REVIEWS

Integrative review: Virtual disaster training

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Abstract

Background: A critical component of disaster preparedness is the training of the healthcare workforce. Because live disaster exercises are expensive and labor intensive, virtual reality simulation may offer a viable solution as a disaster training method. The purpose of this integrative review was to examine the scientific evidence pertaining to the efficacy of virtual reality training in disaster training of healthcare workers. Inclusion criteria were: empiric literature focused on the use of virtual reality simulation (VRS) in disaster training, written in English, peer-reviewed literature and published during the time period of 2005-June, 2012. An exclusion criterion was the use of virtual simulation for modeling the effects of disaster because these articles were not used for immersive training purposes.

Methodology: A five-stage process was followed as the methodological strategy for the integrative review. These stages included identification of the problem and purposes, a defined search strategy (method), evaluation and analysis of data and the presentation of findings. A search of diverse databases was performed. These databases include PubMed, the Cumulative Index of Nursing and Allied Healthcare Literature, Education Resources Information Center, Academic Search Complete, Computer Source, and Computer/Applied Science.

Results: Principle findings identified three major themes including: descriptions of the participant's VRS experiences, learning results after participation in VRS and an exploration of how knowledge construction occurs in the virtual environment. Eleven research articles were selected for inclusion in the review.

Conclusions: The review found there are too few studies investigating the efficacy of VRS and disaster training. Rigorous larger studies with measurement of long-term retention are needed. There is also a need to assess the self-efficacy to act in different types of disasters, and evaluate behavioral determinates such as performance in triage, decontamination, and transport.

Key words

Disaster training, Virtual reality, 3-D immersion

1 Introduction

Disasters are increasing at an alarming rate. Worldwide in 2011, there were 325 catastrophic events (175 natural disasters, 150 manmade) resulting in 35,000 deaths [1]. The acute threat or impact of disasters triggered by natural hazards forced at least 14.9 million people to flee or leave their homes worldwide in 2011 and in 2010 there were over 42 million evacuated [2]. The cost of disasters is high both in human suffering and monetarily. Preparation for disaster can lessen these adverse effects. A critical component of disaster preparedness is the training of the healthcare workforce [3]. Yet, there are continuing gaps in the education of healthcare workers in preparing for disaster response [4, 5]. The lack of disaster training opportunities is one challenge to preparedness. Live exercises are expensive and difficult to organize, but virtual environments may offer an accessible and economic tool to meet training needs [6]. The evolution of telecommunication technologies, web-services and software engineering has opened the virtual world with synthetic representations of reality that can help provide realistic training exercises [7-9].

Immersive virtual reality simulation (VRS) is defined as a variety of computer-generated and synthetic experiences with an advanced interface within a human-machine simulation system [10]. Chen, Rebooledo-Mendez, Liarokapis, de Freitas, and Parker [7] describe virtual simulation as the use of shared space, graphic user interface; VRS allows the use of 3-D environments and computer interface to permit participants to interact within a virtual environment [11]. There is a growing body of evidence that VRS can be used in disaster education and training. A few current examples of virtual simulation use in disaster training include the Center for Disease Control's (CDC) recent implementation of virtual reality training for Deployment Safety and Resilience Team members within an immersive environment to prepare for disasters [12]. The Incident Command Training Tool is a virtual reality training exercise based upon the U.S. Department of Homeland Security's Incident Management System [13].

2 Purpose and method

Due to the growing use of VRS in disaster education, greater understanding of the use of VRS and its effectiveness in disaster training of healthcare workers is needed. No existing review of the literature is found examining the use of VRS in the training of healthcare workers for disaster response. The purpose of this integrative review is to examine the state of the scientific evidence of the efficacy of VRS training in disaster training of healthcare workers. More specifically, this paper will answer the question: What is the state of the science related to the use of VRS training in disaster training for healthcare workers? The five-stage process described by Whittemore and Knafl [14] was followed as the methodological strategy for the integrative review. These stages include: identification of the problem, purpose of review, a defined search strategy (method), evaluation and analysis of data and the presentation of findings [14].

