EFFECTS OF PERSONAL LISTENING DEVICES ON PEDESTRIANS' ACOUSTIC SITUATION AWARENESS IN A VIRTUAL REALITY ENVIRONMENT

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ABSTRACT

The technological developments for Personal Listening Devices (PLDs) have been staggering in the recent years; our listening experience has improved drastically but it has also affected our ability to remain cognizant of our acoustic environment. The student population remains the largest user group of PLDs. The distraction from PLDs can be dangerous in situations that require focused attention, such as crossing unsignalized crosswalks on college campuses. In this study, the researchers use a virtual reality (VR) based pedestrian simulator to task participants with crossing a replica campus street while listening to music through air and bone conduction PLDs. As a secondary task, participants were tasked with detecting and localizing (i.e., bi-directionally) a clearly audible ambulance siren during the crossing. It is hypothesized that there will be improved detection and localization performance with bone conduction PLDs, and that speech free music will be as distracting as music with speech. This study will also provide insights towards the use of PLDs as V2P communication interfaces during crosswalk situations.

1. INTRODUCTION

Personal entertainment technologies, such as smartphones and earphones have a come a long way. While they have revolutionized our lives, they have also become a major source of distraction. According to the National Highway Traffic Safety Association's (NHTSA) Fatality Analysis Reporting System (FARS) data, the percentage of pedestrians or vulnerable road users (VRUs) involved in fatal accidents went up by 53 % between 2009 and 2018 [1]. In 2017, pedestrian deaths constituted 16% of all traffic fatalities, and 91% of those involved single vehicles [2]. This indicates that scenarios where pedestrian-vehicle interactions are involved, distractions of any kind can lead to accidents. Of all the pedestrians killed in 2019, 13.2% belonged to the age group of 21-34; 9.4% were reported as running across a road, 3.9% as talking, and 0.5% as using a portable electronic device [3]. The percentage of personal listening devices (PLDs) wearers may not be very high, however, PLD usage can lead to increased hearing thresholds which increases the risk of not being aware of approaching vehicles. A study from 2007 found that the hearing threshold for 3 – 8k Hz were significantly increased (>25 dB HL) due to PLD use; this effect was more pronounced in the 10k – 20k Hz region [4] These forms of distractions can severely affect pedestrians' ability to be situationally aware of their surroundings while navigating a crosswalk.

Pedestrians' usage of media devices, such as PLDs, has become increasingly popular sources of such distractions. As of the first decade of the 21st century, 66% of the millennial age group (18-33) use the Internet to watch videos, and 51% use it to listen to music [5]. The US earphone and headphone market is set to be worth over $9 billion by 2024 [6]. Other distractions such as cellphones have always presented a threat to pedestrian situation awareness. Cellphone usage at crosswalks leads to visual and cognitive distraction. Male and female pedestrians have been known to take longer crossing times, with female pedestrians looking fewer times at approaching traffic, and waiting shorter durations for traffic to stop [7].

In order to investigate the complexities of PLD distractions during street crossings, we developed a full motion pedestrian simulator making use of virtual reality (VR) technology and immersive audio. VR-based pedestrian simulators can be used to recreate dangerous crossing scenarios without risk of injury to the participant. Despite their advantages of providing a safer, controlled environment for studies on pedestrian safety, the ecological validity of experimental environments can vary. Schwebel and O'Neal [8] used a semi-immersive simulator that consisted of three screens in front of a standing participant who was required to step onto a 'curb' to indicate intention to cross, which would then trigger a virtual avatar to complete the crossing on the screens. They were able to demonstrate that pedestrians who were distracted with PLDs or who were texting, got hit by vehicles more so than those talking on the phone or those who were not distracted. Completely immersive VR-based simulators have been shown to provide ecological validity to match real world performance [8-10].

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2. METHODS

2.1. Virtual Reality Environment and Ambisonic Audio

A virtual pedestrian simulator was developed with 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). Our aim was to provide a realistic sense of immersion and natural movement. This would ensure high ecological validity, thus paralleling real life performance. This is important because existing research has shown that the 'uncanny valley' phenomenon exists for VR interactions [11]. It has been demonstrated that for path navigation tasks in VR, mid-fidelity interactions leads to greater deviations and increased task performance time compared to low- or high-fidelity interactions [11-12]. Therefore, it was necessary to use an interaction technique that could be considered high-fidelity despite performance in a VE. This was achieved following two major elements:

2.1.1. Visual Elements

A high-fidelity VE was modeled after a crosswalk from the Virginia Tech campus in Blacksburg, Virginia. This was based on the findings from a previous observation study conducted by the researchers to determine risky crossing scenarios. The selected crosswalk presents a unique scenario: first, the presence of a bus stop at the crosswalk causes the parked buses to create a blind spot for pedestrians wanting to cross, and second, the noise of the idling engine from the buses makes it difficult to ascertain information about approaching vehicles. Figure 1 shows a side-by-side view of the real and virtual crosswalk location.

