External Human-Machine Interface Designed for Autonomous Vehicle-to-Pedestrian Communication: Effectiveness and User Acceptance

Yuan LIU, Matthias ROETTING

Department of Psychology and Ergonomics, Technische Universität Berlin
Marchstraße 23, D-10587 Berlin, Germany

Abstract. External Human-Machine Interfaces (eHMIs) can support the safe and efficient interaction between autonomous vehicles (AVs) and pedestrians in future urban traffic. In the presented study, 4 advice-based eHMIs and 4 information-based eHMIs were designed to display different messages (i.e. road-crossing advice and AV intended actions, respectively) for AVs to communicate with pedestrians. Participants were asked to cross a street with and without eHMIs in a virtual traffic environment wearing the head-mounted display. Results showed that the advised-based eHMIs in the formats of text and well-known symbols gained the best user acceptance and were most effective to improve pedestrians' decision making in the interaction between an AV and a pedestrian. Participants also expressed interest in receiving information about where the AV will stop.

Keywords: Human-machine-interface, autonomous vehicle, vehicle-to-pedestrian communication, crossing behaviors

1. Introduction

The development of vehicle automation will ultimately make it possible that no human drivers are needed to monitor and supervise driving tasks in the future. With no human driver inside, relying on traditional communication methods such as eye-contact and gestures to communicate with pedestrians will be impossible for the autonomous vehicles (AVs). To support the interaction between AVs and pedestrians, displaying messages to pedestrians via an external human-machine interface (eHMI) was proposed as an alternative way for vehicle-pedestrian communication.

To date, a majority of studies focused on developing eHMIs to transmit advice-type of messages to instruct the pedestrian to cross or not (Hudson et al. 2018; Holländer et al. 2019). However, many surveys also indicated that pedestrians expected to receive information about the vehicle's actions or intended behaviors (Merat et al. 2018; Shieben et al. 2019). In this respect, different types of eHMIs, varying in formats of text, light and symbol, were developed in this study to transmit different messages including road-crossing advice and AV's intended actions (i.e. whether decelerates, whether to stop or where to stop) from the perspective of pedestrian and vehicle, respectively. The eHMIs were designed with the expectation to effectively help pedestrians safely and efficiently interact with an AV in the crossing situation. The safe interaction means that pedestrians should not cross the street when the approaching AV maintains speed. The efficient interaction means that pedestrians make faster decision to cross. In this regard, the effectiveness of the eHMIs were examined by looking at their effects on pedestrians' crossing behaviors, specifically, the decision safety and pedestrians' crossing decision time. Additionally, pedestrians' subjective acceptance and perceptions of the eHMIs were also investigated.

2. Method

2.1 External human-machine interfaces

8 visual concepts of eHMI in the formats of text, light and symbol were considered in this study: (1) text-advice, (2) knightrider, (3) ampelmann, (4) ground-advice, (5) text-intention, (6) speed-bar, (7) stick-figure, (8) driving-path. As shown in Table 1 & 2, these eHMIs were designed by employing elements derived from the traffic system or existing studies in order that the eHMIs could be easily understood by participants. Considering that the advice-based eHMIs aimed to give road-crossing advice from the pedestrian's perspective (see Table 1), these eHMIs were coded with traffic colors. Green indicated that the pedestrian could cross. Red indicated that the pedestrian should not cross. Since the information-based eHMIs showed AV's actions (i.e. whether the AV decelerates, whether it will stop and where it will stop) from the vehicle's perspective without any motivation to give suggestion, yellow, the neutral color in traffic, was used in these eHMIs (see Table 2). The eHMI (2) and (6) had animations. The green light-bar of eHMI (2) moved from left to right repeatedly when the AV yielded. If the AV did not yield, the red light-bar stayed static in the middle. The length of the light-bar in eHMI (6) got shorter and shorter when the AV yielded. When the AV stopped, only the middle light stayed and all the other lights in left and right sides were turn off. If the AV did not stop, the light-bar stayed in full length.

