5-2017

Integrating Virtual Reality with Use-of-Force Training Simulations

Ted Mader
University of New Orleans

INTEGRATING VIRTUAL REALITY WITH USE-OF-FORCE TRAINING SIMULATIONS

An Honors Thesis

Presented to

the Department of Computer Science

of the University of New Orleans

In Partial Fulfillment

of the Requirements for the Degree of

Bachelor of Science, with University High Honors

and Honors in Computer Science

by

Ted Mader

May 2017

Table of Contents

List of Figures iv

Abstract v

Introduction 1

Motivation 1

Introducing Virtual Reality 3

Related Work 3

Hardware and Tools 4

HTC Vive 5

Headset 5

Unity 6

Development Process 7

Building the Module 7

Modifications to Simulation 8

Simulation Walkthrough 10

Evaluation 12

Experimental Design 12

Presence Surveys 12

Empatica E4 14

Risks 14

Testing Process 14

Hypotheses 15
Survey Data 15
Physiological Data 16
Results 16
Discussion 19
Conclusion 20
Bibliography 22
Appendix 1: Presence Questionnaire 24
Appendix 2: Introduction Video Script 25
Appendix 3: Screen and Keyboard Checklist and Verbal Quiz 27
General Guidelines 27
Step-by-Step Checklist 27
Verbal Quiz 28
Appendix 4: Virtual Reality Checklist and Verbal Quiz 29
General Guidelines 29
Step-by-Step Checklist 29
Verbal Quiz 30

List of Figures

Figure 1. A virtual environment in the police use-of-force training simulation. 2

Figure 2: HTC Vive accessories included diagram 5

Figure 3. Diagram of transformations to police use-of-force simulation by the virtual reality module 8

Figure 4. File structure diagram of virtual reality module... 8

Figure 5. An overview of the virtual environment for the scenario. 9

Figure 6. Dialogue guides users how to interact with virtual characters and use the gun. 10

Figure 7. The police officer interacts with the suspect, and the suspect attacks using a knife... 11

Figure 8. A question from the survey to compare the types of controls. 13

Figure 9. Results from positive questions. 17

Figure 10. Results from negative questions. 17

Figure 11. Physiological data from the Empatica E4 wristband for each participant....... 18

Figure 12. Results from numbers of participants with supporting physiological data..... 18

Abstract

This project identifies improvements to *presence* and *immersion* in a simulation by integrating virtual reality technology. This simulation provides a virtual environment for training police officers in the use of force when resolving potentially dangerous situations. We integrate the HTC Vive virtual reality system with a previously developed prototype 3D virtual environment that uses artificial intelligence techniques for generating narratives. The interactions made possible with virtual reality technology provide an effective alternative to traditional mouse and keyboard input, and they evoke feelings in users that the events are actually occurring and reacting. Our hypothesis predicts that users experience a greater sense of presence when using virtual reality hardware to interact with the simulation.

Keywords: computer science and technology, virtual reality, presence, HTC Vive

Introduction

This project involves developing a highly immersive interactive training simulation built with cutting edge commercial virtual reality (VR) technology. This simulation provides a virtual environment intended to train police officers in the use of force when resolving potentially dangerous situations. The previous iteration of this simulation consisted of a prototype 3D environment that players viewed on a monitor and controlled via mouse and keyboard. Virtual reality technology allows the development of an environment that will further engage users.

Providing increased realism improves effectiveness of the police use-of-force training simulation [1]. This is accomplished by bringing the training simulation into virtual reality by integrating:

- A head-mounted display that allows users to look around at any part of the virtual environment by head movements.
- Wireless handheld controllers that allow users to interact with objects in the virtual environment by hand motions and room-scale movement.

Improvements brought by these integrations were measured using subjective and objective metrics for *presence* and *immersion*, which are emerging as standard measures of the effectiveness of VR experiences [2, 3, 4].

Motivation

Interactive virtual environments provide users a setting for exploration, interaction, learning, and experiencing consequences. This safe and engaging context can be utilized effectively in education and training [5, 1, 6]. For our purposes, we leveraged virtual environments for training new police officers in using an appropriate level of force when resolving potentially dangerous situations.

Figure 1. A virtual environment in the police use-of-force training simulation.

The prototype 3D virtual environment developed by the PI and computer science graduate students leverages artificial intelligence techniques for adaptation and personalization of the virtual environment's narrative, based on user behavior. These techniques rely on algorithmic solutions for generating and adapting structure for effective narratives. Allowing participants to take the role of a character and engage in and construct narrative with virtual agents through their actions enhances *agency* in the virtual environment [7]. However, this prototype uses conventional keyboard and mouse as input devices and a monitor for display, and its effectiveness could be improved with virtual reality technology. Allowing a user to interact using their head, hands, and feet would improve the virtual environment's ability to generate a feeling of *presence* – the subjective experience of being in a different environment than one's current real world location [2, 3, 8].

Introducing Virtual Reality

Companies have recently been developing affordable, widely-available virtual reality hardware. The technology's potential rises as businesses continue to aggressively invest in virtual reality hardware development. Furthermore, existing software tools allow easy integration of the hardware, providing an opportunity for building on the police use-of-force training simulation.

After introducing a head-mounted display and wireless handheld controllers to the existing simulation, a study was conducted to compare the ability of VR technology to invoke feelings of presence and engagement against that of traditional input devices. The study measured these abilities using established subjective and objective metrics during the evaluation of the simulation's effectiveness [3, 4].

Related Work

Simulations are an effective method of preparing professionals for highly complex working environments [1]. Digital training systems provide cost-effective solutions for preparing business, academia, industry, and military personnel for functioning in real-world scenarios that are difficult to replicate in a classroom environment [6]. However, the effectiveness of virtual reality simulations depends on their ability to eliciting realistic behavior in users. Slater identifies two important factors for influencing realism in virtual reality simulations: *plausibility illusion* and *place illusion* [8].

