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Use of virtual reality exercises in disaster preparedness training: A scoping review

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Abstract

Background: The scope and number of disasters have increased over the years. This has called for more robust disaster preparedness training and plans. The use of virtual reality exercises in addition to tabletop exercises is considered a new approach to the preparation of disaster preparedness plans. Virtual reality exercises are being developed to either replace or complement current traditional approaches to disaster preparedness training.

Objectives: To review and summarize the current existing literature regarding the effectiveness, advantages and limitations of using virtual reality exercises in disaster preparedness as a complementary/replacement mechanism for real-time drills and tabletop exercises.

Methods: In this scoping review, we searched PubMed, Cochrane, EMBASE, PLOS, and Google Scholar for research publications involving virtual reality exercises in disaster training from 2008 to 2022 using "AND" and "OR" operators for the keywords "disaster," "preparedness," "virtual reality," and "tabletop." From a total of 333 articles that resulted in our search and were then evaluated by the authors, 55 articles were finally included in this review.

Results: Virtual reality exercises are found to be better in the formulation of disaster preparedness plans compared to tabletop exercises. Virtual reality exercises can be used as the primary means of creating a real-life-like experience in disaster preparedness training and proved at least as better complementary to tabletop exercises. Virtual reality exercises have many advantages over traditional real-life or tabletop exercises and are more cost-effective, but some drawbacks are still identified.

Conclusion: The advantages of virtual reality exercises are remarkable and underline their benefits and uses versus costs. We highly encourage decision-makers and institutions dealing in disaster preparedness to adopt using virtual reality exercises in training for disaster preparedness.

Keywords

Virtual reality, exercises, disaster preparedness, training

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Introduction

There are numerous approaches to disaster training. These approaches include full-scale exercises that are multiagency, operations-based exercises such as drills, tabletop exercises as well as virtual reality (VR) exercises.[1] The most effective approach to disaster training, in the majority of emergency scenarios, is full-scale exercises.[2] However, full-scale exercises tend to require a significant number of resources, are not ideal in some professions' disaster simulations and are disruptive as well.[3–6] Consequently, most disaster preparedness plans make use of tabletop exercises for simulation and training of disasters.[7] Despite the overarching use of disaster plans by disaster preparedness stakeholders, tabletop exercises do not almost mirror real-life disasters.[8]

The weaknesses in tabletop exercises can be attributed to some factors. These factors include the fact that in many instances, individuals taking part in the simulation discussions make use of assumptions.[9] This is because they may lack a realistic mechanism with which to test some of the actions in the plan they may require in the event of a real-life disaster.[10] Although VR simulations are no less based on assumptions of scenarios, VR may be more realistic due to its high immersive properties.[5] Secondly, due to the unpredictable nature of disasters, it may be possible that even with the VR simulation; planners may be overwhelmed by a disaster.[11]

It can be noticed that virtual reality exercises tend to solve some of the weaknesses that are inherent in tabletop exercises. This is due to the fact that the computer programs used have high computing and analytical capabilities that make it possible for them to incorporate all forms of scenarios from a disaster; something that may not be possible with humans as is the case for tabletop exercises.[12] It is for this reason that VR exercises are in the abstract viewed to be much better when compared to tabletop exercises in both natural and manmade disasters.[13] However, VR environments themselves cannot evaluate the achievement of competency-based learning goals, nor can VR represent all forms and variations of possible scenarios.[5]

Due to increased disasters over the years, there is a pressing need for enhanced disaster preparedness mechanisms. Enhanced disaster preparedness has numerous advantages that include the reduced impact of the disaster on at-risk populations as well as a reduction in the response time for such disasters.[14] Disaster preparedness involves the use of disaster preparedness plans. In the contemporary approach, these plans have been prepared using the tabletop exercises approach.[15] This approach required disaster preparedness stakeholders to hold discussions of simulated emergency situations to determine the steps and actions that might be taken if the disaster occurs in the real sense; the discussions are based upon disaster preparedness plans as well as actual disaster preparedness training.[16]

However, in the recent past, there has been an increase in the use of VR exercises to complement tabletop exercises.[13] Literature is still deficient as regards the effectiveness and limitations of VR compared with tabletop exercises and other traditional disaster training methods and it is relatively less studied in emergency preparedness and further research is needed.

This scoping review therefore seeks to assess various literature sources on the effectiveness of using VR exercises over traditional conventional training methods in disaster preparedness training of various populations over the last 15 years. In addition, this review will identify the advantages and disadvantages of VR in such disaster preparedness training.

