Virtual Reality Triage Training Provides a Viable Solution for Disaster-preparedness

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Abstract

Objectives: The objective of this study was to compare the relative impact of two simulation-based methods for training emergency medicine (EM) residents in disaster triage using the Simple Triage and Rapid Treatment (START) algorithm, full-immersion virtual reality (VR), and standardized patient (SP) drill. Specifically, are there differences between the triage performances and posttest results of the two groups, and do both methods differentiate between learners of variable experience levels?

Methods: Fifteen Postgraduate Year 1 (PGY1) to PGY4 EM residents were randomly assigned to two groups: VR or SP. In the VR group, the learners were effectively surrounded by a virtual mass disaster environment projected on four walls, ceiling, and floor and performed triage by interacting with virtual patients in avatar form. The second group performed likewise in a live disaster drill using SP victims. Setting and patient presentations were identical between the two modalities. Resident performance of triage during the drills and knowledge of the START triage algorithm pre/post drill completion were assessed. Analyses included descriptive statistics and measures of association (effect size).

Results: The mean pretest scores were similar between the SP and VR groups. There were no significant differences between the triage performances of the VR and SP groups, but the data showed an effect in favor of the SP group performance on the posttest.

Conclusions: Virtual reality can provide a feasible alternative for training EM personnel in mass disaster triage, comparing favorably to SP drills. Virtual reality provides flexible, consistent, on-demand training options, using a stable, repeatable platform essential for the development of assessment protocols and performance standards.

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Disasters are inevitable, and when they occur, emergency medicine (EM) personnel must be able to respond rapidly and accurately. Preparing EM personnel for disasters is difficult because of the variability in the types of disasters and their locations; the emotional and physical stresses encountered when working in a potentially unstable or dangerous environment with many injured, disoriented, and panicking people; the limited available information about the victims for medical providers; and the challenges of providing training context to master and maintain infrequently required, but critical skills. Research in disaster medicine suggests that although no training can absolutely prepare EM clinicians to perform triage for a true mass casualty incident, familiarity with the process helps rescuer efficiency and comfort in performing triage tasks.[1–9] This is significant because properly performed triage is a determinant of survival for critically injured casualties.[10]

The basic concept of triage involves assessing the severity of injury and probability of survival for each casualty, placing the casualty into a triage category, and then providing appropriate care to the patients in each category or cohort. Knowledge of proper triage algorithms is an important skill for all first-responder and first-receiver clinical personnel who provide care to these patients. Although first-receiver personnel

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(physicians and trauma specialists) are typically not deployed to the scene of a mass casualty, there are several reasons why these triage skills are important to learn. First, in the event that the physician is in close proximity to the scene, she or he may ask or be asked to help in the triage process. Second, civilian bystanders, friends, or family members may bring victims to the hospital who have not been properly triaged at the scene. Third, first-hand experience in performing contextually based disaster triage provides a deeper understanding of the challenges faced by first-responders performing triage at the scene, which may provide a greater level of the mutual support that leads to increased interdisciplinary team effectiveness. Despite this need, recent mass casualty incidents substantiate that disaster triage is inconsistently performed, due in part to EM personnel who are unfamiliar with triage protocols.[11–13]

Simple Triage and Rapid Treatment (START) is the most commonly used of several mass casualty triage algorithms.[14] The intent of START is to assess and identify conditions that can lead to death if not treated within 1 hour[15] by prioritizing clinical markers of respiration, perfusion, and mental status to identify impaired breathing, severe hemorrhage, and head injury. The effectiveness of the START algorithm as an organizing framework for triage is fairly well supported;[16,17] however, optimal methods for training EM personnel in its use are ill-defined.

Teaching and assessing abilities in performing mass casualty triage are inherently challenging due to the inability to accurately replicate a given disaster environment in a comprehensive way, and the substantial requisite logistical coordination of numerous—and costly—personnel and resources. Disaster drills are the principal form of applied mass casualty training and are accomplished through the use of mock patients—either standardized patients (SPs) or mannequin-simulators—in a contrived ''disaster'' context. Although these drills have benefits,[18–20] they also have significant limitations: 1) they are costly ($35,000–$1,000,000); 2) they are resource-intensive for personnel, materials, equipment, and environmental factors; 3) concurrent assembly of required teachers and learners at a single time is enormously challenging (if not impossible); 4) there is no opportunity for ongoing or on-demand repetition of training; 5) training contexts are inconsistent; and 6) without a repeatable and consistent context, individual performance assessment and feedback is not possible.

