacuation route decision making 3. Decontamination training	1. Facility fire 2. Chemical/ Radiological 2. Mass casualty incidents (miscellaneous)	Preparedness: 100%	Students: 33.3% Nursing students 100% First responders: 33.3% OR staff: 50% NICU staff: 50% All: 33.3%	High income: 83.3% Middle: 16.7%
Computerized virtual reality simulation	6	1. Student/first responder training 2. Improve various disaster management/ decision making 2. Decontamination training	1. Mass casualty incidents (miscellaneous) 2. Earthquake 2. Chemical 2. Radiological	Preparedness: 100%	Students: 66.6% Paramedical students: 50% Nursing students: 25% Medical students: 25% First responders: 33.3% ED nurses: 50% EM residents: 50%	High income: 100%
Full-scale simulation	4	1. Student training 2. Improve various disaster management/ decision making	1. Mass casualty incidents (miscellaneous) 2. Earthquake 3. Chemical 3. Radiological	Preparedness: 100%	Students: 75% Nursing students: 66.6% Medical students: 33.3% First responders: 25% EM residents: 100%	High income: 83.3% Middle: 16.7%
Augmented reality wearable smart glasses simulation	3	1. Telemedicine 1. Damage assessment	1. Mass casualty incidents (miscellaneous)	Preparedness: 100% Response: 100%	First responders: 100% Paramedics 100%	High income: 100%
Augmented reality hazard analysis visual mapping simulation	1	1. Coverage/high-risk maps for preparedness 1. Improve various disaster management/ decision making	1. Facility fires	Preparedness: 100% Response: 100%	National government: 100% (nonmilitary) Community: 100% First responders: 100%	High income: 100%
Virtual reality leap motion control simulation	1	1. Rehabilitation and biofeedback for hand burn/fine motor function	1. Explosion	Resilience: 100%	Patients/survivor: 100%	High income: 100%
Virtual tabletop exercise simulation	1	1. Improve various disaster management/ decision making	1. Biological	Preparedness: 100%	National government: 100% (nonmilitary)	High income: 100%

Table 4. (Continued)

Technology	Number of articles	Purpose for technology (Top 3)	Disaster type for technology (Top 3)	Disaster phase of technology	Intended user	Location of technology
Computational virtual reality analytics simulation	1	1. Coverage/high-risk maps for preparedness 1. Improve various disaster management/ decision making 1. Risk planning	1. Flooding	Prevention/ mitigation: 100% Preparedness: 100% Response: 100% Resilience: 100%	National government: 100% (nonmilitary) Community: 100%	High income: 100%
Computational visual analytics simulation	1	1. Coverage/high-risk maps for preparedness 1. Improve various disaster management/ decision making 1. Risk planning 1. Early warning system	1. Hurricane 1. Food contamination 1. Power shortage 1. Traffics	Prevention/ mitigation: 100% Preparedness: 100% Response: 100% Resilience: 100%	National government: 100% (nonmilitary) Community: 100%	High income: 100%

ED, emergency department; EM, emergency medicine; NICU, neonatal intensive care Unit; OR, operation room.

controlled trial (RCT).[29] RCTs in HFS can be done using parallel study or crossover study. However, out of the 21 reviewed articles across five health disciplines in ten countries, only one RCT[24] was identified and it was not double blinded. The quality and scientific rigor of the HFS technology in each article were therefore not able to be assessed. By contrast, there was no evidence of negative outcomes on HFS technologies.

LIMITATIONS

THIS REVIEW INCLUDED only peer-reviewed scientific literature. Gray literature may provide additional examples of novel HFS technologies. This study addressed the scope of HFS technology use but not study quality. Finally, non-English language studies were not included.

