EVALUATION OF PC-BASED VIRTUAL REALITY AS A TOOL TO ANALYZE PEDESTRIAN BEHAVIOR AT MIDBLOCK CROSSINGS

A Thesis
presented to
the Faculty of California Polytechnic State University,
San Luis Obispo

In Partial Fulfillment
of the Requirements for the Degree
Master of Science in Civil and Environmental Engineering

by
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June 2017

COMMITTEE MEMBERSHIP

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ABSTRACT

Evaluation of PC-Based Virtual Reality as a Tool to Analyze Pedestrian Behavior at Midblock Crossings

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The aim of this research was to analyze if current generation PC-driven virtual reality simulations can be used to accurately mimic and therefore, observe behavior at a crosswalk. Toward that goal, the following research tasks were carried out: a) Designing a 3D virtual crosswalk and recruiting volunteers to wear the HTC Vive headset and to walk across the street, b) Setting up cameras near the midblock crosswalk on University Drive at California Polytechnic State University, San Luis Obispo to observe pedestrians, and c) Comparing pedestrian behavior data from both the virtual and real midblock crosswalk. The comparison was based on the following criteria: a) Pedestrian walking speed, b) Observation patterns prior to crossing the road, characterized by glancing left and right to detect cars, and c) Pedestrians' decisions as to where to cross, defined by if they chose to walk directly on or outside of the midblock crosswalk. Walking speed and the number of pedestrians who looked left and right before crossing were significantly different in both the virtual and real environments. On the other hand, the proportion of people who chose to walk on the crosswalk was similar in both environments. This result indicates that there is a future potential in using virtual reality to analyze pedestrian behavior at roundabouts. Although this study showed that PC-driven virtual reality is not effective in replicating pedestrian walking speeds or pedestrian observation patterns at a midblock crosswalk, researchers may expect PC-driven virtual reality to have greater applications within the transportation discipline once the technology improves over the years. Potential improvements in technology that would help include being wireless, allowing users to walk in a non-confining space, and making the equipment more affordable, allowing the technology to become more mainstream.

Keywords: Midblock Crosswalks, Pedestrian Behavior, Transportation, Simulations, Virtual Reality, PC-driven Virtual Reality, HTC Vive

ACKNOWLEDGMENTS

I would like to thank the Warren J. Baker and Robert D. Koob Endowments for supporting this research project. The funding was used to purchase all the equipment, such as the HTC Vive and Apeman Action Camera Model A66, needed to observe pedestrian behavior in both the virtual and real environment. I would also like to thank my committee, Dr. Anurag Pande, Dr. Kimberley Mastako, and Dr. Zoe Wood for providing guidance on my thesis. I would not have been able to complete my statistical analysis successfully if it were not for my professor, Dr. Andrew Schaffner, who did a great job explaining how JMP can be applicable to our research. Furthermore, I am grateful to have a sister who is supportive of me in completing my master's thesis and parents who have given me an opportunity to pursue my dreams. Finally, I would like to thank my boyfriend, Granger Lang, for inspiring me to work on a virtual reality master's thesis and for helping me with programming whenever I got stuck.

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1. INTRODUCTION

Midblock crosswalks are sites of significant crashes involving pedestrians. In fact, 70% of pedestrian fatalities take place on these crosswalks (“Medians and Pedestrian Crossing Islands in Urban and Suburban Areas,” 2014). These fatalities may occur due to a variety of reasons. First, drivers may not expect to see people using a midblock crosswalk. Second, pedestrians may quickly dart onto the road to catch a bus or train. They may also cross the road without watching for cars or wear dark clothing that is difficult to see at night (“A Guide to Pedestrian Safety,” 2016). Unlike intersection crosswalks, midblock crosswalks force pedestrians to analyze the gap size prior to crossing the road. Judging gap lengths that allow people to cross safely can be difficult to estimate, especially if the drivers are unable to yield to the pedestrians or if the vehicles are traveling at a high speed (Kadali, Vedagiri, & Rathi, 2015). Therefore, transportation engineers are studying ways to reduce these collisions. PC-driven virtual reality, involving head-mounted displays, may offer significant advantages in testing traffic engineering solutions that can help address this problem. Not only has virtual reality become popular in the last few years, but it has also been used for a wide variety of applications, ranging from helping soldiers with post-traumatic stress disorder to providing surgical training for medical students (“Advantages of virtual reality in medicine,” 2015).

Semi-immersive virtual environments have contributed to the transportation engineering field by improving the understanding of how users respond to external stimuli. A past example of a semi-immersive virtual environment includes a simulation that asks children to examine a crosswalk on a monitor and to press a button when they think it is safe to cross (Schwebel, McClure, & Severson, 2014). While there is a lot of research that utilizes semi-immersive virtual environments, fully immersive environments, involving head-mounted displays, have not been applied within the transportation engineering discipline.

1.1 Purpose of Research

The purpose of this study is to determine if fully immersive virtual reality, involving a head-mounted display, can be accurately used to mimic pedestrian behavior at a midblock crosswalk. If the pedestrian behavior data from the virtual crosswalk is similar to the data on the actual crosswalk, it would indicate that current generation PC-based virtual reality is realistic enough to be used for experiments to assess safety effectiveness of traffic engineering solutions designed to improve pedestrian safety at a crosswalk. It would lead to a safer way of evaluating innovative solutions compared to testing them in the real world directly. If researchers are able to establish and validate the VR environment, the findings can be extended to evaluate roadway environment for other vulnerable road users, such as bicyclists, in addition to the pedestrians. Such evaluations are going to useful in roadway environments with mixed modes. This exploration is especially timely as many cities are moving toward transforming existing automobile-oriented arterial streets into complete streets that can accommodate all modes. Therefore, there will be a lot of potential for using PC-based virtual reality for transportation applications for many transportation agencies if data can be successfully obtained from virtual reality settings. Toward that end, the goal of this thesis was to develop a framework to evaluate pedestrians’ behavior at a real crosswalk and compare it to subjects' behavior in a fully-immersive virtual environment created for the same crosswalk.

1.2 Research Tasks

The research objectives of this thesis were achieved using the following tasks:

1. Creating a 3D virtual crosswalk that modeled the crosswalk at California Polytechnic State University, San Luis Obispo (Cal Poly) on University Drive using the Unity Engine and Blender software (see site location in Figure 3.1)
2. Observing real-life pedestrian behavior at the crosswalk
3. Recruiting a sample of volunteers similar to the real-world users at the crosswalk
4. Comparing the pedestrian behavior data obtained from the real crosswalk to the data obtained from the virtual crosswalk simulation

This thesis contains a detailed literature review, followed by the methodology used to compare the virtual environment to the real environment. The last section of the thesis discusses the results obtained in both the real and virtual environments.

2. LITERATURE REVIEW

Prior to analyzing pedestrian behavior data in both a virtual and real environment, it is important to define the terminology related to midblock crossing, pedestrian behavior, and virtual reality. In addition, literature also provides lessons on how simulations have been applied for transportation safety applications to gather behavioral data from participants.

2.1 Midblock Crossings

Midblock crosswalks are located in between intersections. They are typically placed in areas that have high pedestrian traffic: schools, shopping areas, and transit stops (Broek, 2011). In areas that have high vehicular traffic and higher speeds, especially multilane minor and major arterials, medians or refuge islands may be recommended ("Federal Highway Administration University Course," 2006).

Midblock crossings provide convenience for pedestrians since they allow pedestrians to directly cross the street without having to walk to the closest intersection. However, they can put pedestrians at risk; pedestrians may underestimate the speed of the approaching vehicle and the time it takes to safely walk across the crosswalk (Broek, 2011). In addition, some pedestrians may assume that drivers will stop for them since they are legally using a marked crosswalk. Therefore, they may engage in distracting activities, such as listening to music, texting, or reading while crossing (Mwakalonge, Siuhi, & White, 2015).

2.2 Gap Acceptance Behavior

When drivers do not yield to pedestrians, pedestrians are forced to wait until they see a suitable gap prior to crossing the road. Per the *Highway Capacity Manual 2010*, the critical gap or headway is “the time in seconds below which a pedestrian will not attempt to begin crossing the street.” It is expected that pedestrians will cross the road if they see an available gap greater than the critical gap. However, pedestrians may frequently misjudge a gap and unsafely walk across the crosswalk, forcing cars to come to an abrupt halt (Pawar & Patil, 2015). Pedestrians typically accept smaller gaps when motorists are driving at a higher speed compared to a lower speed. They tend to rely on physical distance when deciding to cross the road (Petzoldt, 2014). This can result in potentially unsafe situations.

Gaps and lags can help determine when pedestrians accept a gap. Temporal gap and spatial gap is defined, respectively, as the time and space separating two vehicles prior to crossing. Lag, which represents the first gap the pedestrian sees when he or she crosses the road, can be split into the spatial lag and temporal lag. The spatial and temporal lags are defined, respectively, as the distances and time between the first approaching vehicle and the conflict point once the pedestrian chooses to cross the road. The conflict point is defined as the point of intersection between the pedestrian’s path and the approaching vehicle (Pawar & Patil, 2015). See Figure 2.1 for the visual location of gap and lag.

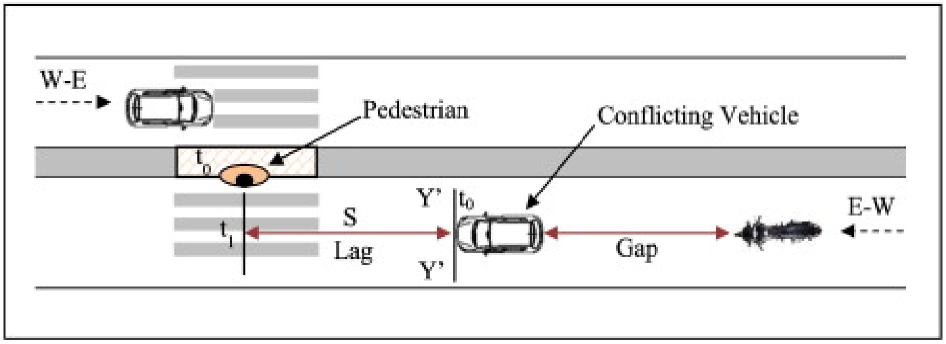


Figure 2.1: Gap and Lag Locations (Pawar & Patil, 2015)

In one study, researchers used both temporal and spatial gaps to observe pedestrians at two midblock crossings in Kolhapur City and Mumbai in the state of Maharashtra, India. They set up two video cameras at each location for 2 hours and collected 1107 pedestrian gaps. Using the binary logit model, they estimated the probability that a pedestrian would accept a gap. It was concluded that the vehicle type affects whether the pedestrian would accept the gap. For example, for a gap of 4.5 seconds, pedestrians were 36% likely to accept a gap if the oncoming vehicle was a truck. In addition, if pedestrians were in a group, they were more likely to accept a smaller gap value. For both crossings, the temporal gap and spatial gap varied from 4.1 s to 4.8 s and 67 m to 79 m, respectively (Pawar & Patil, 2015).

Sun, Ukkusuri, Benekohal, and Waller (2002) studied the interactions between motorists and pedestrians by analyzing Pedestrian Gap Acceptance (PGA) and Motorist Yield (MOY). For PGA, they used three models: critical gap model, probability-based model, and binary logit approach. The critical gap model is deterministic and looks at the minimum gap sizes that half of the pedestrians accepted. The probability-based model uses a random variable from a distribution that best represents the data when analyzing gap acceptances. The distributions include Lognormal, Erlang, Weibull, and Gamma. The K-S and chi-square tests were also used to choose the best-fit distribution for the collected data. The binary logit approach uses multi-attribute regression analyses. For MOY, the discrete probability model and binary logit model were used. The researchers found that the binary logit model is a better model to use compared to the other models because it considers the decision-making process of both the pedestrian and motorist; the age and gender of the pedestrian, waiting time, gap sizes, and the number of pedestrians waiting on the curbside all play a role in the decision-making process (Sun, Ukkusuri, Benekohal, & Waller, 2002).

2.3 Pedestrian Distractions

One research showed that many people actively look left and right prior to crossing the road. Some pedestrians avoided glancing in both directions and it was assumed that others ended up relying on their peripheral vision or sound in order to detect oncoming vehicles (Campbell et al., 2012). Those who were texting while walking looked around their surroundings less often than the pedestrians who were not distracted with electronic devices (Fitzpatrick et al., 2016).

Pedestrians may not look left and right prior to crossing the road because their attention may be drawn to texting or listening to music instead. Therefore, some researchers decided to test the effects of using electronic devices while crossing the road. For example, Schwebel et al. (2012) asked 138 college students to cross the street in a semi-immersive virtual environment. These students were divided into one of four groups: crossing while listening to music, crossing while texting, crossing while talking on the phone, and crossing without an electronic device. Researchers found that the participants in the first two groups tend to not look around their surroundings as they were focused on their electronic devices; they were more likely to be struck by a vehicle in the virtual environment than the other two groups (Schwebel et al., 2012).

Other researchers found that talking on the phone did lead to inattentional blindness. For example, Hyman, Boss, Wise, McKenzie, and Caggiano (2010) observed pedestrians walking through a large plaza at Western Washington University. A person dressed in a brightly colored clown suit rode around the plaza. Researchers then asked pedestrians if they noticed anything unusual while they were walking through the plaza. While 75% of the cell phone users did not see the clown, over half of the people who were not using cell phones noticed the clown (Hyman et al., 2010).

In general, people using electronics tend to have a more difficult time paying attention to other stimuli in the environment. This can be problematic especially if vehicles do not stop for pedestrians at a midblock crosswalk.

2.4 Pedestrian Speeds

Title 23, United States Code (2012) defines a pedestrian as “any person traveling by foot and any mobility-impaired person using a wheelchair.” Even with this general definition, pedestrians all walk differently. Their walking speed differs depending on the country, age, gender, cell phone usage, if they are carrying baggage, and if they are in a group (Knoblauch, Pietrucha, & Nitzburg, 1996).

Several studies were conducted to show how these characteristics affect the walking speed. One study was conducted at eighteen locations with sidewalks in over five cities in India: Delhi, Chandigarh, Chennai, Coimbatore, and Erode. Sidewalk widths were measured and observers recorded the time it took for pedestrians to cross a certain distance for approximately 90 minutes. Due to a hidden camera, observers were able to accurately record the normal walking behavior of the pedestrians. Based on observing over 10,000 pedestrians, it was determined that the average walking speed was 2.53 mph (3.71 ft/s). However, if they were carrying baggage, the speed dropped to 2.39 mph (3.51 ft/s). In addition, it was discovered that pedestrians walked faster in an educational area (3.18 mph or 4.66 ft/s) compared to a shopping area (2.24 mph or 3.29 ft/s) (Rastogi, Thaniarasu, Chandra, 2010).

Another study was conducted in 13 sites in New Zealand. At each site, pedestrian movement was recorded using video cameras for 30 minutes as they walked across a 5m section. Data was tossed out if pedestrians were obstructed by other pedestrians or if they had a physical disability. After observing the walking speeds of 1847 pedestrians, it was discovered that males walked significantly faster than females at 3.36 mph (4.93 ft/s) as compared to 3.21 mph (4.71 ft/s). Furthermore, a one-way Analysis of Variance (ANOVA) showed that there was a significant difference in walking speed among different age groups. Those between 15 to 30 years old walked, on average, 3.27 mph (4.80 ft/s) while those over 55 years old walked 3.07 mph (4.50 ft/s) (Kaye & Walton, 2007).

At a public university in the Midwestern United States, 1197 pedestrians were observed as they walked 50m of a walkway. They were sorted into three categories: subjects who walked with a cell phone held to their ears, subjects who walked and texted during the whole duration, and subjects who did not visibly use their cell phones. There was a significant difference ($p < 0.001$) as observers found that pedestrians who spoke on the phone or texted while crossing walked slower than those who did not use their cell phones at all. It was concluded that cell phones reduced the average walking speed since subjects were more likely to weave and not pay attention (Barkley & Lepp, 2016). Not only does it take longer to cross the street while conversing on cell phones, pedestrians were less likely to successfully cross the road (Schwebel et al., 2012; Neider, Mccarley, Crowell, Kaczmarski, & Kramer, 2010).

Many researchers used a video camera to record the pedestrian walking speed. Some went further as to using a video editing software. For example, Vedagiri and Kadali (2016) extracted video data using AVS Video Editor software that has a forward click option with an accuracy of 30 ms. This forward click option allowed researchers to accurately calculate the crossing time, vehicle time gap, pedestrian waiting time, and changes in pedestrian speeds over time (Vedagiri & Kadali, 2016). Although researchers can rewind a scene multiple times with the software, it may still be difficult recording the pedestrians’ walking speed and analyzing the pedestrians’ characteristics. Some researchers found variables, such as the age of the pedestrian and if the pedestrians were wearing headphones, difficult to identify. This is due to the fixed camera angle and the direction the pedestrians were walking in (Kaye & Walton, 2007). In many cases, researchers had to throw out data that could lead to inaccurate results.

Barkley and Lepp (2016) directly observed pedestrians through a nearby window as pedestrians walked across the 50m walkway. Their speeds were recorded with a stopwatch.

In each of these experiments, pedestrians were unaware that they were being observed. These naturalistic observations allowed researchers to observe pedestrians’ normal walking behavior without any biases. In addition, researchers controlled the walkway area by timing pedestrians only when they walked a specific distance. With the controlled distance and time, they were able to calculate the average speed of the pedestrians. Lastly, in order to compare the average walking speeds, researchers split the pedestrians into groups based on their physical characteristics and actions. This thesis draws ideas provided by Fitzpatrick et al. (2016), Schwebel et al. (2012), Hyman et al. (2010), Knoblauch et al. (1996), Rastogi et al. (2010), Kaye and Walton (2007), Barkley and Lepp (2016), and Vedagiri and Kadali (2016).

2.5 Definition of a Virtual Environment

A virtual environment is an interactive computer-generated display that allows users to feel as if they are in another location.

