Effect of Human–Machine Interface of a Vehicle on Right-Turn Maneuver at Intersections using a Driving Simulator*

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***Abstract*—In the case of vehicles with low speeds at the time of pedestrian fatality, the percentage of pedestrian collisions was the highest for right turns, yet the mechanism of these traffic accidents has not been clarified. In this study, we investigate the behavioral characteristics of drivers when a vehicle makes a right turn in five situations using a driving simulator. We conducted an experiment using a driver assistance system that alerted drivers when the system detected pedestrians at the intersection. A human–machine interface (HMI) was first displayed when the subject vehicle (ego vehicle) stopped in front of the intersection due to a red light. The display was then turned off when the traffic light changed to green, and the ego vehicle started moving. It was displayed again when the ego vehicle entered the intersection. We found that HMI display was effective in increasing the percentage of driver's gazing time at pedestrians and in ensuring safety by the vehicle's stopping to move forward. Furthermore, we found that HMI's effectiveness was the most significant in the situation when three preceding vehicles made a right turn.**

I. INTRODUCTION

According to a report by the Traffic Bureau of the National Police Agency, the number of fatalities due to traffic accidents in Japan has followed a decreasing trend. However, pedestrian deaths (1,002) accounted for 35.3% of traffic fatalities in 2020 (2,839), which was the highest percentage by road user type [1]. Therefore, preventing accidents between vehicles and pedestrians is an extremely important issue in realizing a safe traffic society. When focusing on fatal traffic accidents considering road configuration, 46% of accidents occurred at intersections in 2020 [1]. When we further focus on the behavior of vehicles (in particular, sedans) involving pedestrian fatalities at low speeds, it was reported that the highest percentage of accidents occurred when vehicles collided with pedestrians when turning right [2]; however, the mechanism of right-turn accidents has not been clarified.

To reduce traffic accidents, advanced safety support systems using communication technologies such as vehicle-to-vehicle (V2V) [3] and road-to-vehicle (R2V) [4] data transfer have been developed. Currently, driver assistance technologies for human drivers have been introduced [5], which corresponds to Level 2 of automated driving as defined by the Society of Automotive Engineers (SAE) [6]. In fact, driver assistance systems such as Daimler's S-Class [7] and Lexus Safety System +A [8] have already been commercialized.

Among the driver assistance systems, in addition to providing basic information such as vehicle's traveling speed and turning signals, the human–machine interface (HMI) is considered to help in reducing human error; sensors detect the presence of pedestrians and other vehicles and sends emergency warnings to drivers, including both visual and audible signals [4,8]. However, depending on the display positions, timing, and information presented, HMIs may cause confusion or misunderstanding among drivers, which may lead to unnecessary operations or dangerous behaviors. Therefore, it is necessary to verify the appropriateness of the HMI display and their effectiveness [9,10]. In designing the HMI, it is important to consider how it informs the driver of intentions accurately according to the situation.

In the present study, to clarify the driver's behavioral characteristics when a vehicle makes a right-turn maneuver at an intersection, we conducted experiments using a driving simulator (DS). In addition, to obtain knowledge about the effectiveness of an HMI, we conducted experiments with and without an HMI that showed the presence of a pedestrian at the intersection where the vehicle was turning right and alerted the driver when there was a high risk of collision.

The rest of this paper is structured as follows: Section 2 discusses the research method, and Sections 3 and 4 show the experimental results and discussion. Finally, Section 5 is a conclusion.

II. RESEARCH METHOD

We developed a DS that simulated an intersection in daytime and researched the effectiveness of presenting pedestrian information using HMI when a vehicle was turning right in the presence of pedestrians positioned in the direction of the vehicle's travel. The test protocols employing volunteers in the present study were approved by the ethics committee of Tokyo Metropolitan University.

A. *Participants*

We chose 14 drivers with driving licenses as volunteers. The average age was 22.9 years (SD 0.92). We asked the participants to drive under different scenarios in an urban area with intersections, traffic lights, and pedestrians. Before the experiment, the volunteers were instructed to drive as usual. The volunteers drove one time for each of the "Without HMI", and "With HMI" scenarios.