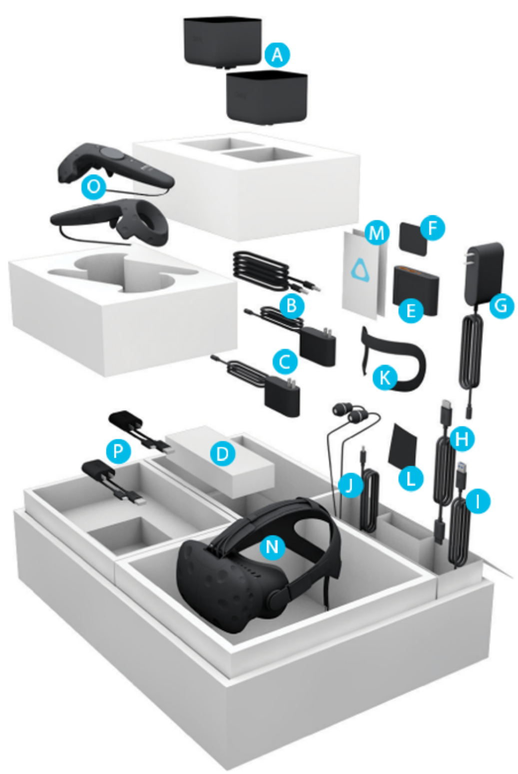
Evoking feelings in users that the events within the simulation are actually occurring and reacting to the user creates *plausibility illusion*. Artificial intelligence techniques for generating narratives are utilized to improve plausibility in the police use-of-force training simulation [9]. Creating the sense of being actually present in the virtual environment attributes to *place illusion*, which we will refer to as *presence* [6]. This project focuses on improving presence in the simulation by providing a more convincing environment using virtual reality technology.

Hardware and Tools

Before the recent massive resurgence of virtual reality technology, for decades, previous attempts at creating commercially successful virtual hardware have failed [10]. These failures have been attributed to problems such as high costs, lack of compatible software, and motion sickness in users. However, since Oculus's successful crowd-funding of their Rift virtual reality headset on Kickstarter, businesses such as Google, Facebook, Microsoft, Sony, HTC, and Samsung have begun aggressively investing in the research and development of virtual reality technology. This has led to the release of several affordable, widely supported virtual reality systems.

HTC Vive

The HTC Vive[1] is a virtual reality system developed by HTC and Valve Corporation. It allows users to interact with virtual worlds as themselves, rather than a character in the world. The HTC Vive bundle includes a virtual reality headset, two wireless handheld controllers, and two 'Lighthouse' cameras. The headset contains screens for each eye and sensors for motion tracking. Each controller is wireless and battery powered, allowing users to interact with the virtual world using a multi-function trackpad, dual-stage trigger, grip buttons, and menu button. Two wireless infrared "Lighthouse" cameras perform motion tracking for the Vive virtual reality system. These are ideally placed in corners of the room, and follow a total of 70 infrared sensors. The complete kit contains nineteen total items:



A. 'Lighthouse' cameras
B. Sync Cable
C. Base station power adapter x 2
D. Mounting kit
E. Link box
F. Link box mounting pad
G. Link box power adapter
H. HDMI cable
I. USB cable
J. Earbuds
K. Alternate face cushion
L. Cleaning cloth
M. Documentation
N. Headset with 3-in-1, audio cables
O. Controller (with lanyard) x 2
P. Micro USB charger x 2

Figure 2: HTC Vive accessories included diagram

[1] "VIVE™ | Discover Virtual Reality Beyond Imagination," https://www.vive.com/us/

Headset

The HTC Vive headset contains a 1080×1200, 90Hz screen for each eye, having enough pixel density to prevent the screen door effect, i.e., lines separating pixels become visible. The display uses a taller aspect ratio than other headsets, providing more vertical area for users to look around without neck movements. The current version requires connecting a bundle of cables to function, including a HDMI, USB, and power cable, and it includes a 3.5mm jack for headphones. The headset contains 37 sensors, including a gyrosensor, accelerometer, and laser position trackers.

Unity

The simulation prototype is built on Unity[2], "a cross-platform game engine with a built-in IDE (integrated development environment) developed by Unity Technologies. It is used to develop video games for web plugins, desktop platforms, consoles and mobile devices." Additionally, the HTC Vive and Unity are extremely compatible for virtual reality development, with the assistance of a few libraries. The SteamVR SDK[3], an official library developed by Valve, provides a set of tools for simplifying Unity development with all major virtual reality headsets. Another useful library is VRTK[4], a toolkit for building VR solutions in Unity. It provides a collection of useful scripts and concepts to cover a number of common solutions such as movement, interaction using touching or grabbing, and controls mapping.

---

[2] "Unity – Game Engine," https://unity3d.com
[3] "SteamVR," https://developer.valvesoftware.com/wiki/SteamVR
[4] "VRTK "Unity – Game Engine," https://unity3d.com– Virtual Reality Toolkit," https://vrtoolkit.readme.io

Development Process

At the start of the development process, I had been situated in my own lab space, separated from a team of graduate students in the department of computer science that worked on developing the core simulation features. Given this, I decided creating an optional virtual reality module without altering the codebase of the core simulation itself would be the best approach. This would not only result in a potentially reusable module for accomplishing similar solutions for future projects by the PI, but prevent conflicting work between myself and the partnering team.

Building the Module

I designed a structure where objects in the core simulation would be selectively transformed, configured, or destroyed for a virtual reality environment. A script called *VRManager* performs transformations to objects in the main simulation for compatibility with the virtual reality features, whereas a script called *VRControls* handles reconfiguring keyboard and mouse controls for input using the handheld controllers.

