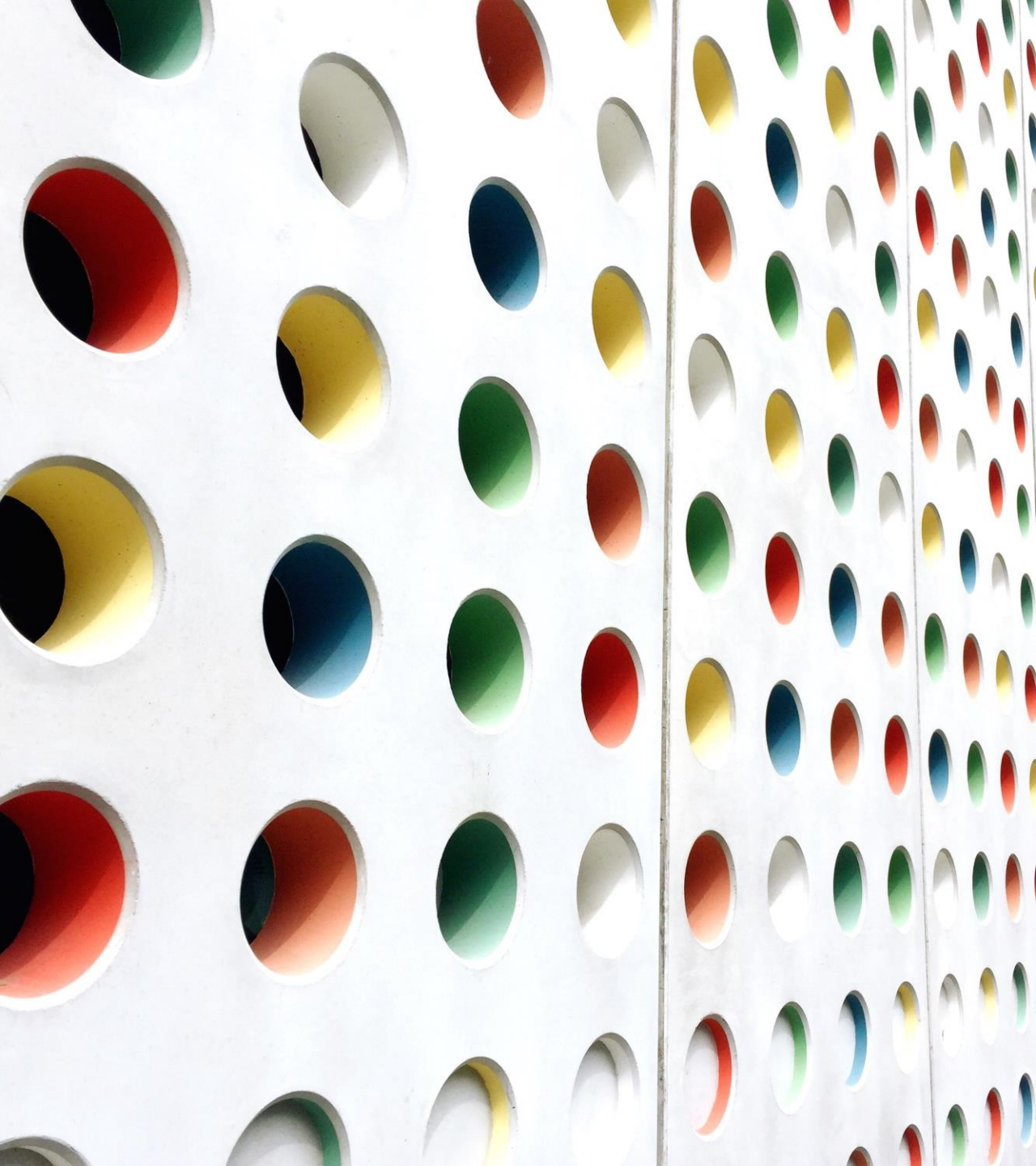




Virtual-world hospital simulation for
real-world disaster response:
Design and validation of a virtual
reality simulator for mass
casualty incident management

J TRAUMA ACUTE CARE SURG

Introduction

Mass casualty incidents (MCIs) may be defined as events in which the demands placed upon a health system exceed that which can be met using its usual resources.

