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Best Practice for Casualty Simulation - Role-playing Actor, High Fidelity Mannequin Simulation, or Virtual Reality?

Robert Sarlay
Wright State University - Main Campus

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Robert Sarlay, Jr. MD

Wright State University

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Abstract

Objective: The purpose of this systemic review of the literature is to determine the best practice with regards to simulating casualties during a disaster response exercise.

Methods: MEDLINE was searched from 1950 till present for the key terms of disaster, simulation, and emergency preparedness. Articles were included which met the following criteria: English language, human subjects, original research using any research design (with or without intervention), and primary focus of disaster preparedness using simulation, virtual reality, or role playing actors.

Results: Of the 386 articles reviewed only 18 met inclusion criteria. The literature is primarily descriptive in nature with regards to simulation in disaster preparedness. Seven articles (38%) were analytical in study design with the rest being observational or descriptive. The populations varied widely among the included articles ranging from participants at a formal training class to medical students to residents and finally nurses and full trained physicians. The majority of studies including the analytical ones used convenience sampling. These articles were assigned a level of evidence and best practice recommendations and conclusions were then determined.

Conclusions: The results show that virtual reality and high-fidelity mannequin based simulation are at least equivalent to the traditional full scale exercise. In addition, both modalities have the advantage of allowing invasive procedures to be performed as well as giving a more realistic time frame experience for the participant. These modalities can be incorporated into future disaster response drills in order to complement each individual modalities strengths and weaknesses.

Best Practice for Casualty Simulation -
Role-playing actor, high-fidelity mannequin simulation, or virtual reality?

Disasters are in the collective memory of the population. People still sing the nursery rhyme “Ring around the rosie, pocket full of posies. Ashes, ashes, we all fall down…{dead}.” This rhyme reportedly refers to the Bubonic Plague, known as the Black Death, which struck Europe in the 14^{th} century. Whether this is true or not, the collective consciousness of the world still remembers the plague. The least complex definition of a disaster is that needs exceed the resources available and are often referred to as “low probability – high impact” events (Hogan & Burstein, 2007). Disasters although infrequent occur with some regularity in particular natural disasters such as hurricanes or wild fires. Disaster can have a great impact on the locale where they occur and on society as a whole. Disasters can be natural such as hurricanes, tsunamis, earthquakes or even outbreaks of emerging infectious disease as well as made by humankind such as war or bioterrorism (Waltzman & Fleegler, 2009). In fact, in the past decade the number and size of disasters has grown. Over the last quarter of a century 3.4 million lives have been lost to disasters (Hogan & Burstein, 2007).

Disasters are outside the normal experience of daily life. In the United States only 10-15 disasters per year result in more than 40 casualties (Hogan & Burstein, 2007). Very few disasters in the United States have exceeded 1,000 casualties. Some examples include: the 1900 Hurricane in Galveston Texas killing around 5,000; the General Slocum steamship fire on June 15 1904 killing 1,021; the September 13, 1928 Hurricane in Okeechobee Florida killing 2,000; and, most recently, the attacks on the Twin Towers in New York City September 11, 2001 killing 2,823 (Auf der Hide, 1989; Templeton & Lumley, 2002). Yet these disasters have a bigger impact than simply looking at casualty counts. The total cost to New Orleans of Hurricane Katrina was in the $40-50 billion range (Kates, Colten, Laska, & Leatherman, 2006). The 2003 outbreak of SARS cost $30-50 billion and affected 8,000 in SE Asia leaving 774 dead and spread to over 29 countries (Levi, Vinter, Segal, & St. Laurent, 2010). With increases in population density, population shifts from rural to urban areas (urbanization), and increasing pervasiveness of technology and our reliance on it, disasters will be experienced more frequently and have a greater impact in the coming decades (Auf der Heide, 1989).

Society often reduces the consequences for predictable and recurrent hazards such as tornados, wildfires, 100-year flood returns, and hurricanes (Kates et al., 2006; Waltzman & Fleegler, 2009). Preparations are meant to mitigate some of the adverse effects of the disaster's impact on the local community. Public health has a role in the planning, preparation, and mitigation of a disaster. Of critical importance to the practice of public health is response to emergencies of all types. Public health must address the inconsistent implementation of disaster response plans in regards to different types of events and with respect to interfacing with different organizations during a response. By understanding the variability between different types of events, creating resilient communities, and improving outcomes after a disaster, public health can continue to be a leader in disaster response. To achieve these goals, research is necessary. However, research as it relates to disasters is difficult because of ethical concerns and the lack of resources which can be devoted to gathering data during the disaster itself. Thus innovative ways to study disasters must be sought so that plans can be assessed in a systematic way. As a way to prepare for disasters, many organizations hold exercises to test their disaster response plans, policies, and procedures. These drills are especially critical since disasters have increased over the past decade placing ever increasing numbers of people at risk from their impact (Green, Modi, Lunney, & Thomas, 2003). Over the past decade because of urbanization and increased population density, 256 million are now annually affected by disasters (Green et al., 2003).

Public health has an integral role in any disaster response. Public health officials and practitioners have unique experience in strengthening infrastructure at the local, regional, state, and national level to maximize utilization of limited resources in their daily work. Such experience readily translates to applications during times of disaster. This unique experience can be significantly enhanced by establishing national standards that can be applied to conduct evaluations and assess outcomes. Standardized casualties and scenarios for use during large disaster response exercises would allow for better research and evaluation of outcomes. Standardization of causalities would allow for optimized training and allow for comparisons to be made in a more objective manner. Several basic questions need to be addressed to develop a best practice in regards to a standardized casualty for use during disaster response exercises. Chief among these questions is determining the best method of portraying casualties in a disaster response exercise thus allowing for further standardization to occur.

