# Using Immersive Simulation for Training First Responders for Mass Casualty Incidents

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## Abstract

***Objectives:*** A descriptive study was performed to better understand the possible utility of immersive virtual reality simulation for training first responders in a mass casualty event.

***Methods:*** Utilizing a virtual reality cave automatic virtual environment (CAVE) and high-fidelity human patient simulator (HPS), a group of experts modeled a football stadium that experienced a terrorist explosion during a football game. Avatars (virtual patients) were developed by expert consensus that demonstrated a spectrum of injuries ranging from death to minor lacerations. A group of paramedics was assessed by observation for decisions made and action taken. A critical action checklist was created and used for direct observation and viewing videotaped recordings.

***Results:*** Of the 12 participants, only 35.7% identified the type of incident they encountered. None identified a secondary device that was easily visible. All participants were enthusiastic about the simulation and provided valuable comments and insights.

***Conclusions:*** Learner feedback and expert performance review suggests that immersive training in a virtual environment has the potential to be a powerful tool to train first responders for high-acuity, low-frequency events, such as a terrorist attack.

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Training is essential for effective disaster response.[1] However, training for high-acuity, low-frequency events provides great challenges for first responders.[2] The infrequent nature of such events leads to less collective experience and little empirical research.[3] The rehearsal necessary for knowledge retention is impeded by few practice opportunities. The high acuity makes realistic simulation extremely difficult, yet also mandates the very performance familiarity that the low frequency inhibits. Increasing the likelihood that appropriate decisions are made in the stress and chaos of the moment requires sophisticated training that goes beyond that of most first responders.[4,5]

The specific roles of first responders vary by department and professional training. Ideally, all first responders should have a basic knowledge of communication needs, triage techniques, and hazard identification. However, advanced medical training allows for better utilization of the high-fidelity mannequins and the acquisition of more complex data.

Postevent analyses suggest recurring failures that even very senior emergency responders commit despite years of experience and high levels of traditional training.[6–13] Some of these errors have potentially significant medical implications. These include, but are not limited to:

1. Failures in adhering to triage protocols, including avoiding overtreatment/secondary management and appropriate resource requests and allocation.[13–16]
2. Poor intraagency, interagency, and scene-to-hospital communications, including failures in information management, communication of safety information, and a lack of patient tracking.[1,13,14,17–20]
3. Failure to recognize both static and dynamic hazards including unstable structures, chemical and biological threats, and secondary explosive devices.[13,14,21]

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The specter of additional terrorist incidents has resulted in numerous efforts to prepare the public health infrastructure and first responders for such eventualities. Lectures, journal articles, table-top exercises, and Web-based programs are among the educational efforts that have been developed to convey information to key personnel. Unfortunately, it has been consistently demonstrated that the possession of ''book knowledge'' does not necessarily translate into application of that knowledge in practice.[17] While disaster drills represent the current ''criterion standard'' in preparation for a wide array of first responders, health care providers, and public health officials, they are limited by several factors. Realism and fidelity, particularly of medical situations, are very difficult to achieve. This is concerning given the importance of abnormal vital signs in all major triage algorithms.[22] Drills can be extremely expensive, often in the hundreds of thousands of dollars.[20,23] The active participation in the drill is usually only a few hours. Mechanisms for prompt feedback for individual participants are often not in place. After-action reports can take months to prepare and are usually aimed toward departmentwide problems. Specific first responders may receive only minimal evaluation. Because of their cost and complexity, drills offer little opportunity for repetitive skill rehearsal. Finally, it is impossible to have all department personnel participate in a single drill, due to everyday duty requirements, sick leave, and circadian patterns in overnight workers.

High-fidelity simulation has the potential to overcome many of the limitations of disaster drills. Simulation technology currently plays a major role in the training of pilots and military personnel. In these settings, simulation has successfully been used to train individuals for a wide range of situations, including potential catastrophes.[24,25] In medical training, simulation technology is increasingly used to train for procedures and to train for acute emergent situations.[18,24,26] The emphasis with simulation-based training is learning how to accurately assess the situation and apply knowledge integrated with psychomotor skills. In addition, simulation training allows the instructor to provide feedback and repeatedly observe the student working through the problem. If properly designed and applied, simulation training provides trainees the opportunity to deliberately practice and develop their skills.[14,19,20]

In this study, we explored the utility of immersive virtual reality simulation for training first responders in a terrorism disaster scenario. We were particularly interested in the following questions:

1. Does immersive virtual reality simulation technology provide a realistic training challenge for even highly experienced first responders?
2. Do first responders find the simulation to be believable and convincing? Does it induce stress and anxiety similar to real situations the providers had experienced previously?
3. Do participants consider immersive virtual reality simulation to be a useful adjunct to their prior, traditional training?
4. Does expert review of learner performance identify areas of performance that need improvement?

