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Acoustic Situation Awareness and its Effects on Pedestrian Safety within a Virtual Environment

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ACOUSTIC SITUATION AWARENESS AND ITS EFFECTS ON PEDESTRIAN SAFETY WITHIN A VIRTUAL ENVIRONMENT

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16. Abstract

To evaluate the dangers of personal listening devices (PLD) and behavior while navigating crosswalks, 1274 pedestrians were naturalistically observed followed by a survey of 135 pedestrians, and two focus groups. Thereafter, an immersive 1:1 street crossing virtual reality (VR) testbed – based campus crossing environments – was used to investigate the effect of PLD distraction on crossing performance and auditory situation awareness. Pedestrians traversed a simulated crosswalk while listening to music through air (AC) and bone (BC) conduction PLDs while detecting and localizing a bi-directional ambulance alert signal. Results show that: (1) societal distractions such as crossing in groups or talking within a group while crossing led to riskier behavior compared to technological distractors; (2) there is a consensus on hand gestures for pedestrian-driver communication; (3) the presence of a bus near the crosswalk and its idling engine significantly increased the time to cross and detect the alert signal; and (4) BC-PLDs playing non-lyrical music led to faster detection while listening to music at a low volume led to faster street crossings and faster detection. In conclusion, findings can serve as guidelines to develop external human-machine interfaces (eHMIs) for automated vehicles and appropriate countermeasures for reducing pedestrian distractions at campus crosswalks.

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TABLE OF CONTENTS

EXECUTIVE SUMMARY

Vulnerable road user (VRU) safety is of the utmost importance, especially on college campuses, and personal listening devices (PLDs), most prevalent among college-attending populations, are possibly impacting that safety. Technology can be distracting, especially when users are performing certain tasks, such as street crossings. These scenarios are commonplace on campuses of rural higher education institutions, where students use multiple unsignalized crosswalks to get to their on- or off-campus destinations.

To evaluate the dangers of PLD use and pedestrian behavior while navigating crosswalks, 1274 pedestrians were naturalistically observed over nine hours at four crosswalks. Naturalistic observations were followed by a survey of 135 pedestrians. Then, two focus group discussions with a total of eight participants, overall, led to the development of a unique three-stage information-gathering protocol. After that, an immersive 1:1 street crossing virtual reality (VR) simulator, which served as a testbed was developed based on the observed campus crossing environments, to investigate the effect of PLD distraction on crossing performance and auditory situation awareness. The VR-based pedestrian simulator tasked participants with crossing a digital twin campus street while listening to music (different songs at varying levels) through air (AC) and bone (BC) conduction PLDs. As a secondary task, participants were tasked with detecting and localizing (i.e., bi-directionally) an audible ambulance siren during crossings. Both naturalistic observations and controlled laboratory studies were approved and conducted on a university campus in southwest Virginia.

The main findings were that the naturalistic observation determined that societal distractions such as crossing in group settings or talking with other members of a group while crossing led to riskier pedestrian behavior compared to technological distractors such as PLDs or cellphone usage. In addition, there was also a consensus on hand gesture meanings for pedestrian-driver communication despite the presence of a diverse population of road users. From the VR study, simulated distracted street crossing investigations determined that the presence of a bus near the crosswalk and the noise from its idling engine significantly increased the time to cross the street, as well as the time to detect the ambulance siren. Also, acoustic music, when played through BC PLDs, led to faster detection times. Furthermore, listening to music at a low volume led to faster street crossings and faster detection of the ambulance siren, ultimately, better acoustic situation awareness.

In sum, findings can serve as guidelines to develop external human-machine interfaces (eHMIs) for automated vehicles, as well as appropriate countermeasures to reduce pedestrian distractions at campus crosswalks. It is recommended that overarching efforts be made to ensure a shared mental model of the crossing environment between drivers, pedestrians, and eventually fully automated vehicles. Also, automated vehicle eHMIs should consider social factors and common VRU hand gestures.

The immersive crosswalk experimental testing environment was presented, discussed, and reported as an extended abstract at the 26th International Conference on Auditory Display; while a peer-reviewed journal article was published in Transportation Part F: Psychology and

Behaviour titled “Technological and Social Distractions at Unsignalized and Signalized Campus Crosswalks: A Multi-Stage Naturalistic Observation Study.”

DESCRIPTION OF PROBLEM

The U.S. Department of Transportation’s (DOT) mission is to ensure our Nation has the world’s safest, most efficient, and modern transportation system [1]. A significant component is focused on pedestrian populations and how to enable safe and efficient mobility for vulnerable road users (VRUs). However, the National Highway Traffic Safety Administration reported 68,000 pedestrian injuries in 2004 [2]. More recently, on average, one pedestrian was killed every 88 minutes in a traffic crash accounting for 16% of all traffic fatalities in 2017 [3].

As Personal Listening Devices (PLDs) become more prevalent in society, pedestrians have begun engaging in distracting entertainment-based activities (i.e., cellphone conversations, texting, listening to music, etc.) while performing other cognitively demanding tasks such as driving and crossing signalized and unsignalized crosswalks. In the mid-1980s, mobile device usage represented about 1% of the U.S. population but rapidly grew to about 14.5% or 38 million users by 1996 [4]. By 2010, it was reported that the estimated number of pedestrian injuries involving mobile devices was about 1,506 [5]. At this point, pedestrians using PLDs are road hazards due to a reduction in situation awareness. Furthermore, mobile phone usage (as represented by wireless data traffic) was reported to have an annual traffic growth of 40x from 2010 to 2017 equating to about 150 million people simultaneously using a mobile device to stream some form of content [6].

Due to the oversaturation of content and a fear of missing out (FOMO), today’s youth often perform cognitively demanding activities like texting, video chatting, streaming, and listening to music while crossing the street. Using PLDs – air conduction (AC) or bone conduction (BC) – while crossing a busy intersection creates a dangerous predicament for users and other nearby parties due to distraction. VRUs sacrifice precious seconds of mental concentration for entertainment when engaging in distracting behaviors during street crossings. Evidence shows that 30% of VRUs involved in crashes at intersections did not see the conflict car due to visual obstruction, and 70% misunderstood the traffic situation despite seeing the conflict car [7] – time is of the essence. Therefore, the effect such distractions have on VRUs’ ability to maintain awareness of their surroundings is critical to safety.

The ability to perceive the immediate environment directly translates to how safe and efficient one can be. The concept of situation awareness (SA) — a person’s mental model of the world around them — was first introduced in 1987 as the (1) perception of the elements in the environment within a volume of time and space, (2) the comprehension of their meaning, and (3) the projection of their status in the near future [8, 9]. Most importantly, SA is considered central to effective and safe decision-making. Therefore, since SA involves perceiving the critical environmental factors, understanding what they mean, and how they might affect what will happen in the near future, maintaining SA is paramount for the overall safety of VRUs. In cases of dynamic task performance such as the stated problem of unsignalized street crossings while distracted (i.e., visual or auditory obstruction), a high level of SA is imperative for the successful and safe completion of the task. With this in mind, the reported research sought to investigate the effects of acoustic situation awareness and personal listening devices on pedestrian safety.

