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CONCEPTS

Disaster Medicine

First Responder Virtual Reality Simulator to train and assess emergency personnel for mass casualty response

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Abstract

As mass casualty incidents continue to escalate in the United States, we must improve frontline responder performance to increase the odds of victim survival. In this article, we describe the First Responder Virtual Reality Simulator, a high-fidelity, fully immersive, automated, programmable virtual reality (VR) simulation designed to train frontline responders to treat and triage victims of mass casualty incidents. First responder trainees don a wireless VR head-mounted display linked to a compatible desktop computer. Trainees see and hear autonomous, interactive victims who are programmed to simulate individuals with injuries consistent with an explosion in an underground space. Armed with a virtual medical kit, responders are tasked with triaging and treating the victims on the scene. The VR environment can be made more challenging by increasing the environmental chaos, adding patients, or increasing the acuity of patient injuries. The VR platform tracks and records their performance as they navigate the disaster scene. Output from the system provides feedback to participants on their performance. Eventually, we hope that the First Responder system will serve both as an effective replacement for expensive conventional training methods as well as a safe and efficient platform for research on current triage protocols.

KEYWORDS
disaster planning, education, educational measurement, emergency medical services, professional competence, transportation of patients, triage

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1 | INTRODUCTION

Mass casualty events from both natural and man-made disasters are on the rise in the United States.[1,2] These mass casualty events create surges of victims that overwhelm healthcare systems, leading to the preventable loss of human lives. Averting surges that jeopardize the emergent care of victims requires a workforce of emergency personnel who are well trained in the fundamentals of disaster response,[3] including targeted hemorrhage control, swift extrication, minimal interventions, and immediate transport to the appropriate receiving centers.[4–8]

Conventional training of first responders for mass casualty events involves 1 of 3 methods: (1) live, large-scale simulations of mass casualty incidents (MCIs) that use manikins and actors cast in a temporary setting[9,10]; (2) table-top drills that resemble board games[11]; and (3) lectures or presentations on mass casualty response, sometimes followed by facilitated discussions about treating specific patient victims.[12] The large-scale simulations are the most realistic and effective but are resource heavy, expensive to construct, available for a limited time (usually 1 day), and are overly reliant on human evaluators to assess participants. Table-top exercises contribute to improving command-and-control systems, communication, and coordination, but they are less effective in teaching and assessing the knowledge and skills about triage needed by frontline first responders. Paper cases after a lecture or presentation suffer a similar fate of table-top exercises. They do not cover the mechanics of the tasks required for triage and treatment. Furthermore, these cases are static and do not involve dynamic changes in patient status attributed to bleeding or worsening mental status, which are real challenges in these scenarios. All 3 are unable to provide the opportunities for sustained practice needed to master the tasks associated with the successful triage and treatment of victims of a mass casualty.

Learning specific triage algorithms such as sort, assess, lifesaving interventions, treatment, and/or transport (SALT) is necessary but not sufficient for effectively confronting a mass casualty scene.[13] Distractions and disruptions in the form of chaos prevent first responders from being able to cognitively process the scenario to properly execute triage algorithms.

Mastery learning, a form of competency-based training, is becoming the standard for procedures education in medicine.[14–16] Mastery learning involves 5 steps, 1 of which involves deliberate practice of a skill-based procedure accompanied by performance feedback from an expert.[14] For first responders to master the skills of triaging and treating the scene of an MCI, they must be provided the resources to practice until they reach a predetermined and acceptable standard of performance. Deliberate practice requires time and resources and is therefore logistically challenging to provide using conventional triage training methods.

Because it provides learners with the ability to practice in environments that more closely mimic real-life situations, virtual reality (VR) provides a superior approach for simulating complex scenarios such as MCIs.[17–19] VR systems are reusable and portable, and once developed they can be cost-effective in comparison to conventional training methods.[10,20] They can be designed to include automated, unbiased assessment of the trainee's performance, provide real-time feedback, and be customized to provide variable levels of difficulty or interchangeable scenarios.

