Teaching Mass Casualty Triage Skills Using Immersive Three-dimensional Virtual Reality

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Abstract

Objectives: Virtual reality (VR) environments offer potential advantages over traditional paper methods, manikin simulation, and live drills for mass casualty training and assessment. The authors measured the acquisition of triage skills by novice learners after exposing them to three sequential scenarios (A, B, and C) of five simulated patients each in a fully immersed three-dimensional VR environment. The hypothesis was that learners would improve in speed, accuracy, and self-efficacy.

Methods: Twenty-four medical students were taught principles of mass casualty triage using three short podcasts, followed by an immersive VR exercise in which learners donned a head-mounted display (HMD) and three motion tracking sensors, one for their head and one for each hand. They used a gesture-based command system to interact with multiple VR casualties. For triage score, one point was awarded for each correctly identified main problem, required intervention, and triage category. For intervention score, one point was awarded for each correct VR intervention. Scores were analyzed using one-way analysis of variance (ANOVA) for each student. Before and after surveys were used to measure self-efficacy and reaction to the training.

Results: Four students were excluded from analysis due to participation in a recent triage research program. Results from 20 students were analyzed. Triage scores and intervention scores improved significantly during Scenario B ($p < 0.001$). Time to complete each scenario decreased significantly from A (8:10 minutes) to B (5:14 minutes; $p < 0.001$) and from B to C (3:58 minutes; $p < 0.001$). Self-efficacy improved significantly in the areas of prioritizing treatment, prioritizing resources, identifying high-risk patients, and beliefs about learning to be an effective first responder.

Conclusions: Novice learners demonstrated improved triage and intervention scores, speed, and self-efficacy during an iterative, fully immersed VR triage experience.

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Keywords: educational technology, immersive virtual reality, task performance and analysis, triage, patient simulation

Technology enabled learning systems (TELS) comprise a spectrum of digital learning activities that have the potential to be effective and efficient in training first responders to respond to mass casualty incidents.[1] TELS incorporate traditional computer-based training activities, but also include unusual technologies such as immersive virtual reality (VR). TELS are appealing as educational tools for first responder training because they can be tailored to unique situations, provide engaging learning experiences, and be reused.[2,3] In 2005, only 14 of 198 federal training courses on terrorism utilized TELS; only 31% were simulation-based, and only 6% used VR systems.[2]

Because of the paucity of VR systems, few studies have measured learning effects in VR environments. In one recent study, the knowledge structure of medical students triaging a single head trauma patient showed significantly higher gain using a fully immersed VR system with a head-mounted display (HMD) compared to using a partially immersed (computer screen) system.[4] We wanted to explore how novice learners would perform when encountering multiple simulated casualties in a fully immersed VR environment. Do they become faster and more accurate in triaging the patients after practice and feedback? Do they improve in their application of lifesaving interventions? Additionally, we wanted to determine whether their perceived self-confidence regarding first responder skills was affected

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by the VR experience. To conduct the study, we used a novel, fully immersive VR environment, in which the learners wore a HMD and interacted with multiple simulated casualties using a gesture-command system rather than a computer joystick or mouse. The study hypothesis was that learners would improve in speed, accuracy, and self-efficacy.

METHODS

Study Design

This was a repeated-measures model of task completion in a VR environment, with subjects serving as their own controls. The study flow is shown in Figure 1. The University of Hawaii Committee on Human Studies and the United States Army Medical Research and Materiel Command Human Subjects Research Review Board approved the research protocol. All participants signed written informed consent.

Study Setting and Population

The study took place in a medical school simulation center and used a convenience sample of medical student volunteers who were recruited by a single e-mail announcement. Mass casualty triage training is not part of the medical school curriculum or clinical rotations. Twenty-four subjects were recruited and enrolled.

Study Protocol

Students were required to achieve a baseline level of triage knowledge before they could begin the hands-on portion of the study. This consisted of listening to and viewing three instructional podcasts for a total of 15:48 minutes, followed by a 20-question graded exam. A score of equal or greater than 85% correct answers was required to continue.