APPROACH AND METHODOLOGY

To study VRUs' street crossing behavior and the effect of distraction in a safe and controlled manner, this research followed a two-phased process consisting of (**I**) a three-stage naturalistic observation study [10] and (**II**) an auditory situation awareness investigation within a controlled environment [11]. The overall research objectives were:

1. To understand pedestrian-vehicle habits at university campus crosswalks.
2. To develop a high-fidelity virtual testbed environment, representative of the campus, in which a user (i.e., pedestrian) can engage in simulated street crossing scenarios.
3. To investigate the effect of personal listening device usage on situation awareness and street crossings.

Phase I: Multi-Stage Naturalistic Observation Study

To observe the dangers of PLD use and pedestrian behavior while navigating crosswalks, pedestrians were systematically observed in a naturalistic manner for a total of nine hours at four crosswalks. Naturalistic observations were followed by a survey of pedestrians and two focus groups with a total of eight participants following a unique three-stage protocol. The three-stage study included video-recorded naturalistic observations in the first stage, a survey distributed to observed and unobserved pedestrians in the second stage; and focus groups with members of the observed and unobserved population in the third stage. The study sought to address the following research questions:

- RQ1 – What is the prevalence and impact of technological (i.e., PLDs) and societal distractions on pedestrians' behavior?
- RQ2 – Is there a shared understanding of the hand gestures used by members of a culturally diverse population?
- RQ3 – What are the communication preferences for pedestrians and drivers at unsignalized crosswalks to make crossing and yielding decisions, respectively?

To understand pedestrian-vehicle habits on a university campus (Objective 1), pedestrians' crossing behaviors were observed at multiple locations on the campus of an institute of higher education located in rural southwest Virginia during the busiest hours of the weekday. Naturalistic observations were made using video recordings, and reviewed by three video coders, in detail, later. The second stage, a survey, was distributed to observed pedestrians after they were observed completing a crossing. The survey included questions regarding their use of listening devices, crossing behavior, and communications with a vehicle driver. The survey was also shared with other pedestrians on the campus who had not been observed directly to increase the number and variability of responses received. Lastly, participants from the survey respondents' list were invited to participate in a focus group to understand street crossing behaviors further and identify key factors pedestrians utilize to make crossing decisions. The study protocol (as seen in Figure 1) was approved by the Institutional Review Board (IRB#20-658).

Naturalistic observations captured through nine hours of video recordings were collected from four unique signalized and unsignalized crosswalks on and near campus. Locations and hours of observation (typically around lunchtime) were selected based on the undergraduate academic schedule to capture the highest amount of foot and vehicle traffic. Pedestrians observed represented a variety of student, faculty, and staff populations traversing between classroom buildings, dining halls, and parking lots. All observation sessions were conducted in weather characterized by clear skies, mild wind, an average temperature of 50º F (10ºC), and between February and March. The time and day of observations and visuals of the crosswalk environment can be seen in Figure 1, while the justifications for the selection of the four crosswalk locations are as follows:

- Location A: Exit of a roundabout (25-mph speed limit)
- Location B: Between classroom and dormitories (25-mph speed limit)
- Location C: In front of a bus stop (25-mph speed limit)
- Location D: Signalized crosswalk connecting campus and town (35-mph speed limit)

Crosswalk locations and duration of observations.

Location	Day	Hours
Location A	Tuesday	1100 – 1400
Location B	Thursday	1100 – 1300
Location C	Wednesday	1200 – 1400
Location D	Tuesday	1100 – 1300

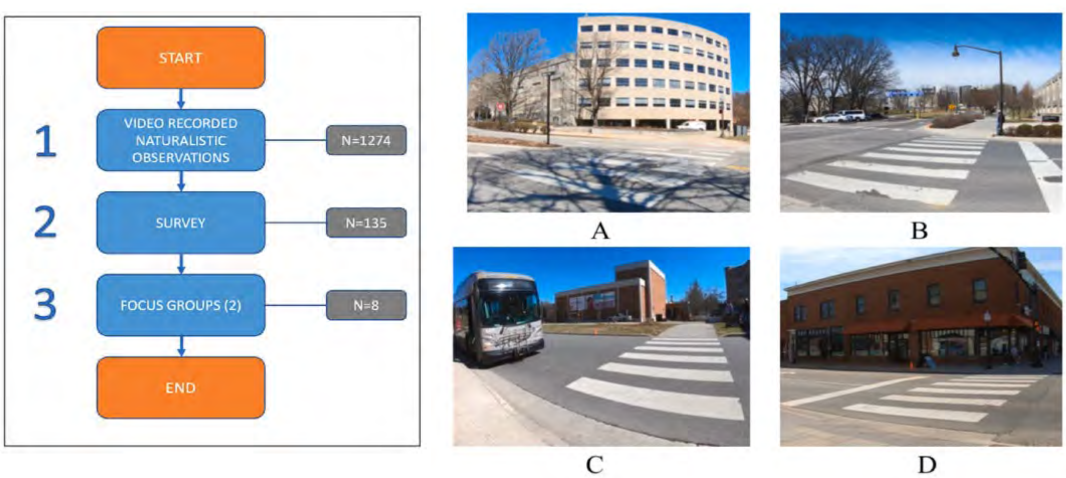

Figure 1. Naturalistic campus crosswalk protocol and location details [10].

At all locations, a GoPro Hero 7 was positioned on a tripod for continuous recordings during the observation period. Videos were recorded in 1080p resolution at 30 frames per second and stored on a micro-SD card. During each observation, up to three researchers were present to monitor equipment, and take notes of crossing behaviors and gestures. All researchers used wristwatches to keep track of the experimental time which were synced before recordings. Two researchers (one on each end of the crosswalk) would hand out flyers to pedestrians which contained a QR code to administer a survey. This interaction was performed only after pedestrians had completed a crossing so that there was no interference or interaction before or during crossings.

Data collection techniques were justified based on a previous naturalistic driving study performed by the Strategic Highway Research Program (SHRP2) [12], and the use of data reductionists for coding video data into predetermined categories of interest [13 – 17]. A list of interested interactions guided coders in establishing a baseline definition for the observations and generating respective data for each observed site based on crossing characteristics associated with behavior and auditory distractor usage. For each description, coders entered "0" for 'No', and "1" for 'Yes.' This procedure adheres to protocols described in existing literature [18, 19].

Survey prioritization was given to pedestrians observed using a PLD, but only approached once their crossing was complete. They were handed a flyer with a scannable QR code to access the survey. In addition, the survey was distributed university-wide through email communication solicitation. Responses were accepted for up to three weeks from the date all flyers had been distributed at all four observation sites. Compensation was in the form of $10 Amazon gift cards randomly awarded to ten survey participants. The survey was created and administered using Qualtrics.

Lastly, two focus groups were conducted as part of the third and final layer of the current study. The purpose was to hear directly from pedestrians about their crossing behaviors, intentions, and reasons behind their decisions when making street crossings on campus. All participants were recruited from the campus student population using email communications consisting of students who were directly observed during the first stage of naturalistic observations or those who were not observed but responded to the solicitation.