Methods

A scoping review approach was used in this study to allow the breadth of knowledge and practices about the use of VR exercises to either replace or complement current traditional approaches to disaster preparedness training as tabletop exercises. We examined a wide range of literature over the past 15 years to assess the effectiveness of VR in disaster preparedness training, to determine its key advantages and disadvantages, and to identify gaps in the current knowledge regarding this emerging topic. This review was conducted from January to April 2023 as per Levac et al.[17] recommendations and the five-step approach stated by Arksey and O'Malley's,[18] including identifying research questions, identifying data sources and search strategy, selecting relevant studies, characterizing data and summarizing the results. We adopted the PRISMA-ScR checklist and flowchart in reporting the methodology of this review (Figure 1).

Identifying the research questions

The scope of our review is to provide a broad and holistic overview of the existing knowledge and practices as regards the effectiveness of VR exercises in disaster preparedness training over traditional tabletop approaches. We targeted three main issues: disaster preparedness, VR simulation, and tabletop exercises. To formulate the scope of our research questions, we focused on a broad research question: what is known from the existing literature about the effectiveness of VR exercises in disaster preparedness training? Another specific research question was: what are the advantages and disadvantages of using VR exercises versus using tabletop exercises for disaster preparedness training?

Data sources and search strategy

To formulate the scope of our research question, the population, intervention, comparison, and outcome (PICO) framework was used as described in (Table 1). While conducting this review, some databases were searched for relevant

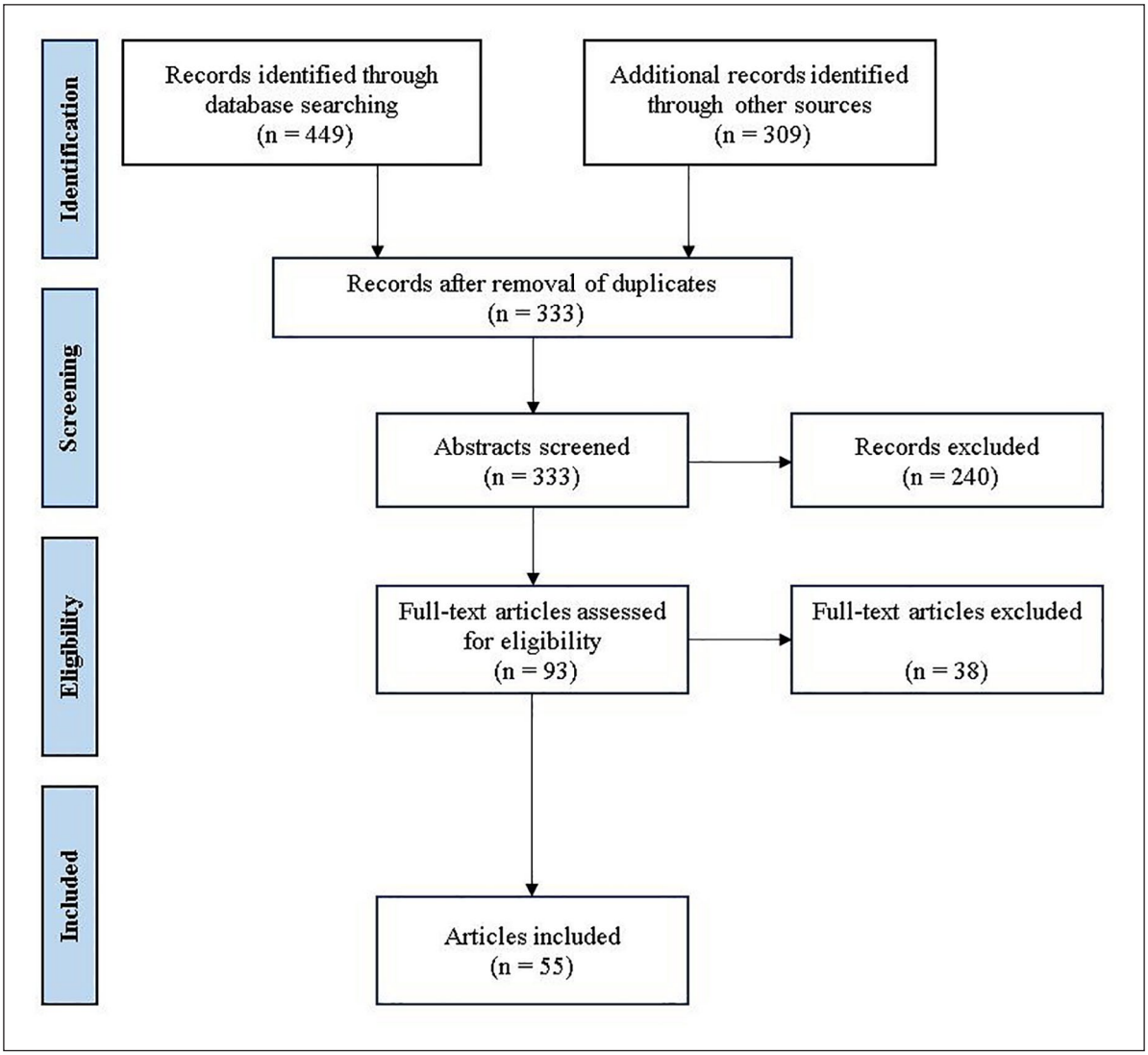

Figure 1. PRISMA flow diagram.