CONCLUSION

AN INTEGRATIVE LITERATURE review that focused on the use of HFS technologies for disaster management had several important findings. Included articles largely focused on disaster simulation trainings for students and first responders in high-income countries. This may be the result of resource disparities between high-income countries and LMICs. Therefore, further studies that evaluate the utility of HFS technologies in LMICs are needed. The types of disasters in which HFS technologies were used did not reflect the human impact of natural disasters such as extreme temperatures. The articles in this review nearly overlooked the response phase, the recovery phase, and the prevention/mitigation phase, and did not evaluate potential users such as humanitarian aid workers and logistic specialists. Future research should be focused on economic disparities, disaster type and phase, and the potential for these technologies to simulate protracted or complex disasters that include multiple heterogeneous causes. This information would help future implementers in assessing how to deal with practical limitations especially in LMICs, such as nonexistent or failed infrastructure, and the technological and literacy challenges of potential users.

HFS has the potential to provide an authentic training environment, secure response, valuable risk planning, and smooth resilient opportunities for disasters while realistically simulating disaster experiences, in which to develop nontechnical skills, that is safe and controlled so that the participants are able to make mistakes, correct those mistakes in real time, and learn from them, without fear of compromising safety. Besides, HFS may be less expensive and easier to organize than large-scale disaster drills; in particular, low- and medium-fidelity simulations may be less expensive and easier to organize than situational disaster task training. Future studies should expand the potential use of HFS technology to additional types of health-care providers, improve their experimental quality, and include cost-effectiveness measures. This will not only permit higher evidence-based HFSs but also bridge the gaps between HFS research and better disaster preparedness, response, resilience, and prevention.

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DISCLOSURE

Approval of the research protocol: N/A.
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Animal studies: N/A.
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REFERENCES

1 Freeman JD, Blacker B, Hatt G, *et al*. Use of big data and information and communications technology in disasters: an integrative review. Disaster Med. Public Health Prep. 2019; 13: 353–67.
2 Coronese M, Lamperti F, Keller K, *et al*. Evidence for sharp increase in the economic damages of extreme natural disasters. Proc. Natl. Acad. Sci. U.S.A. 2019; 116: 21450–5.
3 Farra SL, Miller ET, Hodgson E. Virtual reality disaster training: translation to practice. Nurse Educ. Pract. 2015; 15: 53–7.
4 Lewis R, Strachan A, Smith MM. Is high fidelity simulation the most effective method for the development of non-technical skills in nursing? A review of the current Evidence. Open Nurs. J. 2012; 6: 82–9.
5 Department of Health. A framework for technology enhanced learning. [Internet]. 2011 [cited: November 1, 2019]. Available from: https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/215316/dh_131061.pdf
6 Cant R, Cooper S. Simulation-based learning in nurse education: a systematic review. J. Adv. Nurs. 2010; 66: 3–15.
7 World Bank Country and Lending Groups. Datahelpdesk.worldbank.org [internet]. [cited: November 1, 2019]. Available from: https://datahelpdesk.worldbank.org/knowledgebase/articles/906519-world-bank-country-and-lending-groups
8 Moher D, Liberati A, Tetzlaff J, *et al*. Preferred reporting items for systematic reviews and meta-analyses: the PRISMA statement. PLoS Med. 2009; 6: e1000097.
9 Smith SJ, Farra SL, Ulrich DL, *et al*. Effectiveness of two varying levels of virtual reality simulation. Nurs. Educ. Perspect. 2018; 39: E10–5.
10 Dorozhkin D, Olasky J, Jones DB, *et al*. OR fire virtual training simulator: design and face validity. Surg. Endosc. 2017; 31: 3527–33.
11 Farra S, Hodgson E, Miller ET, *et al*. Effects of virtual reality simulation on worker emergency evacuation of neonates. Disaster Med. Public Health Prep. 2019; 13: 301–8.
12 Ferrandini Price M, Escribano Tortosa D, Nieto Fernandez-Pacheco A, *et al*. Comparative study of a simulated incident with multiple victims and immersive virtual reality. Nurse Educ. Today. 2018; 71: 48–53.
13 Cao Z, Wang Y, Zhang L. Real-time acute stress facilitates allocentric spatial processing in a virtual fire disaster. Sci. Rep. 2017; 7: 1–11.
14 Kinateder M, Warren WH, Schloss KB. What color are emergency exit signs? egress behavior differs from verbal report. Appl. Ergon. 2019; 75: 155–60.
15 Dubovsky SL, Antonius D, Ellis DG, *et al*. A preliminary study of a novel emergency department nursing triage simulation for research applications. BMC Res. Notes. 2017; 10: 15.
16 Farra SL, Smith S, Gillespie GL, *et al*. Decontamination training: With and without virtual reality simulation. Adv. Emerg. Nurs. J. 2015; 37: 125–33.
17 Jain TN, Ragazzoni L, Stryhn H, Stratton SJ, Della Corte F. Comparison of the sacco triage method versus START triage using a virtual reality scenario in advance care paramedic students. CJEM. 2016; 18: 288–92.
18 Mills B, Dykstra P, Hansen S, *et al*. Virtual reality triage training can provide comparable simulation efficacy for paramedicine students compared to live simulation-based scenarios. Prehosp. Emerg. Care. 2019; 1–12.
19 Ngo J, Schertzer K, Harter P, *et al*. Disaster medicine: a multi-modality curriculum designed and implemented for emergency medicine residents. Disaster Med. Public Health Prep. 2016; 10: 611–4.
20 Luigi Ingrassia P, Ragazzoni L, Carenzo L, *et al*. Virtual reality and live simulation: a comparison between two simulation tools for assessing mass casualty triage skills. Eur. J. Emerg. Med. 2015; 22: 121–7.
21 Unver V, Basak T, Tastan S, *et al*. Analysis of the effects of high-fidelity simulation on nursing students' perceptions of their preparedness for disasters. Int. Emerg. Nurs. 2018; 38: 3–9.
22 Broach J, Hart A, Griswold M, *et al*. Usability and reliability of smart glasses for secondary triage during mass casualty