Hospitals represent a critical link in MCI response, with close cooperation of **emergency clinicians, surgeons, and allied health professionals** needed to treat a rapid influx of casualties during such an event that is likely to overwhelm standard operating procedures

The unfortunately increasing incidence of MCIs, coupled with broadened public awareness in the wake of events such as the attacks of September 11, 2001, highlights the need to ensure the preparedness of health systems and professionals to respond.

The necessity of regular training to maintain a baseline level of hospital staff preparedness for MCI response is well recognized on both national and international levels.

The US Federal Emergency Management Agency describes four different exercise types, providing not only progressively increasing complexity and fidelity but also increasing cost and resource demand. These range from brief **orientation seminars**, to **tabletop exercises**, to the **criterion standard of full-scale exercises involving deployment of personnel and equipment**.

However, a number of resident surveys have reported significant gaps in trainees' knowledge and a perceived lack of training in MCI management

Post hoc analyses of both real and simulated MCI responses have consistently identified nontechnical errors, such as communication or team working failures and a lack of clinician training, as causes of suboptimal patient management.

Tabletop exercises, while cost-effective and reproducible, assess knowledge of management plans but do not provide feedback on these crucial aspects of in situ performance , on the other hand full-simulation exercise is complex.

Low-cost **virtual-world technology** offers a novel alternative, which can be run on any **current-generation laptop or desktop computer** without **special hardware**, and has the potential to provide **low cost and universal accessibility**.

Virtual worlds are fully **customizable computer-based three-dimensional environments** in which **multiple users**, represented by individual avatars, may **interact with virtual objects and each other in real time** over the Internet or a private network.

They have been previously used on a **smaller scale** to simulate the prehospital and hospital management of acute trauma or surgical patients but never before to simulate an entire hospital or multipatient MCI.

The aim of this study was to design and validate a novel, virtual-world based system for MCI simulation and performance assessment.

MATERIALS AND METHODS

Virtual Environment

Scenario Design

Virtual Patients and User Interface

In-World Roles

Validation Trial

Assessment Metrics

Face Validation

Virtual Environment

natural language processing and machine learning:

Web-based epidemic intelligence tools and online syndromic surveillance

A virtual hospital was developed, incorporating key clinical areas for mass casualty event management as follows:

- 1. Twelve-bed emergency department (ED)**
- 2. Four-bed resuscitation room**
- 3. Twelve-bed acute receiving ward**
- 4. Eight-bed intensive care unit (ICU)**
- 5. Eight operating rooms (ORs)**

Design of the virtual hospital was based on real-world location. Clinical areas were spread across two floors, interconnected by accessible corridors and stairwells

Scenario Design

A mass casualty event scenario, in which a terrorist bomb was detonated on a public transport bus, was designed.

This was created in conjunction with experts in emergency medicine and trauma, with first-hand experience in both military trauma and civilian disaster management.

It described a suspected terrorist detonation aboard a public transit bus resulting in **multiple casualties from passengers and pedestrians**, with a video brief designed to give a brief background and to allow clinicians to estimate the number and type of casualties.

Virtual Patients and User Interface

Virtual patients (VPs) were scripted to reflect the expected range of injury profiles after such an attack.

Scripts were matched to VP avatars appropriate to sex and gross injury, were pretriaged as either Priority 1 (critical injury) or 2 (major injury).

Throughout the scenario, patients continue to arrive at prescribed intervals, requiring clinician action to ensure appropriate placement, transfer, and treatment.

Clinicians may access patient notes or an attached vital signs.

A computercontrolled clinical team completes a primary assessment after a prescribed delay of 3 minutes to 10 minutes.

Clinical decision making is entirely open to the user, based upon the physiologic and injuryrelated data presented.

