PEDESTRIAN PERFORMANCE ON MID-BLOCK CROSSINGS USING A ROAD INFORMATION ASSISTANCE SYSTEM IN A VIRTUAL REALITY EXPERIMENT[1]

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ABSTRACT: The increase in crash-related pedestrian fatalities, primarily in urban streets, has promoted the development of technological innovations to mitigate this global problem. This article presents the results of an experiment that used virtual reality technology to study the performance of pedestrians at mid-block crossings of urban streets and the impact of a Road Information Assistance System [RIAS]. The RIAS was simulated as a handheld device that displays warning symbols or a combination of symbols and real-time information about the vehicles approaching the crosswalk to assist pedestrians in making the crossing decision. The experiment simulated a connected urban environment that can receive and transmit data from sensors in the infrastructure, vehicles, and pedestrians [via the RIAS]. The study evaluated the walking speeds, the vehicle gaps selected to cross the street, and the number of successful crossing events with no collisions. Three groups of twelve subjects [no RIAS, simple RIAS, and complex RIAS] were selected. The age and gender of the subjects, as well as the RIAS type used to cross the street, had significant effects on the average walking speed. The distributions of the average gap accepted by each of the three groups, based on the RIAS type, were statistically different. The group that used the RIAS device displaying symbols only had the worst performance and the highest average gap accepted when crossing the street.

Keywords: gap acceptance, mid-block crossings, pedestrian safety, virtual reality, walking speed

DESEMPEÑO DE LOS PEATONES EN CRUCES A MEDIA CUADRA AL USAR UN SISTEMA DE ASISTENCIA CON INFORMACIÓN VIAL EN UN EXPERIMENTO DE REALIDAD VIRTUAL

RESUMEN: El aumento en muertes de peatones, principalmente en calles urbanas, ha motivado el desarrollo de innovaciones tecnológicas para mitigar este problema global. Este artículo presenta los resultados de un experimento que usó la tecnología de realidad virtual para estudiar el desempeño de peatones en cruces a media cuadra en calles urbanas y el impacto de un Sistema de Asistencia con Información Vial [SAIV]. El SAIV se simuló como un dispositivo portátil que muestra símbolos de advertencia o una combinación de símbolos con información en tiempo real de los vehículos que se acercan al cruce para ayudar a los peatones a tomar la decisión de cruzar. El experimento simuló un entorno urbano conectado que puede recibir y transmitir datos de sensores en la infraestructura, los vehículos y los peatones [a través del SAIV]. El estudio evaluó las velocidades de caminata, las brechas entre vehículos seleccionadas para cruzar la calle y la cantidad de cruces exitosos sin colisiones. Tres grupos de doce participantes [no SAIV, SAIV sencillo y SAIV complejo] fueron seleccionados. La edad y el género de los participantes, así como el tipo de SAIV usado para cruzar, tuvieron efectos significativos en el promedio de la velocidad de caminata. Las distribuciones de la brecha promedio aceptada por cada uno de los tres grupos, según el tratamiento de SAIV, fueron estadísticamente diferentes. El grupo que usó el SAIV sencillo, mostrando solo símbolos, tuvo el peor desempeño y el promedio más alto de la brecha aceptada para cruzar la calle.

Palabras clave: aceptación de brecha, cruces a media cuadra, seguridad peatonal, realidad virtual, velocidad de caminata

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INTRODUCTION

There were 38,824 road-related fatalities in the United States [U.S.] in 2020, of which 17% were pedestrians. Pedestrian safety studies that can identify crash-related factors and mitigation strategies have become more relevant as an increase of 46% in pedestrian fatalities has occurred in the U.S. since 2011 (NCSA, 2022). The safety of vulnerable road users [VRU] is a top priority of the strategic highway safety plan in Puerto Rico, as 33.5% of the 1,491 roadway fatalities during the 2014-2018 period involved a pedestrian (PRHTA, 2021). Non-intersection locations were related to 74% of the pedestrian fatalities in Puerto Rico, indicating that one of the safety concerns is associated with pedestrians performing mid-block crossings or searching for shorter routes when walking along a roadway (NCSA, 2020). Contributory factors related to crashes at uncontrolled crossings include crossing conflicts, excessive vehicle speeds, inadequate visibility, drivers not yielding to pedestrians, and insufficient separation from traffic.

The Federal Highway Administration [FHWA] established the Safe Transportation for Every Pedestrian [STEP] initiative, as part of the Every Day Counts [EDC] program to encourage the systemic utilization of roadway enhancements to improve pedestrian safety. A STEP emphasis area is the implementation of technological advances to improve the safety of pedestrians on uncontrolled crossings. The proper development and future implementation of connected technology, such as vehicle-to-pedestrian [V2P] and pedestrian-to-infrastructure [P2I], have a high potential for improving road safety. These technologies could be used to inform and alert VRU of existing street and traffic conditions, available transportation services, and unexpected events through the transportation network. The usage of handheld electronic devices has increased exponentially, with over 420 million devices in the U.S. alone, or approximately 1.3 devices for each person (CTIA, 2019). VRUs, such as seniors, persons with limited mobility, and other non-motorized users, could benefit from real-time street and traffic-related data by receiving information and warnings in a connected handheld device that can assist them in making proper decisions on the street network. In evaluating the effectiveness of new technologies, it is vital to analyze if using these electronic devices while performing street crossing maneuvers could lead to unsafe distractions.