Costello (1997) discusses the three types of virtual reality systems. The first one is a 2D non-immersive desktop system that is viewed through a computer screen and allows users to interact with the environment using a keyboard, mouse, or trackball. This system is the least immersive out of the three virtual reality systems. The second system is a semi-immersive projection system that integrates 2D and 3D visualization and may use a large screen monitor, a large screen projector system, or multiple television projection systems. This system is similar to IMAX theaters since it uses a wide field-of-view and thus, increases the feeling of being immersed in the environment. The last system is a fully immersive head-mounted display (HMD) system. With this system, users wear a head-mounted display that may prevent them from seeing the real environment outside of the system. The HMD uses small monitors that are placed in front of each eye. These monitors can provide stereo, biocular, or monocular images. With stereo images, each eye sees slightly different images, allowing users to perceive depth in a scene. In the real environment, people’s eyes are slightly apart from each other. With biocular images, identical images are displayed on each screen. With monocular images, there is only one display screen. Fully immersive head-mounted displays are costlier and require more computing power than the other two virtual systems discussed earlier (Costello, 1997).

More information about these systems, specifically semi-immersive projection systems and fully immersive head-mounted display systems, will be presented within the next pages of this report.

2.6 Brief History of Virtual Environments

Virtual reality is not a new technology. In fact, the idea has been around for decades. One of the beginning stages of virtual reality took place in 1838 when Charles Wheatstone found that the brain processes 2-D images from each eye into a single 3-D object. This allows depth and immersion to be created as users viewed two side-by-side images with a stereoscope. This idea paved the way to many technologies, such as the View-Master stereoscope in 1939 that was used for “virtual tourism” and the Google Cardboard that has been introduced within the last few years (“History of Virtual Reality,” 2016).

Due to these events, virtual reality was born. For the next 49 years, we have continued to see improvements made in the virtual reality field. Today, many companies, such as NASA, IBM, Intel, Boeing, and Rolls Royce, are using virtual reality for research purposes (Costello, 1997).

2.7 Attractiveness of Virtual Environments

Planners and engineers find virtual simulations attractive because they involve a controlled environment; they can easily design a program that ensures that there are a variety of traffic situations. They can understand how the driver's behavior would change if it is snowing or if there is a car crash in the distance. A real traffic environment can be unpredictable and difficult for researchers to control and test all variables that can be applied to a specific roadway (Novak, 2009).

In addition, virtual simulations are attractive because people cannot get hurt. This is beneficial especially if virtual reality is used to teach young children how to perform a task safely; minimal adult supervision can be administered (Schwebel, Combs, Rodriguez, Severson, & Sisiopiku, 2016).

If people wanted to analyze drunk driver behavior on an urban road versus a local road, they can distort images, reduce the peripheral vision, and change the depth and distance perception based on the selected blood alcohol content (Hong, Ryu, Cho, K. Lee, & W. Lee, 2011). If a participant was asked to drive a vehicle with a high blood-alcohol content and he or she hits a tree in the virtual environment, there will be no fatalities.

Researchers have recognized that virtual simulations can help people acquire and retain a new skill. For example, virtual reality has been used to train surgeons to sharpen their medical skills that may otherwise decay from disuse. The Department of Defense states that approximately 100,000 military health care personnel are needed to be trained annually (Siu, Best, Kim, Oleynikov, & Ritter, 2016).

Although virtual simulations are attractive to many people, there are many limitations of using virtual simulations in lieu of real environment testing. More information will be provided later in Chapter 5.2: Limitations and Assumptions.

2.8 Semi-Immersive Virtual Environments in a Transportation Setting

There are many simulations, specifically semi-immersive projection systems that allow users to interact with the environment. Many involve computer monitors that are arranged in a semicircle in front of the user. Others involve room-sized projections shaped in a cube. It is important to analyze past virtual simulations since their ideas can be used to help collect data for this virtual reality research.

2.8.1 Driving Simulations

For many years, the Federal Highway Administration (FHWA) has been analyzing human behavior on the roads using a Highway Driving Simulator (HDS). The simulator uses a vehicle surrounded by a large, cylindrical screen that gives users a 200-degree field-of-view. Inman, Davis, El-Shawarby, and Rakha (2008) analyzed the possibilities of warning drivers who are at risk committing a red-light violation. In this research, the roadway was modeled on US 29 and the intersection of US 29 with State Route 234 in Manassas, VA. During the test, participants drove through the intersection 34 times. A real closed-road test track was also used to verify the findings from the simulation.

After performing these tests, it was discovered that the participants in the virtual environment stopped frequently and were typically 50 feet short of the stop line. However, on the test track, most participants stopped within 3 feet of the stop line. In addition, when the light changed from green to yellow and the driver was either 180 feet or 215 feet from the stoplight, 90% of the drivers stopped on the real test track. Only 64% stopped in the simulator. Researchers suggest that the differences could be attributed to the participants recognizing a pattern in the real environment. Participants may have anticipated that the light would turn yellow as it had 20 out of the 24 times that participants approached the intersection (Inman et al, 2008).

Another driving simulator experiment was conducted in Queensland, Australia. 58 participants were asked to drive through different railroad crossings with and without an Intelligent Transportation Systems (ITS) device. The ITS device warns drivers of an approaching train and was tested as a video in a vehicle, an audio in a vehicle, and as an on-road flashing marker. The simulator was created using VISSIM and recorded the stopping distances, approaching vehicle speeds, and stopping compliance rates. Due to the flexibility of creating multiple controlled scenarios, researchers found that exposure to ITS devices at passive crossings influenced the drivers' behavior significantly; drivers tend to slow down more at a passive crossing than at an active crossing, that contains flashing lights, when warned with an ITS device (Kim, Larue, Ferreira, Rakotonirainy, & Shaaban, 2015).

2.8.2 Route Choice Simulation

Natapov and Fisher-Gewirtzman used virtual simulations to analyze how the visibility and layouts of different businesses affect pedestrian routes. For example, they wanted to know what path pedestrians were more likely to take if they were to go to a café. The simulation was produced in 3D Studio Max v. 7, Autodesk and modeled the Tel Aviv central district. Real-world buildings were created to make the scenery look as realistic and familiar as possible. Similar to the FHWA Driving Simulator, this simulator used a 2.4 m x 7.0 m screen with a 75-degree field-of-view. Participants carried a joystick controller that allowed them to walk around the virtual model and 3D glasses that were equipped with tracking cameras. Researchers found the virtual simulation useful since it was easier to keep track of the pedestrians' route choices (Natapov & Fisher-Gewirtzman, 2016)

2.8.3 Crosswalk Simulations

There are many simulations that are used to study pedestrian behavior on the streets. One study was conducted in 2008 by the University of Alabama at Birmingham. 102 children and 74 adults were recruited to complete simulated road crossings in both a virtual and real environment. The virtual environment was displayed on three monitors arranged in a semicircle in front of the participants (Schwebel, Gaines, & Severson, 2008).

In the first experiment, the participants were asked to watch for traffic on both the three-screen monitors and in real life and to shout "now!" when they deemed that it was safe to walk across the crosswalk. The second experiment consisted of participants standing a short distance away from the curb in the real environment and on a wooden platform in the virtual environment. In the real environment, they were asked to take two steps toward the curb when they felt that it was safe to cross. In the virtual environment, participants were asked to take one step off the curb when they were ready to cross the street (Schwebel et al., 2008).

After the experiment, the volunteers were given a survey that asked about the realism of the virtual environment. The average adult rating was 4.22 out of 5 which suggested that adults found the simulation to be quite realistic. The children's ratings were lower at 3.25 out of 5 (Schwebel et al., 2008).

In a similar experiment involving a three-screen projector, children and adults were told to observe 18 different urban scenarios and to pretend that they were going to use the crosswalk in each of the situations. The scenarios consisted of a crosswalk that had zebra striping versus one that did not and the presence of vehicles traveling in one direction versus two directions. If a participant detected a hazard on the road, he or she was supposed to tell the experimenter what hazard was identified (Meir, Oron-Gilad, & Parmet, 2015).

Another simulation involved the CAVE, which stands for Cave Automatic Virtual Environment. The CAVE consisted of four projection screens: three of the screens were used as wall screens while the fourth screen was located on the floor. The participants were equipped with stereo glasses and trackers that allowed them to observe the 3D virtual environment. Researchers at the Immersive and Creative Technologies Lab of the Cyprus University of Technology wanted to analyze the benefits of using a CAVE simulation for children with autism. The participants were given a six-step procedure on how to cross the road:

1. Stop and wait on the sidewalk.
2. Press the button and wait for the green light.
3. Look left and right when the light turns green.
4. Walk and continue to look around.
5. Use the crosswalk.
6. Cross the road to reach the pavement.

After giving them these instructions, the children had to repeat the steps four times a day over the course of four days. Each of the children had demonstrated progress, especially toward the end. Following those four days, the children were sent out to a real pedestrian crossing and were told to repeat the instructions. When crossing the road, the children appeared to be confident and were able to safely cross the road when they felt that the time was right (Tzanavari, Charalambous-Darden, Herakleous, & Poullis, 2015).

2.8.4 Review of Examples

Many researchers compared the virtual environment with the real environment in order to see if virtual simulations can be used to study transportation system user behavior. Other researchers produced questionnaires and asked participants for their feedback on how a design can be improved to make it as realistic as possible. Can a fully immersive virtual environment, involving a head-mounted display, mimic the behavior users display in the real world?

2.9 Head-Mounted Display Virtual Reality Characteristics

Virtual reality is a three-dimensional, computer-generated environment that allows users to interact with the immersive environment (“Advantages of virtual reality in medicine,” 2015). It is important to understand the software and hardware related to virtual reality since these components help make virtual reality possible.

2.9.1 PC-Driven Virtual Reality Hardware

There are many head-mounted display devices that are currently available to the public, such as the Oculus Rift, Gear VR, HTC Vive, PlayStation VR, and Google Cardboard. The HTC Vive and Oculus Rift are considered more immersive than many of the other devices and are one of the first headsets to be released to the public. Both headsets are PC-driven, meaning that they rely on a computer instead of a smartphone. For this thesis, we decided to just work with the HTC Vive; the HTC Vive allows volunteers to physically walk around in the virtual environment, unlike the Oculus Rift.

The HTC Vive is a head-mounted display that allows users to be completely immersed in a virtual environment. The HTC Vive has its own system requirements and physical characteristics that makes it attractive to users. The HTC Vive requires Windows 7 SP1 or a later version. In order to run the HTC Vive, it is recommended that users buy a computer with an Intel Core i5-4590 or better and a graphics card that is a Nvidia GeForce GTX 970 or better. The HTC Vive asks for 4GB of RAM, an HDMI 1.4 or DisplayPort 1.2 video output, and a USB 2.0 port (Prasuethsut, 2016).

The Vive, which is owned by HTC and was released in 2016, carries 32 motion-tracking sensors all over its surface. There is a small knob on the right side of the headset that allows users to adjust the pupil distance settings. The Vive has a refresh rate of 90 Hz and a 2160 by 1200 LCD monitor (Prasuethsut, 2016).

The Vive uses two controllers that allow users to manipulate and control objects with their hands in the virtual environment. It has a built-in camera that allows users to see both the real and virtual world at the same time ("HTC Vive," 2016).

With the Vive, users are given two options; they can either do the room-scale setup or the seated setup. With the seated setup, users are sitting or standing in one place the whole time ("HTC Vive," 2016). With the room-scale setup, users can walk around a play space that must be at least 6.5ft x 5ft. In order for the Vive to track the user's motions, two base stations must be mounted at opposite corners of the play space with a maximum length of 16.4 feet between them. After mounting the base station in the top corners of the room, users can define the boundaries of the space using the SteamVR Chaperone feature. These boundaries mark the edge of the play area and prevent users from bumping into physical objects (Prasuethsut, 2016).

2.9.1.1 Limitations

Users may be unfamiliar with how to navigate in the virtual reality world especially since each hardware and software may have a different method of navigating. For example, in some games, users can press the circular touchpad on the front of the Vive controller and teleport from one location to another. Due to the user's unfamiliarity with PC-driven virtual reality, some researchers had to familiarize participants with the system first and give them a walkthrough of the simulation. In the walkthrough, they were taught how to perform basic movements and to learn more about how the simulation works (Natapov & Fisher-Gewirtzman, 2016).

In order to have smooth graphics, it is important to have good equipment. First, getting good equipment can be costly. Buying just the HTC Vive is not enough since users will need a VR compatible computer.

2.9.2 PC-Driven Virtual Reality Software

There is various software used to run PC-driven virtual reality simulations, such as the Unity Engine, Unreal Engine, Source Engine, and Cry Engine. The Unity Engine and Unreal Engine are more common than the other types of software used. Both engines are development platforms that are used to create multiplatform, interactive 3D and 2D games. However, for this thesis, we selected the Unity Engine because it is widely used and easy to learn; there are many videos that teach users how to use Unity and how to code in C# ("Unreal Engine VS Unity," 2016; "Unity," 2016).

In order to create simulations, graphics are required. While Unity has its own 3D models that can be added into the simulation, many developers use external software, such as Autodesk Maya, Autodesk 3ds Max, and Blender, and export created objects into the Unity Engine (“Unity,” 2016).

Blender was used for this research because it is a free and open-source computer graphics software that allows users to create 3D and 2D images (Pedro, Le, & Park, 2016). It can be used for modeling, rigging, animation, simulation, rendering, compositing, motion tracking, video editing, and game creation (“Blender,” 2016). This game engine was written in C++ and has support for the Python scripting language (Pedro et al., 2016).

2.9.2.1 Limitations

Many researchers wanted to analyze the importance of making virtual environments realistic. For instance, one experiment sought to examine if virtual environments can be used to reduce job interview anxiety through repeated exposure. Researchers created a virtual job interview simulation that delivered a mock job interview. Four virtual human interviewers were created that ranged in different levels of graphical realism. Pulse rate was collected from a pulse transducer that attached to the index finger. Researchers also measured the eye-blink rate using an eye tracker since an increased rate of eye-blinking can mean that a person is nervous, stress, or angry. Although the virtual human with the lowest level of graphical realism still produced a degree of anxiety, the virtual human that had the highest graphical detail produced the greatest amount of anxiety. Based on a one-way ANOVA test, the difference among the various levels of realism was significant at 5% levels with an F-ratio of 10.520 and a p-value of 0.000 (Kwon, Powell, & Chalmers, 2013). Therefore, the level of realism does play an important role in determining if virtual environments can produce similar data to real environments.

In order to make the simulation realistic, the developer must have time to create the graphics. Creating the graphics may take a long time because the designer must put a lot of details on every single object in order to make the scenery look realistic.

In February 2016, students in a Transportation Planning course at Cal Poly San Luis Obispo were asked to analyze the realism of a specific simulation. Ten college students and one professor volunteered to try the Oculus Rift and to test the demo “SightLine: The Chair.” This demo was originally developed in 2013 and was designed to be an ideal first-time experience for demoing the Oculus Rift (“SightLine,” n.d.). When participants put on the Oculus Rift, they were asked to look around. The scenes changed every time the participants looked in a different direction. The scenes ranged from a forestry area to being on the top of a construction site. After watching the demo, the participants were asked to rate the realism of the demo. Some volunteers noted that the demo did not feel realistic because they could not see their arms or legs nor feel anything. This limitation can be found with both the Oculus Rift and HTC Vive. For example, even if users can pick up objects with the Vive controllers, they cannot physically touch those objects in real-life.

Lastly, it may be difficult finding and retaining volunteers for the simulation, due to cybersickness or visually-induced motion sickness (VIMS) (Curtis et al., 2015). Cybersickness is a psychophysiological response caused by exposure to virtual environments (Barrett, 2004). Prolong usage of the HTC Vive can lead to cybersickness.

The HTC Vive comes with many health and safety warnings prior to use. The simulations can cause seizures, dizziness, and blackouts if someone has a medical condition. It can lead to repetitive stress injury and possibly discomfort after wearing the Vive headset for many hours. Prolonged, uninterrupted use can negatively impact hand-eye coordination and balance ("HTC Vive," 2016).

Virtual environments have led to nausea. In 1993, Regan and Price had 146 participants, consisting of civilians, military personnel, and firefighters wear a head-mounted display and be immersed in a virtual environment for 20 minutes. Following the 20 minutes was a 10-minute post-immersion period. There were 61% of the participants who stated that they experienced some form of cybersickness. A few of the participants found their symptoms so severe that they stopped before the 20-minute immersion period was over (Barrett, 2004).

Users may need to speak with a doctor about any medical conditions that they may have and if it would be safe for them to use the equipment. With these warnings, it may be difficult to get a representative population sample. However, researchers believe that problems with simulator sicknesses can be reduced with improvements in positional tracking, feedback, and better graphics. In addition, users can adapt to the virtual environment with repeated exposure (Barrett, 2004).

Cybersickness depends on the individual, the VR system, and the task performed while using the headset (Table 2.1).

Table 2.1: Factors that Contribute to Cybersickness (Barrett, 2004; Kolasinski, 1995)

Individual	**VR System**	**Task**
Age	Poor Calibration	Duration
Gender	Lagging	Head Movements
Ethnicity	Refresh Rate	Unusual Maneuvers
Previous Illnesses	Flickering	Degree of Control
Past History of Motion Sicknesses	Graphics/Realism of Display	Standing Vs. Walking
Adaptation	Spatial Properties (Field-of-View and Viewing Region)	Self-Movement Speed
Flicker Fusion Frequency Threshold		
Mental Rotation Ability		

The individual column in the table above represents cybersickness that may affect only small groups of people. For example, age differences play a role in cybersickness susceptibility. Users between the ages of 2 – 12 years old are more prone to cybersickness than any other age group. Cybersickness decreases rapidly between 12 – 21 years old and at a much slower rate after 21 years old (Reason & Brand, 1975). Some researchers believe that older users are more resistant to cybersickness because they have hormones that can help users adapt to visuovestibular sensorial conflicts (Harm, 2002). In addition, women are three times more likely to get cybersickness compared to men. Factors, such as pregnancy and menstrual cycle, affect the levels of hormones in the body and thus, can contribute to cybersickness (Burdea & Coiffet, 2003).

