The First Responder Simulation and Training Environment (FiRSTE) Project: Development and Evaluation

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Abstract

This paper describes the First Responder Simulation and Training Environment (FiRSTE) Project. The goal of this project was to create a prototype collaborative virtual reality system to demonstrate its feasibility as a tool for training civilian first responders to weapons of mass destruction. The development process, which was guided by the Rational Unified Process, began with identification of use cases and associated requirements. The implementation of the cases required the solution of a number of challenges, such as simulations of weapons of mass destruction and sensors, their integration into the virtual environment, and the development of specialized hardware for the user interface. A series of three evaluation exercises were carried out, using scenarios created by an emergency response expert, and local emergency personnel as participants. The analysis of behavioral, physiological, and self-report data indicated that: a) Overall, the system provided a realistic and meaningful training experience; b) Communication and collaboration were strongly related to the degree of realism experienced by the responders, while technical difficulties detracted from the experience; and c) Enhanced interaction capabilities, such as haptic devices and more realistic audio, were suggested as methods for extending the prototype.

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Project Rationale

The devastating events of September 11 2001 highlighted the importance of civilian emergency personnel who are the first to arrive on a disaster site that results from a terrorist attack. Since that time, training of these first responders for incidents, such as those resulting from weapons of mass destruction (WMD), has become an important priority. Unfortunately, there are a number of difficult challenges that impair meaningful training due to the nature of the environment where the responders will be required to perform. Realistic training environments require a vast amount of resources, in the form of physical facilities, equipment and personnel required to simulate a disaster. Specialized training facilities are few and widespread, resulting in the need for funding and time for trainees to travel to the facilities and train, which is particularly difficult for financially strapped rural emergency response departments. In addition, using physical facilities and equipment does not allow for flexibility, in that an event can often be run only once, according to a single scenario. Further, the more realistic these types of WMD simulations become, the greater is the possibility of accident. For these reasons training via a virtual reality system would seem ideal as an alternative method for training first responders for incidents resulting from weapons of mass destruction.

The First Responder Simulation and Training (FiRSTE) project was intended to directly address this need. The principal goal of the FiRSTE system was to demonstrate that a virtual environment can provide viable and effective training for first responders. This was accomplished through the development of a prototype system and evaluation of the system via a series of exercises, using scenarios created by an expert in emergency response and a variety of civilian emergency responders as test participants. This two-year project, which began in September 2002, was funded by the U.S. Army's Tank-automotive and Armaments Command (TACOM, grant # DAAE07-02-C-L068). The project was carried out by a team of researchers at the University of Missouri – Rolla in collaboration with the Battelle Corporation. The project has included threads that address specific issues about simulation and design (Berry & Hilgers, 2004; Misra, Decker, Barker, & Hilgers, 2004), as well as psychological issues associated with learning in affectively intense environments (Hall et al., 2004; Tichon, Hall, Hilgers, Leu, & Agarwal, 2003; Wilfred et al., in press). The purpose of this paper is to provide a description of the development process, its component parts, and the summative evaluation of the prototype system.

Figure 1. View of a trainee in FiRSTE environment

FiRSTE System Features

Before describing the development and evaluation of the FiRSTE system it is useful to describe some of its basic features, as depicted in Figure 1. It is designed to allow two first responders to perform a survey operation of a hazardous site within a building. They can view each other via head mounted displays and interact in the virtual environment in many of the ways they do in the physical world. They can perform the survey using buddy-system procedures and mark doors after they have found a room to be uncontaminated. They hold a mock-up of a chemical sensor and read its results as part of a heads up display. The chemical field they survey changes with time, spreading down the hallways of the building, entering new rooms, and so forth. If they encounter a spill, they can mitigate it by putting a blanket over it, if one is available. After mitigation, the chemical field simulation reflects the loss of a source and diffuses the remaining chemical agent. They can change the mode of behavior of the sensor by pressing buttons on the mock-up. If they want to check their remaining air supply, they press a button on the self-contained breathing apparatus they wear and an air gauge is displayed within their field of vision showing the amount. They can communicate with an incident commander who is viewing the team's performance on a pair of associated displays. Faults such as air tank leaks can be interjected into the training. All of the underlying simulations are compliant with High Level Architecture (HLA) Requirements.

Modeling First Responder Trainer

For the development of the FiRSTE system, a formal approach was followed known as the *Rational Unified Process* (Jacobson, Booch, & Rumbaugh, 1999). It is an industry standard and it proposes to deliver extendable, scalable, portable, and re-usable software. Within this process, the development team identified the uses of the VR simulation system and the associated requirements within the application area. These took the form of *use cases,* which were developed in cooperation with a first responder expert. These are modeled in this section.

The training begins with the assumption that terrorists have used a weapon of mass destruction. By definition, a weapon of mass destruction event involves the release of chemical, biological, or radiological agents into the environment. Once the public becomes aware of this situation, emergency response personnel are summoned. These could be any combination of policemen, firemen, public works officials, emergency medical technicians and so forth.

As they reach the site of the event, each has a specific role to follow. An entity with a role to play in an unfolding scenario is called an actor in Unified Modeling Language terminology. The following actors were identified as relevant to first responder training: Command & Control Personnel, Survey Team, Communication Team, and Medical Team.

Defining FiRSTE's scope

In determining the scope and associated boundaries of the virtual reality training system, some decisions are obvious. The WMD agents need to be placed within the virtual world. This most directly impacts the survey team and the associated activities performed by first responders. The other team members can participate in a training event via the trainer who can take the role of the other types of first responder as needed. This can be accomplished via the trainer's presence during the training. He can call out commands to the trainees and respond in the appropriate character.

First responder training requirements

The Rational Unified Process is distinguished from other methodologies via several key features. Its foundational characteristic is that it is *use case-driven***.** A *use case* specifies a sequence of actions including variants that the system can perform, which yield an observable result of value to a customer (called an actor). Requirements within the Rational Unified Process take the form of use cases. System attributes and functions are associated with the use cases. Elaboration of requirements is ongoing and may last through most of the lifecycle of the project.

The basic use case for FiRSTE is *train first responder* which is composed of several other use cases. The fundamental use case included within the *train first responder* use case for the system is *conduct chemical survey operations,* which in turn includes a number of use cases. In fact, most of the value provided by the FiRSTE is given in this family of use cases. These uses of FiRSTE have been derived from a first responder task list provided by an expert from the Battelle corporation.

The actor must be able to survey the virtual environment. This process involves both visual inspections as well as measurements using sensing equipment, such as photo-ionization detectors. While surveying the site, the first responder will perform mitigation activities. These include putting lids on barrels of chemicals, turning off values, throwing blankets over spills, closing windows, etc. The point of this activity is to limit the spread of the WMD agent.

Depending on the particular nature of the training vignette, the first responder may be asked to collect samples of the environment. This might include using a shovel to gather a soil sample or using a cotton swab kit to wipe various surfaces. This capability is included in the sensor simulation but was not realized in the virtual environment. While performing these activities, the first responder must stay in contact with and follow the instructions of the command and control center. This is accomplished via vocal interactions. When the survey is complete, the first responder reports to the decontamination center to receive seven different washings. Note that the decontamination cannot be done realistically within the virtual environment, therefore was not implemented.