This article presents the results of a Virtual Reality [VR] experiment that studied the impact of a potential RIAS device on the ability of a pedestrian to perform a mid-block crossing maneuver in an urban street. The walking speed, the vehicle gap selected to cross the street, and the number of successful crossing events [no collisions] were analyzed using VR scenarios of one-lane and two-lane urban streets. The analysis evaluated the impact on the performance of pedestrians due to the presence and complexity of the information provided by the RIAS device.

LITERATURE REVIEW

Walking Speeds

The skills for crossing a street vary from person to person based on their physical and health conditions. Therefore, a unique average speed might not accurately represent the performance of all population groups and should not be applied indiscriminately for all conditions. An average walking speed of 4.0 ft/s is suggested in the MUTCD (2009) as a typical value to determine the pedestrian clearance time at a signalized intersection. However, Gates et al. (2006) suggested using that walking speed value only for locations with a low number of older pedestrians and disabled persons. Guidance for pedestrian signals suggests using a walking speed of 3.5 ft/s under ordinary circumstances and lower walking speeds to estimate the pedestrian clearance time when slower pedestrians or people on wheelchairs are expected (FHWA, 2012). A VR study by Shuchisnigdha et al. (2017) found an average walking speed of 3.51 ft/s, but 10.8% of the subjects were hit by a vehicle during the simulation. Another VR study found that females have a 4.0 ft/s average walking speed, while males have a range between 3.5 to 5 ft/s. A VR study with vehicles moving at 25 mph found a larger range of walking speeds for females between 2.5 and 8.5 ft/s (Figueroa et al., 2023).

Studies have focused on the street-crossing performance of adults over 65 years who are directly affected by their age, as their capacity for individual mobility becomes limited, and their walking speeds typically get slower than the average pedestrian. Street crossings by elderly adults are more difficult to complete, as their average walking speed is estimated as 2.8 ft/s (FHWA, 2006). Gates et al. (2006) found similarities in walking speeds between persons older than 65 years old and persons with a physical disability and children assisted by an adult. Researchers have found that pedestrians between 21 and 30 years old have faster walking speeds (Tarawneh, 2001), and the speed of approaching vehicles is a significant risk factor for elderly pedestrians (Lobjois and Cavallo, 2007; Lobjois and Cavallo 2009).

Gap Acceptance

The vehicle-pedestrian interaction at a street crossing is affected by the driver's arrival time when the pedestrian arrives at the curb (Várhelyi, 1998). Pedestrians tend to perform riskier crossing decisions and accept smaller gaps at higher vehicle speeds. The use of a rolling gap maneuver is more apparent for pedestrians when crossing more than one traffic lane simultaneously, and there is no safe gap available (Boroujerdian and Nemati, 2016). Researchers noted that the gap accepted by a pedestrian usually depends on the longitudinal distance from the vehicle to the pedestrian, the pedestrian's gender, the vehicle length, and the presence of illegally parked vehicles (Yannis, 2010). Elderly pedestrians have attenuated risk perception, prolonged waiting times and tend to accept a significantly larger gap than their younger counterparts (Hamed, 2001; Holland and Hill, 2007).

Male pedestrians tend to show a low perception of danger while crossing a street; therefore, it is generally accepted that they are more inclined to make riskier crossing decisions and be more willing to unfollow traffic laws than their female counterparts (Holland and Hill, 2007). Males tend to wait shorter amounts of time before crossing a street and exhibit faster walking speeds than females (Tarawneh, 2001; Ferenchak, 2016). Researchers have also observed that women who spoke on mobile phones crossed traffic at a slower speed and less frequently while waiting than those who did not use mobile phones. In the case of male pedestrians, those who spoke on their mobile phones crossed more slowly on non-signalized intersections (Hatfield and Murphy, 2007). A VR study by Figueroa et al. (2023) found that males selected an average gap between vehicles of 4.49 s to cross, whereas females had a higher gap acceptance of 4.80 s when confronted with vehicle speeds of 15 mph. The Figueroa et al. study also found that senior males waited a significant time to find safe gaps in traffic, with an average of 133 gaps observed with traffic generated with a constant gap of 3 s and a 25-mph speed.

Road Information Assistance Systems [RIAS]

Advanced Driver Assistance Systems [ADAS] technologies have been developed recently as an essential aid for drivers by providing warning messages, assistance, and even taking control of the vehicle under some circumstances. In the context of pedestrian crossings, ADAS can assist drivers by warning about the presence of pedestrians and helping maneuver the vehicle for the prevention of a crash (Leon and Gavrilescu, 2021). The alarms include auditory, visual, vibrotactile, and haptic warnings that provide the driver with audible and visual stimuli. Road Information Assistance Systems [RIAS] is a term that can be used for technological assistance devices that are not focused exclusively on drivers.

