An Empirical Study of Pedestrian-Vehicle Interaction Using Virtual Reality

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Abstract

The purpose of this research was to explore gesture interface of pedestrian and to propose socially appropriate movement gestures for vehicles. We conducted an observational study in locations that had 1) high volume of traffic, 2) intersections where constant interactions between pedestrians and vehicles occur, 3) no traffic lights to regulate the flow of traffic. We then developed a virtual crossing task (VCT), with independent variables selected based on the behavioral patterns we observed from the preliminary study. We measured head direction, crossing time, and success rate in crossing. Based on our observation, the speed, the size of the vehicle, and the number of pedestrians were the main factors of change in pedestrian movements (e.g., stopping). In the experiment, participants were more likely to keep caution by changing their head direction to look around when the vehicle was small and slowly approached the crosswalk and when a companion was present. In conclusion, we suggest that the interaction between autonomous vehicles and pedestrians should be understood as social interactions: social institutions and cultural differences should be considered when designing a 'socially' appropriate gesture interface of autonomous vehicles.

Keyword

Pedestrian-Vehicle Interaction, Virtual Reality, Attention

1. Introduction

With the lead of tech companies such as Google [1] and Uber [2], more fleet of autonomous vehicles is on the public road. The recent pedestrian fatalities with autonomous vehicles [3], however, raises the importance of an understanding of the interaction between two entities of road users: pedestrians and vehicles. The key to the introduction and application of the technology is the acceptance and trust of pedestrians as people engage in social interaction not only with other people but also with machines [4], [5].

Figure 1 "the Smiling Car", [6]

In response to the issue, industries have put efforts in resolving the concerns on the lack of communication channels between pedestrians and autonomous vehicles. The industry has invested in resolving this complex and uncertain communications: such as putting a visual display on the surface of a car [6] in order to send out a 'safe' signal or detecting the intentions of pedestrians using computer vision and machine learning methodology [7]. In research, recent methods include observation of interaction between pedestrians with real vehicles [8] or with simulated autonomous vehicles, using the Wizard-of-Oz methods [9], [10]. We contribute to this growing body of research through an exploration of socially desirable and safe movement gestures of vehicles for pedestrians. We first conducted a preliminary study in order to observe interactions between pedestrians and vehicles. The goal was to 1) observe general movement gestures of pedestrians such as staring, nodding, looking around, waving, and stopping when interacting with cars, 2) extract common gesture interfaces, and 3) to gain insight on selecting experimental variables. Next, we developed a virtual crosswalk setting to investigate how each factor affects the participants' behavior. By using virtual reality technology, producing a various type of crosswalk setting is possible: different traffic systems (left-hand and right-hand traffic) flow of pedestrians, and flow of vehicles. It is both cost-efficient, and safer than building an actual road or driving a car for experimental purposes.

2. Preliminary Study

We conducted observational studies to observe the behavioral patterns of pedestrians and their gestures when interacting with vehicles. We selected locations that had 1) high volume of traffic, 2) intersections where constant interactions between pedestrians and vehicles occur, 3) no traffic lights to regulate the flow of traffic. Four sites within Seoul met the criteria. We observed for 30 minutes, recorded all interactions, and categorized the behaviors by agent (pedestrian and vehicles). Figure 2 shows two of the locations we conducted the observation studies. Five researchers coded and rated the interactions and agreed to the narrowed down patterns of pedestrians and vehicles. We finalized 3 conditions for the experiment with 2 to 3 subcategories for each. Table 1 shows all experimental conditions.

Figure 2 Locations for observational study. We selected sites that had no traffic lights but had crosswalks so that we could observe constant interactions between pedestrian and vehicles when there were no traffic rules to control them.

Table 1 List of selected variables from the observational study

Variables	
Car Speed	Go-slow
	Slow-stop
	Sudden-stop
Car Size	Large
	Medium
	Small
Companion	Yes
	No

3. Experiment

3.1 Participants

A total of 37 participants were recruited (M_{age} = 24.14, SD_{age} = 4.92, N_{female} = 17) via on-campus online community. Prior to the test session, we asked participants whether they have had experience on VR devices, side effects such as nausea, dizziness, or vomiting after experiencing any virtual-reality based contents.

3.2 Materials

We used 1) head mounted display (HMD, HTC Vive Pro), 2) TPCAST adapter for wireless connection, and 3) two base stations for motion detection. The Vive Pro had a resolution of 2880 x 1660, a viewing angle of 110 degrees, and a frequency of 90 Hz. Barricades were placed at each corner of the room for safety reasons. Figure 2 illustrates the usual experimental settings.

3.3 Virtual Crossing Task (VCT)

We developed a Virtual Crossing Task (VCT) which is a simulated virtual crosswalk setting where pedestrians interact with driverless vehicles in three different places (urban area in Korea, urban area in a foreign country, and a rural place). The task was developed by using Unity 3D software (2017 version). Components such as building, landscape, and crosswalk were selected from the Steam VR library.