The VR system characteristics that may contribute to cybersickness involve the software and hardware components of the virtual reality simulation. An example in this category is lagging. Lagging is defined as the time between which the user begins an action and the time the action occurs in the virtual environment. When users wear a head-mounted display, such as the HTC Vive, information gets sent from the head tracker to the computer. The computer then processes this information prior to updating the visual display. If there is a lot of lag due to this processing, users will be forced to wait for images to appear when they expect for it to appear earlier. This delay can cause cybersickness (Laviola, 2000).

The task column involves having users perform a specific task in the virtual environment. For instance, Stanney and Hash (1998) wanted to find out if cybersickness can be modified with varying degrees of control scenarios: passive control, active control, and active-passive control. They had 24 college students go through three tasks with shutter glasses that allowed them to view the 3-D graphics: “Doorways” environment, “Windows” environment, and the “Elevator” environment. The “Doorways” environment had subjects traverse from one room to another through doorways that forced users to follow a curved path. The “Windows” environment was similar to the “Doorways” environment except some of the rooms were slightly elevated, forcing users to climb up to get into the next room. Lastly, the “Elevator” environment had users walking forward while having to move over and below a series of obstacles. Users were assigned to each of the control conditions: active, active-passive, and passive. In the active and active-passive control scenario, users were given an analog joystick to control their movement. In the passive condition, users were unable to control their movements and they were told to passively observe the scene as it moves. For active control, users were given the freedom to walk in the x, y, and z-direction. For the active-passive control scenario, some movements were restricted. The degree of freedom of motion was matched to what they had to perform in the task. For example, in the “Doorway” environment, they can only move forward and backward and not up and down.

After giving the users a Simulator Sickness Questionnaire that asked to rate the severity of the virtual environment, a two-way MANOVA and regression model were used to analyze the data. The results showed that while the three tasks (“Doorways”, “Windows”, and “Elevators”) played no role in the level of sickness the users experienced, the control condition was very significant. Stanney and Hash discovered that active control is superior to passive control in minimizing cybersickness, but active-passive control was the best method of reducing cybersickness. Active-passive control was more task-oriented and did not overload users with the extra, unnecessary movements they could use with active control (Stanney & Hash, 1998).

Even though there are many limitations involving cybersickness, cybersickness can be reduced. First, researchers can give users time to adapt to the virtual environment. This is especially important with virtual environments that require users to perform a lot of movements as to not shock the user’s visual and vestibular systems (Laviola, 2000).

In addition, researchers can improve the VR System factors listed in Table 2.1 of this report. For example, in order to increase the performance of the simulation, users can buy a good graphics card.

2.10 Lessons from the Literature Review

Midblock crossings can create risky situations for both the pedestrians and drivers especially since pedestrians may underestimate the time it takes for them to safely walk across the crosswalk. Understanding gap acceptance behavior is important because pedestrians can also misjudge the gap size between two vehicles and assume that it is safe to cross. Their speeds may play a role in when they choose to cross the road. In addition, pedestrians may be distracted by their electronic devices that may prevent them from looking out for cars prior to crossing the street.

Many people have used virtual environments for research purposes in lieu of real environment testing. They find virtual simulations attractive because of the controlled environment it offers and the fact that injuries cannot occur. Although non-immersive desktop systems and semi-immersive projection systems are more commonly used, fully immersive head-mounted display systems have recently gained popularity in the last few years especially since display systems, such as the HTC Vive, have recently been released to the public in 2016. In addition, software, such as the Unity Engine and Blender, makes it easier for beginner developers to create simulations with built-in templates and codes.

Prior to investigating if fully immersive virtual reality can be used to model real life scenarios, it was important to examine past virtual reality research and analyze the data that they collected. In many pieces of literature, researchers thought it was important to compare the virtual environment to the real environment. For example, researchers at the Federal Highway Administration created a roadway and intersection that resembled a real street and calculated the percentage of time the participants stopped at the intersection in both environments. Modeling a real street helped researchers understand how drivers would react if they were really driving on that actual street but under controlled conditions. For the literature about pedestrian safety at a crosswalk at the University of Alabama at Birmingham, researchers asked volunteers to answer questions that related to the realism of the simulation. This allowed researchers to understand if their virtual environment simulation would produce accurate results to a real environment testing.

Although many researchers find virtual environments attractive, there are limitations involving the hardware and software components. Limitations include being unfamiliar with how to navigate in a simulation, costs to buy good equipment for the simulations to run smoothly, having time and knowledge to create the simulations, and cybersickness associated with virtual reality. Even with limitations, there are ways to reduce cybersickness, such as giving users time to adapt to the simulation. In this research, an attempt has been made to address these limitations to observe crosswalk pedestrian behavior in a VR environment.

3. METHODOLOGY

The following section describes the equipment and procedure used in obtaining data for a midblock crosswalk in both the real environment and virtual environment. The real environment testing needed to be conducted first in order to estimate the parameters that would be used to compare the virtual environment to the real environment.

3.1 Description of Location

The site of the experiment is located on University Drive between Highland Drive and N. Perimeter Road at California Polytechnic State University, San Luis Obispo (Cal Poly) (Figure 3.1). On this street, a midblock crosswalk lies west of the Food Processing & Campus Market building and Agricultural Sciences building and east of the H2 Parking Lot. It is frequently walked on by Cal Poly students from 7 am – 10 pm on weekdays. University Drive has two driving lanes and bike lanes traveling in opposite directions.

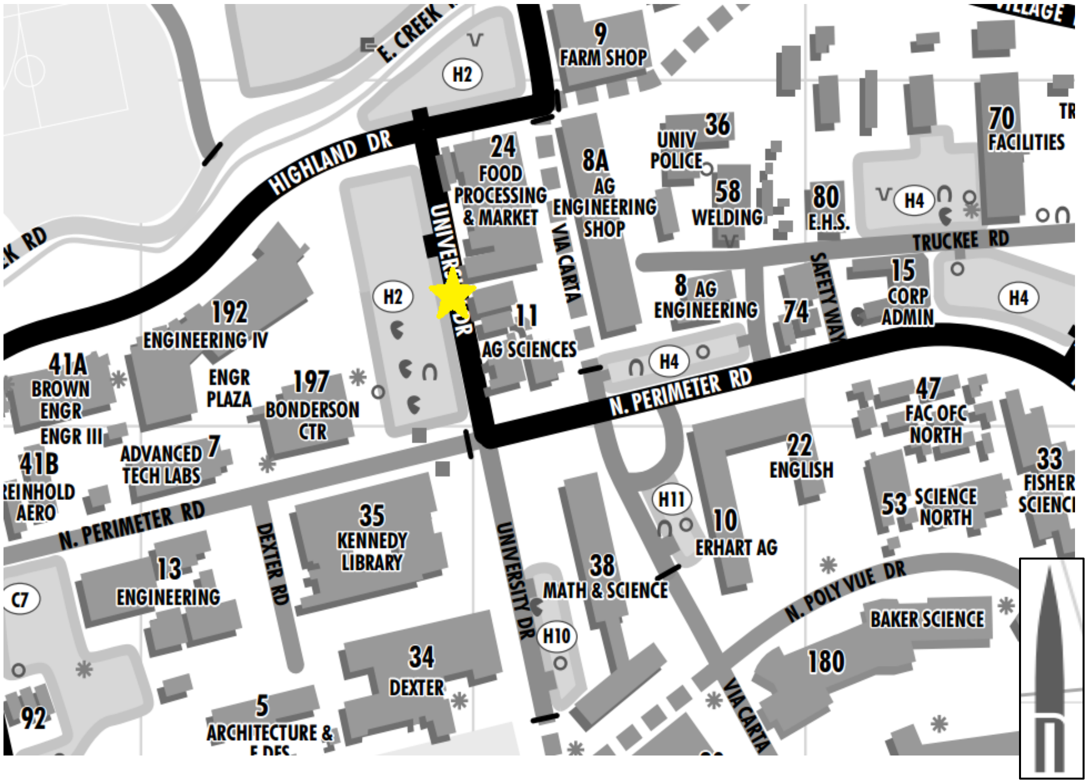


Figure 3.1: Location of Midblock Crosswalk ("Cal Poly Campus Maps," 2017)

Out of all the midblock crosswalks at Cal Poly, the midblock crosswalk on University Drive was the best option for experimental observation. First, there is an adequate number of students who use the crosswalk to get to and from their classes every day. This large sample size makes it easier to collect data in order to compare the real environment with the virtual environment. Second, the flat terrain on University Drive was easier to model in the Unity Engine and to simulate with the HTC Vive. If hills were added to the model, users may feel disoriented since they would be walking up a hill in the virtual environment while walking on a flat surface with the VR headset in the real environment. It is possible to incorporate "fake hills" that users can step on in the real environment, however, it would add another level of complexity to the simulation for this exploratory research.

3.2 Real Environment Observations

Observations were collected in two days. The first day (preliminary phase) captured all pedestrian movement near the midblock crosswalk in February 2017; this data was used to assess which variables should be compared between the virtual and real environment and the direction the volunteers in the virtual environment should walk. The second day took place in May 2017 and only captured pedestrians walking in the eastbound direction toward the Campus Market and coming from the south side of the midblock crosswalk. The purpose of the second day was to collect more pedestrian behavior since the preliminary phase only had 17 pedestrians walking in the eastbound direction while coming from the south side of the crosswalk. Having a sample size of 17 was not adequate to compare to the 47 volunteers in the virtual environment.

3.2.1 Equipment

Data from the real crosswalk was collected with three cameras:

1. Two Apeman Action Camera Model A66 (“Apeman,” 2016) - These cameras were selected because they produced high definition video recordings and could record a 170-degree field-of-view. In addition, the cameras were equipped with accessories that allowed them to be easily mounted on any surface. Their interface was very user-friendly and allowed users to select different loop recording times, video resolution, and to turn off the motion detection mode. The cameras could record for up to 2 hours before they had to be recharged again.

2. iPad Air (“Apple,” 2017) - This device was selected to catch angles that were not captured by the two Apeman cameras. The iPad Air could capture more than 2 hours of recording time with just one tap on the recording button.

3.2.2 *Procedure (Day 1: Preliminary Phase)*

Video cameras were left at the midblock crosswalk on Tuesday, March 7, 2017, from 10:00 am - 11:30 am

Two Apeman cameras were mounted approximately 9.5 feet high at the edge of the Food Processing & Campus Market building and Agricultural Sciences building. These cameras captured the midblock crosswalk and its surrounding area, as shown in Figures 3.2, 3.3, and 3.4. Figure 3.5 gives the locations for each of the equipment. The iPad Air was placed on the retaining wall and recorded the north side of the crosswalk.

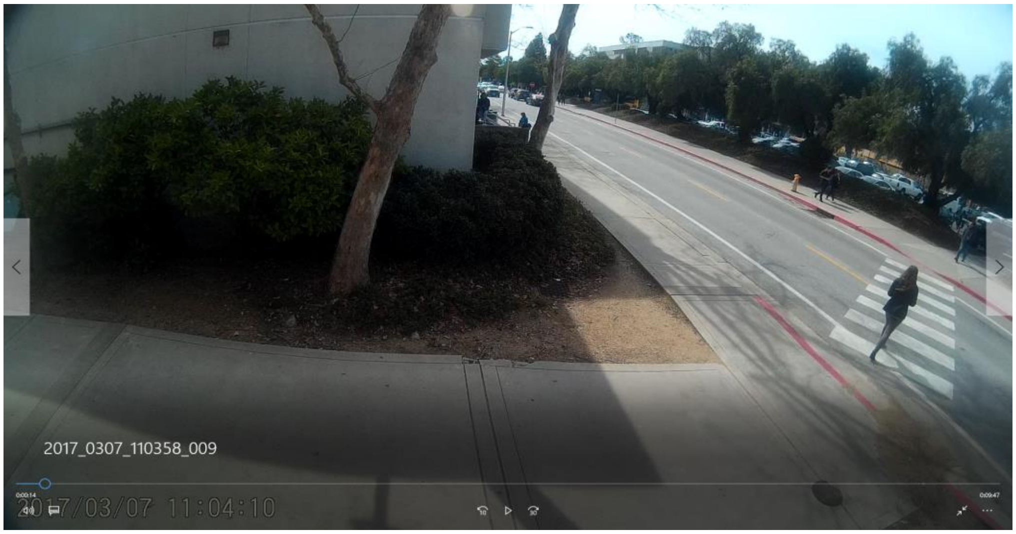


Figure 3.2: View from Apeman Camera 1 During the Preliminary Phase

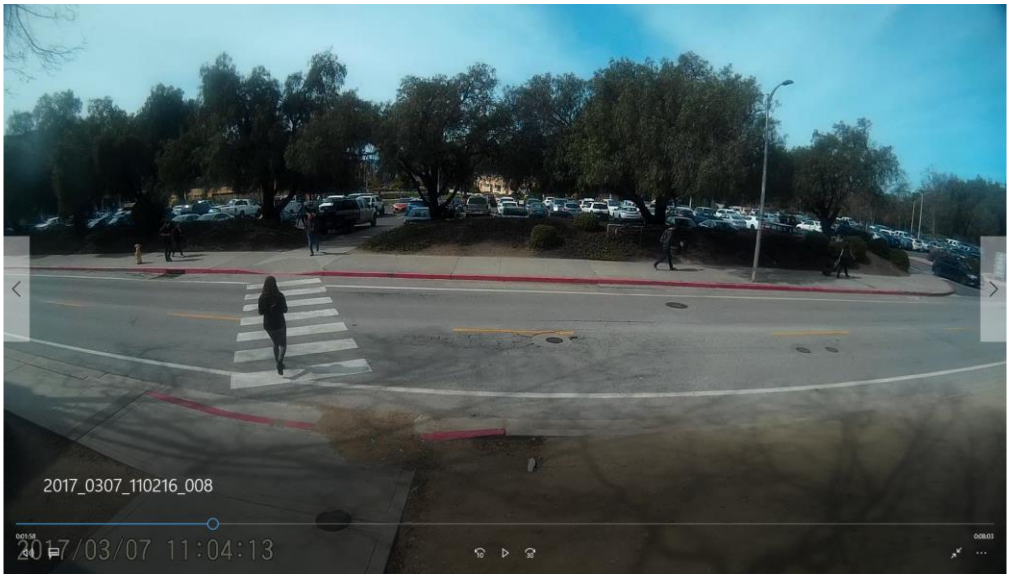


Figure 3.3: View from Apeman Camera 2 During the Preliminary Phase

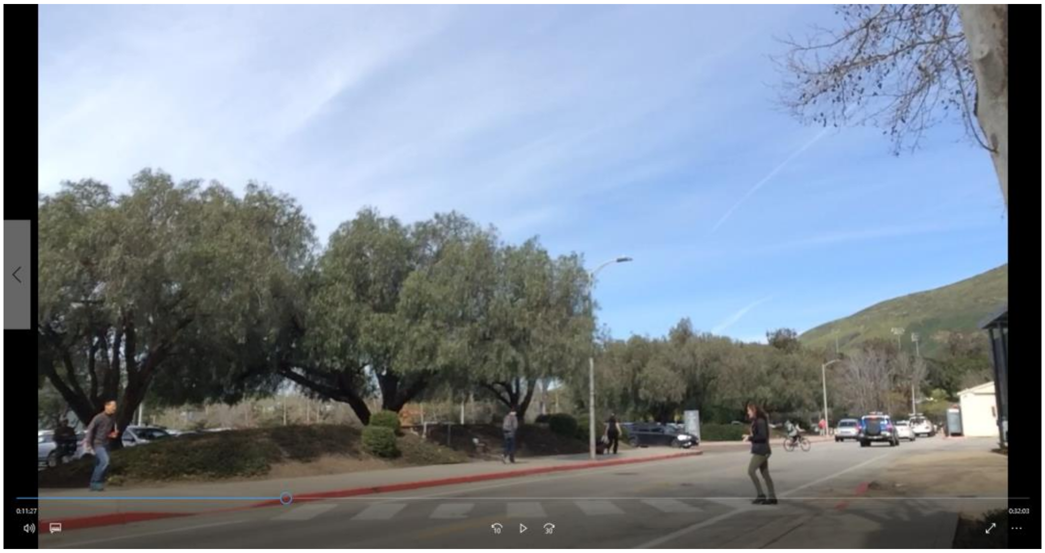


Figure 3.4: View from iPad Air During the Preliminary Phase

Figure 3.5: Apeman Camera (Orange) and iPad (Green) Locations During the Preliminary Phase ("Google Maps," 2017)

Even though the Apeman cameras were equipped with double coated tissue tape that allows the cameras to adhere to a variety of surfaces, duct tape was used as reinforcement. After recording the crosswalk area for 90 minutes, the videos were transferred as a .MOV file to the computer in order to take note of each pedestrian behavior.

3.2.3 Procedure (Day 2: Additional Data for Eastbound Pedestrians)

Two Apeman cameras were placed on the trash can and retaining wall near the midblock crosswalk on Monday, May 8, 2017, from 10:00 am – 12:00 pm. These cameras captured the area south of the midblock crosswalk, as shown in Figures 3.6 and 3.7. The purpose of Figure 3.7 was to record vehicles traveling southbound. Figure 3.8 gives the locations of the two cameras.