3 Results

A search of diverse data bases was performed. These data bases include PubMed, the Cumulative Index of Nursing and Allied Healthcare Literature (CINAHL), Education Resources Information Center (ERIC), Academic Search Complete, Computer Source, and Computer/Applied Science. The inclusion of these diverse data bases decreased the possibility of missing relevant literature. Search terms included: virtual reality, virtual simulation, 3-D immersion, serious game, serious gaming combined with either the search term disaster or mass casualty incident. There were 202 results for these searches. An additional five articles were obtained using the ancestry approach of examining references of relevant research reports [15]. Duplicate articles were removed. Articles were screened with the goal of finding articles that focused specifically on the use of VRS for the purposes of disaster training of healthcare professionals. All abstracts were reviewed for the following inclusion criteria: written in English, peer-reviewed literature and published during the time period of January, 2005- June, 2012. An exclusion criterion was the use of virtual simulation for modeling the effects of disaster because these articles were not used for immersive training purposes.

The process used to obtain the final sample included three steps. Step one was the review of the abstracts for articles believed to meet the inclusion criteria. In step two, the full articles were printed from those identified articles (n=59). Finally, each printed article was read in its entirety for inclusion and exclusion criteria. Many of the articles were informational related to specific product development and implementation. These articles were excluded as they did not inform on the scientific state of immersive virtual reality disaster training. Ten research articles were selected for inclusion in the review (see Table 1).

Table 1. Article Summaries

1st Author/year	Purpose	Design /Subjects	Method	Findings and Critical Analysis of Results
Andreatta, P.(2010)[24]	Compare the relative impact of 2 simulation-based methods for training emergency medicine residents in disaster triage.	Two group Quasi experimental design. Convenience sample of 15 post-graduate residents who were randomly assigned to two groups	Each group received triage training either through VRS or live disaster drill. The independent variable = group assignment. Dependent variables = pretest score, triage score, triage rating and posttest score.	Groups had equivalent knowledge prior to training. VRS group had slightly better scores on actual triage performance. Triage scores were slightly higher for those in the live drill (mean=18.50, Std=2.62). No inferential statistics were analyzed due to small sample size (n=15). Reliability of the pretest/posttest was not reported nor the reliability of the 32 item triage performance rating. Both the test and triage ratings were said to have been derived from the Simple Triage and Rapid Treatment (START), a commonly used triage algorithm. No expert review of these constructed instruments was mentioned to assess if the items truly reflected the algorithm.
Bergeron, B. P. (2008)[11]	The author designed and evaluated two serious games: The Radiation Hazards Assessment Challenge Game and The Nuclear Event Triage Game.	Experimental design using a convenience sample of nuclear first responders. 89 subjects	Control group received traditional didactic training and the experimental group received an intelligent tutoring system and participated in two serious games. Independent variable=training; Dependent variable=scores pretest/ posttest and a six-week posttest.	Tests scores from the posttest administered immediately after experience and in 6 weeks were significantly higher for the virtual simulation group than those from the control group $p<0.01$. The study did have a convenient sample. Although significance in findings were reported, there were no pre and posttest mean scores and standard deviations provided in the article. Reliability and validity information were reported for the test.
Haferkamp, N. (2011)[21]	Evaluate a serious game which enabled its users to train soft skills in a virtual environment under safe conditions.	Descriptive mixed methods Convenience sample of 10 crisis managers 10 students 2 trials conducted	After completing a VRS, with asynchronous text chat, participants completed a debriefing session and a short questionnaire (Likert-type scale) to evaluate the effectiveness of the game in training social skills. Participants were also asked to evaluate: social skills training in the virtual experience (Likert scale), emotions experienced (Likert scale) and evaluate the game itself (Likert scale).	Crisis managers outperformed students in both trials. Students reported higher levels of stress (mean=3.6. Std=1.5 on a 5 point scale) and frustration (mean=3.0, Std=1.29 on a 5 point scale). Both groups felt the VRS was useful in training, but rated the simulation as far from reality (mean=2.0, Std=1.23 on 5 point scale). . Crisis managers preferred a more realistic simulation of disaster; the student sample focused more on the game play itself and achieving cooperation. Asynchronous chat was a limitation of the study. The simulation in this study was not well developed. Another limitation identified was subjects were unclear regarding their assigned role is the game.
Heinrichs, W. L. (2010)[6]	Determine whether a Virtual Emergency Department (VED) is an effective clinical environment for training ED physicians and nurses for MCI's.	Descriptive mixed methods Convenience sampling with 10 physicians and 12 registered nurses	Participants received 30 minutes computer training and then participated as avatars within a virtual emergency room simulation. Participants completed an entry questionnaire, exit questionnaire and focus groups were conducted.	2/3 of participants reported feeling immersed. Training improved confidence in responding to events which was attributed by subjects to participation in the virtual environment. 95% thought the scenarios were useful in team training. 82% thought the VRS was useful in learning clinical skills management. 86% felt confident in the exercise, a 46% change in the mean from prior to the exercise. In this sample the registered nurses had a mean of 9.5 years of experience while the MDs had a mean of 4.0 years. No reliability and validity of the study questionnaires were mentioned.

