IMPACT OF ROAD INFORMATION ASSISTANCE SYSTEMS ON PEDESTRIAN CROSSING SAFETY

SAFER SIM

SAFETY RESEARCH USING SIMULATION

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16. Abstract

A virtual reality (VR) simulation experiment was conducted to examine the potential benefits of using a Road Information Assistance System (RIAS) to improve the performance of pedestrians at a mid-block crossing on one-lane and two-lane urban streets. The simulated RIAS device showed either symbols only (SIMPLE version) or text combined with symbols (COMPLEX version) to provide information about the incoming vehicles in real-time to the pedestrian. The VR experiment looked to simulate as if the pedestrian was using a tablet in a vehicle-to-pedestrian connected environment. The study collected 424 street crossing observations from 36 subjects. The walking speed, the vehicle gap selected to cross the street and the number of crossing events with no collisions with a vehicle were analyzed for two treatment groups using one of the two RIAS devices and a control group that crossed the one-lane and two-lane street unassisted. The results indicate that subjects in the SIMPLE RIAS group had the worst crossing success rate and selected the largest vehicle gap of the three groups. A non-parametric test demonstrated the distributions of the gap values accepted to cross by the three groups were different. The age, gender, and the RIAS level were found to have an effect on the walking speed when analyzed independently. Ordinary Least Squares (OLS) models of the log-transformed walking speed show that the interactions between the three variables are significant to explain the effect on the walking speed of the subjects. A larger sample with additional observations using the RIAS devices are needed to reach conclusions about the effect of the subjects' characteristics and the safety benefits of the use of the technology. The results provide evidence that the use of the RIAS device has the potential to assist

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Acronyms

AASHTO	American Association of State Highway and Transportation Officials
ADAS	Advanced Driver Assistance Systems
ANOVA	Analysis of Variance
AV	Autonomous Vehicle
DOT	Department of Transportation
EDC	Every Day Counts
FHWA	Federal Highway Administration
ft/s	feet per second
IRB	Institutional Review Board
LPI	Leading Pedestrian Intervals
mph	miles per hour
MUTCD	Manual on Uniform Traffic Control Devices
NHTSA	National Highway Transportation Safety Administration
NYC-DOT	New York City Department of Transportation
OLS	Ordinary Least Squares
P2I	Pedestrian-to-Infrastructure
PHB	Pedestrian Hybrid Beacons
PR	Puerto Rico
PR-SHSP	Puerto Rico Strategic Highway Safety Plan
RIAS	Road Information Assistance System
RRFB	Rectangular Rapid Flashing Beacons
STEP	Safe Transportation for Every Pedestrian
UPRM	University of Puerto Rico at Mayagüez
U.S.	United States
UTC	University Transportation Center

V2I	Vehicle-to-Infrastructure
V2P	Vehicle-to-Pedestrian
V2V	Vehicle-to-Vehicle
VR	Virtual Reality
VRU	Vulnerable Road Users

Abstract

A virtual reality (VR) simulation experiment was conducted to examine the potential benefits of using a Road Information Assistance System (RIAS) to improve the performance of pedestrians at a mid-block crossing on one-lane and two-lane urban streets. The simulated RIAS device showed either symbols only (SIMPLE RIAS) or text combined with symbols (COMPLEX RIAS) to provide real-time information about the incoming vehicles to the pedestrian. The VR experiment simulated as if the pedestrian was using the RIAS on a tablet in a vehicle-to-pedestrian connected environment. Four simulation scenarios were created for three configurations: unassisted crossing (NO-RIAS), assisted crossing with the SIMPLE RIAS, and assisted crossing with the COMPLEX RIAS. The scenarios were programmed with constant vehicle speeds of 15 or 25 mph on either a one-lane or a two-lane street. Vehicles were generated in the scenarios with random variable gaps between 3 to 8 s and traffic was programmed to not react to the presence of the pedestrian at the sidewalk or when performing the crossing maneuver. The experiment collected 424 street crossing observations from 36 subjects. The walking speed, the vehicle gap selected to cross the street, and the number of crossing events with no collisions with a vehicle were analyzed for the two treatment groups using the RIAS device and a control group that crossed the one-lane and two-lane street unassisted.

The results indicate that subjects assisted with the SIMPLE RIAS had the worst crossing success rate and selected the largest vehicle gap of the three groups. A non-parametric test demonstrated that the distributions of the gap values accepted to cross by the three groups were different. The age, gender, and the RIAS level were found to have an effect on the walking speed when analyzed independently. Ordinary Least Squares (OLS) models of the log-transformed walking speed show that the interactions

between the three variables are significant to explain the effect on the walking speed of the subjects. A larger sample with additional observations using the RIAS devices are needed to reach conclusions about the effect of the subjects' characteristics and the safety benefits of the use of the technology. The results provide evidence that the use of the RIAS device has the potential to assist pedestrians in making better informed decisions while on the road on a connected infrastructure environment. The display of information and the human interface of the RIAS device need to be further studied to improve the comprehension of the subjects and improve the users' experience.

1. Introduction

1.1 Research Statement

The number of motor vehicle crash fatalities in 2019 in the United States (U.S.) was 36,096, with pedestrians accounting for approximately 16% of the total [1]. Although a 2.7% decline in road fatalities in the U.S. was reported by the National Highway Traffic Safety Administration (NHTSA) in 2019, pedestrian-related crashes still accounted for 76,000 injuries and 6,205 deaths, for about the same proportion of 16% of the total road fatalities. The study of pedestrian safety and the identification of effective countermeasures require understanding issues such as the road context and user behavior. Pedestrian fatalities in urban areas have increased by 62% since 2010, with events occurring outside of intersections being the major crash factor [2]. Pedestrian fatalities are also occurring at significant levels in Puerto Rico's highway network. Road crashes were responsible for 3,043 fatalities in Puerto Rico during the 2010-2019 period, out of which 33% were related to pedestrians [3]. A reduction of 6.2% in the number of road-related fatalities was recorded in 2019 in Puerto Rico, when compared to 2018. The lowest record of road-related fatalities was observed in Puerto Rico with 242 deaths in 2020 [4]. Most probably, this reduction is highly associated with the restrictions imposed during the COVID-19 pandemic. This change in road-related fatalities is a significant positive step toward reaching the goal of reducing the 5-year average of pedestrian fatalities in the territory from 100 to 92 during the 2019-2023 period [5].

Pedestrian safety has been a focus area for the Federal Highway Administration (FHWA) since 2004. FHWA advocates the incorporation of the Every Day Counts' (EDC) Safe Transportation for Every Pedestrian (STEP) initiative for the systematic application of roadway improvements to improve pedestrian safety [6]. As of 2015, 17 States and 34 cities in the U.S., including Puerto Rico, have participated in STEP by studying different strategies to reduce pedestrian and bicycle traffic fatalities [7]. Uncontrolled crossings at midblock or unsignalized intersections are observed as riskier roadway situations for pedestrians. Guide for improving pedestrian safety discover that crashes at uncontrolled crossings are related to crossing conflicts, excessive vehicle speeds, inadequate conspicuity/visibility, drivers not yielding to pedestrians, and insufficient separation from traffic [8]. The STEP countermeasures promoted to improve pedestrian safety on road crossings include crosswalk visibility enhancements, raised crosswalks, pedestrian refuge islands, rectangular rapid flashing beacons (RRFB), pedestrian hybrid beacons (PHB), road diets, and leading pedestrian intervals (LPI). These safety countermeasures rely mostly on improvements to the road physical characteristics or the installment of enhanced traffic control devices to achieve the desired benefits on pedestrian safety. The capacity for transportation agencies and cities to impact all road sites with promise and to construct and implement these safety improvement projects is limited. Modification of the road user behavior in a timely manner to move towards the desired goal of zero road deaths will require incorporating technological strategies and other roadway and vehicle innovations that could reach a larger proportion of road users and conditions.

The use of handheld multimedia devices is growing exponentially [9]. There are over 400 million mobile devices in the U.S. alone, or the equivalent of 1.2 devices for each person approximately. As is the case with drivers, the use of smartphones by pedestrians while using the road network could affect their behavior and bring along significant road safety issues. Hatfield's road crossing maneuver study [10] found that women who spoke on mobile phones crossed traffic more slowly and less frequently while waiting for a gap between motor vehicles than women who did not use mobile phones. The same study found that men who spoke on mobile phones had a slower speed when crossing the roadway at unsignalized intersections.

The proper development and future implementation of smart transportation and connected technology components, such as vehicle-to-vehicle (V2V), vehicle-to-pedestrian (V2P), vehicle-to-infrastructure (V2I), and pedestrian-to-infrastructure (P2I), show high promise for improving road safety and mobility [11]. These emerging technologies can inform users of existing road conditions, available services in their vicinity, and unexpected events through the highway network. In-vehicle technologies mostly focused on assisting drivers, known as Advanced Driver Assistance Systems (ADAS), have been recently implemented in a greater number of motor vehicles. Tasks performed by ADAS include providing vital information about traffic, closure and blockage of roads ahead, congestion levels, suggested routes to avoid congestion, make precautionary alerts, and assess driving performance [12]. More advanced in-vehicle technologies are able to take over the control of the vehicle in certain conditions when detecting threats and can perform basic guidance tasks, such as lane keeping and cruise control, or perform complex driving maneuvers like overtaking vehicles and performing parallel parking.

Vulnerable road users (VRU) could potentially benefit from receiving real-time information about roadway and traffic conditions to assist them in making proper and safe decisions. The Connected Vehicle Project for Safer Transportation of the City of New York looks to incorporate technological innovations that improve the safety for all road users [13]. A project the city is looking to include in the smart transportation plan is the development of pedestrian-oriented applications. The innovation being developed includes a specially designed mobile device that will provide signal timing information and roadway geometric information to assist visually challenged users in crossing an intersection. Other technologies being evaluated as part of the NYC study relate to improving pedestrian detection capabilities in a connected vehicle environment that can mitigate potential conflicts on crosswalks.

Research on how pedestrians can be included in smart transportation innovations and connected technology devices is vital. These devices could assist in predicting the behavior of road users or vehicle trajectories to develop collision-avoidance systems and to function as informative devices that could assist VRU to reduce traffic crashes and facilitate the driving and walking tasks on the highway network.

1.2 Research Objective

The objective of this research project was to evaluate the potential impact that a Road Information Assistance System (RIAS) could have on the ability of a pedestrian to cross a roadway. Virtual reality (VR) equipment was used to simulate mid-block crossing events on urban one-lane and two-lane street scenarios with traffic at different speeds and gaps between vehicles. Two of the three VR configurations in the experiment simulated the context of subjects immersed in a V2P environment with a connected device that showed real-time information of the traffic flow conditions on the road.

Figueroa-Medina et al. [14] used a VR simulation experiment to study the performance of pedestrians when crossing a one-lane or two-lane urban street in scenarios with two different speeds and with fixed or random gaps in the traffic stream. That experiment was used to evaluate the capacity of the VR technology to measure walking speeds and to detect the number of gaps observed and the gap accepted by each pedestrian to cross the road. The experiment was able to record the number of collisions with vehicles at the crosswalk. Furthermore, the study analyzed the pedestrians' crossing speed and their ability to identify safe gaps in traffic to cross the road. The main conclusions from that study are included as part of the literature review in this report.

The primary research question addressed in this study was to establish if a RIAS device is an effective tool in assisting pedestrians to complete the crossing maneuver in a safe manner. One of the three subject groups in the study did not have available the assistance of the RIAS device and needed to cross the road the “old way” by analyzing the traffic flow conditions and selecting a safe vehicle gap based on their own perception of the crash risk. The simulated RIAS device used for the VR experiment is a new tool for the subjects that participated in the study. On the other hand, it has the potential of becoming a distraction having an effect on the performance of pedestrians to safely cross the road and their capacity to react to hazardous traffic conditions.

The second research question looked to identify which factors related to the road, traffic flow, or the subjects, such as gender or age, has the potential of significantly affecting the pedestrian performance or behavior when making the road crossing maneuver. The primary interest of this study was to identify differences, if any, between subject groups related to their crossing success rates (i.e., the proportion of crossings with no collision with moving vehicles), the mean walking speeds, and the selected gaps between vehicles.

1.3 Report Organization

This report consists of five chapters. Chapter 2 contains a review of published literature on topics related to the safety issues of pedestrians, factors of walking speeds and gap acceptance, the use of VR simulation for transportation and human factors research, and the implementation and safety impacts of ADAS or RIAS technologies. Chapter 3 explains the methodological procedure used in this investigation. Chapter 4 discusses the data collected from the VR simulations and the results from the statistical analysis performed. The last chapter of the report provides the conclusions and future research recommendations.

2. Literature Review

This chapter presents the review of literature conducted for this study. The review focused on five topics related to the safety factors that impact the safety of pedestrians when crossing a road. These are the walking speeds, the gap acceptance, the benefits in the use of VR simulation for transportation and human factors research, the implementation and safety impact of ADAS and RIAS technologies, and the distraction effects of handheld devices by road users.

2.1 Pedestrian Behavior on Crosswalks

Figueroa-Medina et al. [14] included a literature review on the pedestrians' characteristics, such as age and gender, the relation with crossing safety, and the differences in average walking speed, and gap acceptance. This report provides a summary of those topics and relevant results found in the investigation.

2.1.1 Pedestrian Characteristics

Age and health conditions are two characteristics that have been found in the literature to have an effect on the safety of pedestrians and their capacity for mobility on the road. Adults over 65 years old and those with developed health conditions have walking speeds that are typically slower than average. Senior pedestrians tend to make riskier choices, whereas younger pedestrians are further willing to infringe traffic regulations [15]. Furthermore, older adults have prolonged waiting times and tend to accept larger minimum gaps in traffic when crossing the road [16]. Figueroa et al. [14]. found that older pedestrians were most exposed to traffic crashes when crossing the simulated urban street, particularly when facing traffic at the higher 25-mph speed in the study.

Differences in road crossing behavior and performance between gender groups are also documented in the literature. Holland and Hill [16] demonstrated that male pedestrians have a lower perception of danger while crossing a road in the presence of vehicles and are more willing to make riskier crossing decisions and disrupt laws as compared to females. Ferenchak

[15] observed that males also tend to wait shorter amounts of time and exhibit faster walking speeds than females.

2.1.2 Average Walking Speeds

The consideration and selection of walking speeds for pedestrians have a significant relevance for road design, safety evaluation, and traffic operation analyses. The Manual on Uniform Traffic Control Devices (MUTCD) indicates that an average walking speed of 4.0 ft/s may be used to assess the sufficiency of the pedestrian clearance time at signalized intersections [17]. Timing guidelines for pedestrian signals suggest using instead an average walking speed of 3.5 ft/s under ordinary circumstances [17].

Figueroa et al. [14] reported that the average walking speeds from subjects performing a mid-block crossing on a VR simulation varied from 4.11 to 4.75 ft/s, depending on the vehicle gap and traffic speed combinations. The observed range for the average crossing speed showed values between 3.0 ft/s and 5.0 ft/s. Figueroa et al. [14] did not find obvious differences in average walking speed between the male and female groups, although the speed variability was slightly larger for the female subjects. Overall, the difference in walking speeds between the 85th percentile and the 15th percentile pedestrian was 2.21 ft/s, which was considered to be relevant in terms of the probability of a pedestrian-vehicle conflict at the crosswalk. This difference in the crossing speed represents that the 15th percentile pedestrian is exposed for 2.66 s longer to the probability of a conflict with a vehicle on the crosswalk than the 85th percentile pedestrian.

2.1.3 Gap Acceptance

Pedestrians tend to take riskier crossing decisions and accept smaller gaps when facing higher vehicle speeds. A pedestrian that needs to cross two or more traffic lanes might not find an appropriate gap in the vehicle stream leading to the use of a rolling gap maneuver to complete the crossing [18]. A rolling gap means that a pedestrian crosses in a pattern using a specific gap for every lane [19]. Yannis [20] states that the gap taken or accepted by a pedestrian to cross a road depends on the gender, the longitudinal distance from the vehicle, the vehicle length, and the presence of illegally parked vehicles.

Figueroa-Medina et al. [14] reported that the gap between vehicles in the traffic stream had an effect on the average number of gaps observed (and not accepted to cross) by the subjects on a VR simulation. Interestingly, the traffic speed did not appear to have a strong impact on the number of gaps observed by the subjects, although the highest values of gaps observed were indeed observed in the scenarios with the higher 25-mph speed (as compared to the 15-mph speed scenario). As expected, the highest number of gaps observed by the subjects was recorded in the scenario with the short constant gap of 3 s, which was the hardest crossing situation in the study. The results also showed that males facing traffic at the 15-mph speed had an average accepted gap of 4.49 s and a standard deviation of 0.18 s. In contrast, female pedestrians in the same VR experiment had a higher average accepted gap of 4.80 s and a similar standard deviation of 0.19 s. The study found that males with 65 years or older waited a significant time to find safe gaps to cross the road, with an average of 133 gaps observed on the scenarios where vehicles had a constant gap of 3 s and a constant speed of 25 mph.

Figueroa et al. [14] reported the crossing success rates of the participants in the VR simulation. The street crossing success rate was used to identify if any of the scenario configurations or subject groups had a higher potential of being hit by a moving vehicle when crossing. None of the subjects from the crossing situation with the longest 5-s gap in the one-lane street configuration was struck by a moving vehicle. But, the lowest crossing success rate of 80% was observed for the high traffic speed setting (25-mph) in the crossing scenario with 3-s gaps. The results showed that the male group in the one-lane street had a slightly better crossing success rate than their female counterparts (97.4% vs. 94.2%). That trend was reversed for the two-lane road crossing with none of the females having a collision with a motor vehicle. When comparing age groups in the one-lane street, the worst crossing success rate was observed for the 66-85 age cohort with 90%.

2.2 Road Information Assistance Systems (RIAS)

Advanced Driver Assistance Systems (ADAS) technologies have lately emerged as an essential aid for drivers to provide alert messages, support, and even take control of the vehicle under critical situations. The vehicle-pedestrian interaction is highly affected by the vehicle's arrival time at the pedestrian crosswalk when the pedestrian arrives at the curb [21]. Leon & Gavrilescu [22] state that ADAS technologies can assist drivers by alerting the pedestrian's presence and help them maneuver the vehicle to prevent a crash. Auditory, visual, vibro-tactile, and haptic warnings are commonly used to provide stimuli to drivers. Road Information Assistance Systems (RIAS) is a broader term preferably used for those technological assistance devices that are not entirely focused on drivers.