A total of 8 conditions with 3 independent variables (3 car size, 3 car speed, and 2 presence of a companion). The size of the vehicle was set to three conditions: large, medium, and small (Figure 3). The speed of the vehicle was set to three conditions: go-slow, slow-stop, and sudden-stop All vehicles were designed to run on one of the 3 options: 3.33m/s, 4.17 m/s, 5.56 m/s in random order. In slow-stop and sudden-stop condition, the vehicle stopped when the distance between a participant and a vehicle was less than 0.5 m.

Figure 3 Stimuli (vehicles) used for car size condition: small (left), medium (center), and large (right) vehicles.

The presence of the companion was set to two conditions: presence and absence. Figure 4 illustrates the appearance of the companion used in the task. In order to avoid the fatigue effect due to repeated exposure to the identical environment, 3 different types of background locations were selected: domestic city, foreign city, and rural area. A total of 54 trials were conducted (one trial for each condition).

Figure 4 Screenshot of a trial with a companion

We measured head direction, crossing time per trial, and success rate (successfully crossing without being hit by the vehicle). We measured head direction in order to find out whether participants 'look around' before or while crossing the crosswalk as it is considered as taking caution and sending a signal to the vehicle to notify one's presence.

Figure 5 Experimental settings

3.4 Procedure

All participants met the criteria and performed practice trial to get adjusted to the virtual reality settings. After getting comfortable with the task, participants started the test trials. First, a sign saying "Get a coin across the street within a time limit without being hit by a car" on the screen for 3 seconds and then disappeared. We set the time limit to 20 seconds and the visual feedback of diminishing time appeared on the right top of the screen. Feedback was given on the success and failure of each trial. If successful, the text "success" appeared on the screen. If the participant collides with the vehicle while crossing, or exceeded the time limit, a failure message appeared. At the end of each trial, a phrase "please move to the indicated (arrow) position for the next run" was shown on the screen, in order to start a new trial. Participants had to turn around in order to start a new trial, given that the task was designed to repeatedly conduct within 5m x 5m space (Figure 5). After the experiment, we conducted a post-experiment interview. We asked each participants of how similar the behavior they had shown in the experiment is to the usual crossing behavior, and how immersive the environment was on a scale of 5 (with '5' being the highest level). The entire procedure took up to 60 minutes per participant.

4. Results

4.1 Success rate

We considered the crossing successful when participants crossed the road without getting hit by a vehicle. If one got hit or overdue the given time, we counted the trial as fail. On average, the success rate for all 37 participants was 97.8%.

4.2 Crossing time

We measured the time it took for the participants to successfully cross the road (N = 37). Crossing time was the longest when large vehicles approached, (M = 8.71, SD = 4.78), followed by medium (M = 8.6, SD = 3.47) and small cars (M = 8.4, SD = 3.88). In car speed condition, crossing time was the longest in go-slow condition (M = 9.14, SD = 4.67) and the shortest in sudden-stop condition (M= 7.99, SD = 3.32) followed by slow-stop (M = 8.59, SD = 4.07) condition. Participants took more time to cross the road when a companion was present (M = 8.76, SD = 4.23), compared to the trials they crossed alone (M = 8.38, SD = 3.93).

4.3 Head direction

A total of 592 trials from 16 participants were included in the analysis. Head direction (x, y, z coordinates of head position) of the participant was measured in every 200ms. We calculated the polar coordinate system of each head position. We then visualized them in a polar grid with 12 labels of polar angles, and time on polar axis. The polar angle increases from the reference point (φ) of 0° in counterclockwise orientation. For the analysis purpose, we controlled the directions of the car position to the right side of the visual field (in the polar grid, any point between 225° and 315°). If participant looked around and the head direction overpassed anywhere between 55° of the front view (between 45° and 315° on the polar grid), we considered it as 'look-around' gesture. For each condition, we counted the number of head position any point between 45° and 315° as those are the locations where one can look at only by moving their head to either left or right. Participants changed their head direction most often when a small car was present (34, 29, 28 times for small, medium, and large cars respectively, Figure 6). Number of head direction changes were 46, 45, and 17 times for slow-stop, sudden-stop, and go-slow conditions respectively (Figure 7). Figure 8 shows that participants changed their head direction more often when crossing with a companion than when there was none (23 and 17 times, respectively).