(Table 1 continued on page 96)

Table 1. (Continued)

1st Author/year	Purpose	Design /Subjects	Method	Findings and Critical Analysis of Results
Heinrichs, W. L. (2008)[17]	Explore the feasibility of using 3D virtual world technologies for training and assessment of health care teams working in high-stress critical care areas such as emergency departments.	Descriptive study with post experience survey N= 13/30 volunteer subjects who were not gamers and reporting to have no MCI training.	Three virtual world studies were presented for team raining and assessment in acute-care medicine: One study, identified as a pilot study, was not included in the review. Participants in the first scenario evaluated their experiences with a Likert-type survey and had their performance evaluated using pre/post test cases. In the other scenario subjects evaluated their experience by Likert-type questionnaire.	In the first scenarios both groups demonstrated increased learning on pre/post case scenarios. There were no significant differences between the groups. Participants felt immersed and able to suspend disbelief. In the second scenario a majority (mean=3.47) felt immersed and thought that the session increased their confidence (compared with 2.00 prior to training) and the simulation exercise would be useful for learning teamwork (mean = 3.77) as well as for learning clinical skills (mean = 3.15) Course instructor debriefed the subjects regarding to learn from the exercise mistakes and thoughts of using this learning method. . 69% of the volunteer subjects had never placed games before this experience, but 62% indicated the experience changed their feelings/attitudes about working as a member or leader of an ED team.
Kizakevich P.N. (2007)[18]	Evaluate a blended didactic and virtual simulation-based curriculum for triage training.	Descriptive study with a convenience sample of 31 Iraqi physicians	Participants evaluated the curriculum with a questionnaire using Likert-type scale for qualitative measure of the presentation and simulation.	Participant evaluation was overwhelmingly favorable with 5=strongly agree Including realism and navigation (mean 4.40, Std=, 20, content and responsiveness (mean=4.42, Std=0.04) and simulation learning content (mean=4.41, Std=.20) No mention was made of the reliability and validity of the quantitative outcome questionnaire. In addition, the physicians were not followed after their participation to assess if learning transfer to their practice had occurred.
Knight, J. F. (2010)[23]	Evaluate the effectiveness of a serious game in teaching of major incident triage by comparing it with traditional training methods	Quasi experimental with a convenience sample of 91 attendees of a Major Incident Medical Management and Support Course	Subjects were randomized into two groups 44 subjects practiced triage using a card sort exercise, 47 participants used a virtual reality triage experience. Following the training each participant undertook an evaluation exercise triaging 8 causalities in a simulated live exercise. Performance was assessed for correct triage category based upon victim injury, use of correct procedure, and time to triage. Assessment was performed by individual evaluator and confirmed by videotaping.	Tagging accuracy and step accuracy (in those who tagged correctly) was significantly higher in the virtual simulation group; there was no difference in time to triage between the two groups. No reliability and validity data were provided for the outcome measurement. The researchers also did not determine if the study results actually changed triaging performance in actual practice. Initially there were identified issues regarding the feedback regarding game performance, but this appeared to be corrected.
van der Spek, E. D. (2010)[22]	Develop a set of guidelines from empirical experiments that enhance the development of serious games.	Descriptive study 10 emergency physicians	Participant's pre-test posttest design. Pre and post participation subjects were evaluated to measure knowledge acquisition. Pathfinder, a method measuring word pairs for mental model elicitation was completed along with conceptual knowledge questionnaire. Participants also completed an engagement questionnaire.	Scores were positive on the engagement scale. Post conceptual knowledge measured pre and posttest was significantly improved after training. No change in mental model structuring was found using the pathfinder method of mental model elicitation. The sample was small (n=10) and it appeared that this was a convenience sample. No data were provided regarding the reliability and validity of the 3 study instruments.