Our purpose is to describe a VR system that we designed for training medical students, residents, fellows, and paramedics in the skills needed to respond to an MCI. We focus on the virtual patients, who are completely interactive and autonomous, and have been designed to behave realistically as a result of their assigned injuries. We also share our initial experiences and observations with using this new system.

2 | METHODS OF DEVELOPMENT

First Responder is a high-fidelity, fully immersive, automated, and programmable VR simulation of a terrorist bombing of an underground subway station. The system was designed to train individuals from the disciplines of emergency medicine, paramedicine, and emergency medical services (technicians). Trainees from these fields enter the virtual MCI scene and use the VR head-mounted display and hand-held controllers to navigate the subway station and grab tools from the virtual medical kit to assess, triage, and treat the injured victims (Figures 1 and 2). Trainees can implement various lifesaving interventions (LSIs), including opening the airway of someone who is struggling to breathe, controlling major hemorrhage with a tourniquet or wound packing, decompressing the chest of a victim who is suffering from tension pneumothorax with a needle, or using an autoinjector to administer an antidote to individuals suffering from chemical exposure. Because this initial First Responder scenario involved the setting of a subway station in which an explosion had occurred, injuries suffered by the virtual patients are consistent with those commonly suffered by individuals exposed to an explosion. Subsequently, we did not include the autoinjector or victims of chemical exposure in this scenario.

We designed First Responder to work most effectively with SALT triage, a protocol proposed by a Centers for Disease Control and Prevention–sponsored working group to standardize triage methods (Figure 3). SALT is evidence informed and endorsed by the American College of Emergency Physicians, American College of Surgeons Committee on Trauma, American Trauma Society, National Association of EMS Physicians, National Disaster Life Support Education Consortium, and State and Territorial Injury Prevention Directors Association.[13,21] SALT has several advantages over other protocols. First, it can be applied to both pediatric and adult casualties. Second, it saves time through the use of voice commands to perform an initial global sort. Third, it eliminates the requirement of having to count respirations or check capillary refill, which are challenging tasks in chaotic environments. Finally, SALT allows for LSIs such as tourniquets to be applied more quickly. As quoted from the Second Hartford Consensus, "No one should die from uncontrolled bleeding."[22]

When implementing SALT, first responders use 2 voice commands to sort patients into categories related to treatment. The trainee first asks those able to walk to assemble in a safe area. These individuals are likely to be minimal (green-tagged) victims suffering from only

FIGURE 1 Mixed-reality image of a first responder trainee treating a virtual patient in the First Responder mass casualty virtual reality environment.

FIGURE 2 Medical toolkit and tools available to first responder trainees while in the First Responder Virtual Reality Simulator. The sort, assess, lifesaving interventions, treatment, and/or transport algorithm also calls for an autoinjector in the medical kit to be used with chemical exposure victims. The autoinjector was omitted from the kit in this scenario because it was not needed.

minor injuries. Next, the responder asks the remaining victims to wave their arms. These individuals will need further assessment but may not have an obvious life-threatening injury. After the global sort, first responders assess and treat individual victims in order of unresponsive, wavers, and then walkers, providing LSIs to the most vulnerable and applying triage tags to communicate the victim's priority for transport to fully resourced emergency departments (Figure 3).

The project was a collaboration between specialists from the digital arts and sciences, emergency and disaster medicine, and performance assessment. Disaster medicine experts modeled the mass casualty cases for our simulation after terrorist attacks that occurred in Paris and Brussels between November 2015 and March 2016.[7,23] Video game development experts used Unity Pro (Unity Technologies), a software platform for developing video games with 3-dimensional graphics.[24] Graphics artists generated the graphical representations of most of the components of the virtual scene, including the subway platform and the subway train car as it appears before and after the explosion. The environment is enhanced by dynamic visual effects, such as lighting, smoke, and scattered debris, and audio effects, such as sirens and the sound of general chaos. Voice actors designed and recorded audio clips for the interactive patient voices. Performance capture actors were used to model the poses and movements of the virtual patients. The scoring and assessment capabilities of the system were developed in collaboration with a psychometrician to identify the critical actions to be documented during the simulation.