Primary causes of pedestrian crashes are related to issues such as speeding, texting while driving, distracted driving, driving while intoxicated, disobeying traffic control devices, and careless driving [23]. An active ADAS device can alert the driver of the presence of a pedestrian at a crosswalk, but in some circumstances, the impact might not be completely avoided as most systems react only when the pedestrian is already in front of the vehicle [22]. Pedestrians have a dynamic range, making it more challenging to recognize and predict their trajectory. A pedestrian usually follows a particular path, crosses a road, walks along the pavement, or turns at an intersection. Trajectory and tracking prediction methods can be used to determine the position of a pedestrian at any point in time [22].

2.3 Pedestrian Distractions

ADAS and RIAS innovations could add an element of distraction to drivers or pedestrians, respectively, in addition to improving the safety of road users. AASHTO warns that drivers with experience using ADAS are more likely to engage in distracted driving while using them than when they are not [24]. The use of mobile devices while on the road can impair pedestrian attention, contributing as a factor for vehicle-pedestrian crashes [25].

A critical safety concern for pedestrians is devising ways to avoid the harmful effects of texting when performing road crossing events. Hatfield & Murphy reported that pedestrians using an electronic device when crossing the road have slower walking speeds and consequently are more exposed to being hit by traffic [10]. Byington & Schwebel observed in a virtual simulation that it is more probable for texting subjects to encounter collisions or near-miss events than non-texting subjects when crossing a road [26].

An essential safety goal is to mitigate the harmful consequences of mobile device usage by encouraging pedestrians to abstain from using their mobile while crossing roads [27]. Recognizing that some pedestrians might still use mobile devices while on the road, it is crucial to explore connected technologies that can assist pedestrians to cross the roadway without becoming a harmful distraction.

Koshravi et al. [28] developed a pedestrian conflict avoidance system to improve the safety of VRU. The Smart Walk Assistant was implemented as an application on a smartphone and a server on a roadside unit. The system includes two wireless communication pathways. The P2I component allows users to send a signal request to the traffic controller and receive the traffic status and the P2V component can exchange information such as location, speed, and heading to provide potential conflict alerts. The system could be more useful for disabled and visually impaired pedestrians. It also provides visualization of real-time signal status on their smartphone, audible messages, and haptic alerts. Wang et al. [29] developed a vision-based application that uses the smartphone embedded camera. The smartphone application has a learning algorithm to recognize the front and rear views of moving vehicles to detect their arrival and alert the pedestrian.

Holländer et al. [30] investigated if a smartphone application could provide personalized guidance to enhance safety for pedestrians. Four user interface design concepts were evaluated as guidance methods by analyzing the crossing behavior of pedestrians using video recordings. The first concept called “BARS" shows the direction of oncoming traffic with a vertical line of the color green or red on the side of the screen of the smartphone. Other concepts included symbols similar to pedestrian signals. The third concept included a map guidance based on “Google Maps” and the fourth concept uses notifications that include icons and the text messages 'WALK' or 'STOP'. The study found that on-screen guidance significantly increased the crossing success rate. The tactile feedback and visual indication of the BARS concept was found to be a promising strategy for designing street crossing applications with an 85.4% crossing success rate. Holländer et al. [30] conclude that pedestrian guidance on smartphones could be helpful for traffic safety and could decrease the adverse effects of smartphone usage while walking.

2.4 Virtual Reality Simulation

VR simulation has become a valuable research tool for the study of human performance and behavior because it can provide the subject with a role-playing situation with almost complete sensory immersion in a controlled environment [31]. Simulators allow the creation of scenarios and allow control of the parameters under investigation [32]. The primary senses stimulated through the VR simulation are sight and hearing, allowing the subject to experience situations that in real life could be dangerous or non-replicable conditions. Pantelidis [33] states that VR can enhance road education strategies because it requires interaction and encourages active participation from the subjects. Different perspectives are achievable in VR when modeling the real world. It also allows the disabled to participate in an experiment or education environment.

Kearney et al. [34] conclude that VR technology can be used to study the human brain and its reactions to sensory and cognitive cues. Shuchisnigdha et al. [35] stated that the available fidelity of VR simulation allows obtaining objective measures of pedestrian behavior, such as average walking speeds, that can match those measured in real-world situations.

VR experiments could be used to confront pedestrians with simulated complex roadway situations. VR also enables researchers to study human behavior and performance, differences in road safety issues, and impacts of new road design features and traffic control devices.

Pantelidis [33], at the early stages of VR technology, established that the main disadvantages of the simulation were equipment cost, the time needed to learn the use of the hardware and software components, and safety effects such as dizziness, disorientation, and nausea.

Stadler et al. [36] studied the suitability and usability of VR tools in the context of communication between autonomous vehicles (AV) and pedestrians. The method worked as a preliminary validation when there was no functional AV prototype. The study showed that the lack of communication between driver and pedestrian needs to be compensated with Human Machine Interfaces. There were no notable differences in efficiency, effectiveness, and satisfaction between the tested concepts; the usability tests improved the evaluation and dismissed various options. Stadler et al. [36] stated that additional tests are essential to evaluate the significance of implicit communication for the decision-making of pedestrians in the AV-Pedestrian scenario.

Figueroa-Medina et al. [14] used an HTC Vive VR headset to simulate roadway crossing situations on urban one-lane and two-lane scenarios. Seventy-five percent of the participants in the study answered in a post-test questionnaire that participating in the VR experiment would help them to better perform road crossing maneuvers in the future. These results show promise that the general public could benefit from using VR technology as an educational tool in transportation and road safety studies.

3. Research Methodology

This chapter discusses the research methodology implemented to meet the objectives of the project. A VR experiment was carried out to analyze the impact of a simulated RIAS device on the ability of pedestrians to safely perform a mid-block roadway crossing in an urban downtown context. Figure 3.1 shows the seven main activities (in yellow), with secondary activities (in gray), that were conducted in the methodology.

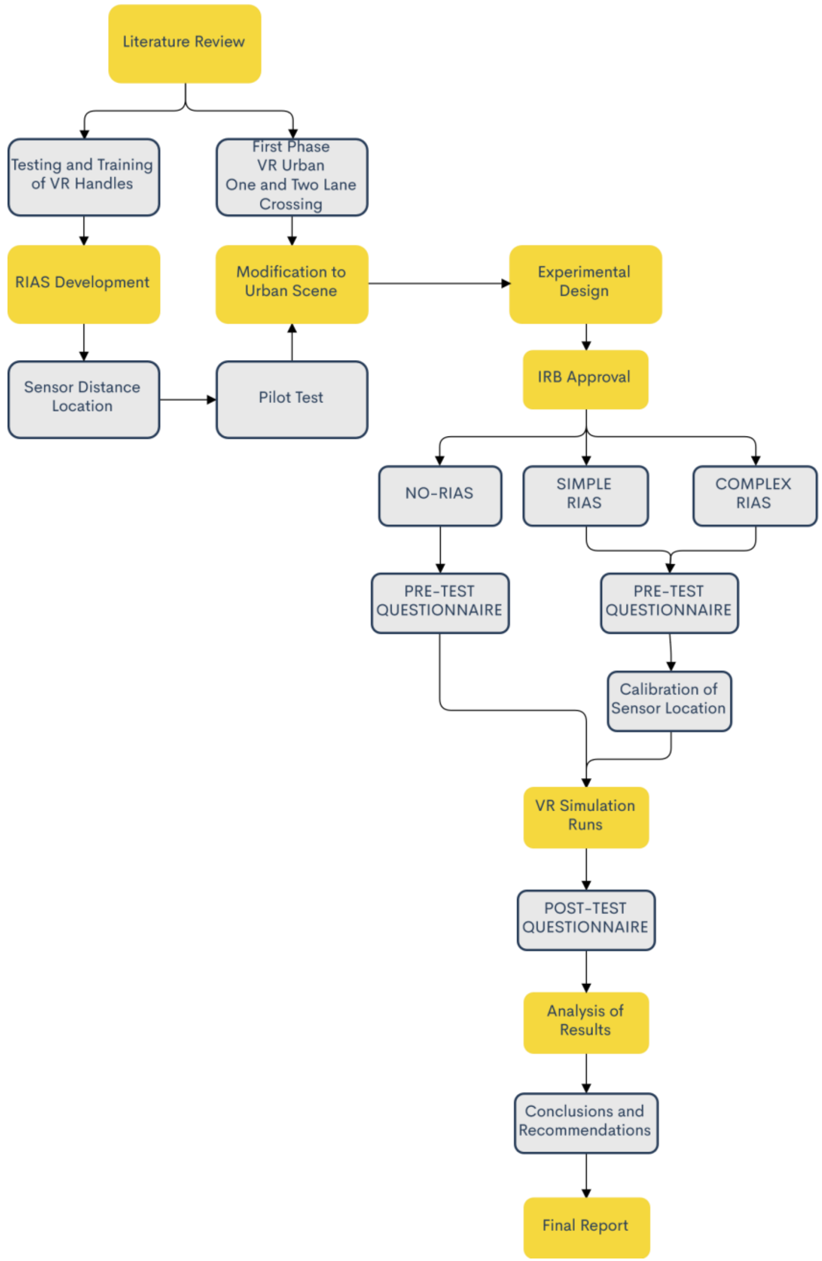

Figure 3.1 Research Methodology

The first major activity consisted of a literature review on topics related to the factors of pedestrian behavior, walking speed, gap acceptance, virtual reality simulation, and the description of ADAS and RIAS devices to improve road safety.

The second task was the training of the research assistants in the use of the VR handles of the HTC Vive VR equipment. The simulated RIAS device was programmed in the experiment with the use of the VR handle. The subjects had to hold and manipulate the VR handle ("the tablet") and had free movement of the RIAS device during the simulation. The display of the RIAS was active when the front camera of the simulated tablet faced the traffic in the simulation. The programming of the RIAS device required the customization of a sensor that established the distance when traffic was too close to the crosswalk. The task included the pilot test of the RIAS device inside the VR environment. The details of the customization of the RIAS device are provided in Section 3.2.1 of the report.

The third major task included the development, programming, and modifications of the VR simulation scene. The base simulation scene used in this study was based on the straight urban roadway segment developed in Figueroa et al. [14]. The basic scene provided two road crossing options: a one-lane street and a two-lane street. The VR basic scene was modified to incorporate the RIAS device that provided real-time feedback information about the traffic conditions on the road. The display of the simulated RIAS showed either symbols only or symbols and text. The details of the scenarios are provided in Section 3.2 of the report.

The fourth task included the design of the experiment. The experiment followed the regulations established by the UPRM Institutional Review Board (IRB). The experimental procedures were approved by the IRB in 2021. The details of the design of the experiment are provided in Section 3.3 of the report.

During the recruitment phase and before starting the VR experiment, each subject was informed about the purpose of the study and the informed consent form was provided to each subject. The subject needed to sign the informed consent form to voluntarily accept to participate in the experiment. A copy of the authorization letter from the UPRM IRB and the informed consent are included in the appendix.

Instructions on how the VR experiment was to be conducted were provided by the researchers to each subject. The VR headset equipment was shown to the subject and placed on the subject's head with the help of the two research assistants after confirming that the purpose of the study was understood. The VR simulation was activated once the headset was securely fixed and the subject gave verbal confirmation that he/she was comfortable with the device. The subject appears standing on the starting sidewalk on the right side of the road at the start of the VR scenarios.

The experiment required subjects to observe the gaps in the incoming traffic and to make a crossing maneuver to reach the sidewalk on the other side of the street without getting hit by the vehicles. The subject was instructed to always wait for the first vehicle to pass the crosswalk location to start the simulation trial. The subject had to watch the traffic from the sidewalk to wait for an adequate gap between vehicles before walking to the sidewalk on the other side of the road. Vehicles ceased to be generated in the simulation once the subject crossed the road and reached the other sidewalk. The subject needed to return to the original sidewalk to continue with the next simulation trial. The VR headset was removed and cleaned following the manufacturer's recommendations once all the trials were over for each subject. This protocol was part of the health procedures to prevent COVID-19 transmission between subjects.

The experimental procedure required the subjects to complete pre-test and post-test questionnaires to gather information about the subjects' perception and attitude regarding their safety while crossing a road, about their experience during the VR simulation experiment, and from using the RIAS device.

The descriptions of the simulation scenarios, the pilot test, the experimental design, and the test procedures are provided in Sections 3.2 and 3.3. Section 3.4 describes the pre-test and post-test questionnaires, the sample description, and the response variables collected in the experiment, respectively.

3.1 Equipment

The HTC Vive Eye Pro VR headset, shown in Figure 3.2, was used for the execution of the experimental procedure. The equipment setup used included a desktop computer, the VR headset, one handle, four detection sensors, and detachable headphones to reproduce sounds inside the simulation. The use of four sensors expanded the VR detection box to a maximum area of 32.8 ft x 32.8 ft, which allowed the simulation of the urban two-lane crossing scenarios. The VR headset also has a mountable antenna that replaces the cable that communicates with the computer, improving the subject’s mobility and reducing safety concerns when immersed in the VR environment.

Figure 3.2 HTC Vive Eye Pro Headset and Experiment Room Setup

The desktop computer used for the setup of the pedestrian VR simulator was a Rave-PC model with an Intel Core i7-4770S processor, 16 GB of RAM memory, and an NVIDIA GeForce GTX 1080 graphics processor with 8 GB. Table 3.1 shows the technical specifications for the HTC Vive Eye Pro VR headset.

Table 3.1 Technical Specifications of the HTC Vive Eye Pro VR Equipment

Component	Description
Screen	Dual OLED 3.5-in diagonal
Resolution	1440 x 1600 pixels per eye (2160 x 1200 pixels combined)
Refresh rate	90 Hz
Field of view	110 degrees
Audio	Hi-Res-certified headset, Hi-Res-certified headphones (removable), high-impedance headphone support, and enhanced headphone ergonomics
Safety features	Chaperone play area boundaries and front-facing camera
Sensors	SteamVR Tracking, G-sensor, gyroscope, proximity, eye comfort setting (IPD) and eye-tracking
Connections	USB-C 3.0, DP-1.2, Bluetooth
Eye Relief	Lens distance adjustment
Controllers	SteamVR Tracking 2.0, Multifunction trackpad, Grip buttons, dual-stage trigger, System button, Menu button, and Micro-USB charging port
Room-scale	Up to 32.8 ft x 32.8 ft using four SteamVR Base Station 2.0
Base Stations	Four (360-degree play area tracking coverage)

3.2 Description of VR Base Scene

The base VR scene was created with the Unity 2019.4.2f1 platform. The scenario consisted of a 1,279.53 ft long straight roadway segment in an urban downtown with buildings and sidewalks on both sides of the street. The roadway cross-section consisted of 10-ft wide lanes and 6-ft wide sidewalks. A one-lane and two-lane versions of the urban street were used. Figure 3.3 shows a view of the two-lane urban street from the perspective of the pedestrian, where the crosswalk and the traffic can be observed. A buffer area was provided between the buildings and the sidewalks to provide better depth perception to the subjects in the VR simulation.

Figure 3.3 Simulated VR Scene of the Two-Lane Urban Street

A billboard display located on the buildings on the far side of the street, as shown in Figure 3.4, was included in the scene. The billboard provided information to the subjects about the simulation trials. Two items of information were shown: the quantity of crossing maneuvers completed and the notification “COLLISION DETECTED” (“FUE ATROPELLADO” in Spanish) in red capital letters. The notification appeared only on those crossing events when the subject was hit by a motor vehicle. The intention of showing the collision notification was to keep the subjects alert during the VR experiment that they were being evaluated during the crossing maneuver and keep them “incentivized” to provide a good-faith effort to cross to the other sidewalk without being hit by traffic. The trial count was provided so the subject could be self-aware of how many trials remained to complete the experiment.

Traffic was generated randomly in the VR simulation. The gaps between vehicles were established from a random value between a range from 3 to 8 s (shown in Figure 3.8 as G_v). The vehicles in the two-lane scenario were generated independently per each lane, so that the vehicles on separate lanes never reach the crosswalk at the same moment. The speed of the vehicles was set on the scenarios at either 15 mph or 25 mph. The two speeds selected for the simulation reflect typical city conditions in a low-speed urban street environment. The constant speeds will not allow vehicles to pass one another. The vehicles were programmed as moving in one direction from left to right in the simulation. Traffic in the simulation did not react to the presence of the crossing pedestrian on the roadway. The moment the subject reached the destination sidewalk on the far side, the generation of vehicles stopped to allow the person to return calmly and safely to the initial position in the origin sidewalk.

Figure 3.4 Billboard Showing Trial Counts and Collision Notification

3.2.1 Development and Calibration of RIAS Device

The VR experiment was developed to study the effect on the pedestrian behavior and performance of using an electronic device functioning as a RIAS device that would provide real-time information about the incoming traffic flow. The RIAS device was simulated in the VR experiment as a hand-held tablet and was conceptualized with a simple and a complex state of the information provided to the subject. The subjects needed to grab one handle of the HTC Vive Eye Pro to activate the RIAS device in the simulation. Once activated, the tablet must be directed toward the oncoming traffic to simulate as if a video of the traffic was being recorded with the tablet camera, as shown in Figure 3.5. The subject had free movement of the tablet inside the VR environment.

Figure 3.5 View of the COMPLEX RIAS Device in the VR Environment

The simple level of the RIAS device provided graphical information to the subject by displaying a symbol per each lane, as shown in Figure 3.6. The symbols used for the simple RIAS were based on the pedestrian signal displays established in the MUTCD, consisting of the WALKING PERSON symbol (meaning WALK) and the UPRAISED HAND symbol (meaning DON'T WALK) [17]. The MUTCD establishes these two pedestrian signal indications are intended for controlling pedestrian traffic at a signalized intersection. The intended interpretation of the WALKING PERSON symbol in this experiment was that the leading vehicle in the left or right lane was far enough from the crosswalk position and the subject can walk using his/her "normal" speed (e.g., did not have to rush or run) to complete the crossing maneuver safely without getting hit. The intended interpretation of the UPRAISED HAND was for the subject to wait for a safe gap in traffic to cross because the leading vehicle in the left or right lane was too close already to the crosswalk position and the subject would not have enough time to safely clear the lane when using his/her "normal" speed. A unique characteristic of the RIAS device was that it was programmed to dynamically change the two symbols based on the actual position of the vehicles in the simulation. The location of the sensor that established the change of the symbols in the simulation was calibrated for each subject based on his/her walking speed.