B. *Driving simulator*

DS enables the subject to drive safely even in dangerous situations, such as vehicle accidents with pedestrians. Therefore, the simulator was utilized to analyze the behavior

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of drivers in traffic situations involving collisions [11]. Figure 1 shows the hardware configuration of the DS used in the experiments, which consisted of an ultrawide 21:9 monitor(34–inch), PC, steering wheel controller, accelerator, brake pedal [12], eye tracking measurement sensor [13], and web camera, which captured images of the driver while driving. The DS was developed by Unity [14], which is a game engine with an integrated development environment for multiple platforms developed by Unity Technologies. Unity took the roles of controlling the scenario and recording the driving data, collected at 5 Hz.

C. *Eye tracking*

This system used the Tobii Eye Tracker 4C of Tobii Technology to measure the gaze of drivers, as shown in Figure 2; it is an improved version of traditional pupil centre corneal reflection (PCCR) remote eye-tracking technology [15]. In this study, we used an installation-type device to measure viewpoints directed at a fixed monitor. To improve measurement accuracy, we calibrated each volunteer before starting the experiments by Tobii's application. Tobii measured the position of the gaze pointing into the specified display, and it outputs the coordinates of the gaze in response to Unity's Excel recording script.

D. *Human–Machine Interface (HMI)*

The information about the presence of a pedestrian at the intersection was presented to the driver when there was a risk of collision between vehicle and pedestrian. The driver assistance system used in DS assumed that the environment was one in which positional information about the vehicles and pedestrians could be shared by a communication system. The system alerted the drivers when the system detected the pedestrian present at the intersection, and if there was a high risk of collision during right turns.

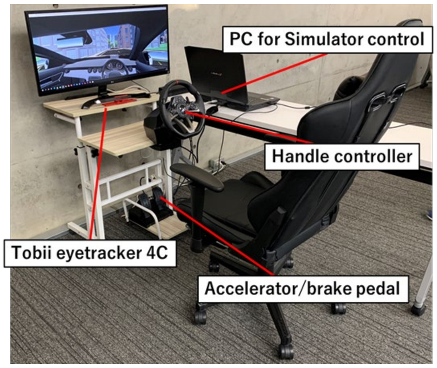


Figure 1. Hardware configuration of the driving simulator.

Figure 2. Tobii eye tracker 4C.

Figure 3. Design of HMI

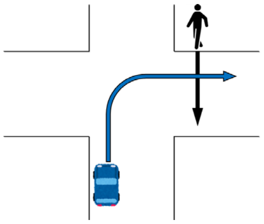
Two icons were displayed on the dashboard in front of the driver's seat, as shown in Figure 3. They consisted of two types of information, a pedestrian crossing, and the location of the pedestrian at the intersection. They were first displayed when the subject vehicle (ego vehicle) stopped in front of the intersection due to a red light. The display was then turned off when the traffic light changed to green, and the ego vehicle started moving. They were displayed again when the ego vehicle entered the intersection and came within a 20-meter radius of the pedestrian. The reason why the HMI was temporarily turned off was to avoid unnecessary disturbances; moreover, it was easier for the driver to notice the display clearly when the system was switched on to alert the driver to any dangerous situation.

E. *Scenario*

There were two scenarios, "Without HMI," and "With HMI" conditions. The course simulated the driving environment in Japan, so it was a left-hand traffic road. There were six intersections; five cases were randomly set for each intersection, including preceding vehicles, oncoming vehicles, and a pedestrian, as shown in Figure 4. At one of the six intersections in one scenario, no other vehicles or pedestrians appeared. The vehicle and pedestrian models used in the simulator are shown in Figure 5; the vehicle was a passenger vehicle (sedans) and the pedestrian was an adult male. All types of vehicles appearing in the DS, including the ego vehicle were of the right-hand-drive sedan type, and their body color was white. The maximum speed of all the vehicles was set to 60 km/h. Mori and Taniguchi indicated that the walking speed of pedestrians is about 1.4 m/s when pedestrian density is less than 1.1 persons/m^2 [16]. Therefore, we set the average walking speed of the pedestrian to 1.4 m/s.

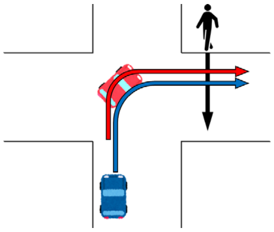
In all intersections, the traffic light was set to red so that the ego vehicle stopped before entering the intersection and was changed to green so that it passed through the intersection. The volunteers drove one time for each of the "Without HMI" and "With HMI" scenarios.