Current ADAS warns the driver, but the collision cannot be avoided in some situations because most systems react only when the pedestrian is in front of the vehicle. Pedestrians have a higher dynamic range than vehicles, making it challenging to detect and predict a trajectory. A pedestrian follows a particular path, crosses a road, walks along the pavement, or turns at an intersection. Trajectory and tracking prediction methods define a pedestrian's position at any point in time (Leon and Gavrilescu, 2021). A significant research topic is devising ways to improve the effects of advanced assistance devices and technologies on the safety of pedestrians when crossing a street. On the other hand, mobile devices could impair pedestrians' and drivers' attention, contributing as a factor to vehicle-pedestrian crashes (Schwebel et al., 2012). Pedestrians exhibit more dangerous behavior when using an electronic device on the street (Byington and Schwebel, 2013). Rahimian et al. (2018) found that pedestrians using mobile phones crossed a street more slowly; consequently, being more exposed to traffic.

Virtual Reality Simulation

VR simulation can provide the user with a role-playing circumstance with almost total sensory immersion in controlled surroundings. The system features include immersion and enable the user to experience activities from an internal perspective (Kearney et al., 2007). Simulation technologies have become a valuable tool for conducting transportation safety research to study human factors and observe the behavior and performance of road users, evaluate roadway safety issues, and assess the effects of new road design strategies or new traffic control devices. VR allows the reproduction of standardized scenarios and the management of the parameters under investigation (de Winter et al., 2017). The user observes the simulated 3-dimensional environment with lightweight head-mounted glasses with a screen, and the technology provides the alternative of adding hand controls for a more reliable experience. The fidelity of VR devices refers to the precision with which accurate sensory cues are reproduced (Kearney et al., 2007). The first senses activated during a simulation run using VR are sight and hearing, allowing the user to encounter roadway situations that, in real life, could be dangerous or even fatal.

METHOD AND EXPERIMENTAL DESIGN

This study used a VR simulation of an urban street to evaluate the gap acceptance decision and the walking speed selected by pedestrians when performing a mid-block crossing maneuver. The basic scene consisted of a straight street segment with one or two lanes in an urban downtown context. The width of the traffic lanes was set at 10 feet, and 6-feet wide sidewalks were located on each side of the street, as shown in Figure 1. Traffic was programmed in the simulation to travel in one direction, from left to right of the display. Vehicles were generated at constant speeds of either 15 mph (low speed) or 25 mph (high speed). The gap between the vehicles in the simulation varied randomly, using a range from 3 to 8 seconds, indistinctly from the lane. The subject started the simulation located on one sidewalk and was instructed to analyze the traffic in the street [after the first vehicle passed the crosswalk] to decide when there was a safe gap to cross the street and reach the sidewalk on the far side. The subjects were instructed that traffic in the simulation would not react to their presence when crossing.

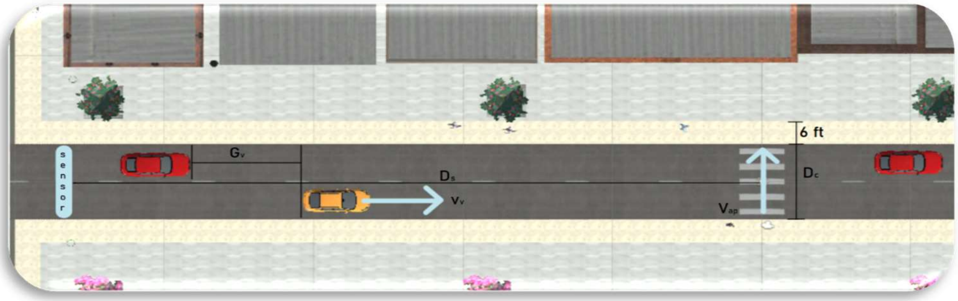


Figure 1: Two-lane urban roadway crossing setting.

The scenario included a billboard display visible to the pedestrian on the street’s far side indicating the number of completed simulation runs the subject had completed. The billboard also showed instant information to the pedestrian if he/she was hit by a vehicle when performing the crossing maneuver. The billboard showed in Spanish the message in blinking red letters “*FUE ATROPELLADO*” [YOU WERE HIT]. This information provided direct feedback to the subject that the crossing maneuver was unsuccessful and that the decision to cross, the gap accepted, the walking speed selected, or a combination of these factors were not safe for the existing conditions.

Thirty-six subjects were recruited for the study, equally divided into men and women and into three age categories 18-25, 26-45, or 46-70 years old. Table 1 shows the combinations of VR scenarios created for the experiment. Every subject completed twelve crossing maneuvers, six for each street size. The experiment collected 418 street crossing maneuvers. Three crossing maneuvers were removed from the database due to recorded gaps higher than the specified value in the experiment design.