In Unity, scenes contain the objects of the virtual world. The objects handling these procedures were packaged into a scene, which I designed to be loaded with the scene containing the main scenario objects. Unity provides the ability to load multiple scenes at once, allowing this to be possible. Before making any desired changes to the main simulation, we had a working, independent virtual reality module to perform the needed changes. However, to create the best experience, changes were done to the virtual world of the main simulation to better accommodate the new means of interaction.

```
—> prefab transferred to VR scene
<— prefab remains in main scene
—X prefab is destroyed

PolicéUseOfForce                  VRManager
├── Prefabs
│   ├── FirstPersonCharacter  —X  destroy
│   ├── Pivot hands_a         —X  destroy after gun is attached
│   ├── Officer               —>  attach to [CameraRig]
│   ├── VRStartingPoint       <—  position [CameraRig] here
│   ├── Gun                   —>  attach to Controller (right)
│   │   # UI
│   ├── Canvas                <—  set render mode and world camera
│   ├── DialoguePanel         <—  configure position and scale
│   ├── PopupText             <—  configure position and scale
│   └── ErrorText             <—  configure position and scale
│
│                                 VRControls
└── Controls
    ├── Draw                      grip pressed (gun disabled)
    ├── Holster                   grip pressed (gun enabled)
    ├── Fire                      trigger pressed
    ├── OpenDialogueBox           touchpad pressed
    └── DialogueMakeSelection     touchpad touch end
```

Figure 3. Diagram of transformations to police use-of-force simulation by the virtual reality module

```
.
├── Prefabs
│   ├── VR                          # VR scene prefabs
│   │   ├── VRManager.prefab        # starts VRManager script
│   │   ├── VRSceneLoader.prefab    # starts VRSceneLoader script
│   │   ├── [CameraRig].prefab      # SteamVR camera rig configured for simulation
│   │   └── [VRTK].prefab           # VRTK configurations
│   └── VRTransition                # VRTransition scene prefabs
├── Scenes
│   ├── VR.unity                    # contains VR prefabs
│   └── VRTransition.unity          # transition scene for VR
└── Scripts
    ├── VRControls.cs               # handles simulation controls specific to VR mode
    ├── VRHandController.cs         # handles animations for BasicVRHands
    ├── VRManager.cs                # applies Steam VR features to PoliceUseOfForce
    └── VRSceneLoader.cd            # loads VR scene if VR is detected
```

Figure 4. File structure diagram of virtual reality module

Modifications to Simulation

Eventually, the PI relocated me into the main lab and integrated me with the partnering team of graduate students. Driven by feedback and requests by the PI, my team introduced various minor changes to the main simulation to better accommodate transformations applied by the virtual reality module, whilst retaining its independence from the virtual reality features. Initially, the scenario space was much larger than the room area and required a means of repositioning the play area around the game world, otherwise users would not have enough real-world space to navigate the virtual environment. I implemented a means of "teleporting" around the environment, which was eventually discarded in favor of reducing the area of the scenario world. The PI determined the teleportation feature would negatively affect immersion. In its current iteration, users can fully navigate the virtual environment by only moving around the real world. Another change to the scenario included rescaling the world to match the perception of the virtual reality user so that objects did not appear too small or large. Scripts for the simulation controls were uncoupled to allow easier reconfiguration. To improve immersion, improved player hand models, additional flora and distant landscapes surrounding the scenario area, ambient sounds, and wind effects, were added to the virtual environment.

Figure 5. An overview of the virtual environment for the scenario.

A transition scene was added to handle proper positioning of the user in the real world before the starting the scenario. In the virtual environment, the transition scene instructs the user to stand in a designated area, reflecting the ideal real world starting location. This prevented awkward interactions resulting from the player standing far from the intended starting location.

Simulation Walkthrough

The iteration of the simulation we used to collect data includes tutorial, transition, and scenario stages. In the virtual reality simulation, the transition stage requires users to position themselves before the tutorial and each attempt at the scenario. In the mouse and keyboard simulation, users can simply continue by pressing a button on the keyboard.

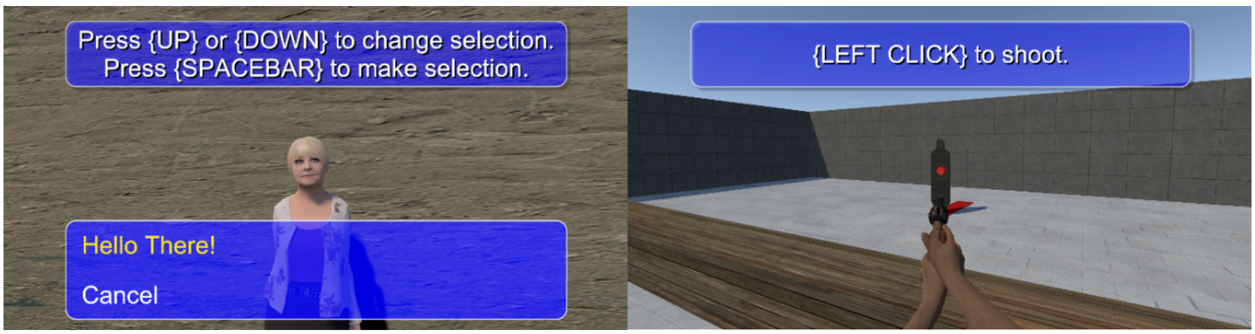


Figure 6. Dialogue guides users how to interact with virtual characters and use the gun.

The tutorial walks users through the controls using guided dialogues, describing how to move around, interact with virtual characters, and draw, fire, or holster a gun. The tutorial displays dialogue specific to the type of input used. After the tutorial, an explanation of the scenario is presented:

> *Two minutes ago, dispatch received this call from a distressed woman: "My son has been living with me for two months, and today I tried to kick him out of my house. But he won't leave! He got angry, and I got scared, so I locked myself in the house, but he's still outside pounding on the door. I think he has*

a knife. Please help me." You are the closest police officer to that address and are on your way to respond.