Figure 6 shows the measurements of the intersections used in the experiment. When collecting data, the center of the intersection was set as the origin (0,0), and the coordinates of the ego vehicle, preceding vehicle, oncoming vehicle, and pedestrian were obtained in relative coordinates. As shown in Figure 6, the position of all vehicles (vehicle position) was set at the center of their fronts. The position where the ego vehicle was stopped before entering the intersection was defined as Area I. We divided the intersection into four areas, and defined each area as A, B, C, and D. The total area of the intersection was defined as Area II. After passing through Area II, the section of the crosswalk where the pedestrian crossed was defined as Area III; we used all these areas for the analysis. However, when we analyzed Area II, we used the data from the time the ego vehicle entered Area II to the time it stopped moving forward in Area II. This was done to eliminate data such as the driver's gaze position while waiting for pedestrians to cross.



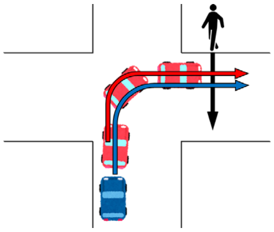
Without any other vehicles:
In Case 1, there are no other vehicles. The pedestrian starts crossing after the ego vehicle has passed through the center of the intersection.

(a) Case 1 (ego only)



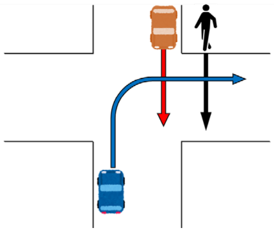
A preceding vehicle makes a right turn:
A preceding vehicle stops at a traffic light, makes a right turn at an intersection. The ego vehicle follows it and turns right. The pedestrian starts crossing after the preceding vehicle turns right and passes the crosswalk.

(b) Case 2 (pre-1)



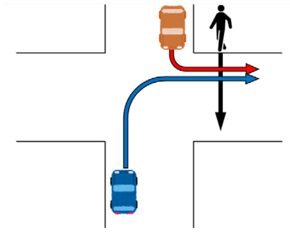
Three preceding vehicles make a right turn:
Three preceding vehicles stop at a traffic light and make a right turn at an intersection. The ego vehicle follows them and turns right. The pedestrian starts crossing after the last preceding vehicle turns right and passes the crosswalk.

(c) Case 3 (pre-3)



The oncoming vehicle goes straight and passes through at the intersection:
An oncoming vehicle travels straight through an intersection. The pedestrian starts crossing when the ego vehicle passes through the center of the intersection.

(d) Case 4 (oncoming-s)



An oncoming vehicle makes a left turn:
The oncoming vehicle turns left at the intersection. The pedestrian starts crossing after the oncoming vehicle turns left and passes the crosswalk.

(e) Case 5 (oncoming-l)

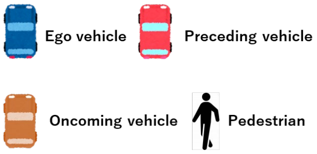


Figure 4. Experimental scenarios

(a) Vehicle (b) Pedestrian

Figure 5. Vehicle and pedestrian model used in the simulator.

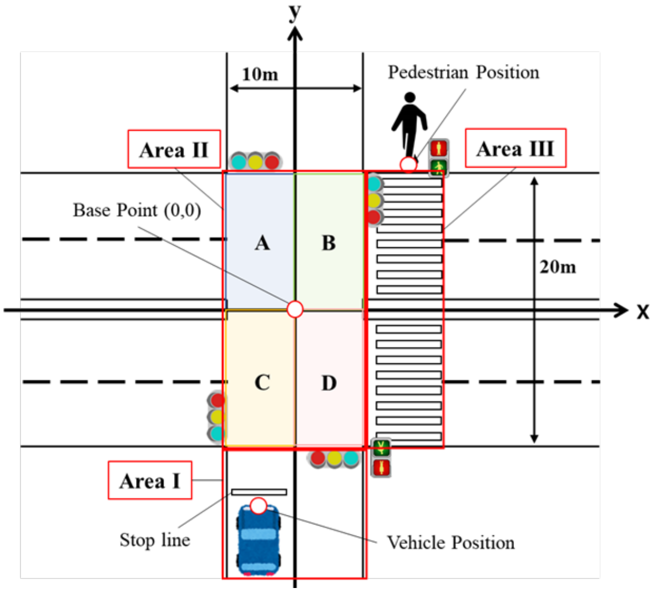


Figure 6. Measurement of intersection, and each position defined in this study.