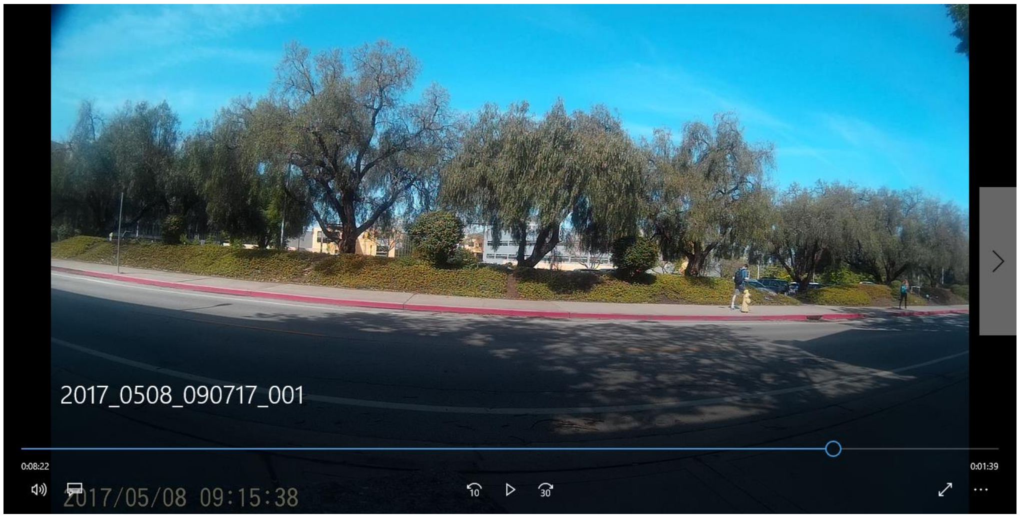


Figure 3.6: Point of View from Apeman Camera 1 During Second Day of Data Collection

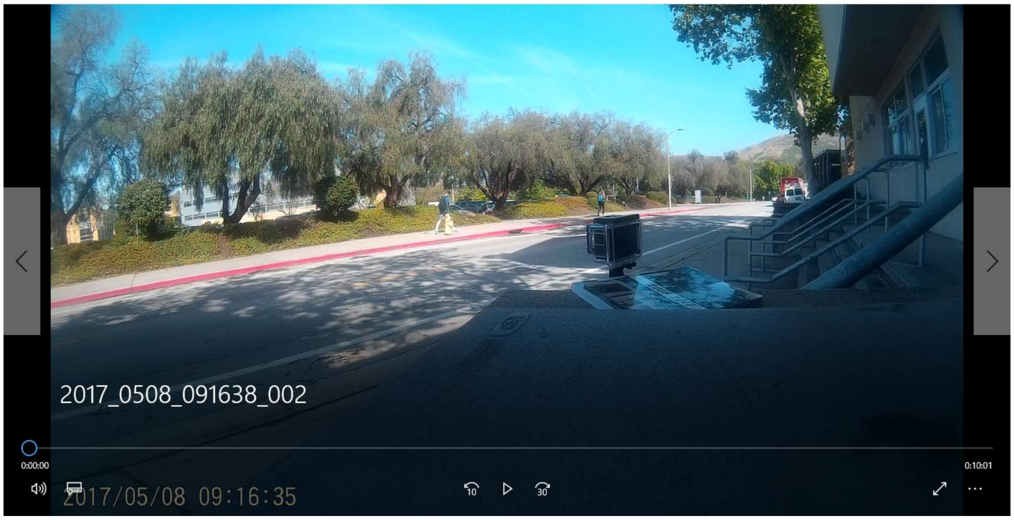


Figure 3.7: Point of View from Apeman Camera 2 During Second Day of Data Collection

Figure 3.8: Apeman Camera (Orange, Green) Locations During Second Day of Data Collection (“Google Maps,” 2017)

After recording the crosswalk area for 2 hours, the videos were transferred as a .MOV file to the computer in order to take note of each pedestrian behavior.

3.3 Virtual Environment Observations

After collecting data from the real environment observations, volunteers were recruited for the virtual simulation.

3.3.1 Equipment to Create Virtual Environment

The Unity Engine and Blender were used to model the midblock crosswalk on University Drive (Figure 3.9). Each object or asset was crafted in the Blender software. In order to make the design resemble the real buildings on University Drive, the dimensions of the actual buildings and roads were measured using Google Maps. Texture and color were added to each object in order to create depth and realism. Once the designs were completed, the objects were imported into the Unity Engine.

Most of the objects in the simulation were built completely in Blender. However, common street objects, such as fire hydrants, were purchased from the Unity Asset Store.

The Unity Asset Store has a large collection of pre-built assets that were created by other users to be sold to the public (“Unity Asset Store,” 2017).

After all the objects were imported into the Unity Engine, animation was added to one car in the model. Only one car was used since there were barely any vehicles on University Drive during the real environment observations (Table 4.1d). This car appeared near the intersection of University and Highland Drive and traveled southbound toward N Perimeter Road. After coming close to the intersection of University Drive and N Perimeter Road, it disappeared. Many seconds later, that same car appeared near the intersection of University and Highland Drive and the process repeated.

Moving the car from one point to another requires programming in C#. The code was written in a Monodevelop script editor of the Unity Engine and attached to the vehicle that needed to be animated. Code was written that would allow the vehicle to detect any movements appearing in front of it; in real life, drivers typically stop if they see a pedestrian up ahead. The vehicle was designed to drive at 25 mph.

After the design and animation were completed, the HTC Vive was connected to the Unity Engine. Although the HTC Vive allows users to walk within a 15ft x 15ft range, teleportation, instead of the typical keyboard functions, was added to the simulation in order to create less motion sickness for the users. Teleportation also gave users the opportunity to move outside of the 15ft x 15ft range in the virtual world while still allowing them to physically walk around in their confined space. For the crosswalk simulation, volunteers would only be able to teleport along the sidewalk and red curb.

Figure 3.9: Model of Midblock Crosswalk on University Drive

3.3.2 Procedure

Prior to the virtual experimentation, a demographic survey was conducted on pedestrians who typically use the midblock crosswalk on University Drive. This survey was used to select a representative sample of volunteers for the virtual simulation and asked about the pedestrian’s gender, age, height, and major. We collected 45 student responses and 3 faculty responses on Wednesday, February 15, 2017, from about 10 - 11 am. Based on the survey, most who responded were males, in the College of Engineering, and were at least 5’ 4”. Most of the pedestrians ranged within the 18 - 34 age group and were mostly students. A total of 47 volunteers were selected after an attempt was made to match the characteristics from the demographic survey (Table 3.1).

Table 3.1: Questions and Responses from the Demographic Survey and Volunteers

Are you a Cal Poly student?	Survey Response	Selected Volunteer’s Response
Yes	45	47
No	3	0

What is your gender?	Survey Response	Selected Volunteer’s Response
Male	28	26
Female	20	21

What is your age?	Survey Response	Selected Volunteer’s Response
18 - 24	39	45
25 - 34	7	2
45 - 54	1	0
55 - 64	1	0

What is your height?	Survey Response	Selected Volunteer’s Response
5’ - 5’ 3”	9	9
5' 4" - 5' 7"	12	13
5' 8" - 5' 11"	12	15
6' 0 and over	15	10

What is your college?	Survey Response	Selected Volunteer’s Response
College of Agriculture, Food, and Environmental Sciences	7	8
College of Engineering	26	23
College of Liberal Arts	4	3
College of Science and Mathematics	6	9
Orfalea College of Business	4	0
College of Architecture and Environmental Design	1	4

It was required that the simulation volunteers were not prone to motion sickness, nor have any health concerns that may prevent them from wearing the virtual reality headset. Potential volunteers were given an informed consent form that gave details on what to expect on the day of the test. The informed consent form (Appendix A) discussed the length of the study (30 minutes) and described the main risks anticipated with the participation in the study. Main risks, included motion sickness, eye strain, seizures, dizziness, and discomfort. If the student agreed to voluntarily participate in this research, they were asked to complete a pre-screening form (Appendix B) that asked about the student’s medical history. If the students passed the pre-screening test, they were asked to sign up for a time slot to participate in the research.

When the volunteers arrived at the research lab, they were given a summary of what was written in the consent form as a reminder of the risks associated with the experiment. The volunteers were then given 5-10 minutes to try the demo simulation, “The Lab: Venice” (“The Lab on Steam,” 2016). They were told to teleport and physically move around in the courtyard (Figure 3.10). This demo allowed the volunteers to become more familiar with using the HTC Vive headset and walking around in the virtual reality simulation.

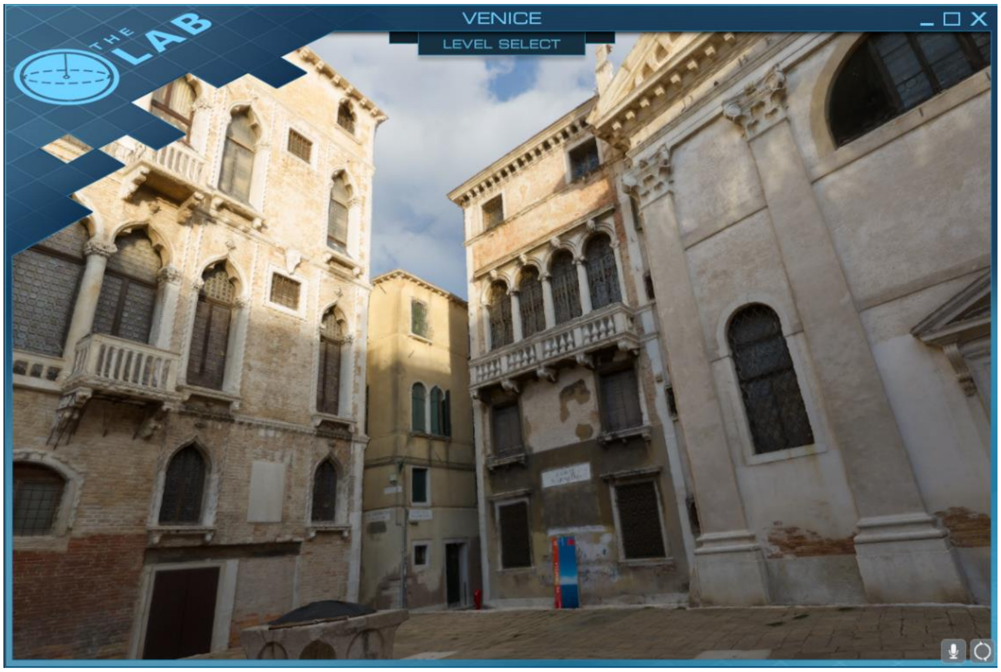


Figure 3.10: Virtual Simulation of “The Lab: Venice” (“The Lab on Steam,” 2016)

After testing the demo, they were asked about their comfort level and if they were ready to try the crosswalk simulation. Volunteers were free to back out of the research at any time if they were to feel discomfort. However, all the volunteers decided to continue with the research. They were then shown a bird’s eye view of the virtual crosswalk and asked if they recognized the location. Then, they were given the scenario below:

Imagine that you just got out from the Kennedy Library. It is about 10:30 am on a Tuesday morning and you were planning to meet a friend at the Campus Market.

The volunteers were told that there would be two Apeman cameras in the research lab; the first camera would be recording the volunteers (Figure 3.11) and the second camera would be recording what the volunteers were visualizing through the headset (Figure 3.12). Figure 3.12 is a replica of the real location in Figure 3.13. Duct tape was taped on the floor in between both base stations and was used to measure the distance that the volunteers walked (Figure 3.11). A stopwatch, that can record in milliseconds (“Stopwatch,” 2010), was used to help calculate the time it took for passengers to traverse a specific distance (Figure 3.12). By knowing the distance and the time, the pedestrian speed could be calculated.

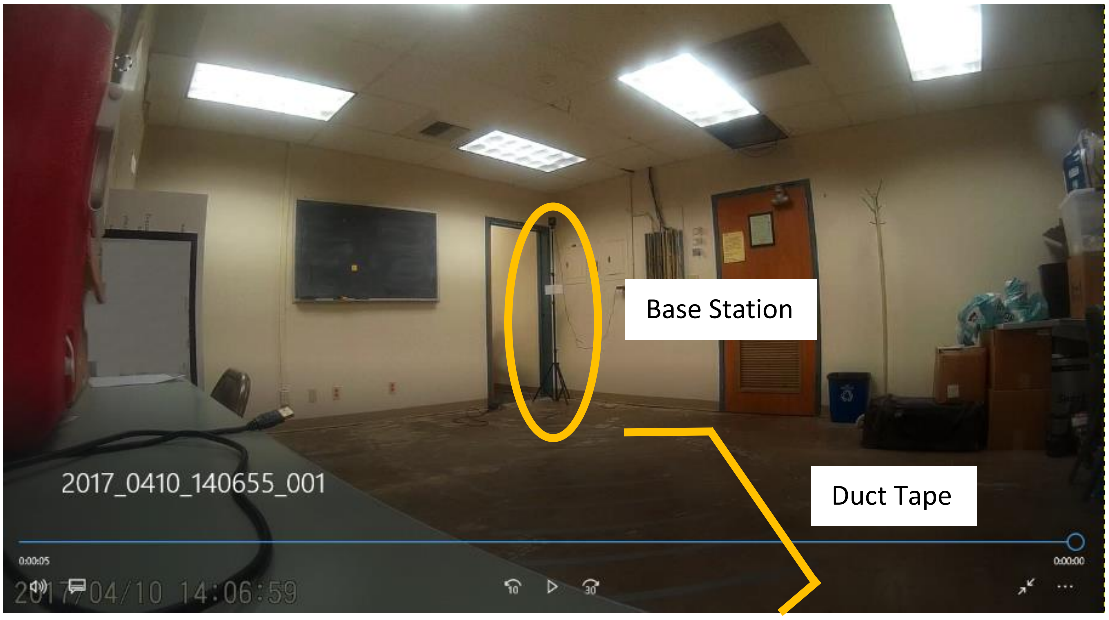


Figure 3.11: View from Apeman Camera 1 in the Research Lab

Figure 3.12: View from Apeman Camera 2 in the Research Lab

Figure 3.13: Real Location of Figure 3.12

When volunteers first wore the headset, they found themselves on the sidewalk directly east of the H2 Parking Lot. The circled area in Figure 3.14 marks the starting point. Figure 3.14 is a replica of Figure 3.15.

Figure 3.14: Starting Point in the Virtual Simulation

Figure 3.15: Real Location of Figure 3.14

Since the base stations (Figure 3.11) could only detect up to 15ft x 15ft, volunteers were told that they needed to teleport to the location where they planned to step off the curb prior to physically walking across the street. They were asked to stop walking once they reached the end of the blue chaperone boundaries and to wait for the next set of instructions. These boundaries only appeared when the volunteers were about to hit the walls of the room indicating that they have walked as far as they physically could in the room. While the volunteers were walking in the crosswalk simulation, we recorded all their movements, such as if they looked left and right prior to crossing.

After the experiment, volunteers were given a survey (Appendix C) that asked about their virtual experience and included questions, such as how they typically behave at a midblock crosswalk. After submitting their responses, they were given a $5.00 Starbucks gift card.

3.4 Methodology Summary

The process needed to analyze pedestrian behavior at a midblock crosswalk involved many steps. First, a location on the Cal Poly campus was chosen that could provide an adequate population sample and factors that can easily be controlled. The midblock crosswalk that was selected was the one on University Drive near the Food Processing & Campus Market building and Agricultural Sciences building. For the real environment, two Apeman Action Camera Model A66 and an iPad Air captured the whole area at the midblock crosswalk for approximately 1.5 – 2 hours for two days. The preliminary phase took place on the first day and was used to determine which variables would be analyzed in the virtual and real environment and the direction the volunteers would be walking in the virtual simulation. For the virtual environment, a model of the crosswalk had to be created using the Unity Engine and Blender. Prior to recruiting for volunteers to test the virtual reality simulation, a demographics survey was conducted that asked pedestrians who were crossing at the midblock crosswalk about their gender, age, height, and major. This survey was used to help advertise for volunteers who would be able to wear the headset. In addition, an informed consent form and a medical questionnaire were given to potential volunteers to made sure that they did not have health concerns that may prevent them from wearing the virtual reality headset. After the volunteers were selected, they were invited to come into the research lab and wear the headset. After recording their behaviors, the volunteers were given a survey that asked about their virtual experience. The data collected from the pedestrians in the real environment and the participants from the virtual environment were compared in the next section.

4. RESULTS

The following section analyzed the data that was collected for both the real environment and virtual environment. The three criteria used to compare the real environment observations with the virtual environment observations are listed below:

- Pedestrian walking speed
- Observation patterns prior to crossing the road, characterized by glancing left and right to detect cars
- Where the pedestrian chose to cross, defined by if they chose to walk directly on or outside of the midblock crosswalk

A detailed analysis was conducted to see if there were factors that affected these criteria in both the real and virtual environment. The real environment could have variables that could not be replicated in the virtual environment, such as texting while crossing. Therefore, it was of interest to see if texting affected the pedestrian walking speed. If texting affected speed, virtual data may not be comparable to the real environment data and therefore, speed would need to be excluded from the analysis.

4.1 Real Environment Observations: Preliminary Analysis

This section is divided into two sections: Data Collection and Analyzing the Results. The preliminary phase consists of data collected for all pedestrian movement near the midblock crosswalk.

4.1.1 Data Collection

Two Apeman cameras and iPad captured 198 pedestrians who were walking alone for approximately 1.5 hours on Tuesday, March 7, 2017. These observations were recorded in Table 4.1. Data for two pedestrians were not recorded since a large bus blocked the view of all the cameras. Table 4.2 shows a brief description of what some of the terms means in Table 4.1.