Implementing FiRSTE

There are three major types of WMD event: chemical, biological, and radiological. Each has distinct properties for the transport and propagation of the contamination through the environment. The spread of a chemical agent can be modeled using the laws of fluid dynamics. Biological agents spread through contact and are carried about by the people in the building. Radiation is a field that can penetrate the walls of the building. The development team chose to limit the investigation into simulating the spread of chemical agents, though the architecture can easily adjust to other types of events.

With the focus restricted to chemical events, attention was directed to the photo-ionization detector (PID) as the first sensor to implement. The reason for this is that response personnel begin a survey operation by determining the area’s volatility and toxicity level, which is the purpose of the PID.

A related modeling problem involves the structure containing the chemical agent contamination. Complex structures containing multiple rooms that are interconnected by doors and hallways are fairly easy to model graphically. However, spreading a chemical agent within this environment in a physically realistic fashion requires modeling the structures in a way that the chemical simulator can understand. Specialty software called *VenomMaker* developed for this project accomplishes this.

One of the important requirements of this project was that the system be compliant with Higher Level Architecture (HLA), including, all of the communication within the virtual environment. During the 1980’s the DoD began to expand its use of simulation technologies to address several fundamental needs: the training of fighting forces, experimentation with new strategies and tactics, examination of proposed fighting systems before committing funds, etc. (Kuhl, Weatherly, & Dahmann, 1999). During the 1990’s the DoD recognized the need to reuse simulations in combined applications in order to leverage the investment made. In particular, they recognized the expanding information networks as critical to cost–effective simulation development. The Director of Defense Research and Engineering assigned the Defense Modeling and Simulation Office the task of promoting the interoperability and reuse of distributed military simulations. They proposed a master plan (Defense Modeling and Simulation Office,

1995) that ultimately resulted in the formulation of the High Level Architecture (HLA), which has become a requirement for DoD funded simulations. It is now widely used both in US defense work and in NATO.

The central concept behind HLA is that an individual simulation (called a ***Federate***) is given an interface (called an ***Ambassador***) through which it can pass information to other Federates via a generic program called the ***Run Time Infrastructure*** (RTI). A collection of interacting simulation components is called a ***Federation***. This makes a given simulation interoperable in that it now can communicate and interact with any number of other simulations. Reusability has been achieved and the investment in the simulation development has been extended.

Parallel to the software modeling was the development of the hardware interfaces. The mock-up of the PID was machined and the treadmill interface was developed. The team also produced a *Virtual Environment Navigation Pad (VENP)* for this project, which utilizes inertial sensors to allow viewing of the virtual environment based upon rotation of the chest. All of this activity is summarized in this section.

Modeling the chemical event

Part of what makes modeling a chemical event difficult is that there is a subtle balance between physical forces that govern the propagation of the element. There are two primary forces: convection and diffusion (Hughes & Brighton, 1991). Convective forces can be viewed simply as the chemical agent riding currents within the basic air medium. For example, the contents of a gas cylinder are under pressure. When the valve is open, the pressure imbalance attempts to resolve itself. This sets air in motion and the chemical agent is blown about.

Diffusive forces are due to molecular motion. Even in the absence of moving air, a chemical agent can fill a room. The molecules of the substance are active. They bounce around off of each other, the surrounding air, and the walls of a room. Eventually, they are everywhere. For example, break open a rotten egg and soon the odor permeates the entire house, even on a still day. Furthermore, the requirements of first responder training specify both of these driving forces are needed. Most terrorists will not be patient enough to wait for the casual spread of the agent. Hence, pressurized releases will likely be involved.

Part of the training of a first responder is to mitigate such a release by controlling the source. Hence, the model must allow a first responder to interact with a contamination sources, meaning that he or she must be able to turn off a source, which is called *mitigation.* A common technique used during survey operations is to simply throw a tarp over the contamination source. However, once this has happened, one cannot neglect the propagation due to diffusion. The remaining agent will spread through an entire building if its path is not hindered. This is also part of the training.

The model governing the propagation of a chemical agent is known as the advection-diffusion equation with a source, which needs to be solved for each chemical subspecies being modeled. Part of what makes this complicated is that the velocity field is not known. In fact, the pressure driving the release of the chemical agent changes the velocity. Technically, this would require solving the Navier Stokes equation, but this has been avoided by using the *control volume* approach.

Numerical Simulation

How accurately must the advection-diffusion equation be solved? This is an important question because it influences the type of numerical method used. In this case, a solution is needed in order to give the appropriate concentration to the simulator of the sensor used in the *survey operations* use case. The number the sensor presents to the first responder serves the purpose of teaching him or her how to use the sensor. Hence, a high degree of accuracy in the estimation of the concentration is not needed. The time dynamics and overall qualitative behavior is most important to teach the proper procedures the trainee must follow. This reduces the computation complexity that must be introduced into the problem.

To this end, the development team pursued the *control volume* approach (Bashforth & Yang, 2001). To summarize briefly, this approach subdivides the building into cells called control volumes (Misra et al., 2004). Think of them as a rectangular box with each room full of them. Within each cell, the concentration of the chemical agent is considered constant.

The method works by determining the forces on the edges of the cell. For example, there can be a force due to a pressure difference between neighboring cells. This will cause particles of the chemical agent to move from one cell to the next in order to create a balance. Likewise, there can be a diffusive force. It is the sum of these forces that makes particles move. The method is a time-stepping method. This means to advance the concentration field in time, the method uses what it knows about the current state to estimate what will happen over the next time increment.

As mentioned, this approach does not explicitly estimate the velocity field using the Navier Stokes equations. Rather it uses simple relationships between force and velocity to determine the flow across an edge. This reduces the computational complexity at the sacrifice of some accuracy that is not needed, as discussed. The system written to accomplish this is called *VenomStinger.*

Figure 2 shows a time slice of a cluster of rooms and hallway filling with one of several gases. The source is in the lower right-hand corner of the bottom room. The white opacity of the cell denotes the level of concentration. More opaque means the higher the concentration. Notice how the gas is slowly working its way out of the room and through the corridors. Of course, in the virtual environment the gas will be invisible.

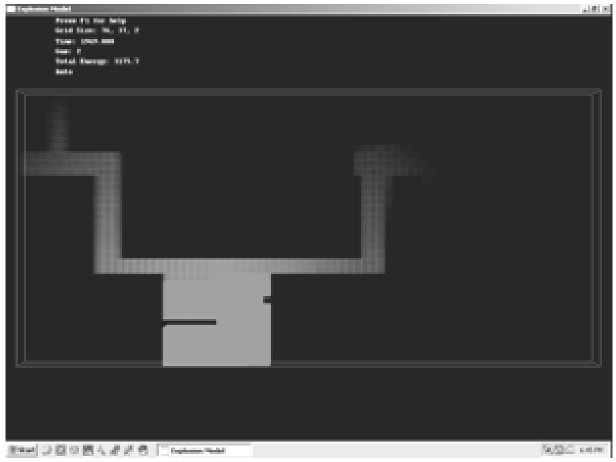

Figure 2. Concentration field in a cluster of rooms

Modeling the sensor

The design process asks how the sensor will be used. Reviewing the use cases shows that the sensor simulator is needed in order to help teach the first responder how the instrument will behave. Again, this simplifies simulation needs somewhat. There is no need to model inaccuracies internal to the instrument, only its ideal behavior. The development team was told that an element critical to its behavior during training is its response time. There is a significant lag time between when a sample is taken and when the PID reports the measurement. Most novice first responders move too quickly with the instrument and lose track of the where a measurement actually occurred. More subtle aspects of its behavior include how it displays information, its limitations on accuracy, and its measurement ranges.