Figure 1. Left: real crosswalk; Right: virtual crosswalk

Along with realistic visuals, the objective of the simulation was to create a room-scale walkable VE. Unreal Engine was used to develop this environment which utilized a system that represented one Unreal Unit as one centimeter. All models, including roadways, foliage, and vehicles were sized to scale based on this system. To ensure the crosswalk was the correct length, a measuring wheel was used to make a life size replica crosswalk within the experimental environment. Figure 2 shows the crosswalk length marked out on the floor of the studio.

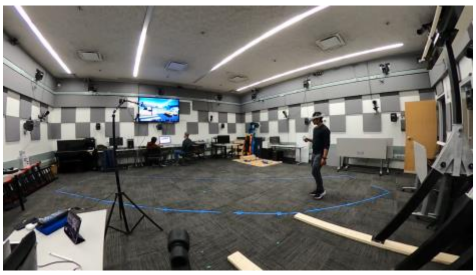

Figure 2. Actual crosswalk length inside the studio

2.1.2. Acoustical Elements

To achieve a realistic acoustic environment, the experimental space consisted of a state-of-the-art audio facility equipped with a high-density loudspeaker array (HDLA). The HDLA is comprised of 24 loudspeakers and one subwoofer, with six speakers being located on each wall in all cardinal directions at approximately 6' off the floor and at relative ear height. Max/MSP was the audio engine that received OSC message events from Unreal which triggered audio playback. In the aforementioned observation study, researchers collected sound pressure level (SPL) values at six locations around the crosswalk being simulated. These points are as shown in Figure 3. Sounds were exported to the HDLA while the environmental sound level was measured in the center of the crosswalk to be 59.5 dBA. Convolution reverberation based on an impulse response from the actual crosswalk location on campus was also included to add a layer of realism.

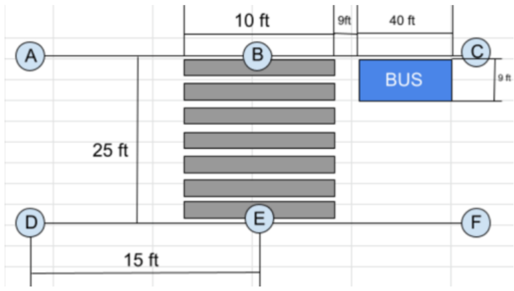

Figure 3. Schematics of recreated crosswalk

The soundscape was made up of several elements that parallel the real environment. The researchers collected sound recordings locally, including the idling bus engine sound and background ambiences. Ambiences were recorded with a 360-degree microphone that captures audio in ambisonics, an immersive audio format that plays back the audio via all 24 loudspeakers to create a realistic portrayal of the spatial recording.

In addition to building a realistic sonic environment, specific sound elements were added for the experimental tasks. Music files were presented through the PLDs via Bluetooth. The ambulance siren, presented at a clearly audible level, was added as a latent alert signal within the soundscape for the select trials as a measure of perceived acoustic situation awareness. A psychometric point of subjective equality (PSE) technique was implemented to determine equal output levels between PLDs for each participant.

2.2. Experimental Design

The study follows a within-subjects design with three independent variables: 2 (Music Type) x 2 (Listening Volume) x 2 (Masking Source). Music Type included lyrical and acoustical versions of the same song. This factor is of interest since it has been shown that the speech processing and listening to music can have different extents of distraction [13]. Listening Volume was set to either a low or high listening level; these were calibrated to roughly 50 and 70 dBA for each PLD type using a PSE perception matching protocol. Lastly, two 'Bus Presence' scenarios were included: (1) without the bus to serve as a baseline; and (2) with an idling bus parked at the curb right in front of the crosswalk. The presence of the bus created a blind spot and introduced a visual and auditory masking noise point source (i.e., idling bus and diesel engine).