Virtual reality (VR) is a well-established and valuable training platform for those rare applied contexts where high-level performance is critical, but difficult to rehearse, e.g., space, military, police, firefighting, and other hazardous or toxic situations.[21–24] In full-immersion VR, the individual wears eye-goggles that allow him or her to experience a normal enclosed space as an interactive environment that he or she can move through and engage elements within, as if doing so in real life. For those unacquainted with immersive VR, the closest reference is the ''holodeck'' from the popular *Star Trek: The Next Generation* series, which demonstrated the use of high-fidelity immersive VR. The environment can be designed and controlled through computer-generated settings that include space layout, furnishings, objects, people, and other contextual aspects such as fire, weather, explosions, etc. VR platforms have facilitated training in clinical medicine across multiple contexts,[25–28] including medical intervention in response to disasters[29] and application of triage abilities.[30,31] Not only can learners acquire, improve, and maintain skills over time within an emergency construct replicated through VR, their level of expertise can be differentiated as well. This makes the platform highly desirable for assessment purposes. However, for VR to be considered as a feasible platform for applied disaster-preparedness training, it must be demonstrated to be as good as, or better than, the current standard of training: the live disaster drill.

The purpose of this study was to determine if a fully immersive VR disaster drill is as effective as a comparable live disaster drill using SPs in teaching and assessing START triage knowledge and skills for EM residents. Specifically, we set out to answer the following research questions: (RQ1) To what degree do pretest scores correlate to START triage performance ratings? (RQ2) To what degree do the START triage performance ratings differ between the groups? (RQ3) To what degree do the posttest scores differ between the groups? And (RQ4) to what degree does performing the START triage activity affect the knowledge base of the participants?

METHODS

Study Design

This was a randomized trial of residents in a VR versus live disaster drill. Although the study was determined to have exempt status after institutional review board review, we obtained informed consent from all participants to assure that they were briefed about the training content, methods, and potentially stressful circumstances prior to engaging in the simulated mass disaster. Participating residents received one hour of conference credit and emergency medical services credit for participation in the disaster event, which is a graduation requirement of the residency program.

Study Setting and Population

We provided START triage training using either a VR or live disaster drill for a sample of 15 PGY 1–4 residents from the University of Michigan Emergency Medicine Residency Program. Participation was voluntary, and residents were only excluded from participation if they had previous training in START triage. We used stratified random assignment to the two independent treatment groups: SP group (SP, $n = 8$) and VR group ($n = 7$). We randomly assigned participants between the two groups. The distribution of residents by year is presented in Table 1.

The study was completed in the offices of the Department of Medical Education and in the VR ''CAVE'' at the University of Michigan. The CAVE is a full-immersion VR environment enclosed by four walls, floor, and ceiling to create a facsimile of ''reality'' using sophisticated three-dimensional computer-based imaging and interactivity. The CAVE is part of the 3-D Laboratory

Table 1
Participating Residents by Postgraduate Year

	Residents/Group Assignment	
PGY	SP	VR
1	1	2
2	2	2
3	4	1
4	1	2

PGY = postgraduate year; SP = standardized patient; VR = virtual reality.

affiliated with the School of Engineering at the University of Michigan.

Study Protocol

Prior to the simulated disaster drills, residents attended a 1-hour lecture about the principles of disaster triage and details that described the intent and application of the START algorithm to mass disaster events. After the lecture, each resident completed the pretest to assess the baseline level of cognitive knowledge about the objectives of disaster triage and the START algorithm specifically. After completing the pretest, each group was scheduled to come to either a simulated disaster drill with SPs or an identical drill using full-immersion VR.