Table 1. Description of the population, intervention, comparison, and outcome framework.

PICO	Summary
Population	Individuals trained in "Disaster preparedness"
Intervention	VR
Comparison	Tabletop exercises
Outcome	Effectiveness of VR

literature over the last 15 years using "AND" and "OR" operators for the keywords of "disaster," "preparedness," "VR," and "tabletop." These databases included PubMed, Cochrane, EMBASE, and PLOS. In addition, we searched Google Scholar using the same keywords to avoid missing any relevant literature that may not have used these keywords in the title or abstract. Search concepts and keywords in the four databases were as follows: #1 ["disaster" AND "preparedness" AND "VR" AND "tabletop"] OR #2 ["disaster" AND "VR" AND "tabletop"] OR #3 ["preparedness" AND "VR" AND "tabletop"] OR #4 ["disaster" AND "preparedness" AND "VR"] Search limits: English language AND publication years from 2008 to 2022. However, as Google Scholar is very wide, we limit the search only to #1 ["disaster" AND "preparedness" AND "VR" AND "tabletop"] to be more specific and concise. We found 758 articles in PubMed (29), Cochrane (7), EMBASE (396), PLOS (17), and Google Scholar (309).

Study selection and inclusion and exclusion criteria

Our inclusion criteria for the articles involved in this review include original articles, reviews, or book chapters published in the English language in a reputable peer-reviewed journal over the last 15 years from 2008 to 2022. In addition, the

Table 2. Advantages of VR exercises in disaster preparedness training.

Advantages	References
Fulfill the needs of users	12,32
Replace hazardous and threatening situations	5,21,31
Testing response plans effectiveness	12,32,42
Its high immersive properties	5,12,21,31,45
Different training scenarios in the same disaster scene	20,21,31,43
Can be repeated and replicated with different working groups	5,20,21,44
Repeated at the trainee's own pace	21,46
Recording of trainees' data during training for assessment and feedback	12,21,31,43
Enhance motivation to learn and improve the level of trainee skills	44
VR simulation exercises were found to be cost-effective	5,12,31,32,37,44

Table 3. Disadvantages of VR exercises in disaster preparedness training.

Disadvantages	References
Lack of familiarity with VR exercises	12,21,31,44
Advanced technology	12,31,32,37
VR requires advanced graphics capabilities	5
High initial development costs because of expensive equipment and programs	6,12,25,37
Worsening of overall net training outcomes if used alone in some emergency scenarios	31
VR may not be suitable for trainees from different groups	5
The risk of habituation may reduce the training effectiveness	41
VR resembles gaming platforms, which may not be taken seriously as real learning	5,12,31
Lacks face-to-face interactions during exercises	5
Lack of multi-user fidelity	31,44
Virtual-induced motion sickness and dizziness during VR training sessions	14,21

articles ought to have shown a relationship between disaster preparedness/plans and either tabletop exercises, VR exercises, or both. Articles were included whether quantitative, qualitative, mixed, or review. The search resulted in a total of 333 articles after removing duplicates. The research team met throughout the screening process to discuss uncertainties regarding the inclusion and exclusion of works from the sample. The articles' titles and abstracts were then screened by the authors for relevancy, and clarity of research aims and methods, resulting in the exclusion of 240 articles.

Data characterization and summarization

In the next stage, the 93 articles, revealed to be eligible for full-text review, were screened by two authors, and a third author was assigned in case of disagreement. No quality assessment was done for the included article as accepted per general guidelines for conducting scoping reviews.[17] A total of 55 articles were finally included in this scoping review. Then, appropriate data were extracted from the included articles including first author, publication year, country, disaster situation, study population, scope/dimensions, conclusion, VR advantages, and VR disadvantages. These data are displayed in the supplementary file (Table S1), Tables 2 and 3, and the main findings are presented in the Results section.

Results

Description of reviewed papers

After searching the literature and the inclusion of relevant papers, a descriptive analysis of these papers was conducted depending on the distribution of research articles by publication year. These articles studied different disaster scenarios with a focus on VR simulation exercises in disaster preparedness. As shown in Figure 2, there is a rapid increase in the number of research over time in the area of using VR for disaster preparedness. Among the 333 articles that resulted from our search, the majority of these articles were published in the years 2022, 2021, 2020, and 2019 (71, 54, 31, and 28) articles, respectively. This increasing trend highlighted more interest of researchers in evaluating the effectiveness of VR and more acceptance of VR simulation by decision-makers in disaster preparedness.