Focus groups were semi-structured and contained questions relevant to the observed crosswalks on campus. Questions were posed from both the pedestrian and driver perspectives. For transcribing purposes, focus groups were held virtually through Zoom, and recorded. Participants were asked to keep their cameras on during the engagement but were not required to do so. As a precaution, one researcher posed the questions while another transcribed the conversation to the best of their ability, capturing all key points mentioned by the participants. Upon completion, all participants were thanked for their time, and compensated with $10 Amazon gift cards.

Phase II: Auditory Situation Awareness in Virtual Reality.

To better understand the dangers of PLD use while navigating crosswalks, participants engaged in simulated street crossings in a 1:1 multimodal immersive pedestrian crosswalk testbed — developed as a digital twin of a campus street — to investigate the effects of auditory distraction on auditory situation awareness and safe crossing behavior. The study sought to address the following research questions:

- RQ1— What is the effect of PLDs on pedestrians' auditory/acoustic situation awareness and crossing performance?
- RQ2 — How does the presence of visual and auditory obstruction, such as a bus at a crosswalk, affect pedestrians' acoustic situation awareness and crossing performance?

The experiment followed a 2 (AC vs. BC PLD) x 2 (high vs. low listening level) x 2 (lyrical vs. acoustic) x 2 (no bus vs. bus) within-subjects repeated measures design. A validation study involving seventeen participants (N=17) was used to (1) validate whether or not an auditory alert signal in the environment was clearly audible and balanced between left and right presentation and (2) determine the effect of the bus presence on crossing time. During the main study, thirty-five participants (N = 35) performed 48 randomized trials of safe simulated crossing. The study was conducted under Institutional Review Board (IRB#20-658) approval. Participants were compensated $10/hr. in the form of an Amazon gift card for their time and efforts. The experiment did not exceed two hours in total duration; participants took periodic breaks to reduce the possible occurrence of virtual cybersickness.

As seen in Figure 2, a high-fidelity testbed environment — representative of the campus — was developed in which a pedestrian can engage in simulated street crossing scenarios (Objective 2). The simulation was mapped to have a 1:1 mapping with the physical space such that translational and rotational movement by the participant in the physical environment would provide a mirrored movement in the virtual environment (VE). The aim was to develop a realistic sense of immersion warranting natural pedestrian movements and behaviors based on a scene observed in Phase I at Location C. This would increase ecological validity by allowing for real-life crossing techniques. Research has shown that the 'uncanny valley' phenomenon exists for VR interactions [20]. It has been demonstrated that for path navigation tasks in VR, mid-fidelity interactions lead to greater deviations and increased task performance time compared to low- or high-fidelity interactions [21]; therefore, it was necessary to target a high-fidelity environment using design and interaction techniques that would accurately reflect the intended intervention environment. This was achieved by focusing and controlling for two major perceptual elements: visual and acoustic.

The testbed utilized a pre-existing facility for the audio components. The environment was moderately acoustically controlled limiting external interference. It had an array of high-definition loudspeakers positioned at standing head height around the perimeter with the center of the space being the acoustic focal point. The space was used throughout the study and remained intact, without interruption, until the completion of all experimental trials.

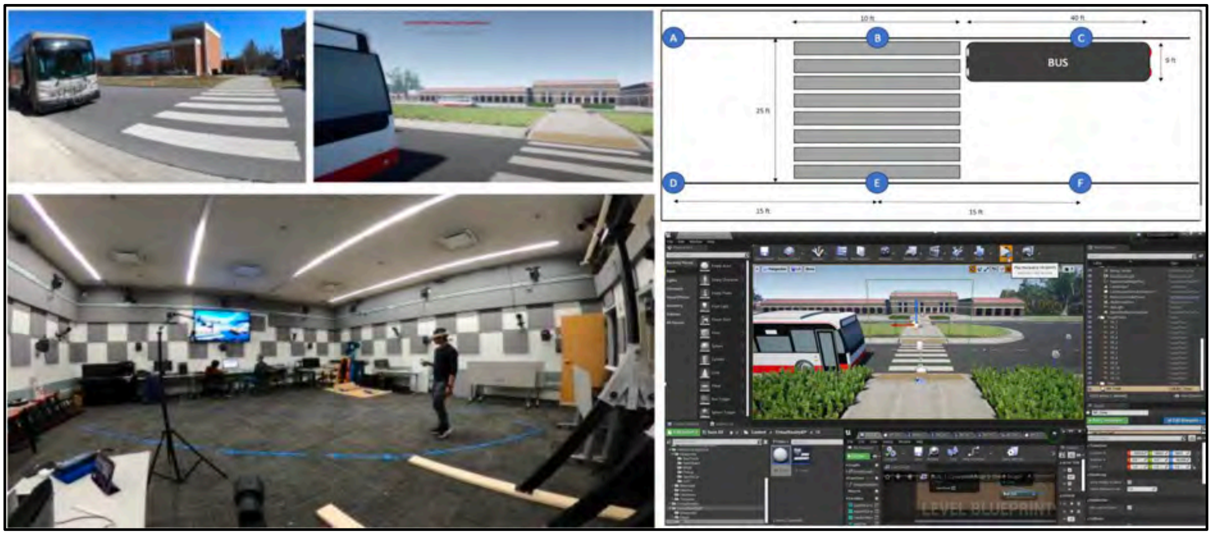

Figure 2. 1:1 multimodal immersive pedestrian crosswalk testbed [11].

Three forms of audio were presented to pedestrians during crossings: (1) distracting music, (2) latent alert signal; and (3) masking interference. First, the distracting music was a popular pop song presented with or without lyrics at a high or low listening level through AC and BC PLDs. Apple Air Pods Pro 1st Generation, used without noise cancellation, and Aftershokz served as the PLDs for AC and BC; respectively. Next, a latent alert signal, an ambulance alarm, was introduced, with a random delay, in the background once from the right and once from the left side of the pedestrian for each factor combination. Lastly, the masking interference was a digital recreation of an idling diesel engine from a university bus presented in 360º immersive audio within the testbed environment. Using a calibrated sound level meter (~1 m), the idling engine was recorded to be 85 dBA from the rear end of a parked university bus; during experimental trials, masking was presented at 80 dBA to minimize noise exposure.

For the visual component, a high-fidelity VE was modeled in Unreal Engine 4 and displayed via Oculus Quest 2, after a densely trafficked crosswalk scenario observed on campus in Phase I (Location C). The selected crosswalk presents a unique scenario: (1) the presence of a bus stop at a crosswalk creates a blind spot (visual distractor) for pedestrians intending to cross; (2) the noise of the idling bus engine (auditory distractor) masks incoming car engine noise which is important for judging vehicle speed and distance. Along with realistic visuals, the objective of the simulation was to create a room-scale walkable VE so that one virtual unit represented one centimeter in the physical environment — outlined on the floor using a measuring wheel and tape. All models, including roadways, foliage, and vehicles were sized to scale based on this system.