Table 1. *Advice-based eHMIs for the communication in yielding (Y) & non-yielding (N-Y) scenarios.*

	Text-advice	Knightrider	Ampelmann	Ground-advice
Y				
N-Y				
Source	Fridman et al. 2017	de Clercq et al. 2019	Traffic system (in Berlin)	Clamann et al. (2017)

Table 2. *Information-based eHMIs for the communication in yielding (Y) & non-yielding (N-Y) scenarios.*

	Text-intention	Speed-bar	Stick-figure	Driving-path
Y				
N-Y				
Source	Fridman et al. 2017	Lagstrom & Lundgren 2015	Vehicle brake symbol	Traffic system (stop line)

2.2 Experiment design and the procedure

Participants' crossing behaviors in the virtual traffic happened in the midblock of the street without any crossing marks and traffic lights. As shown in Figure 1, the street had one lane with a width of 3.5m per way. The traffic flow consisted of randomly 3~8 manually driven vehicles (MVs) and an AV. All vehicles drove at 40km/h. The MVs in the right side of the AV (R-MVs) never yielded. The AV in yielding scenario braked at point "D" and came to a full stop at 7m away from "B". The MVs which followed the AV (F-MVs) yielded with the same deceleration (2.68m/s^2) as the AV. When the AV arrived at point "P", all R-MVs passed "B" and the eHMIs were visualized. The gap between each pair of neighboring R-MVs or F-MVs ranged randomly within 1.3~1.8s. The gap between the leading MVs in each lane and "B" was 0~0.5s randomly.

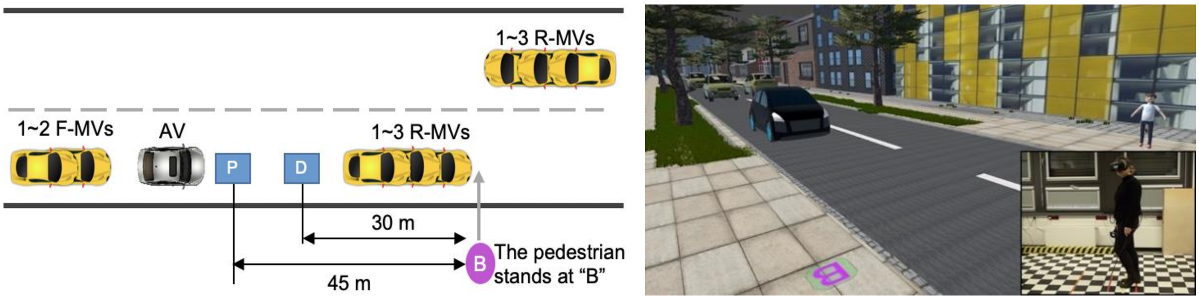

Figure 1. *Left: The virtual traffic flow. Right: An example scene of the virtual traffic (The virtual traffic was displayed in the HTC Vive with a resolution of 2160×1200 pixels).*

The experiment was 9 (eHMI concepts) ×2 (scenarios) ×3 (repetitions) within-subject design. The eHMI concepts consisted of a baseline without eHMIs and the 8 aforementioned eHMIs. There were 2 scenarios: the yielding scenario in which the AV yielded to the pedestrian and the non-yielding scenario in which the AV did not yield to the pedestrian and drove pass the pedestrian in a constant speed. These scenarios were chosen to force the participants (i.e. pedestrians) to evaluate the road-crossing situations carefully without presupposing the AV will always stop for them. The 54 crossing situations were organized in 3 blocks. In the first block, participants repeatedly experienced the 2 scenarios without eHMIs (baseline) for 3 times. The order of the 6 crossing situations were randomized. In the second and third blocks, participants experienced the 2 scenarios with 4 advise-based eHMIs and 4 information-based eHMIs, respectively. The 8 crossing situations within each block repeated 3 times. In each repetition, the 8 crossing situations were randomly ordered. Latin squares with n=3 were used for varying the order of the 3 blocks.