(Table 1 continued on page 97)

Table 1. (Continued)

1st Author/year	Purpose	Design /Subjects	Method	Findings and Critical Analysis of Results
Vincent, D. S. (2008)[22]	To measure knowledge acquisition of triage skills following participation in 3 virtual reality scenarios which include five simulated patients	Descriptive study 24 medical students (four students were excluded due to previous triage training) n=20	Participants participated in three separate virtual reality scenarios including the triage of five patients. 3 outcomes measured included: triage score, intervention score and time to triage for each scenario. Subjects completed a learner satisfaction and self-efficacy questionnaire of VRS experience.	All self-efficacy questions showed a statistically significant increase in scores over time. Triage and intervention scores improved significantly from Scenario A to B, but not from B to C. The VRS training evaluation scores were high (mean=6.5, Std=.61on a 7 point scale). Limitations of the research identified by the researchers were: subjects may have been more technologically sophisticated than the non-volunteers, 25% of the subjects were in either the 3rd or 4th year of medical school and may not have been representative of most first responders. and performance gains may have been due to increased familiarity with the human/computer interface rather than improvement in the triage knowledge structure.
Wilkerson, W. (2008)[19]	This study explores the utility of immersive VRS for training first responders in a terrorism disaster scenario.	Descriptive study 12 paramedics	Participation in VRS using cave automatic virtual environment and high fidelity human patient simulation. Assessed for author defined critical actions using direct observation and video-taped recordings. Participants were interviewed post experience.	Learner feedback and expert performance review suggest that VRS has the potential to be a powerful tool to train first responders for high-acuity, low frequency events. Although not specifically stated, it appeared the participants were a small convenience sample of 12. Researchers also listed no comparison or control group and developmental characters of this intervention limits the conclusions.

3.1 Selection

The purpose of this integrative review was to examine the scientific evidence pertaining to the efficacy of virtual reality training in disaster training of healthcare workers. Inclusion criteria were: Empiric literature focused on the use of VRS in disaster training, written in English, peer-reviewed literature and published during the time period of 2005- June, 2012.

3.2 Validity assessment

The articles were evaluated and compiled into a data matrix which included the following information: expertise of research team, methodology including sampling, setting, design and instruments, results, findings assessment of rigor and limitations. The sources were evaluated for authenticity, methodological quality, information value and representativeness [16]. A ten point system was used to evaluate the sources. No article was deleted due to a lower score, instead those sources with higher scores served as the predominant informant, while those with lower scores were used in a more supportive role.