Figure 3.6 Display of the Simple RIAS Device

The complex level for the RIAS device provided information about the traffic flow conditions in each lane using a text format in addition to the aforementioned pedestrian symbols used for the simple RIAS device. Three lines of information were added for each lane in the display: the speed of the leading vehicle in miles per hour, the time for the vehicle to reach the crosswalk position in seconds, and the distance between the vehicle and the crosswalk position in feet. Figure 3.7 shows the display of the complex RIAS device. The values for the three variables for each lane were calculated in real-time and those were displayed in the simulated tablet.

Figure 3.7 Display of the Complex RIAS Device

The intention behind the use of the two pedestrian symbols in the simple RIAS was to provide recognizable and quick-to-understand information to the subjects. The subjects in the study were given the meaning of the two symbols and text information provided by the RIAS prior to starting the experiment. Graphical displays of information are generally believed to facilitate comprehension, when compared with text messages [37]. An objective behind the design of the two levels of complexity of information for the RIAS device was to observe their impact in the subject performance and behavior in the study.

A virtual sensor was added to the programing of the simulated RIAS device to dynamically change the two pedestrian symbols based on the performance of each subject. A calibration process was conducted at the beginning of the experiment to locate the virtual detection sensor for each subject. The calibration process required the measurement of the "normal" walking speed for each subject to establish the location of the virtual sensor. Each subject crossed the road four times with no traffic to measure their walking speed under "normal" conditions. The average "normal" walking speed from the four crossing maneuvers was calculated for each subject and used to establish the distance threshold for the change of the symbols in the RIAS. The calibration process also allowed time for the subjects to familiarize themselves with the VR environment.

The RIAS device was programmed to use the average walking speed of each subject to determine the sensor's position. The pedestrian symbols on the RIAS would change from the WALK to DO NOT WALK when a vehicle passed over the sensor in the simulation. The change in symbol indicated that the proximity and speed of the vehicle on that lane were unsafe for the subject to achieve the crossing at their average walking speed without getting hit. The RIAS device was customized for each subject in the simulation because everyone has a different average walking speed. Figure 3.8 shows the reference for the variables used to calculate the RIAS sensor location for the two-lane street. Equations 3.1 and 3.2 show the time needed to cross the road and the sensor location were calculated as:

$$t_p = \frac{D_c}{V_{ap}} \qquad (3.\ 1)$$

$$D_s = V_V * t_p \qquad (3.\ 2)$$

where:

$D_s = Sensor\ distance\ location, feet.$

$V_V = Vehicle\ speed, \frac{ft}{s}.$

$t_p = Pedestrian\ crossing\ time, seconds.$

$D_c = Crosswalk\ distance$, *10 or 20 feet.*

$V_{ap} = Average\ pedestrian\ speed, \frac{ft}{s}.$

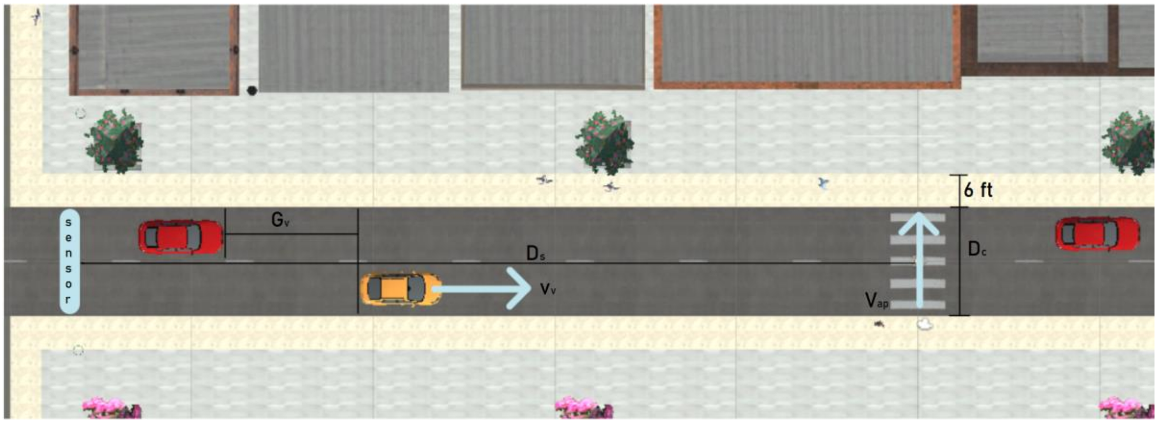

Figure 3.8 Variables for the Calculation of the RIAS Sensor Location

3.3 <u>Experimental Design</u>

The experiment was designed with three configurations based on the level of the RIAS device. The first simulation configuration (NO-RIAS) required the subjects to perform the crossing maneuver without being assisted with a RIAS device. The second configuration allowed subjects to use the SIMPLE RIAS device when performing the crossing maneuver. The third configuration allowed subjects to use the COMPEX RIAS device when crossing the road. An independent group of participants was recruited for each configuration to mitigate the learning effect across treatments.

The three configurations included the same four simulation scenarios. Table 3.2 shows the road and traffic characteristics used for each scenario. Scenario 1 had the one-lane street with traffic at a constant speed of 15 mph. Scenario 2 showed the one-lane street with traffic at a constant speed of 25 mph. Scenarios 3 and 4 showed the two-lane street with traffic at constant speeds of 15 mph and 25 mph, respectively. All four scenarios had vehicles generated randomly with gaps between 3 to 8 s apart. The sequence of the simulation scenarios was assigned randomly for each subject to mitigate the learning effect. Each subject performed three crossing maneuvers in each scenario, in random order, for a total of 12 simulation trials per subject.

Table 3.2 Description of Scenarios for each Configuration

Configurations	Scenarios	Traffic Speed (mph)	Number of Lanes
NO-RIAS **SIMPLE** **COMPLEX**	1	15	One
	2	25	Two
	3	15	One
	4	25	Two

3.4 Survey Questionnaires (Pre-test and Post-test)

The subjects that participated in the experiment completed two questionnaires, one before and one after completing the VR simulation experiment. The post questionnaire was different for each configuration.

The pre-test questionnaire had eight questions divided in two sections. The purpose of the first part of the pre-test questionnaire was to gather the gender and age of the subject and to find out if the person suffered from motion sickness or from a health condition that would prevent the safe use of the VR equipment. The second part of the questionnaire was used to determine the level of exposure of the subjects as pedestrians, their crash experience in the last five years, and their safety perception when crossing a highway.

The post-test questionnaire for the NO-RIAS configuration had seven questions. The purpose was to request the opinion and perception of the subjects regarding the difficulty level experienced when crossing the road in the VR simulation based on the variability of the factors shown in the scenarios: vehicle speeds, gap and time between vehicles, the number of vehicles, and the road width.

The post-test questionnaire for the SIMPLE RIAS configuration had ten questions. This questionnaire was intended to obtain feedback on the difficulty of using the electronic device and the opinion about if the provided information assisted them to cross the road.

For the COMPLEX RIAS configuration, the post-test questionnaire had 11 questions. The purpose was similar to the SIMPLE RIAS configuration, but it also added specific questions regarding the relevance of the speed, time, and distance information provided by the RIAS device and how it helped them to cross the street.

All subjects were asked to provide comments regarding their comfort level when using the VR headset, their opinion of the fidelity of the simulation, and recommendations on how to improve the VR experiment. All the questionnaires are included in the appendix.

3.5 Data Recording and Performance Variables

The position and orientation of the subject's head and the position of all vehicles generated in the scenario were recorded at every time period for each simulation trial. The five performance variables collected in the simulation experiment were:

1. **Number of gaps observed**: the number of gaps observed by the subject before crossing the roadway, including the gap accepted to cross (a measure of time waiting for a gap).
2. **Gap taken**: the size (in seconds) of the gap selected by the subject to cross the road.
3. **Average walking speed:** average speed calculated as the ratio between the distance walked on the pedestrian crossing and the time spent crossing it.
4. **Time spent**: the time it took each subject to cross the road (from the moment the subject entered the traveled way to the moment when exiting the traveled way).
5. **Crossing success rate**: the ratio of the number of trials not impacted by a moving vehicle while crossing the road by the total number of trials performed by each subject.

3.6 Sample Data Description

Three independent subject groups were assembled, one group per configuration. Thirty-six subjects were recruited and divided into three groups of 12 subjects. Each subject group was composed of six men and six women. The design of the experiment assigned two men and two women to three age groups: 18-25, 26-45, and 46-70 years old. Table 3.3 presents the descriptive statistics of the age of the subjects recruited by gender and age group.

Table 3.3 Descriptive Statistics for the Sample Gender and Age

Gender	Age	Average Age	Standard Deviation	Minimum	Maximum
Female	All	38.30	15.88	21	67
	18-25	22.00	0.82	21	23
	26-45	34.82	5.14	28	43
	46-65	59.08	4.42	53	67
Male	All	36.18	13.60	19	55
	18-25	21.36	2.28	19	24
	26-45	33.40	7.38	26	44
	46-65	52.75	1.65	51	55

The experiment collected 432 observations. Three observations were removed during the data cleaning process because the gap accepted by the subject was recorded with a value higher than 8 s, which was the maximum gap value. The raw data from eight observations were not processed by the coding, therefore the walking speed and the gap accepted were not calculated. These 421 observations were only used for the calculation of the success crossing rates. Subjects were hit by a vehicle in eight of the observations (1.9% of the observations). These eight observations were not included for the analysis of the gap accepted to cross and the walking speeds. The reasoning for excluding these eight observations was that the judgement made by the subject was not adequate on those events with collisions, either by selecting too short of a gap or a too slow walking speed, resulting in the subject getting hit by a vehicle. The final database included 413 individual observations.

3.7 Calculation of Walking Speed with a Rolling Gap

The average walking speed for each subject was calculated using the time it took to walk from the origin sidewalk to the sidewalk on the other far side of the street. Some of the subjects performed crossing maneuvers using a rolling gap strategy on the two-lane scenario. In those cases, the subject rolled over sequential vehicular gaps to complete the roadway crossing. Rolling gaps were performed on 17 observations out of the 195 observations on the two-lane scenarios (8.7%). Seven different subjects out of 36 (19%) performed rolling gaps when crossing the road. The rolling gap maneuvers were recorded during the experiment and were reviewed using the trajectories. A rolling gap was observed, for example, when the subject started crossing the first lane when no traffic was present and stopped on the street to wait for a safe gap to be present on the second lane. Once the vehicle on the second lane passes the crosswalk, then the subject starts to walk again to complete crossing the street. Figure 3.9 shows the subject's time-distance graph on the six crossings made on the two-lane street scenarios. The graph presents the trajectories of the pedestrian when crossing the street and returning to the original sidewalk on the simulation. The trajectory of the third trial on Figure 3.9 clearly identifies the presence of a rolling gap event.

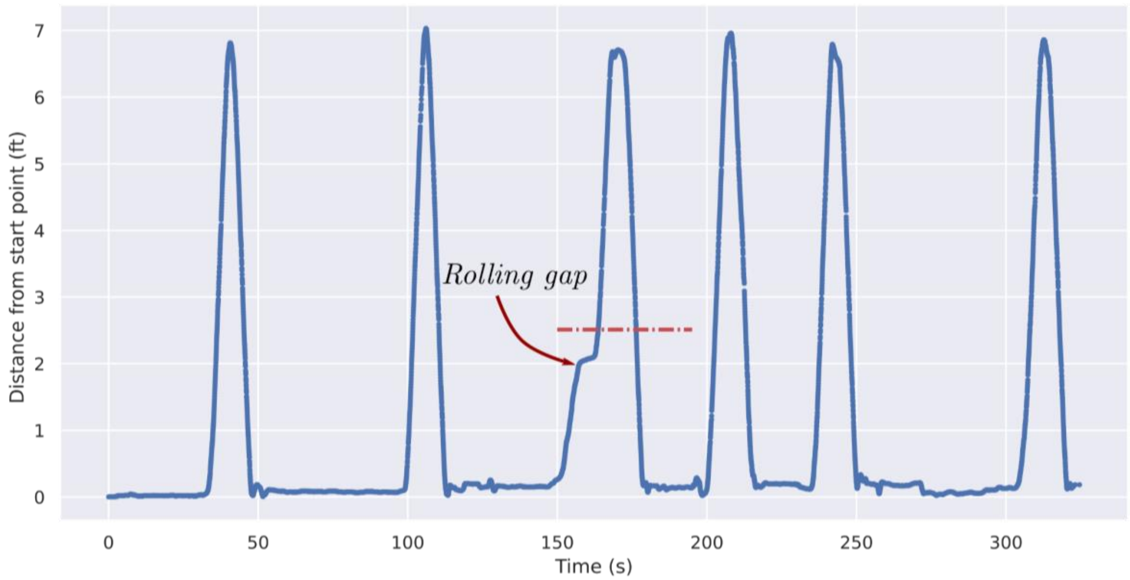

Figure 3.9 Example of a Subject Trajectory with a Rolling Gap

The average walking speed on the crossing maneuvers where the subjects used a rolling gap was estimated using the longest continuous walking time on the trial and not from the total time from sidewalk to sidewalk. The average speed was calculated when the subject accepted the gap to cross the second lane in those events with a rolling gap. The red line added to Figure 3.9 delimits the distance to the far sidewalk after the subject accepted the gap in the second lane. The walking average speed for that specific trial was estimated using the time between the red line and the far sidewalk.

4. Analysis of Results

This chapter presents the discussion of the results obtained from the VR experiment. The discussion of the variables calculated for each road setting is presented in separate sections. The primary variable of interest is the average walking speed from each trial in the experiment. In addition, results from the calibration phase for the location of the RIAS sensor, the crossing success rate, and the gap accepted by the subject to cross the road are discussed.

4.1 Calibration of Sensor Location

The principal objective of the VR experiment was to analyze the ability of the subjects in the experiment to safely cross the road and to respond to hazardous roadway situations and the potential effect of having a simulated RIAS device in their hands to assist them in performing the action. Each subject needed to analyze the road and traffic conditions to make the decision to cross safely to the other side of the road in the simulation. The programming of the RIAS device was customized for each subject based on their specific average walking speed. A calibration process was carried out with each subject assigned to the SIMPLE and COMPLEX configurations. The calibration process required subjects to cross the street without the presence of traffic to obtain their normal average walking speeds. The normal walking speed was used to locate the sensor on the road to change the WALK and DON'T WALK pedestrian symbols on the RIAS display.

The data obtained from the calibration stage to calculate the location of the RIAS sensor was analyzed to observe the performance of pedestrians without the presence of vehicles on the road. A Shapiro-Wilk statistical test without group discrimination indicated that the average walking speeds did not follow a normal distribution with a p-value less than 0.001 at a 95% confidence level.

Figure 4.1 shows the distributions of the walking speed for the scenarios of the one-lane street and the two-lane street. A second test, the Kruskal-Wallis non-parametric test, was used to determine if there were significant differences between the median values of the two speed distributions. The non-parametric test confirmed that the two speed distributions are statistically similar with a p-value of 0.969.

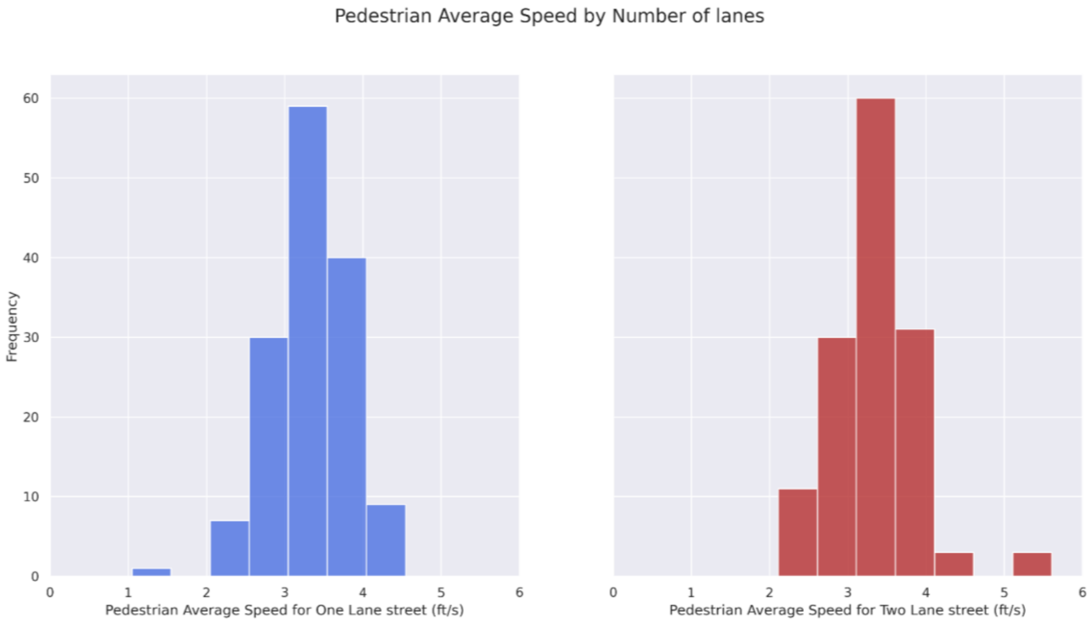

Figure 4.1 Distribution of the Average Walking Speed per Number of Lanes

Table 4.1 shows descriptive statistics for the walking speeds observed in the calibration process. The average walking speed for the one-lane street scenario was 3.35 ft/s, whereas it was 3.36 ft/s for the two-lane street scenario. The standard deviations of the walking speeds were 0.50 ft/s for the one-lane street and 0.56 ft/s for the two-lane street. The 85th quantile for the average speed of the pedestrian in a one-lane street was 3.86 ft/s, while the 50th quantile was 3.39 ft/s. In comparison, the 85th quantile value for the average speed for the two-lane scenario was 3.79 ft/s and the 50th quantile was 3.37 ft/s.