Table 4.1: Real Environment Data Collection (Preliminary Phase) (N = 198)

(a) Gender	
Male	125
Female	73

(b) Noticed Camera Beforehand	
Yes	15
No	183

(c) Walking Direction	
Eastbound	110
Westbound	88

(d) Interaction Between Driver and Pedestrian	
Pedestrian crossed upon seeing oncoming vehicle(s)	40
No oncoming vehicle(s) on the road	144
Pedestrian waited for vehicle(s) to pass upon seeing oncoming vehicle(s)	10
Vehicle(s) blocked crosswalk	4

(e) Pedestrian Speed	
Less than 3.1 ft/s	4
3.1 – 5 ft/s	165
5.1 – 7 ft/s	26
7.1 – 9 ft/s	0
Greater than 9 ft/s	3

(f) Looked Left and Right Prior to Crossing the Road	
Yes	177
No	21

(g) Visible Distraction	
Talking on cell phone	3
Texting/Reading cell phone	15
Eating	6
None	174

(h) Time Period	
Passing	77
Non-Passing	121

(i) Crossing Location	
North side	32
South side	11
Walked directly on midblock crosswalk	155

(j) Distance Between Pedestrian and Midblock Crosswalk	
Did not walk outside of crosswalk	155
Less than 10 feet	12
11 - 20 feet	14
21 - 30 feet	6
31 - 40 feet	4
41 - 50 feet	2
Greater than 50 feet	5

Table 4.2: Description of Terms Used When Analyzing Pedestrian Behavior in the Real Environment

Noticed Camera Beforehand	The Apeman cameras caught some of the pedestrians looking straight into the lens prior to crossing.
Walking Direction	Pedestrians either walked east toward the Campus Market Building or west toward the H2 Parking Lot.
Interaction Between Driver and Pedestrian	Oncoming vehicles were defined as vehicles that were within 80 feet of both sides of the crosswalk. Even if there were no oncoming vehicles present, there may have still been vehicles on the street.
Pedestrian Speed	The speed was measured right when the pedestrian stepped off the curb until he or she reached the yellow line pavement markings that were in the middle of the street.
Crossing Location	The north side and south side were defined, respectively, as the whole area north and south of the midblock crosswalk based on when the pedestrian decided to cross the street.
Distance between Pedestrian and Midblock Crosswalk	The distance was measured between when the pedestrian crossed and the closest edge of the crosswalk.
Time Period	Passing began from the start of the hour to 10 minutes after the hour while non-passing began 10 minutes after the hour until the start of the following hour.

Based on Table 4.1a, 63.1% of pedestrians were male. Over 90% of the pedestrians did not notice the cameras (Table 4.1b) and 55.6% walked in the eastbound direction (Table 4.1c). Over 70% of the pedestrians did not have to face oncoming vehicles on the street (Table 4.1d) and still looked left and right (89.4%) prior to crossing (Table 4.1f). There were 87.9% of all pedestrians who did not have a visible distraction (Table 4.1g) and 83.3% who spent 3.1 – 5 ft/s crossing the first half of the street (Table 4.1e). Over 75% of all pedestrians did not walk outside of the crosswalk (Tables 4.1i, 4.1j) and 61.1% walked during non-passing period (Table 4.1h)

4.1.2 Analyzing the Results

It is important to analyze variables from Table 4.1 that could affect how the volunteers behaved in the real environment that would not have happened if they were in the virtual environment. JMP Pro is a powerful software that allows users to perform a series of tests, such as an Analysis of Variance (ANOVA), stepwise regression, and Odds Ratios Tests, that can analyze all the factors that may influence the volunteers' behaviors ("JMP Pro 12.1.0," 2015).

4.1.2.1 Analysis of Walking Speed

One variable that was analyzed was the pedestrian walking speed. When conducting a statistical analysis, the first step to conducting an ANOVA is constructing a null hypothesis (H_O). The null hypothesis for this variable of interest is that there was no difference in speed no matter what variables from Table 4.1 were considered in the model: $\mu = 0$. The alternative hypothesis (H_A) states that there was a difference in walking speed based on the variables in the model: $\mu \neq 0$. If the ANOVA calculates a p-value less than 0.05, the null hypothesis is rejected and the alternative hypothesis is followed (Grafen & Hails, 2002).

Using the mixed stepwise regression on JMP Pro, there were no variables that affected the speed. This stepwise regression analysis explored all variables listed in Table 4.1.

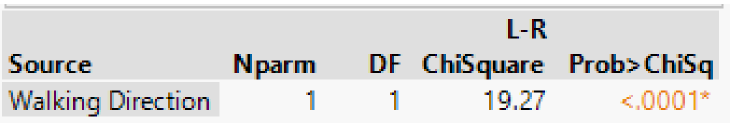
4.1.2.2 Analysis of Pedestrians' Observations Before Crossing

Factors that affected if pedestrians looked left and right prior to crossing the road were analyzed. Using the mixed stepwise regression, it was discovered that there were no variables listed in Table 4.1 that significantly affected the decision of pedestrians to watch for cars at a 95% confidence interval.

4.1.2.3 Analysis of Crossing Location

Variables that affected if a pedestrian chose to walk outside of the crosswalk were considered. Based on the mixed stepwise regression, there was a significant relationship between the walking direction and if a pedestrian chose to walk directly on the midblock crosswalk: $\chi^2(1) = 19.27$, p-value<0.0001 (Table 4.3). The chi-square test calculates how close the two variables are related (Grafen & Hails, 2002).

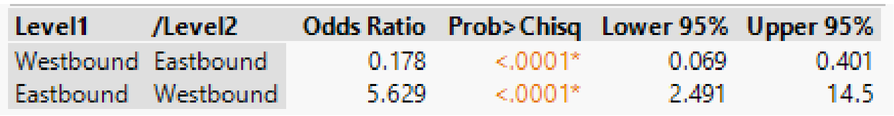
Table 4.3: Factor Affecting Crossing Location Based on Mixed Stepwise Regression (N = 198)



Source	Nparm	DF	L-R ChiSquare	Prob>ChiSq
Walking Direction	1	1	19.27	<.0001*

The Odds Ratios showed that pedestrians were 5.629 times more likely to cross outside of the midblock crosswalk in the eastbound direction than in the westbound direction (Table 4.4). This test was computed from the 36 pedestrians who walked in the eastbound direction and 7 pedestrians who walked in the westbound direction. None of the other variables affected where the pedestrian crossed at a 95% confidence interval.

Table 4.4: Ratio of Walking Direction Based on Crossing Location (N = 198)



Level1	/Level2	Odds Ratio	Prob>Chisq	Lower 95%	Upper 95%
Westbound	Eastbound	0.178	<.0001*	0.069	0.401
Eastbound	Westbound	5.629	<.0001*	2.491	14.5

A deeper analysis was conducted to see how pedestrians crossed whether their path originated from locations 1, 2, or 3 (Figure 4.1) on the west side of the midblock crosswalk. Location 1 represented pedestrians walking southbound toward the midblock crosswalk, location 2 represented pedestrians arriving from the H2 Parking Lot, and location 3 represented pedestrians walking northbound toward the midblock crosswalk.

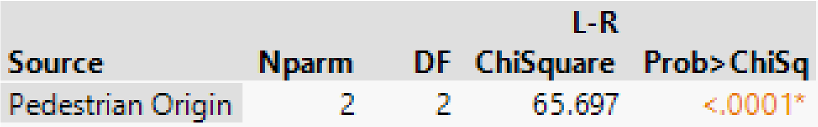
Figure 4.1: Potential Pathways for Pedestrians Walking in the Eastbound Direction ("Google Maps," 2017)

Most pedestrians who chose to not walk on the crosswalk came from location 1 (80.6%), followed by location 3 (29.4%) (Table 4.5). The location that the pedestrians came from did affect whether they chose to use the crosswalk: $\chi^2(2) = 65.697$, p-value<0.0001 (Table 4.6). Pedestrians coming from location 1 were 113.9 times more likely to walk outside of the crosswalk compared to pedestrians coming from location 2. In addition, pedestrians coming from location 3 were 11.46 times more likely to walk outside of the crosswalk compared to pedestrians coming from location 2.

Table 4.5: Number of Pedestrians Walking Outside of the Crosswalk for Each Origin (N = 110)

Pedestrian Origin	Number of Pedestrians	Walked Outside of Crosswalk?	Percent of Pedestrians Outside of Crosswalk
Location 1	36	29	80.6%
Location 2	57	2	3.5%
Location 3	17	5	29.4%

Table 4.6: Factor Affecting Where Pedestrians Chose to Cross in the Eastbound Direction (N = 110)



Source	Nparm	DF	L-R ChiSquare	Prob>ChiSq
Pedestrian Origin	2	2	65.697	<.0001*

After conducting the statistical analysis, it was decided that pedestrians would only be walking in the eastbound direction in the virtual simulation since pedestrians were more likely to walk outside of the crosswalk in the eastbound direction versus the westbound direction (Table 4.4). In addition, the virtual simulation volunteers would start at location 3 (Figure 4.1). Although location 1 had more pedestrians who walked outside of the crosswalk, location 3 was a better option due to how the simulation was created. The only street modeled in Blender was University Drive between Highland Drive and N Perimeter Road. If volunteers were to appear at location 1, they would see a vehicle appear out of nowhere since the vehicle always started near the intersection of University and Highland Drive; the simulation only had one car traveling southbound on University Drive. Thus, this would have caused confusion to the volunteers. Furthermore, focusing on just one location allowed for a more controlled virtual environment.

4.2 Real Environment Observations: Location 3 Analysis

This section is divided into two sections: Data Collection and Analyzing the Results. This section consists of all the data collected for pedestrians walking in the eastbound direction toward the Campus Market while coming from location 3 (Figure 4.1). Since there was not enough pedestrian walking from location 3 on one day, more data needed to be collected on a second day.

4.2.1 Data Collection

Two Apeman cameras captured 24 pedestrians who were walking in the eastbound direction while coming from location 3 for approximately 2 hours on Monday, May 8, 2017. This data was combined with the data from the eastbound pedestrians observed during the preliminary phase and were recorded in Table 4.7.

Table 4.7: Real Environment Data Collection (Location 3 Analysis) (N = 41)

(a) Gender	
Male	27
Female	14

(b) Noticed Camera Beforehand	
Yes	3
No	38

(c) Interaction Between Driver and Pedestrian	
Pedestrian crossed upon seeing oncoming vehicle(s)	4
No vehicle(s) on the road	33
Pedestrian waited for vehicle(s) to pass upon seeing oncoming vehicle(s)	4
Vehicle(s) blocked crosswalk	0

(d) Pedestrian Speed	
Less than 3.1 ft/s	2
3.1 – 4 ft/s	15
4.1 – 5 ft/s	21
Greater than 5.1 ft/s	3

(e) Looked Left and Right Prior to Crossing the Road	
Yes	37
No	4

(f) Crossing Location	
Outside of Crosswalk	10
Directly on Crosswalk	31

(g) Distance Between Pedestrian and Midblock Crosswalk	
Did not walk outside of crosswalk	31
Less than 11 feet	1
11 - 20 feet	4
21 - 30 feet	2
31 - 40 feet	2
41 - 50 feet	0
Greater than 50 feet	1

(h) Visible Distraction	
Talking on cell phone	2
Texting/Reading cell phone	0
Eating	0
None	39

(i) Time Period	
Passing	14
Non-Passing	27

The brief description of what each of the terms means may be found in Table 4.2.

Out of the 41 pedestrians who crossed the street, 27 were male (Table 4.7a) and 38 did not notice the cameras before crossing (Table 4.7b). There were 80.5% who crossed without seeing any oncoming vehicles on the road (Table 4.7c). Over 50% took 4.1 – 5 ft/s to cross the first half of the street while 36.6% took 3.1 – 4 ft/s (Table 4.7d). There were only four pedestrians who did not look before crossing (Table 4.7e). Two of the pedestrians was talking on the phone while walking (Table 4.7h). There were 31 pedestrians who chose to walk directly on the crosswalk (Tables 4.7f, 4.7g) and 65.9% crossed during the non-passing period (Table 4.7i).

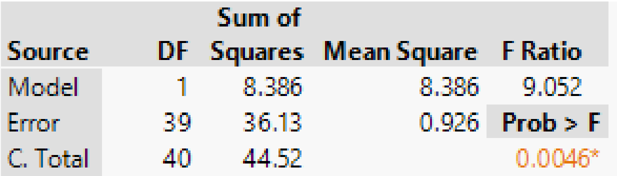
4.2.2 Analyzing the Results

Similar to the preliminary phase, it is crucial to analyze factors that may affect how pedestrians behave in the eastbound direction of the real environment.

4.2.2.1 Analysis of Walking Speed

When analyzing only data from pedestrians walking eastbound from location 3, time period appears to be significant: F(1,39) = 9.052, p-value = 0.0046 (Table 4.8).

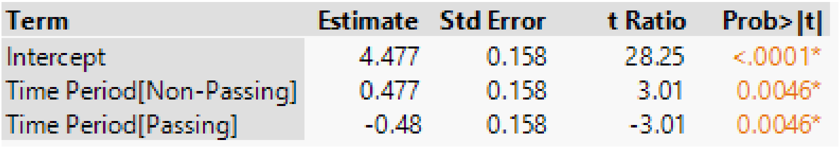
Table 4.8: Factor Affecting Walking Speed Based on Mixed Stepwise Regression (N = 41)



Source	DF	Sum of Squares	Mean Square	F Ratio
Model	1	8.386	8.386	9.052
Error	39	36.13	0.926	**Prob > F**
C. Total	40	44.52		0.0046*

Table 4.9 shows that pedestrians tend to walk slower during the passing period than the non-passing period. However, none of the variables from Table 4.7 were found to be correlated with the time period. Therefore, this could potentially be a limitation since in the virtual simulation, the effect of this variable may be impossible to create.

Table 4.9: Estimates for Parameters Affecting Walking Speed Based on Mixed Stepwise Regression (N = 41)



Term	Estimate	Std Error	t Ratio	Prob>|t|
Intercept	4.477	0.158	28.25	<.0001*
Time Period[Non-Passing]	0.477	0.158	3.01	0.0046*
Time Period[Passing]	-0.48	0.158	-3.01	0.0046*

4.2.2.2 Analysis of the Other Two Criteria

Using the mixed stepwise regression on JMP Pro 12.1.0, there were no variables from Table 4.7 that influenced whether a pedestrian chose to look left and right before crossing and their crossing location.

4.3 Virtual Environment Observations

This section is divided into two sections: Data Collection and Analyzing the Results. The data collected from Chapter 4.1: Real Environment Observations: Preliminary Analysis helped decided which variables to analyze in the virtual environment.

4.3.1 Data Collection

A sample of 47 students, who matched the characteristics of those who filled out the demographics survey (Table 3.1), were selected to volunteer in this virtual simulation over a span of two weeks in April 2017. Their observations were recorded in Table 4.10.

Table 4.10: Virtual Environment Data Collection (N = 47)

(a) Gender	
Male	26
Female	21

(b) Used VR Headset in the Past	
Yes	14
No	33

(c) Discomfort After Testing	
Yes	1
No	46

(d) Recognized Location	
Yes	47
No	0

(e) Confused About How to Navigate	
Yes	10
No	37

(f) Asked if Needed to Use Crosswalk	
Yes	18
No	29

(g) Looked Left and Right Prior to Crossing the Road	
Yes	21
No	26

(h) Crossing Location	
Outside of crosswalk	7
Directly on crosswalk	40

(i) Pedestrian Speed	
Less than 1.51 ft/s	16
1.51 – 2 ft/s	13
2.1 – 2.5 ft/s	11
Greater than 2.5 ft/s	7

(j) Distance Between Pedestrian and Midblock Crosswalk	
Did not walk outside of crosswalk	40
Less than 11 feet	0
11 - 20 feet	2
21 - 30 feet	2
31 - 40 feet	0
41 - 50 feet	0
Greater than 50 feet	3

(k) Time When Crossed	
Less than 11 seconds	3
11 – 20 seconds	25
21 – 30 seconds	13
Greater than 30 seconds	6

Students were asked directly if they used a VR headset in the past, had motion sickness after participating in the virtual simulation, and recognized the location of the simulation. The Apeman cameras recorded their movements, such as the time it took for them to cross the virtual street. Table 4.11 shows a brief description of what some of the terms means in Table 4.10.

Table 4.11: Description of Terms Used When Analyzing Pedestrian Behavior in the Virtual Environment

Used VR Headset in the Past	This section asked if the pedestrian has ever used a VR headset, such as the HTC Vive, Oculus Rift, Gear VR, and PlayStation VR, prior to volunteering.
Discomfort After Testing	After wearing the headset for approximately 15 – 20 minutes, volunteers were asked if they felt motion sickness, dizziness, or any discomfort that may prevent them from performing typical daily tasks.
Recognized Location	Prior to giving instructions on walking to the Campus Market, volunteers were shown the model of University Drive and asked if they could identify that location.
Asked if Needed to Use Crosswalk	When given instructions for walking toward the Campus Market, some volunteers asked if they were supposed to use the crosswalk prior to crossing the street.
Confused About How to Navigate	Once volunteers put on the headset, some were confused about how to cross the street and may have walked in a different direction. The purpose of the VR demonstration was to familiarize the volunteers with walking around in a virtual environment.
Time When Crossed	Once the volunteer was placed in the virtual simulation, the timer started. If the volunteer stayed in the simulation too long, he or she may have noticed a vehicle driving in the same loop.

After participating in the virtual simulation, volunteers were asked to fill out a survey. Two of the questions asked if the volunteers used the midblock crosswalk on University Drive frequently and the number of times they used it (Figures 4.2 and 4.3).

