Investigating pedestrian and autonomous car interactions in virtual reality

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Abstract. The rise of autonomous vehicle technology could affect the interactions between pedestrians and vehicles. In field studies focusing on pedestrian crossing behaviour while facing autonomous vehicles, participants are rarely allowed to cross the street due to safety considerations. The lack of physically crossing the road might influence the participants' behavior. In our study, we constructed intersections in virtual reality to investigate these potential behavioral shifts. The participants were asked to indicate the critical time for crossing the road when autonomous or manual driven cars approached, while using two methods, which were either crossing the road by walking or stepping forth and back at appropriate times. In the present report, we will focus on presenting the methodology and our findings from a pilot study. Complete results will be presented during the conference.

Keywords: virtual reality, autonomous driving, pedestrian behavior, critical gap

1. Introduction

Every year, the lives of approximately 1.3 million people are cut short due to road traffic crashes (World Health Organization 2018). Furthermore, human errors are accountable for 94% of serious crashes (Singh 2015). Properly designed autonomous vehicles can prevent errors and, consequently, accidents (Mueller et al., 2020; Van Brummelen et al. 2018). On the other hand, autonomous vehicles also introduce new challenges, especially in understanding pedestrian behaviors (Rasouli & Tsotsos 2020).

Due to safety considerations, in prior studies about pedestrian behaviors interacting with autonomous cars, risks of accident were mitigated by replacing the crossing part with other indirect methods, e.g., by moving a slider to indicate their willingness to cross the road. (Dey et al. 2021; Habibovic et al. 2016). In a recent study, the pedestrians moved one step forward in the first moment they would cross the street and one step backward in the last moment they would cross the road (Rodríguez Palmeiro et al. 2018). Participants reported taking their decision to cross based on the vehicle appearances and the attentional states of the drivers. Interestingly, neither the appearance of the car nor drivers' attentional state was found to affect pedestrians' decisions significantly when analyzing objective measures. One possible reason for the lack of objective effects could be the discrepancy between real life and the experimental condition introduced by the stepping mechanism.

Virtual reality (VR) technology is an effective tool for pedestrian behavior research (Deb et al. 2017). However, some existing VR studies also asked the participants to show their crossing decision through indirect means such as pressing buttons or expressing the willingness verbally (Chang et al. 2017; Nuñez Velasco et al. 2019), without discussing whether the lack of actually crossing the road could lead to a behavioral change. There are indeed studies that asked the participants to actually cross the road in VR, such as the VIRE platform. Still, it also did not focus on studying the potential behavioral change. (Farooq et al. 2018). The study by Carassa et al. 2002 supports the necessity of further exploring the topic, as depending on how the participants explore the virtual environment (self-governed vs. passive), their spatial representations are shown to be organized differently, which might result in a shifted crossing behavior.

Therefore, the main objective of the present study is to develop and test a methodology to assess the potential behavioral shift caused by the lack of actually crossing the road. To frame the scope of our study, we chose Rodríguez Palmeiro et al. (2018) as a reference study. Additionally, we wish to test our approach by studying whether crossing the road would eliminate the contradiction in the result between the self-reported behavior and the recorded measures of pedestrian behavior. We address the following research questions: (1) Do pedestrians' crossing behavior change when they are asked to indicate the crossing intentions through stepping in comparison to directly crossing the road in VR? (2) Do pedestrians' crossing decisions differ as a function of the driver's attentional state on the autonomous vehicle? We also wish to evaluate our approach in VR using a survey and established questionnaires.

2. Method

We adapted the mentioned reference study and converted the field study part into VR. We constructed an intersection with an approaching car and a bus as a visual cue of the destination using the Unity game engine (Figure 1).

Figure 1. *(left) An Aerial View: Black arrow shows the path of the vehicle. The orange arrow shows the path of the pedestrian. (right) A VR scene seen from participants' point of view.*

Participants were equipped with an HTC Vive headset with six degrees of freedom to control their VR avatars (digital representation) through walking and turning in the real world (Figure 2). Participants are asked to interact with scenarios with different crossing mechanisms (directly crossing or indicating crossing by stepping). Participants' position was continuously tracked, and after the experiment, verbal interviews were conducted, and questionnaires were administered.

In our study, the used vehicle model has the appearance of a medium-sized coupe with a roof sign showing the message "self-driving." To increase the immersiveness, we replaced the avatar of the virtual driver with a 2D plane that shows a video of a real human driver, taken from the frontal view (ref. Figure 1). Inspired by the Wizard of oz(Woz) technique, we pre-recorded the videos of the driver to mimic a real-time projection of a real driver without informing the participants about it.

Participants in our study can move in an area of approximately 2.5mx4.2m which is limited by the facility and the coverage of the base stations. Therefore, to better replicate the scenario in the reference study, we modeled a two-way street of 7.5m wide in Unity and applied a gain of 2.0 to the movements in the direction parallel to the crossing. This approach has been validated to be a feasible technique to use to fit walking exploration of large virtual environments within the confines of small physical environments (Williams et al. 2006).