Purpose Statement

In recent years, technology has provided some alternatives to the traditional role-playing actor used during the prior decades for full scale drills. The emerging technologies of virtual reality and high-fidelity simulation mannequins have potential to replace or augment traditional actors in full scale drills. If these new technologies are equivalent to the current standard, then developing standardized casualties for use with these technologies will allow for a more scientific comparisons of disaster response exercises and the development of training which would be cost effective, relatively easy to conduct, comprehensive, effective, and most importantly repeatable. An evidence based approach was used to determine how these new technologies of virtual reality and high-fidelity mannequins compared to the current standard of role-playing actors.

Literature Review

Full Scale Drills

As early as 1959 Lieutenant Colonel Vincent Hack advocated for realistic training for military and civilian preparedness programs based on the success of using moulaged patients during World War I and II to train enlisted medics. These programs were shown to reduce training time and improve performance (Krohmer & Bern, 1985). Lt. Colonel Hack described the military's use of simulated casualties in conjunction with comprehensive instruction for training. He described moulage as the single best medium to make lasting impression on student's minds (Hack, 1959). His article provided a supply list and technique descriptions so that these same techniques could be used by civilian's in their training as well as stressing the need to brief the casualty on the specifics of acting the injury (Hack, 1959). Hack's article provided the foundation of using a role-playing actor as a casualty during a preparedness exercise and progressed into civilian training. Civilian disaster response exercises which use realism such as moulaged casualties have been shown to reduce training time and improve performance according to the literature (Krohmer & Bern, 1985). Gregory Brehm exposed the benefits of full scale drills in 1978. He stressed that realism and props provided an effective, efficient, and realistic way to drill so that people would act appropriately during the exercise (Brehm, 1978). He also advocated for instructing the casualties on their injuries and necessary treatments which should occur (Brehm, 1978). Full scale drills were the only practical method to test procedures, personnel, and facilities in disaster response in the first three decades after World War II. Full scale drills therefore evolved into the standard method of exercising disaster preparedness response.

Full scale drills have proven beneficial to the communities and participants who engage in them. The Agency for Healthcare Research and Quality (AHRQ) found full scale drills to be effective to improve knowledge of procedures, triage, patient care, and patient flow (Ballow et al., 2008). Green and colleagues noted that full scale disaster drills are used not only in the United States, but widely throughout the world as a tool for the evaluation and improvement of disaster response (Green et al., 2003). Green et al. (2003) have proposed a standardized evaluation tool to help measure outcomes objectively when full scale drills are conducted. Hsu et al. (2004) performed a systemic review of the literature to study the effectiveness of hospital mass-casualty incident response training in 2004. Hsu et al. (2004) concluded that hospital disaster drills were effective in training staff, however, more attention was needed in regards to evaluating these drills in a scientific manner. Hsu et al. (2004) found in seventeen out of twenty-one studies reviewed, hospital staff were trained to respond to disaster with full scale drills that addressed knowledge, skills, behaviors, and clinical outcomes. Williams, Nocera, and Casteel (2008) performed a systemic review in 2008 including out of hospital responders unlike Hsu et al. who only looked at hospital response. Williams et al. (2008) concluded the evidence was insufficient to determine whether full scale drill training was effective in improving response. Despite this finding, full scale drills remain the current standard method of exercising most disaster response plans. Further evidence that full scale drills are the standard is the inclusion of these drills in accreditation requirements. The Joint Commission on Accreditation of Healthcare Organizations (JACHO), requires two emergency preparedness drills per year each of which must be full scale in nature that is not a table top exercise (Tabletop drills not enough for testing disaster plans, January 2003).

Besides being the current standard of training, full scale drills do have some other benefits. Full scale drills allow responders to become familiar with procedures, identify problems in different components of response, and allow the opportunity to apply lessons learned to disaster response (Hsu et al., 2004). Full scale drills allow for process and procedures to be observed in the real world environment as well as practice moving real bodies from the disaster site to care facilities. A proper full scale drill can be designed to significantly challenge first responders and overwhelm resources.