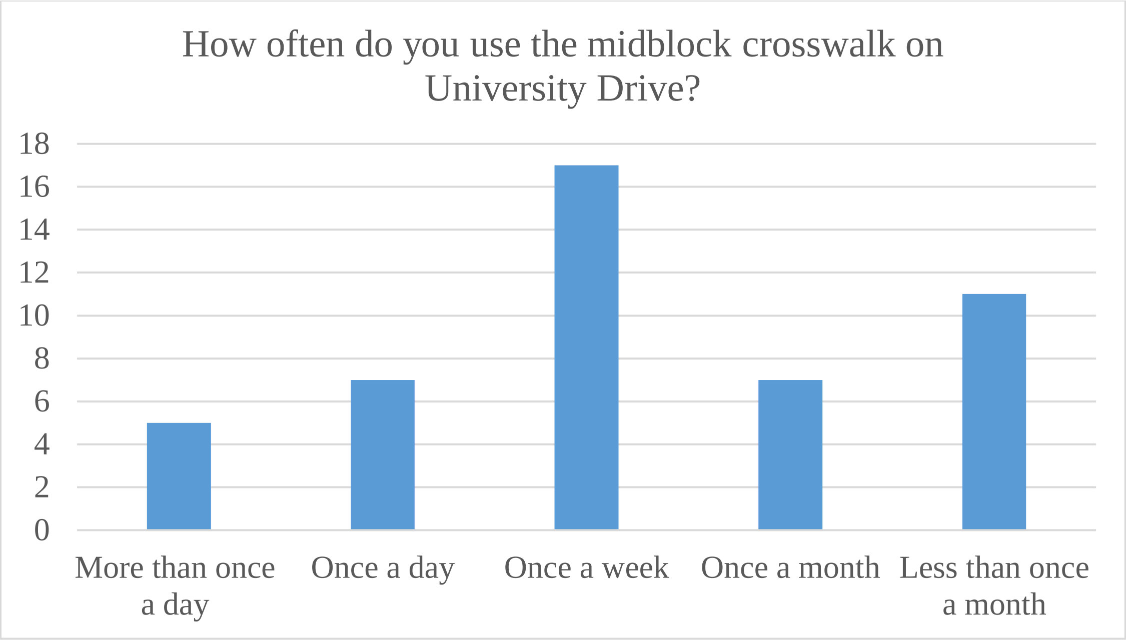


Figure 4.2: Statistics on Frequency of Using Crosswalk on University Drive

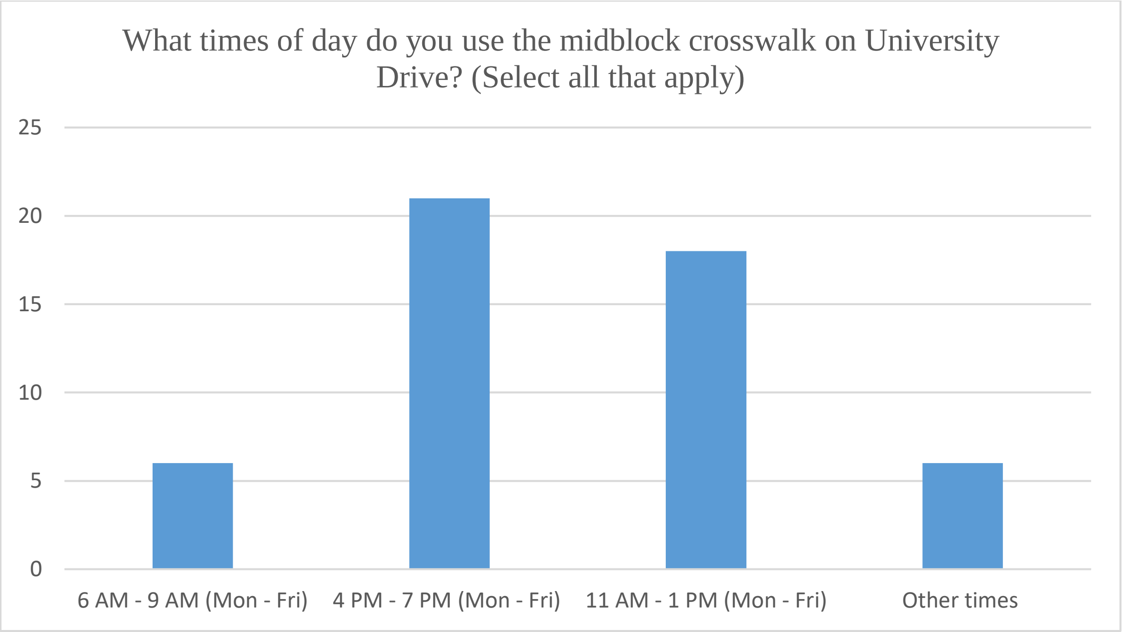
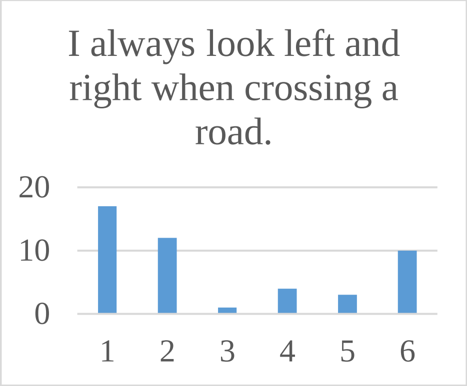


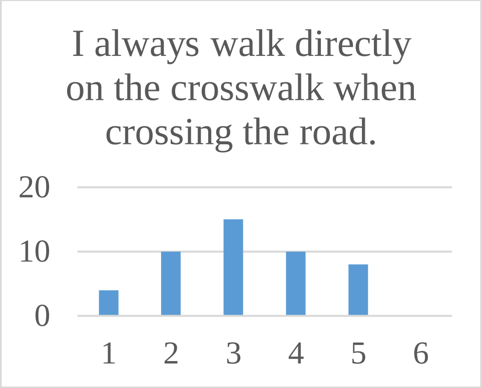
Figure 4.3: Statistics on Time Volunteers Used Crosswalk on University Drive

In addition, volunteers were asked to indicate their level of agreement or disagreement with the following statements (Figure 4.4). The scale ranged from 1 to 6:

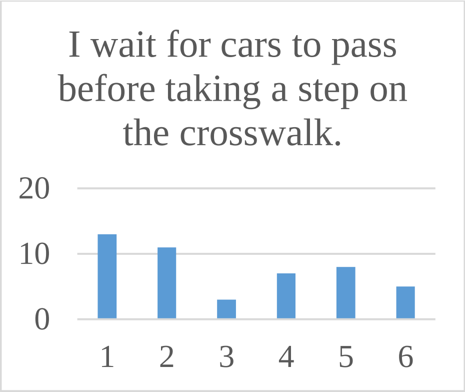
1 = Strongly Agree
2 = Slightly Agree
3 = Neutral
4 = Slightly Disagree
5 = Strongly Disagree
6 = Don’t Know



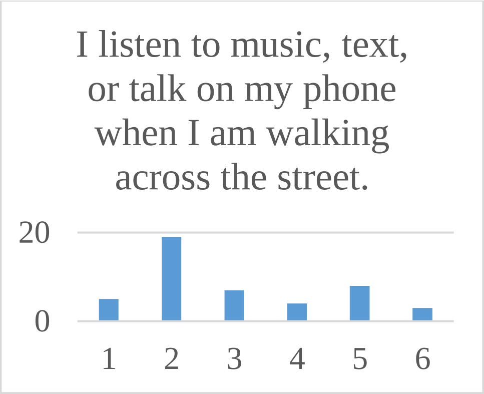
(a)



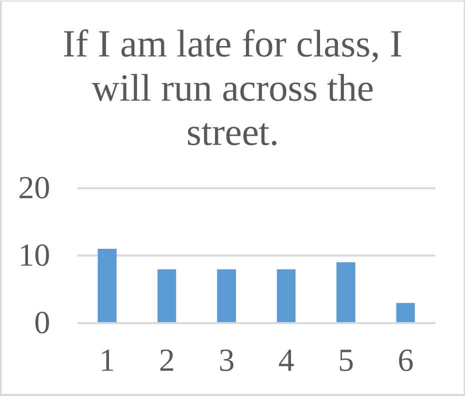
(b)



(c)



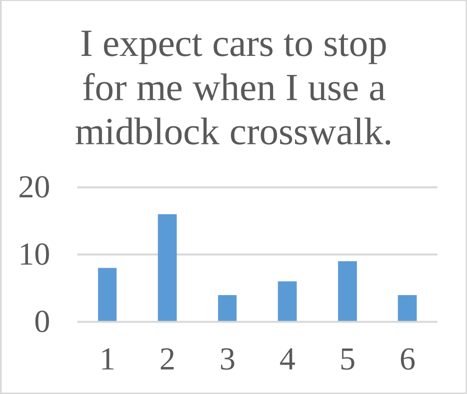
(d)


If I am late for class, I will run across the street.
20
10
0
1
2
3
4
5
6

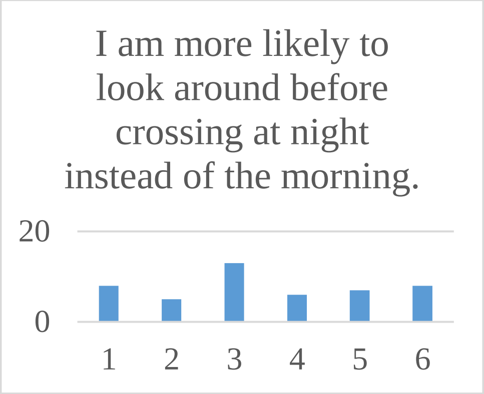
(e)


I jaywalk often.
14
12
10
8
6
4
2
0
1
2
3
4
5
6

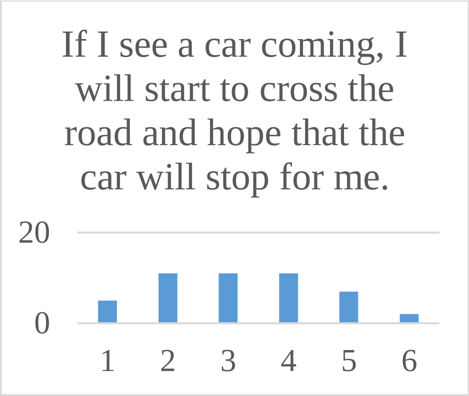
(f)


I expect cars to stop for me when I use a midblock crosswalk.
20
10
0
1
2
3
4
5
6

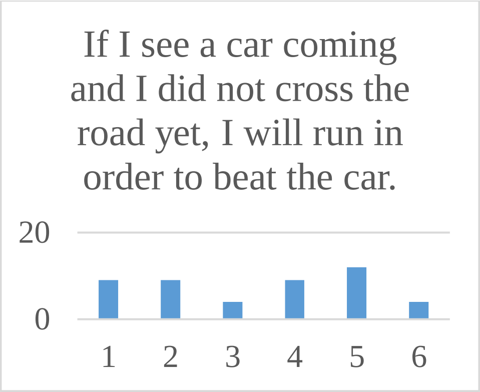
(g)


I am more likely to look around before crossing at night instead of the morning.
20
0
1
2
3
4
5
6

(h)


If I see a car coming, I will start to cross the road and hope that the car will stop for me.
20
0
1
2
3
4
5
6

(i)


If I see a car coming and I did not cross the road yet, I will run in order to beat the car.
20
0
1
2
3
4
5
6

(j)

(k)

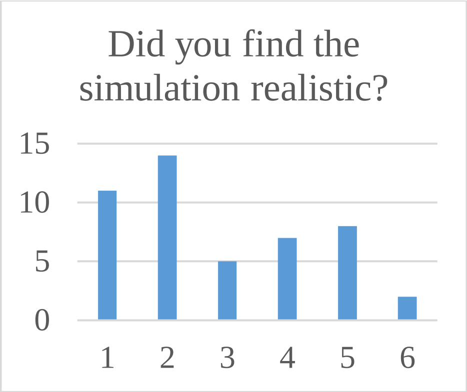


Figure 4.4: Survey Responses from a Scale of 1 (Strongly Agree) to 5 (Strongly Disagree) and 6 (Don't Know)

Approximately 55% of the volunteers were males (Table 4.10a). Most students have not worn a VR Headset in the past (Table 4.10b) nor felt sick after testing the virtual simulation (Table 4.10c). While everyone recognized what the virtual model was representing in the real environment (Table 4.10d), 55.3% of the students did not look left and right prior to crossing the road (Table 4.10g). In fact, there were 10 students who were unsure of how to walk in the virtual world (Table 4.10e). Prior to physically crossing the street, they were told to teleport to the location where they planned to cross. These volunteers either teleported away from the direction of the Campus Market or started walking when they were supposed to teleport first. A little less than half the number of students asked if it was required for them to walk on the crosswalk (Table 4.10f) even though they were told to pretend that they were physically in that location. Most volunteers chose to directly walk on the crosswalk (Tables 4.10h, 4.10j) and had an average walking speed less than 1.5 ft/s (Table 4.10i). Most volunteers took about 10 – 20 seconds to cross the street (Table 4.10k).

From the post-survey, most students use the midblock crosswalk once a week (36.2%), followed by less than once a month (23.4%) (Figure 4.2). Most students use the midblock crosswalk between 4 pm to 7 pm Mondays through Fridays (44.7%), followed by 11 am to 1 pm Mondays through Fridays (38.3%) (Figure 4.3). When using the crosswalk, most students claimed that they always look left and right when crossing the road (Figure 4.4a) and will run across the street if they were late to class (Figure 4.4e). They were mostly neutral when it came to always walking directly on the crosswalk when crossing the road (Figure 4.4b) and looking around before crossing during the night instead of the morning (Figure 4.4h). For the statement about waiting for cars to pass before crossing the road, most students either strongly agreed to this statement or slightly agreed (Figure 4.4c). The survey showed that most volunteers slightly agree to listening to music, texting, or talking on the phone while walking across the street (Figure 4.4d) and expecting cars to stop for them when they use the midblock crosswalk (Figure 4.4g). Students were either neutral or slightly agree with jaywalking often (Figure 4.4f). For the two statements about how the students would behave if they see a car approaching (Figures 4.4i, 4.4j), the responses were almost evenly scattered.

The last question asked if the volunteers found the virtual simulation to be realistic (Figure 4.4k). Many found it to be realistic and stated that they felt as if they were physically in that location once they put the headset on. Others suggested that in order to make the simulation more realistic, people and sound should be added to the scene.

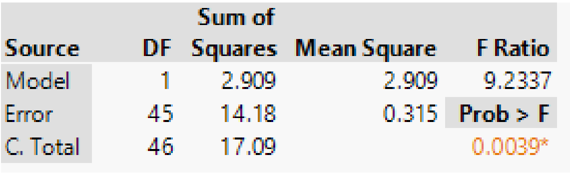
4.3.2 Analyzing the Results

Prior to comparing the real environment observations with the results from the virtual environment observations, it is important to analyze factors that could affect how the volunteers behaved in the virtual environment that would not have happened if they were in the real environment. A few questions that arose were if there were factors that affected the volunteer's walking speed, if they looked left and right prior to crossing the road, and where they chose to cross the street. These factors were used to compare to the real environment observations.

4.3.2.1 Analysis of Walking Speed

The first variable that was analyzed was seeing what variables affect the volunteers' speeds. The variables that were analyzed are listed in Table 4.10. The variable, "Confused about how to Navigate," was the only significant variable after conducting a mixed stepwise regression: F(1,45) = 9.2337, p-value = 0.0039 (Table 4.12).

Table 4.12: Factor Affecting Walking Speed Based on Mixed Stepwise Regression (N = 47)

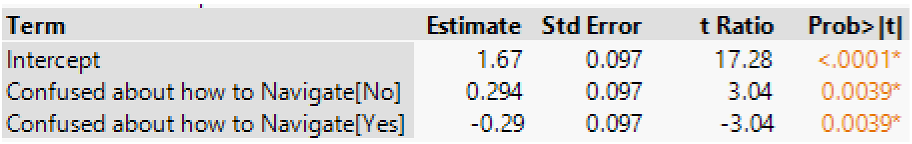


Source	DF	Sum of Squares	Mean Square	F Ratio
Model	1	2.909	2.909	9.2337
Error	45	14.18	0.315	Prob > F
C. Total	46	17.09		0.0039*

Volunteers who were confused about how to cross walked slower (1.38 ft/s) than those who understood the instructions that were given to them about walking in the

Campus Market direction (1.96 ft/s) (Table 4.13). Those who followed the instructions successfully did not have to repeatedly ask what to do or walk in the opposite direction.

Table 4.13: Estimates for Parameters Affecting Walking Speed Based on Mixed Stepwise Regression (N = 47)



Term	Estimate	Std Error	t Ratio	Prob>|t|
Intercept	1.67	0.097	17.28	<.0001*
Confused about how to Navigate[No]	0.294	0.097	3.04	0.0039*
Confused about how to Navigate[Yes]	-0.29	0.097	-3.04	0.0039*

Questions arose about what factors affected what made volunteers confused about how to cross in the first place. Could it be because they had never worn a virtual reality headset in the past or did not find the simulation to be realistic? However, the mixed stepwise regression showed that these variables did not affect the confusion among the volunteers.

All the volunteers recognized the virtual midblock crosswalk location (Table 4.10d) whether they used the midblock crosswalk more than once a day or less than once a month (Figure 4.2) and were given the same scripted instructions on how to cross the street. Perhaps, the volunteers who were confused about how to move in the simulation only used a VR headset in the past once. In addition, the VR headsets that they may have used, such as the Oculus Rift, Google Cardboard, and Gear VR do not allow users to walk around nor teleport. The Google Cardboard and Gear VR is not PC-driven since they rely on smartphones. The post-survey that was given to all the volunteers did not ask about the specific VR devices they have used in the past nor the duration of using a VR headset. Pedestrian speed will still be compared in both the virtual environment and the real environment. However, the lack of questions pertaining to past VR involvement on the post-survey will be taken into consideration when comparing both environments.

4.3.2.2 Analysis of the Other Two Criteria

The second factor that was analyzed was finding variables that affected whether a person chose to look left or right prior to crossing the road. Using the variables from Table 4.10, it appeared that there were no variables that affect if a person chose to watch for cars. Approximately 60% of the volunteers either strongly agreed or slightly agreed on the post-survey when it came to always looking left and right when crossing the street (Figure 4.4a). In contrast, only 44.7% looked left and right prior to crossing the road in the virtual crosswalk simulation (Table 4.10g). The large differences in percentages may show that people behave differently in the virtual crosswalk simulation than they would if they were physically at that crosswalk location. To verify that this statement is true, this percentage was compared to the percentage of pedestrians who looked left and right before crossing the road in the real environment in Chapter 4.4: Comparing the Real and Virtual Environment Observations.