The simulation runs on any modern VR-ready desktop or laptop computer with a capable graphics card. The simulation can be wirelessly streamed to a VR headset such as the Meta Quest (from Meta, formerly Facebook Reality Labs, Menlo Park, CA) or HTC Vive Pro (High Tech Computer (HTC) Corporation, Taoyuan City, Taiwan) so that trainees are free to move about the simulated environment untethered to a computer.[25,26] Alternatively, high-end systems such as the Varjo XR-3 (Varjo Technologies, Helsinki, Finland) can be used to fully realize the high-fidelity features of First Responder.[27]

During the development of First Responder, we recognized and intended to improve on the work of others in this space.[28–35] The next sections describe the key features of our system.

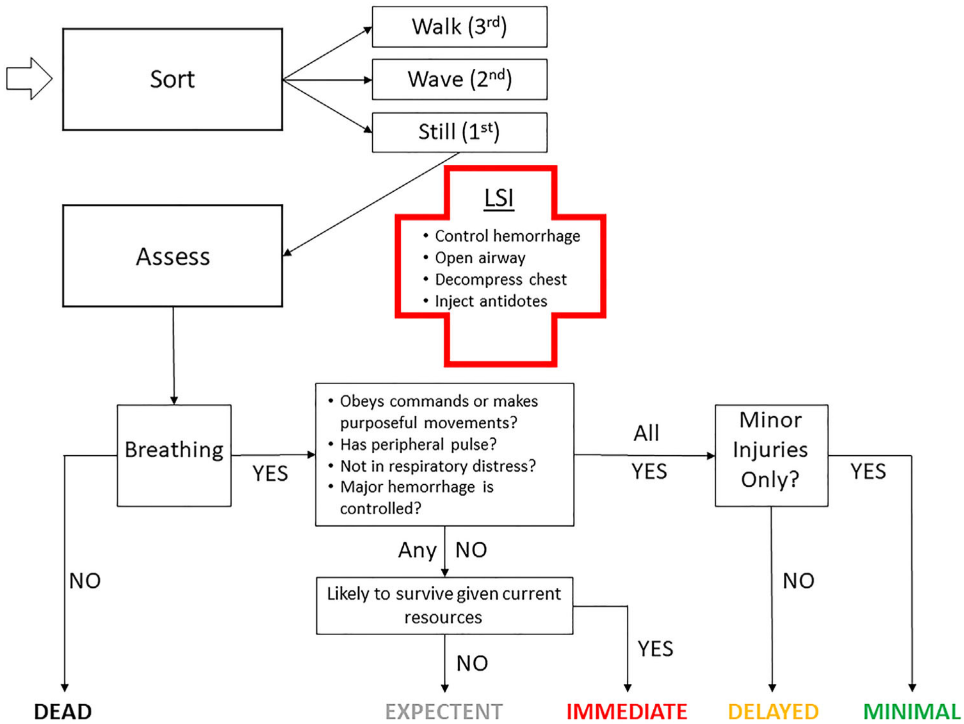

FIGURE 3 Our recreation of the sort, assess, lifesaving treatments mass casualty triage algorithm. (Adapted from Lerner et al.[13]) LSI, lifesaving intervention.

2.1 | Customization

The virtual environment in First Responder can be made more or less challenging by altering the environmental settings or the number and severity of patients. Clear, quiet environments with few patients suffering from simple injuries can be used for novice trainees as they learn the fundamentals of triage. As trainees advance in skill, the environment can be made more chaotic, thus requiring a higher cognitive load. Chaos is created by decreasing the lighting and visibility and increasing the amount of smoke and debris or the volume level of ambient noise. The number of patients in the scenario and the severity of their injuries is made possible through the creation of the programmable universal patient.