Before starting the experiment, a consent form was signed, and a demographic questionnaire were filled by participants. After that, participants did some practice until they understood the procedure and behaved naturally in crossing the street. During the experiment, participants were informed of the presence of eHMIs in each block. In each trial, they were instructed that they wanted to cross the street to meet a friend in the opposite side. They were asked to cross in a normal walking speed. Their tasks in each trial were: 1) check the traffic before crossing, 2) when feel safe to cross, walk forwards (3 steps) as soon as possible. To reduce fatigue effect, participants took a short break after each block or every 8 trials. A questionnaire for measuring the user acceptance of each eHMI was provided after all the trials. Finally, the participants were interviewed with semi-structured questions. The whole procedure lasted for about 90 min and participants got rewards for their time afterwards.

2.3 Participants

30 participants (40% females and 60% males, mean age=28.80 years, SD=7.59) took part in the experiment. No Participants had color blindness. All participants had normal or correct-to-normal vision. 76.67% participants had a motor vehicle driving license (average driving year=6.72 years, SD=4.49). 22 participants were German. The foreign participants were living in Germany when they took part in the experiment.

3. Results

3.1 Pedestrian's crossing behaviors

Pedestrians stepped into the street before the AV came to a full stop in 64.58% of the crossings with an eHMI, comparing to 28.89% of the crossings without an eHMI. There was no difference among eHMIs on decision safety (DS) in the yielding scenario since all pedestrians safely crossed. In the non-yielding scenario, pedestrians made the safe decision (i.e. wait) in 97.78% of cases with an eHMI, comparing to 81.11% of cases without an eHMI. Cochran's Q test and post-hoc pairwise comparisons revealed significant differences on DS among the eHMIs ($\chi^2(8)$ =56.814, p<.001) and the DS for each eHMI was significantly higher (p<.001) than the baseline (no eHMI).

Pedestrian's crossing decision time (CDT) was calculated, in the yielding scenario, from the time that the eHMI was visualized to the time that the pedestrian stepped into the street. Results of Friedman test showed that the type of eHMI significantly influenced the CDTs (averaged in three repetitions per eHMI; Figure 2, Left): $\chi^2(8)$ =147.15, p<.001, W=.61. Pairwise comparisons showed that participants' CDTs were significantly shorter for the text-advice (z=-4.35, p<.001, r=.56), ampelmann (z=-3.75, p<.001, r=.48) and ground-advice (z=-4.43, p<.001, r=.57) than for the baseline. No significant differences on CDT (p>.0013) were found among these three eHMIs or between other eHMIs and the baseline. The CDTs for the speed-bar and stick-figure were significantly higher (p<.001) than the other six eHMIs.

3.2 Subjective acceptance and perceptions

The questionnaire for measuring user acceptance (Van Der Laan et al. 1997) consisted of two subscales: usefulness and satisfying. As to the usefulness, results of Friedman test revealed that the differences among the rating scores (RSs) for the eHMIs were significant ($\chi^2(7)$ =116.11, p<.001, W=.55). Pairwise comparisons showed that text-advice was perceived significantly more useful than 5 of the other eHMIs: knightrider (z=-4.45, p<.001, r=.57), text-intention(z=-4.22, p<.001, r=.54), speed-bar (-4.79, p<.001, r=.62), stick-figure (z=-4.79, p<.001, r=.62) and driving-path(z=-3.21, p=.0013, r=.41). There were no significantly differences (p>.0017) among the RSs for the eHMIs of text-advice, ampelmann and ground-advice. The RSs for the speed-bar and stick-figure were significantly (p<.001) lower than the other eHMIs. As to the satisfying, the differences of RSs among the eHMIs were also significant ($\chi^2(7)$ =81.54, p<.001, W=.39). The RSs for the text-advice and ampelmann were significantly (p<.001) higher than 4 of the other eHMIs: knighterider, text-intention, speed-bar and stick-figure. The RSs for the speed-bar was significantly (p<.0017) lower than 6 of the other eHMIs excepting the stick-figure. No significant differences (p>.0017) of RSs were found among the text-advice, ampelmann and ground-advice and driving-path, or between the speed-bar and stick-figure.