## METHODS

### Study Design

This was a descriptive study utilizing virtual reality and high-fidelity patient simulators to explore the possibilities of immersive virtual reality simulation for training first responders. The protocol was approved by our institutional review board. Each of the subjects provided informed consent prior to participation.

### Study Setting and Population

To optimize the value of our study, we enlisted paramedics for the formal assessment of our training scenario. Many of the participants had additional applicable experience, such as training in START,[27] or other specific rapid triage methods typically used in mass casualty protocols.

### Study Protocol

***Simulation Technology.*** The technologic base for this study was a high-resolution, cave automatic virtual environment (CAVE)[28] integrated with a high-fidelity human patient simulator (HPS) that was programmed to portray a wide range of human conditions. The CAVE (Figure 1) is currently the most advanced system for immersive virtual reality. The CAVE generates the illusion of immersion by projecting stereo images on the walls and the floor of a room-sized cube. It provides its users with the convincing illusion of being fully immersed in a three-dimensional world that is computer-generated. The immersive experience includes unrestricted navigation (look-around, walk-around, and fly-around), interaction with virtual objects and physical objects placed in the environment, and enhancement through directional sound.

The users entering the CAVE wear lightweight liquid crystal display (LCD) shutter glasses for stereoscopic viewing. To create the stereo effect, the images for the left and the right eye are projected in a rapid, alternating sequence. The LCD shutter glasses alternately block the right and the left eye in synchronization with the projection sequence. The CAVE installation at the University of Michigan uses three walls and the floor as projection screens. The floor projection allows three-dimensional objects to appear inside the CAVE, thereby confronting the user in a convincing way. The images are generated for the position of the viewer using a motion tracker that continuously measures the position and orientation of his or her head. These measurements are processed by rendering algorithms that calculate and adjust the projected images in real time as the viewer moves about. The CAVE operates in ''see-through'' mode, and users can see physical objects, like their own hands, other participants, or equipment brought into the CAVE. Applications can integrate physical objects into the virtual environment. In this study, a Laerdal (Laerdal Inc., Wappingers Falls, NY) SimMan HPS was placed inside the CAVE and integrated into the virtual world. Incorporation of the HPS allowed for haptic interaction and greatly increases the demands on the subjects. For example, while most drills use supplied written patient vital signs, our subjects were forced to manually assess each victim for

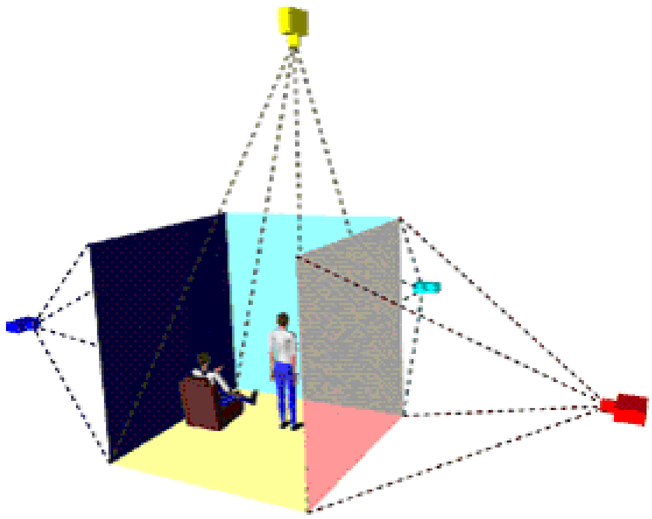

**Figure 1.** Virtual reality cave automatic virtual environment (CAVE).

any information. All treatments, such as basic airway maneuvers, were also demonstrated, not simply verbalized.

Fifteen active paramedics were enrolled in the study, all with at least 4 years of experience. Paramedics were asked to arrive in their ''turn-out'' gear involving boots, jackets, and protective equipment.