With these observations, a generic sensor was developed (Berry & Hilgers, 2004). Future iterations of FiRSTE will include more complicated sensors such as the HAPSITE, which is capable of sensing 240,000 chemicals. The architecture developed should allow easy migration of more advanced devices.

In order to identify characteristics relevant to the survey use case, the user guide for the PID by RAE System (RAE system, 2002) was used. The operational characteristics identified as relevant are: sensing rate, processing times which can vary from a few seconds to a few minutes, the set of measurable chemicals, and the characteristics of the display.

Modeling complex structures

The release of a chemical agent into the environment has been studied, though most of the work done and the associated software focus on modeling the behavior of *plumes* in open air situations (Fernando et al., 2001). That is, the code takes the release of the agent and models it spreading across an open area. First responders use these models to identify areas to evacuate, where to set up command posts, and so forth.

The release of a chemical agent within a building is less studied, though some work has been done (Winters & Chenoweth, 2002). Most of this has focused on accurate prediction, not qualitative behavior, therefore leading to extensive simulation runtimes.

From a macroscopic (or global) perspective, one might wonder what information such models provide. To city officials, either a building is contaminated and should be evacuated or it is not. Knowing the level of contamination within a room is largely unimportant. Once it is identified as contaminated, first responders must follow a certain protocol.

However, the desire to safely train first responders creates the need for a microscopic (or local) view of a specific building. In order to train first responders to survey a site, one must simulate their equipment, but this in turn forces one to model the propagation of the WMD agent within the building. The aforementioned advection-diffusion equation requires knowledge of the boundaries the contaminant encounters. This creates the need to efficiently describe the building to the chemical dispersion software.

In modeling a building, the fundamental piece of knowledge needed is the physical dimensions of any rooms involved (or potentially involved) in the release of the agent and its configuration. Next, one must be concerned with the connections between rooms. Doors, windows, and ventilation can connect rooms to each other. If the agent can slip out of a crack, the neighboring room gets contaminated. The question then becomes how the trainer must supply the information. The simplest means would be to extract this information from the same environment model being used by the VR engine. This is challenging because the parsing of the image file to extract this information is complex and very dependent on the type of model file being used.

In an effort to facilitate the specification of the complex structure, the development team created a software tool (dubbed *VenomMaker*) that allows great flexibility in specifying the structure. A screenshot of it in use is shown in Figure 3. It allows trainers to import images of floor plans of existing buildings. Then it has drawing tools for tracing the floor plans. Multiple floors can be created and joined by stairs. Contamination sources and doors can be placed in the model. It allows the specification of the type of chemical source present (chosen from those measurable by the PID) and the initial state of the contamination. It then exports the rough structure in a map file that can be detailed using Valve®, a freeware 3D modeling tool. It also exports a configuration file that instantiates the complex structure model for use in driving the chemical contamination simulator *VenomStinger* (Misra et al., 2004).

Figure 3. VenomMaker tool

Hardware Interfaces

One of the design requirements imposed by domain experts is that the virtual reality simulation cannot feel like a video game to the first responder being trained. In particular, this prohibits typical interface metaphors such as the keyboard, joystick, and monitor screens. Furthermore, the simulation was required to induce enough stress in the trainee to produce physiological changes, such as an increase in heart rate and respiration.

Trainees using FiRSTE dress in the same equipment they would wear in a typical field exercise including self-contained breathing apparatus. In order to simulate the activity a first responder produces during survey operations, it was decided that traditional wall mounted displays are not effective. This caused the development team to consider lightweight displays that can fit inside of the breathing mask. During testing it was noted that peripheral vision presented a small distraction so shields were developed to encase the display within the mask.

Treadmill Interface

Motion control in the virtual environment presented multiple difficulties. Using a treadmill in order to navigate the environment offers the advantage of inducing physical stress. Most of the commercial virtual reality treadmill systems are expensive and complex, and therefore did not meet the design constraint of affordability for rural civil defenders.

Hence, the team developed two different exploratory locomotion interfaces. One is a treadmill system using a low cost, department store unit as the base. Magnetic sensors were installed that communicate with the simulation system through an external card. One challenge in this however is the problem of the resistance of the belt. It is difficult to start the motion and the stopping often resulted in a small slide past the desired point in the virtual environment. To cope with this, a safety harness system was used in conjunction with bungee cords to lighten the first responder. It was observed that most people quickly learned how to use the bungee cords to shift their weight in order to accurately start and stop the treadmill.

The treadmill can only signal speed in the virtual environment and not direction. The approach taken was to embed a directional control within a prototype of the sensor that first responder will carry. A shell of approximately the same size and shape was machined. A small wheel control is embedded within the prototype PID. The first responder carries this in the simulation and moves the wheel with his or her thumb to change direction. The functionality of the PID is simulated and visualized by FiRSTE. The prototype merely provides the sense of carrying the object, as well as buttons for mode control.

Figure 4. Trainee in FiRSTE on the treadmill

Figure 4 shows the treadmill in action. The trainee is seen wearing a head mounted display within the self-contained breathing apparatus. The PID is presented to him as part of a traditional heads-up display.

Virtual Environment Navigation Pad

The VENP was built to address shortcomings in the treadmill system. While performing survey operations, a first responder must look around, in, under, and over obstacles in the environment. The treadmill in conjunction with the PID allowed translation and rotation within a plane, but did not allow an act as simple as looking up.

The VENP uses an inertia cube fastened to a trainee's chest to determine the orientation of his or her view. The chest was chosen because a person wearing a Level A suit must rotate his or her whole upper body to change the view. The pad is a circular disk resting upon inner tubes that carry most of the trainee's weight. As he or she walks in place, sensors measure the pressure relative to each other and an algorithm determines forward or backward motion. This information is passed through a NI 6602 DAQ card into drivers that interpret the motion and orientation. Figure 5 shows the VENP being used during one of the evaluation exercises.