As the primary task, participants were instructed to visually judge the oncoming vehicle traffic and perform a “safe” crossing while listening to distractor music through a given PLD. As a secondary task, they were told to maintain Auditory Situation Awareness (ASA) during the cross and signify to the experimenter if they heard an alert signal by raising the appropriate hand (Right or Left) while clicking a handheld remote trigger. A total of 48 trials were completed, 32 trials with an alert signal (left & right) and 16 without an alert signal.

FINDINGS

Phase I: Multi-Stage Naturalistic Observation Study

A detailed report is published in *Transportation Part F: Psychology and Behaviour* titled Technological and Social Distractions at unsignalized and Signalized Campus Crosswalks: A Multi-Stage Naturalistic Observation Study [10]. The following is a summary of the findings:

Naturalistic Signalized and Unsignalized Crosswalk Observations

A total of 1,274 pedestrians (Location: A = 756; B = 314; C = 82; D = 122) comprised of students, faculty, staff, and university visitors of diverse ages, genders, and races were naturalistically observed and systematically recorded crossing signalized and unsignalized crosswalks on and near campus. Two video raters working independently coded the recorded videos as binomial categorical data. Based on a pilot study, interesting pedestrian crossing behaviors and distractors were identified (see Table 1). For each description, coders entered "0" for 'No', and "1" for 'Yes'. For example, after the dataset from Location A was coded, an inter-rater reliability score was generated to gauge the level of agreement between coders. This was calculated as agreements/(agreements + disagreements), an index of concordance as provided by [22]. This was done for each behavior and distractor with the average across all factors generating the final score. The score for Location A was 0.65. Previous observation studies considered the minimum reliability score of at least 0.70 [18; 19]. Based on this, before proceeding further, raters met to discuss their understanding of the definitions by referring to Table 1. After the discussion, all sites were coded based on the agreed-upon process resulting in the inter-rater reliability scores; as seen in Table 2.

Table 1. Pedestrian Behavior and Distractor Definitions [10].

Pedestrian Behavior and Distractor Definitions.

Behaviors	Left/Right Check (Before)	Whether a pedestrian checks both sides of a two-way street, or approaching side of a one-way street before stepping off the curb and onto the crosswalk.
	Left/Right Check (After)	Whether a pedestrian checks both sides of a two-way street, or approaching side of a one-way street after stepping off the curb and onto the crosswalk.
	Follow Walk Sign	Whether a pedestrian follows the walk sign at a signalized crosswalk.
	Crosswalk Use	Whether a pedestrian walks on the crosswalk for at least 50% of the crosswalk's length.
	Crossing After Vehicle	Whether a pedestrian steps on the crosswalk closely behind a vehicle, while it is still clearing the crosswalk or has just cleared the crosswalk.
	Crossing Before Vehicle	Whether a pedestrian steps on the crosswalk in front of a vehicle such that the driver has a clear view of the pedestrian.
	Communication Initiation	Whether a pedestrian initiates communication with the driver to indicate their crossing intent, while still on the curb; can be implicit or explicit.
	Implicit Communication	Pedestrian communication including but not limited to gaze directed towards driver, stepping off the curb and on to the street, or any other non-verbal body language that would indicate intent to cross.
	Explicit Communication	Pedestrian communication including but not limited to hand gestures or verbal language to indicate intent to cross, express 'please yield', gratitude, or displeasure.
	Following Behind	Whether a pedestrian follows behind a group or individuals in front of them who have begun crossing without exhibiting any safety measures of their own.
Distractors	Air Conduction (AC) Personal Listening Device (PLD)	Whether a pedestrian uses an air conduction system of earphones while crossing the street; for example: Air Pods, Bose QC Earbuds, Beats Studio Buds
	Bone Conduction (BC) Personal Listening Device (PLD)	Whether a pedestrian uses a bone conduction system of earphones while crossing the street; for example: Aftershokz Aeropex
	Phone To Ear	Whether a pedestrian uses a phone held to their ear while crossing the street.
	Eyes On Phone	Whether a pedestrian uses a phone such that their gaze is towards the ground while crossing the street.
	Group Crossing	Whether a pedestrian crosses with more than one other pedestrian simultaneously.
	Talking Within Group	Whether pedestrians are talking to each other while crossing the street in group crossings.

Table 2. Inter-rater Reliability Scores [10].

Inter-rater Reliability Scores.

Location	Location A	Location B	Location C	Location D	Average
Score	0.99	0.99	0.75	0.93	0.92

Auditory distractor usage such as AC and BC PLDs were noted as well as societal distractors such as group crossings and engaging in conversation. Due to its novelty and being in the early stages of adoption, the number of pedestrians using BC PLDs was extremely low (n = 5) resulting in no significant associations due to this distractor.

At Location A, PLD and societal distractors such as Group Crossings and Engagement in a Conversation had significant associations with pedestrian behavior. AC PLDs caused pedestrians to check both ways before crossing and cross at the crosswalk more so than when there was no PLD usage. Talking within a group was the only societal distractor that caused increased precautionary behavior, namely Crosswalk Use. The prevalence of AC PLDs was 17.5%, and the prevalence of Group and Talking Within a Group was 34.6% and 33%; respectively. Subsequently, Group and Talking Within a Group distractor led to fewer likelihood of most other precautionary behaviors, such as Communication Initiation, Implicit Communication, and Explicit Communication. However, these also led to fewer chances of Following Behind. Based on these observations, it can be said that pedestrians tended to practice safe crossings, especially when PLDs were involved. Societal distractions, on the other hand, impacted behavior more so leading to increased risk-taking, and had a higher prevalence than technological distractions.

At Location B, AC PLDs, Talking Within a Group, and Phone to Ear had significant effects on pedestrian behaviors. Pedestrians were 2.37 times more likely to check left and right before crossing when using AC PLDs, and those talking on the phone were 9 times more likely to cross after a vehicle. Those engaged in a conversation while crossing were 0.47 times less likely to check left and right before crossing. Unlike Location A, technological distractors influenced pedestrian behavior more so than did societal distractors, although technological distractors led to pedestrians adopting safer behaviors. The similarity with Location A was that those engaged in a conversation in group crossings were less likely to check both ways before crossing; the prevalence was 22%.

Location C showed interesting results. Once again, the use of PLDs and social distractions turned out to be significant, but this time both showed an increased likelihood of precautionary behaviors. Those using AC PLDs were more likely to look for approaching traffic; AC PLD prevalence was 14.6%. When crossing in groups or conversing within the group, pedestrians were nearly six times more likely to cross after a vehicle, which showed that pedestrians waited to make sure there were no approaching vehicles before crossing. The prevalence of group crossings and talking within groups was 22% each. However, at the same time, the likelihood of crossing in front of a vehicle was even greater. The increased prevalence of societal distractions and this contradiction could be attributed to the crosswalk location. The crosswalk is located on a straight stretch of road providing a direct line of sight distance greater than the previous crosswalks (e.g., Location A & B), but also has a bus stop directly at the crosswalk. The buses would wait at the same spot in front of the crosswalk but were not present throughout the observation period. Buses arrived once every 20 min and waited for 5 min. The presence of a parked bus created a wide blind spot for pedestrians. Thus, every time there was a bus present, pedestrians had to peek past the bus, watch for traffic, and make the decision to cross before or after any approaching vehicle.