***Scenario Development.*** Scenario development was done by the project team, which included a senior emergency medicine (EM) attending physician and an EM chief resident. Both have substantial additional experience in disaster response, tactical EM, fire/rescue/emergency medical services (EMS) operations, and out-of-hospital education. ''Best-practice'' techniques for first-responder triage, communication responses, decision-making, and actions were drawn from the core literature by the emergency physicians on the team.[29–31] Critical actions, such as assessing every victim, were defined by the physicians, with additional input provided by representatives from law enforcement, fire, and EMS.

A scenario was developed of a terrorist explosion at a sporting event. In collaboration with the University of Michigan Department of Public Safety, locations of interest for a disaster scenario were identified. A concession stand at the Michigan Football Stadium was selected as the disaster site. The photographs, along with blueprints, existing computer-aided design (CAD) models, and other tools were used to assist with geometric modeling of the disaster site. In addition, levels of detail were applied to obtain different accuracy levels of the concession stand from different viewpoints. Texture maps were derived from the photographs to reduce the concession stand model's complexity while creating realistic appearances. The site of the disaster was programmed to the level of the actual bricks, fences, and other physical objects that would be encountered.

A library of 12 virtual humans, or avatars, was developed with injuries ranging in severity from minor lacerations to fatal wounds and burns. Each avatar placed in the virtual disaster site consists of a texture-mapped polygon mesh and is either static or dynamically animated. For each avatar, photographs of an actual individual's injuries were used to create the texture maps. Depending on the placement of the avatars and their distance from the user, they are modeled as flat outlines (two-dimensional characters) or three-dimensional full-sized virtual humans. A scripted timeline of vital signs, level of consciousness, and response to action or inaction on the part of the first responder was developed for each of the avatars. An HPS was programmed with the appropriate physical findings and vital signs to match the critically injured avatars. The avatars had a physical reaction, not audible. A verbal response was transmitted by the person operating the high-fidelity simulator. As the first responder moved to one of the victims, the victim's image was overlaid on the human patient simulator and the first responder was required to assess vital signs and query the HPS as part of the triage and decision-making process. The vital signs changed with time to reflect progression of injury. A patient assessed early in the scenario could have had more reassuring vitals than if that patient was reached 15 minutes later. The scenario for the data we report included two fatalities (massive head trauma and acute myocardial infarction), three emergent victims (airway-threatening facial burns, massive arterial laceration, and tension pneumothorax), three urgent victims (multiple burns, penetrating eye laceration, and massive hand trauma), and various nonemergent victims ranging from minor lacerations to psychiatric complaints. The scripting program allowed sounds to be attached to sound sources, such as background sounds, explosions, screaming, crying, ambulances, and fire engines, to add stress and fidelity. Time marks in each scenario defined when movement or sound effects took place and allowed the team to later evaluate specific aspects of the first responders' decision-making and reactions. The scenario was scripted for 20 minutes of interactive training.

***Procedures.*** Participants were given a detailed orientation to the CAVE and the objectives of the scenario. Participants were asked to think out loud. Once in the training situation, first responder performance was assessed by observing verbal statements (e.g., commands) and actions taken using the checklist (see Figure 2). Each provider's actions were compared against the predefined checklist of decisions. Each provider was video-recorded as he or she responded to the scenario. The recordings were made from the rear of the CAVE, which provided a full view of actions taken by the participants, as well as the VR environment in which the participants were working. These recordings were used in the evaluation of their performance to prevent recall bias on the part of observers. Upon completion of the scenario, each participant participated in a structured interview conducted by the same member of the research team (LDG; see Table 2). This interview probed participants' general reactions as well as their assessments of realism, usability, and other aspects of the training scenario. All interviews were audio-recorded and transcribed for analysis. Common themes

**Time Action**

_____ First radio contact.

_____ Type of incident identified. Cue required? (Y/N)
Incident reported as
__________________________________________.

_____ Scene safety inquiry from dispatch? (Y/N)

_____ Scene safety survey? (Y/N)

_____ Request for additional resources. Cue from dispatcher required? (Y/N)
Police? (Y/N) Cue? (Y/N)
Fire? (Y/N) Cue? (Y/N)
EMS? (Y/N) Cue? (Y/N

_____ Approximate number of victims identified? (Y/N) Cue required? (Y/N)
- Number of victims estimated as _______.

_____ Number of ambulances requested. _____ Appropriate? (within +/- 5) (Y/N).

_____ Crowd control needs identified? (Y/N) Plan communicated to dispatch? (Y / N)

_____ Staging Area/Approach communicated? (Y/N) Cue required? (Y/N). Effective Choice? (Y/N).

_____ Triage area identified? (Y/N) Cue required? (Y/N) Effective Choice? (Y/N).

_____ Hospitals Disaster Notification Requested? (Y/N)

_____ Unstable structure presented on screen.

_____ Hazard identified? (Y/N) ______Hazard communicated? (Y/N)

_____ Secondary device presented on screen.

_____ Secondary device identified? ______Secondary device communicated?

_____ Contact with first victim.

_____ Time spent with Victim 1 - Triage Category B / R / Y / G. Actual Category _____
Assigned correctly (Y / N) Comments ______________________________.