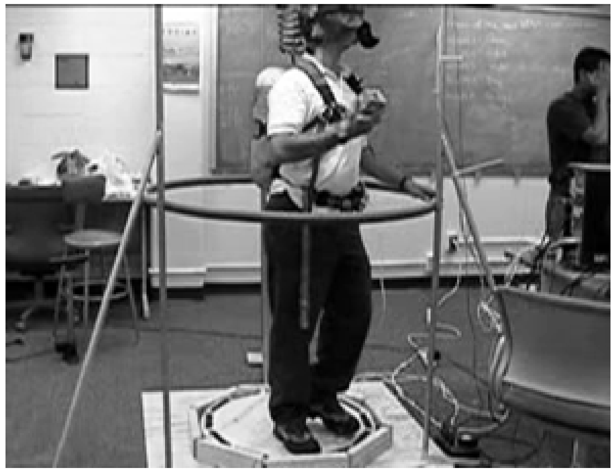

Figure 5. Virtual Environment Navigation Pad

Distributed Virtual Environment Generation

The FiRSTE system chose to build its virtual environments using the Half Life® gaming engine. There were a number of reasons it was chosen. First, it is built for interior environments, allowing quality rendering of light and ease of navigation through doors and rooms with furniture. Extensive resources exist for the software developer's kit. It works very well with freeware 3D modeler products known as Valve® and Milkshape®. Finally, and perhaps most importantly, it is designed to manage internet gaming. This is particularly important to use cases underpinning the development of FiRSTE as it was always required that a survey operation be performed using the buddy-system. That is, two trainees need to be able to move through the environment in tandem, interacting with each other. Half Life® has a client-server capability designed just for this type of LAN gaming.

The internet capability also became the gateway for implementing the High Level Architecture capability. The environment was distributed so that one federate is the WMD event simulator and the other federate is the virtual environment. The Federation Object Model has the sensor as the fundamental object. To update the sensor in such as manner so as to not impede the real-time performance of the training simulation was a primary concern. To achieve this, it was decided to pre-compute the concentration fields, store them as a data base and to separate the chemical sensor simulation from the virtual environment. As the Trainee federate causes a change in location within the structure, this information is communicated via the RTI to the Sensor federate, which in turn queries the concentration data base for the level of toxin at this location in time and space. The Sensor federate takes into account lag times due to internal processes and then this information is returned via the RTI to the Trainee federate and the result is displayed on the heads up display of the PID.

Since there was a desire to avoid joysticks and keyboards, some activity in FiRSTE is done by voice command. For instance, consider the act of mitigating a spill. The survey team can do this by throwing blankets or tarps over the contamination to reduce the diffusion. To pick up a blanket, a first responder must merely walk over it.

Figure 1 shows a trainee from the perspective of his or her survey buddy. The blanket is carried to the contamination site. When the first responder is ready to drop the blanket, he or she calls out “Dropping blanket” and an operator performs a keyboard operation that drops the blanket. This key strike is also communicated throughout the federation so that the WMD federate now knows it has one less source. This will be reflected in the values it reports from this point forward. There are other times an operator must intervene. This includes turning on/off the flashlight, removing the PID from the heads up display, marking a door with chalk, and causing a sudden air loss. Note that there is a button on the air gauge of the self-contained breathing apparatus that displays an avatar of the air gauge reading when depressed.

Evaluation Methodology

Overview and Goals

The evaluation of the FiRSTE system components and prototypes was ongoing throughout the development process. The evaluation was carried out through the collaboration of FiRSTE team’s first responder expert from the Battelle Corporation, and UMR’s Laboratory for Information Technology Evaluation (http://campus.umr.edu/lite). The evaluation to be described here is the summative evaluation of the prototype system, consisting of three exercises.

The fundamental goal of the FiRSTE project was to create a prototype, which would demonstrate the feasibility of a virtual environment as a viable tool for training first responders to weapons of mass destruction. Therefore, the first goal of the evaluation was to determine the degree to which the environment provided a realistic training experience, by considering participants behavioral and physiological responses within the environment, and their self report following the experience. A second goal was to determine the factors that appeared to be most important in mediating the degree to which the environment was experienced as realistic. The third goal was to identify additional functions that could be added that would increase the effectiveness of the environment, by soliciting suggestions from the participants after they experienced the environment.

Participants

Seven first responders and two incident commanders participated in these exercises. The first responders were from the Rolla Missouri fire department, the Waynesville Missouri Rural Protection District (WRFPD), and the Fort Leonard Wood Fire department, in exercises 1-3 respectively. Two responders served in each exercise with the exception of exercise three, which included three responders. In exercise three, one responder participated in day one; a second in day two; and a third participated both days. A captain from the Rolla fire department served as the incident commander for the first exercise and a trainer from the Battelle Incident Response Training Team, with a great deal of experience and expertise in first response, served as the incident commander for exercises two and three. All of these participants had the appropriate certifications and training, and would, in fact, be among those most likely called upon first should an incident occur, such as those depicted in the simulations.

Materials and Equipment

FiRSTE System

For these exercises two interfaces were set up in the same room so the two FiRSTE responders were close enough to communicate verbally and the incident commander was also placed close enough to the interfaces to communicate with the responders. One of the interfaces utilized the treadmill for locomotion and one used the Virtual Environment Navigation Pad (VENP), described in detail above. Both responders wore air tanks as they would in a real first responder situation, and masks that were modified to allow for the inclusion of head mounted displays. The masks were also modified to minimize any vision beyond the display so that the responders only visualized the virtual environment. Two virtual environments were created for the exercises, and each environment supported two “vignettes”. One virtual environment was a warehouse with a large open room and second floor with multiple rooms, including a break room, offices etc. The other virtual environment was a college campus building, which consisted of three floors and several class rooms, offices, hallways, bathrooms etc. including a particularly complex floor plan on the top floor with small offices and multiple corridors.

Vignettes

Each virtual environment supported two vignettes, and each environment was modified slightly to meet the requirements of the given vignette. These four vignettes were created by the first responder expert from the Battelle Corporation specifically for these exercises. Each vignette consisted of: a) An introduction, which described the general type of vignette and the way that it was intended to be used in training; b) An outline, which described the specific incident/information that lead up to the first responders being called to the scene; c) Immediate effects, which listed the conditions as they existed when the first responders came on the scene; and d) First responder requirements, which described the specific tasks the first responders were required to carry out. It was also emphasized on each that these vignettes only portrayed notional events and did not represent an actual event.

A two page document was created with this information for each event for the incident commander and responders to use in briefing before the events. The specifics of the first responder requirements differed somewhat from event to event, however, in general, they were required to carry out the following activities: a) Use the Emergency Response Guidebook 2000 issue as a reference; b) Use the NIOSH pocket guide as a reference; c) Provide environmental information to the Incident Commander (IC); c) Establish entry and exit routes; d) Conduct a thorough search; e) Provide detection findings; f) Mitigate hazard if possible and g) Mark contaminated areas. A brief summary of each vignette is presented in Table 1 below. It’s important to note that these synopses are short summaries of the two page versions provided to responders, which included many more details important to the response team. These two page documents were used for briefing before each event took place.

1. Campus Building Non-Terrorism Incident
Graduate students working in an agricultural lab dropped 2.5 liters of a chemical in a lab. The students began showing severe symptoms such as severe muscular twitching. An evacuation has been called for, though it is not clear if all those in the building received the warning, or if the chemical spread to other rooms, so all rooms in the area need to be checked.
2. Warehouse Terrorism Incident
Two workers in a warehouse notice a suspicious individual and upon encountering him the individual flees and drops a container, which begins to leak pressurized vapor. The two workers begin to suffer symptoms like involuntary muscle spasms and become unconscious. Some other workers are overcome in trying to help these workers. Others are evacuated.
3. Campus Building Terrorism Incident
A terrorist organization has obtained a pre-cursor for a nerve agent and authorities have reports that the pre-cursor has been hidden in restrooms in a campus building, and six terrorist are also suspected to be in the building. First responders are required to search the building for the pre-cursor.
4. Warehouse Non-Terrorism Incident
Workers at a warehouse were stacking drums and a fork-lift accidentally punctured one. Accident occurred with some workers in close proximity. 5 workers still remain unaccounted for when first responders arrive.