The findings of the studies were reviewed and analyzed. Three major themes were identified by two independent reviewers. These themes were: i) Participant experience -descriptions of the participant's experience in the virtual environment, ii) Participant learning - learning results of participation in the VRS and iii) Knowledge construction - an exploration of how knowledge construction occurs in the virtual environment. The greatest number of sources measured learning post experience, with a slightly lower number describing the virtual reality experience. Only one article sought to describe how knowledge was developed in the virtual environment.

3.3 Major themes of the studies

3.3.1 Participant experience

The following are 5 studies that investigate the use of VRS and participant experience. Heinrichs, Youngblood, Harter and Dev [6] evaluated participant VRS experiences in two scenarios using Likert-type questionnaires and two focus groups of volunteer subjects evaluated the scenarios. In both scenarios the authors found a majority of participants felt immersed (66%) and found an increase in confidence (Mean=3 on a 5 point scale, pre-test 18% to posttest 86%) following participation in VRS. The study is limited by the use of a small convenience sample. There was inconsistency in the scenarios presented resulting from revision of the scenarios and changes to the user interface based upon participant feedback.

Also using a Likert-type scale Kizakevich et al. [18] found in this convenience sample of physicians' (n=31) feedback was overwhelmingly favorable examining realism, navigation, content, responsiveness and simulation learning content (overall mean=4.38 of 5, Std =.036). Unfortunately, learning was not evaluated after participation in the VRS. Heinrichs, Youngblood, Harter, Kusumoto and Dev [17] report that participants felt immersed in a VRS emergency department (mean=3.47 with 5=high) and that VRS was useful for learning teamwork and clinical skills (mean=3.77). Vincent, Sherstyuk, Burgess, and Connolly [19] and Wilkerson et al. [20] reported that participants gave high evaluation scores to VRS training (mean=6.5.Std=.61 on a 7 point scale). The participants in these studies represented a diverse group of healthcare workers. The results of the studies were positive for the VRS experience with the majority of participants having reported feeling immersed in a realistic experience. In a study by Haferkamp, Kraemer, Linehan and Schembri [21] participants found that VRS was useful in training, but rated the simulation as far from reality (mean=2.0, Std=1.23 on a 5 point scale). The authors identified the use of asynchronous chat as a barrier to participation in the VRS and may have been responsible for the lower scores for the reality of the simulation of this study in comparison to other studies.

Limitations of these studies include the use of convenience samples and some studies lacking randomization of subjects. Overall the sample sizes were small (n=10-31). The participant experiences were described using focus groups, Likert-type questionnaires and post-experience interviews. Little information is provided regarding reliability and validity of questionnaires or coding of qualitative data from focus groups or interviews.

3.3.2 Participant learning

The following are examples of three articles that investigate participant learning in VRS. Bergeron [11] administered pre/post and six-week tests to measure knowledge acquisition in VRS participants and traditional methods participants and found significantly greater learning in both groups (n = 89), but at six weeks the VRS group had significantly higher learning retention than the traditional group (p=.01). In addition, Van der Spek, Wouers, and Van Ostedendorp [22] used a pre/posttest design reported significantly improved post conceptual knowledge following a VRS experience (n = 10). Knight, Carley, Tregunna, Smithies, deFreitas, Dunwell and Machway-Jones [23] discovered that triage tagging accuracy and triage step accuracy was significantly higher in a VRS training group than the group trained using a card sort exercise with no difference in time to triage (n = 91). Vincent et al. [19], found improvement in triage scores (mean=6.5, Std=.83 on a 7 point scale), speed and self-efficacy (p=.001) after fully immersive VRS. The use of student volunteers in this study may have resulted in more technically sophisticated participants and because student were used as their own controls the increase in the scores may have been due to repetition of the scenario. Sample size was small (n=20) which again limits the generalizability of the findings.