*(This evaluation was repeated for each victim. Victims not approached/triaged were graded as "incorrect")*

______ Total triage time ______.

______ Attempt to separate walking wounded? (Y/N)

______ Bystanders employed? (Y/N)

______ Return to most critical victim once triage is complete? (Y/N)

**Figure 2.** Checklist.

in the interviews were identified by one member of the research team (LDG) and reviewed by other members. Disagreements were reconciled through discussion. To prevent bias, subjects were not aware of their evaluation scores before debriefing data were collected.

### Data Analysis

Most data were dichotomized into "done" or "not done." Complex tasks where a specific action could be performed with variable effectiveness were further divided into "done well" or "needs improvement." The decision to assign each category was made by consensus using predefined criteria. For example, if the number of patients estimated or ambulances requested was less than half or greater than double the actual number, "needs improvement" was assigned. The consensus committee consisted of a senior attending physician with extensive experience in disaster and tactical medicine and a senior EM resident with EMS experience.

## RESULTS

Table 1 summarizes the performance of the participants on several critical actions related to this scenario. Approximately one-third of the participants adequately identified the nature of the incident to the dispatcher when first entering the stadium, and only one participant made an explicit scene safety inquiry and survey. One person confirmed that there were victims, but did not confirm the incident as appearing to result from an explosion. The majority of the participants correctly requested additional EMS resources, but few requested additional police presence or fire support.

A majority of the participants assessed the number of victims, but 50% failed to provide this information to dispatch. Similarly, many failed to request a specific number of ambulances to assist at the scene. None of the participants provided for crowd control or requested assistance for that purpose.

Most of the participants provided some communication about the location of staging and approach to the site, and a majority also identified a triage site. However, many of the participants chose a logistically poor site, and specifics of how to find the scene or triage area were often vague. Of those who identified a staging approach, more than half chose to have staging personnel approach from a parking lot separated by 20 stairs (the approach they came up with) rather than from a different lot on flat ground. Only 14.3% requested that the local hospital be notified of the incident. Half of the participants made use of bystanders to aid in their response or treatment, and almost all attempted to separate the walking wounded from the more seriously injured victims.

While immersed in the disaster scenario, none of the participants took note of the secondary explosive device, even though it was lying on the ground in plain sight. One subject did mention that a secondary device should be considered but then was distracted by the demands of the victims and did not survey the disaster scene for such a device. Only one participant took into account that the severely damaged, swaying metal concession stand roof could collapse and cause additional harm. All participants went under this compromised structure to attend to victims.

Of the 12 possible victims in the scenario, all participants made contact with at least 7, but only 6 participants made contact with all 12 victims. While many of the missed victims were walking wounded, several providers failed to assess urgent or even emergent patients. Of the 139 individual triage decisions that this group of first responders made, 41.7% were correct from the standpoint of the appropriate status of the simulated victim; 46.8% were ambiguous, often because the participant did not make a clear verbal statement as to the classification; and 11.5% were clearly incorrect. While every participant had been trained at some point on a system for triage, only one actually formally triaged every patient. Most of the paramedics used mental status and the apparent nature of the injury to assign triage categories. Pulse rate was checked on some patients, but respiratory rate was rarely assessed. Strikingly, many patients were triaged based solely on position—patients that were standing were triaged "green" while those seated or supine were triaged "yellow."