Full scale drills have several limitations: they are expensive in terms of time, money, effort, and resources particularly if the exercise diverts resources away from real response (Christie & Levary, 1998; Idrose, Adnan, & Abdullah, 2007). As a result, standard full scale drills are infrequent occurrences for most responders. Without regular and frequent drills, skills and procedures are not learned which means retention suffers leading to coordination and communication problems during actual disasters. In other words, drilling only once in a while is the same as not drilling at all (Burstein, 2006). Compounding the limitation of drills which are only done periodically, the drills do not or cannot address the multiple variables associated with the uncertainties of a particular event causing the drills to be narrowly focused (Leikin, Aitchison, Pettineo, Kharasch, & Wang, 2011). Realistic casualties for these full scale drills require that the role-playing actors stage, have moulage applied and have some acting skills. Although some authors such as Krohmer and Bern (1985) have commented on the effectiveness of moulaged actors, other authors to include Ballow et al. (2008) claim there is little data in the literature about the development and design of moulage casualties or their effectiveness for training even though they are a key element in providing realistic training in full scale drills. This conflict in the literature could be from the use of poorly trained role-playing actors as the norm in most drills use versus highly trained professional role-playing actors. Even well trained and coached role-players have a limited range of medical and/or traumatic diseases which can be portrayed. Furthermore, full scale drills often do not include pediatric patients because of the difficulties involved such as coordinating with a local school to get volunteers although some authors have advocated the use of home schooled children in this vital role as they have much more flexibility in their schedules (Schwenke, 2009). Full scale drills also do not often include large number of casualties necessary to truly stress first responders as each role-playing actor requires an average of 15 to 20 minutes for proper moulaging as well as time-intensive coaching for their role (Krohmer & Bern, 1985). Finally, full scale drills are often predictable and allow participants to move through them in rote fashion (Cowan & Cloutier, 1988). Since the attacks of September 11, 2001, more emphasis has been placed on disaster preparedness thus more frequent and extensive drills have been conducted. Well rehearsed plans have been credited for successful responses seen in London and Madrid after major bombings as well as the repeated bombings which occur in Israel (Burstein, 2006).

Because of the limitations of full scale drills, alternative means of exercising disaster response skills have begun in recent years. Although full scale drills are a form of simulation in that they mimic a real disaster, they do have limitations. Full scale drills for healthcare disaster response include all aspects of disaster response to include the use of role-playing actors on-site, during transport, during triage, at the hospital, and beyond. Recognizing the limitations of full scale practice, high-risk industries like aviation, nuclear power, and the military have used other forms of simulation to teach complex tasks which are high impact but low frequency in the real world (Kobayashi, Shapio, Suner, & Williams, 2003). Modern simulation might be said to have started with the aviation industry when the Link Flight Simulator was used to train World War I pilots which resulted in a 90% reduction in nighttime and bad-weather collisions (Reznek, Harter, & Krummel, 2002). The cost effectiveness of modern flight simulations in the aviation industry is well documented (Reznek et al., 2002). Building on the success of simulation in these other industries, the healthcare industry has recently begun to integrate more advanced simulations into its training curricula.

High-fidelity Mannequin Simulation

High-fidelity mannequin simulation is one alternative to augment full scale drills. High-fidelity mannequins are computer driven aids which can accurately represent physical exam findings such as lung sounds, heart sounds, pulses, etc. and physiologic responses to interventions and medications as well as being able to provide verbal communication (Kobayashi et al., 2003). Modern simulation mannequins have over 40 realistic findings grouped in seven anatomic areas and are designed to interface with conventional medical monitoring devices (Reznek et al., 2002). The simulation mannequin will respond to 70 medications and/or physical interventions as well (Reznek et al., 2002). Each mannequin costs between $30,000 and $200,000 (Kobayashi et al., 2003). These highly realistic and interactive mannequins allow a greater immersion in the training experience thereby teaching skills and knowledge not readily provided by traditional lectures or full scale drills. These high-fidelity mannequins are replacing role-playing actors and low-fidelity mannequins because they allow for invasive or dangerous interventions to be practiced in a fully interactive and realistic manner and equally important they allow variations in physiology which cannot be achieved by role-playing actors (Kobayashi et al., 2003). The benefits of high-fidelity mannequins besides allowing for invasive procedures are that educators can control the learning process. High-fidelity mannequins provide a natural framework for integrating basic and clinical science without risk to patients, allowing individual learners to make mistakes in safety, learn from those mistakes, and improve their performance through repetition (Vincent, Berg, & Ikegami, 2009). Mannequins are also used to improve clinical decision making and communication among team members (Kobayashi et al., 2003). High-fidelity mannequins have been used to train responders in the management of victims of disaster with improvement noted post training (Leikin et al., 2011). Specifically, high-fidelity simulation has been shown to effectively teach triage and treatment skills (Vincent et al., 2009).

Limitations to the use of high-fidelity mannequins include the initial cost of the mannequins, the operational costs of facilities to house them, skilled operators, and maintenance of the mannequins which were until recently tethered to a control console and support equipment although wireless models are now offered by many manufacturers. These limitations combined result in having low numbers of the mannequins available for any given exercise. High-fidelity simulation has potential for use in disaster preparedness to augment full scale drills using role-playing actors.

Virtual Reality

Another alternative to replace or augment full scale drills is virtual reality training which is the most technologically advanced form of simulation (Reznek et al., 2002). This form of simulation can be traced back to the 1960's at MIT and Harvard but it wasn't until the 1980's that the term "virtual reality" was coined (Reznek et al., 2002). Immersive virtual reality involves a system which completely integrates a person into the computer world whereas desktop virtual reality allows the user to interact via a computer screen and input (Reznek et al., 2002). The difference between these forms of virtual reality would be like comparing a military flight simulator which can move with realistic sounds and has a physical cockpit to a home computer based flight simulator software (Reznek et al., 2002). The virtual environment created by the computer allows a user to interact and manipulate the environment. Realism is added with speakers and haptic feedback providing force and tactile sensations (Reznek et al., 2002). Virtual reality simulators have been developed for a variety of medical uses including casualty management, delivery room management, emergency department management, and for invasive procedures and surgeries (Reznek et al., 2002).

Virtual reality has some notable limitations baring its practical use. First is the cost of the equipment, computers, and experts to program and maintain the systems. Secondly, immersive virtual reality systems tend to be at fixed locations resulting in limitations of access by all responders who might need training as the system cannot be brought to remote locations. Furthermore, due to the nature of the systems, only a limited number of operators can interact at one time further reducing the usefulness.

