ORIGINAL RESEARCH

Training Healthcare Personnel for Mass-Casualty Incidents in a Virtual Emergency Department: VED II

Wm. LeRoy Heinrichs, MD, PhD;[1,2,3] Patricia Youngblood, PhD;[1] Phillip Harter, MD;[4] Laura Kusumoto, MA;[5] Parvati Dev, PhD[2]

1. SUMMIT, Stanford University Medical Center, Stanford, California USA
2. Innovation in Learning, Inc., Los Altos, California USA
3. Professor (Emeritus) and Past Chair, Department of Obstetrics and Gynecology, Stanford University Medical Center, Stanford, California USA
4. Department of Surgery, Division of Emergency Medicine, Stanford University Medical Center, Stanford, California USA
5. Forterra Systems, Inc., San Mateo, California USA

Correspondence:
Wm. LeRoy Heinrichs, MD, PhD
8 Campbell Lane
Menlo Park, California 94025 USA
E-mail: wlh@stanford.edu

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Keywords: chemical, biological, radioactive, nuclear, and explosive; mass-casualty incidents; Incident Command; training; simulation; Serious Virtual World; Virtual Emergency Department

Abbreviations:
CBRNE = chemical, biological, radiological, nuclear, or explosive
ED = emergency department
MCI = mass-casualty incident
OLIVE = online, interactive, virtual environment
SUMMIT = Stanford University Medical Media and Information Technologies
SVW = Serious Virtual World
VED = Virtual Emergency Department

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Abstract
Introduction: Training emergency personnel on the clinical management of a mass-casualty incident (MCI) with prior chemical, biological, radioactive, nuclear, or explosives (CBRNE)-exposed patients is a component of hospital preparedness procedures.
Objective: The objective of this research was to determine whether a Virtual Emergency Department (VED), designed after the Stanford University Medical Center's Emergency Department (ED) and populated with 10 virtual patient victims who suffered from a dirty bomb blast (radiological) and 10 who suffered from exposure to a nerve toxin (chemical), is an effective clinical environment for training ED physicians and nurses for such MCIs.
Methods: Ten physicians with an average of four years of post-training experience, and 12 nurses with an average of 9.5 years of post-graduate experience at Stanford University Medical Center and San Mateo County Medical Center participated in this IRB-approved study. All individuals were provided electronic information about the clinical features of patients exposed to a nerve toxin or radioactive blast before the study date and an orientation to the "game" interface, including an opportunity to practice using it immediately prior to the study. An exit questionnaire was conducted using a Likert Scale test instrument.
Results: Among these 22 trainees, two-thirds of whom had prior Code Triage (multiple casualty incident) training, and one-half had prior CBRNE training, about two-thirds felt immersed in the virtual world much or all of the time. Prior to the training, only four trainees (18%) were confident about managing CBRNE MCIs. After the training, 19 (86%) felt either "confident" or "very confident", with 13 (59%) attributing this change to practicing in the virtual ED. Twenty-one (95%) of the trainees reported that the scenarios were useful for improving healthcare team skills training, the primary objective for creating them. Eighteen trainees (82%) believed that the cases also were instructive in learning about clinical skills management of such incidents.
Conclusions: These data suggest that training healthcare teams in online, virtual environments with dynamic virtual patients is an effective method of training for management of MCIs, particularly for uncommonly occurring incidents.

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Introduction
Preparation for mass-casualty incidents (MCIs) remains a priority of the medical community in the post-9/11 era. Staged disaster drills (Incident Commands) have been the primary method for practicing skills necessary to manage large numbers of sick and/or injured patients. These drills are expensive to provide/conduct and require abundant resources, including volunteers to play patients, moulage artists, and participation of many healthcare and safety personnel, taking instructors and trainees away from their normal duties for extended periods of time.[1,2] Tabletop drills are another method of

use for training for the management of massive numbers of casualties in which participants gather around a table and talk through their probable emergency responses using maps and que sheets.[3] Such exercises typically involve administrators and do not provide the emergency department (ED) staff with the opportunity to participate and practice for the management of massive numbers of casualties; moreover, for some, they are not as engaging as live drills.