At Location D, the only signalized crosswalk, technological distractors had the most influence. PLD users were 15 times more likely to cross after a vehicle, even though its prevalence was only 13.1%. This could be because it was a signalized crosswalk, and most pedestrians crossed after vehicles had finished clearing the crossing. AC PLD usage also had higher communication instances, although most were to express signs of gratitude after having begun crossing. There was no significant association between Group Crossings and Following Behind, however, AC PLD had a significant association. This could be the result of it being a signalized crosswalk and distracted AC PLD users simply following those in front without bothering to check for traffic. A similar finding to previous locations (A, B, & C) was the reduced tendency to check both ways when crossing in groups and talking in group crossings. Group crossings accounted for 37% of all crossings. Thus, pedestrian crossing behavior is affected by social distractors similarly at signalized and unsignalized crosswalks.

Survey Responses

A total of 224 pedestrians were handed flyers yielding 135 survey responses (N = 135) with 49.6% being male respondents, 49.6% being female respondents, and 0.8% identifying as non-binary. The survey provided demographic data of the population observed, insights on PLD usage rates, and pedestrians' self-perceived awareness of road crossing behaviors. Respondents' ages ranged from 18 to over 65 (M = 23.29 years, SD = 6.44 years). The age group 18–25 comprised 86% of the responses received; this confirms that the observed population consisted of the age group with the highest rate of PLD usage. Ninety-eight percent reported being undergraduate or graduate students, 0% being faculty, and 2% being university staff members. The ethnicity of respondents varied as follows: 65.2% Caucasian, 16.3% Asian, 6.7% Hispanic, 6% Mixed, 3.7% African American, and 2.1% as Other or Prefer Not to Say. Of the responses, 53.3% were from pedestrians who were observed crossing with the remainder being respondents who were not observed directly and accessed the survey via email.

A majority (97%) of respondents reported listening to media such as music, podcasts, or audiobooks through PLDs while walking on campus, with AC interfaces being the most popular (90.2%). Of these, 59.9% use advanced functions such as active noise cancellation. Concerning the frequency of use, 15% reported using them 'always', 30.3% 'most of the time', 14.4% 'half the time', and 31.8% reported 'sometimes'; only 8.5% reported 'never' using them while walking on campus. These results show that the chances of a driver coming across a pedestrian who is distracted via PLDs while crossing is over 90%. Of those who were observed crossing and reported listening to music while crossing, 48.5% were listening to music at a 'medium level' which was described as 'can hear others talking around you but cannot hear environmental sounds'; 36.3% reported listening at 'low level' which was described as 'can hear others talking around you, as well as environmental sounds'. Lastly, 15.2% reported listening at a 'high level' described as 'cannot hear others talking or environmental sounds'. Regarding music preference, the two most popular music genres were Pop (21.3%) and Hip-Hop (13.4%).

In terms of pedestrians' responses to making left and right checks before crossing, and after beginning to cross. Seventy-seven percent of pedestrians 'always' checked both ways before crossing and were much less likely to check again after having started to cross. Comparatively, although only 46% of pedestrians checked both ways after starting to cross, they were more likely to continue scanning after starting. Of those observed, when encountering a vehicle at the crosswalk, 53.4% reported initiating communication with the driver, while 46.5% did not initiate communication. Responses from unobserved respondents indicated 82.5% as initiating communication, and only 17.5% as not doing so. A substantial portion (83%) of survey respondents reported they would initiate communication, and only 53% were observed to do so.

Regarding forms of communication, 50% of observed pedestrians made explicit communication such as gesturing with their hand, and 50% displayed implicit forms of communication such as eye contact and stepping onto the crosswalk. Compared to that, unobserved pedestrians reported making explicit forms of communication 43.8% of the time, and implicit communication 56% of the time with a driver.

Focus Groups

Following the survey, ten survey participants were invited to engage in a semi-structured focus group discussion. Eight participants ($n_1 = 5$, $n_2 = 3$) engaged to understand pedestrian decision-making factors. Prompt questions were presented from the perspective of both pedestrians and drivers. Participant ages ranged from 18 to 35 with 66.7% in the range of 18–25 years, and 33.3% 26–35 years old. Participants' ethnicities were distributed as follows: 55.6% Caucasian, 33.3% Asian, and 11.1% Middle Eastern. All participants were university students with the first focus group (n_1) consisting of (3 M, 2F) and the second (n_2) (3 M, 0F).

Six out of eight participants mentioned that using PLDs affected their crossing behaviors. Five said their walking pace was affected by the choice of music where they would walk faster with high tempo "upbeat," "rock," or "happier" music, and slower with "relaxed," or "introspective" beats or podcasts. At least four participants said that they would take additional steps using PLDs to check both ways before crossing, exhibiting increased precautionary behavior. When asked if there would be any reason for them to not check both ways before crossing, only one participant said, "If with a large group," and they defined 'large group' as three or more pedestrians. In instances of group crossings, four participants would blindly follow a 'friend' in front, while four participants would make crossing decisions themselves regardless of crossing with 'friends.' If, however, they were crossing with a group of 'strangers,' six participants indicated they would blindly follow the actions of the group, and two participants said they would still prefer to do their evaluation before crossing.

Regarding communicating with drivers at unsignalized crosswalks, three participants preferred to initiate communication by looking at the driver's eyes but did not perform any explicit forms of communication to make their intentions clear. One mentioned they would avert their walking direction from the crosswalk to allow the vehicle to pass first. Three participants said they would rather wait at the curb to see the driver's behavior. They would wait to see the vehicle begin to slow down or have the driver explicitly communicate to them to cross. The remaining participants did not have a preference on who initiated communication.

Questions were also posed to participants from the perspective of a driver since seven out of the eight participants also drive on campus. All eight participants indicated that they would become extra cautious when approaching the crosswalks. They would slow down and expect their slowing down action to be interpreted as a form of implicit communication to pedestrians to cross. If pedestrians still did not begin to cross after initiating a slow-down, four participants said they would use hand gestures to the pedestrians to go ahead and cross. Participants, as drivers, identified certain factors that they would use to decide to yield to pedestrians. These were the distance of pedestrians from the crosswalks regardless of their walking direction, their speed when approaching the crosswalk, and the time of day. They would consider pedestrians one to two steps away from the curb as those with crossing intentions. If they felt their driving speed was fast enough to cause a rear-end crash from yielding suddenly, they would prefer to keep going and not slow down despite posted signs to yield to pedestrians. Twenty and 35 feet were identified as safe stopping distances for vehicles going 25 miles per hour by two participants; respectively. If there was not enough daylight for pedestrians to be able to see the drivers, they would flash their high beams to communicate yielding action.