Methods

An initial comprehensive search strategy was designed to gather as many potential relevant articles as possible. The search strategy employed to search MEDLINE via PUBMED database from 1950 to present with the terms disaster, simulation, and emergency preparedness in varying combinations. After the initial search was conducted, the results were limited to articles written in English and those articles with humans as the subjects. The abstracts for these citations were then reviewed for inclusion. Inclusion criteria used to select articles included original research using any research design with or without intervention. To be selected the primary focus of the article had to be disaster preparedness using simulation, virtual reality, or role playing actors during an exercise drill. Articles were excluded that were solely commentaries or not focused primarily on disaster preparedness. If the citation could not be excluded based on the abstract review, then the full article was then reviewed in order to determine its suitability. Full review of the remaining articles provided those articles which were used in this best practice review. There were few primary research studies relating to disaster preparedness exercises using role-players, virtual reality, or simulation identified by this search strategy. Additionally, two articles were excluded because they involved non-human subjects despite the filter limitation to human subjects only.

After all relevant articles were identified each article was reviewed for design, level of evidence, and results. The level of evidence assigned to each study was based on the criteria proposed by Sackett in 2000 as follows:

Table 1. *Level of Evidence*

Level of Evidence	**Type of Study**
1A	Systemic reviews of randomized controlled trials (RCTs)
1B	Individual RCTs with narrow confidence intervals
1C	All or none case series
2A	Systemic reviews of cohort studies
2B	Individual cohort studies and low-quality RCTs
2C	Outcomes research
3A	Systemic reviews of case-control studies
3B	Case-controlled studies
4	Case series and poor-quality cohort and case-control series
5	Expert opinion

Adapted from *Evidence-Based Medicine: How to Practice and Teach EBM. 2nd Ed.* by David L. Sackett, Sharon E. Straus MD, W. Scott Richardson MD, William Rosenberg, R. Brian Haynes MD., 2000, Edinburgh, Scotland: Churchill Livingstone Inc., pg. 173-177.

Results

Of the initial 386 possible articles identified by the search strategy to include use of filters only 18 (21%) were determined to be relevant to this review. That means 368 were ineligible for inclusion in the analysis. The literature is primarily descriptive in nature with regards to simulation in disaster preparedness. Of the eighteen articles identified for inclusion, only seven (38%) were analytical in study design; the rest of the studies were observational or descriptive in their design. Table 2 summarizes the analytical studies in this review. The populations varied widely among the included articles ranging from participants at a formal training class to medical students to residents and finally nurses and full trained physicians. The majority of studies including the analytical ones used convenience sampling. Five of the seven studies had a level of evidence rated at 2B; the remaining two studies were rated as 3B. Three of the studies investigated high-fidelity mannequin simulation and the remaining four studied virtual reality.

Table 2. *Analytical Article Summaries*

Primary Author	Year	Level of Evidence	Purpose	Design	Sample Population	Measures	Major Findings	Limitations
Subbarao	2006	3B	High-fidelity mannequin simulation	Case matched study	54 participants	43 question pre and post test	Paired student t test showed improvement in knowledge	Small sample size; test not validated
Triola	2006	2B	Virtual reality (VR) patient versus Standard Patient (SP)	Randomized Trail	55 providers	Pre and post test assessments	No difference in effectiveness or capabilities between VR and SP. Both groups equivalent in regards to comfort level, screening skills, and care for patients	Not blinded; small sample size
Gillett	2008	2B	High-fidelity mannequin simulators versus trained actors	Prospective Cohort Study	Trauma team of 2 physicians, 2 nurses and 2 residents	8 scenarios with 17 critical actions each evaluated	Miss rate of 0.74% [95% CI 0.01 to 4.5%] equal between the two cohorts; Critical actions no difference between live actor or simulation; Opinion of participants that simulator more realistic	Survey instrument no validated; Paired cases not identical
Summerhill	2008	3B	Curriculum to teach bioterrorism knowledge and skills	Prospective Cohort Study	25 intervention group and 30 control group	Objective test given after training	Intervention group mean test score 66.8% versus control group score of 50% which was a statistically different	Small sample size; not randomized

Table 2 (Cont'd): *Analytical Article Summaries*

Primary Author	Year	Level of Evidence	Purpose	Design	Sample Population	Measures	Major Findings	Limitations
Andreatta	2010	2B	Virtual reality versus standard patient drill	Randomized Trial of Matched Groups	15 Emergency Medicine residents	Pre and post test questionnaire	No difference in performance between two groups; VR drill did not have differential impact on learning compared to SP	Small size; convenience sample
Franc-Law	2010	2B	Virtual reality simulator compared to control group	Prospective Cohort Study	22 Medical Students	Compared differences mean time to triage and triage accuracy scores	Measured patient flow and triage accuracy which was higher in the intervention group than the control group	Small sample size; no blinding; single reviewer
Wallace	2010	2B	High-fidelity mannequin simulation versus actors	Randomized Trial	Staff of urban Emergency Department during scheduled disaster drill with 166 actor patients	Critical interventions	Use of actors underestimated resource utilization during drills as compared to mannequins in part because of short times to verbalize critical actions. No difference noted in critical actions performed.	Cohorted patients so possible learning bias

With regards to the descriptive or observational studies, four focused on virtual reality, three described the use of standardized patients, one dealt with high-fidelity mannequin simulation, and three examined combined modalities. One of the combined modality articles was entirely narrative in nature. The other two were quantitative descriptive analyses in nature using a combination of role-playing actors and high-fidelity mannequin simulations but lacked any outcome measurements. Table 3 summarizes the non-analytical studies identified by the search strategy and included in this review.