During the past decade, hospitals, public health organizations, and governmental agencies are being required to develop Disaster Action Plans for responding to MCIs caused by a large variety of agents and threats. A training component is explicit in all such plans. As an example, the US Hospital Emergency Preparedness Program (HEPP) is charged to realize the following preparedness goal: "Integration: Ensuring the integration of public and private medical capabilities with public health and other first responder systems, including—1. Periodically evaluating preparedness and response capabilities through drills and exercises".[4]

The Joint Commission also specifies in its Standard EM.03.01.03 for hospital accreditation: "The organization (must) conduct exercises to assess the Emergency Operations Plan's (EOP) appropriateness; adequacy; and the effectiveness of logistics, human resources, training, policies, procedures, and protocols. Exercises should stress the limits of the plan to support assessment of the organization's preparedness and performance. The design of the exercise should reflect likely disasters but should test the organization's ability to respond to the effects of emergencies on its capabilities to provide care, treatment, and services".[5] Exercises are to be performed twice annually.

These mandates, originally focused on terrorist targets of CBRNE events and later, for all-incidents,[6] have created funded opportunities to include new learning technologies to ramp-up traditional methodologies beyond tabletop and Incident Command exercises for conducting such multi-level drills and training. Virtual worlds enable multi-level, simultaneous simulations in multiple areas of a facility or region while providing evaluation and management of multiple victims of likely disasters. This study evaluated the effectiveness of a new method—Virtual Environments—for training hospital teams of Doctors of Medicine (MDs) and Registered Nurses (RNs) to respond to MCIs.[7]

Background

Few online Serious Virtual Worlds (SVWs) for training emergency healthcare professionals have been described,[8–22] and fewer still have been evaluated and the results reported.[10–12,14,21,22] Serious Virtual Worlds are designed for a primary purpose other than pure entertainment. Most of those described are conceptual, limited to individual emergency procedures, focused on emergency medical technician (EMT) management of emergencies, or are in development. However, the detailed design of a Virtual Emergency Department (VED) by Garcia and his advisors[8] in a seminal dissertation in 1995–1996 was put into limited practice with a field trial by 2000.[9] The forward-looking SVW by Halvorsrud, named the MATADOR Project, was the first VED evaluated, also in a field trial, with medical practitioners and students over the NORDUNET network between Oslo, Norway and Umea, Sweden. Dr. Halvorsrud, the Project Director, reported: "The simulator was well received by the participants in the field trial. Four of the trauma teams managed to establish a correct diagnosis and save the patient. Two of the student teams needed a second chance before handling the situation correctly. On average, the professional teams needed less time to save the patient, compared to the student teams. Both the students and the professionals found the medical scenario credible, and showed great enthusiasm during the simulations. Ten of the 12 professionals (83%) would recommend the simulator, as is, for colleges."[10]

The MATADOR project was remarkable because of its foresight in using online simulation for training emergency medical teams in a 3D environment with a virtual victim, and the research team's commitment to studying the method's impact on learning. That experience paved the way in 2003–2004 for the Stanford University Medical Media and Information Technologies (SUMMIT) research laboratory, jointly with the Simulation Center at the Karolinska Institutet in Stockholm, to initiate developing and evaluating the next-reported, online VED, after MATADOR. This was called the VED-I.[11–13] Based upon *Atmosphere*, a *beta* version software (Adobe Systems, San Jose, CA), an online VED I with six virtual trauma patients was developed with a unique, elementary physiology model operating for each. The physiology model is a dynamic *In Silico* (Java scripted) representation of the body's physiology. The same six patient scenarios, implemented in the VED I as closely as possible as in the Simulation Center with a high-fidelity human patient trainer, were the basis for a pre-test/post-test experimental design. The results showed no perceptible differences in learning by 31 fourth-year medical students and interns. The lack of perceivable differences in learning[12] was not published immediately, in part because of uncertainty about the surprisingly positive conclusion regarding the impact on learning with the VED I, and this decision was complicated by the withdrawal of the company's online server that prevented additional studies. The latter prompted the SUMMIT group to initiate, in 2004, a collaboration with a game company, Forterra Systems, Inc., which offered an online, interactive, virtual environment (OLIVE) as a platform upon which to design and develop a new virtual world.[13]

