Effect of the External Human Machine Interface (eHMI) of Automated Vehicle on Pedestrian's Recognition

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ABSTRACT

The interaction between a pedestrian and an automated vehicle equipped with an external human machine interface at an unsignalized crosswalk is discussed. The external human machine interface has the potential to provide an effective communication cue from which the pedestrian can judge whether the automated vehicle is yielding to them.

1 INTRODUCTION

Traffic participants such as human drivers, cyclists, and pedestrians interact with each other in mixed-traffic environments (e.g., at intersections, in parking lots, and at crosswalks (i.e., pedestrian crossings)). In such situations, a participant must judge whether another participant is yielding to him/her. Previous research on the interaction between the human driver and pedestrian at an unsignalized crosswalk found that vehicle and driver behaviors are important in the decision making of the pedestrian [1]. Such interaction not only improves the safety of the pedestrian but also realizes smoother transportation. It therefore seems that vehicle and driver behaviors are effective communication cues. However, automated vehicles (AVs) are not always directly driven by a person, and interactions between traffic participants become difficult when an AV is involved because the necessary interactions are human based. Previous research found that pedestrians hesitated in crossing a crosswalk in front of an AV controlled by a driver who wore a costume that had the appearance of the driver's seat and who was thus not visible to the pedestrian [2]. This implies that pedestrians do not feel safe in the presence of a vehicle without a driver when there is a lack of communication cues needed to judge whether to cross. The use of an external human machine interface (eHMI) for the AV has thus been suggested as way of providing effective communication cues that inform other traffic participants of the automated driving status of the autonomous system and plan of maneuvering. eHMIs for AVs have thus been researched and developed by many institutes and manufacturers.

A previous study focused on possible features of the eHMI and applied some of these features in experiments; e.g., experiments have been conducted by presenting a walking silhouette, the text 'Braking', a flashing smile, a horn sound, music, and a verbal warning 'Safe to cross' to convey the intent of the AV to the pedestrian [3]. However, it was difficult for participants to precisely interpret the message content of the eHMI. Another study conducted a subjective evaluation involving photographs and questionnaires to investigate the pedestrian's recognition of several features and contents of eHMI [4]. However, it was difficult for participants to perceive the vehicle behavior from those materials. It therefore seems that results were not affected by vehicle behavior, which is an important communication cue. A test track experiment investigated the pedestrian's recognition of the intentions of an AV on the basis of whether a driver was present in the AV and whether an eHMI was installed on the AV [5], but the vehicle behavior was controlled manually by the passenger sitting next to the driver using a joystick connected to a laptop that controlled the vehicle. As a result, the vehicle behavior was different from participant to participant.

The present study investigates the effect of the content of an eHMI of an AV on the pedestrian's recognition of whether the AV is yielding to the pedestrian when the AV approaches the pedestrian with several deceleration profiles.

2 METHOD

2.1 Experimental environment

Figure 1 shows the experimental environment and situation. The simulated AV approached the participant waiting at the side of an unsignalized crosswalk. The length of the unsignalized crosswalk was 5.6 m. The AV sent communication cues to the participant according to the combination of the vehicle deceleration profile and the content of the eHMI.

2.2 Equipment

2.2.1 Simulated AV

The behavior of the AV was set in advance for each run and controlled mechanically and systematically using devices and actuators that adjusted the accelerator and brake strokes as shown in Fig. 2. The system provided velocity feedback control and the velocity was extracted from controlled area network (CAN) data. Two cases of vehicle behavior were set as experimental conditions as shown in Fig. 3.

2.2.2 eHMI

The present study investigated the pedestrian's recognition of the AV's intention to yield to the pedestrian when the AV conveys content such as its intention and the automated

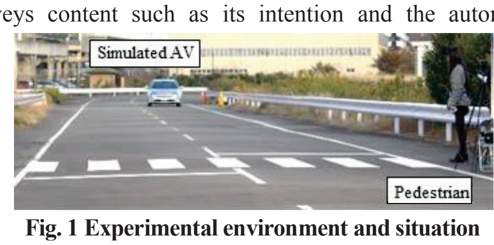

Fig. 1 Experimental environment and situation

Fig. 2 Speed control device and brake control actuator in the AV

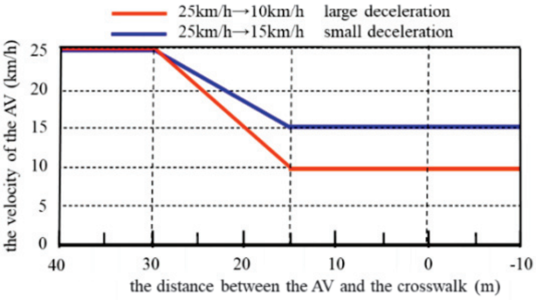

Fig. 3 Relationship between the velocity of the AV and the distance between the AV and crosswalk