During the VR portion of the study, one investigator ran the VR computer program and made sure that the subjects did not trip while wearing the HMD. Learners received a scripted orientation to the VR program and then spent about 5 minutes practicing the gesture-based commands in a test scene. After completing each VR triage scenario, the HMD was removed and learners watched a short DVD movie (iDVD, 2007, Apple Inc., Cupertino CA) that demonstrated a standardized expert approach to triage within the VR scene.

Technology. The VR scene was created using Flatland (University of New Mexico, Albuquerque NM),[5] an open-source information visualization system that runs on Linux OS (http://www.linux.org/). Visual and audio content were rendered in active stereo mode. Users wore a Fifth Dimension Technologies (5DT, Inc., Irvine CA) HMD, stereo earphones, and three motion tracking sensors (Ascension Technology Corporation, Burlington VT), one for the head and one for each hand (Figure 2). Each triage scenario consisted of five casualties with various injuries situated in a dark room. Although auditory and visual distracters are possible in the VR scene, such as police sirens, helicopters with lights, and alarms, the distracters were turned off for this exercise. Users examined VR patients (Figure 3) and engaged virtual instruments and supplies by using a pose- and gesture-based command system. For example, when a user raised his or her left hand overhead, a virtual equipment tray appeared, and the subject could then "pick up" a virtual instrument using the right hand and could then use the virtual instrument or perform an intervention on a VR casualty. VR casualties were not programmed to respond to interventions. After

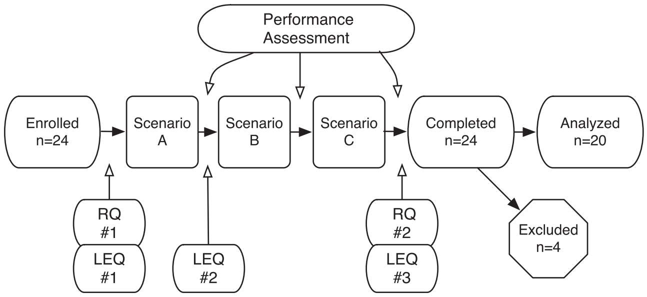

Figure 1. Study design. RQ = reaction questionnaire; LEQ = learner evaluation questionnaire.

Figure 2. A medical student, wearing a head-mounted display (HMD) and two sensor gloves checks the pulse of a simulated casualty in the virtual environment.

Figure 3. The same student checks a simulated casualty's carotid pulse in the virtual environment, using a virtual hand that is mapped to the right sensor glove. The fingers of the virtual hand move up and down at the pulse rate when positioned over the carotid, radial, or femoral regions. Pulse rate and strength also appear in the left upper visual field of the head-mounted display (HMD). Some students described "feeling" the pulse of the VR patient.

completing an intervention, subjects assigned each VR casualty to a triage category using a four-color triage tag within the VR environment. They also selected the main problem and main required intervention from a pick list. The gesture-based command system has been described in greater detail elsewhere.[6] When triage was completed, subjects were automatically transported to the next simulated casualty without needing to navigate within the VR scene. A short video of a subject triaging five VR casualties may be viewed at http://bloodgoesroundandround.com.

Scenarios. Three scenarios consisting of five adult casualties were created in the VR world. Each scenario consisted of three "immediate" patients, one "minimal" patient, and one "delayed or expectant" patient. The immediate injuries were one hemorrhagic shock, one tension pneumothorax, and one airway management problem. Delayed casualties included a patient with a leg fracture and a patient with blunt abdominal trauma. One "expectant" casualty had massive head trauma and anisocoria. Minimal patients had minor wounds with normal vital signs. Learners were required to identify the main abnormality (one or none), perform an intervention (one or none), and place each casualty into the appropriate triage category. Main abnormalities fell into these categories: airway, breathing, circulation, neurologic, and "other" (such as fracture or psychological injury). Intervention options included applying a tourniquet, using a HemCon (HemCon Medical Technologies, Inc., Portland OR) bandage, applying a regular bandage, performing a needle chest decompression, and inserting a nasopharyngeal airway. In some instances, "no intervention" was the appropriate response.