The Virtual Emergency Department—VED II

An online Virtual World matching the physical layout and décor of the real ED at the Stanford University Medical Center was developed by game developers at Forterra Systems, Inc. (San Mateo, CA), purchased in November 2009 by SAIC, Inc., McLean, VA. Using the OLIVE platform, they re-created the ambulance entrance (designated as the Triage Area), waiting area, and a five-bed critical care suite (Immediate Treatment Area) utilized in this study. Additional rooms, including one for Delayed Treatment patients, an x-ray room, and a morgue were not utilized. The researchers, guided by two ED physician subject matter experts, followed the hospital's Disaster Action Guidelines along with clinical practice guidelines to create the simulation exercises for responding to a MCI, in the

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Figure 1—Screenshot of physician, two nurses, and virtual patient

event of a CBRNE terrorist attack. Twenty unique patient case scenarios were developed in which patient avatars (computer-generated "persons") present with the symptoms and clinical findings of either nerve agent (sarin) exposure or trauma from a "dirty bomb".[23] These avatars were of different ages and genders, had various co-morbidities, presented with different types of injuries, had different levels of injury severity, and their vital signs were programmed to deteriorate clinically at different rates of time directly related to the severity of the injuries. Without appropriate and timely treatment, most would succumb within 30 minutes after arrival at the hospital. Appropriate diagnostic cues and therapeutic actions, including a fluids and a pharmacopoeia of 11 drugs, were available for selection and implementation.

Methods

The objective of this IRB-approved (Stanford University School of Medicine) research was to determine whether the VED II, populated with 10 virtual patient victims who suffered from a dirty bomb blast (radiological) and 10 who suffered from exposure to a nerve toxin (chemical), is an effective clinical environment for training ED physicians and nurses for the management of such MCIs.

Subjects

The study was conducted on three occasions with three volunteer teams made up of MDs and RNs. Two of the teams were from the Stanford Medical Center: one was comprised of four MDs and two RNs, and the other was comprised of three MDs and four RNs. The third team was from the San Mateo General Hospital and was comprised of three MDs and six RNs who volunteered to participate in the formative evaluation of the Virtual Environment simulation exercises, conducted in April and July 2008.

Procedures

Prior to the study, participants were provided with a set of PowerPoint slides designed by the research team to review the relevant pathophysiology and diagnostic and therapeutic measures for clinical management of patients exposed to sarin or to a dirty bomb. For each iteration of the study, the combined teams of MDs and RNs received 30-minute training sessions on the interface and the virtual environment to ensure that they knew how to operate their avatars and how to interact with their colleagues using headsets and voice over IP (VoIP). All three teams then participated in two consecutive scenarios of a MCI—either the release of sarin on a commuter train or the explosion of a dirty bomb at a local bank. The first two teams practiced both the sarin and the blast trauma exposures, and the third team completed two sarin exposure cases (Figure 1). For each scenario, they formed two teams—those assigned to the Triage Area and those assigned to the Immediate Treatment Area—and began to act out their assigned roles in the online role-play for 10–15 minutes. No prior indication was given for which set of victims the subjects would receive for practicing. The victim's roles were played by trained role-players who, when asked, responded verbally to caregivers, and they initiated victim actions on cues, e.g., initiating seizures when the blood pressure reached a pre-set level.

During the exercise, the subjects assessed and treated 10 victims/patients of either exposure who arrived at the hospital by ambulance or as walk-ins. After the role-play, the subjects participated in an instructor-led debriefing of their "in-world" experience. The educational method of role-playing followed by instructor-led debriefing is based upon the method of experiential learning.[24] Upon completing the exercises and debriefing, participants filled out an exit questionnaire and contributed to a focus group discussion on strengths and limitations of the Virtual World team training method. Quantitative results from this study were collected from a quiz that was administered at the beginning of the evaluation, and an exit questionnaire that was completed at the end. The entry questionnaire had 15 questions measuring the participants' knowledge of relevant clinical skills pertaining to sarin exposure and of the Stanford Disaster Action Guide (DAG) upon entry into these sessions, prior to the training scenarios.

The 16 May Stanford group performed each of the scenarios once during their exercise (sarin followed by dirty bomb), whereas the 17 May Stanford group performed the dirty bomb scenario twice and did not perform the sarin scenario. The reason for this difference is that the research team became concerned that performing two completely different scenarios in one day was too complex of a task for participants who were also using an unfamiliar technology. The decision was made to run through the dirty bomb scenario twice on 17 May, to let them learn and succeed through repetition. A similar decision was made for the San Mateo group—having them run the sarin scenario twice.