The third variable that was analyzed was seeing what affected where the pedestrian crossed. After conducting the mixed stepwise regression, it was discovered that there were no variables in Table 4.10 that affected if a pedestrian chose to walk outside of the crosswalk.

There were only 7 out of 47 volunteers who chose to walk outside of the crosswalk in the virtual simulation (Table 4.10h). In Figure 4.4b, many volunteers were neutral when it came to always walking directly on the crosswalk when crossing the road. The number of those who walked directly on the crosswalk in the virtual environment was compared to those in the real environment in Chapter 4.4: Comparing the Real and Virtual Environment Observations.

4.4 Comparing the Real and Virtual Environment Observations

Pedestrian speed, observation patterns, and crossing location were collected in both the real and virtual environment. Observation patterns were characterized by if pedestrians looked left and right prior to crossing the street. The 41 pedestrians walking in the eastbound direction from location 3 (Figure 4.1) were compared to the volunteers in the virtual environment in order to make both environments as consistent as possible.

4.4.1 Comparing Walking Speeds

Speed consisted of the time it took for pedestrians/volunteers to traverse from one location to another. In the real environment, speed was calculated by measuring half of the street and dividing by the time it took for the pedestrians to traverse that distance. In the virtual environment, speed was calculated using duct tape that measured every foot until it reached the edge of the chaperone boundaries. The Apeman cameras clearly showed what tape marking the person was standing on.

Figure 4.5 showed the speeds for both the real environment and virtual environment. Even though the graph does not follow a normal distribution, the speeds calculated for the virtual environment were much lower than those calculated for the real environment. If only pedestrians walking in the eastbound direction from location 3 were observed, the average speed would amount to approximately 4.63 ft/s with a mean standard error of 0.165 ft/s, similar to the pedestrian speed found in the literature review (Rastogi, Thaniarasu, Chandra, 2010). In the virtual environment, the average speed was 1.83 ft/s with a mean standard error of 0.0889 ft/s.

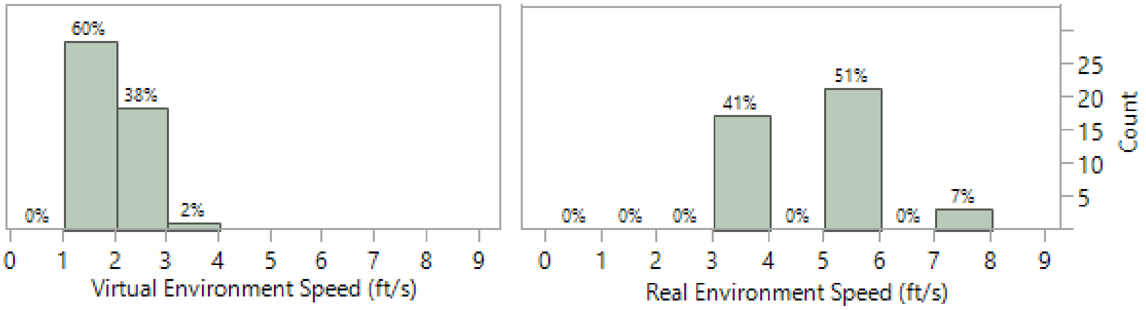
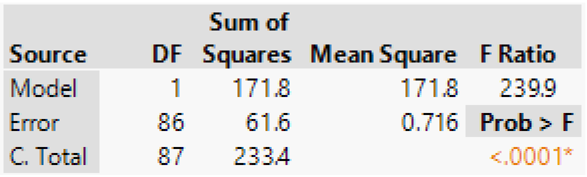


Figure 4.5: Distribution of Speeds for Both Environments

Table 4.14 stated that the speeds in both environments were very different from each other: F(1,86) = 239.9, p-value <0.0001.

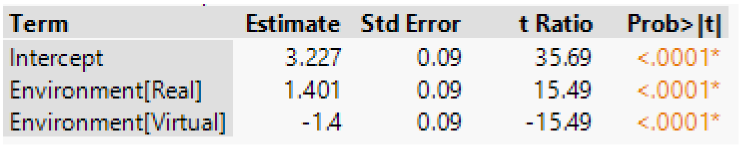
Table 4.14: Comparing Speeds in Both Environments



Source	DF	Sum of Squares	Mean Square	F Ratio
Model	1	171.8	171.8	239.9
Error	86	61.6	0.716	**Prob > F**
C. Total	87	233.4		<.0001*

The speeds in the real environment (4.63 ft/s) is much faster than the speeds in the virtual environment (1.83 ft/s) (Table 4.15).

Table 4.15: Estimates for Comparing Speeds in Both Environments



Term	Estimate	Std Error	t Ratio	Prob>|t|
Intercept	3.227	0.09	35.69	<.0001*
Environment[Real]	1.401	0.09	15.49	<.0001*
Environment[Virtual]	-1.4	0.09	-15.49	<.0001*

4.4.2 Comparing Pedestrians' Observations Before Crossing

Pedestrians either looked left and right before crossing the road or not at all. In the real environment, the two Apeman cameras captured a close-up view of the pedestrians' faces and if they moved their heads to the left and right. In the virtual environment, the volunteers' point of views were displayed on a monitor. Every action that the volunteers made were recorded with the Apeman cameras.

For pedestrians walking from location 3 in the eastbound direction, 90.2% looked left and right prior to crossing the road. In the virtual environment, only 44.7% watched out for vehicles (Figure 4.6).

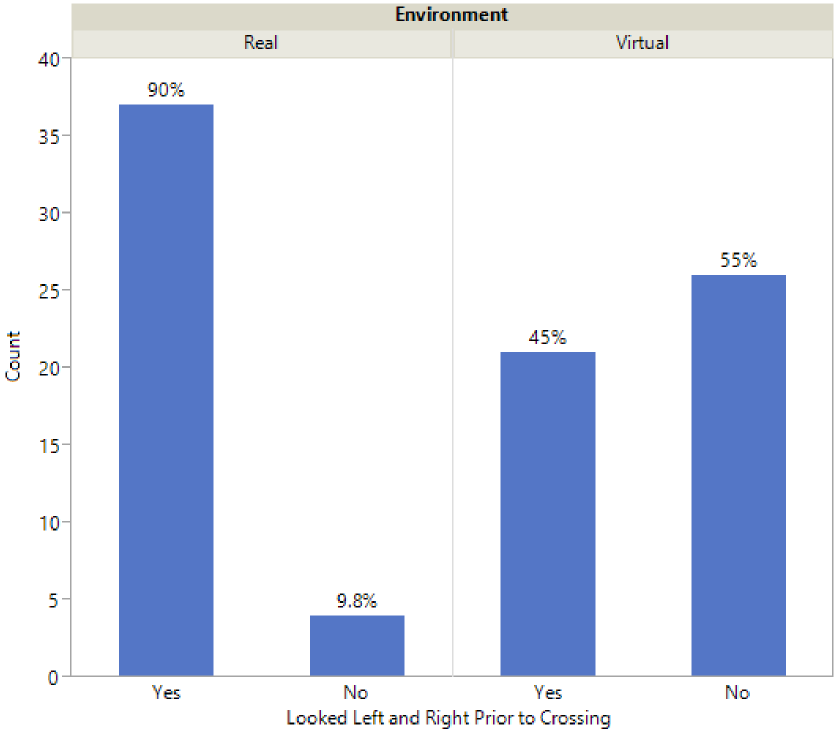


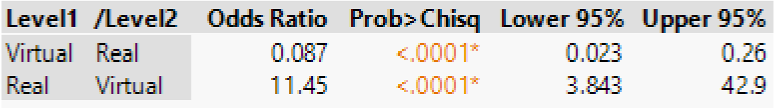
Figure 4.6: Bar Chart for Pedestrians' Observations Before Crossing for Both Environments

The environments were significantly different when it came to pedestrians looking left and right before crossing the street: $\chi^2(1)$ = 22.09, p-value = 0.0010 (Table 4.16). Pedestrians in the real environment were 11.45 times more likely to watch for vehicles on the road (Table 4.17).

Table 4.16: Factor Affecting Pedestrians' Observations Before Crossing in Both Environments

Source	Nparm	DF	L-R ChiSquare	Prob>ChiSq
Environment	1	1	22.09	<.0001*

Table 4.17: Ratio for Looking Left and Right Before Crossing in Both Environments



Level1	/Level2	Odds Ratio	Prob>Chisq	Lower 95%	Upper 95%
Virtual	Real	0.087	<.0001*	0.023	0.26
Real	Virtual	11.45	<.0001*	3.843	42.9

4.4.3 Comparing Crossing Locations

Volunteers had to teleport to the location where they planned to cross in the virtual simulation while the pedestrians just physically crossed the street in the real environment. Over 20% of the pedestrians walked outside of the crosswalk in the real environment compared to 15% in the virtual environment (Figure 4.7).

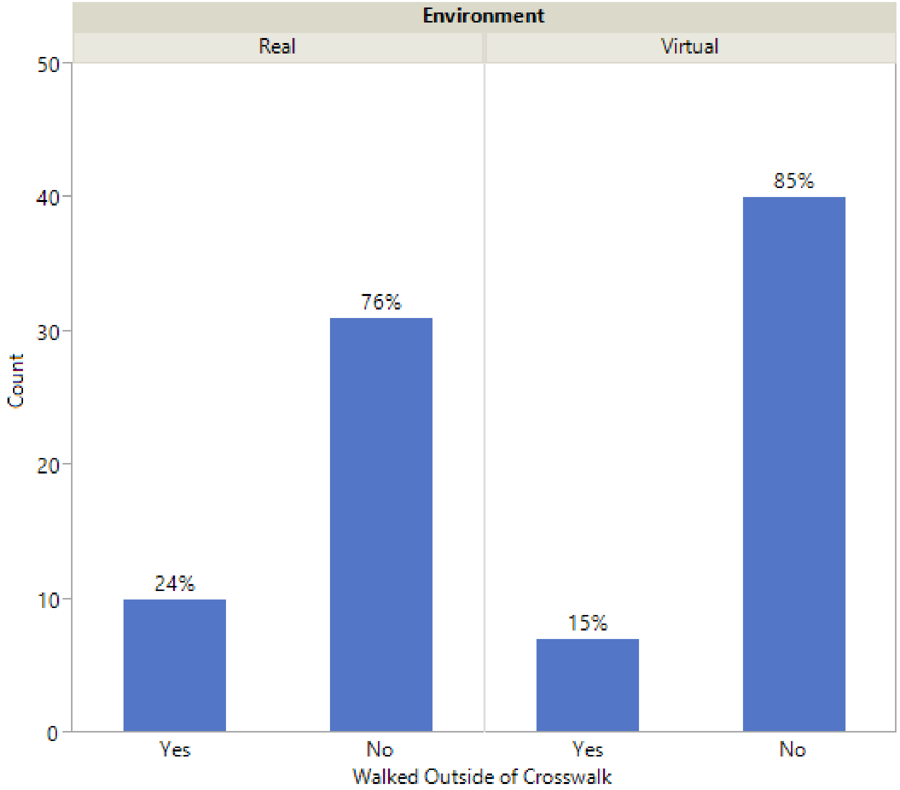
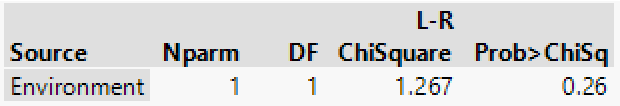


Figure 4.7: Crossing Location Bar Chart for Both Environments

Based on the JMP analysis, there was not a significant difference in the proportion of people walking outside of the crosswalk for both environments: $\chi^2(1) = 1.267$, p-value = 0.26 (Table 4.18).

Table 4.18: Factor Affecting Crossing Location in Both Environments



Source	Nparm	DF	L-R ChiSquare	Prob>ChiSq
Environment	1	1	1.267	0.26

Figures 4.8 and 4.9 show the locations of where the pedestrians crossed in the virtual and real environments.

Figure 4.8: Map of Crossing Location in the Real Environment

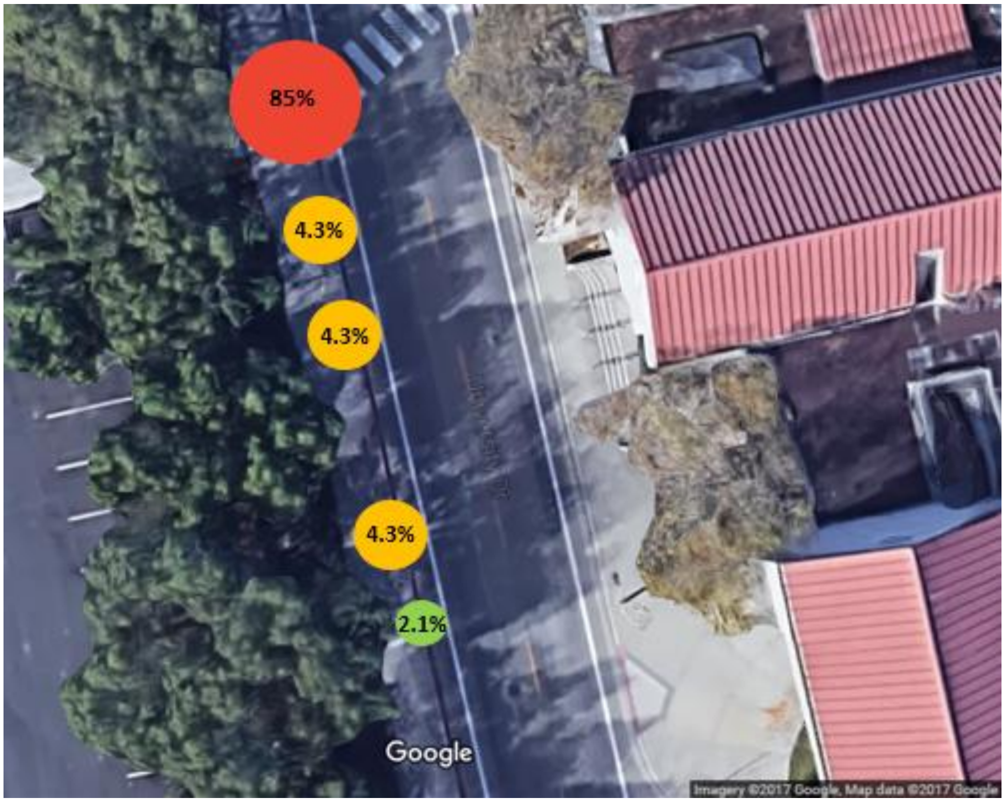


Figure 4.9: Map of Crossing Location in the Virtual Environment

4.5 Results Summary

There were three criteria that were used to compare the real environment with the virtual environment: pedestrian walking speed, pedestrian observations prior to crossing the road, and pedestrian decision-making when it came to where to cross. Factors that may affect these three criteria in the real and virtual environment were analyzed using the mixed stepwise regression.

The data collection for the real environment was split into two days in order to get an adequate sample size.

When analyzing where the pedestrian crossed during the preliminary phase, it was discovered that there was a significant relationship between the walking direction and their crossing location (Table 4.3). Pedestrians were more likely to walk outside of the crosswalk in the eastbound direction toward the Campus Market building than in the westbound direction toward the H2 Parking Lot (Table 4.4). Since crossing location was one of the criteria that was used to compare the virtual and real environment, virtual volunteers were only told to cross in the eastbound direction.

For the eastbound location analysis, time period was the only factor affecting the pedestrian speed (Table 4.8). However, Figure 4.5 showed that almost all the volunteers in the virtual environment walked much slower than the pedestrians in the real environment. Furthermore, there were no factors that affected crossing location or if pedestrians looked left or right prior to crossing the road in the real environment.

In the virtual environment, volunteers who were confused about how to teleport and walk around in the simulation tend to walk slower than those who were able to cross the street without assistance (Table 4.12). In addition, there were no factors that affected whether a person chose to look left or right prior to crossing the street or where they chose to cross.

Based on the three criteria, it appeared that crossing location was the only criteria that was similar in both the virtual and real environments (Table 4.18). Even though 53.2% of the volunteers stated that they felt the virtual simulation was very or slightly realistic (Figure 4.4k), PC-driven virtual reality may not be able to accurately replicate real-life pedestrian behavior due to the differences in walking speeds and the proportion of people who looked left and right before crossing in both environments (Tables 4.14 and 4.16).

5. CONCLUSION

Virtual reality has recently gained popularity in the last few years. Companies, such as HTC, allowed us to assess if PC-driven virtual reality can be used to study pedestrian behavior. In this thesis, the objective was to determine if PC-driven virtual reality could be used to accurately observe pedestrian behavior at a midblock crosswalk. If the data from the virtual environment matched the data obtained from the real environment, it would indicate that PC-driven virtual reality may be a useful tool that can be used to improve pedestrian safety at a crosswalk and possibly be used for other transportation applications.

5.1 Discussion of Results

The parameters that were compared in the virtual and real environments were a) pedestrian walking speed, b) pedestrian observations, characterized by looking left and right prior to crossing the road, and c) specific location relative to the crosswalk where the pedestrian chose to cross. After looking at the results, it appeared that the walking speed was significantly different in both types of environments; the average speed in the real and virtual environment was 4.63 ft/s and 1.83 ft/s, respectively. In addition, there were more people who looked left and right before crossing the street in the real environment versus the virtual environment. There was no significant difference in the proportion of people who chose to cross outside of the crosswalk in both environments.

5.2 Limitations and Assumptions

There were many limitations and assumptions that needed to be made in both the virtual and real environment.

5.2.1 Real Environment

There were some pedestrians who noticed the cameras right before crossing the street and made sure to cover their faces with their hands. As a result, this could have influenced how they crossed the road. There could be a chance that the pedestrians noticed the cameras prior to being within view of the cameras.