Using VR in disaster preparedness

During a disaster, individuals may be subjected to uncertainty and immersed in a marked loss of reference points. In addition, with the element of surprise during a disaster, the situation will be more complex, and complexity is not scalable. When responding to a disaster, it is important to adopt the correct responses and actions to reduce the suspected

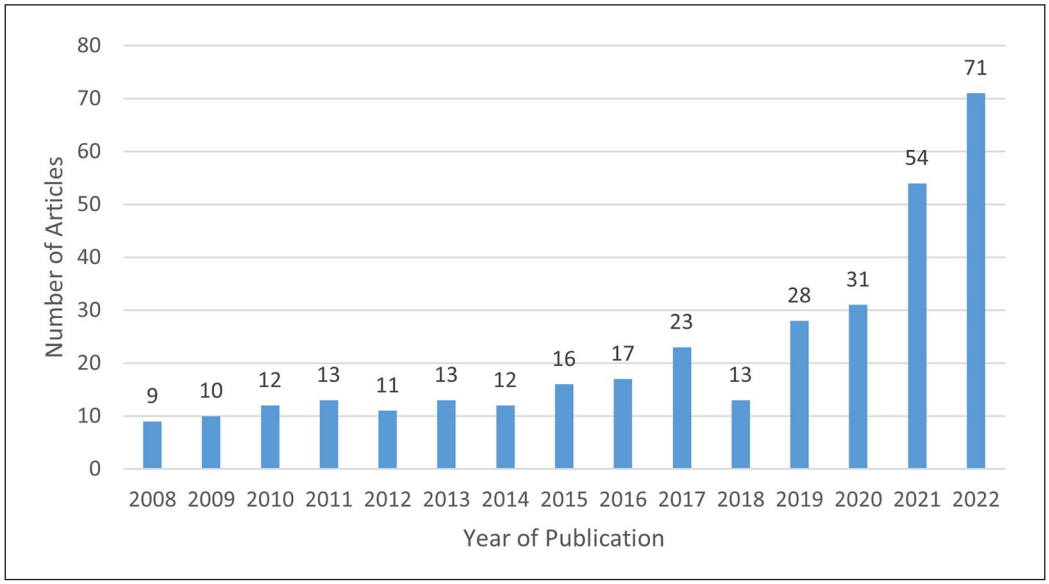

Figure 2. Distribution of reviewed research articles by publication year.

dramatic consequences.[4,19] Therefore, we should prepare for a disaster by, training individuals and rapid response teams and formulation of emergency plans; disaster preparedness is the phase of our interest in this review.[2]

VR is a three-dimensional virtual world that enables individuals to feel as if they are on the scene.[20] It is defined as "an environment-building technology that enables participants to immerse themselves into their surroundings and interact with the elements." The use of VR technology provides many benefits for building an environment for disaster preparedness, as it can be difficult to conduct disaster scenarios in real life. However, VR may help in simulating disaster situations with the avoidance of subjecting trainees to dangers. VR enables trainees to simulate the disaster scene and respond correctly toward different dangerous situations so that they can behave similarly in real-disaster situations.[21] This simulation ensures the accurate results of VR experiments in disaster preparedness research.[22]

VR exercises versus tabletop exercises

One of the primary areas of comparison between the two approaches to disaster preparedness training is cost. In research conducted by Descatha et al.,[6] tabletop exercises are relatively cheap. In a 1-day training session organized during the research for health disaster preparedness, a total of 28 individuals took part in the tabletop exercise with a cost of $1285 being incurred. While the study does not provide comparative costs for real-life disaster stimulations, it intimates that they are relatively expensive mainly due to the opportunity cost incurred in terms of work disruption.[23]

However, an evaluation of other available literature on the cost of VR exercises reveals that the initial cost of these exercises is indeed high when compared to that of tabletop exercises. This is attributed to several factors such as the need to undertake capacity building for the exercises' instructors and most importantly the cost of acquiring VR exercise computer programs as well as associated equipment.[24]

Farra et al.[37] in their study revealed that initially, VR is more expensive, with an average cost of $229.79 per individual for the live drill versus $327.78 for VR. While, after repetition of training over 3 years, the virtual simulation became less expensive and costs were reduced to $115.43 per trainee, while, the costs of live exercises remained fixed. That may be explained by the fact that VR simulation can be used across a large number of participants and over a longer duration with minimal additional costs, while any live drill will require additional costs.[25]