Results

Subject Demographics

The group of 22 medical professionals included 12 nurses and 10 physicians. The RNs in the study had an average of 9.5 years of practice experience at the time of the exercise, whereas the MDs had an average of 4.0 years post-graduate experience. There was a significant difference between the Stanford and San Mateo groups in their years of professional experience: the San Mateo MDs had an average value of 7.0 years of experience and the RNs had an average value of 12.3 years of experience; whereas the Stanford MDs had an average value of 2.7 years of experience and the RNs had an

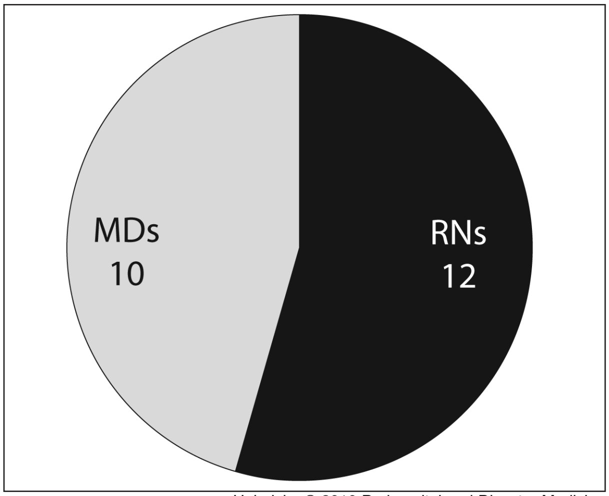

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Figure 2—Participants' professional training
(MD = medical doctor; RN = registered nurse)

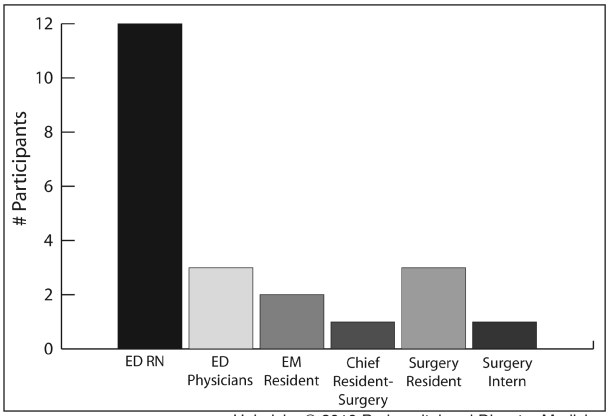

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Figure 3—Positions/Roles of participants
(ED = emergency department; EM = emergency medicine; RN = registered nurse)

average value of 6.8 years of experience (Table 1). All 12 of the RNs were ED nurses, whereas the physicians came from the ED and the surgery department (Figure 3). Seven of the MDs were resident physicians—one was an intern. Although one might have preferred that all participants were emergency department professionals, inclusion of the surgery department physicians is valid for emergency response training, because in a real mass-casualty event, physicians from the entire hospital would be called upon to assist in the ED.

These medical professionals spend little or no time playing games or using virtual worlds with avatar representatives (Figure 4). The majority never play games, and the mean score on the frequency of play was 1.4 on the Likert-type scale, between "never" (0) and "occasionally" (2). Approximately two-thirds of the participants had been trained to conduct triage at some point prior to the exercise and one-half had received training on CBRNE content (Figures 5a and 5b).

Entry Questionnaire

The entry questionnaire measured the knowledge of relevant clinical skills pertaining to sarin exposure and of the Stanford Disaster Action Guide (DAG) prior upon entry into these sessions, prior to the training scenarios. The 16 May Stanford team had a mean value of the scores of 8.7 (58%) correct answers out of 15 (n = 6). The 14 July San Mateo team had a mean value of the scores of 8.6 (57%) correct answers of 15 (n = 9). The 17 May quiz at Stanford was on the topic of responding to dirty bomb injuries rather than a sarin exposure, so it is not comparable.

