Negative Effect of External Human-Machine Interfaces in Automated Vehicles on Pedestrian Crossing Behaviour: A Virtual Reality Experiment

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Abstract. Communication between pedestrians and automated vehicles is playing a key role in enhancing the safety of future traffic environment. The current study attempted to suggest new insights into designing external human-machine interfaces (eHMIs) in automated vehicles for traffic safety as examines negative effects of the eHMI on pedestrian crossing behaviour in a situation where an automated vehicle yields to pedestrian. Virtual Reality systems simulated three experimental conditions: baseline (no eHMI), showing "After you" and "I'll stop" via eHMI on an automated vehicle in residential areas. The experiment using human participants resulted that conveying information via eHMI led pedestrians to do less careful exploratory behaviour toward other traffic. The result also showed the greater number of traffic collisions when the eHMI showed information compared to non-eHMI condition. The findings of this study are also being used to help how to design the eHMI on automated vehicles in shared spaces.

Keywords: Driving automation, External human-machine interface, Pedestrian crossing, Interface design, Virtual reality.

1 Introduction

Driving automation is expected to bring new paradigms to surface transportation. This technology has promised a myriad of benefits, including energy resumption, traffic efficiency, and reducing traffic accidents. Following levels of driving automation defined by SAE International [1], automated vehicles with low levels of driving automation are already realised in the current market via several motor companies. Unlike the low levels that demand human drivers to intervene vehicle controls if necessary or when the automation issues a request to intervene in system failure, high levels of automation are able to undertake all dynamic driving tasks themselves. The highly developed automated vehicle is considered to be one of Mobility as a Service for improving quality of life in rural areas as well as to reduce drivers' workload produced by vehicle controls.

As driving automation develops, communication between road users and automated vehicles has become an important research topic to improve traffic safety. Implicit communication among road users, such as making hand signals and eye-contact, enables them to communicate their intention, resulting in traffic efficiency and safety. However, considering symbiotic traffic environments with pedestrians and vehicles equipped with high levels of driving automation, the lack of communication possibly occurs due to the absence of human drivers. Developing explicit communication tools for effective human-vehicle communication is expected to address such problems.

Presenting information via external human-machine interfaces (eHMIs) on automated vehicles is considered to be one of solutions to reduce latent accident risk by failure in communication between road users and automated vehicles. Accordingly, interface design concept has been suggested with respect to several factors, such as display colour [2–3], message voice [4], interpretability [4], location [5], and screen size [6] and communication partner [7]. In recent years, a myriad number of studies on eHMIs have emerged with expected benefits to road users as automated vehicles feature the eHMI.

However, it cannot affirm that information from the eHMI produces positive outcomes. One possible concern is that pedestrians are likely to shape inappropriate attitude towards the automated vehicle. Crossing after checking road situations is essential role of traffic participants, however, if they judge to cross relying on the information via eHMIs, they might not deal with latent traffic risk. Whilst pedestrian attitude towards automated vehicles, including trust or acceptance, has been widely investigated [8], the research to date has tended to focus on positive effects of eHMI rather than negative effects.

The current study seeks to address negative effects of eHMIs on automated vehicles. Virtual reality (VR) experiments using human participants were conducted to observe pedestrians' crossing behaviour when the eHMI on automated vehicle is projected.

2 Methods

2.1 Participants

Fifty-seven non-elderly participants (30 females) aged between 22 and 45 years (M = 30.39 years, SD = 8.35) took part in the current study. All participants were monetarily reimbursed JPY 3000 for their partaking. This experiment using human participants complied with the ethics code of Keio University and was approved by the ethical review board (REF No. 2020-63). Written informed consent was obtained from each participant.