Both simulated disaster scenarios involved an explosion that had taken place in an office building and included multiple diversely injured victims and casualties. The live disaster drill included SP victims who wore costumes and received cosmetically rendered wounds created by a professional movie make-up artist. For victims who were designated to be pulseless, a "no pulse" mark was placed on the wrists as a cue for the resident when he or she examined the patient. If a pulse was present, residents were required to verbally request respiratory and pulse rates (which were then provided by the faculty evaluator). The SPs were provided with a script to follow when responding and otherwise interacting with the triage physician.

To assure as direct a comparison to the SP method as possible, we created a VR environment that was an exact replica of that training context. The VR space included the same office layout, facilities, and furnishings and the same locations, personal characteristics, and injuries of the victims. The VR drill incorporated exactly the same scenario and identical scripts for the virtual patients as those for the SP drill. In the VR scenario, residents assessed respiratory rate by observing the virtual patients, but were required to verbally request a pulse rate (which was then provided by the faculty evaluator). Figure 1 depicts an example of the same simulated patient from both drills.

Each resident was responsible for triaging 14 victims during the disaster drill, without the support of reference materials. Each of their performances was monitored, timed, and assessed using the triage rating scale by one of the researchers who has advanced training in START (JF). Upon completion of the triage activity, each subject was provided with the results of his or her assessment and had the opportunity to ask questions during a debriefing with the rater (JF). Finally, the residents completed the posttest 2 weeks after the disaster drills to assess the level of knowledge retention after an intervening period.

Figure 1. Example of comparable SP and VR victims. SP = standardized patient; VR = virtual reality.

Measures

The independent variable for the study was group assignment with two levels (VR and SP). The dependent variables were pretest score, triage score, triage rating, and posttest score.

Pretest. The pretest included 24 multiple-choice questions covering multiple aspects associated with the START algorithm applied to a mass casualty. Questions included factual, conceptual, applied, and analytical levels of knowledge. For example, the question "RPM stands for:" tested factual knowledge of a relevant acronym, whereas the question "Triage of each disaster victim should take no more than:" tested conceptual knowledge about time relevance in performing triage. Questions such as "Acceptable airway maneuvers using the START algorithm include:" tested the ability to apply knowledge in context, whereas "Which patient should be categorized yellow (delayed treatment)?" tested the ability to conduct analysis. Only one correct answer was assigned to each question, and the sum total of correct responses provided the total performance score. The pretest results served to confirm equivalent baseline knowledge between the two groups prior to performing START triage training in the separate simulated contexts and also as baseline data to compare both triage scores and posttest results. The pretest is available from the corresponding author by request.

Triage Performance. We rated residents on their ability to ensure the safety of the scene, call for additional resources and personnel, determine the status of victims in a timely fashion, place victims in the appropriate triage category, and apply a visible, correctly labeled triage tag to each victim during their simulated drills. The triage assessment instrument consisted of a 32-item, 5-anchor-point rating scale with descriptive anchors related to task-based performance of the START algorithm. For example, the item "Assure scene is safe" included anchors for Not Done, Incomplete, Delayed, Adequate, and Comprehensive; while the item "Check respiration rate" included anchors for N/A, Needs Prompt w/ errors, Independent w/ minor errors, Independent w/o errors, Independent/Efficient w/o errors; and the item "Respond to outcome of respiration assessment" included anchors for Delayed, Inappropriate Treatment, Incorrect Assessment, Incorrect Category, and Well Done. Other items, such as "Time/patient ≤ 1 min" and "Write time on tag" included anchors for the number of patients successfully triaged: 0–2, 3–5, 6–8, 9–11, and 12. A space was available for comments to allow the evaluator to provide feedback to the participants about specific performance details. Ordinal values were assigned to the anchors relative to their indication of competence in performing the tasks associated with each item stem. For example, "0–2 patients" was assigned a value of 1, "3–5 patients" assigned a value of 2, "6–8 patients" assigned a value of 3, "9–11 patients" assigned a value of 4, and "12 patients" assigned a value of 5. The triage rating was calculated as the mean score of all items. Although the rating scale was explicitly derived from the START triage algorithm, five emergency physicians with expertise in START triage evaluated the scale to confirm its usability, accuracy, and completeness. The triage rating scale is available from the corresponding author by request. The total number of patients correctly triaged within the 1-minute time interval specified by the START algorithm value was used as the triage score.