### Postencounter Interview Results

There were a number of common themes that emerged in the debriefing interviews. One concern of the research team was the time needed to orient the trainees to the simulation scenario. If this was too high, the feasibility of the simulator as a training tool would be

Table 1
Critical Incidents in the Disaster Scenario and Distribution of Responses by the Participants

| Action | Done Well | Needs Improvement | Not Done |
|---|---|---|---|
| Type of incident identified | 5 (37.5) | 1 (7.1) | 8 (57.1) |
| Scene safety inquiry | 1 (7.1) | — | 13 (92.9) |
| Scene safety survey | 1 (7.1) | — | 13 (92.9) |
| Requested additional resources | | | |
| Police | 3 (21.4) | — | 11 (78.6) |
| Fire | 4 (14.2) | — | 10 (71.4) |
| EMS | 10 (71.4) | — | 4 (14.2) |
| Estimated number of victims | 6 (42.9) | 2 (14.3) | 6 (42.9) |
| Number of ambulances requested | 6 (42.9) | 1 (7.1) | 7 (50.0) |
| Requests/provides for crowd control | 0 (0) | — | 14 (100) |
| Staging/approach communicated | 4 (30.8) | 5 (35.7) | 5 (25.7) |
| Triage area identified | 7 (50.0) | 1 (7.1) | 6 (42.9) |
| Hospitals notified | 2 (14.3) | — | 12 (85.7) |
| Hazard identified and communicated | 1 (7.1) | — | 13 (92.9) |
| Secondary device identified and communicated | 0 (0) | — | 14 (100) |
| Attempts to separate walking wounded | 13 (92.9) | — | 1 (7.1) |
| Bystanders employed | 7 (50.0) | — | 7 (50.0) |
| Returned to most critical victim once triage complete | 6 (42.9) | — | 8 (57.1) |

Data are reported as *n* (%). One case was lost due to audio recording malfunctions.
EMS = emergency medical services.

seriously limited. All participants agreed that the 10- to 15-minute orientation to navigation and interaction with the virtual reality environment was completely adequate. There was consensus that with less than 5 minutes in the CAVE environment, they were comfortable with it and could focus on the decision-making tasks demanded by the scenario. The subjects found the translation of the virtual reality images of injured victims projected on the human patient simulator effective. One firefighter/paramedic noted, "It's not often you walk up to a scene and your heart sinks, going 'Wow.' This actually gets you in there. Your heart starts beating a little faster. It's excellent. I don't see many things you haven't touched on or covered." This comment reflects the acknowledgment of several participants that the reality of the simulation raised their anxiety levels quite dramatically, which in turn contributed to the intensity of their experience.

Table 2
Questions Used in the Structured Interviews for All Participants

1. What is your evaluation of the scenario you just participated in?
2. Summarize what you thought was going on in the situation.
3. Describe your goals and plans for responding to the situation. What were your priorities?
4. What aspects of the simulation did you find most realistic? (suggestions for making it more so)
5. What aspects of it did you find most confusing or distracting?
6. What was missing from the scenario that you expected to see/hear/do? What would you have done in reality that you didn't/couldn't do in the simulation?
7. Was the orientation to the CAVE and simulation sufficient? What should be added or deleted?

For the paramedics, the interaction with the HPS was more difficult than anticipated. Assessing for vital signs, asymmetrical breath sounds, and basic examination maneuvers were complicated by the noise, radio distractions, and competing demands at the scene. Some of the participants became involved with trying to determine how to treat the myocardial infarction fatality, as there was no obvious trauma, even though they could find no pulse, pressure, or respirations, rather than triaging the victim "expectant" and moving to others.[32,33]

An important contribution to the reality of the simulation was the presence of background sounds (initial explosion, sirens, crowd noise) and the interactions via two-way radio with a live, simulated dispatcher. All of the participants noted that the chaos and distraction provided by the noise, and the need to both interact with the "dispatcher" and filter the radio traffic characteristic of such situations led to task and stimulation overload, which replicates what they face in a real disaster situation. One participant commented, "You've got the sirens in the background, the radio traffic distracting you and pulling you away from the task at hand. That sensory overload is really good."

One interesting response during the debriefings was the claim that they had thought about the possibility of a secondary device even though none had actually seen it. Only one paramedic verbalized it during the training experience. All were distracted by the urgency of making and facilitating triage decisions.

Overall, participants were very enthusiastic about the simulation and provided valuable comments and insight. As expressed by one of the paramedics, "From a triage standpoint, it's the best experience I've ever had, other than an actual mass casualty . . . . You get new people on that (CAVE) a couple of times and you're going to really feel experienced." The trainees uniformly thought that they could never train enough for mass casualty incidents and suggested that this is something that should be done frequently, up to once a month. When asked about the value of the scenario, there was almost universal agreement that it required them to "stretch" their skills and problem-solving abilities.

Many participants suggested that one of the most important potential benefits of this technology was the opportunity to repeatedly enter the scenario and repeat the interaction, particularly with the addition of variations in the simulation (different injuries, different victim locations, different levels of support from other personnel, etc.). They would allow the opportunity to consolidate correct responses by repeatedly running through variations of the scenario.