2.2 Apparatus

We used HTC Vive VR systems to simulate a Japanese residential road environment (e.g., [9]). A head mount display presented the simulated road, with two screens (90 FPS, 2160×1200 binocular resolution, a field of view of 110 degrees). Two controllers included a trigger and clip buttons, and a trackpad. Lighthouse that is a tracking system on two HTC base stations beamed infrared lasers to the HMD and controllers in order to track participants' movement and orientation data. As each base station has a 150-degree horizontal field of view and a 110-degree vertical field of view, distance between two base stations was 3.6m. The participant was positioned between the two base stations. To run the materials, we used two computers (DELL Alienware Aurora R7 with Intel Core i7-8700 CPU, 16 GB RAM, and NVIDIA GeForce GTX 1080 GPU and Alienware Area-51 R5 with Intel Core i9-7940X CPU, 32 GB RAM, and NVIDIA GeForce GTX 1080 Ti). Fig. 1 indicates the experimental environment setup at Keio University.

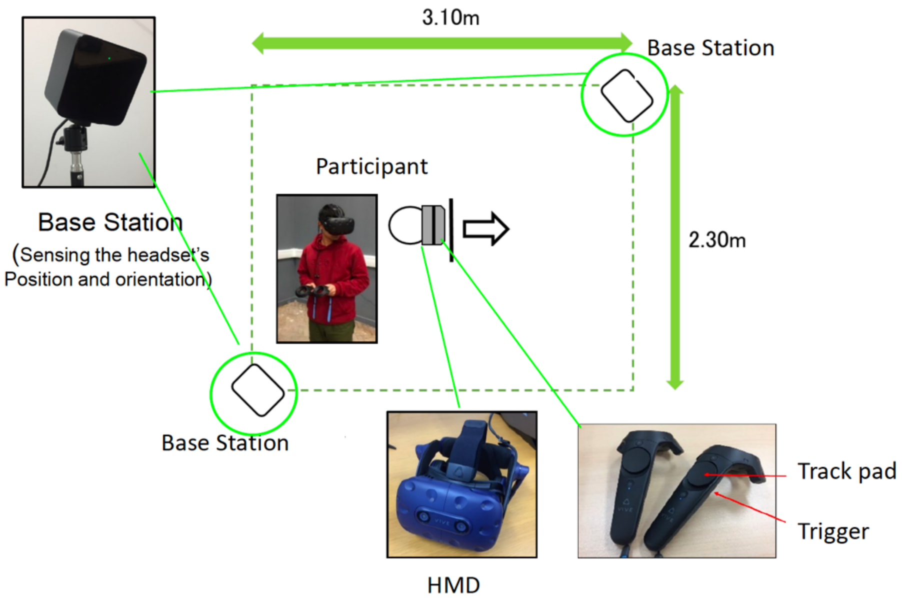

Fig. 1. Experimental setup.

2.3 Experimental Design

A between-subject design was used, with eHMI manipulations: no eHMI (Baseline), displaying a text message of "After you" (eHMI-A), and displaying a text message of "I'll stop" (eHMI-E) (see Fig. 2). As text-based eHMIs do not require participants to learn what displayed information means like anthropomorphic symbols [10], the current study prepared two types of text messages (eHMI-E and eHMI-A) [4]. Eleven experimental events were simulated on a two-way two-lane residential road. The participant experienced a critical event after the exposure to ten traffic events which were designed to shape pedestrian attitude towards the eHMI. In the critical scenario, there were two trucks and an automated vehicle on the road when the participant was on the start point. Here, the two trucks and the automated vehicle stopped in the left and right side of the participant respectively. The automated vehicle yielded the road to the pedestrian, with projecting two types of text messages or not displaying any signals, the participant then started to cross the zebra crossing as shown in Fig. 3.

Fig. 2. The three eHMI manipulation types

Careful exploratory behaviour of pedestrians is required to cope with an approaching vehicle from the left side. The pedestrian could not find the vehicle without looking toward the left side because a large truck obstructed to have a wide view of traffic environment, consequently, collisions occurred for the pedestrians who could be not aware of the vehicle. As the reason why the pedestrian did not check the left side, pedestrians' decision-making depending on only information via the eHMI on the automated vehicle from the right side is considered (see Fig. 3). More specifically, if the participant crosses the zebra crossing with decisions based on information via the eHMI, they might have collisions with the approaching vehicle due to reliance on the eHMI. This can be considered to be a negative effect as providing information via the eHMI on automated vehicles.