Table 1. Brief Summaries of Each of the Vignette's Used in the Evaluation Exercises

Event Recording Devices

As the events took place the responders were videotaped, and the activity in the virtual environment was dynamically captured. These videos were then synchronized into a four panel movie that included the activity of each responder within the interface associated with the corresponding video of the virtual environment. A screenshot of one of these synchronized movie panels is displayed in Figure 6. In addition, responders' heart rates were monitored at 15 second videos using *Cardiosport*™ wrist watches and heart monitors.

Figure 6. Screen Shot of Synchronized Video Wall Used for Analysis of Videos

Post-Questionnaire

A Post Questionnaire was used, which included a set of quantitative/Likert items that asked the responders to rate statements on a 5 point scale that ranged from “no/very poor” to “yes/very good”, and qualitative open-ended items. The quantitative items consisted of a set of items developed for this evaluation and a modified version of Witmer and Singer’s Presence Questionnaire (Witmer & Singer, 1998). The specialized questionnaire consisted of the following items: a) An item rating the overall concept; b) Three items about the effectiveness of the chemical contamination representation and sensor instruments; and c) An item rating the ability of the simulation to meet training tasks. The presence questionnaire consists of five subscales: a) “Involved/Control,” which includes items that address perceived control of events, responsiveness to user initiated actions, how involved in the experience the participant became; b) “Natural,” which measures the extent to which the interactions felt natural, the environment was consistent with reality, and how natural was the control of locomotion; c) “Interface Quality,” which address whether control or display devices interfere or distract from task performance and the extent to which the participants felt able to concentrate; and d) “Resolution,” the effectiveness/realism of the environments resolution. The qualitative open-ended items asked responders to comment on strengths and weaknesses of the system.

Procedure

The evaluation consisted of four exercises, and each exercise consisted of a number of events. Exercise 1 consisted of two events, and exercise 2 and 3 consisted of four events. Exercise 1 was carried out on April 21; exercise two was carried out on May 17; and exercise three was carried out on June 28 and 29, all in 2004. For the first two exercises, the events were carried out in one day. In exercise 3, two events were carried out the first day and two events the second day. The events took between 11 and 24 minutes. Each event utilized one of the vignettes described earlier.

Date	Exercise.Event	Vignette
April 21	1.1	(#2) Warehouse Terrorism Incident
April 21	1.2	(#3) Campus Building Terrorism Incident
May 17	2.1	(#2) Warehouse Terrorism Incident
May 17	2.2	(#3) Campus Terrorism Incident
May 17	2.3	(#1) Campus Non-Terrorism Incident
May 17	2.4	(#2) Warehouse Terrorism Incident
June 28	3.1	(#4) Warehouse Non-Terrorism Incident
June 28	3.2	(#3) Campus Terrorism Incident
June 29	3.3	(#2) Warehouse Terrorism Incident
June 29	3.4	(#1) Campus Non-Terrorism Incident

Table 2. Dates and Vignettes Associated with Evaluation Events

Each event began with a briefing session where the incident commander and responders reviewed the vignette. Following the briefing, participants went to a different room where the equipment was set up. The responders took assigned stations using either the treadmill or VENP device for locomotion and put on equipment with the help of experimenters. (Responders alternated between the treadmill and VENP). The incident commander was placed in close proximity to both responders in order to facilitate communication. The responders were given a few minutes to use their locomotion devices to explore the outside of the virtual structure they would enter for the exercise. Following this, heart rate monitors were started and responders stood in place for a few minutes to establish a base line heart rate. Recording equipment was started and the event then began. After the responders completed the bulk of their required activities they exited the virtual structure and the incident would end. The events took from 11 to 24 minutes. After completion of each event, responders took off their equipment, exited the room, and went to the briefing room to complete the post test questionnaires.

Evaluation Results

Field and Video Notes

Description

Researchers used two different types of qualitative data collection methods. First, detailed field notes were recorded by an observer (RH) for each event. During the event, RH noted the physical interaction between the participants and equipment and verbal interaction amongst the participants. Second, for the majority of events, external videos of the responders and internal videos of the virtual environment were recorded and synchronized by a second observer (JW). The video-recordings consisted of 2 hours and 5 minutes of recorded activities. The video recordings were reviewed and JW noted activities and interactions seen on the videos. Both sets of data were then analyzed to determine: (a) the degree to which the exercises were realistic and meaningful; b) factors that lead to or detracted from these outcomes; and c) any other relevant phenomena that emerged from the data that effected the participants' interactions.

The field notes and video notes differed in the following ways: a) The field notes were recorded during the event, while the video notes were taken while reviewing the videos two weeks after the final event.. Thus, the field notes were more sensitive to nuances of the live situation, while the video analysis allowed for a more reflective analysis since the videos could be viewed in detail multiple times. b) The field notes consisted of a set of statements about the activity, while the video notes consisted of summaries, interpretation, and supporting examples. The field notes were written as brief bulleted statements intended to record actions as literally as possible without interpretation. This resulted in a set of statements that could be categorized and counted for a descriptive quantitative analysis. The field notes were categorized and summaries of categories were gleaned from the notes within each category. With the videos, the ability to view multiple versions, fast forward, rewind etc. precluded the need to record the same level as detail found in the field notes. Therefore, the video notes were more general and interpretative, and did not lend themselves to the same quantitative descriptive count as with the field notes.

After both observers independently reviewed their respective sets of data (i.e., field and video notes) they began to analyze and categorize their findings. These initial analyses indicated that technical difficulties associated with hardware and software most strongly accounted for unrealistic and non-meaningful activity. Most of these difficulties could be attributed to either an external hardware problem or problems with the software that controlled the virtual environment. Second, the analysis indicated that the first responders did have real and meaningful interactions with the virtual environment. These interactions took the form of activities that were performed according to protocol, or activities where mistakes occurred in which responders did not act in accordance with proper protocol, or got lost in the environment. In these activities, the first responders had difficulties that could also easily occur in the "real world" and were not the result of technical system difficulties. Finally, the analysis indicated that communication played a very important role in these activities, particularly in adding a dimension of realism to the activities.

From the analysis emerged a set of categories. These categories were a) Realistic Activity – correct; b) Realistic Activity – incorrect; c) Technical Problems – Hardware; d) Technical Problems - Software; and e) Communication and Collaboration. The communication category included communication between the responders and among the responders and the incident commander. The communication category is not mutually exclusive with respect to the other categories and is represented as a different dimension that cut across the other categories, as noted below in the frequency analysis of the field notes.