driving status of the autonomous system. The intention and status were conveyed to the pedestrian via text, which ensured that the information was transmitted to the pedestrian. The eHMI was a liquid-crystal display (LCD) set on the dashboard of the AV facing outward. Table 1 gives specifications of the LCD. The text message was displayed on the LCD large enough to read. The eHMI content, as one experimental condition, was set to No-eHMI, "After you", "I'll stop", and "In automated driving mode" as shown in Fig. 4. In the cases of "After you" and "I'll stop", there was no text message on the display at the beginning of driving, but the text message was continually displayed once the AV was within 25 m of the crosswalk. In the case of "In automated driving mode", the text message was continually displayed from the beginning of driving because it is not expected that an AV will turn on a message relating to its operational status in front of a crosswalk.

2.3 Participants

Participants were 14 non-elderly drivers (age: 18–64 years) who held a driver's license, 13 non-elderly (age: 18–64 years) and 14 elderly non-drivers (age: 65 years and older) who did not hold a driver's license, and 15 elementary school students (age: 8–10 years). Each participant had normal or corrected-to-normal vision and normal ability in walking.

2.4 Tasks

Participants were asked to press a button when they judged the AV had yielded to them. The timing of pushing the button was sent to the AV in real time and synchronously recorded with CAN data, such as data of the velocity, acceleration stroke, and brake stroke. In addition, participants were asked to report their subjective confidence in judging that the AV was yielding on a five-point Likert scale immediately after the vehicle passed through the crosswalk. In all cases, the AV passed through the crossing to complete the experimental run; participants were asked to judge whether the AV had intended to yield to them before passing through the crossing. Values on the five-point Likert scale were "Extremely", "Very", "Moderately", "Slightly", and "Not at all" in answer to "How strongly did you feel the AV was yielding to you".

Table 1. LCD specifications

size	15.6 inch wide
Active Area (mm)	344.16(H)×193.59(V)
Pixel pitsh (mm)	0.17925(H)×0.17925(V)
Resolution	1920(H)×1080(V)
Contrast ration	800:1 (Typ)
Brighttness(cd/m2)	Tyd. 400

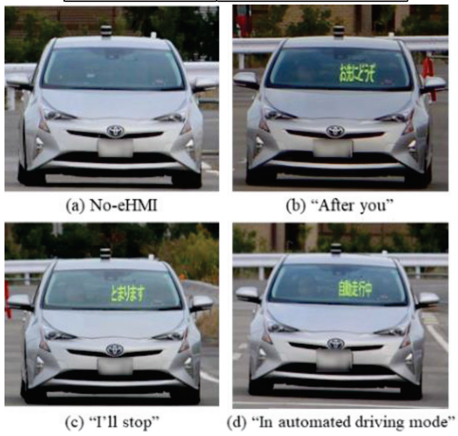

Fig. 4 eHMI content

2.5 Experimental procedures

Informed consent was obtained from each participant at the beginning of the experiment. Participants then stood at the crosswalk and wore a safety belt that prevented them from crossing the crosswalk. Each participant underwent practice trials to grow accustomed to the task procedures before measurements were made. The participants were told that the vehicle was an AV approaching them under all experimental conditions. The experiment involved two cases of vehicle behavior and four types of eHMI content. The experimental conditions were thus combinations of vehicle behavior and eHMI content. In addition, participants experienced the conditions including No-eHMI before they experienced the other conditions.

3 RESULTS

Figure 5 shows the results of whether the participants judged that the AV yielded to them. In the case of large deceleration, most participants judged that the AV yielded to them when they watched the approaching AV except when the text "In automated driving mode" was displayed. In the case of small deceleration, about one-third of participants judged that the AV did not yield to them when the content was No-eHMI. These results imply that deceleration is a communication cue with which to judge whether an AV is yielding to a pedestrian in the interaction between the AV and pedestrian. Despite the small deceleration, most participants judged that the AV yielded to them when the text "After you" or "I'll stop" was displayed. Fisher's exact test is applied to the subjective judgements. In the case of small deceleration, there was marginally significant difference between No-eHMI and "I'll stop" for the elderly non-drivers and there were significant differences between No-eHMI and "I'll stop" for