Table 3. *Descriptive Article Summaries*

Primary Author	**Year**	**Level of Evidence**	**Purpose**	**Design**	**Population or Setting**	**Measures**	**Major Findings**	**Limitations**
Gofrit	1997	4	Using "Smart Victims" during disaster drills	Descriptive Study	Eight full scale hospital disaster drills with 898 casualties with 178 of those being "Smart Victims"	"Smart Victims" critiqued care given	Integrating "Smart Victims" among simulated casualties contributed quality of medical care measures during exercise evaluations	"Smart Victims" could not assess skills, lack of stressful environment, need to recruit enough "Smart Victims" for large scale drills
Freeman	2001	5	Virtual Reality used to train emergency response skills	Descriptive Study	First Responders target audience of training	None	VR training can be used to improve cognitive skills	No objective measurements given to support conclusion
Kyle	2004	4	Combined Simulation Modality to reinforce concepts learned in didactic lectures	Descriptive Study to determine feasibility and acceptance of teaching method	Target audience emergency responders to included clinician and non-clinicians; 25 clinicians and 5 non-clinicians participated	None	Large scale multimodality simulation can be used to train both clinicians and non-clinicians for disaster events	Extensive man-hours involved in design and execution
Atlas	2005	5	Narrative comparison of the strengths and weaknesses of highly skilled role-players and patient simulators for use in biothreat recognition	Descriptive Study	None	None	Effective training in recognition and response to biothreat disease should involve realistic presentations	Expert opinion only based on the experience of the authors
Leiba	2006	4	Highly skilled role-playing actor used to assess level of prepared-ness for anthrax response	Descriptive Study	23 drills with one role-playing actor	Compliance with anthrax response protocols	91% EDs admitted patient; only 43% contacted all relevant officials;	Sentinel drills do not improve knowledge need more effective method of education on bioterrorism

Table 3 (Cont'd): *Descriptive Article Summaries*

Primary Author	Year	Level of Evidence	Purpose	Design	Population or Setting	Measures	Major Findings	Limitations
Kobayashi	2006	4	Create repeatable and immersive simulation of a disaster scenario combining role-playing actors and high-fidelity mannequins	Descriptive Study	12 teams totaling 48 participants recruited from state-wide prehospital system with average of 8 years clinical experience	Evaluation tool to measure critical on-scene response and timeliness by expert consensus	9 of 12 teams entered hazard area without protective equipment; 74.4% of critical actions completed across all 12 secessions	Evaluation tool not externally validated; Incorrect or unnecessary actions qualitatively recorded only; scenario not structured to determine outcome measures; No com-parison study secession with traditional designs; no follow-up on retention; no objective assessment of intersession consistency
Vincent	2008	4	VR training to acquire triage skills	Descriptive Study	Convenience sample of 24 medical students	Repeated measures task completion scores	Scores improved between first and second iteration but not second and third; Self-efficacy improved significantly	Did not correlate with traditional methods; Training effect?; Selection bias; Scoring method not validated
Wilkerson	2008	4	Evaluate the possible utility of VR simulation for training first respon-ders to mass casualty event	Descriptive Study	12 paramedic volunteers	Assessed by observation for decisions and actions taken with critical action checklist	Only 37.5% identified the type of event correctly; 92.9% did not inquiry or survey for scene safety	No control group; Small number of participants; Critical action checklist created by expert consensus
Cardeosa	2010	4	Use of highly skilled role-playing actor to assess compliance with avian influenza protocols	Descriptive Study	9 Emergency Department and 9 Primary Care Centers	1 of 4 simulated cases portrayed by actor who used a checklist to determine if critical actions were completed	89% of centers did not respond correctly; Use of actors revealed errors made by medical staff	Used to test deviation from established plans only no outcome measures
Kestler	2010	4	Development of High-Fidelity Mannequin simulation for Severe Malaria	Descriptive Study	Scenario conducted 5 times at weekly simulation days for 29 learners, 16 participants & 13 observers	Learning objectives derived from MEDLINE search severe malaria plus expert opinion	Simulation was rated as "very effective" instructional method by 66% of participants and equivalent to patient care by 67%	No outcome measurements; no control group; no long term effectiveness studied
Heinrichs	2010	4	Determine if VR ED is an effective tool to train ED physicians and nurses	Descriptive Study	10 physicians and 12 nurses	Exit questionnaire using Likert Scale	86% felt confident or very confident after the training	Inconsistency in scenarios for each group; Small sample size