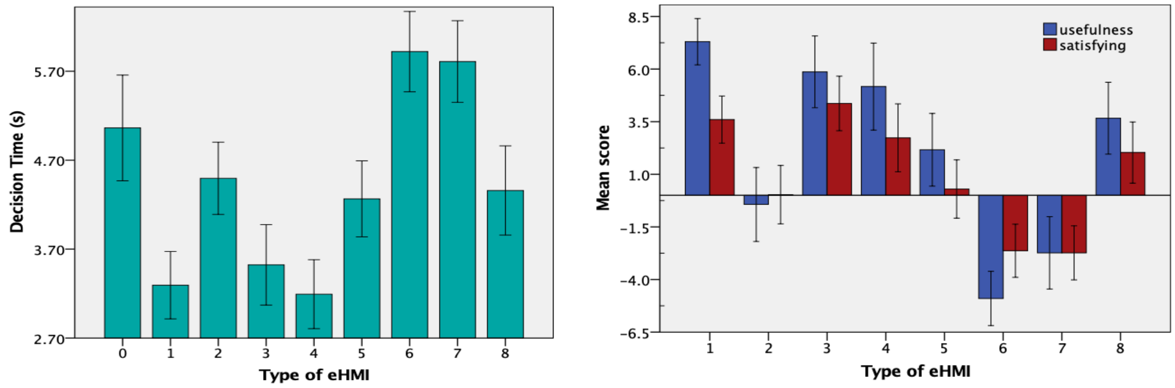

Figure 2. *Left: Mean decision time for each eHMI across three repetitions. Right: Mean rating scores for user acceptance according to the type of eHMI. Error bars denote a 95% confidence interval. (The numbers from 0 to 8 on the horizontal axis represent: No eHMI (the baseline) and the (1) to (8) eHMIs, respectively.)*

In the interview, participants expressed their understandings of the eHMIs and indicated what they liked / don't liked about the eHMIs. It showed that all participants understood the messages conveyed by the eHMIs of text-advice, text-intention, ground-advice, ampelmann and driving-path, and they liked the green/red color-coding of the advice-based eHMIs. 90% participants stated they liked the concept of the "stop line" in driving-path which gave a direct message of where the AV would stop. Although being familiar with the symbols of ampelmann, some participants worried the berlin-style symbols not easy to understand and distinguish by people in other cities/countries. The knightrider, speed-bar and the stick-figure were the ones hardest to understand. When encountered the speed-bar, some participants told that it took long time to make decision because they had to see how the bar is changing and figure out whether the car will stop. After being informed of the messages conveyed by the speed-bar, the majority thought the speed-related messages were unnecessary since it was normal that vehicles adjusted speeds according to the traffic flow in real traffic.

The question on the preference of these two kinds of eHMIs (advice-based *vs*. information-based eHMIs) was asked finally. 36.7% participants insisted that they wanted to take responsibility to make their own crossing decisions instead of being told to cross or not. 63.3% participants expressed their preference on the color-coded advice-based eHMI or the driving-path with "stop line" since the messages can be quickly extracted. However, 56.7% participants who considered the complex situations in real traffic suggested that self-assessments of pedestrians based on the information from the AV about its intended actions would be safer. After answering this question, 43.3% participants particularly mentioned that the driving-path was their favorite or the second favorite eHMI.

4. Discussion

Using virtual traffic environment, the results in this experiment indicated the introduction of a properly designed eHMI could improve pedestrians' crossing-decision making by improving the decision safety and decreasing the decision time. In addition, pedestrians were more willing to step into the street before the AV came to a full stop when an eHMI was employed. Among the eHMIs, text could give explicit messages, but was hard for pedestrians to quickly get messages from far and unsuitable for providing access to people who cannot read (de Clercq et al. 2019). The symbols used for the eHMI should be international in order to be understood by people from all over the world. Besides, signs displayed on the ground without any visible connection to the AV might be not easy to notice since pedestrians always focused their attention on the vehicle firstly instead of somewhere else on the ground, as told by the participants.

Advice given in proper formats was proved to be most effective to support the interaction between an AV and a pedestrian in this experiment. However, as pointed by participants in the interview, giving advice to pedestrians in more complex situations might bring about some negative effects. For instance, being misleading to other pedestrians and reducing pedestrians' attention on the traffic. In this regard, it might be more meaningful, in complex situations, to find a proper way to show the AV's intended actions from the vehicle's perspective instead of simply giving advice. In this experiment, although there were some participants who thought the design of the diving-path still should be improved, the "stop line" was regarded as intuitive and showing where the AV will stop was considered helpful by some participants even for more complex situations with multiple pedestrians.