However, the development costs and the personnel approach for a VR simulation should be considered as the cost of different versions of a VR can vary considerably. This is partly due to the different hardware, the location (number of required sensors), and the scenarios themselves (e.g., number of participants, design of the virtual learning environment). A Valve Index VR complete set can be purchased for approx. 999 USD, an Oculus Quest 2 set for approx. 299 USD.[26,27]

Therefore, concerning cost on a one-to-one basis, the cost of VR exercises is much higher when compared to that of table exercises. However, a one-to-one evaluation of cost between the two is not an effective means of comparison especially since it does not take into account the need to evaluate disaster preparedness with a long-term perspective. In this regard, the true cost of each of the two approaches can only be evaluated based on a long-term perspective. Therefore, despite their high initial cost, VR exercises are relatively cheap in the long run.[28]

This could be attributed to the fact that, unlike tabletop exercises, VR exercises are versatile because of the high analytical and computing capabilities of computer programs used in VR.[12] For this to be possible, VR exercises need to be tailored to suit particular disasters, this is achieved using computer-generated virtual environments made possible by VR exercises.[29]

Another core area of comparison is the ease of adoption. It may be easy to assume that VR exercises are easy to adopt due to their reliance on technology. However, it is not necessarily that VR exercises are easier to adopt when compared to tabletop exercises. Individuals involved in disaster preparedness training using tabletop exercises for the first time are more likely to use less time adapting to the exercises when compared to individuals exposed to disaster training for the first time using VR.[30] In a study conducted by Ingrassia et al.,[28] the level of accuracy on day one of training using tabletop exercises was 58% when compared to 52% for the control group in which VR was used. In this context, the level of accuracy will imply the ability of those undergoing training to adapt and learn skills demanded by the particular disaster being simulated.

The advantage that tabletop exercises hold over VR exercises in terms of ease of adoption is only short-lived since in subsequent days of training, the level of accuracy for VR exercises increased exponentially and exceeded that of tabletop exercises. In the research study by Ingrassia et al.,[28] a third day of training using VR exercises resulted in an accuracy of 92% which was higher than that of tabletop exercises which stood at 84% on the third day of training. Other than accuracy, the time taken to complete each situation in a scenario decreased in both cases, however, in VR exercises, the decrease was much faster when compared to that of tabletop exercises.

The challenges associated with the adoption of VR exercises include the fact that the level of familiarity with such exercises may be low at first. This is because the use of VR exercises is a new phenomenon in disaster preparedness exercises and as such the level of use for systems with VR is in its infancy. It is also the case that the technology used in VR exercises is complex in nature and as such, the period of adoption required by trainees is generally longer when compared to that of individuals using tabletop exercises. However, as noted earlier, in the long run, the advantage that tabletop exercises hold over VR exercises, concerning ease and the time taken to adopt, fades out.[12]

Tabletop exercises are also generally rigid because they can hardly anticipate unforeseen challenges that may occur during the disaster course. Edzen[30] holds that this is due to the nature of planning that takes place in situations where tabletop exercises are used. The planning for tabletop exercises is based on known problems as well as solutions gleaned from past disasters. Also, VR is not expected to operate outside of human anticipation, nor can it be adapted to unexpected scenarios in the shortest possible time, at least not if the new scenario differs from the old one in more than an insignificant way. The implication of this is that it does not take into account unplanned problems due to the limited capacity of human beings to anticipate events that they have never experienced. Therefore, if a disaster event that has no precedent occurs, then both tabletop and VR exercises may be difficult for disaster responders to adequately address issues that may arise in terms of both time and reducing exposure to at-risk populations.

It is such gaps (failure to anticipate unprecedented problems) that VR exercises seek to fill. This is because the technology behind VR makes use of algorithms based on previously stated assumptions of the virtual scenario and its learning goals that run independently of human thought during the training session. As a result of this, such algorithms can come up with numerous potential problems and solutions even for a scenario that might not have precedence.[31]

When responding to disaster situations, it is inevitable that in some instances, there will be multiple casualties that may be competing for attention. This also implies that it may be the case that there will be competition for the various limited resources available during a disaster.[32] Consequently, during disaster training, it may be necessary to determine the casualties and/or areas to be allocated the limited resources especially if the impact of the disaster is a huge one.[12] Both tabletop exercises and VR exercises help in the triage and provide nearly identical simulation efficacy for trainees compared to the live simulation. However, VR training resources represent an exciting new direction for authentic and cost-effective training in terms of determining the priority of needs and resources to be evaluated when compared to tabletop exercises.[8]