Discussion

Overall there is very little high quality evidence in the literature with regards to optimum design and modality of how to use casualties in exercises for disaster preparedness practice. Despite the limitations of small sample sizes and samples of convenience, the analytical studies found by the search strategy do provide some insight into how to teach disaster preparedness. Andreatta et al. (2010) showed that virtual reality provided similar learning outcomes to the traditional role-playing actor patient drills. Andreatta et al. (2010) found no statistically significant difference in performance between the intervention group using virtual reality and the control group. However, the control group which used a role-playing actor did show an effect in better post test scores than the virtual reality group (Andreatta et al., 2010). Franc-Law also concluded that virtual reality has benefits as compared to traditional methods. Franc-Law randomly assigned a convenience sample of 22 participants into two groups and measured patient flow and triage accuracy (Franc-Law, Ingrassia, Ragazzoni, & Corte, 2010). Results showed the intervention group triaged more rapidly and had a higher performance than the control group (Franc-Law et al., 2010). Triola conducted the most relevant study in regards to virtual reality versus role-playing actor. Triola showed in a randomized trial involving 55 providers that there was no difference in effectiveness or capabilities between the control and intervention groups, virtual reality was equivalent to a standardized role-playing actor for learning (Triola et al., 2006). Triola also showed that true standardized role-playing actors as patients are a valid modality comparable to high-fidelity mannequins and virtual reality as compared to the random pool of patients traditionally used in full scale drills.

With regards to the analytical articles which dealt with high-fidelity mannequin simulation, Gillett et al. (2008) showed that high-fidelity mannequin simulation was equivalent to live actors in regards to prompting providers to complete critical actions. Only one critical action was missed for both the intervention and control group giving a miss rate of 0.74% [95% CI 0.01 to 4.5%](Gillett et al., 2008). Gillett et al. (2008) concluded that high-fidelity mannequin simulation is underutilized in disaster preparedness. Even with the limitations of expense and operator expertise, the benefits of the simulators should be embraced for use during disaster drills. By eliminating inherent variability in actors, providing dynamic pathology, and allowing invasive procedures, mannequins would support objective measurements using standardized simulations to allow comparison within facilities over time and between different facilities. Summerhill showed that high-fidelity mannequins used to teach disaster preparedness had a significantly better effect on knowledge than the control group in a case control study done in 2008 (Summerhill et al., 2008). However, this effect diminished at one year follow-up (Summerhill et al., 2008). Subbarao, Bond, Johnson, Hsu, and Wasser (2006) proved high-fidelity mannequin training was effective in teaching disaster response using a matched case control design. Subbarao showed a statistically significant difference between pre and post test scores on a group of 54 participants (Subbarao, Bond, Johnson, Hsu, & Wasser, 2006). Practical knowledge in regards to high impact low frequency events could be obtained by using high-fidelity mannequin simulation modality. Subbarao et al. (2006) did call for an economic cost benefit analysis to determine the potential benefit of using simulators given their large initial capital expense and upkeep costs. Wallace, Gillett, Wright, Stetz, and Arquilla (2010) showed in a randomized controlled trial that full scale drills using role-players underestimate the time to provide care and the burden to facilities. Twelve cases were evaluated during a disaster drill to compare actors to mannequin simulation. All critical actions took longer to perform on the high-fidelity mannequin simulators than it took to verbalize for an actor (Wallace, Gillett, Wright, Stetz, & Arquilla, 2010). Full scale drills could potentially provide a false sense of resources and time necessary to treat casualties because of this difference.

The current standard of full scale drills using role-playing actors has several additional drawbacks besides giving a false sense or resource use. In particular, the after action reports from full scale drills rarely report about the quality of care given to the role-player actors. In order to address the lack of ability to manifest details of care during a full scale exercise, some authors from the descriptive articles have suggested using smart actors. Gofrit, Leibovici, Shemer, Henig, and Shapira (1997) in particular advocated the use of physicians as actors during full scale drills so that victim treatment could be rated. These highly trained professional would be able to identify deficits in knowledge. However, as role playing actors, invasive procedures and alterations in physiologic findings still would not be possible. Additionally, using these smart actors would require additional recruitment and logistical considerations when planning full scale drills above what is already an extremely resource intensive endeavor. A unique use of highly skilled actors is described by Leiba et al. (2006) in their article on the use of trained actors to evaluate bioterrorism preparedness. Leiba et al. (2006) sent trained actors to emergency departments with signs and symptoms of Anthrax even going so far as to plant an x-ray in the radiology department and allowing blood to be drawn for analysis to determine if anthrax would be correctly diagnosed and appropriate measures taken and notifications made. Leiba et al. (2006) found only 61% of the departments tested considered Anthrax and only 43% notified all relevant public health officials. Similarly, Cardeosa et al. (2010) used highly trained standard patients to evaluate not only emergency departments but also primary care clinics response to potential pandemic influenza. Cardenosa et al. (2010) found 87% non-compliance with established public health protocols for pandemic influenza. These articles show that standard patients can be used in a variety of ways to test readiness so that errors can be found and corrected.

Four of the descriptive articles evaluated use of virtual reality to teach preparedness skills instead of full scale drills. The authors focused on determining if virtual reality was effective by itself as a teaching modality. The authors did not use objective validated measurements nor did they have any type of control group for comparison. In addition to the lack of control groups, the sample sizes were small and generally composed of a convenience sample. Wikerson did conclude that virtual reality does have the advantage of allowing invasive procedures and immediate student feedback as well as repetition so that practice can lead to mastery of skills (Wilkerson, Avstreih, Gruppen, Beier, & Woolliscroft, 2008). Freeman et al. (2001) echoed these advantages by discussing the fact that using virtual reality simulation to teach disaster skills allows for practice without jeopardizing a patient, varied and rare events can be presented, the process allows for repetition, events can be reconstructed and discussed after training, and teams can rehearse together.