Test Group	Medical Doctors (MDs)	Registered Nurses (RNs)
Stanford	2.7	6.8
San Mateo	7.0	12.3

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Table 1—Participants' professional training

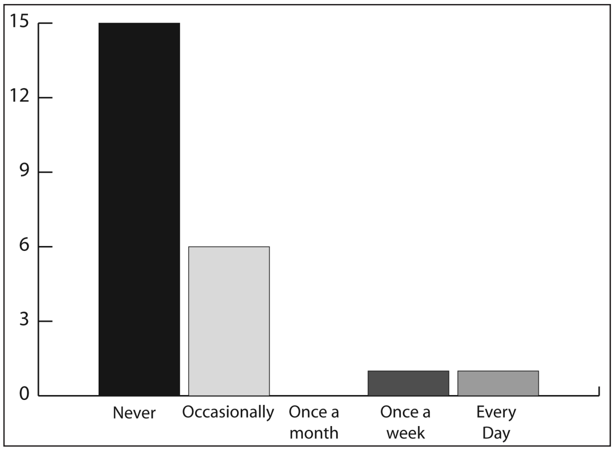

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Table 4—Frequency of game play/avatar use

Exit Questionnaire

The questions used in the exit questionnaire are listed in the Appendix. The quantitative results from the exit questionnaires are illustrated in Figures 5a and b.

The first question addressed immersion in the simulation and 15 of the 22 participants (68%), felt immersed much or all of the time (Figure 6). The next question addressed the participants' level of comfort taking a role in the simulation and interacting with others. Everyone felt they learned how to interact in the simulation, with varying levels of comfort (Figure 7). However, it is apparent that some training was necessary to use the virtual world, and having some practice also was important to most users.

The answers to the question regarding the technical difficulty of the software (Figure 8), showing the Stanford group as two subgroups; because, in this case, the results between them were significantly different. Though the sample sizes are small and may not be statistically significant, it is interesting to see that the Stanford group that performed both scenarios reported greater technical difficulty with the exercise than the subgroups that were allowed to run the same scenario twice.

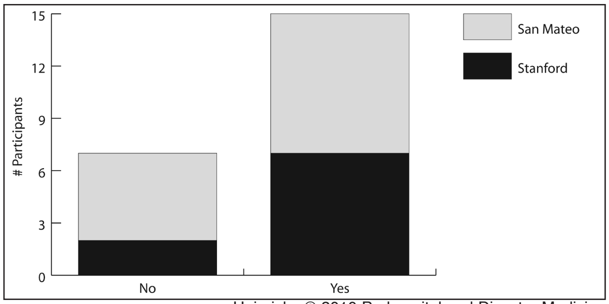

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Figure 5a—Prior training in code triage

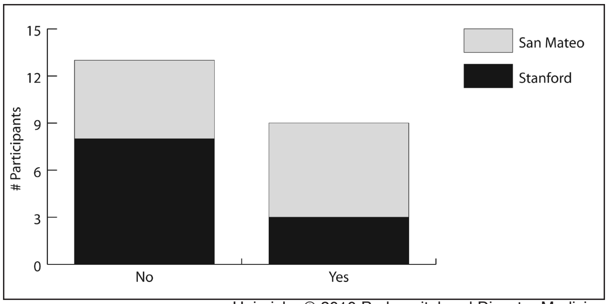

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Figure 5b—Prior training in CBRNE

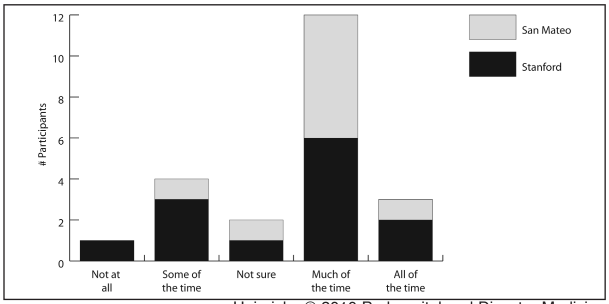

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Figure 6—Feeling immersed in simulation

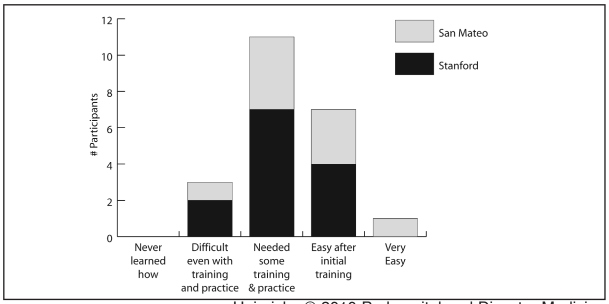

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Figure 7—Comfort interacting with others in simulation