A low speed observation of 1.05 ft/s was observed from a subject in the one-lane street scenario. This observation came from the first trial of the calibration process from that subject. A probable reason for this performance is that the subject was still adjusting to the VR equipment and becoming familiar with the simulated environment. On the other three trials from this subject, the average walking speed was 3.38 ft/s. Nevertheless, the lowest average walking speed observed was for a different subject, that registered an average speed of 2.55 ft/s.

A maximum walking speed of 5.54 ft/s was registered in the two-lane street scenario. According to the visual observations of these subjects on the higher end of the distribution, they ran while performing the calibration in the simulation.

Table 4.1 Average Walking Speeds from the Calibration

Number of Lanes	Average Speed (ft/s)	Standard deviation (ft/s)	Minimum (ft/s)	50th pctl (ft/s)	Median (ft/s)	85th pctl (ft/s)	Maximum (ft/s)
1	3.35	0.50	1.05	2.87	3.39	3.86	4.48
2	3.36	0.56	2.11	2.80	3.38	3.79	5.54

The location of the RIAS sensor was calculated using the average walking speed from each subject. Figure 4.2 shows the calculated distance for the RIAS sensor based on the number of lanes in the roadway. The distance values on both graphs were generated from equations 3.1 and 3.2 based on the pedestrian average speeds collected in the calibration stage. The average distance for the sensor for the one-lane street was 111.21 feet and 222.89 feet for the two-lane street. The standard deviation for the distance on the one-lane street was 14.42 feet, and 33.90 feet for the two-lane street. The maximum distance of 334.98 feet was calculated for one subject on the two-lane street that had the lowest average speed of 2.19 ft/s in the two-lane street scenario. A Kruskal-Wallis test was conducted to determine if there were significant differences between the distributions of the sensor location based on the number of lanes of the roadway. The result from the test indicated that there is a significant difference between the distributions with a p-value less than 0.001 at a 95% significance level.

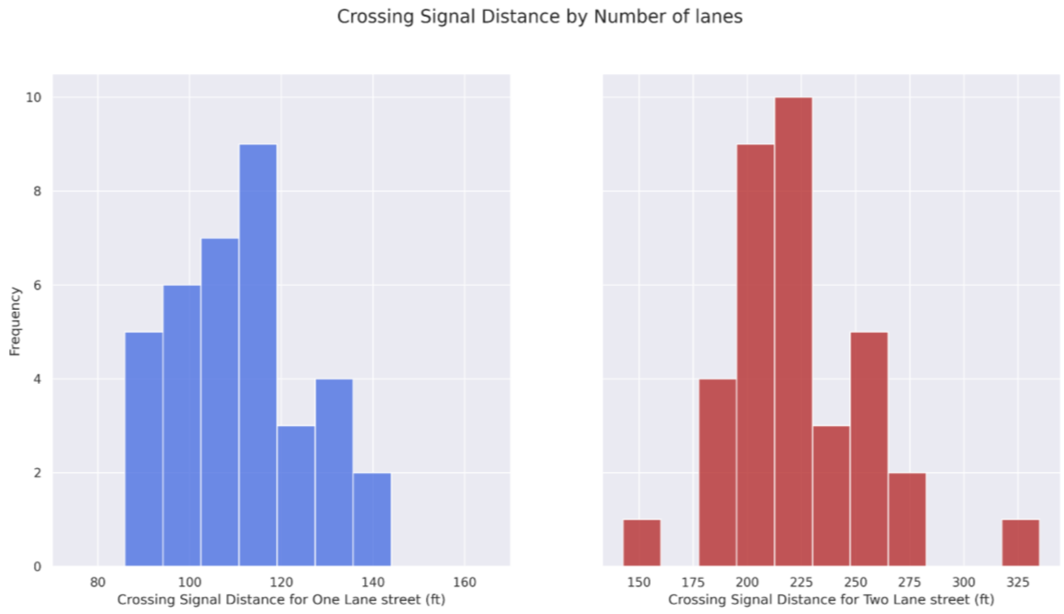

Figure 4.2 Distribution of the Distance of RIAS Sensor per Number of Lanes

4.2 Crossing Success Rates

The crossing success rate was computed for each subject in the experiment to identify if one of the subject groups had any pattern of collisions by a moving vehicle when crossing the street. The experiment collected 421 crossing maneuvers, of which eight resulted in a crash with a vehicle. These maneuvers were considered only for the analysis of the crossing success rates. Only successful crossings were used for the analyses of the gaps accepted and the walking speeds.

Table 4.2 shows the crossing success rates based on the RIAS configuration, in combination with the respective average walking speed and average gap accepted to cross. As previously noted, subjects in the scenarios that included the RIAS device had a lower safety performance crossing the street than those without the RIAS. The subjects in the SIMPLE RIAS configuration had the lowest crossing success rate (95.8%) in the study. Those subjects that crossed the road without the assistance of the RIAS device had an almost perfect crossing success rate of 99.3%. These initial results might indicate that users had difficulty in using or understanding the RIAS device when crossing the road.

Table 4.2 Speeds, Gap Accepted, and Crossing Success Rates by RIAS Level

Device	Average Walking Speed (ft/s)	Average Gap Accepted (s)	Crossing Success Rate (%)
NO-RIAS	4.20	6.6	99.3
SIMPLE RIAS	4.12	6.8	95.8
COMPLEX RIAS	4.14	6.4	98.6

4.3 Vehicle Gap Accepted to Cross

Figure 4.3 shows the distributions of the vehicle gap accepted to cross the street for each RIAS configuration. The highest average value of 6.8 s was observed for the subjects in the SIMPLE RIAS configuration. The average gap value for this configuration was almost a half second larger than the average gap accepted (6.4 s) for the group of subjects that used the COMPLEX RIAS. On the other hand, the NO-RIAS group had a slighter higher average gap (6.6 s) than for the COMPLEX RIAS group, as to indicate that the information obtained from the RIAS provided some advantage to cross the street.

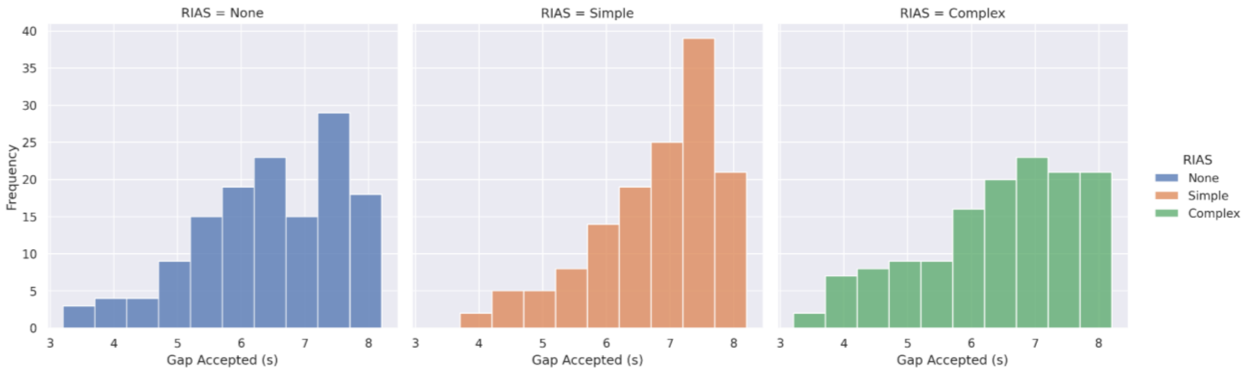

Figure 4.3 Distributions of the Vehicle Gap Accepted to Cross per RIAS Configuration

A non-parametric ANOVA Kruskal-Wallis test was used to investigate the differences between the median values for different factors due to the lack of normality in the data. This test indicates whether there is a significant similarity or difference between the median values of the distributions. Table 4.3 shows the test for the gap accepted to cross based on the three RIAS configurations. There is a difference of 0.5 s between the median values of the gap accepted of the NO-RIAS and the SIMPLE RIAS subject groups. The group of subjects that did not have the RIAS available had the smaller median value for the gap accepted to cross. Since the p-value of the Kruskal-Wallis test (0.014) is less than 0.05, the null hypothesis is rejected. This result indicates that at least one of the median values of the gap accepted to cross based on the RIAS configuration is statistically different.

Table 4.3 Kruskal-Wallis Test for the Gap Accepted to Cross vs RIAS Level

Descriptive Statistics

RIAS	N	Median	Mean Rank	Z-Value
Complex	136	6.63470	195.1	-1.42
None	139	6.49615	194.6	-1.50
Simple	138	7.00341	231.2	2.92
Overall	413		207.0	

Test

Null hypothesis H_0: All medians are equal
Alternative hypothesis H_1: At least one median is different

DF	H-Value	P-Value
2	8.55	0.014

Additional tests were performed to analyze if the median values of the gap accepted to cross were statistically similar based on the number of lanes and on the gender of the subject. Table 4.4 shows the test results for the gap accepted to cross based on the one-lane and two-lane street configurations. The subjects had a higher gap accepted value (6.87 s) on the one-lane street than the subjects in the two-lane street (6.60 s). Since the p-value of the Kruskal-Wallis test (0.011) is less than 0.05, the null hypothesis is rejected. The test result confirms that the median values of the gap accepted to cross from the two-lane street configurations are statistically different.

Table 4.4 Kruskal-Wallis Test for the Gap Accepted to Cross vs Number of Lanes

Descriptive Statistics

NumLanes	N	Median	Mean Rank	Z-Value
1	218	6.86862	221.1	2.54
2	195	6.60029	191.2	-2.54
Overall	413		207.0	

Test

Null hypothesis H_0: All medians are equal
Alternative hypothesis H_1: At least one median is different

DF	H-Value	P-Value
1	6.44	0.011

Table 4.5 shows the test results for the gap accepted to cross based on the gender of the subjects. The female subjects had a higher median value (6.90 s) for the gap accepted than the

male subjects (6.68 s). Since the p-value of the Kruskal-Wallis test (0.09) is not less than 0.05, the null hypothesis cannot be rejected. The result of the test indicates the median values of the gap accepted to cross from the two gender configurations are not statistically different.

Table 4.5 Kruskal-Wallis Test for the Gap Accepted to Cross vs Gender

Descriptive Statistics

Gender	N	Median	Mean Rank	Z-Value
Female	205	6.90364	217.0	1.70
Male	208	6.67819	197.1	-1.70
Overall	413		207.0	

Test

Null hypothesis H_0: All medians are equal
Alternative hypothesis H_1: At least one median is different

DF	H-Value	P-Value
1	2.88	0.090

4.4 Walking Speeds

Figure 4.4 shows the average walking speeds from the calibration phase and the experimental phase. Table 4.6 shows the comparison of the descriptive statistics for the average walking speed calculated from the calibration process and the simulation experiment. The objective of the comparison was to verify if the walking speeds selected by the subjects without and with the presence of traffic in the simulated scenarios were the same. The descriptive statistics show the subjects had a higher average walking speed, and dispersion, under pressure during the simulation experiment as compared with the walking speed during the calibration with no traffic. The general assumption was that subjects will use a faster speed to cross the road in the presence of traffic. A Shapiro-Wilk statistical test without group discrimination was used. The p-value of the Shapiro-Wilk test (~0.000) is less than 0.05, the null hypothesis that the median walking speeds are equal in the two distributions is rejected. These results indicate that the average pedestrian speeds did not follow a normal distribution at a 95% confidence level, as did the average pedestrian speeds obtained from the calibration sessions.

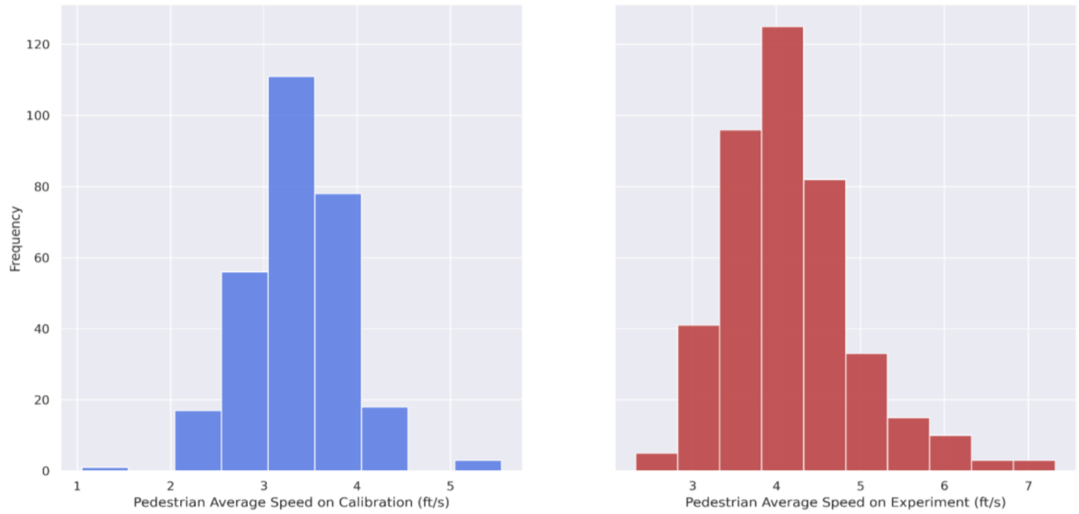

Figure 4.4 Walking Speed Distributions

Table 4.6 Comparison of Average Walking Speeds

Phase	Mean (ft/s)	Standard deviation (ft/s)	Minimum (ft/s)	Median (ft/s)	Maximum (ft/s)
Calibration	3.36	0.53	1.05	3.38	5.54
Experiment	4.16	0.76	2.32	4.06	7.08

A non-parametric Kruskal-Wallis test was applied to compare the median values from both speed distributions. The result from the test indicated that there is a significant difference between the two speed distributions with a p-value of 0.001 at a 95% significance level. The sample in the calibration phase had an average walking speed of 3.36 ft/s, whereas the average speed in the experimental phase was significantly higher at 4.16 ft/s. The percentage difference between the two speeds is 21.3%. The standard deviation of the walking speed in the experimental phase is also higher than for the calibration phase with a difference of 43.4%. The higher average and standard deviation values in the experimental phase is inferred to be related to the presence of vehicles in the simulation and the increased stress imposed on the subjects to perform a safe crossing without getting hit by a vehicle, validating the initial hypothesis.

Figure 4.5 shows the distributions for the average walking speed based on the number of lanes. The results from a Kruskal-Wallis test indicated there was no significant difference between the two distributions with a p-value of 0.401. The average walking speed for the subjects on the one-lane street was 4.13 ft/s, while the average speed for the subjects on the two-lane street was 4.18 ft/s. The standard deviation values for the speeds were 0.76 and 0.75 ft/s for the one-lane street and the two-lane street, respectively.

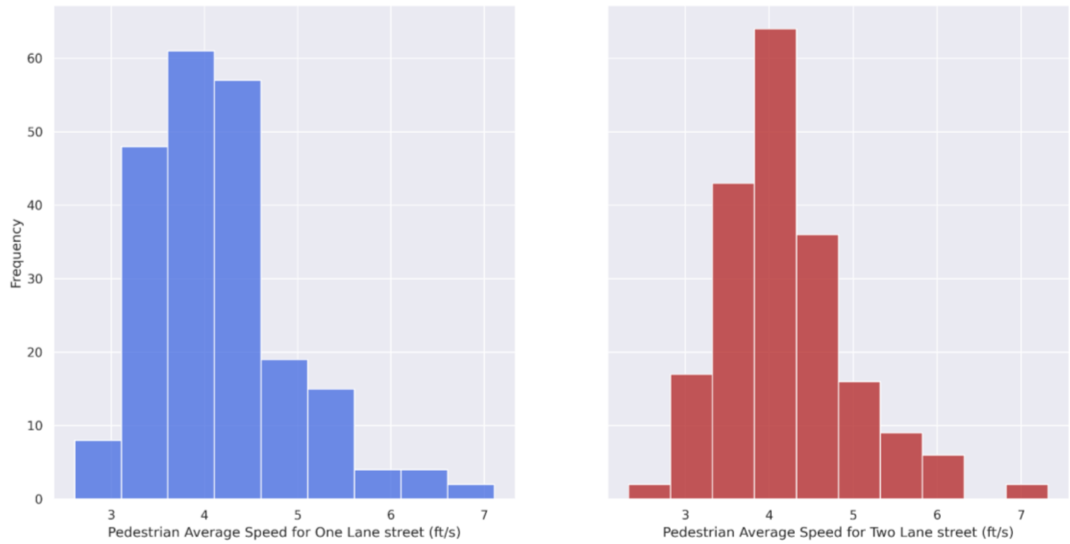

Figure 4.5 Walking Speed Distributions per the Number of Lanes

Figure 4.6 shows the distributions for the average walking speed based on the 15-mph and 25-mph vehicle speeds. The average walking speed for the subjects on the scenarios with traffic at 15 mph was 4.16 ft/s, whereas the average walking speed for the subjects on the scenarios with traffic at 25 ft/s was 4.15 ft/s. A Kruskal-Wallis test was conducted to identify if there were statistical differences between the two distributions. Since the p-value of the test (0.698) is not less than 0.05, therefore the null hypothesis was rejected. The results indicate there is no significant difference between the two walking speeds based on the vehicle speeds.

Figure 4.6 Walking Speed Distributions per the Traffic Speed

Figure 4.7 shows the distribution of the average walking speed by RIAS configuration. As observed from Table 4.2, the differences in average walking speeds based on the RIAS configuration are about 0.2 ft/s, with the major difference of 1.6% observed between the NO-RIAS and the SIMPLE RIAS configurations.