Outcomes

Three outcomes were measured for each scenario: triage score, intervention score, and time to triage. For triage score, 1 point was given for each correct answer that was selected by the learner in the VR environment: 1) was the main problem correctly identified, 2) was the required intervention correctly identified, and 3) was the triage category correctly identified? Thus, each learner could receive a maximum of 15 points per scenario. For intervention score, 1 point was awarded for each intervention that was performed correctly in the VR environment. Thus, each learner could receive a maximum of 5 points per scenario.

Learner Satisfaction and Self-efficacy. Subjects completed a reaction questionnaire[7] (RQ) for the completed VR experience. The RQ is an instrument that has been used to assess learner satisfaction with Web-based training material. The questionnaire was adapted to assess the relevance of the training to the learner's perceived role as a first responder rather than to the learner's usual clinical role. Subjects completed a self-efficacy questionnaire before the VR experience, after Scenario A, and after Scenario C. The questionnaire was modeled after the learner evaluation questionnaire (LEQ), an instrument designed to measure medical student attitudes toward curriculum.[8] We modified a subscale of the LEQ, the self-efficacy scale. The questions were changed to take the viewpoint of a first responder instead of a medical student. Two additional self-confidence questions were included. Each question was scored on a 5-point Likert scale with points labeled "never" (1) to "always" (5; Table 1).

Data Analysis

Learners served as their own controls. The design was a repeated-measures model comparing task completion between scenarios. Previous simulation research with manikins[9] demonstrated that task completion was improved most between the baseline and subsequent scenario, with a difference of about 30%. Thus, for a correlation of r = 0.80, 20 subjects were required (tested against a constant correlation of r = 0.50, $\beta = 0.80$, $\alpha = 0.50$, tails = 2; source of estimation, SPSS Sample Power, SPSS Inc., Chicago IL). Results are reported as mean ± standard deviation (SD). Times were compared between the three scenarios using one-way analysis of variance (ANOVA) for each student. Triage score and intervention score were analyzed using one-way ANOVA for each student. Self-efficacy questions were analyzed using one-way ANOVA for each student. Post hoc analysis was performed using Scheffe's correction.

RESULTS

Demographics

Twenty-four students scored >85% on the didactic test and completed the VR exercise. Four of the students were subsequently excluded from the analysis because they had participated in a manikin-based triage research project within 6 months that used similar

Table 1
Self-efficacy

	Before	After	p Value
1. I feel confident that I will learn to be an effective first responder.	4.0 (0.69)	4.2 (0.62)	0.034
2. I feel confident that patients will consider me an effective first responder.	3.8 (0.64)	4.1 (0.60)	0.006
3. I feel confident in my ability to prioritize the treatment of patients in a mass casualty situation.	3.2 (0.89)	4.2 (0.52)	0.001
4. I feel confident in my ability to prioritize the use of resources in a mass casualty situation.	3.1 (0.97)	4.2 (0.75)	0.001
5. I feel confident in my ability to identify high risk patients for immediate treatment in a mass casualty situation.	3.4 (0.88)	4.2 (0.77)	0.008

Data are reported as mean (±SD). 5-point Likert scale: 1 = never to 5 = always.

triage scenarios. Most learners were in their first year of medical school (MS1; 12/20; 60%), but the study also included 3 MS2 (15%), 3 MS3 (15%), and 2 MS4 (10%) learners.

All five self-efficacy questions showed a statistically significant increase in scores over time. Students became more confident that their patients would consider them effective first responders (p = 0.006), more confident in prioritizing treatment (p = 0.001), more confident in prioritizing resources (p = 0.001), and more confident in identifying high-risk patients (p = 0.008). Students expressed initial confidence that they would be able to learn how to be an effective first responder, and this score also increased (p = 0.034; Table 1).

Triage score improved significantly from Scenario A to Scenario B, but not from Scenario B to Scenario C (Figure 4). The 26% improvement from A to B was felt to be clinically significant. The intervention score also improved significantly from Scenario A to Scenario B, but not from Scenario B to C (Figure 5). The average improvement between Scenario A and Scenario B of more than one correct intervention for five simulated casualties was felt to be clinically significant. Time to triage improved from Scenario A to Scenario B and from Scenario B to Scenario C (Figure 6). The overall improvement by 4:12 minutes is likely to be clinically significant.