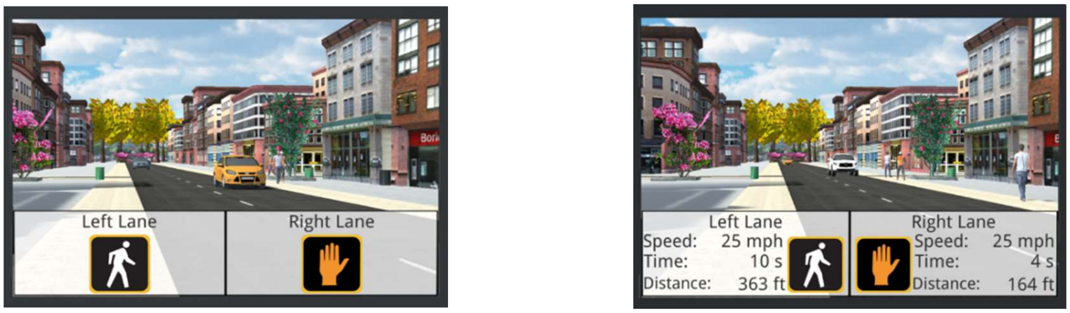
Table 1: VR simulation scenarios.

Configuration	Scenario	Vehicle speed (mph)	Number of lanes
A: No RIAS B: Simple RIAS C: Complex RIAS	1	15	One
	2	25	One
	3	15	Two
	4	25	Two

Description of RIAS devices

The VR experiment studied the effect on the crossing performance of subjects when using the RIAS device to cross the street. The simulated RIAS provided real-time information about the closest vehicles approaching the mid-block crossing. Twelve subjects were assigned to each one of the three configurations in the experiment. Group A included subjects that crossed the street without the assistance of the RIAS. Group B had subjects crossing the street using the simple RIAS, and Group C included subjects crossing with the assistance of the complex RIAS. Figure 2 shows the device displays created for the simple RIAS and the complex RIAS for the two-lane scenarios. The RIAS display for the two-lane street showed information for each lane. The RIAS display for the one-lane street showed one set of information. The subjects were informed about the meaning of the symbols and messages shown in the RIAS prior to the experiment.

The simple RIAS showed the crossing assistance information in the form of the WALK and DO NOT WALK symbols that are used for pedestrian signal indications at intersections, as specified in the MUTCD. The "walking person" symbol meant that the conditions were safe to cross the road. The "upright hand" symbol meant that the conditions were not safe to cross the road. For the complex RIAS, the WALK and DO NOT WALK symbols were accompanied by real-time information about the speed, the time, and the distance for the nearest vehicles to the crosswalk. The hypothesis for the complex RIAS was that by showing more information, the subject would require more time to process and recognize the level of risk imposed by the traffic conditions. Two potential issues could also arise with the RIAS; to become a distraction affecting the ability to safely cross the street, or that subjects would not understand the information provided by the device and would not be comfortable using it.



a) Simple RIAS configuration

b) Complex RIAS configuration

Figure 2: Simulated displays of RIAS device used for the two-lane street.

The symbols and the information were programmed to change in the RIAS display in real time based on the proximity of the vehicles to the crossing and the average walking speed that was calibrated for each subject. The calibration was performed at the beginning of the experiment to calculate the average walking speed of each subject. The subject crossed the street four times with no traffic present to get the estimate. A virtual sensor for the RIAS device was then located on the scenarios with active traffic using the subject's average walking speed obtained from the calibration. When a vehicle passed over the road sensor in the simulation, the pedestrian symbols would change from the WALK to the DO NOT WALK message, meaning that the proximity and speed of the vehicle were not safe for the subject to complete the crossing at the average "normal" walking speed without getting hit by the vehicle. In this way, the RIAS device was customized for each subject in the simulation.

PEDESTRIAN PERFORMANCE RESULTS

This section discusses the results for the walking speeds selected by the subjects during the calibration process and the simulation experiment. Also, the results of the gaps selected by the subjects to cross the street and the crossing success rate are discussed with their implications.

Calibration of Sensor Location

The data obtained to calculate the location of the RIAS sensor from the calibration stage were analyzed to observe the performance of pedestrians without the presence of vehicles on the road. Figure 3 shows the distributions of the walking speed for the calibration scenarios for the one-lane and two-lane streets. A Shapiro-Wilk test without group discrimination showed that the average pedestrian speeds did not follow a normal distribution at a 95% confidence level. The non-parametric Kruskal-Wallis test was then used to confirm that the two speed distributions are statistically similar, with a p-value of 0.969. The average walking speed for the one-lane street was 3.35 ft/s with a standard deviation of 0.50 ft/s, while the average speed was 3.36 ft/s for the two-lane street with a standard deviation of 0.56 ft/s.

Crossing Success Rates

A total of 415 crossing maneuvers were collected from the experiment, with only seven crossing maneuvers [1.7%] resulting in a crash with a motor vehicle. The crossing maneuvers resulting in a crash were considered only to calculate the crossing success rates. The analysis of the gap accepted [or selected] and the walking speed used by the subjects to cross only considered the maneuvers that were successful without getting hit by a vehicle.