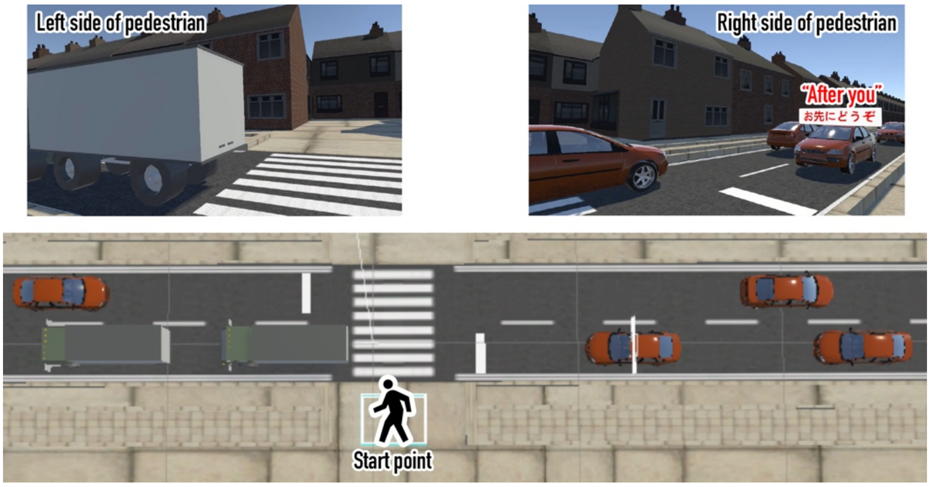

Fig. 3. Experimental road environment.

2.4 Procedure

Upon arrival, the overview of experiment was briefly explained by an experimenter, and informed consent was obtained from each participant. A practice was provided to become familiar with the VR setup, such as using controller and checking motion sickness. After the practice, participants moved on the experimental trial. In total, eleven critical events on the residential road were presented to the participant, and participants were asked to cross after checking traffic environment by pressing the trigger on the controller. Each participant responded three subsequent questionnaire items with 5 Likert-scale on the screen after the trial. The duration of the experiment was around 40 mins.

2.5 Statistical Analyses

To look into negative effects of the eHMI on pedestrian crossing behaviour, we classified three types of pedestrian behaviour: looking toward the left during crossing, stopping on the middle of zebra crossing, and having near misses with the oncoming vehicle. Here, the pedestrian behavioural data collected from the VR system were used to examine the negative effect across three experimental conditions (Baseline, eHMI-A, eHMI-E). More specifically, data in the 11th event were facilitated for statistical analyses as the participant shaped their attitude towards the automated vehicle throughout the ten events. The data collection was submitted to Chi-squared analysis. As data from 11 participants were not tracked correctly, these data were eliminated. All statistical analyses were implemented in IBM SPSS version 26.

3 Results

Table 1. The cases whether pedestrians did look toward the left, stop on the zebra crossing, and avoid collisions with the vehicle from the left side or not (Y = Yes; N = No).

	Looked		Stopped		Collided	
Condition	Y	N	Y	N	Y	N
Baseline	16	1	14	3	3	14
eHMI-A	11	5	11	5	5	11
eHMI-E	11	2	11	2	3	10

As aforementioned, we set three time points with respect to pedestrian crossing process. Looking toward the left side and stopping on the zebra crossing during the crossing, and whether the pedestrian was able to avoid collisions with a vehicle from the left side. Table 1 describes the number of pedestrians according to their behaviour at three time points: looking toward the left during crossing, stopping on the zebra crossing during crossing, and having collisions with an approaching vehicle from the left. The observed cases for each time point were 17, 16, and 13 in the Baseline, eHMI-A, and eHMI-E respectively.