2.2 | Universal virtual patient

The universal virtual patient is the cornerstone of the First Responder system. Individual patients can be completely customized with respect to ethnicity, gender, and SALT category and types, severity, and numbers of injuries. In addition, patient attributes such as pulse, respiration, hearing, mood, position, and mobility can be configured. Scenarios are populated with virtual patients that are either selected by the trainee in the simulation or generated by the instructor using a universal patient configuration file. Scenes can be populated with as many as 32 patients. Each patient can be customized with up to 15 different injuries, including puncture wounds, amputations, lacerations, embedded shrapnel, tension pneumothorax, minor scrapes, respiratory distress, and hearing loss.

Patients are programmed to continually check the status of their injuries. The assignment of specific injuries and their severity is linked to an appropriate response set for those injuries that then controls the patient's behavior during the encounter, including vital signs (pulse and respiration), initial pose, ability to walk or respond to commands, and dialogue responses. In addition, the patient's health can be programmed to decompensate during the time they are left unattended.

Patients are programmed to follow simple commands and respond to trainees' questions with simple answers based on the types and severity of their injuries. User input is captured using Automated Speech Recognition (ASR) with the Windows Dictation Recognizer in Unity. Queries are matched to predefined phrase sets that can be easily modified to fine tune the patient's vocabulary and ability to understand user input. Patients not only respond to key SALT triage protocol commands, such as "walk" or "wave," but also will comply with other commands if their injuries allow, including "stand," "sit," "lie down," or "move your arm/leg." Patient voices are linked to a library of audio files that were generated by voice actors to create authentic dialogue appropriate for interactions in a high-stress chaotic environment. Trainees are also able to take a patient's pulse by receiving haptic feedback through the system's hand controllers. Other vital signs, such as respiration rate and airway assessment, are obtained through observation of the patient's actions or vocalizations. If necessary, the trainee can reposition the patient to open his or her airway and receive auditory and visual feedback indicating the patient's response.

2.3 | Stand-alone and moderated options

First Responder can be run in stand-alone (autonomous) mode, which employs the ASR for direct communication between trainee and virtual patients and enables users to configure and initialize the simulation without the use of a moderator to operate the system. This stand-alone mode is intended to make it easy for the system to be deployed to fire departments, police stations, community hospitals, academic medical centers, and other training institutions without requiring additional personnel. In moderated mode, a moderator can disable the ASR and can control various parameters of the simulation, including patient dialogue and behaviors. They can also implement different scenes for orientation or training, start and stop the simulation, and manipulate other parameters such as the rate of patient decompensation and user options for movement control.

2.4 | Orientation stage

Before entering the MCI scene, trainees can interact with practice patients, figure out how to find and obtain tools from the medical kit (Figure 2), and learn how the controller works to help them navigate the scene and how to take a pulse with the controllers. Once trainees become familiar with the mechanics of the environment, they move to the MCI scene to practice or be assessed on their performance in triaging and treating the patients. The advantage of this approach is that it removes (or minimizes) the element of familiarity with the technology from the assessment of the trainees and maximizes their ability to focus on the purpose of the simulation rather than the underlying technology.

2.5 | Triage kit

The triage kit's medical supplies were carefully selected to address some of the top causes of death from penetrating trauma as identified by the Committee on Tactical Combat Casualty Care (eg, 60% extremity bleeding/33% tension pneumothorax)[36–38] (Figure 2). These include a tourniquet, pressure bandage, hemostatic gauze, and needle for chest decompression. (Note that the SALT algorithm also calls for an autoinjector in the medical kit to be used with chemical exposure victims. The autoinjector was omitted from this scenario because it was not needed.) Each injury has an acceptable tool for treatment (except for the closed airway, which requires a jaw-thrust maneuver), and when applied the system records the interaction and elicits the appropriate response. For example, proper application of the tourniquet will stop any bleeding distal to the tourniquet but will not stop bleeding proximal to placement. Similarly, proper placement of the needle will result in chest inflation in a patient with tension pneumothorax, but improper placement will have no effect. The quantity of each tool can be controlled to accommodate differences in the level of trainees (novice to expert trainees). Each kit also contains colored triage tags that match the SALT triage protocol: black for dead, gray for expectant, red for immediate, yellow for delayed, and green for minimal. Once applied, tags turn into glowing bracelets to help trainees keep track of their progress during the encounter.