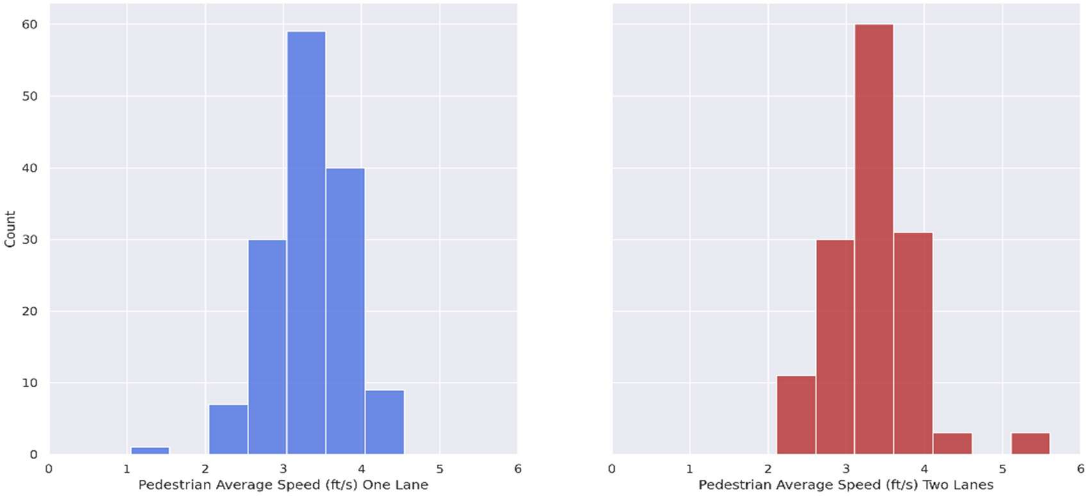


Figure 3: Distribution of the average walking speed per number of lanes.

The crossing success rate was computed for each subject in the experiment to find any pattern of hits by a vehicle when crossing the roadway for the subject groups. Table 2 shows the crossing success rates based on the RIAS configuration, in combination with the respective average walking speed and average gap accepted. Subjects with the Simple RIAS had the lowest crossing success rate of 95.8% in the experiment. The subjects that crossed the street without the assistance of the RIAS resulted in an almost perfect crossing success rate of 99.3%. These results might show that users had difficulty using or understanding the RIAS device when crossing the road.

Table 2: Walking speed, gap accepted and crossing success rate by RIAS configuration.

Device	Average Walking Speed (ft/s)	Average Gap Accepted (s)	Crossing Success Rate
No RIAS	4.192	6.593	0.993
Simple RIAS	4.124	6.784	0.958
Complex RIAS	4.140	6.397	0.986

Gap Accepted to Cross

Figure 4 shows the distribution of the gap accepted to cross for each RIAS configuration. The highest average gap accepted was observed for the subjects using the Simple RIAS. This average gap value was almost 0.4 seconds larger than the minimum average gap accepted for the subject group that used the Complex RIAS to cross the road. Interestingly, the group with no RIAS resulted in an average gap value higher than for the Complex RIAS group, showing that the information obtained from the Complex RIAS supplied some advantage. A Kruskal-Wallis test confirmed that the distributions were not statistically the same, with a p-value of 0.014.

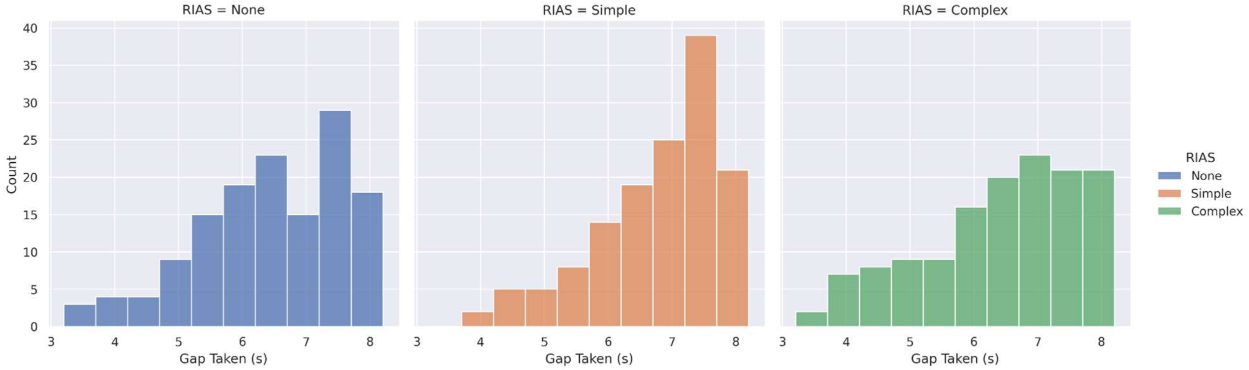


Figure 4: Distribution of the gap accepted by RIAS configuration.