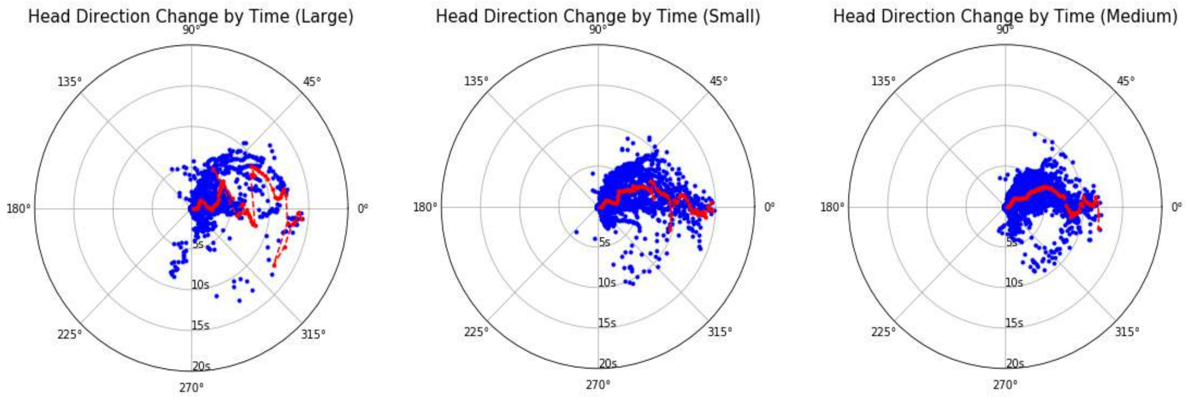

Figure 6 Head direction change by car size. Blue dots indicate head position of individuals in every time frame. Red curve indicates the mean head position of each time frame. Participants looked around the most frequent (by changing their head direction toward the position of the vechicle) when the vehicle was small.

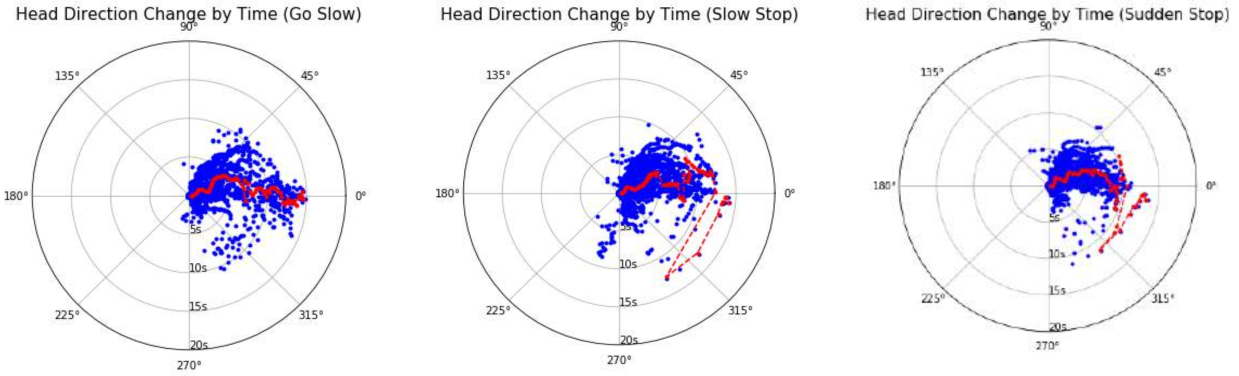

Figure 7 Head direction change by car speed. Participants looked around the most frequent when the vehicle slowly stopped.

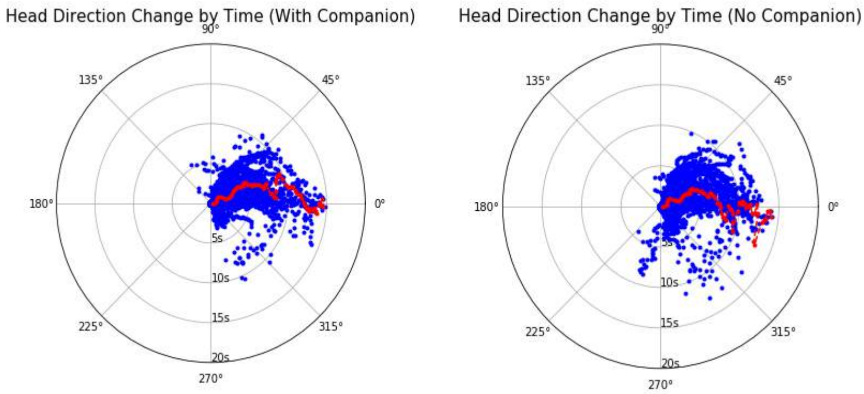

Figure 8 Head direction change by presence of companion. Participants looked around more when they crossed with companion.

5. Conclusion

In our preliminary study, we explored general gesture interfaces that pedestrians and vehicles give out in the real road setting to gain insight on how pedestrians and vehicle drivers interact. We implemented findings from our exploration by developing a virtual crossing task, a virtual-reality based simulated crossing scenarios, where participants, as pedestrians, could simulate different types of movement gestures. For example, we as researchers could manipulate different situational factors such as the number of the autonomous vehicles, or the number of companions, at no cost (i.e., by not actually putting participants in danger). Our results indicate that how many situational factors (e.g., size, speed, traffic, and road settings) are important in crossing decision for pedestrians.

We contribute to the growing body of research and development on socially acceptable gestures of autonomous vehicle. It is proposed that the designers of autonomous vehicle should consider different reactions to autonomous vehicles in different situations (e.g., road regulations, flow of traffic, or nations) when designing interfaces that aid crossing decisions for pedestrians and driving algorithms of future autonomous vehicles.

Acknowledgement

This research was supported by 2018 interdisciplinary research project funded by the Korean Psychological Association.

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