Virtual Patients and User Interface

To facilitate transfers, users must communicate with other in-world colleagues (via a virtual online telephone system) to confirm bed space and appropriateness of transfer before the receiving user accepts the patient in question.

In addition, the system includes an editable “whiteboard” function, which may be used as an ongoing patient record

In-World Roles

While users are free to walk through the entire hospital, they are expected to assume certain key strategic/operational roles.

at least one lead clinician coordinating each of the five simulated clinical areas (ED, resuscitation room, acute receiving ward, ICU, and OR), in keeping with standard MCI response policy.

In addition, one user may assume the role of overall incident command role/site lead.

External information such as expected number of casualties and time of arrival is related via the site lead to disseminate to other areas, as appropriate

In-World Roles

Additional **stressors** can be placed upon users by the introduction of confederate (faculty) avatars as distractors, for example, reporters or next of kin

All users take part simultaneously in the simulation, logging in on separate computers located anywhere with Internet access.

Validation Trial

The simulation was developed in an iterative process of software development between clinicians and software developers

The use of the finalized simulation was subsequently tested in a feasibility and validity trial.

Trainees and consultants (attendings) were invited to participate and were segregated by training grade

They received a lecture-based teaching session on mass casualty events and disaster response, followed by an orientation session and introduction to the simulation.

Validation Trial

The online simulation was played within a standard Internet browser (Microsoft Explorer 8, Microsoft Corp., Redmont, VA). Subjects were provided with headsets for in-world communication.

Once all subjects had demonstrated their ability to use the interface, a prerecorded “newscast” video clip was played, setting the context and announcing a nearby disaster event.

simulation was started, and **arrival of the first casualties commenced several minutes later**. The simulation continued until all scripted **patients had arrived**, had been **assessed**, and had been **appropriately treated**.

Assessment Metrics

All in-world actions are recorded by a background software script and saved at the end of the simulation.

Overall performance was assessed by analyzing **patient transfer decisions** and **the time taken to complete patient assessment and transfer**.

Risk events were defined as patient transfers to an inappropriate clinical area.

Individual subject technical skills performance was graded on a 1- to 5-point Likert scale across a range of critical behaviors and tasks, as defined by a regional disaster planning expert panel

Nontechnical skills performance was scored based on the validated **T-NOTECHS score**

Assessment Metrics

All subjects were observed by three independent clinician observers with expertise in skills assessment and emergency medicine/disaster planning.

Interrater reliability for all scores was calculated using Cronbach α in IBM SPSS Statistics 20
the mean scores were used in the final analysis.

Scores were compared across groups using **appropriate statistical tests**, to determine the simulation's capacity to differentiate between experts and novices (construct validity).

Face Validation

Following scenario completion, the subjects filled in a feedback and validity questionnaire, with statement responses on a Likert scale of 1 (strongly disagree) to 7 (strongly agree).

Responses of 5 or higher were deemed positive.

Results were anonymized and summarized using Microsoft Excel (Microsoft Corp., Redmond, WA)

RESULTS

52 VPs

34 were preexisting inpatients and

18 MCI victims

Of these

6 casualties had experienced severe injury (“Priority 1”)

the rest were categorized as “Priority 2,”

Lower-priority patients were not included in this simulation

Validation Trial

A total of 21 clinicians were recruited

The clinicians were segregated by training grade into **three groups**:

novices/junior residents (n = 8),

intermediates/residents (n = 7),

and experts/consultants (attendings) (n = 6).

During the first trial with the intermediate group, a technical **failure** led to performance metrics not being recorded, so only questionnaire responses from this group were included in the final data.

Final comparisons were performed between the **junior trainee group** and **the expert consultant/attending group**

Critical Events

A total of 14 critical events were recorded

A greater number of **risk or critical events** identified in the junior group (n=11) vs (n=3)

These were related to **resource allocation**, **patient prioritization**, and **decision making**.

Failure to assess bed availability or transfer of patients from the ICU, for example, resulted in a shortage of beds, with ventilated patients blocking space in the ED.