Posttest. The posttest was composed of the same content as the pretest, but with the sequencing of questions and response options varied to control for potential test/retest effects. The posttest results provided data to assess the training impact of the drills, compared to the baseline pretest results to determine if either type of disaster drill had a differential impact on learning over the other.

Data Analysis

Our sample was quite small, and therefore we calculated measures of association (Cohen's *d*)[32] to supplement descriptive analyses of the data. Cohen's *d* is an appropriate effect size for the comparison between two means and can be readily calculated as the difference between the means divided by the pooled standard deviations (SDs). Effect size values of 0.2, 0.5, and 0.8 are considered small, medium, and large, respectively. We analyzed descriptive data (reported as mean ± SD), calculated effect size between the pretest scores of the two groups, and verified that they had equivalent baseline knowledge. The Pearson coefficient for bivariate correlation was computed with two-tailed significance ($p < 0.05$) to determine the relationship between the pretest scores and the triage performance ratings for both groups (RQ1). To determine differences between the groups on the triage performance ratings (RQ2) and the posttest scores (RQ3), we again analyzed descriptive data and calculated Cohen's *d* to support descriptive analyses. Effect size (Cohen's *d*) was also computed for both groups to determine the effect of the triage activity on participants' knowledge as measured by their pre- and posttest scores ($p < 0.05$) (RQ4). Although we confirmed acceptable normality of the distribution of pre-/posttest results and triage performance ratings by calculating homogeneity of variance statistics, we nonetheless encourage interpretation of the results as evidence supporting descriptive analyses of the variable relationships, not causal. Descriptive and correlation analyses were conducted using SPSS v. 16 (Chicago, IL), and effect sizes were calculated using Microsoft Excel v. 11.5.5 (Microsoft Corp., Redmond, WA).

RESULTS

The mean (±SD) pretest score of the SP group was 17.25 (±2.60) for 69% correct, compared to the mean for the VR group of 17.14 (±3.63) for 69% correct. We therefore determined that the groups had equivalent knowledge before completing the triage activities. Pretest scores for both groups significantly correlated to the triage performance ratings, confirming that the performance rating scale and knowledge test measured the same construct ($r = 0.75$, p = 0.01).

Table 2
Performance by Experience Level

Experience Level	Pretest	Triage Rating	Triage Correct	Posttest
PGY1 (interns)	14.33 ± 3.51	3.61 ± 0.33	11.33 ± 2.31	14.67 ± 1.53
PGY2	17.25 ± 2.63	3.24 ± 0.40	11.00 ± 1.63	18.00 ± 1.83
PGY3	18.40 ± 3.00	3.56 ± 0.26	11.60 ± 1.95	19.4 ± 2.70
PGY4	18.00 ± 3.00	3.66 ± 0.11	12.67 ± 1.16	18.33 ± 3.79

PGY = postgraduate year.
All scores are given as mean ±SD.

The mean (±SD) triage performance rating of the SP group was 3.47 (±0.41), compared to the mean for the VR group of 3.55 (±0.17), with a small effect (Cohen's $d = 0.25$) in favor of the VR group performance. Similarly, the mean total of correctly triaged patients from the SP group was 11.38 (±1.92) for 81% correct, compared to the mean for the VR group of 11.86 (± 1.57) for 85% correct, indicating a small effect (Cohen's $d = 0.27$) in favor of the VR group performance.

The data revealed a large effect (Cohen's $d = 0.63$) in favor of the SP group performance on the posttest, with the SP group mean score of 18.50 (±2.62) for 74% correct, compared to the VR group mean score of 16.71 (±3.04) for 67% correct. The difference between the pre- and posttest scores improved for the SP group, indicating that the drill had a medium effect on the participants' knowledge (Cohen's $d = 0.48$). Cohen's d calculation for the VR group did not reveal a comparable effect size.

The results by experience level are shown in Table 2. We did not perform an inferential statistical analysis due to the small sample size. This is especially apparent in the knowledge assessments, but also appears consistent in the application of the triage algorithm.