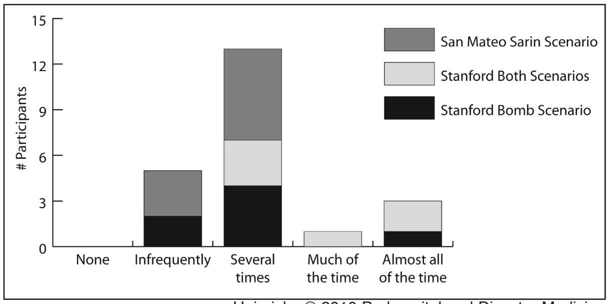

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Figure 8—Experienced technical difficulties in the simulation

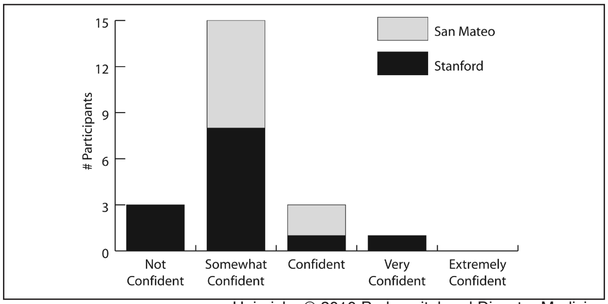

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Figure 9—Confidence prior to exercises

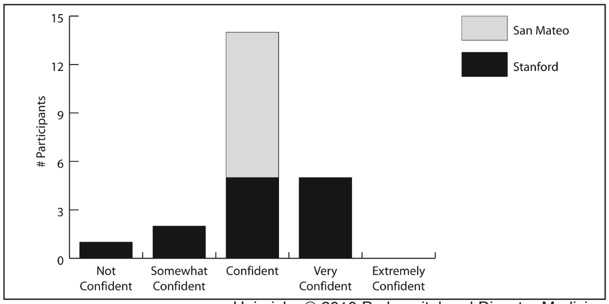

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Figure 10—Confidence after exercises

The next question on the exit questionnaire reflected participants' confidence in their ability to handle these incidents prior to the exercise. The participants were asked to respond using a Likert Scale with 1 = Not Confident and 5 = Extremely Confident. The majority of the participants were "Somewhat Confident" at the outset. The mean value for the answers to this question was 2.1. The following question reflected participants' confidence their ability to handle these incidents after the exercise. There was a shift in the level of confidence from that before the exercise (Figures 9 and 10). The majority of the participants were "Confident" after the exercise, and 19 of 22 (86%) either were "Confident" or "Very Confident". The mean value for the answers to this question was 3.0, representing a 46% change in the mean from prior to the exercise.

The next question assessed whether participants felt differently about being part of a MCI response following the exercise. The majority of the participants answered, "Yes", their feeling had changed (Figure 11).

The next two questions addressed participants' assessment of whether this technology is useful for clinical skills training and team training. Eighteen of the 22 participants, (82%), thought that these exercises would be "Useful", "Very Useful", or "Extremely Useful" for clinical skills training, with half of them rating it "Very Useful" or better. However, >10% rated it as "Not Useful". Ninety-five percent of the participants gave it "Useful", "Very Useful", or "Extremely Useful" ratings for team skills training (Figures 12 and 13).