Users begin the scenario when ready. Users take the role of a police officer and have the option to talk to a suspect, as well as draw their gun and fire. If the police officer gets too close or points the gun at the suspect, he will begin advancing towards the officer and attack with a knife if in range. If the officer retreats to cover, the suspect surrenders.

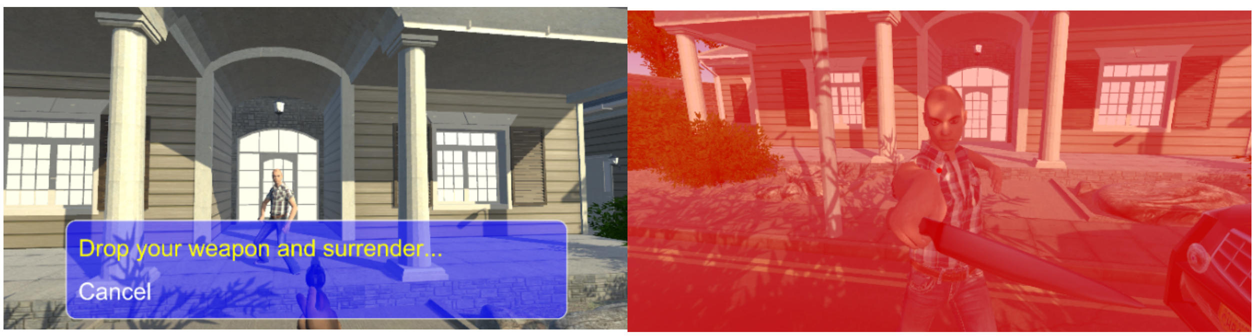


Figure 7. The police officer interacts with the suspect, and the suspect attacks using a knife.

At the end of every attempt, a score on a 0 to 4 scale is displayed. The following scores are awarded based on specific criteria:

- Score 0 if officer died.
- Score 1 if suspect died and did not threaten the officer.
- Score 2 if the suspect died and did threaten the officer.
- Score 3 if suspect surrendered and threatened the officer.
- Score 4 if suspect surrendered and did not threaten the officer.

The simulation keeps track of the number of attempts and sends users to the transition stage where they can reattempt the scenario when ready.

Evaluation

Experimental Design

My team performed a research study to gather data for a *within subjects* experiment to test the effectiveness of the virtual police training simulation. Participation involved users playing the two versions of the simulation: the desktop version using keyboard and mouse input and the version using virtual reality equipment. The sessions were expected to last about half an hour, with users capped at ten play sessions per version. The study required participants to be at least 18 years of age and will be able to choose to withdraw at any time during the study. We collected three kinds of data:

- The actions the participant takes while playing the simulation.
- Physiological data, including heart rate, skin temperature, and skin conductance.
- Answers to survey questions after sessions.

These measures have been proposed as effective methods of gauging effectiveness of virtual reality environments [11]. The collected data remained completely anonymous, and there were no means of connecting names of participants with the data. The results of the research may be published without use of the identities of participants.

Presence Surveys

Built on the underlying factors of presence, a *presence questionnaire* measures the sense of presence in users in virtual reality environments. Experimentation using this questionnaire supports reliable and consistent results that allow the evaluation of experienced presence in users [3]. The questions asked by the presence questionnaire can be viewed in appendix I. To collect data for the *within subjects* experiment, we created a survey using the original Likert Scale[5] (1 to 7) questions from the *presence questionnaire*.

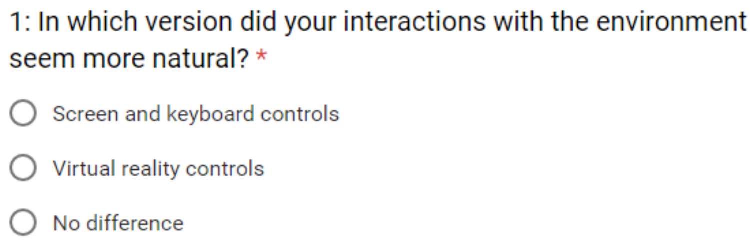


Figure 8. A question from the survey to compare the types of controls.

Instead of using the Likert Scale, we asked users to compare the two types of controls. For each question, participants selected if they favored the virtual reality controls, mouse and keyboard controls, or neither. The questions were framed either positively or negatively. Examples of positive questions are:

- "In which version did the mechanism which controlled the movement through the environment seem more natural?"
- "Which environment seemed more consistent with your real-world experiences?"
- "In which version were all your senses more engaged?"

Examples of negative questions are:

- "In which version was the information coming from your senses more inconsistent or disconnected?"
- "In which version were you more aware of events occurring in the real world around you?"

[5] "Likert Scale | Simply Psychology," https://www.simplypsychology.org/likert-scale.html

Empatica E4

The E4 wristband from Empatica monitors physiological signals in real-time. The wristband collects data to be stored in internal memory and retrieved via USB through provided software. The device measures heart rate, skin temperature, and skin conductance. Each of these physiological measures determine the following [11]:

- Increased stress, intensity of emotions, and defensive responses, i.e. fight-or-flight, increase *heart rate*.
- Increased stress results in sweat on the palms, which increases *skin conductance*.
- Increased stress decreases *skin temperature* as heat moves to the body's core.

Risks

This study involved minimal risks to participants. Depending on choices, users may have experienced violent content in the simulation, such as attacking or being attacked. When using the virtual reality equipment, users may have experienced motion sickness. Participants were able to withdraw at any time if feeling disturbed or uncomfortable. Participants may have tripped or walked into walls or furniture when using the virtual reality equipment, and were discouraged to run or jump. An investigator assisted to prevent these problems from occurring.