Frequency

The field notes consisted of a set of bulleted single statements, representing a verbatim description of an observed activity, each statement was classified in one of the first four categories described above. Most statements were easily identified as falling into one of those four categories. However, there was a great deal of overlap between the first four categories and communication/collaboration category. For example, a statement that involved communication between the responders and the incident commander was within one of the task activity categories and the communication/collaboration category. Therefore, the statements were categorized according to an activity dimension consisting of the first four categories as levels and a second communication dimension, which was divided into three levels: a) communication among the incident commander and one or more of the responders; b) communication between just the responders; or c) a statement that did not involve communication. Each statement in each event was then classified according to these two dimensions and the resulting frequencies are displayed in Table 3.

Communication Dimension	**Activity Dimension**				**total**
	Realistic Activity		Non-Realistic Activity		
	Correct	Incorrect	Hardware	Software	
CC	93	18	6	1	118
CR	15	4	1	3	23
NC	64	14	30	20	128
total	172	36	37	24	

CC: Communication with incident commander; CR: Communication Between Responders; NC: No communication

Table 3. Frequency of Statements in Each Task and Communication Category

Summary of Results by Categories

What follows is a summary of the results based on the field notes and video analysis within the context of the five general categories. Following each summary are examples from the field notes and/or the video representing the summary. Video clips from the exercises that are referred to in the examples have been posted on the web in *real media*® format at *http://campus.umr.edu/firste/clips*.

Realistic activity correctly performed. As noted in the frequency data in Table 3, most common statements relate to correctly performed realistic activity. Further, the majority of these statements included some form of communication between the responders and the event commander. Most of these statements indicate a situation in which the responders reported their status to the commander. They sometimes consisted of a fairly rapid exchange among the commander and both responders with regard to how to proceed with a given situation. This was especially true when the responders located particularly important information such as some sign that a chemical incident had occurred based on the scene or readings. An example of this is illustrated in a series of statements from exercise/event 2.1 where the responders find evidence of toxic chemical levels and an unconscious body. At the same time, they were almost out of oxygen. This resulted in a great deal of communication with and direction from the incident commander. A series of statements from the exercises follow:

- *treadmill responder giving readings to the captain .. it appears there is something present*
- *report that they have found a gas can and that readings are increasing*
- *captain notes that oxygen is at 15 minutes*
- *treadmill responder notes that there is nothing to mitigate with and asks captain for advice*
- *captain advices that they should just look for breaches in container and then leave/exit*
- *captain asks for readings*

  …
- *treadmill responder calls captain and says they are exiting structure*
- *Captain reminds them that they need to keep each other in sight*
- *Captain asks how they are on air*
- *Treadmill responder reports victim found at bottom of stairwell*
- *VENP responder says he spots a second victim ("suspect")*
- *Captain asks what readings are.*
- *Treadmill responder says "22.9" … captain says "on what?"*
- *Two responders compare readings and they sound similar, report what the reading is on "VC"*
- *Captain "been in approximately 8 minutes"*
- *Tread mill responder heads into other room followed by VENP responder*
- *VENP "I picked up something in that room, see that" Captain "Where do you want to drop it at" … his numbers are going off chart …*

The video analysis also indicated that correctly performed realistic activities constituted the majority of activities. This analysis indicated that a typical activity of this sort consisted of a close interaction between the routine activities of the responders integrated with constant communication with the incident commander. The video analysis also indicates that these activities were associated with a high degree of presence and immersion with responders and commanders largely "in character during these types of activities". The following example is recorded in the video notes for exercise 2.2.

> *The responders enter the men's restroom and pick up the tarp located in the room. They then located the hazard in the last stall, report readings to the commander, and mitigate the hazard by throwing the tarp over it.* (video example 1)

Realistic activity incorrectly performed. The vast majority of the statements that were assigned to this category represented the responders being lost within a building, or losing sight of each other. As with the correctly performed tasks, many of these statements were also classified as representing communication with the commander. In a typical incident the responders would become lost within the building, or would lose one another; they would then begin communicating with one another and the commander to seek help in rectifying the situation. The following representative set of statements, comes from exercise 2.2.

- *Captain asks "where art you at?" ... "see the door right to your right" --- i.e., captain is directing them as to where to find the stairway*
- *Downstairs trying to figure the way out ... Treadmill responder asks "near what room number did we come in at" ... Captain notes that, if numbers are getting smaller than you are going the wrong direction ... directing them to the correct room ... having some problems ... pretty lost ...*
- *Captain "wait a minute go back" ... give them explicit directions about where to go ... Captain "where are you now" Treadmill responder "in that big room" ...*

The video analyses also indicated that the most common type of mistake made was responders getting lost or losing sight of one another. There were also a few cases where they forgot to check a specific location that was indicated by their briefing. As with the other realistic activities, the video analysis indicated that the responders were clearly acting in character. They were demonstrating some degree of stress, while staying on task in attempting to correct mistakes. The phenomenon of getting lost within a dark building with a number of corridors and rooms, which the responders had not encountered before, seemed quite believable and realistic. The phenomenon of getting lost is exemplified by the end of exercise 3.3, when the responders performed all their activities well, according to protocol up to the point that they were leaving the building, At that point, they had trouble locating the place where they had entered.

> *One responder asks, as they attempt to exit "we came in over here, that's right?" As she comes to recognize that this is not the correct exit she says "shoot, where did we come in?" The other responder asks "did we go in that door?" to which she replies "which one, over there?". He says "no, back over here". She then remembers that the door her partner points out was where they came in and said "oh, that's right we came in on the other side."* (video example 2)

Unrealistic activity due to hardware problems. The bulk of the hardware difficulties were associated with the VENP device, although this appeared to differ significantly from one event to another, indicating that some combination of the calibration, set up and/or individual differences played an important role. The VENP device was consistently slower than the treadmill so, the responder often had trouble keeping up. This was more extreme at times when the VENP was not responsive and on a few occasions the VENP had to be recalibrated in the middle of an event. It's important to note, that during hardware difficulties, the communication went down – noticeably different than the incorrectly performed realistic tasks when communication would increase - most of the hardware difficulties notes were classified as non-communication. Exercise 1.1 was one of the events that was most effected by the VENP hardware difficulties. The statements classified as hardware difficulties for that event/exercise follow.

- *VENP responder had some trouble catching up*
- *VENP responder got stuck*
- *Had trouble getting out of break room (VENP responder)*
- *VENP responder had to stop and unwind chord*
- *VENP responder has difficulty getting through door*
- *VENP responder definitely seems to be having more trouble locomoting with speed and with direction*
- *VENP responder appears to be stuck against the wall and not moving*
- *VENP responder having trouble keeping up …*
- *stuck on wall again (VENP responder)*
- *lots of difficulty navigating through boxes for VENP responder*

The video analysis was consistent with the analysis of field notes – there were few software difficulties outside of problems with the VENP device. The video analysis also indicated some additional insights into these hardware challenges. First, it illustrated, in more detail, the specific problems associated with the VENP. These problems included a) the VENP not responding; b) avatar moving backwards when the responder was trying to move forward or vice versa; c) the cords attached to the sensors worn by the responder with the VENP sometimes becoming tangled, requiring the exercise to stop while the responder unwound; d) responders, in a few cases, stepping on the edge of the pad and having trouble keeping their balance. Second, the video analysis indicated that the problems were largely dependent on the given event. As mentioned earlier, video analyses were only carried out for exercise 2 and 3. The VENP problems occurred most dramatically in exercise 2.1 and 3.1. There were almost no difficulties in 2.2 – 2.4, with a moderate number of difficulties in 3.2 – 3.4. This indicates that the VENP difficulties were probably associated with given responders or settings, and could probably be alleviated with some more detailed study of the conditions under which the VENP works most effectively. The video analysis also indicated more dramatically that the degree of presence exhibited by the responders clearly decreased as a consequence of these technical difficulties. The problems with the VENP caused frustration that would not be a part of a "real world" scenario. Exercise 3.1 had a number of difficulties with the VENP as illustrated by the following problems identified in notes associated with the video analysis of that event.