Heinrich et al. [12] rated Emergency Medicine Crisis Management using a rating scale for behavioral performance in a VRS group and a Human Patient Simulator group. No significant differences in the scores were identified between the groups. Andreatta [24] compared a VRS experience versus a live drill in assessing triage knowledge and found that there were no significant differences in triage performance between the two groups, but those who participated in the live drill had higher scores on the post test (mean=18.5, Std 2.62).

Measurement of the psychomotor skill of triage was a focus of more than one study; participant scores in accuracy and efficiency of triage were significantly higher in virtual simulation learners. Those studies which measured cognitive knowledge acquisition most often measured using pre/posttest. In each of the studies, concepts were measured with different tools. Although most used pre/post testing, little information is given related to the development, validity and reliability of most of these tools.

3.3.3 Knowledge construction

Although there is only one article associated with this theme, the authors felt that the phenomenon of this study, the construction of knowledge during VRS, was significant enough to be identified as a theme. Different theories exist regarding the construction, storage and recall of information, examinations of how VRS promotes and supports learning and retention needs to be examined. Van der Spek et al. [22] used Pathfinder, a method measuring word pairs for mental model elicitation, to evaluate learner mental model structure pre and post VRS completion. The study found no change in mental model construction post VRS. An author identified limitation of the study was that performance gains may have been due to increased familiarity with the human/computer interface rather than improvement in the triage knowledge structure.

4 Discussion

Disasters occur at a rate of approximately one per day worldwide [1]. A well-trained healthcare workforce is needed to respond to these disasters. Current levels of training are not sufficient to prepare the workers. Cost restraints and logistic constraints make live simulation difficult, yet are critical in educating responders. VRS offers a potentially cost effective and efficient viable alternative. There are too few studies investigating the efficacy of virtual simulation and disaster training. Larger studies with n=100 or more, with reliable and valid tools need to be performed with more detailed and rigorous interventions and measurement of long-term retention (12 or more months) and consideration of such extraneous variables as technological sophistication of the subjects, ease of navigation and reality of the VRS. There is a need to investigate the self-efficacy to act in different types of disasters, and behavioral determinations such as performance in triage, decontamination, and transport of victims need to be rigorously assessed.

VRS is experientially reported to help learners achieve learning outcomes [11, 19, 22-24]. Participants' self-report that these environments are realistic and not difficult to use [6, 17]. Qualitative studies should be conducted which continue to describe the experience of those following VRS. Specific questions need to address how participants would describe the experience of virtual disaster training including immersiveness, reality, and the ability to navigate within the environment. The current studies involve a wide range of delivery systems including total immersion in a cave automatic virtual environment to simple mouse and monitor interaction [20, 24]. All of these studies use a different method to deliver the VRS. Further research is required to discover which of the variety of methods available for VRS are most efficient and effective in delivering content and providing realistic experiences for learners. Additional research questions that should be considered include: What type of virtual reality systems are most cost effective, portable, yet produce desired learning outcomes (i.e., knowledge, attitude, and/or behavior)? What content is best taught with virtual simulation? A large number of these studies focused on triage, are there other circumstances such as decontamination and patient transport that are just as appropriate?

Finally, there is some limited quantitative data which supports the use of VRS to achieve sustained learning outcomes [11]. Additional studies are needed which explore the relationship of virtual learning with the acquisition and retention of learning of disaster training concepts. It is recommended that the following be further explored:

1) Determine what pedagogical programs and learning theories are supported by virtual simulation.
2) Examine how learning and retention are affected by an individual's participation in virtual disaster environments.
3) Determine how feelings of immersion, presence, and viewpoint affect learning and retention.

4) Explore if autonomous learning or collaborative learning in the virtual reality environment is superior to traditional learning environments.

Because virtual simulation is a new learning strategy, a body of evidence is needed to support the use of this modality in delivery disaster education.

5 Limitations

The integrative review was limited in the number and quality of the articles available for inclusion. Although this is in some ways a limitation, it also is in itself an important finding in pointing to the need for further rigorous scientific exploration in this area.

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