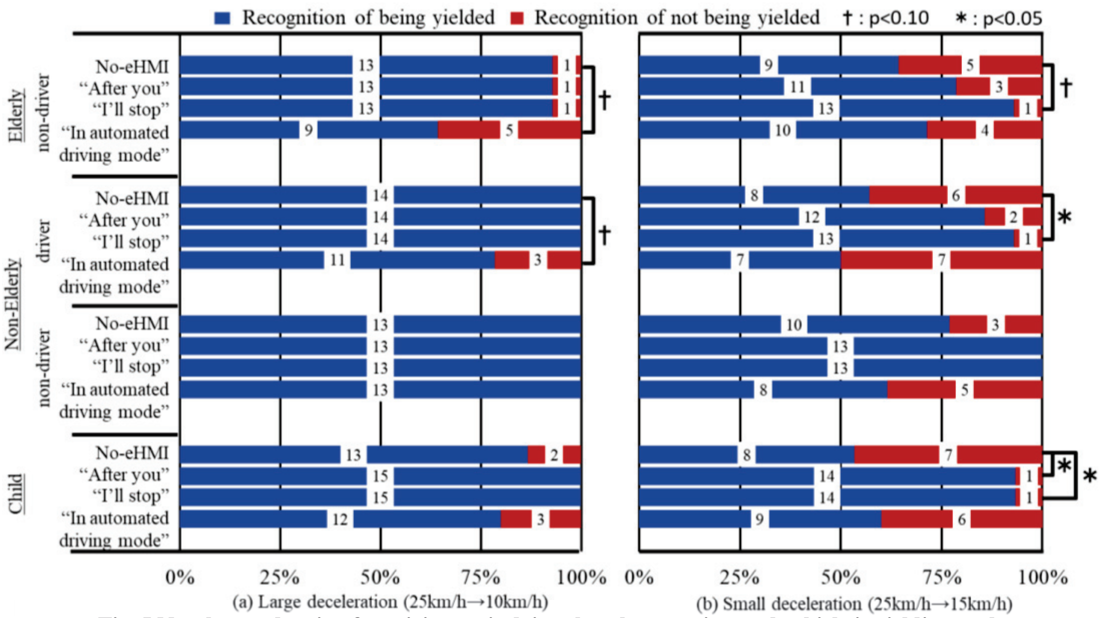

Fig. 5 Number and ratio of participants judging that the experimental vehicle is yielding to them

the non-elderly drivers and the elementary school students and between No-eHMI and "After you" for the elementary school students. This suggests that although the small deceleration of the AV results in indefinite judgment of the vehicle yielding, it is possible to judge that the AV is yielding when eHMI content such as "After you" and "I'll stop" is conveyed. Such eHMI content appears to be an effective communication cue. In the case of "In automated driving mode", one-fifth of participants judged that the AV was not yielding to them despite large deceleration, and the number of participants who judged the AV with small deceleration yielded to them was similar when the content was No-eHMI. Applying Fisher's exact test to the subjective judgement shows marginally significant differences between "No-eHMI" and "In automated driving mode" for elderly non-drivers and non-elderly drivers when there was large deceleration. This implies that the content "In automated driving mode" interferes with the effect of deceleration. The results of whether the participants judged that the AV was yielding are similar for all participant groups.

Figure 6 shows the distance between the AV and crosswalk when participants first judged that the AV was yielding to them. The data of participants who judged that the AV did not yield to them were excluded from the analysis. A Steel–Dwass test is applied to the distance between the AV and crosswalk. Results show that there was marginally significant difference between "I'll stop" and "In automated driving mode" for the non-elderly drivers in the case of large deceleration. Additionally, in the case of small deceleration, there were significant differences between "I'll stop" and "In automated driving mode" for the elementary school students. Despite the marginally significant and significant difference, there was little difference in the distance among all eHMI content and all participant groups.

Figure 7 shows results for the subjective confidence of participants' judgment of yielding as reported on a five-point Likert scale. The data of participants who judged that the AV did not yield to them were excluded from the analysis. Participants tended to judge that the AV yielded to them with lower confidence in the case of small deceleration than in the case of large deceleration. These results imply that deceleration improves the confidence of a pedestrian judging the yielding of an AV. Meanwhile, in the cases of "After you" and "I'll stop", the confidence of a pedestrian judging the yielding of the AV increased to the same level as that for large deceleration. A Steel–Dwass test applied to the subjective confidence of a participant judging the yielding of the AV reveals marginally significant and significant differences between No-eHMI and the contents "After you" and "I'll stop". The results suggest that although the small deceleration does not provide participants with definite confidence, it is possible for participants to be confident that the AV is yielding to them by conveying eHMI content such as "After you" and "I'll stop". In the case of large deceleration, the content "In automated driving mode" resulted in subjective confidence of the participant judging yielding that was no higher than that for other eHMI contents. A Steel–Dwass test applied to the participant's subjective confidence shows marginally significant and significant differences between "In automated driving mode" and other eHMI contents. These results imply that content such as "In automated driving mode" is not a good communication cue with which to judge whether an AV is yielding to a pedestrian in the interaction between the AV and pedestrian. There is the possibility that the display of "In automated driving mode" makes the intention of the AV ambiguous to pedestrian. The results of subjective confidence were similar for all participant groups.