Walking Speeds

Figure 5 shows the average walking speeds for the calibration phase and the experimental phase. The goal was to verify if the walking speeds selected by subjects without and with the presence of traffic in the simulation were similar. A non-parametric Kruskal-Wallis test confirmed the two speed distributions are statistically different. The sample in the calibration phase had an average speed of 3.36 ft/s, while the average speed in the experimental phase was significantly higher at 4.16 ft/s, for a percent difference of 21.3%. The standard deviation of the speed in the experimental phase was also higher than in the calibration phase, with a difference of 43.4%. The higher average speeds and standard deviation values in the experimental phase are inferred to be related to the presence of vehicles and the increased stress imposed on the subjects to perform a safe crossing without getting hit by a vehicle.

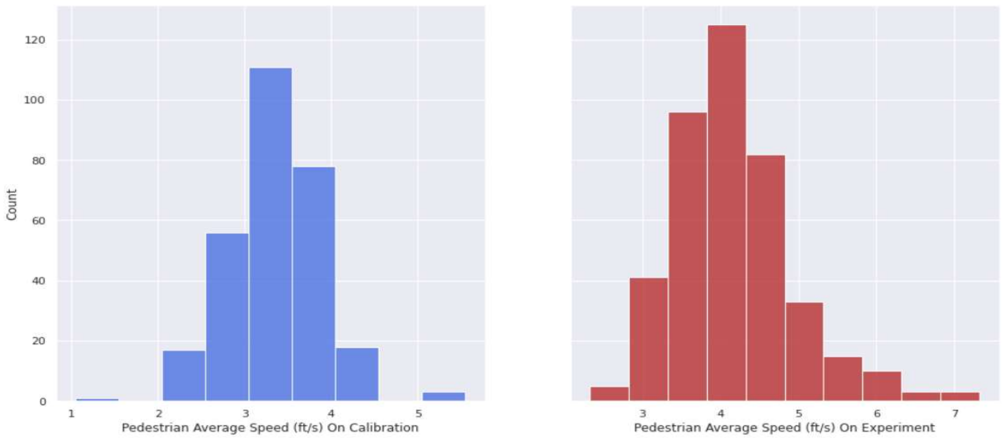


Figure 5: Distributions of walking speeds for the calibration and experimental phases.

The distributions for the average walking speed were analyzed to identify differences based on the number of lanes [1-lane vs. 2-lanes] or the vehicle speeds [15 vs. 25 mph]. A Kruskal-Wallis test showed there was no significant difference between the two speed distributions based on the number of lanes with a p-value of 0.401. The average walking speed for crossing the one-lane street was 4.13 ft/s, while the average speed for the two-lane street was 4.18 ft/s. The standard deviations were 0.76 and 0.75 ft/s for the one-lane street and the two-lane street, respectively. Similarly, a Kruskal-Wallis test showed there was no significant difference between the two distributions based on the two vehicle speeds.

Figure 6 shows the distribution of the average walking speeds by RIAS configuration. As noted in Table 2, the difference in walking speeds based on the RIAS configuration is minimal. A major speed difference of 1.6% was observed between the no RIAS and the Simple RIAS configurations. As expected, a Kruskal-Wallis test confirmed that the speed distributions were statistically similar, with a p-value of 0.05. It can then be inferred that the use of the RIAS itself did not influence the walking speeds selected by the subjects.

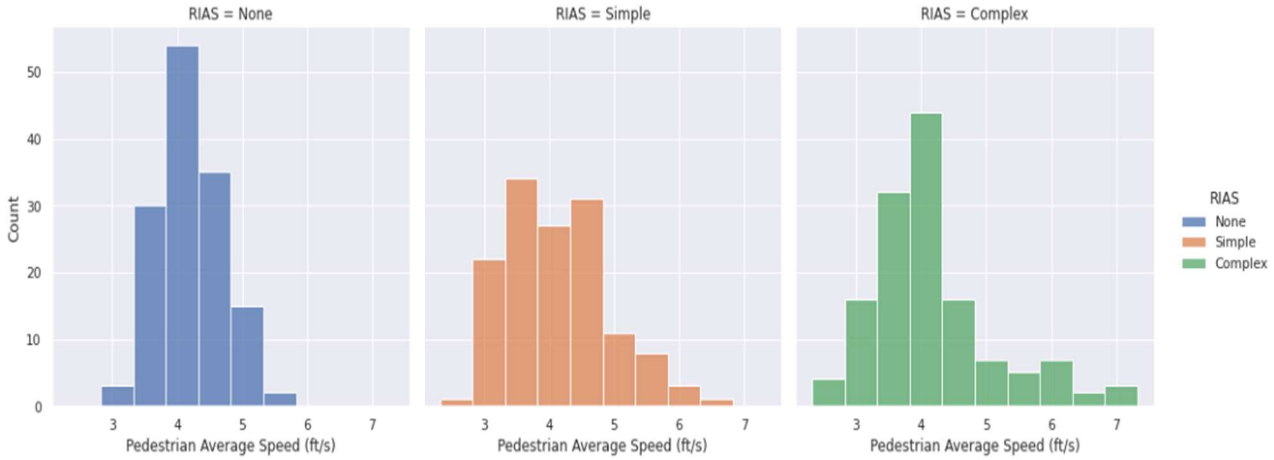


Figure 6: Comparison between walking speeds based on the RIAS configuration.