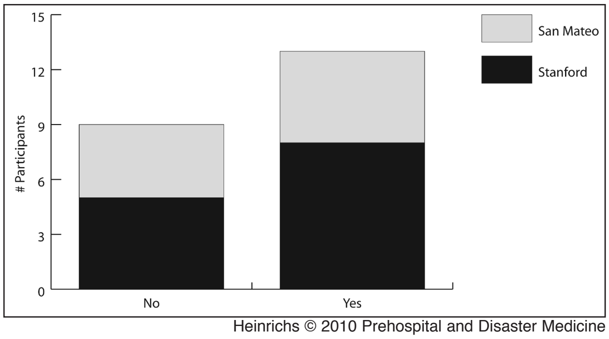

Figure 11—Feelings changed about responding to a mass-casualty incident

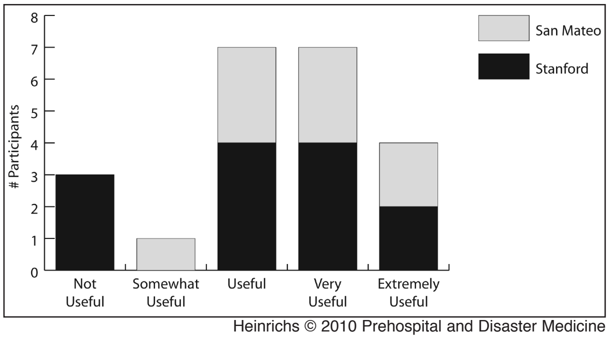

Figure 12—Usefulness for clinical skills training

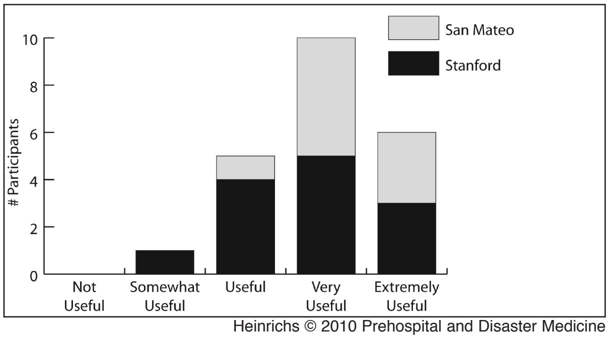

Figure 13—Usefulness for team skills training

Exit Questionnaire Comments

The participants provided general comments and comments on the limitations of the technology. Not all of the participants chose to write comments, and some wrote multiple comments. Random comments are listed below.

General Comments

(Five of 24)

- It really becomes apparent how team-oriented the whole effort is;
- Discovered importance of each individual role in code triage;
- Great way to simulate a disaster. Far superior to any other exercise/drill that I have participated in;
- These programs are extremely helpful; and
- Really enjoyed this study—very fun, intense, and useful for practice of teamwork and communication skills.

Comments on Limitations of the Technology

(Four of 16 comments)

- Simply the technical/communication aspect—it seems limited at times or can be difficult to effectively communicate at times;
- I have never used any avatar format before and moving around was my biggest challenge;
- Getting used to computer system. An easier way to get a quick overview of patient would be helpful; and
- Too difficult and cumbersome to assess patients.

Focus Group Discussions

The following comments are from the focus group discussions:

Overall Impression

(Three of 10 comments)

- Great way to train people; esp. teamwork in situations that don't occur everyday;
- What's good about this is you actually feel more involved with it, than with the dummy (instrumented manikin-based simulation). I felt like I can immerse myself more in this than working with the dummy…; and
- Good to be able to record the drill and play it back. It gives you a "God's eye view" that you don't get with a live drill, this is great for the debrief and giving feedback.

Recommended Changes

(Three of seven comments).

- Too hard to assess patients; takes too many steps—attaching to the bed, pulling up the monitor, pressing a button to get their appearance…this is too much; it doesn't take that long in real life;
- Should be able to click on the patient and get everything about the patient—the monitor would come up, you'd get the appearance, heart, lungs—all at once; not a click by click thing; and
- It would be much better if the patient's response to treatment were a little faster (blood pressure goes up faster, after receiving fluid and blood). Then we would know we were on the right track and could move on to the next patient.

Discussion

The functions of an earlier VED I were extended greatly with the OLIVE platform to enable multiple teams to care for many victims, simultaneously, in several locations in the VED II. For example, the VED II permits users to conduct triage operations outside of the hospital, and other teams to work inside the hospital at the same time. Further, having the capacity to care for up to 10 unique, dynamic patients/victims affected by either of two different types of incidents provides a simulation experience that was described by study subjects as "realistic", "immersive", and "challenging". Several comments indicated the superior training available with this learning technology, compared with the traditional Incident Command methods.