Figure 2. *A user with HTC Vive in the experiment facility*

2.1 Independent variables

The scenarios differed in the following three variables: driver's attentional state, yield behavior, and the crossing mechanism. The attentive driver represents drivers actively steering the vehicle and focusing on the traffic situation. The pre-recorded driver holds the steering wheel and seeks eye contact with the pedestrian. In the inattentive case, the driver has his hands off the wheel and types on a smartphone, conveying that the vehicle is driving autonomously. The second independent variable is the stopping behavior: In reality, the autonomous car or the car driver could either notice the pedestrian and start braking before the crossing (yield) or disregard the pedestrian and continue driving (pass). For both cases, the car starts from approximately 60m from the crossing and accelerates to 25 km/h. Then, the vehicle would either yield and stop in front of the intersection or maintain its speed and pass the crossing. For better immersion, we control the vehicle through scripts based on the physical engine of Unity. The last independent variable is the crossing mechanism. The participant will be asked to show their crossing decisions in two ways: stepping as shown in the reference study forth and back, or actually crossing the street at the latest moment they felt appropriate. The last-moment constraint is because we wanted to measure the minimal accepted gap of the pedestrians as a dependent variable as elaborated in subsection 2.3.

Using a within-subject experiment design, we would have 8 combinations (2 driving behavior x 2 stopping behaviors x 2 crossing mechanisms), and we repeated the experiments twice. To avoid confusion caused by switching between the crossing mechanisms, we will run through the 4 variants with either mechanism (chosen randomly) and the same 4 variants with the other mechanism. Then we repeat the trials, reversing the order of the crossing mechanism. The order of the variants is also randomized (pseudo-random) for each crossing mechanism to avoid bias.

2.2 Procedure

When the participants arrive at the laboratory, the experimenter will welcome them and explain the experiment's setup. Then, after receiving informed consent, the experimenter will give detailed oral instructions on the procedure.

The experimenter will then ask the participant to move to the marked starting point and help the participant to wear the VR headset. Then the experimenter starts the test run, and the participant will then have the opportunity to get familiar with both crossing methods. After that, the experimenter will start the experiment.

After each completed interaction during the experiment, the experimenter will conduct a short oral interview to gather the self-reported factors that have influenced the participant's decision-making, the perceived difference to realism, and the participant's stress level (post-interaction interview). After the entire experiment, the experimenter will conduct another final oral interview (post-experiment interview) with the participant, followed by the last survey. The survey covers age, gender, perception of driver's attentional state, trust level based on a modified brief sensation seeking scale. Additionally, we used the presence questionnaire (four-factor model with 19 key variables) and the immersive tendency questionnaire (Witmer et al. 2005) to evaluate our research methodology's fidelity considering the participants' technical affinity. Finally, the experimenter provided an oral debriefing that explained the aim of the study, the Wizard of Oz aspect, and the variables measured.

2.3 Dependent variables

We adapted two dependent variables from the reference study. They were critical gaps and perceived driver's attentional state taken into account when deciding to cross the street. The critical gap or the critical headway is defined as "the time in seconds below which a pedestrian will not attempt to begin crossing the street" (Transportation Research Board 2010). It can be derived based on the position and velocity of the approaching vehicle when the pedestrian stepped back. These data are recorded via a script in the background. Secondly, We assess the perceived attentional states and how they affected the decision-making through related questions during the post-interaction interviews, post-experiment interviews, and the final questionnaire.

2.4 Participants

We plan to recruit 20 to 50 participants. They are required to have a good command of English and normal health conditions. In addition, the participants need to be used to interact with right-hand traffic. We will screen the interested persons with a revised short version of the Motion Sickness Susceptibility Questionnaire (MSSQ) (Golding 1998). We calculated a threshold for MSSQ short score based on an expected maximal exposure time and will reject those potentially subject to cybersickness. We plan to recruit via posters in facilities of the ETH campus, posts on social media, and individual recruitments.

Upon collecting enough data (N≥20), we will analyse the critical gap data and the self-reported stress, self-reported visual cues by means of frequency counts, means, and standard deviations. We will perform an analysis of variances on the dependent variables.

3. Results

Originally, we allowed the model of the vehicle to collide with the avatars of the participants, and such collisions were signalised through vibration to a controller held by the participants. However, it turned out that the scare level was perceived to be high, and participants tended to perform evasive manoeuvres, which led to an increased risk of tripping or bumping into the walls. Therefore, we removed the possibility of collisions and replaced it with a mechanism in which the vehicle disappears, either when the participants reach the midline of the road or when a possible collision will occur.

4. Discussion and Conclusion

Due to the actual pandemic situation, results will only be available at the date of the conference. However, we were able to discover potential limitation during our pilot studies: Firstly, participants needed time to get used to the last moment constraint we enforced to the crossing mechanism. A potential solution would be to gamify the crossing to motivate the same behavior but in a more subtle and intuitive way. Limited by time and human resources, both the driving behavior and the recording of the driver's face are pre-determined. To improve it, we could connect a driving simulator (Figure. 4) with the VR scene and recruit test drivers to steer the vehicle in real-time.

Figure 3. *The driving simulator in the laboratory*

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