F. *Analysis parameter*

The parameters analyzed in this study as follows.

- $\text{Time}_{\text{Visible}}$

While the ego vehicle was passing through the intersection, there were times when the view of pedestrian was blocked by other vehicles or A-pillars of the ego vehicle. $\text{Time}_{\text{Visible}}$ indicates the total time at which pedestrians could be seen in Area II.

- $\text{Time}_{\text{Pedestrian}}$

$\text{Time}_{\text{Pedestrian}}$ indicate the averaged total time at which driver looked at the pedestrian in Area II.

- Time_{HMI}

Time_{HMI} indicate the averaged total time of the driver looked at HMI display in Area I or Area II.

- Time to Collision (TTC)

In this study, we used TTC to evaluate a vehicle's ability to avoid a collision with a pedestrian. This study defined TTC as the time it took for the ego vehicle to reach the point of potential collision with the pedestrian from the time when the driver first gazed at the pedestrian in Area II. It was assumed that the vehicle was traveling at its current speed. TTC (s) was calculated as follows: (1) using the distance D (m) between the vehicle and the pedestrian, and the vehicle speed V (m/s) when the driver first gazed at the pedestrian in Area II.

$$\text{TTC} = \frac{D}{V}\ [s] \qquad (1)$$

TABLE I. ITEMS OF QUESTIONNAIRE

Q1	Was the information provided by HMI helpful?
Q2	Was the timing of HMI displays appropriate?

G. *Questionnaire*

After the experiments, we asked the volunteers to answer a questionnaire regarding the HMI in the DS as a subjective evaluation, in addition to questions on driving experience. The questionnaire items, presented in Table I, consisted of two questions with five possible responses: 1. Strongly disagree, 2. Disagree, 3. Neither agree nor disagree, 4. Agree, and 5. Strongly agree. We also asked volunteers to freely describe their specific requests and impressions of HMI.

III. RESULTS

Figure 7 shows the position of the ego vehicle when the driver first gazed at the pedestrian in Area II. The percentage of pedestrians found in each of the defined areas A, B, C, and D is shown, with the percentage of pedestrians found both with and without HMI as 100%. In the case without HMI, the percentage of pedestrians detected in areas A (7.0%) and C (39.3%), which were far from the pedestrians, was higher than the 3.7% and 37.7%, respectively, in the case with HMI. With HMI, the highest percentage was in area B, which was the closest to the pedestrians, at 56.4%. Figure 8 shows the average TTC in five cases when the driver first gazed at the pedestrian within Area II. We conducted a t-test between the two groups with and without HMI, but no significant difference was found in either case.

Table II shows $\mathrm{Time}_{\mathrm{Visible}}$, $\mathrm{Time}_{\mathrm{Pedestrian}}$, and the percentages of the driver's average gazing time at pedestrian when the ego vehicle made a right turn at an intersection in Area II in the conditions with and without HMI. The results showed an increase in four conditions of the cases with HMI: Case 1 (73.8% to 74.1%), Case 2 (76.9% to 81.5%), Case 3 (60.8% to 73.4%), and Case 4 (65.5% to 71.1%) compared to without HMI. For Case 5, the percentage decreased by 2.2% from 65.7% to 63.5%. We confirmed that the driver's average gazing time at pedestrian in situations where the presence of pedestrians could be confirmed by the HMI display increased.

Figure 9 shows the percentage of ego vehicle that stopped moving forward to avoid a collision with a pedestrian in Area II for both with and without HMI. In Area II, the percentages of vehicle's stopping in the cases with HMI increased in four cases, comparing to the cases without HMI: Case 1 (42.9% to 64.3%), Case 2 (50.0% to 64.3%), Case 3 (14.3% to 71.4%), and Case 4 (57.1% to 64.3%). In only Case 5, the percentage decreased from 35.7% to 28.6% in the case without HMI. The percentage of vehicles that stopped in Area II increased the most in Case 3, when three preceding vehicles turned right, an increase of 57.2%. We conducted hypothesis testing for the difference in the population proportions between the two groups with and without HMI, which was a two-sided test with a p-value less than 0.05 considered to be statistically significant. In Case 3, we confirmed a significant difference between the conditions with and without HMI ($p = 0.0023$).