Lastly, participants were asked to perform hand gestures they used as pedestrians to mean the following: ‘Please yield,’ ‘Please pass,’ ‘Gratitude,’ and ‘Displeasure.’ During the first stage of naturalistic observations, pedestrians were observed mostly communicating these messages through hand gestures. The majority (N = 7) of participants had the same gesture for ‘Please Yield’, which was a stationary palm facing towards the driver. It was also mentioned that the palm would be extended from the body in this case. One participant had the unique gesture of two fingers pointing down to indicate walking intent. To mean ‘Please Pass,’ all participants agreed on a forward waving gesture. There were differences in the orientation with three participants performing it along the horizontal plane, and five participants doing it along the vertical plane. This gesture also made use of the forearm to indicate the complete motion. Gratitude expression had the most variations, although the majority (N = 5) gestured with a steady open palm facing the driver and held closer to the body, compared to the ‘Please Yield’ gesture. This was often accompanied by a slight wave or a nod, as compared to a more stationary gesture for yielding. One participant used two joined palms, synonymous with a gesture of prayer, and two participants made thumbs-up gestures to thank drivers for yielding. Finally, displeasure was expressed by a shrugging of shoulders and extending arms on both sides by five participants; the remaining participants said they refrained from making hand gestures to express any displeasure.

In sum, results show that societal distractions such as crossing in group settings or talking with other members of a group while crossing led to more risky pedestrian behavior, than did technological distractors such as PLDs or cellphone use. However, results also show that the chances of a driver coming across a pedestrian who is distracted via PLDs while crossing is over 90%, although those using AC PLDs were more likely to look for approaching traffic. Regarding pedestrian-driver communication, both implicit and explicit forms of communication occur during crossing interactions. There was also a consensus on hand gesture meanings for pedestrian-driver communication despite the presence of a diverse population. Notably, pedestrian crossing behavior is affected by social distractors similarly at signalized and unsignalized crosswalks. Lastly, and worth further exploration, the presence of a parked bus created a wide blind spot for pedestrians attempting to cross an adjacent crosswalk.

Phase II: Auditory Situation Awareness in Virtual Reality

The multimodal immersive crosswalk testing environment was presented, discussed, and reported as an extended abstract at the 26th International Conference on Auditory Display [11] while a detailed journal report will be published. The following is a summary of the findings:

Pedestrian ASA while listening to music and attempting to cross a virtual crosswalk was measured by left and right localization and detection time of an alert signal. Walking time was defined as the time spent on the crosswalk while the difference between when the alert signal was played and when the trigger button was pressed represented the detection time. If the participant failed to respond, the maximum detection time was recorded. Both dependent measures were captured for the control and treatment groups.

Validation Study

Data collected from the control group validated that (1) the bus would interfere with crossing, and (2) the alert signal presentation was clear and balanced. A total of N = 17 participants (*10 M; 7 F*) with an average age of 21.5 years (S.D. = 3.97) completed the study. All participants reported having normal hearing while no participants reported using a BC device as a preferred PLD. Virtual reality (VR) familiarity was reported as 65% using a virtual reality headset at least once in the past six months, 29% had never used one, and 6% used it at least once a week. Average walking time and detection time can be seen in Table 3 and Table 4, respectively.

Table 3. Control group walking time means and standard deviations.

Control Group: Walking Time - Descriptive Statistics

	Mean	Std. Deviation	N
Walking Time - Left 1 - No Bus	10.4006	7.70610	17
Walking Time - Left 1 - Bus	14.9129	7.59258	17
Walking Time - Right 1 - No Bus	10.1841	7.14727	17
Walking Time - Right 1 - Bus	16.0353	7.18926	17
Walking Time - Left 2 - No Bus	11.3024	9.50101	17
Walking Time - Left 2 - Bus	15.5324	7.06392	17
Walking Time - Right 2 - No Bus	9.8888	7.52331	17
Walking Time - Right 2 - Bus	17.5788	7.06092	17
Walking Time - No Sign 1 - No Bus	11.5488	6.78853	17
Walking Time - No Sign 3 - Bus	15.6465	8.45507	17
Walking Time - No Sign 2 - No Bus	11.3571	8.31931	17
Walking Time - No Sign 4 - Bus	13.9335	7.57994	17

Table 4. Control group detection time means and standard deviations.

Control Group: Detection Time - Descriptive Statistics

	Mean	Std. Deviation	N
Detection Time - Left 1 - No Bus	5.3506	8.14337	17
Detection Time - Left 1 - Bus	9.2147	9.90768	17
Detection Time - Right 1 - No Bus	5.0471	7.66111	17
Detection Time - Right 1 - Bus	8.1559	10.15221	17
Detection Time - Left 2 - No Bus	8.1412	10.33914	17
Detection Time - Left 2 - Bus	6.7188	7.41568	17
Detection Time - Right - No Bus	3.4453	2.16192	17
Detection Time - Right 2 - Bus	7.2182	10.48081	17

Table 5. Control group alert signal comparisons.

Control Group: Alert Signal Detection Time Pairwise Comparisons

SignalDet	(I) Bus	(J) Bus	Mean Difference (I-J)	Std. Error	Sig.[a]	95% Confidence Interval for Difference[a] Lower Bound	Upper Bound
Left 1	No	Yes	-3.864	3.241	.251	-10.735	3.006
	Yes	No	3.864	3.241	.251	-3.006	10.735
Right 1	No	Yes	-3.109	1.825	.108	-6.978	.760
	Yes	No	3.109	1.825	.108	-.760	6.978
Left 2	No	Yes	1.422	3.227	.665	-5.419	8.264
	Yes	No	-1.422	3.227	.665	-8.264	5.419
Right 2	No	Yes	-3.773	2.470	.146	-9.010	1.464
	Yes	No	3.773	2.470	.146	-1.464	9.010

Based on estimated marginal means

a. Adjustment for multiple comparisons: Least Significant Difference (equivalent to no adjustments).

As expected, the presence of the bus had a significant effect on pedestrian walking time with a mean difference of 4.826 seconds ($p < 0.001$). The presence of the bus reflects a real-world visual obstruction justifying inclusion in the treatment group. Regarding detection time, there was no significant difference between Left and Right presentation despite the presence of the bus; see Table 5. This validated that the presentation of the alert signal is balanced and loud enough to be detected in the absence of auditory distraction (i.e., PLDs).

Main Study

Data was collected from N = 35 participants (*22 M; 13 F*) with an average age of 23.5 years (S.D. = 3.96 years). The majority of the participants (97%) reported an AC interface as their preferred PLD while 3% preferred a BC interface. Regarding VR familiarity, 63% reported having used a VR headset at least once in the past six months, 34% had never used one, and 3% used it at least once a week. All participants reported having normal hearing.

Walking times with AC PLDs (Table 6) range from 12.24 to 18.32 seconds averaging 15.84 seconds across all conditions. No main effects were observed for music type ($p = 0.517$), music volume ($p = 0.603$), and alert signal direction ($p = 0.853$); however, bus presence was significant ($p < 0.001$). The difference between lyrical and acoustic music was 0.253 seconds with better performance with lyrical content. Listening to music at a low volume resulted in better crossing performance with a difference of 0.183 seconds compared to at a high volume.