5. Conclusion

The presented experiment revealed that the eHMIs could improve the safety of the interaction between an AV and a pedestrian. Participants preferred the green/red color coding of the advice-based eHMIs. The advice-based eHMIs in the formats of text and well-known symbols gained the best user acceptance and were proved to reduce pedestrians' decision time significantly. The experiment also showed that pedestrians were interested in receiving information about where the AV will stop. In future studies, we will explore the effects of different eHMI concepts on pedestrians' crossing behaviors in more complex traffic situations.

6. References

Clamann, M., Aubert, M., & Cummings, M. L. (2017). Evaluation of vehicle-to-pedestrian communication displays for autonomous vehicles. Proceedings of the Transportation Research Board 96th Annual Meeting, Washington DC.

de Clercq, K., Dietrich, A., Núñez Velasco, J. P., de Winter, J., & Happee, R. (2019). External human-machine interfaces on automated vehicles: effects on pedestrian crossing decisions. Human factors, 0018720819836343.

Fridman, L., Mehler, B., Xia, L., Yang, Y., Facusse, L. Y., & Reimer, B. (2017). To walk or not to walk: Crowdsourced assessment of external vehicle-to-pedestrian displays. arXiv preprint arXiv:1707.02698.

Holländer, K., Colley, A., Mai, C., Häkkilä, J., Alt, F., & Pfleging, B. (2019). Investigating the Influence of External Car Displays on Pedestrians' Crossing Behavior in Virtual Reality.

Hudson, C. R., Deb, S., Carruth, D. W., McGinley, J., & Frey, D. (2018). Pedestrian perception of autonomous vehicles with external interacting features. In International Conference on Applied Human Factors and Ergonomics (pp. 33-39). Springer, Cham.

Lagstrom, T., & Lundgren, V. M. (2015). AVIP-Autonomous vehicles interaction with pedestrians. Master of Science Thesis, Chalmers University of Technology.

Merat, N., Louw, T., Madigan, R., Wilbrink, M., & Schieben, A. (2018). What externally presented information do VRUs require when interacting with fully Automated Road Transport Systems in shared space?. Accident Analysis & Prevention, 118, 244-252.

Schieben, A., Wilbrink, M., Kettwich, C., Madigan, R., Louw, T., & Merat, N. (2019). Designing the interaction of automated vehicles with other traffic participants: design considerations based on human needs and expectations. Cognition, Technology & Work, 21(1), 69-85.

Van Der Laan, J. D., Heino, A., & De Waard, D. (1997). A simple procedure for the assessment of acceptance of advanced transport telematics. Transportation Research Part C: Emerging Technologies, 5(1), 1-10.

Acknowledgement. This work is supported by China Scholarship Council.

Gesellschaft für
Arbeitswissenschaft e.V.

Digitale Arbeit, digitaler Wandel, digitaler Mensch?

66. Kongress der
Gesellschaft für Arbeitswissenschaft

TU Berlin
Fachgebiet Mensch-Maschine-Systeme

HU Berlin
Professur Ingenieurpsychologie

16. – 18. März 2020, Berlin

GfA-Press

Bericht zum 66. Arbeitswissenschaftlichen Kongress vom 16. – 18. März 2020

TU Berlin, Fachgebiet Mensch-Maschine-Systeme
HU Berlin, Professur Ingenieurpsychologie

Herausgegeben von der Gesellschaft für Arbeitswissenschaft e.V.
Dortmund: GfA-Press, 2020
ISBN 978-3-936804-27-0

NE: Gesellschaft für Arbeitswissenschaft: Jahresdokumentation

Als Manuskript zusammengestellt. Diese Jahresdokumentation ist nur in der Geschäftsstelle erhältlich.

Schriftleitung: Matthias Jäger
im Auftrag der Gesellschaft für Arbeitswissenschaft e.V.

Screen design und Umsetzung
© 2020 fröse multimedia, Frank Fröse
office@internetkundenservice.de · www.internetkundenservice.de