2.6 | Navigation in virtual space

First Responder provides users with an economy of scale. The system can be implemented in a room in which the actual physical area is much smaller than the virtual area of the virtual subway platform. Trainees are able to walk in the virtual space if using an untethered, wireless, virtual headset. However, to compensate for the difference in scale, trainees can use hand-held controllers to "teleport" (point to the spot they want to go and click) or strafe/glide (small movements) through the virtual space. This means that the physical space for the encounter does not have to be the full size of the virtual subway platform, which if converted to actual physical space would be approximately 60 by 30 feet.

2.7 | Automated performance assessment

The First Responder system records and tabulates essentially every action the trainee performs during the simulation encounter. These include trainee movements, treatments applied, appropriateness of treatment selected, critical commands issued, patient status before and after treatment, dialogue between trainee and patient, time to treat each patient, number of patients correctly treated, and whether the trainee applied the correct triage tag. In addition, the automated scoring system records the total time from start to finish and the time spent with each patient in the scene. The automated scoring system produces a score screen that contains basic performance information at the end of the encounter (Figure 4). A more detailed HTML-formatted performance report is also generated that contains trainee performance information for each patient treated during the encounter, including a picture of the patient to facilitate recall (Appendix 1). Faculty evaluators use the performance report to provide feedback to the trainee through a post-encounter debriefing on his or her performance. All metrics can be stored in a relational database for structured queries and eventual reports. These metrics will eventually be used to develop standards of performance for the assessment of various types of trainees.

3 | DISCUSSION

First Responder is the first fully automated, fully immersive VR system for training and assessing personnel in proper response to an MCI. The system has been designed for portability and practical use by agencies responsible for training medical students, residents, fellows, and

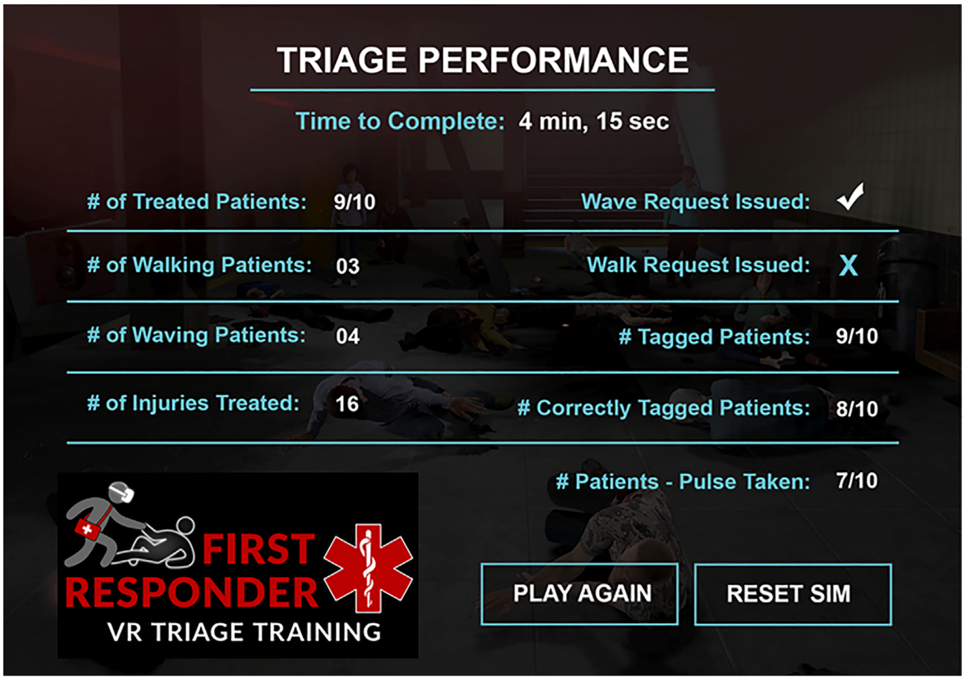

FIGURE 4 Display of the first responder's performance score that appears in the head-mounted display at the conclusion of the virtual reality training or assessment encounter.