VR Training Evaluation

The students rated the simulation phase of the course highly (Table 2). They also felt that the pace was just right (4.2 ± 0.39 on 7-point Likert scale, 1 = too slow and 7 = too fast). The level of difficulty was also rated as good (4.5 ± 0.83 on 7-point Likert scale, 1 = too easy and 7 = too hard). The students also agreed that the course was relevant to them as health care providers (6.5 ± 0.61 on 7-point Likert scale, 1 = strongly disagree, 7 = strongly agree).

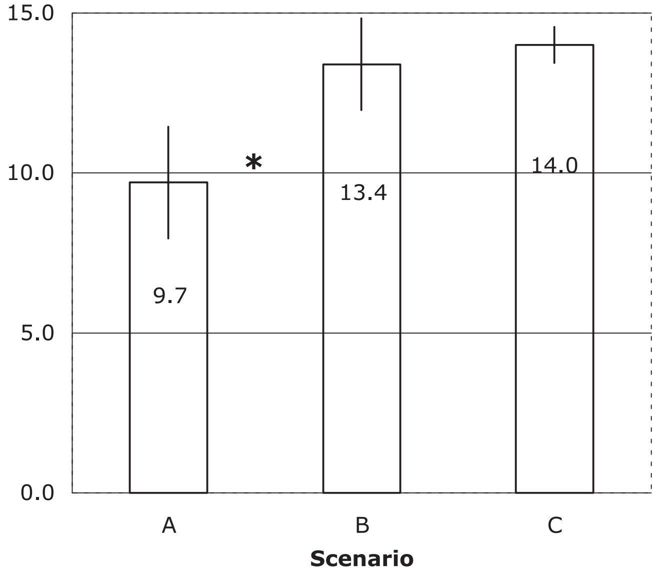

Figure 4. Average triage score per learner (maximum = 15). Lines and numbers in bars are standard deviations (SDs). *p < 0.001. *y*-Axis label = triage score.

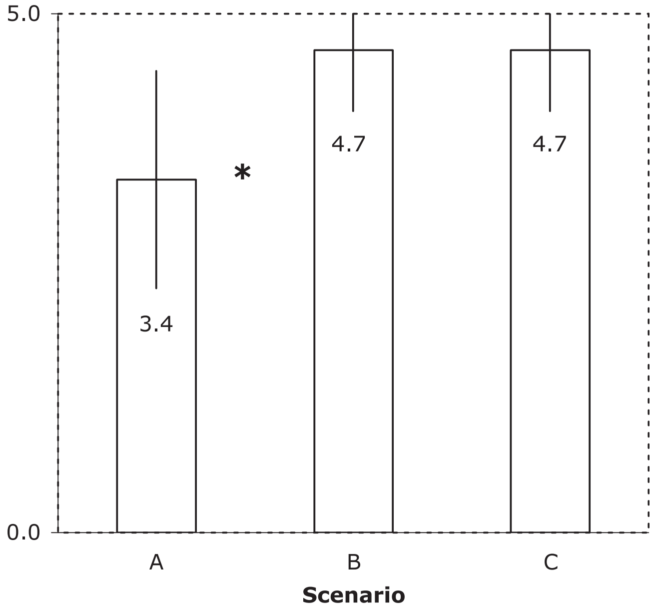

Figure 5. Average intervention score per learner (maximum = 5). Lines and numbers in bars are standard deviations (SDs). *p < 0.001. *y*-Axis label = intervention score.