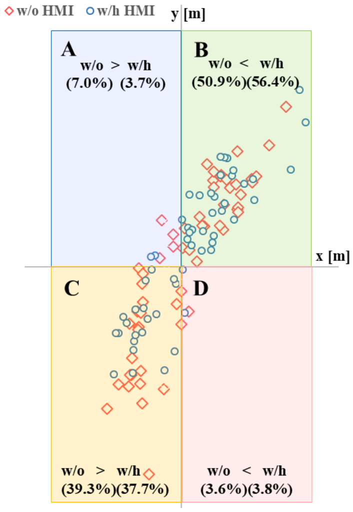


Figure 7. Position the driver first gazed at the pedestrian within Area II.

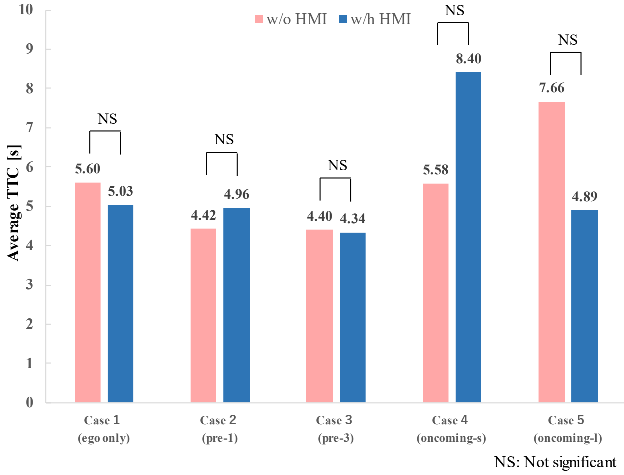


Figure 8. Average TTCs in five cases when the driver first gazed at the pedestrian within Area II.

TABLE II. $\mathrm{TIME}_{\mathrm{VISIBLE}}$, $\mathrm{TIME}_{\mathrm{PEDESTRIAN}}$, AND THE PERCENTAGE OF GAZING TIME AT PEDESTRIAN

Experimental scenarios	$\mathrm{Time}_{\mathrm{Visible}}$ (a)				$\mathrm{Time}_{\mathrm{Pedestrian}}$ (b)				The percentage of gazing time [%]	
	w/o HMI		w/h HMI		w/o HMI		w/h HMI		w/o HMI	w/h HMI
	mean [s]	SD	mean [s]	SD	mean [s]	SD	mean [s]	SD	{(a) / (b)}×100	{(a) / (b)}×100
Case1 (ego only)	2.01	1.95	2.26	1.91	1.49	1.37	1.67	1.48	73.8	74.1
Case2 (pre-1)	1.54	1.35	1.31	1.04	1.19	1.14	1.07	0.88	76.9	81.5
Case3 (pre-3)	2.26	1.14	1.34	0.92	1.37	0.81	0.99	0.69	60.8	73.4
Case4 (oncoming-s)	1.66	1.88	1.19	1.23	1.09	1.35	0.84	0.92	65.5	71.1
Case5 (oncoming-l)	2.59	1.56	2.74	2.01	1.70	1.22	1.74	1.21	65.7	63.5

SD: standard deviation

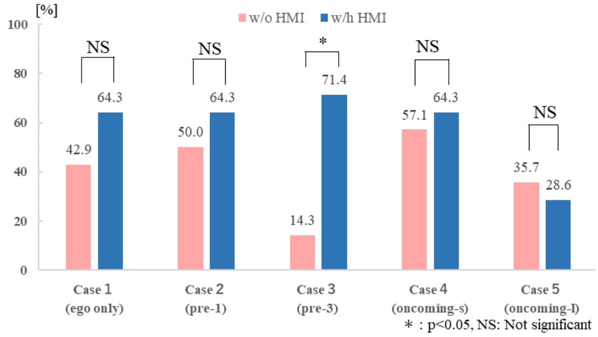


Figure 9. Percentage of ego vehicles that stopped moving forward in Area II.