paramedics to effectively respond to MCIs. Scenario customization and the universal patient supports the use of mastery learning methods to train healthcare personnel to standard levels of performance while providing a mechanism for advanced practitioners to maintain their triage and treatment skills. The First Responder system will also provide a living laboratory for studying the efficacy of different triage protocols. To review the features of the VR simulation, we assembled a mixed-reality demonstration video of First Responder (available at go.osu.edu/firstresponder).

We have already experienced interesting preliminary discoveries about mass casualty response skills from beta testing and early implementation of First Responder. In contrast to the novices who typically engage with patients in the scene immediately after the global sort, we noticed that disaster medicine experts briefly pause at that point to perform a visual assessment of the remaining patients, which saves time in the long run. Another anomaly observed during early implementation was that more expert-level participants were initially scoring low on applying the proper triage tags (data not shown). This led to the discovery that the program was originally designed to be fixed rather than dynamic. In other words, the tag status was being determined before application of field treatments instead of once the patient was stabilized. This was corrected according to the triage protocols recommended by Lerner et al[13] and Lee et al,[39] and the system now calculates the correct tag classification after the patient has been treated. Finally, we observed the importance of providing a specific location for the walking wounded to assemble during the encounter, otherwise patients tended to walk toward and follow the first responder, inhibiting his or her ability to triage and treat the more severely injured patients.

We are hoping that First Responder will contribute to the vast literature on disaster medicine response by using the system to replicate comparisons to conventional training such as large-scale exercises[20,28–30] and the cost-benefit analysis.[10] Furthermore, we plan more direct comparisons to other products (games, simulations for the same purpose) to more fully understand how the effectiveness of VR for training first responders is affected by varied levels of immersiveness and patient interactivity.[20,31–35]

3.1 | Limitations

The First Responder system was designed to be used with learners employing the SALT triage protocol. Other triage algorithms such as Simple Triage and Rapid Treatment (START) can be used, but the automated assessment system would need to be modified.[40] For now, in these situations, learners would need to be observed and assessed manually. In addition, our system does not yet have the capability to check capillary refill (a step that occurs in START triage before application of a tourniquet).

3.2 | Future plans

The First Responder system is now being adapted to create a sustainable and adoptable simulation that can be used by a variety of training programs, including academic medical centers, regional hospitals, fire and rescue departments, emergency medical technician programs, and other individuals and organizations involved in responding to MCIs.

The overall goal is to create a system that is flexible enough to allow for dissemination, adoption, and sustainability for a wide variety of end users without the need for continued support by us, although we will explore development of a paid support model to provide ongoing assistance to end users. Other important steps planned for the future include expanding the types of cases and scenarios to include, for example, victims of chemical exposure and the associated treatment tool, the autoinjector. We also plan to assess and evaluate how the simulation will be deployed across different settings, including the resources required, ease of installation, and support necessary for continued effective use.

The continuing proliferation of MCIs in the United States requires a highly skilled medical and para-medical workforce. The development of an effective, sustainable, and adoptable training and assessment system will contribute to preparing first responders to effectively master the skills of triaging and treating the scene of an MCI, which will result in the saving of lives.

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CONFLICT OF INTEREST

The authors declare no conflict of interest.