4 CONCLUSIONS AND FUTURE WORK

The effect of the eHMI of an AV on a pedestrian's judgment that the AV is yielding to him/her was investigated focusing on the content of the eHMI. It was clarified that the deceleration is an effective communication cue with which the

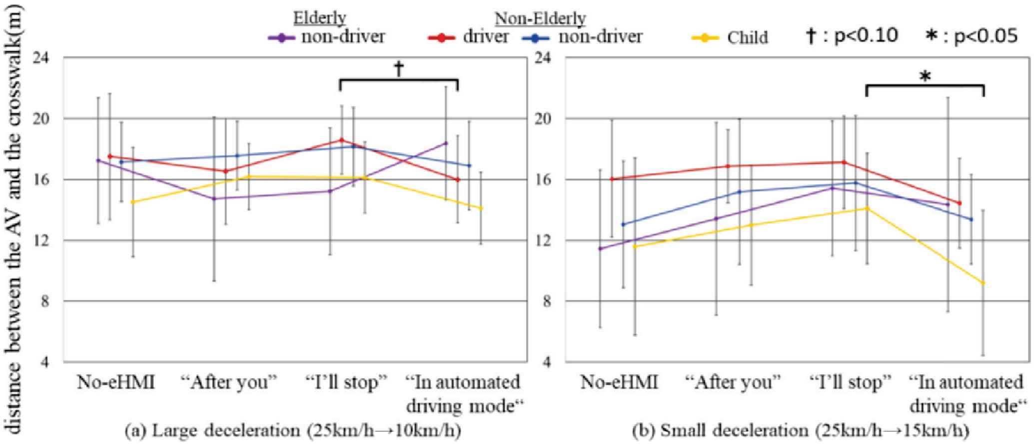

Fig. 6 Distance between the AV and crosswalk when participants judged the experimental vehicle had yielded to them

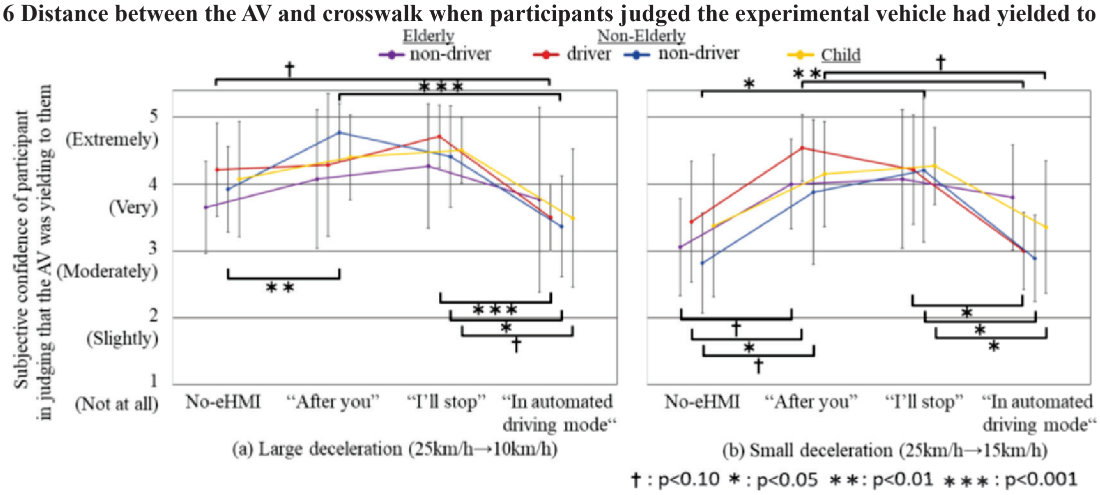

Fig. 7 Subjective confidence of the participant in judging that the AV was yielding to them

AV conveys the intent of yielding to the pedestrian. In addition, when the deceleration is not enough for the pedestrian to judge that the AV is yielding to him/her, the content of the eHMI is the additional communication cue. Meanwhile, when the AV conveys the automated driving status of the autonomous system to the pedestrian, the pedestrian hesitate in judging that the AV is yielding to them. The pedestrian's judgment of whether the AV is yielding to them is similar for all participant groups.

The interaction between the pedestrian and the AV was not investigated in the case that the deceleration behavior of the AV was difficult to take as a communication cue because the velocity of the AV was too low. Additionally, the text messages displayed in the present experiment were language dependent. Pedestrians who do not understand the language used cannot understand and interpret the text message. In addition, traffic culture is different in each country, and interaction between vehicles and pedestrians regarding priority on the road are different. There is the possibility that these factors affect the pedestrian's judgment. On the above basis, there is the possibility that the AV and eHMI education is necessary for interaction between a pedestrian and AV that improves the safety and sense of security of the pedestrian and realizes smoother transportation.

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