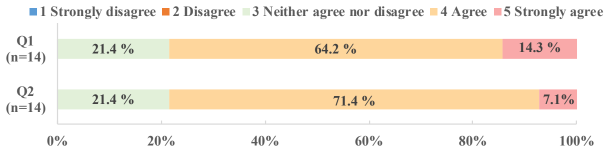


Figure 10. Percentage of each item of the questionnaire.

The results of the questionnaire are shown in Figure 10. In Q1, for the usefulness of the HMI display, the percentage of volunteers who answered 4 (Agree) was the highest (64.2%), and for Q2, regarding the timing of the display, the percentage of volunteers who answered 4 (Agree) was the highest at 71.4 %.

IV. DISCUSSION

First, we considered the positions where the drivers first identified pedestrians in Area II. Comparing the positions with and without HMI, the percentages were higher in Areas A and C in the case without HMI, which were far from the pedestrians, whereas the percentage was higher in area B, which was the closest to the pedestrians, in the case with HMI. This might indicate that the HMI display delayed the timing of the first moment of the driver's attention to the pedestrian in Area II. In this study, the driver was informed of the presence of the pedestrian by the HMI when the ego vehicle stopped under a red light (Area I). Table III shows the number and percentage of driver gazing at HMI display in Area I and Area II. Most drivers (92.9%) checked the HMI display when they stopped ego vehicle in Area I. Therefore, it was assumed that the driver confirmed the presence of pedestrians in the sidewalk in the direction of the vehicle's travel before entering the intersection. And thus, in the case with HMI, the time when the drivers first identified the pedestrians in the intersection might be later than the case without HMI.

As shown in Figure 9, the percentage of the ego vehicle stopped moving forward in Area II increased when the information was provided by the HMI display in all cases except for Case 5. The increased percentage in the four cases suggested that the information provided by the HMI increased driver's attention to pedestrians, and caused the drivers to stop the vehicle to ensure safety. For Case 5, the percentage of ego vehicle that stopped in Area II decreased by 7.1% (35.7% for the condition without HMI display vs. 28.6% for the condition with HMI display); however, the percentage of ego vehicle that stopped in Area III was 14.3% (n=2) for the condition without HMI display and 21.4% (n=3) for the condition with HMI display. Therefore, when the percentage of ego vehicles that stopped in Area III was taken into account, the percentage was 50.0% for both conditions, indicating that there was no difference between the conditions with and without HMI. In Case 5, the oncoming vehicle turned left, the pedestrian started crossing after it passed through the crosswalk. Moreover, it passed through the crosswalk shortly after the ego vehicle entered the intersection. As there were no pedestrians in the direction of travel and safety had already been ensured, there was no change in the percentages of ego vehicle that stopped under the conditions with and without HMI.

TABLE III. NUMBER AND PERCENTAGE OF DRIVERS GAZING AT HMI DISPLAY IN AREA I AND AREA II (N=14)

	Case 1 (ego only)		Case 2 (pre-1)		Case 3 (pre-3)		Case 4 (oncoming-s)		Case 5 (oncoming-l)		Averaged percentage of driver's gazing HMI in total cases
	[n]	[%]	[n]	[%]	[n]	[%]	[n]	[%]	[n]	[%]	[%]
Area I	13	92.9	14	100.0	14	100.0	11	78.6	13	92.9	92.9
Area II	5	35.7	7	50.0	9	64.3	8	57.1	9	64.3	54.3

The most significant difference in the percentage of ego vehicles stopped moving forward in Area II was seen in Case 3, the scenario in which three preceding vehicles turned right at the intersection in the same direction as the ego vehicle. The pedestrians standing on the sidewalk did not start walking when the three preceding vehicles passed. The ego vehicle itself tried to turn right following the preceding vehicles, making it difficult to pay attention to the pedestrians. Therefore, this scene is considered to be the most dangerous among the five cases.