- *The VENP is moving backward when it should be moving forward (5 instances)*
- *The VENP responder is having difficulties with the overhead cabling being in the way*
- *The VENP responder is having trouble maneuvering around the boxes.*
- *The VENP responder loses his balance due to the sensor pad but is supported by the handrail.*

- *The VENP responder is too tall and has to bend under the cabling.*
- *Stepping in the wrong place on the VENP can cause the sensor pad to become unstable. (2 instances)*
- *The VENP is moving forwards when it should have not been moving. (3 instances)*
- *The VENP is staying in place while it should have been moving forward. (3 instances) (video example 3)*

Unrealistic activity due to software difficulties. The relatively few software difficulties consisted of: (a) on a few occasions a responder got "stuck" behind a door and couldn't close it; (b) complications when a computer operator had to intervene to push a key for some activity, such as dropping a blanket on a spill or marking a door; and (c) most dramatically, the program failed ("crashed") during two of the ten events. In one case the event began from where it left off and, in the other case, it was near the end of the event, so that responder's environment was not re-started.

The video analysis also indicated that, overall, there were few software problems. However, it also indicated that there were problems with responders getting "stuck" in the doors on several events, though usually no more than once or twice per event. One exception was exercise 2.3 where there were a number of problems with one responder having difficulty getting through doors. This clearly negatively impacted the degree of presence this responder felt in the environment. The video analysis also revealed that there were some cases where objects in the environment appeared unnatural, such as a responder appearing to hover above the floor as they walked, though these did not occur frequently and they did not appear to affect the responders' degree of presence in the environments. Exercise 2.3, in which the responder had a number of problems with the doors is illustrated in the following notes from the video analysis.

- *A door closes on the VENP responder right as he reaches it.*
- *Another door closes as the VENP responder enters and causes him to be pushed back.*
- *A door opens towards the VENP responder and pushes him backwards.*
- *A door closes on the VENP responder and he became stuck on the door. The door pushed him back when it closed and forwards as it reopened.*
- *The VENP responder reports "them doors are kicking my freaking ass."*
- *The VENP responder attempts to enter a room, but the door only partially opens and then rapidly starts closing and opening.*
- *A door pushes the treadmill responder backwards as it opens.*
- *The VENP responder gets stuck behind an open door and a wall and has to backtrack to a different exit.* (video example 4)

Communication and Collaboration. As noted above, in the discussion of the field notes analysis, communication, particularly among the commander and responders, was a central part of most of the activities carried out in the events. This communication clearly added to the realism and perceived presence of the responders. In fact, communication between those participating in these types of emergency events is central to the successful performance of duties. It was also clear that communication decreased significantly during technical difficulties and this, in turn, significantly decreased the meaningfulness of the exercise.

An illustration of the two responders working together is provided by a scenario recorded in the video analysis at the beginning of exercise 3.3

> *The commander asks one of the responders to lead the team and the responder indicates to partner "follow me." The responder in the lead periodically asks partner if he is following and occasionally turns around to verify. As they come to the stairwell one partner notes unconscious bodies and reports "ah, we got a few bodies." They report the levels on their recording devices. They discus the hazard and one responder notes that she can not look down due to lack of these types of sensors on the treadmill device, so they other comes to her aid and they note this is appears to be a bottle that contains the hazard. They report this to the commander.* (Video example 5)

The communication and collaboration aspect played a key role in improving the presence of the participants. The more they were able to communicate with each other and collaborate in their activities, the more realistic the exercise was to them.

The analysis of the qualitative data highlights both the strengths of this virtual environment and the challenges in making it realistic. When the participants are able to communicate with each other and interact with the virtual environment without problems, the experience was realistic to them. However, when problems such as hardware or software failure occurred, the realism failed for the participants.

In the next section, we describe other data collected during these experiments.

Heart Rate

The heart rate data was included primarily to assure that the exercise was physically demanding, since this was an important requirement identified early in the project. Heart rate data was collected for exercises two and three, at 15 second intervals. Table 1 below displays the base heart rate (average of two minutes of reading preceding exercise) and the average heart rate during the exercise for each event, and each responder in exercises 2 and 3.

In order to examine changes in heart rate over the course of the events and to standardize these changes across exercises and events that differed in total time from 11 to 24 minutes, the scores were divided into ten sets for each exercise, each representing 10 percent of the total time. Readings for each 10 percent segment were averaged. Table 3 is the average of all of these segments across events.

Event/	device	Mean Heart Rate

exercise		Before Exercise	During Exercise	% Increase
2.1	VENP	70.40	75.60	6.88
	Treadmill	94.80	94.43	-.39
2.2	VENP	59.80	70.17	14.78
	Treadmill	72.60	91.59	20.74
2.3	VENP	97.00	106.83	9.83
	Treadmill	73.25	78.50	5.25
2.4	VENP	74.33	96.40	22.07
	Treadmill	65.20	78.08	12.88
3.1	VENP	96.60	106.15	8.99
	Treadmill	74.60	91.16	16.56
3.2	VENP	88.20	92.72	4.88
	Treadmill	99.40	105.55	5.83
3.3	VENP	83.75	89.53	5.78
	Treadmill	71.60	88.25	18.87
3.4	VENP	79.20	86.16	6.96
	Treadmill	71.60	88.82	9.39
Overall mean		79.52	90.00	10.48

Table 3. Mean Heart Rate Before and After Each Exercise and Percent Increase

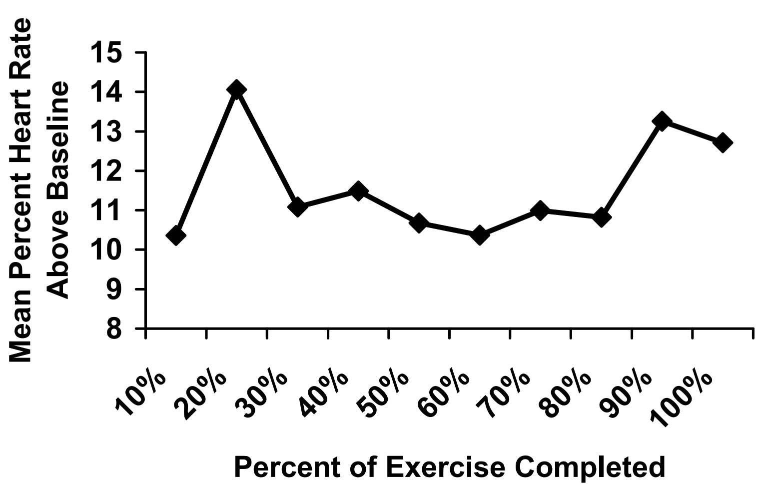

Figure 7. Heart Rate Over the Course of Events for all events and responders combined.