Pedestrians had better ASA from the left side but only differed by 0.08 seconds. Lastly, crossing time was reduced by 2.95 seconds due to the bus.

Walking times when using the BC PLD (Table 7) range from 12.96 to 17.57 seconds with an average of 15.37 seconds across all conditions. No main effects were observed for music type (p = 0.723), music volume (p = 0.658), and alert signal direction (p = 0.823); however, similar to the AC PLD, the presence of the bus was significant ($p < 0.001$). The difference between lyrical and acoustic presentation was 0.20 seconds with acoustic content yielding better performance. A higher listening volume resulted in a slightly faster performance (0.187 seconds) while better ASA was achieved from the right side with a difference of 0.108 seconds. Lastly, crossing performance was noticeably better without the bus present.

Table 6. Air conduction treatment group walking time means and standard deviations.

Treatment Group: Walking Time - Air Conduction
Descriptive Statistics

	Mean	Std. Deviation	N
Walking Time - AC - High - Left - Lyrical - No Bus	15.0203	7.71855	35
Walking Time - AC - High - Left - Lyrical - Bus	17.6603	6.80879	35
Walking Time - AC - High - Left - Acoustic - No Bus	13.2720	7.56995	35
Walking Time - AC - High - Left - Acoustic - Bus	18.3163	7.31667	35
Walking Time - AC - High - Right - Lyrical - No Bus	13.9209	8.11136	35
Walking Time - AC - High - Right - Lyrical - Bus	17.1917	7.27686	35
Walking Time - AC - High - Right - Acoustic - No Bus	15.1011	7.83521	35
Walking Time - AC - High - Right - Acoustic - Bus	16.9757	7.30513	35
Walking Time - AC - Low - Left - Lyrical - No Bus	12.2414	6.73073	35
Walking Time - AC - Low - Left - Lyrical - Bus	17.6846	6.78294	35
Walking Time - AC - Low - Left - Acoustic - No Bus	15.3266	9.76549	35
Walking Time - AC - Low - Left - Acoustic - Bus	16.8823	7.01852	35
Walking Time - AC - Low - Right - Lyrical - No Bus	15.0189	7.95909	35
Walking Time - AC - Low - Right - Lyrical - Bus	16.9754	7.44367	35
Walking Time - AC - Low - Right - Acoustic - No Bus	15.0109	7.93591	35
Walking Time - AC - Low - Right - Acoustic - Bus	16.8509	7.29989	35

Table 7. Bone conduction treatment group walking time means and standard deviations.

Treatment Group: Walking Time - Bone Conduction
Descriptive Statistics

	Mean	Std. Deviation	N
Walking Time - BC - High - Left - Lyrical - No Bus	13.9851	7.83699	35
Walking Time - BC - High - Left - Lyrical - Bus	16.7803	5.31339	35
Walking Time - BC - High - Left - Acoustic - No Bus	13.7166	8.43600	35
Walking Time - BC - High - Left - Acoustic - Bus	16.8300	5.91373	35
Walking Time - BC - High - Right - Lyrical - No Bus	12.9600	7.16521	35
Walking Time - BC - High - Right - Lyrical - Bus	17.5666	7.19570	35
Walking Time - BC - High - Right - Acoustic - No Bus	14.4866	7.36735	35
Walking Time - BC - High - Right - Acoustic - Bus	15.9054	5.87753	35
Walking Time - BC - Low - Left - Lyrical - No Bus	15.0720	8.44151	35
Walking Time - BC - Low - Left - Lyrical - Bus	16.1494	6.73994	35
Walking Time - BC - Low - Left - Acoustic - No Bus	14.4869	7.52386	35
Walking Time - BC - Low - Left - Acoustic - Bus	16.3869	6.53804	35
Walking Time - BC - Low - Right - Lyrical - No Bus	13.8226	7.64500	35
Walking Time - BC - Low - Right - Lyrical - Bus	17.4423	5.55301	35
Walking Time - BC - Low - Right - Acoustical - No Bus	14.3109	8.00499	35
Walking Time - BC - Low - Right - Acoustical - Bus	16.0523	7.32035	35

Detection times with AC PLDs, Table 8, range from 3.67 to 12.41 seconds averaging 7.13 seconds across all conditions. A significant main effect was observed for music volume ($p < 0.001$) and bus presence ($p = 0.002$), while music type ($p = 0.723$) and alert signal direction ($p = 0.823$) were not. There was a difference in crossing time when listening to high vs. low-intensity music (4.052 seconds) with higher performance when the volume was low; when the bus was present, crossing time was reduced by 2.487 seconds. Crossing performance was faster when listening to music without lyrics with a difference of 0.937 seconds. Lastly, ASA alert detection was faster from the left side with a 0.943-second difference.

Detection times with BC PLDs (Table 9) range from 3.76 to 12.58 seconds averaging 6.33 seconds across all conditions. A significant main effect was observed for music type ($p = 0.016$), music volume ($p < 0.001$), and bus presence ($p = 0.001$), while alert signal direction ($p = 0.637$) was not. Detection performance was faster when listening to acoustic music with a 1.314-second difference, while there was a 2.792-second difference in detection time when listening to music at a low volume. The presence of the bus reduced detecting time by 2.386 seconds. A slight difference in detection performance was observed (0.265 seconds) favoring left-side presentation.

Table 8. Air conduction treatment group detection time means and standard deviations.

Treatment Group: Detection Time - Air Conduction
Descriptive Statistics

	Mean	Std. Deviation	N
Detection Time - AC - High - Left - Lyrical - No Bus	9.4486	10.78825	35
Detection Time - AC - High - Left - Lyrical - Bus	10.4229	11.44642	35
Detection Time - AC - High - Left - Acoustic - No Bus	6.0446	7.79264	35
Detection Time - AC - High - Left - Acoustic - Bus	8.8954	8.41599	35
Detection Time - AC - High - Right - Lyrical - No Bus	7.6974	8.94191	35
Detection Time - AC - High - Right - Lyrical - Bus	12.4063	12.62011	35
Detection Time - AC - High - Right - Acoustic - No Bus	5.8926	6.05075	35
Detection Time - AC - High - Right - Acoustic - Bus	12.4091	12.74505	35
Detection Time - AC - Low - Left - Lyrical - No Bus	3.6749	3.12494	35
Detection Time - AC - Low - Left - Lyrical - Bus	5.2920	3.77243	35
Detection Time - AC - Low - Left - Acousic - No Bus	5.1386	5.98122	35
Detection Time - AC - Low - Left - Acousic - Bus	4.3183	2.35697	35
Detection Time - AC - Low - Right - Lyrical - No Bus	5.3046	6.41521	35
Detection Time - AC - Low - Right - Lyrical - Bus	6.5103	7.99877	35
Detection Time - AC - Low - Right - Acoustic - No Bus	3.8611	3.29127	35
Detection Time - AC - Low - Right - Acoustic - Bus	6.7014	6.63085	35

Table 9. Bone conduction treatment group detection time means and standard deviations.