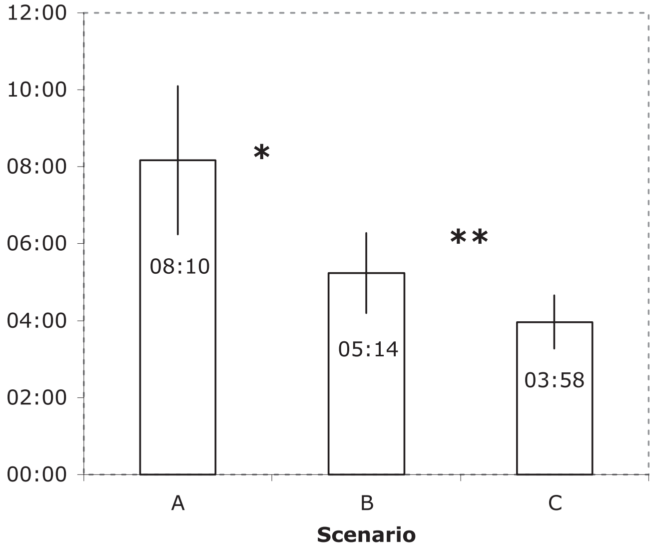

Figure 6. Time to triage one scenario consisting of five simulated patients. Line and numbers in the bars represent standard deviations (SDs). *p < 0.001, **p < 0.05. *y*-Axis label = time to triage.

DISCUSSION

We showed that novice learners improved their performance in the VR environment after two iterations of VR training, with triage and intervention scores improving significantly during the second scenario. Learners worked significantly faster with each new set of VR patients, with time to triage improving significantly with each additional scenario. Learners also reported increasing levels of self-confidence throughout the exercise. Students reported that they were more confident in prioritizing treatment, prioritizing resources,

Table 2
Evaluation of VR Triage Course

	VR Simulation
1. The material covered was relevant to my duties as a health care team member.	6.5 (0.61)
2. The course objectives were adequately explained.	6.3 (0.97)
3. The course was well organized.	6.5 (0.69)
4. The material was presented in an interesting way.	6.8 (0.55)
5. The course communicated the material effectively.	6.7 (0.59)
6. As the course progressed, my questions were answered.	6.8 (0.44)

Data are reported as mean (±SD). 7-point Likert scale: 1 = strongly disagree, 4 = neutral, 7 = strongly agree.
VR = virtual reality.

and identifying high-risk patients for treatment. They were also more confident that their patients would consider them an effective first responder. Self-efficacy has been shown to influence learner performance[10] and may also predict performance on objective structured clinical examinations.[11]

Our application is unique in its combined use of fully immersive VR, a gesture-based command system, and multiple simulated patients. Other computer-based training systems, such as the Virtual Medical Trainer,[12] MediSim,[13] and Sim-Patient[14] are partially immersive, menu-driven VR applications that display the simulation on a computer screen. BioSimMER[15] was an immersive emergency simulation relating to a biologic attack that used a HMD and simple motion gestures for navigation; development was discontinued 8 years ago, possibly due to the complexity and high cost of the technology in 1999. The JUST VR[16] system was designed to simulate training under stressful conditions and uses a rear a projection system in which a virtual assistant helps the user with navigation and tasks using natural language. Project TOUCH is an immersive VR application from which our current application was derived. Learners wear an HMD and use a joystick to navigate within a VR environment occupied by a single patient with head trauma. Interestingly, TOUCH investigators recently demonstrated that fully immersed students had a higher gain in knowledge structure than students who viewed a computer screen and used a mouse to diagnose and treat the simulated patient.[4]

LIMITATIONS

Students who volunteered may have been more technically sophisticated than nonvolunteers, resulting in better scores with additional VR exposure. Twenty-five percent of the subjects were students in their third or fourth year of medical school. Due to their clinical experience, they may not have been representative of most first responders and may have biased the results in favor of a greater training effect.

We introduced a new gesture-based command system for navigating in the VR environment. Some of the performance gains that students exhibited may have been due to increasing familiarity with the human/computer interface, rather than improvement in their triage knowledge structure.

We do not know the degree to which the improvements in triage and intervention scores, time to triage, and self-efficacy in this immersive VR environment correlate with other traditional methods of teaching triage such as manikin-based simulation. We also do not know how results in this immersive VR environment would compare to more traditional computer-based simulations that are partially or nonimmersive. In future studies, we plan to compare the performance of learners in a fully immersed VR environment with performance during a manikin-based simulation.

CONCLUSIONS

We conclude that principles of mass casualty triage can be effectively and efficiently taught to novice learners using an immersive three-dimensional VR training environment. Further studies would be valuable to determine how immersive VR training could complement or augment current mass casualty incident training methods.

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