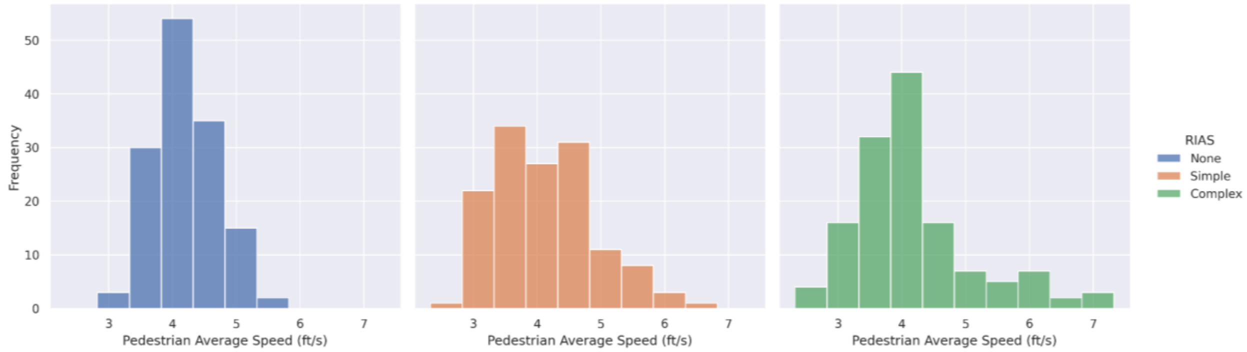

Figure 4.7 Walking Speed Distributions by RIAS Configuration

Figure 4.8 shows the box plots for the walking speed based on the RIAS treatment. The SIMPLE RIAS has an asymmetric distribution with a median of 4.01 ft/s and has the largest variability to the right side of the three distributions. The lower quartile is 3.46 ft/s and the upper quartile is 4.57 ft/s. In contrast, the COMPLEX RIAS with a median speed of 3.91 ft/s has a positive skewed distribution, but with outlier values to the right of the distribution. The lower quartile speed is 3.61 ft/s and the upper quartile is 4.46 ft/s. The distribution of the walking speed without RIAS also has a positive asymmetric distribution with a median value of 4.14 ft/s, a lower quartile of 3.85 ft/s, and an upper quartile of 4.51 ft/s.

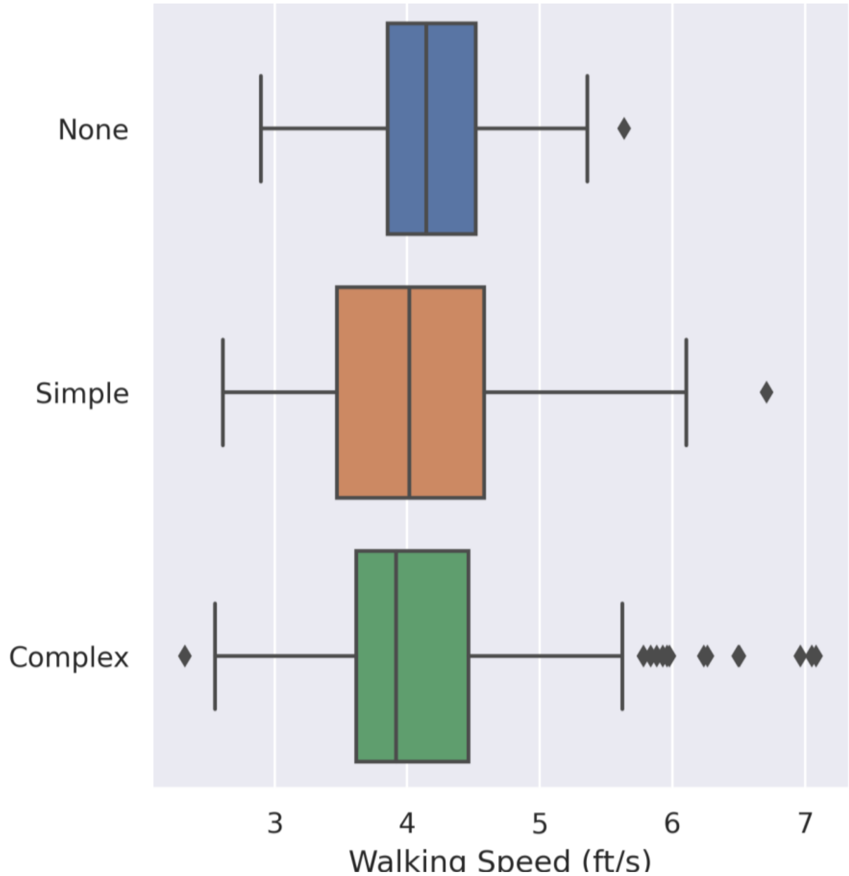

Figure 4.8 Box Plots of Average Walking Speeds by RIAS Configuration

Table 4.7 shows the results from the Kruskal-Wallis non-parametric test to evaluate if the median values for the walking speed distributions based on the RIAS configurations are statistically similar. Nevertheless, the p-value of the Kruskal-Wallis test (0.051) is barely larger than 0.05, thus in theory there is evidence to not reject the null hypothesis. Although minimally, the results from the test indicate the median values of the distributions are statistically similar. As the test results are essentially at the limit of the significance level, additional analyses were performed to evaluate if the use of the RIAS device had an effect on the walking speeds selected by the subjects.

Table 4.7 Non-Parametric Test for the Median Walking Speeds vs RIAS Configuration

Descriptive Statistics

RIAS	N	Median	Mean Rank	Z-Value
Complex	136	3.91418	193.5	-1.62
None	139	4.14367	226.7	2.39
Simple	138	4.01637	200.5	-0.79
Overall	413		207.0	

Test

Null hypothesis H_0: All medians are equal

Alternative hypothesis H_1: At least one median is different

Method	DF	H-Value	P-Value
Not adjusted for ties	2	5.96	0.051
Adjusted for ties	2	5.96	0.051

Figure 4.9 shows the walking speed distributions based on RIAS configuration and the vehicle speeds in the simulations. Table 4.8 presents the descriptive statistics of the average walking speed of the subject based on the 15 mph and 25 mph traffic speed scenarios. The subjects had a higher average walking speed of 4.21 ft/s when utilizing the COMPLEX RIAS for a vehicle speed of 15 mph. In contrast, for the 25-mph vehicle speed the average walking speed was the lowest with 4.07 ft/s. The walking speed distribution of the COMPLEX RIAS also has a higher dispersion with a standard deviation of 1.03 ft/s for 15 mph compared to 0.72 ft/s for 25 mph.

Table 4.8 Average Walking Speeds per Vehicle Speed and RIAS

Vehicle Speed (mph)	RIAS	Walking Speed (ft/s)			
		Average	Standard Deviation	Minimum Value	Maximum Value
15	All	4.16	0.82	2.32	7.08
	None	4.20	0.52	2.89	5.36
	Simple	4.06	0.81	2.60	6.70
	Complex	4.21	1.03	2.32	7.08
25	All	4.14	0.68	2.62	6.49
	None	4.20	0.49	3.32	5.63
	Simple	4.19	0.72	3.07	5.92
	Complex	4.07	0.81	2.62	6.49

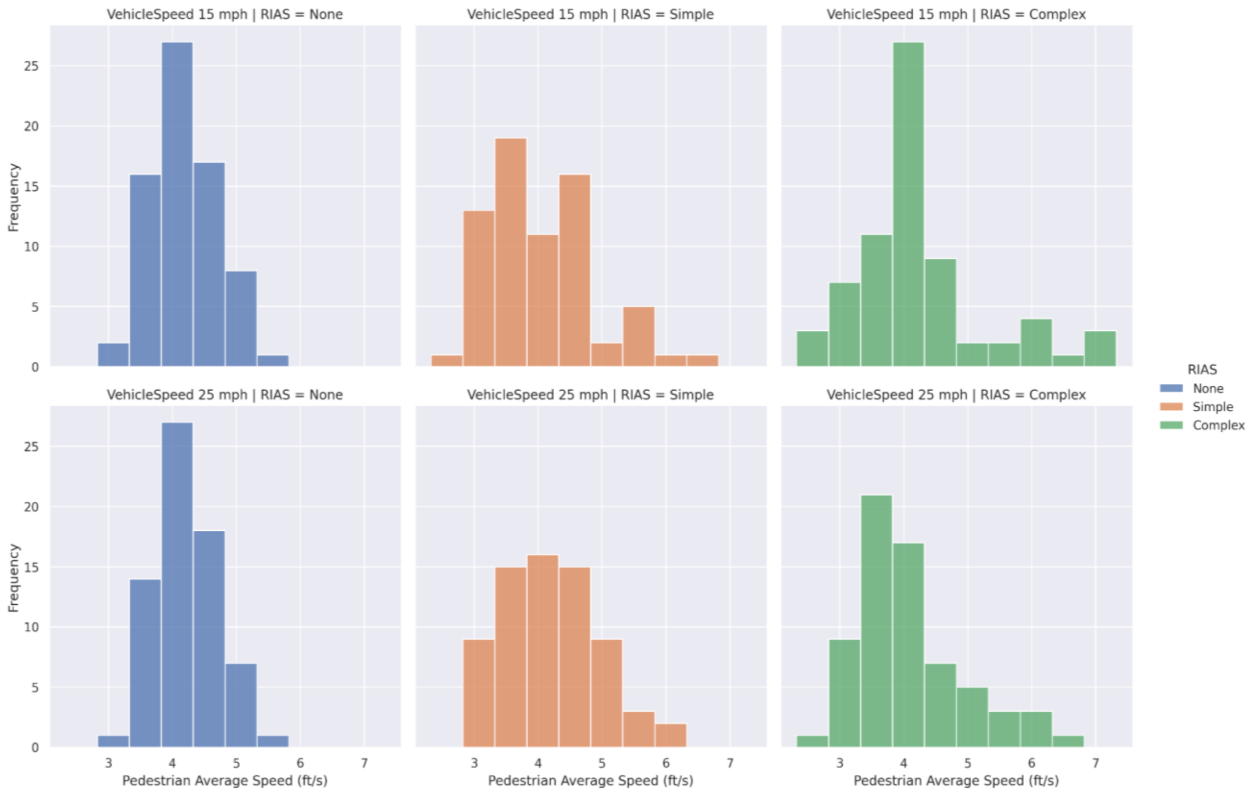

Figure 4.9 Walking Speed Distributions per RIAS Configurations and Vehicle Speed

Figure 4.10 shows the distributions of the walking speed by RIAS and the number of lanes. Table 4.9 presents the descriptive statistics of the average walking speed of the subject based on the number of lanes of the urban street. The average walking speed was higher with NO-RIAS, one-lane 4.18 ft/s and two-lane 4.22 ft/s. The scenarios without the RIAS device in the one-lane street had the lowest walking speed dispersion of 0.50 s. The possibility of the RIAS device directly affecting the walking speeds selected by some of the pedestrians to cross the street seems to be present. Additional statistical tests were performed on the walking speed results to identify which factors and combination of factors might be associated with the differences in walking speeds aforementioned discussed.

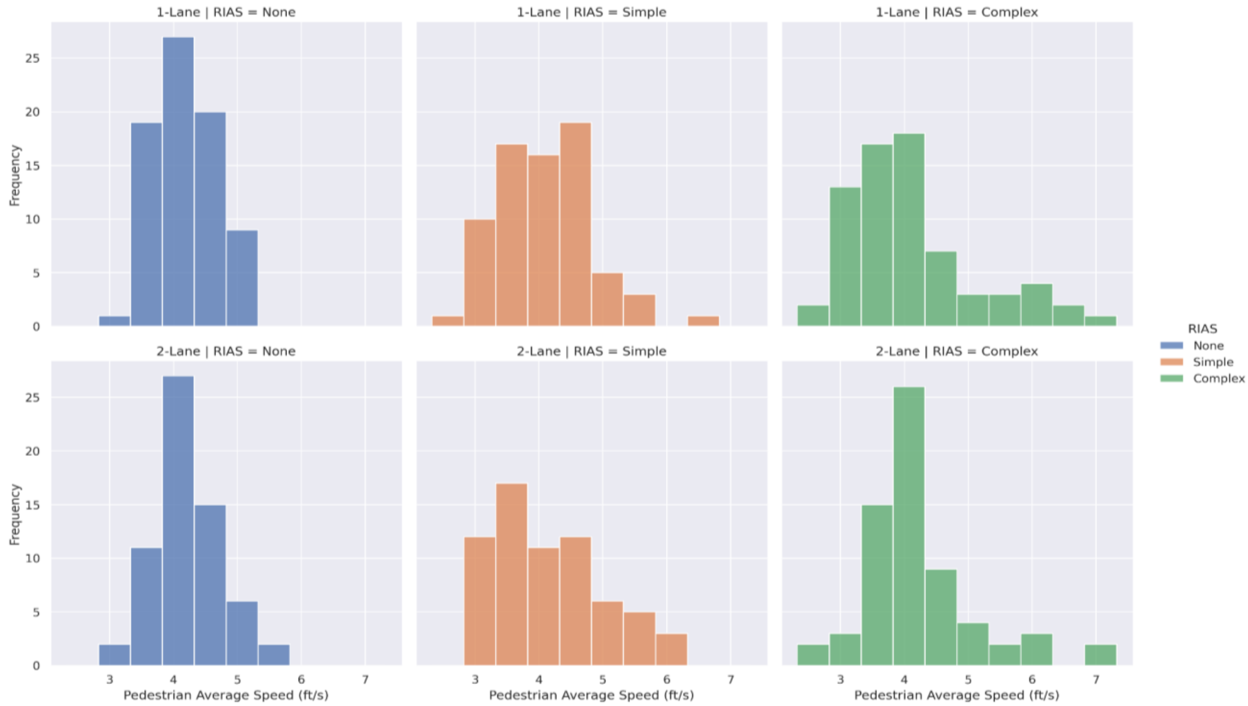

Figure 4.10 Walking Speed Distributions by RIAS Level and Number of Lanes

Table 4.9 Average Walking Speeds per Number of Lanes and RIAS

Number of Lanes	RIAS	Walking Speed (ft/s)			
		Average	Standard Deviation	Minimum Value	Maximum Value
1	All	4.12	0.76	2.60	7.08
	None	4.18	0.50	3.32	5.21
	Simple	4.11	0.73	2.60	6.71
	Complex	4.09	1.00	2.62	7.08
2	All	4.17	0.75	2.32	7.05
	None	4.22	0.52	2.89	5.63
	Simple	4.13	0.52	3.02	6.10
	Complex	4.20	0.85	2.32	7.05

4.5 Calibration of a Regression Model for the Walking Speed

A Kruskal-Wallis test was performed, a non-parametric approach to the one-way ANOVA, to analyze the effect of the combined factors in the walking speed of the subjects participating in the experiment. Table 4.10 presents the summary of the results of the Kruskal-Wallis test performed for each variable separately and discussed in the previous sections. The effect of the age, gender, RIAS configuration, the number of lanes, and vehicle speeds, was analyzed with respect to the average walking speed.

Table 4.10 Kruskal-Wallis Test Results on the Average Walking Speed

Parameter	DF	H-value	p-value
Age	2	6.30	0.043*
Gender	1	3.55	0.060*
RIAS	2	5.96	0.051*
Lanes	1	0.70	0.401
Vehicle Speed	1	0.15	0.698

Note: * Indicates the parameter has a significant effect on the response variable.

The AGE variable was defined with three categories, taking a value of zero (0) for the 18-25 years old group, a value of one (1) for the 26-45 age-group and a value of two (2) for the 46-70 age group. GENDER is a binary variable taking a value of zero (0) for females, and one (1), otherwise. The RIAS variable was defined with three categories, taking a value of zero (0) for the NO-RIAS condition, a value of one (1) for the SIMPLE RIAS, and a value of two (2) for the COMPLEX RIAS. LANES is a categorical variable taking a value of one (1) for the one-lane street, and two (2) for the two-lane street. VEHICLE SPEED is a categorical variable taking a value of 15 for the 15-mph speed, and 25 for the 25-mph speed.

The H-value of the Kruskal-Wallis test was used to calculate the p-value. A level of significance of 0.10 was used as the threshold value for the discussion of the parameters. The results of the analysis indicate that the AGE, GENDER, and the RIAS configuration have a significant effect on the average walking speed as the p-values are lower than 0.10. The p-values for these three variables indicate there is a statistically significant difference between the median values of the walking speed for the levels of these variables. The LANES and VEHICLE SPEED variables were found to not have any effect on the median values of the walking speed.

The non-parametric statistics conducted to verify if there was an effect from individual factors on the median walking speed revealed that none of those variables had statistical differences. A regression model was used to analyze the walking speed as a response variable and combine the different factors to explain the variability incorporated in the sample.

An Ordinary Least-Squares (OLS) regression model of the form illustrated in Equation 4.1 was calibrated for estimating the average walking speed of the subjects based on three explanatory variables. The OLS regression model is expressed as:

$$Y = \beta_0 + \beta_1 X_1 + \beta_2 X_2 + \cdots + \beta_n X_n \qquad (4.1)$$

where:

Y is the dependent variable
$\beta_i, (i = 0,1, \dots, n)$ = are the regression coefficients
$X_i, (i = 0,1, \dots, n)$ = indicates the independent variables

A logarithmic transformation was performed on the response variable to fulfill the assumption of heteroscedasticity. The error term has a constant variance and stabilizes the normality and variance of the residuals of the model. The OLS used the logarithmic transformation over the response variable. Table 4.11 shows the results from the OLS model calibration process with the coefficients of the model parameters and the p-values in parentheses.

Table 4.11 OLS Models for the Logarithmic-Transformed Average Walking Speed

Parameters	Levels	Base Model	Full Model w/o Interaction	Model only AGE-RIAS	Full Model - All Interactions
AGE	1	0.0271 (0.003)	0.0264 (0.004)	0.0116 (0.427)	0.0111 (0.503)
	2	0.0278 (0.002)	0.0276 (0.003)	-0.030 (0.049)	-0.007 (0.654)
GENDER	1	-0.019 (0.008)	-0.019 (0.008)	-0.018 (0.008)	-0.003 (0.792)
RIAS	1	--	-0.012 (0.190)	-0.020 (0.181)	-0.021 (0.165)
	2	--	-0.011 (0.204)	-0.071 (0.000)	-0.072 (0.000)
AGE-RIAS	1-1	--	--	-0.039 (0.056)	-0.038 (0.061)
	1-2	--	--	0.0822 (0.000)	0.0836 (0.000)
	2-1	--	--	0.0666 (0.002)	0.0659 (0.002)
	2-2	--	--	0.1015 (0.000)	0.1017 (0.000)
AGE-GENDER	1-1	--	--	--	-0.003 (0.882)
	2-1	--	--	--	-0.044 (0.010)
Constant		0.6035(0.000)	0.6115(0.000)	0.6349 (0.000)	0.6283 (0.000)
R^2		*4.26%*	*4.78%*	*17.04%*	*18.78%*
Adjusted R^2		*3.56%*	*3.62%*	*15.19%*	*16.55%*
Lack-of-Fit		*0.022*	*0.000*	*0.010*	*0.137*

*p-values are shown in parenthesis.