The data from the real environment was collected for 1.5 – 2 hours on two days. It was assumed that the pedestrians using the crosswalk were representative of those who matched the demographic survey, although many pedestrians refused to fill out the demographic survey. Pedestrians who used the midblock crosswalk multiple times were not double counted in order to avoid pseudoreplicates when conducting the JMP analysis. However, it was possible that a few pedestrians were recorded twice if they chose to use the crosswalk later within the 1.5 – 2 hours of observations on both days. Characteristics, such as the color of the clothes the pedestrian was wearing, helped identify pedestrians whose behavior may have been observed previously.

Visible distractions consisted of texting, talking on the phone, and eating. Pedestrians who were listening to music while crossing the road were not taken note of since the video cameras did not provide clear footage of pedestrians who were wearing earphones. It was possible that earphones could contribute to changing the way pedestrians cross the road. However, based on the JMP analysis, visible distractions did not appear to affect pedestrian behavior in a way that was different from those who were not visibly distracted.

Some pedestrians may not move their heads left and right when watching out for vehicles on the roads. As a result, it may have been difficult to tell if those pedestrians were looking in both directions prior to crossing the road.

5.2.2 Virtual Environment

Advertising for virtual volunteers may have led to survey bias. A solicitation email was sent to almost every single department on the Cal Poly campus. Some departments sent out the advertisements to all their students immediately, while others ignored the advertisement emails. Thus, there may have been an overrepresentation of students from the same majors. In addition, the words, “$5 Starbucks Gift Cards,” may have caught the attention of those who drink coffee frequently. On the other hand, these gift cards may not be a strong incentive for students to dedicate 30 minutes toward volunteering. Furthermore, there were twice as many females who chose to volunteer compared to males. However, we were able to find an adequate number of volunteers who had similar characteristics to those who responded to the demographic survey (Table 3.1).

One of the post-survey questions asked if the volunteers found the simulation to be realistic. The volunteers may have had very different definitions as to what realistic meant. Realism could pertain to the details of the buildings, feeling the wind, hearing the cars rush by, or not having a virtual reality headset attached to one’s head. There were some volunteers who stated that the simulation felt realistic. Yet, some discussed that the simulation could be more realistic if there were other people added to the model. Adding people into the simulation could be time-consuming due to the large details that would need to be made to make a person realistically move. Other students thought that the buildings could always use more texturing and lighting.

In the virtual environment, 44.7% of the volunteers looked left and right before crossing the street compared to 90.2% in the real environment (Figure 4.6). This low percentage in the virtual environment could be attributed to volunteers knowing that they cannot be hurt in the simulation.

While giving instructions on crossing the street, 18 of the 47 volunteers asked if they had to walk on the crosswalk. The other volunteers who did not ask for clarification may have assumed that they needed to use the crosswalk even though the instructions said to pretend that they were physically in that location. In real-life, people may not think about if it is required to use the crosswalk. In fact, according to the post-survey, most of the volunteers were neutral when it came to always walking on the crosswalk when crossing the road (Figure 4.4b).

There were 10 of the 47 volunteers who were confused about how to walk in the virtual environment and had to be directed on what to do while in the simulation. In real-life, many students are not instructed on how to cross the street; they typically have a destination that they need to get to.

Given the small room and 15ft x 15ft maximum distance between the two base stations, there was no way that the volunteers could traverse the whole crosswalk. Since the volunteers started on the sidewalk in the virtual simulation, they were told to teleport to the location where they were about to cross the street. This would allow them to cover more walking distance on the crosswalk. However, in real-life, pedestrians have a lot of space to move around. Walking speed in the real and virtual environment was collected for only half of the street due to the limited virtual room size.

Chapter 4.4: Comparing the Real and Virtual Environment Observations explained the large differences in speeds in both environments. The volunteers in the virtual environment may have walked slower than the pedestrians in the real environment because the volunteers may not be concerned about getting to their destinations quickly. In fact, in the post-survey, 40.4% of the volunteers stated that they would run across the street if they were late for class (Figure 4.4e). Furthermore, volunteers may not have walked fast because they could feel the wire constraints. Even if there were chaperone boundaries that would have prevented them from hitting physical objects in the room, they may not have trusted the boundaries completely. During the virtual demonstration, some volunteers expressed concern and wanted to know the exact location of the chaperone boundaries. The boundaries only appeared when the volunteers were only one or two feet away from them. Many volunteers may not have felt comfortable with wearing a virtual reality headset because they had either never used one or used it a few times. Unfortunately, many people may find the HTC Vive to be too expensive. If these devices become more mainstream, the results of this research may change. For example, walking speed may increase by 2 – 3 ft/s in the virtual environment and match the real environment.

In Table 4.9, pedestrians walked slower during the passing period than the non-passing period in the real environment. This variable would be difficult to replicate in the virtual environment because volunteers were not rushing for class; prior to signing up for a volunteer slot, they were told that this VR experimentation would take approximately 30 minutes.

Lastly, some volunteers suggested that adding sound to the model would make the simulation more realistic. Based on the literature review, some pedestrians rely on sound upon detecting oncoming vehicles (Campbell, 2012). Therefore, this could influence whether a person looks left and right prior to crossing the street. The reason why sound was not added to the crosswalk simulation was because of its complexity. Different sounds were needed to be added to the model. For example, if a volunteer steps in front of a vehicle, the sound of slamming on the breaks would need to occur. If the volunteer walks away from the crosswalk, the vehicle would need to accelerate again. If the volunteer steps onto the street and the vehicle is many feet away, we would need another type of sound that would show that the vehicle is slowing down. If the sounds do not match up to the vehicle correctly, this may create confusion for the volunteers. Even though it may be difficult to incorporate sound into a simulation, future research should attempt to add sound to their models since sound will increase immersion.

5.3 Future Work

Although most of the data collected in both environments appeared to be significantly different, PC-driven virtual reality may have the potential to benefit the transportation field in a more simplistic way. Given that the crossing location was the only variable that was not significantly different in both environments, potential research questions that can be studied through virtual reality in the future includes:

- Where do pedestrians choose to cross at roundabout intersections?
- Where should the paved walkway be located in a new development? If virtual reality can reveal the location where most pedestrians choose to walk in the same location, that area can be converted into a newly paved walkway.
- The virtual reality setup may also be able to help with the prediction of routes pedestrians may choose to reach a certain destination.

Based on the findings herein, PC-driven virtual reality, as it currently exists, may not be effective in analyzing steep roadways or involving users to walk long distances due to technological limitations. In addition, evaluating pedestrian behavior can be difficult since volunteers will know that they cannot get hurt in the simulation.

Perhaps, in the future, PC-driven virtual reality will be wireless and not constrain users to a limited space. As the technology continues to improve over the years, users may be able to pick up objects with their own hands and see their own feet, therefore, increasing immersion. As of right now, the data collected herein indicates that existing limitations may render it unsuitable to study complex pedestrian behaviors.

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Appendix A: Informed Consent Form

Informed Consent Form

INFORMED CONSENT TO PARTICIPATE IN A RESEARCH PROJECT, “Application of Virtual Reality in a School Setting”.

A research project on virtual reality simulations is being conducted by Kristina Mai, a graduate civil engineering student, in the Department of Civil and Environmental Engineering at Cal Poly, San Luis Obispo, under the supervision of Dr. Anurag Pande. The purpose of the study is to analyze the possibilities of using virtual reality in a school setting.

You are being asked to take part in this study that will take approximately 30 minutes. The study is divided into four components:

Instructions/Safety Information (Approx. 5 minutes): We will go over the risks that are anticipated with this simulation and confirm if what you say in the pre-questionnaire (next page) is true. We will also go over another overview of what to expect within the 30 minutes of this research session.

Both the demonstration and the research simulation will require you to stand the whole time, walk around and to look around in your surroundings. The virtual environments are interactive and will require that you use the HTC Vive Controllers to navigate. The HTC Vive headset (approx.. 1.2 pounds) will be placed over your head and will completely cover your view of the real world. The lens will be placed close to your eyes.

Virtual Reality Demonstration (Approx. 5-10 minutes): You will be told to put on the HTC Vive headset and to walk around in a virtual reality environment. You will learn to be more familiar with the blue chaperone boundaries that will prevent you from walking out of the range of the HTC Vive. This simulation is a pre-built simulation that has already come with the HTC Vive headset. This demo will give you more familiarity with the virtual reality equipment and what virtual simulations are like. After the demo, we will ask you about your well-being and if you wish to continue with the virtual reality simulation.

Virtual Reality Simulation (Approx. 5-10 minutes): You will be given a set of instructions for what to do for this simulation. The experimenters will be able to see what you will be seeing through the headset and we will be recording you and your point of view for data purposes. You will be wearing headphones to block the outside noise in order to make the virtual reality experience more immersive. We ask that you bring contact lenses if you typically wear glasses. This is to prevent the HTC Vive headset lenses from scratching and to make the headset more comfortable for you.

Reflection (Approx. 5 minutes): You will be given a survey about your experiences of the simulation.

The main risk anticipated with participation in this study is motion sickness and eye strain. Motion sickness and eye strain may occur if you are not used to simulations. Seizures, dizziness, and blackouts may occur especially if you have a medical condition. Prolonged exposure can impact hand-eye coordination and balance and lead to repetitive stress injury. You will be holding onto the Vive controllers and may have to press a series of buttons. You may feel discomfort from wearing the headset. The headset weighs approximately 1.2 pounds and will add additional force to your body. Vomiting may happen and there is a possibility of falling or tripping over the HTC Vive headset cord while wearing the headset.

Due to the immersive nature of the virtual reality simulations, some contents viewed may appear intense and very realistic. This may cause your heart rate to increase, blood pressure to spike, panic attacks, anxiety, PTSD, fainting, and other adverse effects.

The HTC Vive headset and controllers will be used by multiple participants. There is a risk of germs being passed from other subjects. Users may sweat from participating in the simulations since the headset will be tightened over the user’s face. After each use, the headset and controllers will be wiped with water and a clean napkin.

If you should experience sickness, injury and/or discomfort, please notify the experimenters as soon as possible. You may contact the Cal Poly Health Center at 805-756-6181. Please be aware that you are not required to participate in this research and may discontinue your participation at any time without penalty.

Please refer to the HTC Vive Safety and Regulatory Guide (attached) for more safety information.

A $5.00 Starbucks gift card will be offered to each participant. Potential benefits associated with the study include reducing pedestrian crashes and contributing to knowledge in the field of transportation.

Your confidentiality will be protected. No identifying data (such as names or addresses) will be obtained or published. Data from the simulation will be collected anonymously.

If you have questions regarding this study or would like to be informed of the results when the study is completed, please feel free to contact Kristina Mai at klmai@calpoly.edu and/or Dr. Anurag Pande at apande@calpoly.edu. If you have concerns regarding the manner in which the study is conducted, you may contact Dr. Michael Black, Chair of the Cal Poly Institutional Review Board, at (805) 756-2894, mblack@calpoly.edu, or Dr. Dean Wendt, Dean of Research, at (805) 756-1508, dwendt@calpoly.edu.

If you agree to voluntarily participate in this research project as described, please indicate your agreement by completing and submitting the following questionnaire. Please print a copy of this consent form now for your reference, and thank you for your willingness to participate in this research. Should you pass the 5-10 minute screening process, we will contact you with more information about what to expect.

Appendix B: Pre-Screening Form

Virtual Reality Simulation (Screening)

Virtual environments may offer significant advantage in transportation research. While there is a lot of research that utilizes 2D virtual simulations, 3D virtual reality has not yet been applied within the transportation engineering discipline. My thesis is on analyzing the possibilities of using virtual reality in a school setting.

Please note that your responses will be used in the screening process. This questionnaire will remain confidential for your privacy. It would take approximately 5-10 minutes to complete this questionnaire.

Should you pass the screening process, we will contact you with more information about what to expect.

If you have questions regarding this study or would like to be informed of the results when the study is completed, please feel free to contact Kristina Mai at klmai@calpoly.edu.

You must be 18 or older to participate in this research.

a) I am 18 or older
b) I am under 18

You must be a Cal Poly student in order to participate in this research.

a) I am a Cal Poly student
b) I am not a Cal Poly student

What is your full name? ____________________

What is your Cal Poly email address? _____________________ (include @calpoly.edu)

What is your phone number? ___________________________

1) What is your gender? (Please choose only one of the following)

a) Male
b) Female
c) Prefer not to answer

2) What is your age?

a) 18-24
b) 25-34
c) 35-44
d) 45-54
e) 55-64
f) 65 or above
g) Prefer not to answer

3) What is your height? (Please round up)

a) Under 5 feet
b) 5’ – 5’ 3”
c) 5’ 4” – 5’ 7”
d) 5’ 8” – 5’ 11”
e) 6’ and Over
f) I do not know my height/Prefer not to answer

4) What is your college?

a) College of Agriculture, Food, and Environmental Sciences
b) College of Architecture and Environmental Design
c) Orfalea College of Business
d) College of Engineering
e) College of Liberal Arts
f) College of Science and Mathematics
g) Prefer not to answer

Note that some questions are taken from the Physical Activity Readiness Questionaire (PAR-Q).

1) Due to the immersive nature of the virtual reality simulations, some contents viewed may appear intense and very realistic. This may cause your heart rate to increase, blood pressure to spike, panic attacks, anxiety, PTSD, fainting, and other adverse effects. Has your doctor ever said that you have a heart condition and that you should only do physical activity recommended by a doctor?
a) Yes
b) No

2) Do you feel pain in your chest when you do physical activity?

a) Yes
b) No

3) The headset may emit radio waves that can affect pacemakers or other implanted medical devices. Are you currently using a medical device that may prevent you from participating in this research?

a) Yes
b) No

4) Are you easily prone to dizziness?

a) Yes
b) No

5) Do you ever lose consciousness?

a) Yes
b) No

6) Are you prone to excessive drowsiness or fatigue?

a) Yes
b) No

7) Do you easily get motion sickness?

a) Yes
b) No

Please briefly explain the last time you felt motion sickness.

____

8) Similar to many other products that produce visual effects, this simulation can trigger epilepsy, seizures, fainting, or severe dizziness even in people who do not have a history of these conditions. Have you ever had a seizure, epilepsy, or loss of awareness from watching TV, playing video games, or experiencing virtual environment simulations?

a) Yes
b) No

9) Have you experienced intensive eye strain, altered, blurred, double vision, or other visual abnormalities that may prevent you from participating in the research?

a) Yes
b) No

10) Do you get headaches on a daily basis?

a) Yes
b) No

11) Do you often get repetitive stress injury that may occur from playing video games?

a) Yes
b) No

12) The research simulation will require you to stand the whole time and to walk around in the virtual environment. Will this prevent you from participating in the research?

a) Yes
b) No

13) If you wear glasses on a daily basis, will you be able to wear contact lenses when you participate in the research?

a) Yes
b) No
c) I don’t wear glasses.

14) Are there any other reasons that may prevent you from participating in this research? Please explain.

15) Do you have any questions or concerns?

Thank you for completing this questionnaire.

Appendix C: Post-Questionnaire Form

Virtual Reality MidBlock Crosswalk Simulation (Post-Questionnaire)

Thank you for participating in our research. Please answer the questions below. You can choose to omit any questions. It will take approximately 5 minutes to complete this survey.

All information you provide will be anonymous and will be grouped with responses from other participants.

1. Have you ever participated in any virtual reality simulation (involving a headset) in the past?

   a) Yes
   b) No

   If selected Yes, please briefly explain:

2. After testing the simulation, did you experience motion sickness or feel disoriented?

   a) Yes
   b) No

   If selected Yes, please briefly explain:

3. Do you recognize this location?

   a) Yes
   b) No

4. How often do you use the midblock crosswalk on University Drive?

More than once a day	Once a day	Once a week	Once a month	Less than once a month
○	○	○	○	○

5. What times of day do you use the midblock crosswalk on University Drive? (Select all that apply)

   a) Between 6 AM and 9 AM Monday-Friday
   b) Between 4 PM and 7 PM Monday-Friday
   c) Between 11 AM and 1 PM Monday-Friday
   d) Other times (including holidays and weekends)

For the following statements, please indicate your level of agreement or disagreement with each. If you do not have an opinion, please select “Don’t know”.

1= Strongly Agree 2 = Slightly Agree 3 = Neutral 4 = Slightly Disagree 5 = Strongly Disagree 6=Don’t know

1. Did you find the simulation realistic?

2. I always look left and right when crossing a road.

3. I always walk directly on the crosswalk when crossing the road.

4. I wait for cars to pass before taking a step on the crosswalk.

5. I listen to music, text, or talk on my phone when I am walking across the street.

6. If I am late for class, I will run across the street.

7. I jaywalk often.

8. I expect cars to stop for me when I use a midblock crosswalk.

9. I am more likely to look around before crossing at night instead of the morning.

10. If I see a car coming, I will start to cross the road and hope that the car will stop for me.

11. If I see a car coming and I did not cross the road yet, I will run in order to beat the car.

General Information about the Participant:

1. What is your gender? (Please choose only one of the following)
   a) Male
   b) Female
   c) Prefer not to answer

2. What is your age?
   a) 18-24
   b) 25-34
   c) 35-44
   d) 45-54
   e) 55-64
   f) 65 or above
   g) Prefer not to answer

3. What is your height? (Please round up)
   a) Under 5 feet
   b) 5’ – 5’ 3”
   c) 5’ 4” – 5’ 7”
   d) 5’ 8” – 5’ 11”
   e) 6’ and Over
   f) I do not know my height/Prefer not to answer

4. What is your college?
   a) College of Agriculture, Food, and Environmental Sciences
   b) College of Architecture and Environmental Design
   c) Orfalea College of Business
   d) College of Engineering
   e) College of Liberal Arts
   f) College of Science and Mathematics
   g) Prefer not to answer

Comments:

Thank you for your participation. If you receive any symptoms from wearing the headset, do not drive, operate machinery, or engage in any other visually or physically demanding activities that may potentially have serious consequences. Wait until all symptoms have completely subsided for several hours.