In a multi-casualty incident, it may be necessary to undertake coordination that involves prioritization such that resources may be allocated from the neediest casualty to the less needy. To achieve this successfully, it is important to have an all-rounded view of the various aspects of a disaster zone. This is possible in VR exercises, dynamic patient simulations that use map systems, and video-based simulations, as well as real-world exercises.[33] According to Putcher et al.,[33] this is due to the fact that VR exercises are not only immersive but all make realistic visualized of all possible scenarios in a disaster and proceed to prioritize them if they have been developed beforehand. On the other hand, such conceptualization may not be possible in tabletop exercises due to their inherent weakness of relying on human beings to think of disaster scenarios; a human being's capability to conceptualize as many scenarios as possible is limited by the fact that human beings tend to rely on past experiences. While past experiences are important in disaster preparedness planning, having a forward look is equally important.[34]

As highlighted before, VR exercises are more realistic and immersive. This is made possible by their ability to use three-dimensional (3D) simulation. As a result of the 3D simulation, a VR exercise effectively stimulates a trainee's

spatial, auditory, and visual senses hence enabling them to fully participate in the session.[35] It is therefore the case that VR exercises not only reinforce the ability of an individual to learn but also increase the rate at which an individual retains knowledge acquired from such stimulation. Additionally, the design of VR is such that it enables individuals engaged in disaster preparedness training to have a 360° view of a disaster simulation scenario hence providing a more realistic feel of the training when compared to tabletop exercises.[36] Farra et al.,[37] therefore see VR exercises as being a helpful instructional method in disaster preparedness training.

In this regard, it is easy to see that VR exercises perform better when compared to tabletop exercises. This is because tabletop exercises do not involve aspects of 3D simulations; discussions undertaken in tabletop exercises can at best articulate simulation in two dimensions (2D). The implication of this is that such simulations are not as immersive as those in VR exercises.[12,25,38,39]

An important measure of comparing tabletop exercises with VR exercises is their ability to incorporate visual cues in the simulation processes.[8] Most importantly, continuous visual cues are generally viewed as being more effective in instructional conveyance as opposed to static cues.[37] Often the visual cues used in table exercises are static in nature. This implies that the material used in the simulation is often printed on a static frame such as paper.[6]

On the other hand, VR exercises make use of advanced technologies such as video game applications. It is therefore the case that in VR exercises, it is possible to have continuous and multilayered simulations on video, which further ensures that the visual cues from the simulation are better understood. This is further enhanced by the fact that it is possible for visual reality to make use of 360° views as mentioned above.[4,8,40,41]

Advantages of VR exercises

The application of VR-based technologies to disaster preparedness training entails many significant potential benefits compared to other forms of traditional training.[12] Table 2 illustrates the main advantages of VR exercises. VR can be tailored to the specific needs of users and organizations and the settings they are designed for.[12,32]

It is challenging to control the possible hazards associated with some live exercises as in fire training, despite the many precautions taken to promote safety.[31] VR simulation exercises can replace situations where there are causalities or destructions to real assets, providing simulation to disaster situations to avoid subjecting trainees to dangers.[5,21,31] Organizations can utilize VR-based simulation to test response plans to major causalities incidents, and so testing these response plans effectiveness as well as can assess them to identify areas for improvement in disaster response plans, such as specific needs for training.[12,32,42]

With VR, we can study many factors and different training scenarios in the same disaster scene by adjusting some of the parameters.[20,21,31,43] Moreover, the same experience from VR exercises can be repeated and replicated with different working groups in different geographical locations.[5,20,21,44] The recording of trainees' data during training is one of the strengths related to VR that allows reflective thinking and improvement of preparedness plans.[31] Trainees can use the available VR exercises repeatedly and at their own pace to help get the experience and feel of training.[21,44–46] VR exercises' scenarios, trainees' responses, and interactions can be stored for evaluators' assessment and feedback.[12,21,31,43]

VR training is characterized by immersive properties as it provides trainees with a higher level of realism and immersion compared to classroom exercises and web-based training.[5,31] Availability of resembling environmental components such as buildings, streets, rivers, and bonds, so immersed in a suburban or residential-like setting.[5,12,45] VR is associated with the development of "AVATAR" which is the VR trainee person into which the VR exercises put trainees into an immersive educational experience of actions and feedback for actions.[5,12,21,45] The inclusion of audio and video resources helps more immersion of trainees into the situation under training.[5,12,21,45] VR simulation exercises enhance motivation to learn and improve the level of trainee skills due to the variety and interactivity of its visual simulation.[44] In addition, VR simulation exercises were found to be cost-effective. It saves costs of real-life mobilization of resources and personnel; also, large numbers of trainees using the VR exercises and diverse applications and repeatability could augment cost savings.[5,12,31,32,37]