Table 3 shows the results from a Kruskal-Wallis test, a non-parametric approach to the one-way ANOVA, used to identify the effects in the walking speed of the independent factors, age, and gender, the number of lanes, vehicle speeds, and the RIAS configuration. The AGE variable had three levels, taking a value of zero for the 18-25-year-old group, one for the 26-45-year- old group, and two for the 46-70-year-old group. The GENDER was defined as a binary variable taking a value of zero for females, and one, otherwise. The RIAS variable was defined with three levels, taking a value of zero for the NO RIAS condition, a value of one for the SIMPLE RIAS, and a value of 2 for the COMPLEX RIAS. The LANES variable took a value of zero for the one-lane street and a value of one for the two-lane street. The VEHICLE SPEED variable was assigned a value of zero for the 15-mph speed and a value of one for the 25-mph speed.

Table 3: Kruskal-Wallis test results on the average walking speed.

Parameter	DF	h-value	p-value
AGE	2	5.77	0.056*
GENDER	1	4.09	0.043*
RIAS	2	5.91	0.052*
LANES	1	0.56	0.455
VEHICLE SPEED	1	0.04	0.837

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

The h-value statistic for the Kruskal-Wallis test is used to calculate the p-value of the parameter. A level of significance of 0.10 was selected as the threshold value to indicate that there is a statistically significant difference between the median values of the walking speed. The results show that the AGE, GENDER, and RIAS have a significant effect on the average walking speed. The LANES and VEHICLE SPEED variables were found not to influence the median values of the walking speed.

A walking speed regression model was calibrated to identify factors that could explain the variability observed in the experiment. A logarithmic transformation of the response variable was made to stabilize the normality and variance of the residuals of the model. Table 4 shows the results of three OLS regression models with the coefficients of the model parameters and the p-values in parentheses.

Table 4: OLS model coefficients with the logarithmic transformation of the walking speed.

Parameters	Levels	Base Model	Full Model w/o Interaction	Model only AGE-RIAS	Full Model - All Interactions
Constant	-	**0.603** (0.000)	**0.611** (0.000)	**0.635** (0.000)	**0.628** (0.000)
AGE	1	**0.025** (0.005)	**0.024** (0.006)	0.010 (0.479)	0.010 (0.540)
	2	**0.027** (0.003)	**0.027** (0.003)	**-0.031** (0.039)	-0.008 (0.612)
GENDER	1	**-0.019** (0.006)	**-0.019** (0.007)	**-0.019** (0.004)	-0.003 (0.795)
RIAS	1		-0.0126 (0.231)	-0.020 (0.181)	-0.021 (0.154)
	2	--	-0.011 (0.237)	**-0.071** (0.000)	**-0.072** (0.000)
AGE-RIAS	1-1	--	--	**-0.040** (0.049)	**-0.038** (0.058)
	1-2	--	--	**0.081** (0.000)	**0.083** (0.000)
	2-1	--	--	**0.068** (0.001)	**0.068** (0.001)
	2-2	--	--	**0.102** (0.000)	**0.103** (0.000)
AGE-GENDER	1-1	--	--	--	-0.003 (0.832)
	2-1	--	--	--	**-0.046** (0.006)
R^2		*4.15%*	*4.58%*	*16.99%*	*18.86%*
Adjusted R^2		*3.46%*	*3.44%*	*15.18%*	*16.69%*
Lack-of-Fit		*0.016*	*0.000*	*0.303*	*0.534*

Note: p-values are shown in parenthesis. Bold values show significant parameters.

The first model was calibrated by adding one explanatory variable at a time. The best specification of the OLS regression model [BASE model] found only the AGE and GENDER variables to be statistically significant. The BASE model indicates that older subjects and females have higher walking speeds than their counterparts in the experiment. A subsequent calibration of the OLS regression [FULL model] included the RIAS variable, but this resulted to be non-significant. Both models, without considering interactions between variables, only explain 4.6% of the variability in the response variable.

When adding the effects of interactions between explanatory variables in the regression model, it was found that the interaction of the RIAS variable with the AGE and GENDER variables is significant, which indicates that the levels of RIAS could be significant in the model if the interactions with these variables are considered. Therefore, a model AGE-RIAS was calibrated with the variables AGE, GENDER, RIAS, and the interaction between RIAS and AGE. This regression model resulted in better goodness-of-fit and adjusted R^2 values with the significance of all variables and meeting the assumptions of normality and constant variance in the residuals of the model.

A "*full*" 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 16.7%, which was an improvement over the model without interactions and the model that only considers the AGE-RIAS iterations. The results indicate the interaction between the COMPLEX RIAS treatment and the older age group provides the greatest absolute positive impact on the average walking speed. The age group over 45 years old using the COMPLEX RIAS increased their speed up to 1.26 ft/s more than their counterparts.