The first calibration of the model was performed adding one explanatory variable at a time. The best specification of the OLS regression model (BASE model) included the AGE and GENDER variables that were found to be statistically significant for the median values. Subsequent calibrations of the OLS regression model were conducted with all the explanatory variables without considering interactions between them.

The results of the FULL MODEL W/O INTERACTIONS confirmed that the AGE and GENDER variables were found to be statistically significant in explaining the average walking speed. However, the model presents a lack-of-fit with a p-value equal to zero, which indicates that terms must be included in the model for it to be appropriate. The full model w/o interactions when adding the RIAS variable, was found to be not significant.

The interaction of the RIAS variable with the AGE and GENDER variables, when adding the effects of interactions between explanatory variables, was found to be significant. These results indicate that the levels of RIAS could be significant in the model if the interactions with these variables are included.

A model with the interactions (MODEL ONLY AGE-RIAS) was implemented with the variables AGE, GENDER, RIAS, and the interaction between RIAS and AGE. The results of this model provide a better goodness-of-fit and adjusted R^2 values with significance of all variables and meeting the assumptions of normality and constant variance in the residuals.

The FULL MODEL-ALL INTERACTIONS model with all the significant interactions was calibrated using the backward elimination technique. The best fit of all possible linear models was obtained with an adjusted R^2 value of 16.6%. The interaction between the COMPLEX RIAS treatment and the older age group has the greatest absolute impact on the average walking speed. The age group over 45 years old had the greatest impact when the COMPLEX RIAS treatment was applied, increasing their speed up to 1.26 ft/s.

4.6 Pre-Test and Post-Test Questionnaires

Subjects participating in the experiment were required to fill two questionnaires: one prior to conducting the VR runs and one after. The responses to the questionnaires are tabulated and analyzed separately in the following sections.

4.6.1 Responses to the Pre-Test Questionnaire

Three questions were included in the pre-test questionnaire. Subjects were asked about the amount of time they walk daily on the road network, in addition to their age and other demographic information. This question was aimed to identify how experienced the subjects were and their level of exposure as pedestrians on the road. Table 4.12 shows the results of the walking time per RIAS configuration and includes the age for each subject. The NO-RIAS group walks an average of 10.3 minutes per day, whereas the SIMPLE RIAS group walks 13.1 minutes, and the COMPLEX RIAS group walks 16.1 minutes. Based on the subject age, the average daily walking time on a road was 6.6 minutes for the 18-25 years old group, 13 minutes for the 26-45 years old group, and 20 minutes for the 46-70 years old group. There is a positive linear correlation of 0.35 between the subject’s age and the daily time walking. In summary, as the person's age increases there is a tendency to walk more and be exposed to road conditions.

Table 4.12 Approximate Time Walking on a Road

NO-RIAS		SIMPLE		COMPLEX	
Age	Daily Walk (min)	Age	Daily Walk (min)	Age	Daily Walk (min)
22	15	21	2	22	5
21	5	23	10	23	5
35	5	28	5	39	5
43	0	32	2	31	30
67	20	53	0	58	60
57	15	61	30	59	0
23	1	24	0	20	30
19	3	19	3	24	0
31	30	33	30	26	5
44	10	26	20	44	13
55	15	52	50	51	20
52	5	51	5	55	20

Figure 4.11 shows the responses to the question: *"How confident do you feel in safely crossing a one-lane and a two-lane road segment outside of an intersection?"* This question was geared into the stated confidence of the subjects in being able to safely cross a road segment outside of an intersection without getting hit by a vehicle on the road. Overall, the subjects stated more confidence in being able to cross the one-lane road (41%) than for the two-lane road (33%). This response was expected as subjects recognize the higher complexity and higher risk involved in crossing the road with a higher number of lanes. Twenty-one percent of subjects selected the NEUTRAL response to the two-lane road crossing than to the one-lane road crossing (27%), indicating they are more certain of the response provided in the one-lane situation. There is a 4-1 difference in the stated response of VERY UNSURE for the two-lane road crossing versus the one-lane road crossing.

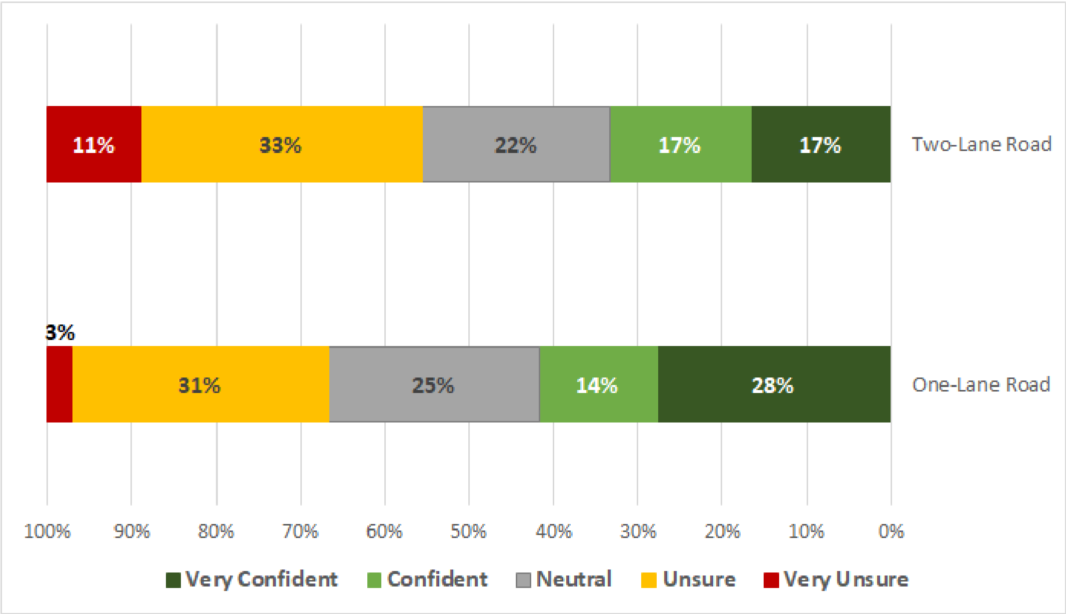

Figure 4.11 Stated Confidence of Safely Crossing a Road Outside of an Intersection

Figure 4.12 shows the responses to the question: *"Which factors do you analyze when deciding to cross a road segment outside of an intersection?"* This question required the subject to select from a list of five factors that were associated with the design of the VR experiment. The subject was allowed to select as many factors of those five. The subjects were not informed these factors were present in the scenarios when answering the questionnaire. The objective of this question was to establish the potential relations between the stated preference of the subjects and the results from the VR experiment.

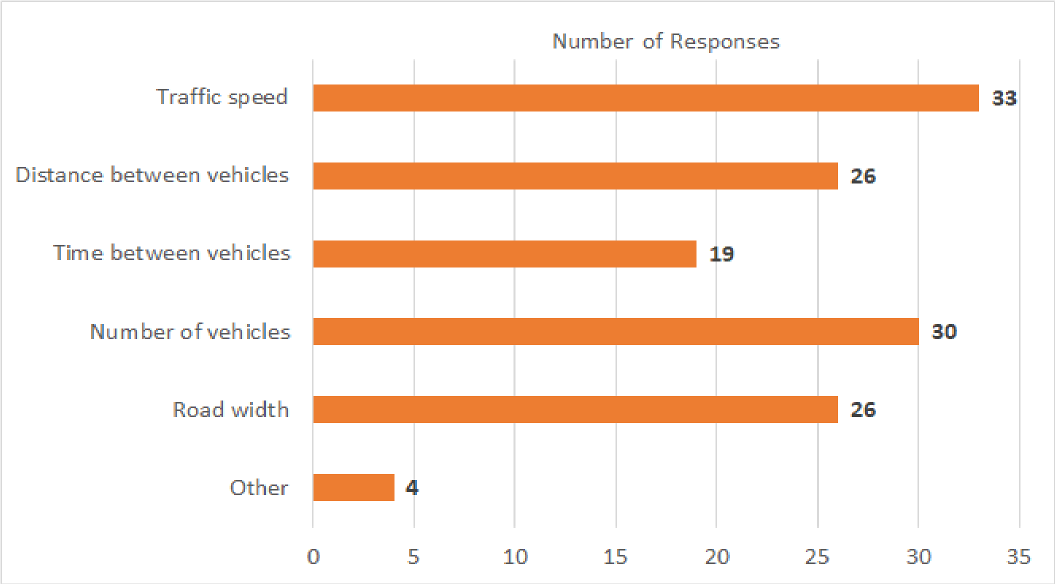

Figure 4.12 Stated Factors to Decide When to Cross a Road Outside an Intersection

The traffic speed was the factor mostly selected by the subjects (92%), followed by the number of vehicles (83%). The time between the vehicles was the least selected factor from the list, although still a significant number (53%) of subjects stated that they analyzed this factor as well. More subjects selected the distance between vehicles (72%) instead of the time between vehicles when crossing the road. As distance and time between vehicles are related with the traffic speed, one factor might be compensating for the other in the analysis made by the subjects when crossing a road.

4.6.2 Responses to the Post-Test Questionnaire

Figure 4.13 shows the responses to the question: *"How difficult was to safely cross the road in the simulation, based on the following factors?".* Analyzing the total responses received, the road width (83%) and the quantity of vehicles in the simulation (77%) were the factors that most participants identified to provide no difficulty when crossing the simulated road. On the opposite spectrum, the distance between the vehicles was the factor that most subjects (55%) identified to provide the most difficulty to cross the street in the simulation. The vehicle speed received the second largest percentage of subjects (39%) with difficulty in crossing the street in the simulation. There are some contradictions with the responses provided in the pre-test questionnaire.

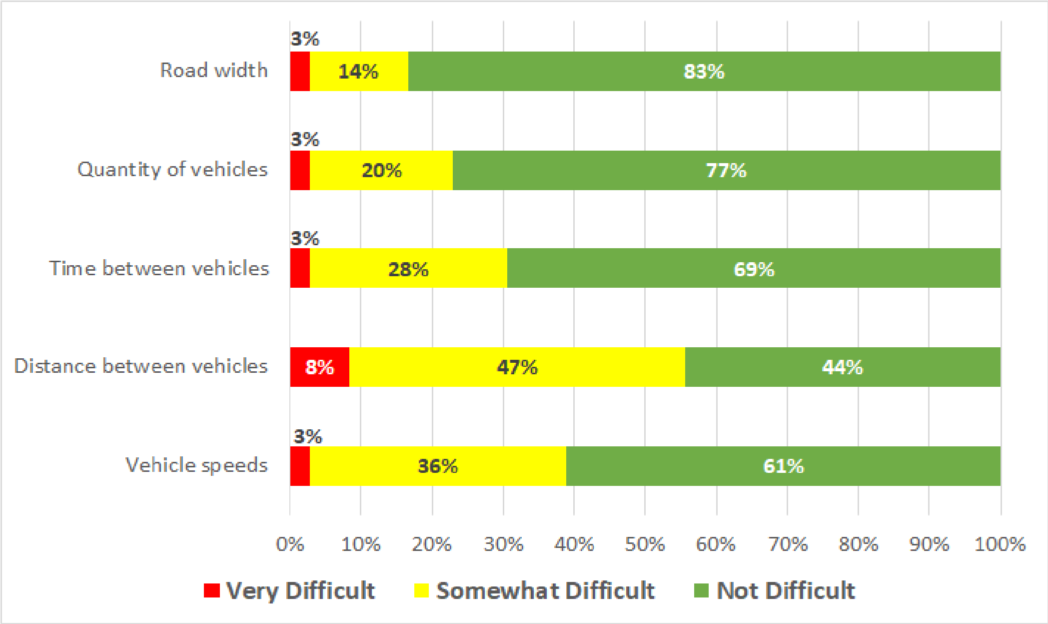

Figure 4.13 Stated Crossing Difficulty Based on Road and Traffic Factors

Figure 4.14 shows only the results for the "NOT DIFFICULT" response based on RIAS configuration to the question: *"How difficult was to safely cross the road in the simulation, based on the following factors?".* The objective of analyzing only the "NOT DIFFICULT" response was to identify patterns based on the use of the RIAS in the simulation. The factors VEHICLE SPEEDS and DISTANCE BETWEEN VEHICLES show the highest increases in the number of subjects that perceived reduced difficulty when using the RIAS. The DISTANCE BETWEEN VEHICLES factor was perceived as NOT DIFFICULT by 19% of the subjects in the NO RIAS configuration. A higher percentage had the same perception of NOT DIFFICULT for the DISTANCE BETWEEN VARIABLES factor when using the SIMPLE RIAS (31%) and the COMPLEX RIAS (50%). The COMPLEX RIAS that shows the speed, and the distance and time to the crosswalk of the leading vehicle appears to enhance the comprehension of subjects of these two factors in the decision to cross the street.

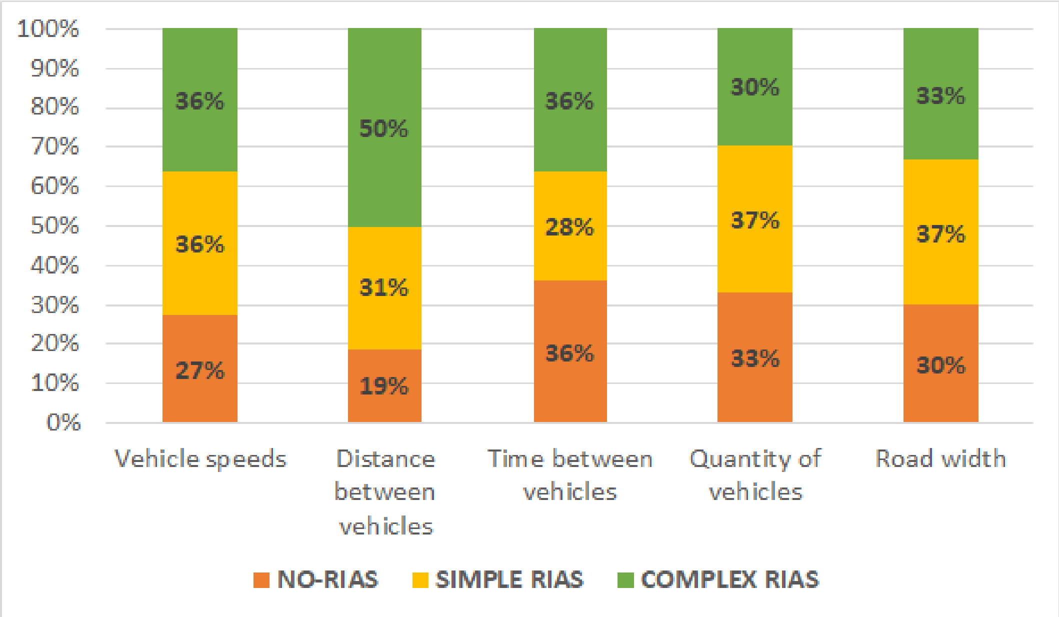

Figure 4.14 Road and Traffic Factors that Provided No Difficulty

A significant group of subjects (75%) stated that participating in this VR experiment would help them decide to safely cross a road in the future. Two of the subjects from the configurations with a RIAS device (8.3%) stated that the experiment would not help them in their decision to cross a road in the future.

The subjects that participated in the two configurations with a RIAS device were asked "*How useful is it to use the electronic device as a tool to cross the road safely?*" and if *"Would you use the electronic device in real life?".* These questions were aimed to establish the opinion of the subjects regarding the potential benefits of using a RIAS device in a connected environment, even though the participants were not instructed about smart cities or smart transportation in the experiment. Overall, the COMPLEX RIAS was perceived to be VERY USEFUL by 83% of the participants in that group, compared to 67% of the participants in the second group. Similarly, more participants (58%) that used the COMPLEX RIAS in the simulation stated to be willing to use the device in real life, compared to 25% of the participants in the SIMPLE RIAS device. The level of undecidedness was higher for the SIMPLE RIAS with 58% of the participants compared with 33% of the participants in the COMPLEX RIAS group.

Two additional questions were included for the subjects that used the RIAS device based on the comparison between the one-lane street versus the two-lane street. When inquired *"How did the information provided on the RIAS device help you cross the one-lane and two-lane road?",* only 8% of the participants, on both road width conditions, responded NOTHING. As expected, more subjects (67%) in the two-lane street crossing expressed that the information provided by the RIAS device helped them very much to cross the road compared to 58% of the participants in the one-lane street crossing. The second question, *"How did the information provided on the COMPLEX RIAS device help you cross the one-lane and two-lane road?",* was included only for those subjects in the COMPLEX RIAS configuration. The COMPLEX RIAS provided four elements of information to the participants: the speed of the traffic, the distance and time to reach the crosswalk for the leading vehicle in each lane, and the pedestrian symbols for WALK and DON'T WALK. The time for the leading vehicle to reach the crosswalk was selected by all participants in both lane scenarios as very helpful information to cross the street. The speed of the vehicles had the second highest selection by the subjects, with 92% in the one-lane street and 100% in the two-lane street configurations giving a VERY HIGH rating. The pedestrian symbols had the lowest percentages of subjects in the VERY HIGH rating with 75% in the one-lane street and 83% in the two-lane street configurations. The pedestrian symbols were the only element to receive a NOTHING rating by 8% of the participants in both street configurations.

The perception of the subjects in favor of the COMPLEX RIAS is evident, even though the COMPLEX RIAS was assumed to require more concentration on the part of the person to analyze the information and use it properly. The results show that it is possible that the pedestrian signal indications were not providing enough relevant information to the pedestrians about the traffic conditions, or maybe there is no sufficient understanding on the meaning of the symbols outside of a signalized intersection, or simply the subjects did not understand what the change in the pedestrian symbols really meant in the RIAS device.