DISCUSSION

First-responder and first-receiver medical personnel are critical to securing efficient and effective care for injured victims of disasters. The use of algorithms such as START provides a framework to aid in the triage process, and training to acquire and maintain these triage skills is important for all EM clinical personnel. It is relatively straightforward to teach and assess knowledge of the START algorithm in a nondisaster context;[33–35] however, focusing solely on these knowledge components misses the vital mastery of associated skills and affective elements. Especially in a mass casualty environment, cognitive dissonance resulting from affective overload can interfere in the application of knowledge and skills. Cognitive dissonance refers to the psychological effects that occur when a person perceives a logical inconsistency among his/her cognitions and needs to accommodate new information to reconcile current beliefs and reality. In a disaster situation, the environment and scale of trauma may be unlike anything the physician has experienced or trained for, and that contradiction could lead to dissonance that manifests as anxiety, guilt, shame, anger, stress, and other negative emotions that adversely affect performance. Therefore, training associated with the development of mass disaster triage abilities is improved through applied contexts (e.g., mock disaster drills), rather than nonapplied contexts (e.g., classrooms, Web-based tutorials). Disaster drills that incorporate SPs and/or mannequin patient simulators are typically used for applied triage training, but high costs and challenges associated with logistical coordination prevent their routine use and when they are conducted, these drills principally target training of emergency medical technicians, not EM residents and physicians.

The advantages of VR drills over other alternatives are significant for both training and assessment. Immersive, repetitive practice in the content domain is a well-established method for mastering knowledge, skills, and affective control to the extent that they are less susceptible to external stressors leading to dissonance.[4–6,36–43] Additionally, VR supports the repeatability, consistency, and feasibility of routine on-demand training that allows learners to participate as needed. This stability provides a platform for the development of assessment and evaluation protocols that will lead to the establishment of performance criteria and standards.

The flexibility of VR encourages the development of broadly variable disaster contexts using software-generated modifications. That is, the office setting for the disaster scenario used for this study could be modified to include additional and/or different victims and/or an altered floor plan, or it could be modified such that the disaster setting is not an office explosion at all, but rather a subway explosion or more specifically a subway explosion at a particular subway location. In virtual space, it is easier to design and use variable disaster contexts to prepare EM personnel for differences and commonalities between events, as well as to customize training for areas where specific skills are likely required (tornados vs. tsunami, high-rise explosion vs. subterranean explosion, urban metropolis vs. remote village).

The results of our study and those of others[29–31] suggest that a carefully designed VR environment can provide a simulated disaster environment that is comparable to those created using SPs. The VR disaster drill did not have a differential impact on learning based on pre-/posttest analysis, and we found no significant difference between the triage performance of those clinicians who performed START during an SP disaster drill and those who performed START using a VR disaster drill. Although the costs associated with developing VR scenarios can be substantial ($20,000–$100,000), amortized over the number of potential learners, applications, and repeated scenario use, it provides a more cost-effective solution than live disaster drills. Overall, this suggests that VR can provide a realistic alternative for training EM personnel in the management of mass casualties, either independently or in conjunction with SP drills.

LIMITATIONS

The limitations of this study are principally associated with the size of the convenience sample. However, the design of the study was descriptive in nature, and therefore the results are intended to present the potential benefits of VR as a viable training alternative to SP training or no training at all. The results from the triage rating and the number of correctly triaged patients suggest that both the SP and the VR environments were complex enough to challenge the residents, while still performing to an acceptable standard. Given the limited amount of START training provided to the residents prior to participating in the disaster drills, we believe these average performance markers to be an accurate assessment of their knowledge and skills.

CONCLUSIONS

The results of our study suggest that a well-designed, full-immersion virtual reality environment for mass casualty training can provide similar learning outcomes to traditional standardized patient training. Virtual reality provides consistent on-demand training options, using a stable, repeatable platform essential for the development of assessment protocols and performance standards. Additionally, virtual reality flexibility facilitates the design of broadly variable disaster contexts using straightforward software-generated modifications. We encourage continued evaluation of these alternative training methodologies using larger and variable samples, including first-responder clinical personnel (emergency medical technicians, police, firefighters, etc.).

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