Kestler, Kestler, Morchi, Lowenstein, and Anderson (2010) proposed using high-fidelity mannequin simulators to teach recognition and treatment of severe malaria in 2010 using a convenience sample of 29 participants. Kestler et al. (2010) theorized that high-fidelity mannequin simulation has potential to serve as a surrogate for clinical experience for bioterrorist presentations of disease. However, Kestler et al. (2010) did not look at long term effectiveness of the teaching method. Furthermore no evidence was presented in regards to improved patient outcomes from this method of learning. Of the participants involved, 66% responded that they felt simulation was very effective and 67% felt the simulation was equivalent to patient care (Kestler, Kestler, Morchi, Lowenstein, & Anderson, 2010).

The multimodality articles identified by the search strategy had no objective measurements yet provide insight into how these modalities can be used in combination. The first article by was a narrative by Atlas et al. (2005) describing the success of the University of Louisville Center for the Deterrence of Biowarfare and Bioterrorism's training using standardized patients. Atlas et al. (2005) describe in detail the well developed protocols and conditions that their standardized patients can portray as causalities of bioterrorism with the help of moulage for more realism and the usefulness of these patients in training clinicians in regards to bioterrorism response. The authors describe how high-fidelity mannequin simulators are often used in conjunction with the standardized patients to allow for practice of therapeutic interventions (Atlas et al., 2005). This combination of live actors and high-fidelity mannequins have been used in drills involving major biothreats such as smallpox, botulism, and Ebola; unfortunately, the authors did not report any objective measures of how well this combination worked or how effective it was (Atlas et al., 2005). Atlas et al. (2005) conclude in their experience that realistic presentations achieved by these methods are critical and effective since most major biothreats are not routinely seen in clinical practice, but provide nothing more than their expert opinion and experience to back up their statement. Kobayashi et al. (2006) evaluated twelve secessions of a nine victim incident using high-fidelity mannequins and professional actors in an attempt to capture data on clinical performance of prehospital providers in a repeatable objective manner. The authors were limited by the lack of outcome measures, an externally validated observation tool, and a control group using traditional exercise designs for comparison (Kobayashi et al., 2006). Nonetheless, Kobayashi et al. (2006) showed that quantitative information regarding clinical performance in a multimodality drill can be obtained. Similarly, Kyle et al. (2004) showed that large-scale multimodality patient simulation can be used to train responders in a realistic useful way but failed to have any comparison group using more traditional methods.

Despite the limitations of these articles, the benefits of using virtual reality and/or high-fidelity mannequin simulations as adjuncts to improve parts of the traditional full scale drill can begin to be seen in the above multimodality articles. Virtual reality and high-fidelity mannequin simulation have been shown in the literature to be equivalent to highly trained role-playing actors with the main additional benefits of allowing invasive procedures to be practiced and displaying abnormal physiology. Use of these modalities allows evaluation of not only processes and procedures, but also clinical skills evaluation thus giving a more realistic time frame for treatment and interventions during an exercise. This realism is necessary so that actual patient throughput can be evaluated versus just voicing what critical procedures would be done for a role-player and thus showing where bottlenecks in the processes and procedures would occur better than using traditional role playing actors as evidenced by Wallace et al. (2010).

The question is then how to best integrate these modalities into disaster response exercises. The six-step approach to the development of medical education curriculum proposed by Kern, Thomas, Howard, and Bass (1998) serves as a good construct to guide the best practice approach to disaster response training. Kern et al. (1998) advocated the following steps: 1) problem identification and general needs assessment, 2) needs assessment of targeted learners, 3) goals and objectives, 4) educational strategies, 5) implementation, 6) evaluation and feedback. During the planning phase of the exercise, the fourth step is dependent on the first three steps being clearly identified. By defining the goals and objectives and identifying targeted learners' needs one can successfully choose the appropriate simulation strategy to achieve the educational aims and student success. The exact mixture of modalities will be entirely dependent on the objectives of the exercise requiring exercise designers to be familiar with the strengths and weaknesses of each modality. With this knowledge, the best modality to accomplish each goal and objective can then be incorporated into the exercise.

Further benefit can be gained from the foundation of choosing the appropriate modality by standardizing the actual patient presentations. By using a database of standard casualties to include those of a medical, general trauma, blast trauma, radiologic, biologic, or chemical nature as well as spanning all age groups tailored for the exercise but reproducible would allow for objective assessment. Included in this database would not only be detailed instructions for briefing and training role-playing actors, but also validated protocols for use with high-fidelity mannequins. For example, if the objective of the exercise is to evaluate communication processes, evaluate transportation coordination and times then using role-playing actors along with low-fidelity mannequins serving as deceased casualties so that responders have bodies to move through the system is the best use of resources. However, if the goals of the exercise were to evaluate compliance of first responders with critical actions such as securing an airway, or starting intravenous fluids, then high-fidelity mannequins and/or virtual reality - allowing completion of invasive procedures would be the best solution. The objectives will drive the modality chosen to achieve the learning goals. Table 4 summarizes the strengths and weakness of each modality so that planners can determine which modality will best achieve the goals and objectives of their exercise.