Testing Process

Ideally, the PI was present during a study. However, a single team member was able to carry out the required steps. We required the participant to read and sign an informed consent form, which will be kept by the investigators, and the participant received an unsigned personal copy of the form. We presented the participant with a video about the study and associated risks. The script for this video can be viewed in appendix 3. Before the first play session, investigators ensured the participant was wearing headphones and the activated sensor wristband. In order to increase randomness in the data, the PI decided to have participants play the mouse-keyboard and virtual reality simulations in differing orders. When monitoring participants during the virtual reality simulation, investigators prevented them from tripping on cables or colliding with real world objects. After the tutorial stage, an investigator performed a verbal quiz to make sure subjects understand how to interact with the simulation. In the second session, the participant played the other version. Afterwards, the participant took a survey containing questions that will compare the experiences. Checklists for the testing process steps and the verbal quizzes for both simulations can be viewed in appendices 4 and 5. In total, 22 people participated in our study.

Hypotheses

Survey Data

Our null hypothesis states we can clearly measure that there are no differences in experienced presence between using virtual reality controls and non-virtual reality controls.

The alternative hypothesis states that people experience higher presence when interacting with the simulation using virtual reality controls. In the final survey, each question served as individual hypotheses to support our general alternative hypothesis. We expected that users will select the virtual reality simulation as responses to positive questions, and the mouse and keyboard simulation to the negative questions. We considered results significant when $p < 0.05$.

Physiological Data

The null hypothesis states we can clearly measure that people do not experience any differences in heart rate, skin temperature, or skin conductance between using virtual reality controls and non-virtual reality controls.

The alternative hypothesis states that people experience higher heart rate and skin conductance and lower skin temperature when using the virtual reality controls. We considered results significant when $p < 0.05$.

Results

Using the collected data from the *positive* questions (responses with virtual reality controls are considered successful) and the binomial exact test[6], we derived the following results:

Question	P-value	Success or Failure
In which version did your interactions with the environment seem more natural?	< 0.0001	Success
In which version did the mechanism which controlled the movement through the environment seem more natural?	< 0.0001	Success
Which environment seemed more consistent with your real-world experiences?	0.0004	Success
In which version did you adjust to the environment more quickly?	0.4159	Failure
In which version were all your senses more engaged?	< 0.0001	Success
In which version did you feel more involved?	< 0.0001	Success
In which version were you better able to learn new techniques that enabled you to improve your performance?	0.5841	Failure
In which version were you more likely to have lost track of time?	< 0.0001	Success
In which environment was it easier to survey or search the environment using vision?	0.0022	Success
Which environment's visual aspects involved you more?	< 0.0001	Success
In which version were you better able to examine objects?	< 0.0001	Success

[6] "Sign and binomial test – GraphPad," https://graphpad.com/quickcalcs/binomial1.cfm

In which version was it easier to examine the objects from multiple viewpoints?	0.0262	Success
In which version was your sense of objects moving through space more compelling?	< 0.0001	Success
In which environment was your sense of moving around more compelling?	< 0.0001	Success
Which environment allowed you to control events more?	0.4159	Failure
Which environment was more responsive to actions that you initiated?	0.4159	Failure
In which environment was it easier to anticipate what would happen next in response to the actions that you performed?	0.4159	Failure
In which environment did you experience less delay between your actions and expected outcomes?	0.2617	Failure
At the end of which version did you feel more proficient in moving and interacting with the environment?	0.0669	Failure
In which version did the auditory aspects of the environment involve you more?	0.0669	Failure
In which version were you better able to identify sounds?	0.2617	Failure
In which version were you better able to localize sounds?	0.2617	Failure
In which version was it easier to concentrate on the assigned task or required activity rather than the mechanism used to perform that task or activity?	0.1431	Failure

Figure 9. Results from positive questions.

Using the collected data from the *negative* questions (responses with mouse and keyboard controls are considered successful) and the binomial exact test, we derive the following results:

Question	P-value	Success or Failure
Which version's visual display quality distracted you more from performing assigned tasks or required activities?	0.9978	Failure
Which version's control devices interfered with the performance of assigned tasks or with other activities more?	0.9978	Failure
In which version was the information coming from your senses more inconsistent or disconnected?	0.7383	Failure
In which version were you more aware of events occurring in the real world around you?	0.7383	Failure

Figure 10. Results from negative questions.

Using the collected data from the Empatica E4 wristband, we determined the following physiological measures of each participant for each type of controls:

	Screen and Keyboard Controls			Virtual Reality Controls		
	Avg. Heart Rate	Avg. Skin Conductance	Avg. Skin Temperature	Avg. Heart Rate	Avg. Skin Conductance	Avg. Skin Temperature
1	92.36077	1.274387948	29.68203	89.21679	2.272121741	29.3217
2	76.68999	2.26369234	30.57542	97.34781	0.007058844	30.08438
3	69.54255	0.173946012	29.55234	93.28822	0.14598	29.86356
4	101.843	0.505350189	31.20191	77.61375	1.026217515	30.6565
5	66.59121	11.54714801	32.08922	76.29338	12.26386446	31.46921
6	71.96516	3.101729086	32.72039	87.13103	5.263905096	31.81596
7	66.74796	4.285835635	32.67378	77.847	7.380404994	32.21828
8	92.206	1.514237731	30.68759	92.50182	1.872756067	30.03473
9	54.05715	2.03460883	30.50059	87.67895	1.758665643	29.80526
10	89.58912	0.20347604	32.7041	83.19086	0.378058451	31.96648
11	85.84356	0.217890239	33.0517	95.15121	0.178347525	31.86996
12	90.21457	3.998313096	31.72339	90.32761	2.304212966	31.32727
13	84.39114	0.129377925	32.50263	88.4671	0.298714755	31.72979
14	78.33746	0.554526781	30.71204	85.19854	0.694904573	31.06992
15	85.44402	10.53729823	30.36633	77.78777	13.53612226	30.42477
16	97.82346	0.642728136	32.68742	87.23371	0.240282793	32.05889
17	104.13	0.704708484	33.0955	96.65304	0.529796355	33.60346
18	66.8685	0.174966849	27.83869	86.71173	0.213470654	28.05134
19	71.16255	0.28133171	31.674	100.1707	0.240097054	31.28412
20	72.39835	2.216489594	32.15044	76.23893	2.654827589	30.94766
21	76.03564	2.962413193	32.8247	90.08419	3.063555467	32.63007
22	89.01866	1.299854505	31.05527	93.73348	1.961813843	31.71859

Figure 11. Physiological data from the Empatica E4 wristband for each participant.