Perceptions regarding the RIAS Device and the VR Simulation

Subjects were asked after ending the experiment about their perceptions of the difficulty of factors in the street crossing simulation, the use of the RIAS device, and their level of comfort when immersed in the VR environment. When asked about the factors in the simulation generating difficulty in cross the street, 55% of subjects identified the gap [or distance] between the vehicles, and 39% of subjects identified the vehicle speeds. On the contrary, the road width [83%] and the number of vehicles [77%] were the factors that most participants identified to have provided them with lesser difficulty in crossing the simulated street. When analyzing the responses based on the RIAS used, the vehicle speed and the gap between vehicles showed the highest increase in the number of subjects that perceived less difficulty when using the RIAS to cross the street. The COMPLEX RIAS, which shows in real-time the speed, distance, and time from the closest vehicles to the crosswalk, appeared to enhance the comprehension of subjects of these two factors in their decision to cross the street.

Subjects that used the RIAS were asked about their perception of the usefulness of the device and their willingness to use such a device in the future if available. These questions aimed to establish a point of view on the use of a RIAS device in a future connected environment, even though participants were not trained about smart cities in the experiment. The Complex RIAS was perceived to be very useful by 83% of the participants, compared to 67% of participants from the Simple RIAS group. Similarly, more participants [58%] that used the Complex RIAS stated to be willing to use the device in real life, compared to just 25% in the Simple RIAS group. Participants were also asked about the usefulness of the four elements of the information displayed in the Complex RIAS. The time for the vehicle to reach the crosswalk was selected by all participants as very helpful information for crossing the street. The speed of the vehicles had the second highest preference by the subjects, 92% on the one-lane street and 100% on the two-lane street. The pedestrian symbols, the only assistive information displayed in the Simple RIAS, had the lowest preference by the subjects.

The level of comfort with the VR simulation was also inquired. Overall, 72% of the subjects stated they felt comfortable in the VR simulation. More subjects [83%] felt comfortable in the VR simulation when analyzing only the No-RIAS group. The Simple RIAS group had both the lowest percentage [58%] of subjects with a "*comfortable*" opinion and the highest percentage [25%] with an "*uncomfortable*" opinion. This perception could be linked to a misunderstanding of the meaning of the pedestrian symbols used in the SIMPLE RIAS or even about the general use of the device. The use of the Complex RIAS had a much higher percentage of subjects [75%] with a "*comfortable*" opinion than the Simple RIAS. This result implies that the Complex RIAS, even though it had more information to process than just the two symbols in the Simple RIAS, the subjects felt more comfortable using that device.

CONCLUSIONS

This article discussed the results from a VR simulation experiment that evaluated the use of a RIAS device in helping pedestrians make a crossing maneuver in an urban street. The design of the experiment included the effects on the crossing performance of pedestrians from traffic generated at either 15-mph or 25-mph speeds with random gaps between 3 s and 8 s, on a one-lane or two-lane street, and the use of a RIAS device displaying only symbols or adding real-time information. The main conclusions from this VR experiment are:

- The presence of active traffic in the simulated street increased the walking speed used by the participants due to the increased pressure to cross the street successfully when facing the traffic.
- The people that used the RIAS device displaying only the pedestrian symbols had the worst crossing performance in the study. Those people also selected the highest average gap to cross the street.
- The use of the two RIAS devices affected the average gap accepted and the walking speed used by the people to cross the street.
- The age and gender and the level of RIAS have a significant effect on the average walking speed of the participants. Males selected slower walking speeds when crossing the street than females.
- The implication of age on the average walking speed varies with the presence of interactions with other explanatory variables. The middle-age group exhibited higher walking speeds than their younger counterparts. When the interaction between age and RIAS is present, the oldest age group exhibited lower speeds than their younger counterparts, although the interaction effect for this group with the complex RIAS has the highest positive impact on walking speeds.
- The complex RIAS device [with real-time information] resulted in a better crossing performance than the simple RIAS device. The perception of the subjects in favor of the complex RIAS is clear, even though this device was assumed at first to require more concentration on the part of the person to analyze the information and to use it properly.
- The pedestrian symbols most likely do not supply enough relevant information to the pedestrians about the traffic conditions, there was no understanding of the meaning of the symbols outside of a signalized intersection, or simply the participants did not understand the explanation about the change in the pedestrian symbols really meant in the RIAS device.

RECOMMENDATIONS FOR FUTURE RESEARCH

The results from this VR simulation experiment could be useful to assist the community of transportation professionals in formulating new policies for crossing safety. VR technology can be used to identify potential safety treatments for pedestrians in urban settings and strategies targeted to different age groups and gender.

The promise of future RIAS devices, such as those simulated in this study, requires further study that assesses the understanding of users of the meaning of the information provided and a validation study to identify the best human interface. Future research could also consider the effect on walking speeds and crossing performance at road geometry configurations of higher complexity, such as curved alignment, intersections, and roundabouts.

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