Table 4. *Comparison of Simulation Modalities*

Role-Playing Actors		**High-Fidelity Mannequin Simulator**		**Virtual Reality**	
Strengths	**Weaknesses**	**Strengths**	**Weaknesses**	**Strengths**	**Weaknesses**
Standard for past several decades	Costly	Dynamic Pathology	Operator expertise needed	Dynamic Pathology	Non-portable fixed location
Large numbers of causalities possible	No on demand repetition	Invasive procedures possible	Capital expense and maintenance costs	Invasive procedures possible	Capital expense and maintenance cost
Realism achieved with moulage	Little individual performance feedback	Repetition possible	Limited number of simulators because of cost	Repetition possible	Operator expertise needed
	Disparity of effectiveness (volunteer versus trained)	Individual feedback easily accomplished		Individual feedback easily accomplished	Limited number of participants due to limited equipment
	Limited invasive procedures	Learn or maintenance of skills		Learn or maintenance of skills	
		Portability			

Conclusion

The results of this review show that virtual reality and high-fidelity mannequin based simulation are at least equivalent to the traditional full scale exercise. In addition, both modalities have the advantage of allowing invasive procedures to be performed as well as giving a more realistic time frame experience for the participant. However, no cost benefit analysis has been conducted to see if the capital expense in obtaining these technologies is beneficial as compared to full scale drills. Furthermore, the different modalities need to be studied to determine the relative effectiveness of each modality for acquisition and retention of knowledge and skills.

Incorporating standardized patient profiles using the appropriate model would allow for development of proficiency standards to assess disaster response. One can certainly expect to see future disaster drills employing mixed modalities in order to complement each individual modalities strengths and weaknesses.

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Appendix A: Public Health Competencies Met

Specific Competencies
Domain #1: Analytic Assessment Skill
Defines a problems
Determines appropriate uses and limitations of both quantitative and qualitative data
Selects and defines variables relevant to defined public health problems
Identifies relevant and appropriate data and information sources
Evaluates the integrity and comparability of data and identifies gaps in data sources
Applies ethical principles to the collection, maintenance, use, and dissemination of data and information
Partners with communities to attach meaning to collected quantitative and qualitative data
Makes relevant inferences from quantitative and qualitative data
Obtains and interprets information regarding risks and benefits to the community
Applies data collection processes, information technology applications, and computer systems storage/retrieval strategies
Recognizes how the data illuminates ethical, political, scientific, economic, and overall public health issues
Domain #2: Policy Development/Program Planning Skills
Collects, summarizes, and interprets information relevant to an issue
States policy options and writes clear and concise policy statements
Identifies, interprets, and implements public health laws, regulations, and policies related to specific programs
Articulates the health, fiscal, administrative, legal, social, and political implications of each policy option
States the feasibility and expected outcomes of each policy option
Utilizes current techniques in decision analysis and health planning
Decides on the appropriate course of action
Develops a plan to implement policy, including goals, outcome and process objectives, and implementation steps
Translates policy into organizational plans, structures, and programs
Prepares and implements emergency response plans
Develops mechanisms to monitor and evaluate programs for their effectiveness and quality
Domain #3: Communication Skills
Communicates effectively both in writing and orally, or in other ways
Solicits input from individuals and organizations
Advocates for public health programs and resources
Leads and participates in groups to address specific issues
Uses the media, advanced technologies, and community networks to communicate information
Effectively presents accurate demographic, statistical, programmatic, and scientific information for professional and lay audiences
Attitudes
Listens to others in an unbiased manner, respects points of view of others, and promotes the expression of diverse opinions and perspectives

Specific Competencies
Domain #4: Cultural Competency Skills
Utilizes appropriate methods for interacting sensitively, effectively, and professionally with persons from diverse cultural, socioeconomic, educational, racial, ethnic and professional backgrounds, and persons of all ages and lifestyle preferences
Identifies the role of cultural, social, and behavioral factors in determining the delivery of public health services
Develops and adapts approaches to problems that take into account cultural differences
Attitudes
Understands the dynamic forces contributing to cultural diversity
Understands the importance of a diverse public health workforce
Domain #5: Community Dimensions of Practice Skills
Establishes and maintains linkages with key stakeholders
Utilizes leadership, team building, negotiation, and conflict resolution skills to build community partnerships
Collaborates with community partners to promote the health of the population
Identifies how public and private organizations operate within a community
Accomplishes effective community engagements
Identifies community assets and available resources
Develops, implements, and evaluates a community public health assessment
Describes the role of government in the delivery of community health services
Domain #6: Basic Public Health Sciences Skills
Identifies the individual's and organization's responsibilities within the context of the Essential Public Health Services and core functions
Defines, assesses, and understands the health status of populations, determinants of health and illness, factors contributing to health promotion and disease prevention, and factors influencing the use of health services
Understands the historical development, structure, and interaction of public health and health care systems
Identifies and applies basic research methods used in public health
Applies the basic public health sciences including behavioral and social sciences, biostatistics, epidemiology, environmental public health, and prevention of chronic and infectious diseases and injuries
Identifies and retrieves current relevant scientific evidence
Identifies the limitations of research and the importance of observations and interrelationships
Attitudes
Develops a lifelong commitment to rigorous critical thinking
Domain #7: Financial Planning and Management Skills - N/A

Specific Competencies
Domain #8: Leadership and Systems Thinking Skills
Creates a culture of ethical standards within organizations and communities
Helps create key values and shared vision and uses these principles to guide action
Identifies internal and external issues that may impact delivery of essential public health services (i.e. strategic planning)
Facilitates collaboration with internal and external groups to ensure participation of key stakeholders
Promotes team and organizational learning
Contributes to development, implementation, and monitoring of organizational performance standards
Uses the legal and political system to effect change
Applies the theory of organizational structures to professional practice