Using the physiological data from the 22 participants, we counted the number of participants who responded more strongly when using the virtual reality controls to determine the following results:

Physiological Measure	Screen and Keyboard	Virtual Reality (Supports Hypothesis)	P-value	Success or Failure
Higher Avg. Heart Rate	6	16	0.0262	Success
Higher Avg. Skin Conductance	8	14	0.1431	Failure
Lower Avg. Skin temperature	6	16	0.0262	Success

Figure 12. Results from numbers of participants with supporting physiological data.

Discussion

The binomial exact test and data collected from surveys support the following improvements to presence by virtual reality technology:

- Interacting with the environment seemed more natural.
- Controlling the environment with the input device seemed more natural.
- The environment seemed more consistent with real-world experiences.
- Senses and involvement in the environment were heightened.
- Visually exploring the environment seemed easier and more compelling.
- Navigating the environment seemed more compelling.
- Users experienced more unexpected stimuli.

These improvements to the visual immersion and navigation of the virtual environment support our general alternative hypothesis stating that people experience higher presence when interacting with the simulation using virtual reality equipment.

According to our collected physiological data, Users experienced increased heart rate and decreased skin temperature when using virtual reality controls. These physiological measures support the following:

- Users experienced increased stress.
- Users felt more intense emotions.
- Users reacted to stimuli more frequently with defensive responses, i.e. fight-or-flight response.

However, the collected data cannot support the following improvements to presence:

- Adjusting to the environment and navigating within it seemed easier.
- Concentrating on and learning new techniques seemed easier.
- The environment seemed more responsive and anticipatable.
- Auditory aspects seemed more identifiable and compelling.

There are many potential reasons why our collected data does not support these improvements. The most likely of these are:

- Current virtual reality hardware limited immersion. Some users had difficulty adjusting to unfamiliar controls, while most were familiar with the screen, mouse, and keyboard. As people become more familiar with virtual reality interactions, future iterations of virtual reality hardware will bring improvements in this area.
- Users lacked time to prepare for the scenario. In future versions, we could expand on the tutorial to better prepare users for interaction with the virtual environment.
- Users were unfamiliar or fascinated with the virtual reality hardware. This could attribute to difficulty adjusting to new controls and focusing on the assigned task.

Conclusion

Using the HTC Vive and compatible software, we integrated virtual reality technology with an immersive interactive training simulation. My team conducted a research study to compare the changes with the screen and keyboard version of the simulation. According to the collected data from presence questionnaires, virtual reality technology brought improvements to presence by making the environment seem more compelling, natural to interact with, and visually immersive. This improves the simulation’s ability to elicit realistic behavior in users. As virtual reality hardware continues to improve and users become more familiar with interacting with environments using virtual reality systems, the potential for this technology to bring improvements to virtual environments will only increase.

Bibliography

[1] R. T. Hays and M. J. Singer, Simulation Fidelity in Training System Design: Bridging the Gap Between Reality and Training, New York City: Springer Science & Business Media, 2012.

[2] C. Constantin and D. Grigorovici, "Virtual environments and the sense of Being There: an SEMmodel of presence," *Proceedings of the 6th Annual International Workshop on Presence,* 2003.

[3] B. G. Witmer and M. J. Singer, "Measuring presence in virtual environments: a presence questionnaire," *Presence: Teleoperators and Virtual Environments,* vol. 7, no. 3, pp. 225-240, 1998.

[4] J. v. Baren and W. A. IJsselsteijn, "Measuring presence: a guide to current measurement approaches," *Omnipres Project,* 2008.

[5] C. Dede, "The evolution of constructivist learning environments: Immersion in distributed, virtual worlds," *Educational Technology,* vol. 35, no. 5, pp. 46-52, 1995.

[6] D. B. Maxwell, "Gauging Training Effectiveness of Virtual Environment Simuation Based Applications for an Infantry Soldier Training Task," University of Central Florida, Orlando, 2015.

[7] N. Wardrip-Fruin, M. Mateas, S. Dow and S. Sali, "Agency reconsidered," *Proceedings of the Digital Games Research Association,* 2009.

[8] M. Slater, "Place illusion and plausibility can lead to realistic behaviour in immersive virtual environments," *Philosophical Transactions of the Royal Society of London B: Biological Sciences,* vol. 364, no. 1535, pp. 3549-3557, 12 Dec 2009.

[9] R. M. Young, S. G. Ware, B. A. Cassell and J. Robertson, "Plans and planning in narrative generation: a review of plan-based approaches to the generation of story, discourse and interactivity in narratives," *Sprache und Datenverarbeitung, Special Issue on Formal and Computational Models of Narrative,* vol. 37, no. 1-2, pp. 41-42, 2013.

[10] R. T. Azuma, "A Survey of Augmented reality," *Presence: Teleoperators and Virtual Environments,* pp. 202-205, 1997.

[11] B. E. Insko, "Measuring presence: subjective, behavioral and phsyiological methods," *Being There: concepts, effects and measurement of user presence in synthetic environments,* vol. 5, pp. 109-120, 2003.