Disadvantages of VR exercises

Despite many advantages, VR is still not perfect since it shows some sort of weaknesses from a technological, organizational, and psychological point of view.[5] The main disadvantages of VR exercises are summarized in Table 3. The most significant drawback of VR exercises is the unfamiliarity of the leadership of such potentials of these applications, hence the reluctance to adopt such training solutions.[12,21,31,42,44] Lack of familiarity with VR exercises and applications renders users when first interfaced with these applications.[12,21,31,43] Existing technology may lie short of accommodating technology demand for VR exercises.[12,31,32,37] VR requires advanced graphics capabilities that may not at all times be available with standard computer equipment and that could render to achieve smooth training implementation and reduce immersion and interaction of trainees.[5] However, VR-based training was found to be cost-effective, it needs high initial development costs because of expensive equipment and to provide high-quality programs.[6,12,25,37]

VR may not be suitable for trainees from different ethical groups, cultures, religions, and age groups. In addition, VR may not be suitable for trainees from different genders, as

males differ from females in their psychological level of simulation perception and behavior—they react and respond to emergencies. These are important considerations, which may significantly limit the effectiveness of VR simulation training.[5] However, training on threatening situations such as fire hazards needs to be repeated regularly to ensure that stress will not affect individuals' decisions during the actual life events tasks, the risk of habituation may reduce the training effectiveness.[31]

The nature of VR simulation training resembles gaming platforms, which may not be taken seriously as a real learning process but as fun to play with.[5] Trainees may show an attitude of playing a game, but not fully focus on acquiring new knowledge, skills and critical thinking, which in turn may affect the validity of training benefit.[5,12,31] The overall training outcomes should be carefully interpreted to find out which sections of traditional exercises would be supplemented, or even substituted, with VR simulation training to enhance the net VR training outcomes.[31] VR training still lacks the direct evaluator hands-on experience and no face-to-face interactions like real-life exercises provide.[5]

Although the findings demonstrated the applicability of VR simulations to different training scenarios, these do not entirely cover all disaster scenarios that could happen.[44] VR training lacks multi-user fidelity and seems to be insufficient for training on emergencies that require the presence of two or more individuals in the same task such as firefighting and rescue evacuations. This issue represents a gap in transferring skills from solitary VR simulations and should be considered.[31] Virtual-induced motion sickness (VIMS) and dizziness are other drawbacks reported during VR training sessions and younger trainees are less sensitive to developing motion sickness but need higher levels of immersion in the virtual scenario. Motion sickness and scenario immersion are important factors that should be taken into mind during studying the rationale of VR training.[14,21] Several countermeasures against VIMS exist, but a reliable method to prevent or ease VIMS is unfortunately still missing. However, Keshavarz et al.[47] tested the role of olfaction as a countermeasure against VIMS and their results showed that the pleasant odor resulted in significantly less VIMS compared to the control group. Moreover, Hemmerich et al.[48] suggested a beneficial effect of a visible horizon in the reduction of MS. They observed that the presence of a stationary earth-fixed horizon while performing a time-to-contact task in VR, significantly lowers VIMS.

Discussion

In this scoping review, we aimed to formulate a holistic overview regarding the effectiveness, advantages, and limitations of using VR exercises in disaster preparedness as a complementary/replacement mechanism for real-time drills and tabletop exercises. We reviewed the current existing literature over the past 15 years from 2008 to 2022. From our review, there is a clear increased interest of researchers in evaluating the effectiveness of VR exercises in disaster preparedness planning with a rapid increase in the number of research over time.

This review compiled 55 articles summarized in the supplementary file (Table S1). The majority of reviewed papers ($N=16$, 29%) were published in 2022, followed by 2021 ($N=7$, 12.7%). Articles conducted in the USA dominated the review, with nearly one-third of all reviewed publications ($N=20$, 36%). In addition, nine papers were from China (16.3%), three papers were from both the UK and Iran, and two papers were from Taiwan, Italy, and Germany. Only one publication was included from each of the following countries: Japan, Republic of Korea, Philippines, Switzerland, Bulgaria, France, Norway, Austria, Sweden, New Zealand, Finland, Czech Republic Greece, and Morocco. Almost three-fourths of articles reported results of VR exercises dealing with mass casualty incidents including natural disasters ($N=40$, 72.7%). A large number of articles also focused on exercises testing response to disease pandemics and biological hazard emergencies ($N=7$, 12.7%). Few other included articles focused on other threats such as chemical, fire, and radiological emergencies ($N=6$, 5, 3 articles, respectively). The majority of articles focused on the outcomes and effectiveness of VR simulation exercises in disaster preparedness training. Sixteen articles focused on the advantages of VR and limitations of VR.