incidents. Proc. Annu. Hawaii. Int. Conf. Syst. Sci. 2018; 2018: 1416–22.
23 Carenzo L, Barra FL, Ingrassia PL, *et al*. Disaster medicine through google glass. Eur. J. Emerg. Med. 2015; 22: 222–5.
24 Follmann A, Ohligs M, Hochhausen N, *et al*. Technical support by smart glasses during a mass casualty incident: a randomized controlled simulation trial on technically assisted triage and telemedical app use in disaster medicine. J. Med. Internet Res. 2019; 21: e11939.
25 Ko S, Zhao J, Xia J, *et al*. VASA: interactive computational steering of large asynchronous simulation pipelines for societal infrastructure. IEEE Trans. Vis. Comput. Graph. 2014; 20: 1853–62.
26 Winkler D, Zischg J, Rauch W. Virtual reality in urban water management: Communicating urban flooding with particle-based CFD simulations. Water Sci Technol. 2018; 77: 518–24.
27 Wu YT, Chen KH, Ban SL. Evaluation of leap motion control for hand rehabilitation in burn patients: an experience in the dust explosion disaster in formosa fun coast. Burns. 2019; 45: 157–64.
28 Centre for Research on the Epidemiology of Disasters. The Human Cost of Weather Related Disasters: 1995–2015. [Internet], 2015 [cited: November 1, 2019]. Available from: http://www.unisdr.org/files/46796_cop21weatherdisastersreport2015.pdf
29 Bogossian FE, Cant PR, Seaton PC. Locating gold standard evidence for simulation as a substitute for clinical practice in prelicensure health professional education: a systematic review. J. Clin. Nurs. 2019; 28: 3759–75.
30 So M, Dziuban EJ, Franks JL, *et al*. Extending the reach of pediatric emergency preparedness: a virtual tabletop exercise targeting childrens needs. Public Health Rep. 2019; 134: 344–53.
31 Weichelt B, Yoder A, Bendixsen C, *et al*. Augmented reality farm MAPPER development: lessons learned from an app designed to improve rural emergency response. J. Agromed. 2018; 23: 284–96.