Participants would listen to music through two types of PLDs – air (AC) and bone (BC) conduction while all trials were repeated for each PLD. The song to be played was selected based on the results of a survey. The survey was administered to the same population from which participants were recruited, and asked respondents about their favorite music genre. Survey results showed that Pop and Hip-Hop were the most popular genres. Next, we identified the most popular song within those genres at the time when the survey was administered (January 2021) using websites such as Top40 or Billboard. Another condition was to find a song that matched both genres, and had lyrics as well as a captivating tune to provide better immersion. Based on the above conditions, the song presented to participants was Astronaut in The Ocean by Masked Wolf released in June 2019 with an average tempo of 150 beats per minute.

One-third of the trials presented an auditory signal – an ambulance siren, that played from the left or the right side of the participant. Participants were not informed of the bidirectional nature of the signal presentation.

To serve as an overall baseline of VE street crossing performance, data from a control group was performed after the experimental group. This group did not wear any PLDs, therefore, was not exposed to direct auditory distraction. However, the masking source (i.e., bus present with engine idling) was still present.

2.3. Task

Participants were tasked with wearing a VR headset to cross a one-way street (from the curb to the median) while listening to music via PLD. In addition, a secondary task was to detect and localize (bi-directionally) an auditory alert signal (i.e., ambulance siren). The flow of traffic moved from the observer's left to right within the VE. Participants would listen to the preselected song through the appropriate PLD (AC or BC) while making the crossings. To indicate that they had detected the auditory alert signal's directionality (left or right of the observer), participants were asked to press a button on the VR controller as soon as they perceived the signal. Next, they were instructed to point their arm in the direction from which they perceived the point source of the auditory signal. The auditory signal played from a single speaker, at approximately ear level, either on the right or left side of the crosswalk, but participants were not informed about the dichotomous nature of the signal presentation.

Participants would walk across the experimental environment to engage in the VR crossing. Since the virtual environment was developed with a 1:1 mapping with the physical space, their movement in the physical translated to the same spatial movement in the virtual environment. Once they had finished crossing, they could enable Passthrough on the headset, and return to the starting position for the next trial.

3. ANTICIPATED RESULTS

The current study has completed data collection and is in the stage of filtering and processing the data. The researchers seek to utilize the data collected to investigate the effect PLDs can have on pedestrians' auditory situation awareness. More specifically, the following research questions are of interest:

a. Is there a main effect of Music Type, Listening Level, or Masking Source on pedestrian's signal detection capability?

b. To what extent is ability to localize a bi-directional signal hampered due to PLD usage while crossing a street?

c. Is there a difference in detection and localization performance between air and bone conduction type PLDs?

d. Does bias for signal detection change over time from using PLDs?

We will use ANOVA analyses to look for main and interaction effects of our factors on signal detection time, and localization accuracy. We will use Signal Detection Theory (SDT) to calculate each participant's bias. Furthermore, we intend to use SDT data to apply the Quantitative Analysis of Situation Awareness (QASA) model [14], which would provide a combined quantitative description of the participants' situation awareness.

4. DISCUSSION

Our expectations are that there will be a main effect of Listening Level and Masking Source on the signal detection time and localization performance. If we do see a main effect of Music Type, it will indicate that processing speech has a greater extent of distraction due to increased mental workload [13], [15]. However, since the participants were instructed to detect and localize the auditory signal while crossing, it is possible that they might not have been paying sufficient attention to the music, thus not being affected by the Music Type to the extent expected. Future studies that provide enhanced listening immersion during task performance might help to test this hypothesis further.

We also seek to explore the notion that acoustic situation awareness and, in turn, localization performance is better when wearing BC PLDs [16]. This is expected because BC PLDs allow for the ears to remain open to environmental sounds, thus allowing users to be more receptive of auditory cues within their immediate physical environment [17-18] .

A unique result that the researchers expect to see is that participants might make safer crossings while wearing PLDs, as compared to the control group. While this is contrary to the expectation that PLDs will generally lead to more distracted crossing behavior such as fewer acceptable gap crossings and more missed opportunities, previous observation studies have shown that distracted pedestrians tend to be cautious than non-distracted pedestrians [19-20]. In the event that this is the case for the current study, it would further authenticate the fact that VR-based pedestrian simulators are an effective tool to study pedestrian safety.

Lastly, findings from this study can set the grounds for future studies on providing distracted pedestrians with the necessary alerts, such as V2P communications, to create safer crosswalks within a campus environment. By providing recommendations on safe listening levels, or passing auditory alerts through PLDs to overcome masking noise sources, we can ensure that PLD users can maintain the same auditory situation awareness as the open ear condition.

5. ACKNOWLEDGMENT

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