Figure 4.15 shows the responses to the question: "*How comfortable did you feel in the virtual reality simulation?*" A similar percentage of the subjects in the overall sample (72%) stated feeling comfortable with the VR simulation. The percentage of subjects in comfort with the VR simulation is higher (83%) when analyzing only the subjects in the NO-RIAS configuration. As the research study introduced the use of a RIAS device while immersed in the VR simulation, it should have been expected that the level of comfort of some of the subjects would decrease. The SIMPLE RIAS configuration had both the lowest percentage (58%) of subjects in the COMFORTABLE opinion and the highest percentage (25%) in the UNCOMFORTABLE opinion with respect to the VR simulation. This perception could be linked to a lack of understanding from the subjects regarding the meaning of the pedestrian symbols used in the RIAS or even the use of the device. The simulation of the COMPLEX RIAS configuration had a much higher percentage of subjects (75%) with a COMFORTABLE opinion than for the SIMPLE RIAS. This result implies that the COMPLEX RIAS, even though it had more information to process than the two symbols in the SIMPLE RIAS, the subjects felt more comfortable with that device.

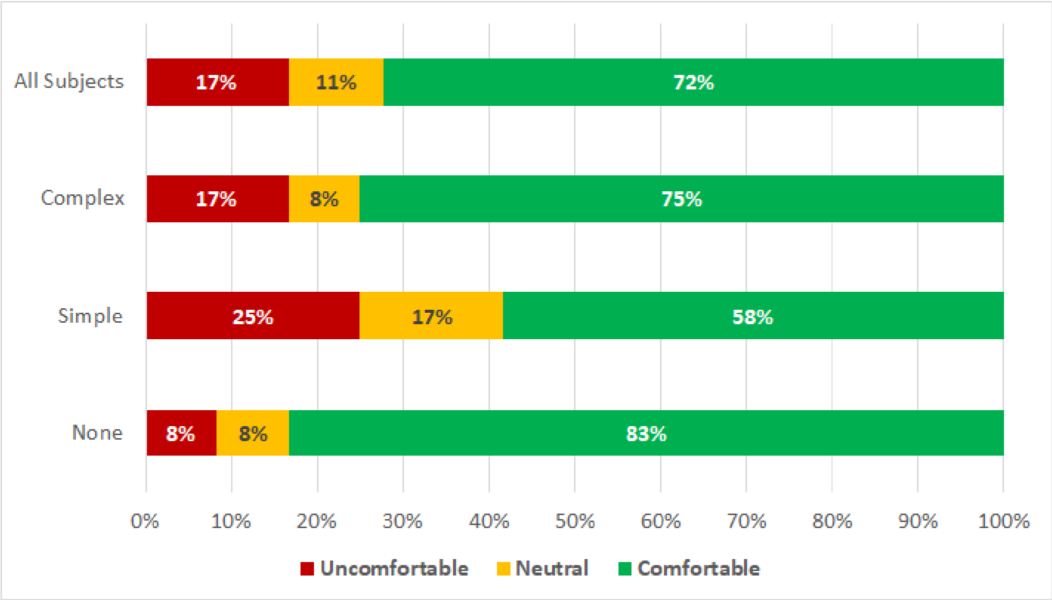

Figure 4.15 Stated Level of Comfort when Immersed in the VR Simulation

Figure 4.16 shows the responses to the question: "*How safe did you feel in the virtual reality simulation?*" A similar response was obtained when the subjects were asked how safe they felt during the VR simulation. Overall, 86% of the participants felt safe whereas 8% felt insecure when using the VR equipment. The group in the SIMPLE RIAS configuration had the lowest percentage (75%) of participants feeling safe and the highest percentage (25%) feeling insecure when using the VR equipment. The groups in the NO-RIAS and the COMPLEX RIAS had the highest percentage of participants (92%) that stated feeling safe while using the VR technology.

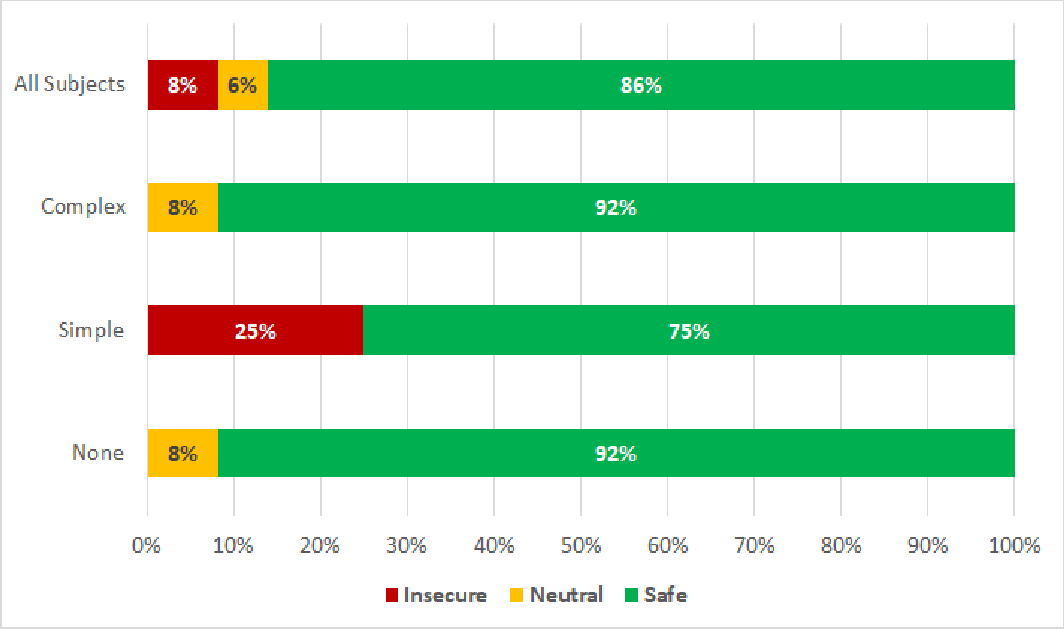

Figure 4.16 Stated Level of Safety when Immersed in the VR Simulation

In the question regarding *"How real did you perceive the simulation of the virtual environment?", 89%* of the participants provided a REAL or VERY REAL opinion regarding the quality of the VR environment. Ninety-two percent that participated in the SIMPLE RIAS and the COMPLEX RIAS groups provided that opinion. None of the participants from any of the experiment configurations stated that the VR simulation felt FICTIONAL or VERY FICTIONAL.

The responses from a question related to the perceived quality for five elements of the constructed VR environment are shown in Figure 4.17. The lights and shadows, the simulated vehicles, and the pedestrian avatars were perceived to have an EXCELLENT or GOOD quality by 94% of the subjects. The physical elements in the simulation, such as the buildings and the road, received EXCELLENT or GOOD ratings from 92% of the participants. The sound element received the lowest quality perception with 3% of participants giving a DEFICIENT rating. Overall, the large majority of the participants are providing EXCELLENT or GOOD reviews to the quality of the VR simulation elements.

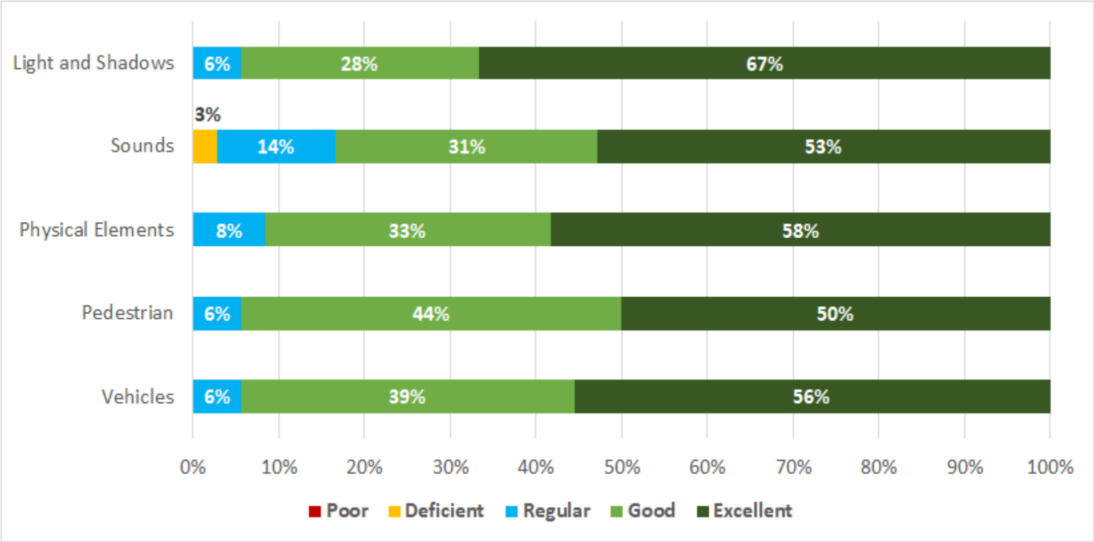

Figure 4.17 Perceived Quality of Elements of the VR Simulation

These responses regarding the quality and positive perception of the subjects about the VR simulation establish the need to further study the potential use of this technology as an educational tool for road safety campaigns.

5. Conclusions and Recommendations

A VR experiment was conducted to evaluate the potential effectiveness of a simulated RIAS in helping pedestrians make a crossing maneuver in an urban street. The design of the experiment evaluated the effect of the crossing performance of pedestrians based on two fixed 15-mph and 25-mph vehicle speeds, random gaps between 3 s and 8 s, one-lane and two-lane streets, and a SIMPLE and a COMPLEX RIAS device. The simulated RIAS device was designed with two versions: one with two symbols called SIMPLE RIAS and another with the same symbols, but with three data values related to the incoming vehicles called COMPLEX RIAS. The study analyzed the effect of the level of complexity of the RIAS device on the crossing performance. Three pedestrian performance variables were measured in the study: the gaps accepted to cross the street, the walking speed, and the crossing success rates of the participants.

The primary conclusions that resulted from the results from the VR study are:

- The subjects that used the SIMPLE RIAS device had the worst performance of the three groups when crossing the street. This group of subjects could be identified as the most conservative in the study as they had the highest average value for the gap accepted when crossing the road of the three groups.
- The walking speeds measured in this VR study were not normally distributed as found in other studies.
- Subjects in the one-lane street and the two-lane street scenarios exhibited walking speeds of 3.36 ft/s for crossing events without the presence of traffic. These two speed distributions were statistically similar.
- The difference between the 15th percentile and the 85th percentile walking speed in the sample without traffic was about 1 ft/s. For a two-lane street of 20-feet wide, these speeds represent a walking time difference of almost 2 s more on the street.

- Pedestrians facing oncoming vehicles when crossing a street selected a higher speed due to the higher perceived risk.
- Average pedestrian crossing speeds increased to 4.16 ft/s when the pedestrians had the pressure of crossing successfully when facing the traffic in the simulation.
- The number of lanes and the speed of the incoming vehicles did not have an effect on the walking speed selected by the subjects.
- The group of subjects that did not use the RIAS device could be identified as more aggressive by accepting an average gap ½ second shorter than the group in the SIMPLE RIAS configuration when crossing the street. Notwithstanding that, this group had the best performance when crossing the street by avoiding collisions with the incoming vehicles.
- Subjects were more aggressive when crossing the two-lane street by selecting lower vehicle gaps compared to the one-lane street scenarios.
- The distributions of the gap accepted to cross the road were found to be statistically different between the three subject groups. The statistical test of the difference in walking speed distributions marginally rejected the null hypothesis with a p-value of 0.051.
- The age and gender and the level of RIAS were found to have an effect on the median walking speeds of the participants when analyzed independently.
- The OLS model shows evidence of a difference in performance in the decision to cross the street relative to the use of the RIAS device.
- The results of the OLS model indicate that males tend to select slower walking speeds when crossing the road than females.
- The implication of the age group variables on the average walking speed from the OLS models varies depending on the presence of interactions with other explanatory

variables. The 26-45 age group exhibited higher walking speeds than their younger counterparts.

- The 46-65 age group exhibited lower speeds than their younger counterparts when the interaction between the age and RIAS variables is included. The interaction effect for this group with the COMPLEX RIAS had the highest positive impact on the walking speeds.
- The COMPLEX RIAS device tends to provide better performance and behavior from pedestrians than the simple RIAS device.

The primary conclusions that resulted from the questionnaires are:

- The speed of the oncoming vehicles and the number of vehicles on the road were the two factors that most subjects stated they analyzed when making the decision to cross a street. The time between the vehicles, which could be associated with the gap accepted to cross the street, was the factor least selected by the subjects on the pre-test questionnaire.
- Subjects changed their perception after the VR experiment as the gap between vehicles was identified by the largest number of subjects as the factor with high difficulty in crossing the street.
- The speed of vehicles was perceived as a difficult factor by the second largest number of subjects after the VR experiment was completed.

In summary, the results of the VR research study provided evidence on the potential of a RIAS device to assist pedestrians in making better-informed decisions when crossing the road. The majority of subjects in the study perceived the RIAS as a very useful tool in assisting them to cross the street and were willing to use it in real life if available. A sound majority of the subjects that participated in this study felt comfortable and safe while using the VR technology. The VR technology will continue to improve the fidelity and sensory realness of the simulated scenarios. New headsets and computers will enhance the display resolution and refresh rates of the images shown to subjects. As these innovations become available, researchers will certainly be able to capture and simulate additional road conditions that can be used to study human factors and positively improve road safety.

Recommendations

It is recommended that the results of this VR simulation study be disseminated to the community of transportation professionals to assist them in formulating new policies aimed at identifying potential safety treatments for pedestrians in urban settings considering VR and strategies targeted to different age groups and gender.

The development of the RIAS device simulated in this study is a good start. Further study is required to assess the understanding of the users in the meaning of the information provided and a validation study must be performed to identify the best human interface.

Future research will need to consider the effect on the walking speeds and the crossing success rate of pedestrians at other urban settings or roadway configurations such as curved alignment or nearby intersections, and higher vehicle speeds.

6. Acknowledgments

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Appendices

Appendix A: IRB Approval Letter

Institutional Review Board
CPSHI/IRB 00002053
University of Puerto Rico – Mayagüez Campus
Dean of Academic Affairs
Call Box 9000
Mayagüez, PR 00681-9000

Protocol Approval

Approval Date	*April 28, 2021*
Protocol Number	*2021040012*
Protocolo Title	*Impact of Road Information Assistive Systems on Pedestrian Crossing Safety*
Main Researcher	*Natacha N. Cardona Rodríguez*
Type of Review	*Project Request*
Approval	*Expedited*
Category(ies)	*7*
Exemption Request(s)	*Exemption of use of adult consent for research with minors form*
Expiration Date	*April 26, 2022*

Any modifications or amendments to the approved protocol or its methodology must be reviewed and approved by the IRB before they are implemented, except in cases where the change is necessary to reduce or eliminate a potential risk for participants. The IRB must be informed immediately if an adverse event or unexpected problem arises related to the risk to human subjects. The IRB must also be notified immediately if there is any complaint about the research or if a breach of confidentiality has ocurred.

Dr. Pedro M. Vásquez Urbano *Associate Dean of Academic Affairs*	CPSHI / IRB - RUM No. 00002053 APPROVED

Telephone: (787) 832 - 4040 x 6277, 3807, 3808 – **Fax**: (787) 831-2085 –**Webpage**: www.uprm.edu/cpshi
Email: cpshirum@uprm.edu

Appendix B: Informed Consent Form

ESTUDIO DE ACEPTACIÓN DE BRECHA FORMULARIO DE CONSENTIMIENTO INFORMADO

Investigadores: Natacha N. Cardona Rodríguez, Andrés D. Chamorro Parejo y Dr. Alberto M. Figueroa Medina

Título de Proyecto: Impact of Road Information Assistive Systems on Pedestrian Crossing Safety

1. **¿QUÉ ES ESTE FORMULARIO?**
   Esto es un Formulario de Consentimiento Informado. Le proveerá información acerca de este estudio para que usted pueda tomar una decisión informada sobre su participación. Usted debe tener 18 años o más para dar consentimiento informado.

2. **¿QUIÉN ES ELEGIBLE PARA PARTICIPAR?**
   Individuos que se encuentran entre las edades de 18 a 70 años. Personas que experimentan cinetosis (mareo por movimiento) en un vehículo de motor, ya sea como pasajero o conductor, o en otros modos de transporte, no deberían participar.

3. **¿CUÁL ES EL PROPÓSITO DE ESTE ESTUDIO?**
   El propósito de esta investigación es analizar cómo los usuarios vulnerables de las carreteras podrían beneficiarse potencialmente de recibir información en tiempo real que los pueda ayudar a cruzar una carretera de manera segura. La investigación trata sobre cómo los peatones pueden integrarse a la tecnología conectada, predecir el comportamiento o la trayectoria de un usuario de la carretera cuando reacciona para desarrollar sistemas de prevención de colisiones y sistemas de asistencia de información son relevantes para reducir los accidentes de tráfico y facilitar la tarea de conducción.

4. **¿DÓNDE ESTE ESTUDIO TOMARÁ LUGAR Y CUÁNTO DURARÁ?**
   Esta sesión de estudio se llevará a cabo en el salón 115-B en el Edificio de Ingeniería Civil y Agrimensura de la Universidad de Puerto Rico en Mayagüez. El estudio durará aproximadamente 20 minutos por participante e incluirá cuestionarios y el uso del simulador de realidad virtual.