Treatment Group: Detection Time - Bone Conduction
Descriptive Statistics

	Mean	Std. Deviation	N
Detection Time - BC - High - Left - Lyrical - No Bus	5.9343	6.12391	35
Detection Time - BC - High - Left - Lyrical - Bus	12.5766	11.84350	35
Detection Time - BC - High - Left - Acoustic - No Bus	4.3611	2.92052	35
Detection Time - BC - High - Left - Acoustic - Bus	8.5829	10.07859	35
Detection Time - BC - High - Right - Lyrical - No Bus	6.4531	7.76092	35
Detection Time - BC - High - Right - Lyrical - Bus	11.4743	12.17935	35
Detection Time - BC - High - Right - Acoustic - No Bus	5.5860	7.62084	35
Detection Time - BC - High - Right - Acoustic - Bus	6.8346	5.85002	35
Detection Time - BC - Low - Left - Lyrical - No Bus	4.4611	4.52557	35
Detection Time - BC - Low - Left - Lyrical - Bus	4.3677	2.88470	35
Detection Time - BC - Low - Left - Acoustic - No Bus	3.7597	2.77209	35
Detection Time - BC - Low - Left - Acoustic - Bus	5.5309	5.91090	35
Detection Time - BC - Low - Right - Lyrical - No Bus	5.4126	6.54896	35
Detection Time - BC - Low - Right - Lyrical - Bus	5.2109	3.50629	35
Detection Time - BC - Low - Right - Acoustic - No Bus	5.1254	6.16650	35
Detection Time - BC - Low - Right - Acoustic - Bus	5.6000	6.29405	35

CONCLUSIONS

In 2013, it was reported that the estimated number of pedestrian injuries in 2010 that involved mobile devices was about 1,506 with a statistically significant upward trend in estimated injuries for both pedestrians and drivers [23]. The number would be exacerbated on college campuses due to higher rates of usage of mobile devices among this demographic leading to diminished situation awareness, and in-attentional blindness/deafness. Research has shown that distracted pedestrian behavior can lead to dangerous predicaments at crosswalks. Audio and visual distractions take up significant mental resources, which could be necessary for navigating a crosswalk or interacting with a vehicle driver. These distractions can further lead to accidents resulting in minor injuries or fatalities. The current work aims to provide recommendations to identify pedestrian distractions and understand how such distractions degrade pedestrians' ability to make safe crossings. This was accomplished through two studies.

The first study, which was a three-stage naturalistic observation study consisting of naturalistic observations, a survey, and focus groups with members of the observed population and survey respondents, identified the presence of social and technological distractions. The primary conclusion was that social and technological distractions were both equally prevalent among the college-attending population. It was found that pedestrians were more likely to be distracted by social distractions such as speaking with a friend or crossing in a group setting, than by technological distractions such as PLDs or phones. It was also seen that pedestrians tend to overestimate their crossing ability, which suggests the need to verify survey responses with naturalistic observations. Furthermore, the study also found evidence for the need to standardize eHMI signals to convey automated vehicles' intent at unsignalized crosswalks. A consensus was found for different hand gesture meanings despite the observed diversity in the sample population, which would suggest that standardizing the visual signals through the use of hand gesture symbols could be beneficial for interactions between pedestrians and automated vehicles where a driver may not be present.

In the second study, one of the more complex crosswalks (Location C) observed in the first study was simulated in virtual reality. The virtual environment had the 1:1 spatial mapping with the real world, where one step in the real world would translate to an equal displacement in the virtual world. Audio recordings from the real-world spaces were adjusted to fit the virtual environment and played through an array of speakers mounted on the walls of the experiment room. In the study, participants completed street crossings while listening to distracting audio through PLDs and had to detect and localize (left or right) an ambulance siren. It was seen that the presence of a bus near the crosswalk and the noise from its idling engine significantly increased the time to cross the street, as well as the time to detect the ambulance siren. Acoustic music, when played through bone conduction PLDs, led to faster detection times. Further, listening to music at a low volume led to faster street crossings and faster detection of the ambulance siren.

RECOMMENDATIONS

Based on the findings from the first study, it is recommended that overarching efforts be made to ensure a shared mental model of the crossing environment between drivers or automated vehicles, and pedestrians. This could be achieved through signage near crosswalks, and eHMIs on automated vehicles in the absence of drivers. Signages should remind pedestrians to pay attention to the environment, look left and right before crossing when technologically distracted, and generally, adopt an individualistic mindset to not simply follow the group or pedestrians in front, especially when socially distracted. Other recommendations include designing eHMIs for automated vehicles that consider social acceptance and understanding of common hand gestures that have shared understanding across the user population. Such eHMIs should also prioritize initiating interaction with pedestrians since pedestrians expect vehicles to initiate communication given their larger road presence.

From the second study, recommendations include installing blind spot mirrors near crosswalks where visibility is an issue. These could be installed as part of the crosswalk infrastructure, or even be included as part of the vehicles such as buses that obstruct pedestrians' view of oncoming traffic. The auditory distraction from the sound of such buses should also be considered when designing methods to improve auditory situation awareness. PLD technology developers should consider automatically lowering the listening level, or automatically turning off any form of noise cancellation when pedestrians approach unsignalized crosswalks, or the presence of idling parked vehicles is detected. Further, the effect of speech in any auditory alert designed to improve pedestrians' situation awareness near a crosswalk should be considered carefully. Acoustic music showed slightly better detection performance with bone conduction PLDs, suggesting that the presence of speech might act as a distractor. Therefore, to minimize additional cognitive workload when presenting auditory alerts, non-speech-based sounds might have an advantage.

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APPENDIX

Publications, presentations, and posters resulting from this project:

1. Dam, A., Tamboli, S., Oberoi, P., Pierson, J., Patrick, R., Jeon, M. (2021). Acoustic Situation and Its Effects on Pedestrian Safety within a Virtual Environment. ICAT Creativity + Innovation Day. May 3rd, 2021. https://icat.vt.edu/events/2021/05/bridging-physical-distance---icat-creativity---innovation-celebr/acoustic-situation-awareness-and-its-effects-on-pedestrian-safet.html
2. Dam, A., Oberoi, P., Pierson, J., Tamboli, S., Jeon, M., & Patrick (2021). Acoustic Situation Awareness and Its Effects on Pedestrian Safety within a Virtual Environment. Center for Human-Computer Interaction Symposium. May 6th, 2021. – Awarded Best Project.
3. Dam, A., Duff, C., Jeon, M., & Patrick, R. (2022). Effects of personal listening devices on pedestrians' acoustic situation awareness in a virtual reality environment, Proceedings of the 24th International Conference on Auditory Display, Virtual, June 24–27.
4. Dam, A., Patrick, R., & Jeon, M. (2022). Acoustic Situation Awareness and Its Effects on Pedestrian Safety within a Virtual Environment. CATM Virtual Research Symposium 2022. February 7-8, 2022.
5. Dam, A., Oberoi, P., Pierson, J., Jeon, M., & Patrick, R.N.C. (2023). Technological and social distractions at unsignalized and signalized campus crosswalks: a multi-stage naturalistic observation study, *Transportation Research Part F: Traffic Psychology and Behaviour, 97,* 246-267.