This review identified diverse advantages, disadvantages, and challenges of VR usage for disaster preparedness training. As revealed from this review, it is evident that VR exercises are much more effective in planning disaster preparedness training. This is the case when several evaluation metrics are put in place. In this review, the evaluation metrics included cost (both in the short and long terms), ease of use, level of user immersion, as well as suitability as an instructional method. In all these metrics, VR emerged as better when compared to any conventional training method.

The primary weakness of tabletop exercises relative to VR exercises is that they rely on human beings to define the problems and possible solutions for disaster scenarios.[33] This may not be effective given that in their inherent sense, human beings tend to rely on past experiences to make up possible scenarios in case of a disaster.[49] However, as the 11th September 2001 terrorist attacks highlighted, past experiences may not be enough to enable human beings to make adequate conceptualizations of possible disaster scenarios.[50] VR exercises help to bridge this divide by providing a more superior analytical and computing capabilities that make it possible to evaluate all the possible iterations of a disaster with issues ranging from the number of casualties and severity of injuries to required resources being extensively evaluated by VR.[51]

Meanwhile, in designing VR exercises, educators have to take into consideration that it will support the construction of knowledge, provide coaching simultaneously, promote

reflection, and at the same time integrate evaluation and assessment.[37] In addition, VR simulation is appropriate for disaster preparedness training, providing challenge, enjoyment, and mastery.[52] The VR can benefit more areas in the training system as fire evacuation, especially in overcrowded places. That is due to the cost of fire evacuation drills in such places and the tendency for accidents to occur during the emergency response.[53] VR can help to investigate behavior in crises and evaluate crisis communication in a realistic simulation. Though VR is a promising technique to simulate real-world emergencies, participants' behavioral modes and mental states still cannot exactly replicate real-world situations. Therefore, we are still in need to improve the sense of presence in the virtual environment, as the higher the sense of presence the more accurate the simulation of individuals' responses in real-disaster situations.[54]

Regarding pandemic emergencies, VR simulation training for medical personnel on disaster preparedness on how to respond to such pandemics has many advantages as it can provide a safe environment for training to increase their technical skills and enable them to quickly and efficiently deal with the epidemic and protect patients from potential harm.[14,55–61] In addition, the general population needs systematic training to acquire disaster preparedness skills and be prepared for any potential risks. Designing a VR training system was found to improve public health emergency preparedness and help them to respond effectively to emerging infectious diseases.[62–64]

The application of VR is highly trending as a disaster management technology. Although bounded by content, the medium of information is crucial in ensuring the information is conveyed properly. The VR simulation excels in the retainment of spatial working memory, increases knowledge level, and improves the time on tasks and the number of errors when compared with other traditional training methods.[65]

Overall, a disaster–preparedness curriculum including simulation-based training has, in general, a positive effect on the knowledge base and skills to respond to disaster among trainees.[40]

Limitations

This review may have some limitations that should be taken into account. Our search was limited to only some databases, while, other academic databases, such, as Scopus and CINAHL, and gray literature were not searched. In addition, articles published in English from 2008 to 2022 were only included in this scoping review. In this review search concerning the PICO scheme, the authors did not make a clear delimitation of the population but used "disaster preparedness," but other keywords might have returned additional or different results. These limitations of our search strategy may result in missing some relevant studies. Another limitation of this scoping review is the lack of rigorous quality appraisal of the included articles, however, that is accepted in the scoping review approach. Another limitation is that VR compared with tabletop exercises is relatively less studied in emergency preparedness and further future research is needed. Moreover, virtual environments sometimes cause VIMS among trainees as well as participants' mental states and behavioral modes cannot exactly replicate real-life situations. This may be mitigated by reducing the time of VR exercise with improvement of the sense of presence in the virtual simulation. Despite many limitations in this review, the findings provide a holistic and comprehensive scope of the existing concepts and help to draw conclusions regarding the efficiency of VR simulation in disaster preparedness training.

Conclusion

The advantages of VR exercises are remarkable and underline their benefits and uses versus costs. They are more effective than tabletop exercises in planning for disaster preparedness training. Individuals and institutions dealing in disaster preparedness are encouraged to adopt the use of VR exercises in training for disaster preparedness. Even in instances where VR exercises may not be used as the primary form of disaster preparedness training for either natural or manmade disasters, it is recommended that they be used as complementary training methods to tabletop exercises.

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Author contributions

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Ethical approval

Since this is a review article and we did not interact with, interview, or intervene with human or animal subjects; therefore, ethical approval from the Institutional Review Board was not required. As this is not a systematic review, a scoping review protocol does not have to be registered in advance.

Informed consent

Not applicable.

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Supplemental material

Supplemental material for this article is available online.

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