The trainees also felt that additional settings would be very valuable, such as motor vehicle crashes, mass transportation accidents, and urban structural incidents. However, the briefings also pointed out weaknesses. Entering the virtual world, some participants experienced initial motion sickness as they acclimated to the shutter glasses and the intense three-dimensional impact of the simulation. Regarding the disaster scenario, the reality is that dozens of people from the crowd would want to assist. Bystander and crowd control would have been a significant problem. Additionally, different victims, especially those with relatively minor injuries, would have likely been demanding attention, further complicating the responder's efforts.

## DISCUSSION

Based on the performance of the participants in this scenario and the responses to the structured, postencounter interview questions, immersive training in a CAVE environment has the potential to provide a previously unavailable realism and level of involvement, while simultaneously allowing for the individual feedback and rehearsal necessary for learning and retention. During the debriefing, a recurring theme was the realism that the background noise, chaos, and radio traffic provided. This replicates what is faced in a real disaster situation. The opportunity to experience this chaos, make mistakes, have the mistakes identified, and then go through the scenario again is a major strength of this training technology compared to other training modalities these individuals had experienced. Indeed, in most multiple casualty drills conducted with actors and moulage, a major drawback is the inability to run through the training exercise repeatedly until correct behaviors are learned.

One example is the failure to recognize the danger of collapse posed by the metal roof. A parallel situation occurred in the aftermath of the September 11, 2001, attacks, when emergency personnel established command centers at the World Trade Center and moved these centers repeatedly, only to be killed when the buildings collapsed. Similarly, if the first responders had found the secondary device, the scenario would have taken a different direction and the responder would have moved victims away from the possible second explosion. Scene safety is a part of all paramedic training, so they have all been exposed to the concept. In a realistic and stressful situation, they were unable to translate this knowledge into consistent action. This, of course, is not unexpected. The importance of practical as opposed to didactic training is the impetus behind not just simulation training, but professional training in general. The opportunity to repeatedly practice putting their knowledge into action is a critical need of our first responders. High-fidelity simulation in an immersive virtual reality environment is a compelling way to meet this need.

It was noted that none of the participants in the study provided for crowd control. This may reflect the simulated nature of the crowd and the fact that the simulated victims generally stayed in one place. Also, the simulation did not include a crowd of bystanders who might interfere with the participant's responses.

The remarkable flexibility of the virtual environment should also be emphasized. With minimal programming effort, avatars can be switched, creating countless scenarios. Special avatars representing victims of unique hazards, such as chemical weapons, can be developed and added. Finally, scenarios can be easily scripted to emphasize specific skills, such as radio communications or describing scenes. This application is particularly salient as remote command becomes adopted in more incidents. As noted, most participants criticized the minimal response on the part of the simulated bystanders to the participants' actions or commands, as they would expect many demands for attention from the crowd in actual disasters. More dynamic and interactive avatars are being developed and implemented, but these interactions will add significantly to the complexity of the simulation and might well further degrade the initial performances of the trainees.

Virtual reality CAVE training has often been compared to going through the exercise on a flat screen computer model. In terms of effectiveness and cost to develop, distribute, and execute as a training paradigm, a computer module would be much cheaper, but it would not be as realistic, nor raise the level of stress in the participant.

## LIMITATIONS

The lack of a control or comparison group leaves open the question of the relative benefit of immersive simulation technology versus another modality. The numbers of participants are also relatively small, although the difficulty of recruiting, compensating, and scheduling these participants needs to be acknowledged as a constraint on obtaining a larger sample size. The developmental character of this intervention also limits the conclusions one can make about generalizability to other populations or situations. However, as a formative evaluation of the methodology and simulation content, this study provides useful information for subsequent development and refinement of advanced technology methods for training first responders.

## CONCLUSIONS

Immersive training in a virtual reality environment seems to be a powerful tool for training first responders for high-acuity, low-frequency events. This study suggests that it may be a valuable adjunct to other modalities of training. The errors committed by our subjects have repeatedly been identified in postevent reviews.[33] While the subjects knew what should be done and can readily identify appropriate actions in a classroom or other relatively less stressful exercise, once immersed in the chaos of a high-fidelity disaster scenario, these errors are again committed. Perhaps through training, such as offered in an immersive environment, skills necessary to avoid such errors can be learned.

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