5. **¿QUÉ SE ME PEDIRÁ HACER?**
   i. Se le pedirá que llene un breve cuestionario antes y después del experimento. El cuestionario previo al estudio se utilizará para determinar aspectos demográficos y su nivel de exposición peatonal. La información demográfica incluye detalles tales como edad, género, etc.

   ii. El investigador le explicará cómo usar el equipo de realidad virtual (VR) y le proveerá instrucciones generales para los escenarios de simulación. El equipo consta de unas gafas, auriculares y dos controladores manuales. Una vez en la simulación de VR, usted deberá caminar en el escenario como normalmente lo hace en una carretera siguiendo las reglas de seguridad.

   iii. Una vez puesto el equipo, se llevará a cabo un escenario de prueba para que se sienta cómodo con el equipo y experimente con una simulación de realidad virtual. Si en algún momento siente molestia o cinetosis/mareos, informe de inmediato al investigador para detener la simulación. Una vez usted se sienta completamente cómodo con el equipo y viendo la realidad virtual, usted comenzará con los escenarios experimentales. No habrá ningún tipo de penalidad, o efecto adverso al estudio porque su participación no pueda ser completada.

iv. Después de completar los escenarios, se le proporcionará un cuestionario posterior al experimento para recopilar información sobre su decisión de cruzar o no cruzar la carretera y para obtener recomendaciones para mejorar la experiencia de realidad virtual para futuros estudios de investigación.

6. ¿EXISTE ALGÚN RIESGO O BENEFICIO ASOCIADO CON LA PARTICIPACIÓN?

En términos de la operación del equipo de realidad virtual, existe un leve riesgo de cinetosis (mareos). Un pequeño porcentaje de los participantes podrían experimentar sensación de náuseas o náusea actual. El experimento ha sido trabajado para minimizar el riesgo. Se recomienda que si usted ha experimentado cinetosis (mareos) mientras viaja o maneja un vehículo real, usted no debería participar en este experimento.

El experimento requiere que usted camine una distancia corta, simulando el cruce de una calle de un carril, por lo que existe un leve riesgo de que tropiece al caminar. Para reducir este riesgo, uno de los investigadores caminará a su lado en todo momento de la simulación. Se recomienda que si usted ha tenido alguna operación en alguna rodilla o tobillo, o si tiene alguna condición que le dificulte caminar, usted no debería participar en este experimento.

Si durante la simulación, usted siente malestar o náuseas, debe informar al investigador inmediatamente para que la simulación pueda ser detenida. La interrupción de la simulación debería reducir la molestia rápidamente. Si usted no se siente mejor tan pronto la simulación es interrumpida, los investigadores pueden gestionar para que alguien los guíe a su hogar o a buscar atención médica si es necesario.

Los beneficios de participar en este estudio incluyen la adquisición de conocimiento sobre las condiciones del tráfico vehicular y el diseño de una carretera que inciden en la decisión de una persona para cruzar una carretera de manera segura, y también adquirir conocimiento sobre los factores humanos del comportamiento de los peatones.

7. ¿QUIÉN VERÁ LOS RESULTADOS Y/O MI DESEMPEÑO EN ESTE ESTUDIO?

Los resultados de esta investigación serán publicados en revistas de investigación científica y serán presentados en conferencias y simposios de entidades científicas profesionales. Los resultados podrían ser utilizados por los investigadores aprobados para propósitos internos. Ningún participante será identificable en los reportes o publicaciones ya que ni el nombre ni las iniciales de ningún participante serán utilizados. Para mantener la confidencialidad de los archivos, los investigadores utilizarán códigos para identificar a cada sujeto, en vez de nombres, para toda la data colectada mediante cuestionarios y la data colectada durante su utilización del simulador. La data será asegurada en el Laboratorio de Ingeniería de Transportación de la Universidad de Puerto Rico en Mayagüez y solo será accesible por el investigador principal, y cualquier otro investigador aprobado para el estudio.

Es posible que su archivo de investigación, incluyendo información sensitiva y/o información de identificación, pueda ser inspeccionado y/o copiado por agencias federales o del gobierno estatal, en el curso del desempeño de sus funciones. Si su archivo es inspeccionado por alguna de estas agencias, su confidencialidad será mantenida en la medida permitida por la ley.

8. ¿RECIBIRÉ ALGÚN TIPO DE COMPENSACIÓN MONETARIA POR PARTICIPAR DE ESTE ESTUDIO?

No. Su participación en este estudio es completamente voluntaria.

9. ¿QUÉ PASA SI TENGO UNA PREGUNTA?

Si tiene alguna pregunta sobre el experimento o cualquier otro asunto relativo a su participación en este experimento, o si sufre de alguna lesión relacionada a la investigación como resultado del estudio, puede comunicarse con los investigadores, Natacha N. Cardona al teléfono (787) 526-3604 o al correo electrónico natacha.cardona@upr.edu, Andres Chamorro Parejo (939)-272-6568 o al correo electrónico andres.chamorro@upr.edu , o Dr. Alberto M. Figueroa al teléfono (787) 832-4040 ext. 3465 o al correo electrónico alberto.figueroa3@upr.edu. Si durante o después del estudio, usted desea discutir su participación o preocupaciones en cuanto al mismo con una persona que no participe directamente en la investigación puede comunicarse con el Comité para la Protección de los Seres Humanos en la Investigación del Recinto Universitario de Mayagüez al (787) 832-4040 ext. 6277 ó 6347 o cpshirum@uprm.edu. En caso de que el participante lo desee, una copia de este formulario de consentimiento informado será proveída para que la guarde en sus archivos.

10. ¿QUÉ PASA SI ME NIEGO A PROVEER MI CONSENTIMIENTO?

Su participación es voluntaria, por lo tanto, usted puede negarse a participar o puede retirar su consentimiento y dejar de participar en el estudio en cualquier momento y sin penalidad alguna.

11. ¿QUÉ PASA SI ME LESIONO?

Como usted es parte de la comunidad del Recinto Universitario de Mayagüez (ya sea empleado o estudiante) el seguro médico del Recinto le cubre en caso de tener algún riesgo o incomodidad.

12. DECLARACIÓN DE CONSENTIMIENTO VOLUNTARIO DEL SUJETO

Al firmar abajo, yo, el participante, confirmo que el investigador me ha explicado el propósito de la investigación, los procedimientos del estudio a los que voy a someterme y los beneficios, así como los posibles riesgos que puede experimentar. También se han discutido alternativas a mi participación en el estudio. He leído y entiendo este formulario de consentimiento.

____________________________________ ____________

Nombre en letra de molde del participante Fecha

____

Firma del participante

13. DECLARACIÓN DEL INVESTIGADO

Al firmar abajo, yo, el investigador, indico que el participante ha leído este Formulario de Consentimiento Informado y yo le he explicado a él/ella el propósito de la investigación, los procedimientos del estudio a los que él/ella va a someterse y los beneficios, así como los posibles riesgos que él/ella puede experimentar en este estudio, y que él/ella ha firmado este formulario de consentimiento informado.

____ ____________

Firma de la persona que obtiene el consentimiento informado Fecha

Appendix C: Pre-test Questionnaire

Fecha: ____________________

Número de participante: _________

LABORATORIO DE SIMULACIÓN DE CONDUCCION Y REALIDAD VIRTUAL
CUESTIONARIO ANTES DEL ESTUDIO

El siguiente cuestionario es confidencial, la información que usted provea no será utilizada para conseguir su identidad. Usted será identificado con un número dado por el investigador, de esta manera se podrá validar la información obtenida durante la simulación. Tiene el derecho de no contestar cualquiera de las preguntas en este cuestionario.

SECCIÓN 1: DATOS DEMOGRÁFICOS

1. Indicar su edad: __________ años

2. Indicar su género:

☐ Masculino	☐ Femenino	☐ Prefiero no indicar

3. ¿Tiene usted alguna de las siguientes condiciones: diabetes, epilepsia, operación de la rodilla o tobillo o prótesis?

☐ Sí	☐ No

Si su respuesta es SÍ en esta pregunta, favor de indicarlo de inmediato al investigador.

4. ¿Experimenta síntomas de mareo al manejar o al ir de pasajero en un vehículo de motor?

☐ Sí	☐ No

Si su respuesta es SÍ en esta pregunta, favor de indicarlo de inmediato al investigador.

SECCIÓN 2: HISTORIAL DE EXPOSICIÓN DE RIESGOS COMO PEATÓN

1. Aproximadamente, ¿cuántos minutos al día camina usted por una carretera?

   _______ minutos

2. ¿Cuán confiado/a se siente usted de poder cruzar de manera segura una carretera de un carril en un lugar fuera de una intersección?

☐ Muy confiado	☐ Algo confiado	☐ Depende, Ni confiado Ni desconfiado	☐ Algo desconfiado	☐ Muy desconfiado

3. ¿Cuán confiado/a se siente usted de poder cruzar de manera segura una carretera de dos carriles en un lugar fuera de una intersección?

☐ Muy confiado	☐ Algo confiado	☐ Depende, Ni confiado Ni desconfiado	☐ Algo desconfiado	☐ Muy desconfiado

4. ¿Cuáles de los siguientes factores analiza usted para decidir cruzar una carretera fuera de una intersección? Marque con una X todas las que apliquen.

   _______Velocidad del tráfico vehicular

   _______ Distancia disponible entre vehículos

   _______ Tiempo entre vehículos

   _______ Cantidad de vehículos

   _______ Ancho de la carretera

   _______ Otro: (Favor de indicar) ______________________________

5. ¿Ha estado usted involucrado en algún accidente o choque de tránsito en los últimos 5 años?

☐ Sí	☐ No

Si respondió SI a la pregunta anterior, favor de indicar su relación con dichos eventos. Marque con una X todas las que apliquen.

   _______ Como conductor de un vehículo de motor

   _______ Como pasajero de un vehículo de motor

   _______ Como peatón

   _______ Como ciclista

   _______ Como usuario de e-scooter

   _______ Otro: (Favor de indicar) ______________________________

Appendix D: Post-test Questionnaire for NO-RIAS Configuration

Fecha: ______________________

Número de participante: ________

LABORATORIO DE SIMULACIÓN DE CONDUCCION Y REALIDAD VIRTUAL
CUESTIONARIO DESPUES DEL ESTUDIO

El siguiente cuestionario es confidencial, la información que usted provea no será utilizada para conseguir su identidad. Usted será identificado con un número dado por el investigador, de esta manera se podrá validar la información obtenida durante la simulación.

Favor de contestar las siguientes preguntas usando su experiencia con la simulación de realidad virtual. Tiene el derecho de no contestar cualquiera de las preguntas en este cuestionario.

1. ¿Cuán difícil se le hizo cruzar de manera segura la carretera en la simulación, según los siguientes factores?

	Muy difícil	Algo difícil	Nada difícil	No sé
Velocidad de los vehículos	☐	☐	☐	☐
Distancia entre los vehículos	☐	☐	☐	☐
Tiempo entre los vehículos	☐	☐	☐	☐
Cantidad de vehículos	☐	☐	☐	☐
Ancho de la carretera	☐	☐	☐	☐

2. ¿Entiende que haber participado en esta simulación le ayudará a cruzar una carretera de manera segura en el futuro?

☐ Sí	☐ No	☐ No estoy seguro

Favor explicar su respuesta: ____

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3. ¿Cuán cómodo se sintió usted en la simulación de realidad virtual?

☐ Muy incómodo	☐ Algo incómodo	☐ Neutral	☐ Algo cómodo	☐ Muy cómodo

4. ¿Cuán seguro se sintió mientras utilizaba el equipo de realidad virtual?

☐ Muy inseguro	☐ Algo inseguro	☐ Neutral	☐ Algo seguro	☐ Muy seguro

5. ¿Cuán real usted percibió la simulación del ambiente virtual?

☐ Muy ficticia	☐ Algo ficticia	☐ Neutral	☐ Algo real	☐ Muy real

6. ¿Cómo cataloga usted la calidad de las siguientes características del ambiente virtual?

	Pobre	**Deficiente**	**Regular**	**Buena**	**Excelente**
Vehículos de motor	☐	☐	☐	☐	☐
Peatones	☐	☐	☐	☐	☐
Elementos físicos (árboles, edificios, etc.)	☐	☐	☐	☐	☐
Sonido	☐	☐	☐	☐	☐
Iluminación y sombras	☐	☐	☐	☐	☐

7. ¿Que mejoraría usted del escenario de realidad virtual?

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Appendix E: Post-test Questionnaire for SIMPLE RIAS Configuration

Fecha: ____________________

Número de participante: ________

LABORATORIO DE SIMULACIÓN DE CONDUCCION Y REALIDAD VIRTUAL
CUESTIONARIO DESPUES DEL ESTUDIO

El siguiente cuestionario es confidencial, la información que usted provea no será utilizada para conseguir su identidad. Usted será identificado con un número dado por el investigador, de esta manera se podrá validar la información obtenida durante la simulación.

Favor de contestar las siguientes preguntas usando su experiencia con la simulación de realidad virtual. Tiene el derecho de no contestar cualquiera de las preguntas en este cuestionario.

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1. ¿Cuán difícil se le hizo cruzar de manera segura la carretera en la simulación, según los siguientes factores?

	Muy difícil	Algo difícil	Nada difícil	No sé
Velocidad de los vehículos	☐	☐	☐	☐
Distancia entre los vehículos	☐	☐	☐	☐
Tiempo entre los vehículos	☐	☐	☐	☐
Cantidad de vehículos	☐	☐	☐	☐
Ancho de la carretera	☐	☐	☐	☐

2. ¿Cuán útil es utilizar el dispositivo (tableta) como herramienta para cruzar la carretera de manera segura?

☐ Mucho	☐ Poco	☐ Nada

3. ¿Cómo le ayudo la información provista en el dispositivo (tableta) para cruzar la carretera?

	Mucho	Poco	Nada
Carretera de un carril	☐	☐	☐
Carretera de dos carriles	☐	☐	☐

4. ¿Utilizaría usted este dispositivo (tableta) en la vida real?

☐ Sí	☐ No	☐ No estoy seguro

5. ¿Entiende que haber participado en esta simulación le ayudará a cruzar una carretera de manera segura en el futuro?

☐ Sí	☐ No	☐ No estoy seguro

Favor explicar su respuesta: ______________________________

____

6. ¿Cuán cómodo se sintió usted en la simulación de realidad virtual?

☐ Muy incómodo	☐ Algo incómodo	☐ Neutral	☐ Algo cómodo	☐ Muy cómodo

7. ¿Cuán seguro se sintió mientras utilizaba el equipo de realidad virtual?

☐ Muy inseguro	☐ Algo inseguro	☐ Neutral	☐ Algo seguro	☐ Muy seguro

8. ¿Cuán real usted percibió la simulación del ambiente virtual?

☐ Muy ficticia	☐ Algo ficticia	☐ Neutral	☐ Algo real	☐ Muy real

9. ¿Cómo cataloga usted la calidad de las siguientes características del ambiente virtual?

	Pobre	Deficiente	Regular	Buena	Excelente
Vehículos de motor	☐	☐	☐	☐	☐
Peatones	☐	☐	☐	☐	☐
Elementos físicos (árboles, edificios, etc.)	☐	☐	☐	☐	☐
Sonido	☐	☐	☐	☐	☐
Iluminación y sombras	☐	☐	☐	☐	☐

10. ¿Que mejoraría usted del escenario de realidad virtual?

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Appendix F: Post-test Questionnaire for COMPLEX RIAS Configuration

Fecha: ________________________

Número de participante: _________

LABORATORIO DE SIMULACIÓN DE CONDUCCION Y REALIDAD VIRTUAL
CUESTIONARIO DESPUES DEL ESTUDIO

El siguiente cuestionario es confidencial, la información que usted provea no será utilizada para conseguir su identidad. Usted será identificado con un número dado por el investigador, de esta manera se podrá validar la información obtenida durante la simulación.

Favor de contestar las siguientes preguntas usando su experiencia con la simulación de realidad virtual. Tiene el derecho de no contestar cualquiera de las preguntas en este cuestionario.

---

1. ¿Cuán difícil se le hizo cruzar de manera segura la carretera en la simulación, según los siguientes factores?

	Muy difícil	Algo difícil	Nada difícil	No sé
Velocidad de los vehículos	☐	☐	☐	☐
Distancia entre los vehículos	☐	☐	☐	☐
Tiempo entre los vehículos	☐	☐	☐	☐
Cantidad de vehículos	☐	☐	☐	☐
Ancho de la carretera	☐	☐	☐	☐

2. ¿Cuán útil es utilizar el dispositivo (tableta) como herramienta para cruzar la carretera de manera segura?

☐ Mucho	☐ Poco	☐ Nada

3. ¿Cómo le ayudo la información provista en el dispositivo (tableta) a cruzar la carretera de un carril?

	Mucho	**Poco**	**Nada**
Velocidad de los vehículos	☐	☐	☐
Distancia entre los vehículos	☐	☐	☐
Tiempo entre los vehículos (Gap)	☐	☐	☐
Señales peatonales	☐	☐	☐

4. ¿Cómo le ayudo la información provista a cruzar la carretera de dos carriles?

	Mucho	**Poco**	**Nada**
Velocidad de los vehículos	☐	☐	☐
Distancia entre los vehículos	☐	☐	☐
Gap (Tiempo entre los vehículos)	☐	☐	☐
Señales peatonales	☐	☐	☐

5. ¿Utilizaría usted este dispositivo (tableta) en la vida real?

☐ Sí	☐ No	☐ No estoy seguro

6. ¿Entiende que haber participado en esta simulación le ayudará a cruzar una carretera de manera segura en el futuro?

☐ Sí	☐ No	☐ No estoy seguro

Favor explicar su respuesta: ____

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7. ¿Cuán cómodo se sintió usted en la simulación de realidad virtual?

☐ Muy incómodo	☐ Algo incómodo	☐ Neutral	☐ Algo cómodo	☐ Muy cómodo

8. ¿Cuán seguro se sintió mientras utilizaba el equipo de realidad virtual?

☐ Muy inseguro	☐ Algo inseguro	☐ Neutral	☐ Algo seguro	☐ Muy seguro

9. ¿Cuán real usted percibió la simulación del ambiente virtual?

☐ Muy ficticia	☐ Algo ficticia	☐ Neutral	☐ Algo real	☐ Muy real

10. ¿Cómo cataloga usted la calidad de las siguientes características del ambiente virtual?

	Pobre	Deficiente	Regular	Buena	Excelente
Vehículos de motor	☐	☐	☐	☐	☐
Peatones	☐	☐	☐	☐	☐
Elementos físicos (árboles, edificios, etc.)	☐	☐	☐	☐	☐
Sonido	☐	☐	☐	☐	☐
Iluminación y sombras	☐	☐	☐	☐	☐

11. ¿Que mejoraría usted del escenario de realidad virtual?

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