3.1 The ratio of pedestrians who looked toward the left during crossing

As shown in Table 1, relatively small number of looking toward the left during crossing was observed in the Baseline compared to two eHMI conditions. Data provided a favourable difference in the ratio of pedestrian who looked toward the left during crossing between the Baseline and eHMI-A conditions, $\chi^2(1) = 3.57$, $p = .059$. This indicates that the ratio of pedestrians who performed scanning behaviour was higher in the Baseline than the eHMI-A.

3.2 The ratio of pedestrians who stopped on the crosswalk during crossing

In the process of crossing which a vehicle is coming from the left, pedestrians should stop to avoid collision with the vehicle. Whilst there was no change in the cases for the eHMI-A and -E conditions between time points of looking and stopping during crossing, two more cases were observed in the Baseline between these two time points (see Table 1). However, the ratio of pedestrians who stopped on the crosswalk during crossing and did not have collisions with the oncoming vehicle was also the highest in the Baseline compared to those of eHMI-E and -A. For the stopped cases, the ratio of the Baseline, eHMI-E, and eHMI-A was 0.82, 0.85, and 0.69 respectively. The Chi-squared test did not find significant differences among all experimental conditions.

3.3 The ratio for no collision cases

The ratio for no collision cases was 0.82, 0.77, and 0.69 respectively (Table 1). Data in terms of collision number provided that providing the intention of automated vehicles via the eHMI possibly provokes higher collision risk compared to when no information is displayed on the automated vehicle. This tendency seems similar to the observation for the stopped cases during crossing. Likewise, data did not provide significance, all $\chi^2 < 0.98$, $p > 0.32$.

4 Discussions

The main objective of this study was to observe a negative effect of eHMI messages in automated vehicles on pedestrian crossing behaviour. We classified three types of behaviour with regard to pedestrian crossing process (looking the left side, stopping on the middle of crosswalk, and collision with the upcoming vehicle).

Results found that pedestrians are likely to allocate their attention on the sides during crossing when automated vehicles do not project any signs via eHMIs. In comparison with this case, the lesser number of scanning behaviour was observed in both eHMI conditions. As the participant had more exploratory gaze behaviour in the Baseline than the eHMI-A, providing information via eHMIs with road users may lead relatively high reliance on automated vehicles, resulting in careless crossing behaviour without comprehensive understanding of traffic situations. Also, no significance in terms of stopping and collisions may indicate that the eHMI has a substantial impact on the beginning of crossing process. Next study should collect data of pedestrians' gaze behaviour to investigate their cognitive process to make decision in crossing [11].

One possible concern tangled with negative effects of the eHMI on crossing behaviour is pedestrians' attitudes towards automated vehicles. The higher levels of trust or reliance, the lesser careful crossing behaviour, resulting traffic accidents. This study provided empirical findings as analysed the number of pedestrians who checked traffic environment, made stopping after being aware of the approaching vehicle from the left side, and avoided vehicle collisions. Several participants in the post-experiment interview reported that they thought that the yielding vehicle displayed the message via the eHMI with comprehensive understanding of encountering traffic environment. This tendency indicates pedestrians' inappropriate trust towards the automated vehicle. Future study is expected to investigate pedestrian attitude towards eHMIs with questionnaire items, such as users' trust or acceptance [8].

These findings should be highlighted with several limitations. First, even though the participant experienced eleven traffic events in this VR study, all prepared events were very similar. This VR environment was limited in observing the precise number of near misses. Lastly, an equal participant number for each experimental condition is also important to bring convincing statistical findings. However, aforementioned findings can contribute to designing the eHMI for automated vehicles as well as developing training methods for road users who will share the road with automated vehicles.

This study found that displaying allocentric messages via eHMIs contributed to pedestrians' relatively careless scanning behaviour toward the left before crossing compared to when non-information was provided from automated vehicles. Findings from this study suggest a different point of view in terms of negative effects of eHMIs in certain traffic situations inconsistent with positive effects of eHMIs on road safety reported in previous studies.

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