The mean value of the scores suggest that in spite of some relevant, prior training, the participants' prior knowledge about management of MCIs was poor among both groups. These data indicate the need for systematic training and rehearsal of MCI management and the treatment of sarin and dirty bomb victims. While disaster drills and tabletop exercises will continue to be useful methods for practicing the responses of the hospital staff to a MCI, distinct advantages accrue for using Virtual Worlds as a complement to those methods. These include: (1) the exact layout and location of resources of the ED are replicated; (2) trainees do not have to be present at the same location to play their avatar roles; (3) drills can be conducted at any time of day or night; (4) a variety of patient conditions can be modeled to simulate the complexity of a real MCI, even deaths; (5) scenarios can be run more than once in a short period of time allowing trainees to learn from their mistakes; and (6) trainees' performance during the simulation can be captured for playback and assessment after the event. In contrast to training of healthcare teams within a surgical center with one or more mid- or high-fidelity manikins, virtual environments can accommodate simultaneous simulations in several locations of a facility, and dozens of unique victims in its emergency area. Activities that transpire in any region of the training environment can be reviewed during after-action reviews. Although the VED II provides a core hospital environment without which an Incident Command practice could not be effectively performed, role-players with non-medical responsibilities must fill in other major components of the Hospital Incident Command System required by the Joint Commission.[5] These include public affairs, health and safety, and liaison activities within the Incident Command structure.

One limitation of these studies is the inconsistency in offering similar scenarios for each study group—one was presented with two sarin practices, another with two dirty bomb practices, and the third, one of each. Therefore, the results probably are less consistent than would have been produced by more users and use of the same sets of scenarios. Also, during the interval between the Stanford studies in May and the San Mateo study in July, the user-interface was altered in response to recommendations provided by the May groups. The benefit of these adjustments is evident in Figure 8. Such changes are acceptable in formative research, but not thereafter in summative research designs.

Other organizations more recently have begun developing Virtual Worlds with game platforms for training healthcare professionals. The Carley and Mackway-Jones team in the UK uses *Moodle*,[14] an open source environment, and the group led by Professor Ramesh Ramloll at Idaho State University[19] has implemented *Second Life*, a quasi-open source virtual environment (the server is restricted). The Anesoft Library of Virtual Cases is comprised of dozens of examples using a proprietary platform.[20] The Texas A&M-Corpus Christi group, led by Claudia McDonald, has implemented BreakAway, Inc.'s *Pulse!!* Platform.[25] One of the newest groups, led by Jeffrey Taekman at Duke University, has teamed with *Virtual Heros*[26] and another group, at the University of Maryland, is implementing OLIVE.[22] The SVWs developed on these different platforms serve different learning objectives, but with the common theme of emergency preparedness training. These groups have yet to publish use-studies of these systems.

Conclusions

This report on a VED II describes first results using OLIVE, a multi-played online simulation system that offers multiple, unique and dynamic virtual patients that can be triaged and managed clinically in the same moment, simulating a MCI. The system provides a solution to the fundamental training needs for meeting hospital preparedness requirements. Caregivers report ease of use and very good affirmation of the value of training with this experiential training method.

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Appendix—Exit Questionnaire (CBRNE = chemical, biological, radiological, nuclear, and explosive)

1. During this exercise, to what extent did you feel "immersed" in responding to the mass-casualty incident? (i.e., felt you were actually doing it?) (1 = Not at all; 5 = All of the time)
2. How easy or difficult was it to learn to take the role of an RN or MD (medical first responder) in these simulation exercises? (e.g., control of your avatar; communicating with others in the emergency department) (1 = Very difficult; 5 = Very easy)
3. Did you experience any technical difficulties when you were working through the simulation exercises today? (1 = No Interference; 5 = Often)
4. Prior to today's exercises, how confident did you feel about your ability to respond to a mass-casualty incident? (1 = Not Confident; 5 = Extremely Confident)
5. After completing the simulation exercises today, how confident do you feel about your ability to respond to a mass-casualty incident? (1 = Not Confident; 5 = Extremely Confident)
6. Did this study change your feelings/attitudes in any way about working as a member or leader of an emergency department Team (Triage, Immediate or Overall) responding to a mass-casualty incident? (1 = Yes; 0 = No)
7. How useful do you think these simulation exercises would be for learning the clinical skills necessary to treat victims of a CBRNE event? (i.e,. initial assessment and treatment) (1 = Not Useful; 5 = Extremely Useful)
8. How useful do you think these simulation exercises would be for learning the teamwork skills/behaviors necessary for responding to a CBRNE event? (1 = Not Useful; 5 = Extremely Useful)

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