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REFERENCES

1. Jones SG. *Statement before the House Judiciary Subcommittee on Crime, Terrorism, and Homeland Security: The Evolution of Domestic Terrorism*. Center for Strategic and International Studies. February 17, 2022. Accessed: May 17, 2022. https://www.jstor.org/stable/pdf/resrep39859.pdf
2. Fortunato O, Dierenfeldt R, Basham S, et al. Examining the impact of the Obama and Trump candidacies on right-wing domestic terrorism in the United States: a time-series analysis. *J Interpers Violence*. 2022:37(23-24):NP23397-NP23418.
3. Aylwin CJ, König TC, Brennan NW, et al. Reduction in critical mortality in urban mass casualty incidents: analysis of triage, surge, and resource use after the London bombings on July 7, 2005. *Lancet*. 2006;368(9554):2219-2225.
4. Landman A, Teich JM, Pruitt P, et al. The Boston marathon bombings mass casualty incident: one emergency department's information systems challenges and opportunities. *Ann Emerg Med*. 2015;66(1):51-59.
5. Parrish GA, Bondani KJ, Bullard TB, et al. The Orlando nightclub shooting: firsthand accounts and lessons learned. *MDEdge Emerg Med*. 2016;48(8):348-356.
6. Reeping PM, Jacoby S, Rajan S, et al. Rapid response to mass shootings: a review and recommendations. *Criminol Public Policy*. 2020;19(1):295-315.
7. TRAUMABASE Group. Paris terrorist attack: early lessons from the intensivists. *Crit Care*. 2016;20:88.
8. First Responder Guide for Improving Survivability in Improvised Explosive Device and/or Active Shooter Incidents. US Dept of Homeland Security, Office of Health Affairs; 2015. Accessed Feb. 27, 2017.https://www.dhs.gov/sites/default/files/publications/First%20Responder%20Guidance%20June%202015%20FINAL%202.pdf
9. Kman N, Bachmann D, Folley A, et al. Emergency preparedness simulation cases for medical students: crush and organophosphate exposure. *MedEdPORTAL*. 2013;9:9330.
10. Farra SL, Gneuhs M, Hodgson E, et al. Comparative cost of virtual reality training and live exercises for training hospital workers for evacuation. *CIN: Comput Inform Nurs*. 2019;37(9):446-454.
11. McGlynn N, Claudius I, Kaji AH, et al. Tabletop application of SALT triage to 10, 100, and 1000 pediatric victims. *Prehosp Disaster Med*. 2020;35(2):165-169.
12. Deluhery MR, Lerner EB, Pirrallo RG, et al. Paramedic accuracy using SALT triage after a brief initial training. *Prehosp Emerg Care*. 2011;15(4):526-532.
13. Lerner EB, Schwartz RB, Coule PL, et al, et al. Mass casualty triage: an evaluation of the data and development of a proposed national guideline. *Disaster Med Public Health Prep*. 2008;2(S1):S25-S34.
14. Ericsson KA. Deliberate practice and acquisition of expert performance: a general overview. *Acad Emerg Med*. 2008;15(11):988-994.
15. Sawyer T, White M, Zaveri P, et al. Learn, see, practice, prove, do, maintain: an evidence-based pedagogical framework for procedural skill training in medicine. *Acad Med*. 2015;90(8):1025-1033.
16. McGaghie WC, Issenberg SB, Cohen ER, et al. Medical education featuring mastery learning with deliberate practice can lead to better health for individuals and populations. *Acad Med*. 2011;86(11): e8-e9.
17. Iyer AV, Dunlop SR, Thakkar DJ et al. Evaluation of Current Technologies for Training, Web Apps, and New Technologies. Purdue University. Joint Transportation Research Program; 2021 Mar 1. Accessed March 22, 2022. https://rosap.ntl.bts.gov/view/dot/57452
18. Allcoat D, von Mühlenen A. Learning in virtual reality: effects on performance, emotion and engagement. *Res Learn Techno*. 2018;26:2140.
19. Reen FJ, Jump O, McSharry BP, et al. The use of virtual reality in the teaching of challenging concepts in virology, cell culture and molecular biology. *Front Virtual Real*. 2021;2:670909.
20. Mills B, Dykstra P, Hansen S, et al. Virtual reality triage training can provide comparable simulation efficacy for paramedicine students compared to live simulation-based scenarios. *Prehosp Emerg Care*. 2020;24(4):525-536.
21. SALT mass casualty triage: concept endorsed by the American College of Emergency Physicians, American College of Surgeons Committee on Trauma, American Trauma Society, National Association of EMS Physicians, National Disaster Life Support Education Consortium, and State and Territorial Injury Prevention Directors Association. *Disaster Med Public Health Prep*. 2008;2(4):245-246.
22. Jacobs LM, McSwain Jr NE, Rotondo MF, et al. Improving survival from active shooter events: the Hartford consensus. *J Trauma Acute Care Surg*. 2013;74(6):1399-1400.
23. De Crée C. When our beer, chocolates, waffles and denial no longer suffice: medical responses to the March 2016 Brussels suicide bombings. *J Trauma Care*. 2016;2(1):1009.
24. Unity Pro. [Online] Unity Technologies. http://unity3d.com
25. Meta Oculus. oculus.com. [Online] Facebook Reality Labs. Menlo Park, CA. https://www.oculus.com/quest-2/
26. HTC Vive Pro Series. HTC Corporation. Taoyuan City, Taiwan. https://www.vive.com/us/product/#pro%20series
27. Varjo XR3. [Online] Varjo Technologies USA HQ. https://varjo.com/products/xr-3/
28. Ingrassia PL, Ragazzoni L, Carenzo L, et al. Virtual reality and live simulation: a comparison between two simulation tools for assessing mass casualty triage skills. *Eur J Emerg Med*. 2015;22(2):121-127.
29. Ferrandini Price M, Tortosa DE, Fernandez-Pacheco AN, et al. Comparative study of a simulated incident with multiple victims and immersive virtual reality. *Nurse Educ Today*. 2018;71:48-53.
30. Gillett B, Peckler B, Sinert R, et al. Simulation in a disaster drill: comparison of high-fidelity simulators versus trained actors. *Acad Emerg Med*. 2008;15(11):1144-1151.