Post Questionnaire

Mean Responses

Table 4 displays the mean questionnaire scores for the specialized items and scales of the Presence Questionnaire (see questionnaire description in the materials section above).

Item/Scale	Mean**
The overall concept of using a simulation as an enhancement to your formal training.	4.89
The position and appearance of contaminant zones.	3.88
The ability to perform sensor functions.	3.67
The simulated detector as a tool to conduct monitoring and detection.	3.92
The ability of the simulation to meet training tasks.	4.89
Presence Questionnaire Subscale: Involvement/Control*	4.14
Presence Questionnaire Subscale: Natural*	4.32
Presence Questionnaire Subscale: Resolution*	3.31
Presence Questionnaire Subscale: Interface Quality*	3.47

*Mean of items that make up the scale.
**Scale: (1 = no/very poor; 2 = poor; 3 = neutral; 4 = good; 5 = yes/very good)

Table 4. Mean Responses on Questionnaire Items and Scales

Open Ended Responses

As mentioned above, the responders answered a set of open-ended questions on the questionnaire, which were aimed at determining ways that the system could be improved. An examination of the comments indicated that they could be grouped into three categories. These categories, a description, and representative comments follow.

Category 1: Difficulties with the VENP device. Not surprisingly, based on the field note and video analyses, many of the suggestions for improvement centered on the VENP locomotion device. Responders pointed to the problems identified above, that the VENP was not responsive to their movement, and that the chords attached to the sensors included on the VENP device were often distracting. Finally, it was sometimes difficult for the responders to keep their balance.

Representative comments:

- The platform system needs to be more stable, larger and with a safety area to avoid trips or falls caused by vertigo from the scenario.
- Some way to have wires and cords swivel overhead, as opposed to becoming more tangled as you turn.
- The walking pad needs some work, there were times when I was walking that I did not move and I had to move around a little to be able to walk.

Category 2: Realism of VENP device. Despite the comments with regard to the difficulty of locomotion with the VENP, a number of responders noted that the VENP created a more “realistic” experience and some even expressed a preference for the VENP as a tool for training. With the VENP system the responders were required to literally turn on the pad in order to turn in the environment, while on the treadmill this was accomplished by turning a wheel on the PID device they were holding in their hands. Also, the VENP system included sensors attached to the body, which was the reason for the chords that often interfered, that allowed the responders to literally turn from side to side or look down in order to achieve the same movement in the virtual world.

Representative Comments:

- I liked using the VENP better than the treadmill.
- I liked being able to move around on the pad like you were walking around.
- The VENP was more real like than the treadmill. Treadmill it was too easy to turn.
- While on the Treadmill, I would like to be able to look down and up.
- The wheel mouse on the treadmill works well, but is not realistic.

Category 3: Additional Interaction Functionality. Many of the additional comments were requests for significant increases in functionality, such as increasing the ability of the responders to interact with the environment via tactile senses; increasing the number of possible emergencies and complexity of measurement devices; increasing the realism of the surviving victims; adding more realistic sounds; and adding more ways for the first responder to directly control the environment, in general.

Representative Comments:

- Hands, so you can pick up the tarp and check the victim for pulse.
- More sensor types, more H-M types, solids, liquids, gas clouds.
- Interactions w/victims.
- More hands on functions not just a blanket and analyzer.
- More sound.

Conclusions

Goal 1: Realistic and Meaningful Training Experience

The data from all of the analyses indicated that the FiRSTE system did, indeed provide a meaningful training experience for first responders. The responders clearly spent the majority of their time in the environment carrying out meaningful activities, "in character", and exhibiting a high degree of presence. This was also supported by the heart rate data which indicated a large increase in heart rate for the responders in comparison to their heart rate before beginning the exercises, and the heart rate remained at a high rate throughout. Mean scores well above the mid-point on Witmer and Singer's presence questionnaire further supported the contention that the environment provided a realistic training experience for the participants.

Goal 2: Mediational Factors that Effected Realism

Communication proved to be intimately related to the realism of the virtual environments. The video analysis, in particular, points to the exercises as a rich interplay of activity and communication, where the responders are constantly communicating to one another and with their incident commander soliciting direction and providing feedback. It seems clear that the realism of the events relied heavily on the human interaction that the FiRSTE system affords. Interestingly, communication appeared to increase as activities became more challenging and responders made errors, such as getting lost. These mistakes in protocol and associated communication, rather than decreasing the degree of realism, appeared to enhance it. One would expect responders in the "real world" in a dark environment, with only flashlights, with a number of rooms and hallways, and the task of locating dangerous contaminants to have similar difficulties. Such difficulties appeared in a realistic fashion in the FiRSTE environment. This indicates that it is particularly important that these virtual environments include challenges that reflect the "real world" as much as possible.

The factors that most detracted from the degree of presence experienced by the responders were technical problems. In particular, the Virtual Environment Navigation Pad (VENP) exhibited technical difficulties. The device was periodically unresponsive to the participants' movement. In addition, responders who used the pad also had sensors on their bodies to detect movement of the body and the cords attached to these sensors some times interfered with movement. The fact that these difficulties interfered with the realistic flow of events in the virtual world is illustrated vividly in field notes and videos of the responders' activities. Interestingly, participants reported that the pad, when it was functioning correctly, provided a greater degree of realism than a treadmill which served as the second locomotion device. The fact that the responders movement on the pad, such as turning and bending, was directly translated to the virtual environment enhanced the degree of presence they experienced in the environment. This contrast illustrates a basic challenge to developers of these environments. The most realistic and interactive types of devices, which can lead to a greater degree or realism, are also most prone to technical difficulties, which can significantly detract from the realism of the environment.

Goal 3: Additional Functionality

When participants were asked how the system could be improved to enhance the training experience, most suggestions pointed to extending the existing environment to include more sophisticated interaction. A number of the responders suggested that the system could benefit from the addition of a tactile system, such as sensors included on the hands, which would allow them to handle objects in the environment. Similarly, they asked for a greater degree of interaction with the victims in the environment who were injured yet still alive. They also noted the importance of auditory phenomena in "real world" scenarios such as the sound of gas escaping from a container, which were not present in the FiRSTE system.

With respect to these suggestions, it's important to point out two important qualifications. First, although such improvements would very likely improve the environment's effectiveness, it's important to note that the addition of such functionality would significantly increase the cost of the system and the technical sophistication. As noted, the technical sophistication can also lead to more technical problems, which can have a negative impact on the system's effectiveness. Second, note that the suggestions for improvement were largely suggestions to extend, as opposed to modify, the FiRSTE system, indicating that the FiRSTE prototype can serve as an important foundation for future development.

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Acknowledgements

This work was supported in part by a grant from the U.S. Army's Tank-automotive and Armaments Command (TACOM, grant # DAAE07-02-C-L068).