When we looked at TTCs, which was an evaluation for collision avoidance, the average TTC for Case 3 was 4.40 s under the condition without the HMI display, and 4.34 s under that with the HMI display, which were the shortest among all cases under both conditions (Figure 8). Figure 11 shows a dangerous situation that occurred without HMI. When the ego vehicle passed through the intersection in Case 3 without the HMI display, the driver's gaze remained on the preceding vehicle, and the driver did not notice the pedestrian walking; the driver passed through the intersection without stopping the ego vehicle. Therefore, the presence of other vehicles traveling in the same direction as the ego vehicle in Case 2 and 3 may cause the driver to pay attention to the preceding vehicles other than pedestrians that they should have. In these cases, the HMI can improve safety by directing the driver's attention to pedestrians.

The number and percentage of the drivers gazing at the HMI display in Areas I and II are shown in Table III. The average percentage (92.9%) of drivers gazing at the HMI display in Area I was higher than that (54.3%) in Area II. As shown in Figure 12 and Table III, the average gazing time at

Figure 11. Dangerous situation that occurred without HMI. *(The driver kept his eyes on the preceding vehicle and passed through the intersection without noticing the pedestrian who had started walking.)*

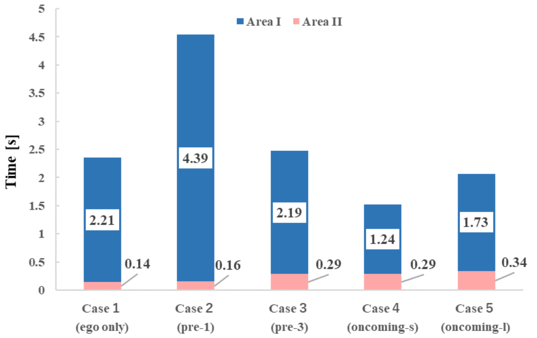


Figure 12. Average time that the drivers gazed at the HMI display.

the HMI display was longer in Area I than in Area II for all five cases. Conversely, most of the drivers gazed at the pedestrian inside the intersection (Area II), for which the percentages of gazing time at pedestrians were 63.5–81.5%, as shown in Table II. These results implied that the driver was more often directly checking for pedestrians while the ego vehicle made a right-turn maneuver in the intersection, even when the HMI display was shown.

The icons in this study were displayed on the dashboard. When the ego vehicle was approaching the pedestrian, the walking pedestrian and the icons on the screen were moving apart on the screen, which might make it take time for the driver to change the gazing target from the pedestrian to the HMI display. The gazing at the HMI display did not allow the drivers to check their outside environment; if the visual display of the HMI is far away from the pedestrian that truly needs attention, there is a risk that it will take time to reorient gaze from the HMI display to the pedestrian, thereby inducing a delay in judgment. In urgent situations, such as when the ego vehicle is approaching a pedestrian, auditory information, such as an alarm, may be required to avoid interference with the driver's visual perception of the environment. Conversely, when the vehicle is not moving, there is enough time for a driver to grasp the surrounding situation; hence, it is considered that a high level of safety can be maintained by clearly communicating information to the driver through visual presentation. Therefore, it is necessary to present information according to the situation and characteristics of the driver.

There were some limitations to this study. We conducted an experiment with adult drivers with an average age of 22.9 years and relatively little driving experience. There is a possibility that elderly drivers might tend to process information at a slower rate while driving compared to younger drivers. In this experiment, we were unable to confirm the effects of age on the processing time of information using the HMI display. It is necessary to clarify the differences in the provision of information by the HMI display for elderly drivers depending on their age and driving proficiency in future work. In addition, the pedestrian model used in this experiment was based on a limited scenario in which only one adult male walked in one direction. However, in an actual traffic environment, pedestrians with various attributes, such as the number of pedestrians, clothing, gender, age, are mixed together; hence, it is very complicated. Therefore, it is necessary to expand the scenario by introducing pedestrians of shorter stature, such as children, various colors of clothes, and pedestrians from different directions.

V. CONCLUSION

In this study, using a DS capable of measuring driver's gaze, we investigated the effect of the presence of other vehicles and pedestrians on the driver's characteristics at the intersection where the vehicle was turning right. We conducted experiments with and without HMI, which showed the presence of a pedestrian at the intersection where the vehicle was turning right and alerted the driver. It was found that when turning right at an intersection, the percentage of gazing time at pedestrians was affected by the presence of other vehicles. The results also indicated that the HMI display was effective in increasing the percentage of gazing time at pedestrians and ensuring safety. Furthermore, we found that HMI's effectiveness was the most significant in the situation when three preceding vehicles made a right turn.

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