31. Stansfield S, Shawver D, Sobel A, et al. Design and implementation of a virtual reality system and its application to training medical first responders. *Presence-Teleop Virt*. 2000;9(6):524-556.
32. Vincent DS, Sherstyuk A, Burgess L, et al. Teaching mass casualty triage skills using immersive three-dimensional virtual reality. *Acad Emerg Med*. 2008;15(11):1160-1165.
33. Wilkerson W, Avstreih D, Gruppen L, et al. Using immersive simulation for training first responders for mass casualty incidents. *Acad Emerg Med*. 2008;15(11):1152-1159.
34. Koutitas G, Smith S, Lawrence G. Performance evaluation of AR/VR training technologies for EMS first responders. *Virtual Real*. 2021;25(1):83-94.
35. Lowe J, Peng C, Winstead-Derlega C, et al. 360 virtual reality pediatric mass casualty incident: a cross sectional observational study of triage and out-of-hospital intervention accuracy at a national conference. *JACEP Open*. 2020;1(5):974-980.
36. Committee on Tactical Combat Casualty Care: Recommended Devices and Adjuncts. Department of Defense, Defense Health Agency. 2021. https://jts.amedd.army.mil/index.cfm/committees/cotccc
37. Deaton TG, Auten JD, Betzold R, et al. Fluid resuscitation in tactical combat casualty care; TCCC guidelines change 21-01. 4 November 2021. *J Special Oper Med*. 2021;21(4):126-137.
38. Turner CDA, Lockey DJ, Rehn M. Pre-hospital management of mass casualty civilian shootings: a systematic literature review. *Crit Care*. 2016;20:362.
39. Lee CWC, McLeod SL, Van Aarsen K, et al. First responder accuracy using SALT during mass-casualty incident simulation. *Prehosp Disaster Med*. 2016;31(2):150-154.
40. Benson M, Koenig KL, Schultz CH. Disaster triage: START, then SAVE—a new method of dynamic triage for victims of a catastrophic earthquake. *Prehosp Disaster Med*. 1996;11(2):117-124.

SUPPORTING INFORMATION

Additional supporting information can be found online in the Supporting Information section at the end of this article.

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