Appendix 1: Presence Questionnaire

- Do you ever get extremely involved in projects that are assigned to you by your boss or your instructor, to the exclusion of other tasks?
- How easily can you switch your attention from the task in which you are currently involved in a new task?
- How frequently do you get emotionally involved (angry, sad, or happy) in the news stories that you read or hear?
- Do you easily become deeply involved in movies or TV dramas?
- Do you ever become so involved in a television program or book that people have problems getting your attention?
- How mentally alert do you feel now?
- Do you ever become so involved in a movie that you are not aware of things happening around you?
- How frequently do you find yourself closely identifying with the characters in a story line?
- Do you ever become so involved in a video game that it is as if you are inside the game rather than moving a joystick and watching the screen?
- On average, how many books do you read for enjoyment in a month?
- How physically fit do you feel today?
- How good are you at blocking out external distractions when you are involved in something?
- When watching sports, do you ever become so involved in the game that you react as if you were one of the players?
- Do you ever become so involved in a daydream that you are not aware of things happening around you?
- Do you ever have dreams that are so real that you feel disoriented when you awake?
- When playing sports, do you become so involved in the game that you lose track of time?
- How well do you concentrate on enjoyable activities?
- How often do you play arcade or video games? (OFTEN should be taken to mean every day or every two days, on average.)
- How well do you concentrate on disagreeable tasks?
- Have you ever gotten excited during a chase or fight scene on TV or in the movies?
- Have you ever gotten scared by something happening on a TV show or in a movie?
- Have you ever remained apprehensive or fearful long after watching a scary movie?
- How frequently do you watch TV soap operas or docu-dramas?
- Do you ever become so involved in doing something that you lose all track of time?

Appendix 2: Introduction Video Script

Thank you for participating in the University of New Orleans, Computer Science, Police Use of Force Simulation.
During your session with us, you'll be interacting with a prototype of a police training simulation via both Monitor, Keyboard, and mouse and virtual reality headset with controllers.
The expected duration of your session will be approximately 30 minutes.
Please note, depending on the choices made, you may experience violent acts.

To start off, you will take a brief questionnaire.
Data received in this study will be recorded anonymously using your participant number.
A researcher will be with you always in case you need any assistance.
You will then be directed to your first round of simulations.
You will first play through a Tutorial, where you will familiarize yourself with the controls.
Once completed, an introduction to the scenario will appear, and then the simulation will commence.
When the simulation is complete, you will receive a score.
You will repeat the simulation at least once, but feel free to play as many times as you like.
When you are ready to leave, please tell your accompanying researcher.
You will then be asked to complete a second questionnaire.
Once completed, you will then be directed to play the simulation again, this time using a different set of controls.
Just like the previous round, you will play through the simulation at least 2 times, and can play as many times as you like.
At the end of the simulation, you will then be asked to fill out the third and final questionnaire.
Once completed, you will be done with the study.

Before getting started, here are a few things you should know.
In this study, we are using the HTC Vive Virtual Reality Headset, Camera, and Controllers.
Your movements and actions in the real world will be tracked in the simulation.
However, with the headset on, your perception of the environment around you will be impaired.
The headset is wired to a computer which may be a potential tripping hazard.
A researcher will be with you always, monitoring you and the cable as you move around.
Because of this, we ask that you move slowly and deliberately when you have the virtual reality headset on.
As you approach a wall in the room, a blue grid representing the wall will also appear in the simulation.
Please do not attempt to move beyond this grid.

When using the virtual reality controls, you will have a left and right controller.
The simulation uses:

- the trackpad on top of the controller
- the trigger on the bottom of the controller
- and either of the grip buttons on the side of the controller.

When using the Monitor, Keyboard, and Mouse, the keys WASD or Up/Down/Left/Right Arrow and Spacebar will be used on the keyboard.
Mouse Movement and Left and Right Mouse Buttons will also be used.

Thank you very much! We appreciate your participation in our study!

Appendix 3: Screen and Keyboard Checklist and Verbal Quiz

General Guidelines

- You are the investigator. The person playing is the participant.
- You can answer questions about the purpose of this study, but only after it is over and not in the presence of waiting participants.
- You cannot make suggestions about what actions the participant should take, even if they ask for help or hints. If asked, you can say "I can't answer that question until after the study if over."
- You can answer questions about the controls.
- You can tell the participant that the goal is to get 4 out of 4 and that it is possible to achieve this score.

Step-by-Step Checklist

- ☐ Ideally, Dr. Ware is present. At least one of the following people must be present: ET Garcia, Dharmesh Desai, or Ted Mader.
- ☐ The participant MUST read and sign an informed consent form.
- ☐ Keep the signed consent form.
- ☐ Give the participant a second copy of the consent form to take home. It does not need to be signed.
- ☐ Assign a unique ID number to the participant and writes it at the top of this page.
- ☐ Ask the participant to sit at Computer 1 and put on the headphones.
- ☐ Show the participant the introduction video.
- ☐ While the video is playing, set up the first survey on Computer 2 and enter the participant's number on the first screen.
- ☐ After the video is finished, strap the Empatica watch to their arm. Press and hold the button for two seconds until the light turns green.
- ☐ Ask the participant to take the first survey on Computer 2.
- ☐ While the participant is taking the first survey, set up the screen and keyboard simulation on Computer 1.
- ☐ After the participant finishes the first survey, bring the participant back to Computer 1.
- ☐ Make sure the image displaying the controls is visible on the second screen.
- ☐ Put the headphones on the participant.
- ☐ The participant plays the screen and keyboard version of the simulation.
- ☐ When the participant is finished with the tutorial, give them the verbal quiz about the controls.
- ☐ When the participant is finished playing, set up the second survey on Computer 2 and enter the participant number on the first page.
- ☐ The participant takes the second survey on Computer 2.
- ☐ While the participant is taking the second survey, set up the virtual reality version of the simulation on Computer 1 and confirm that sound is coming through the headphones.
- ☐ After the participant finishes the second survey, bring the participant back to Computer 1.
- ☐ Show the participant the Vive hand controllers but do not hand them to the participant yet.