The mean (SD) **time from patient arrival to disposition** was significantly higher in the junior group, 560 (299) seconds versus 339 (321) seconds.

Skills Assessment

Interrater reliability for technical and nontechnical scores was excellent.

T-NOTECHS scores for nontechnical ability were **lower in the junior cohort**, 14.0 (2.0) vs 21.5 (3.7).

Similarly, the mean technical scores assessing the completion of tasks relating to each subject's role responsibility were also lower, 2.29 (0.34) vs 3.96

Validity Questionnaire

Interrater reliability for technical and nontechnical scores was good.

T-NOTECHS scores for nontechnical ability were **lower in the junior cohort**, 14.0 (2.0) vs 21.5 (3.7).

Similarly, the mean technical scores assessing the completion of tasks relating to each subject's role responsibility were also lower, 2.29 vs 3.96

Validity Questionnaire

The participants' questionnaire responses were excellent.

with almost all universally agreeing that the simulation was **effective** and **realistic**.

All agreed that it would be an **effective** and **realistic training tool** for mass casualty events and that it was an **enjoyable** addition to their training and might **help improve their own practice**

Specific free text responses commented on the :

- quality of simulation of resource management required (n = 5),**

- the simulation of stressors present in a real incident (n = 5),**

- the realistic nature of the scenario (n = 3),**

- and the realism of the layout and graphics (n = 4).**

All trainees with previous disaster response training thought that the simulation had significant advantages over existing MCI training methods.

DISCUSSION

This study describes the novel design, implementation, and validation of a virtual-worlds based simulation model for the planning, assessment, and training of clinicians' and hospital systems' responses to an MCI.

Although other training opportunities exist, the most comprehensive and immersive of these full-scale simulation exercise is **highly complex**, requiring a **high level of human, material, and financial investiture**.

Accordingly, full-scale exercises are rare events, **without opportunity to improve or refine responses** through practice.

MCI training has lacked a validated system of performance assessment until now, in part because of the difficulty of large-scale data capture during live exercises.

this study demonstrates the ability of virtual worlds to record and assess all aspects of a simulated MCI response, from individual patient movements to overall nontechnical and team performance.

Furthermore, the visual layout and in-world appearance can be customized to match actual hospitals to better prepare local staff for site-specific responses or scenarios.

The low hardware requirements in this case performed on the subjects' personal laptops as well as institutional desktop computers without dedicated graphics capability and Internet-based nature of the program allow **easy**, distributed access to health systems of all sizes and capabilities, at **low cost**.

The feasibility of virtual worlds for mass casualty event simulation and training has been previously demonstrated in smaller trials.

The present study for the first time, incorporating **whole-hospital simulation, multiple simultaneous users, and multiple patients**, to allow whole clinician teams to participate and practice crucial skills required within the context of an MCI

finding of significant differences between novice and expert clinicians highlights not only the feasibility of virtual worlds as a training tool for MCI response but also current training gap that exists for junior trainees.

For example, The recognized need to prioritize the availability of “downstream” beds with higher levels of care in MCIs, was more readily acted upon by the expert group, whereas junior trainees focused primarily on the “upstream” management of acutely presenting patients.

Such problems further demonstrate potential advantages of training in a virtual reality environment to improve disaster response and the quality of care provided to casualties in the event of an actual MCI because actions can, in this context, be recorded, replayed, and reflected.

limitations

This study is limited to an internal validation study, with a virtual world modeled on a single center, with staff drawn from the same single trauma center. **Lacking external data, there are limits to the generalizability of these findings.**

small sample size was limited by available staff at the study center.

In summary, The use of virtual-world environments is particularly suited to clinical scenarios such as MCIs as high level and complex risks.

The **customizable, accessible, low-cost** nature of this technology has obvious benefits when compared with the current alternatives.

Even with minimal resources, centers worldwide may access reproducible, customized disaster scenarios through this system, to provide clinician training and ensure institutional preparedness.

*Thank
you*