- ☐ Let the participant know you will tap their shoulder to talk to them.
- ☐ Help the participant put on the Vive headset.
- ☐ Hand the participant the Vive hand controllers one at a time. Make sure their wrists are through the wrist straps do they don't drop the controllers.
- ☐ Put the headphones on the participant.
- ☐ Watch the participant the whole time they are playing. Focus on the cable and the participant, not the screen, whenever possible.
- ☐ When the participant has finished the tutorial, give them the verbal quiz about the controls.
- ☐ While the participant is playing, set up the third survey on Computer 2 and enters the participant number on the first page.
- ☐ The participant takes the third survey on Computer 2.
- ☐ Press and hold the button on the Empatica watch for 2 seconds until the light turns off. Remove the watch from the participant.
- ☐ Make sure you have the signed consent form and give it to Dr. Ware.
- ☐ Make sure you removed the Empatica watch from the participant.
- ☐ Make sure both game logs and the Empatica data are committed to SVN.
- ☐ At the end of the day, clean all equipment.
- ☐ At the end of the day, make sure the Vive hand controllers and the Empatica watch are plugged in and charging.

Verbal Quiz

Ask these questions after the tutorial, but before the actual simulation starts. The participant must show you the answer rather than just say it. For example, the participant should press the grip button rather than just say "grip button." If the participant gets a question wrong, show and tell them the answer. At the end of the quiz, if the participant got any questions wrong, repeat it until they get all questions right.

Q: How do you walk around?
    A: With the W, A, S, and D keys or the arrow keys.
Q: How do you draw the gun?
    A: Left mouse button.
Q: How do you raise the gun?
    A: Left mouse button.
Q: How do you fire the gun?
    A: Left mouse button.
Q: How do you lower the gun?
    A: Right mouse button.
Q: How do you put the gun away?
    A: Right mouse button.
Q: How do you talk to other characters?
    A: Spacebar.
Q: How do you switch between dialog options when talking?
    A: Arrow keys.

Appendix 4: Virtual Reality Checklist and Verbal Quiz

General Guidelines

- You are the investigator. The person playing is the participant.
- You can answer questions about the purpose of this study, but only after it is over and not in the presence of waiting participants.
- You cannot make suggestions about what actions the participant should take, even if they ask for help or hints. If asked, you can say "I can't answer that question until after the study if over."
- You can answer questions about the controls.
- You can tell the participant that the goal is to get 4 out of 4 and that it is possible to achieve this score.

Step-by-Step Checklist

- ☐ Ideally, Dr. Ware is present. At least one of the following people must be present: ET Garcia, Dharmesh Desai, or Ted Mader.
- ☐ The participant MUST read and sign an informed consent form.
- ☐ Keep the signed consent form.
- ☐ Give the participant a second copy of the consent form to take home. It does not need to be signed.
- ☐ Assign a unique ID number to the participant and writes it at the top of this page.
- ☐ Ask the participant to sit at Computer 1 and put on the headphones.
- ☐ Show the participant the introduction video.
- ☐ While the video is playing, set up the first survey on Computer 2 and enter the participant's number on the first screen.
- ☐ After the video is finished, strap the Empatica watch to their arm. Press and hold the button for two seconds until the light turns green.
- ☐ Ask the participant to take the first survey on Computer 2.
- ☐ While the participant is taking the first survey, set up the virtual reality version of the simulation on Computer 1 and confirm that sound is coming through the headphones.
- ☐ After the participant finishes the first survey, bring the participant back to Computer 1.
- ☐ Show the participant the Vive hand controllers but do not hand them to the participant yet.
- ☐ Let the participant know you will tap their shoulder to talk to them.
- ☐ Help the participant put on the Vive headset.
- ☐ Hand the participant the Vive hand controllers one at a time. Make sure their wrists are through the wrist straps do they don't drop the controllers.
- ☐ Put the headphones on the participant.
- ☐ Watch the participant the whole time they are playing. Focus on the cable and the participant, not the screen, whenever possible.
- ☐ When the participant has finished the tutorial, give them the verbal quiz about the controls.
- ☐ When the participant is finished playing, set up the second survey on Computer 2 and enter the participant number on the first page.

- The participant takes the second survey on Computer 2.
- While the participant is taking the second survey, set up the screen and keyboard simulation on Computer 1.
- Make sure the image displaying the controls is visible on the second screen.
- After the participant finishes the second survey, bring the participant back to Computer 1.
- Put the headphones on the participant.
- The participant plays the screen and keyboard version of the simulation.
- When the participant is finished with the tutorial, give them the verbal quiz about the controls.
- While the participant is playing, set up the third survey on Computer 2 and enters the participant number on the first page.
- The participant takes the third survey on Computer 2.
- Press and hold the button on the Empatica watch for 2 seconds until the light turns off. Remove the watch from the participant.
- Make sure you have the signed consent form and give it to Dr. Ware.
- Make sure you removed the Empatica watch from the participant.
- Make sure both game logs and the Empatica data are committed to SVN.
- At the end of the day, clean all equipment.
- At the end of the day, make sure the Vive hand controllers and the Empatica watch are plugged in and charging.

Verbal Quiz

Ask these questions after the tutorial, but before the actual simulation starts. The participant must show you the answer rather than just say it. For example, the participant should press the grip button rather than just say "grip button." If the participant gets a question wrong, show and tell them the answer. At the end of the quiz, if the participant got any questions wrong, repeat it until they get all questions right.

Q: How do you walk around?
    A: By walking around the room.
Q: How do you draw the gun?
    A: Right grip button while hand is at your side.
Q: How do you fire the gun?
    A: Right trigger.
Q: How do you put the gun away?
    A: Right trigger while the gun is at your side.
Q: How do you talk to other characters?
    A: Press the trackpad.
Q: How do you switch between dialog options when talking?
    A: Tap the trackpad.