Attitudes of Person at Driver's Seat of Level 3-4 Automated Vehicle Affect Human Driver Entering Roadway

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Abstract

In the transportation society, traffic participants communicate with each other in order to give way for smooth traffic. Although research on automated driving has been remarkable in recent years, conventional communication methods, such as eye contact, cannot be used in automated vehicles because person sitting at driver's seat do not control the vehicles. Therefore, this study focused on communication methods using external human-machine interface (eHMI) to realize safe, secure, and comfortable transportation. We experimentally investigated how the attitude of a person sitting at driver's seat in a car traveling on the main line affects the driving operation and psychological aspects of a driver who is about to enter a situation wherein a vehicle traveling on the main line gives way to a car that is about to enter a road from a parking lot of an off-road facility. The results showed that when the person sitting at driver's seat gazed at a smartphone, assuming the car was an automated vehicle, the driver's subjective evaluation of the driving operation and "smoothness" of merging onto the main line showed a reaction of hesitation in merging. This suggests that a specific and clear presentation of information by the eHMI is necessary when providing information on "intendment of give way."

Keywords: Automated vehicle, Manual driver, External human-machine interface, Traffic psychology

1 Introduction

Automatic driving has the potential to solve the problems of traffic accidents caused by drivers, older adult drivers returning their licenses, and the shortage of drivers for buses and trucks; moreover, it is expected to significantly contribute to the realization of a safer, more secure, and more comfortable society. Notably, Waymo in the U.S. and Baidu in China have begun operating self-driving cabs. In Japan, the conditions for operating Level 4 automated vehicles were newly stipulated in the amendment to the Road Traffic Law in April 2023 [2]. Level 4 automated driving services can now be realized in the automation levels stipulated by the Society of Automotive Engineers (SAE) [1].

The current traffic environment is facilitated by communication among traffic participants. Automobiles provide information on their subsequent actions and current status to their surroundings, employing direction indicators and stop lights (official communication) [3]. When such communication is insufficient, intentional expressions such as hand signs, thank you hazards, and raising hands (explicit communication) are used [4,5]. However, level 3 and 4 automated vehicles are not expected to communicate through eye contact or gestures with the person in the driver's seat (or the person in the passenger seat in the case of level 5). This poses a major challenge not only in terms of safety and comfort but also in terms of a sense of security. Therefore, research has been conducted on a method of presenting information outward from an automated vehicle using an external human-machine interface (eHMI) [6-9].

At a stage when automated vehicles are spreading, it is impossible to avoid the mixing of conventional vehicles and automated vehicles. In a previous study, we investigated the presentation of information from automated vehicles to drivers and whether eHMI, proposed for pedestrians, can also be applied to drivers [10]. The results showed that when eHMI presents the next action from the automated driving system, the driver selects the information that makes them safer when choosing from the current behavior of the automated driving vehicle and the information presented by eHMI. Additionally, it is suggested when the eHMI was created in accordance with the SAE Automated Driving System (ADS) Marker Lamp [11], presenting the info "in automatic operation" from the automated vehicle to the surrounding drivers, the drivers interact with automated vehicles in the same way as conventional vehicles [12]. Therefore, we believe that a more active and specific

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presentation of information is necessary when vehicle behavior and person sitting at driver's seat attitudes differ between manual and automated driving, such as traffic situations that require yielding.

Since drivers are accustomed to communicate with other drivers, when automated and conventional vehicles are mixed, especially in the initial stages of such mixing, the drivers may try to communicate with people in other cars to confirm safety and driving intentions, regardless of whether the other person has driving authority. However, as the person sitting at driver's seat in an automated vehicle do not have driving authority, the driving intention of the automated driving system and the attitude of the person in the automated vehicle may not match. This may lead to the incorrect estimation of the driving intention or increasing of the difficulty in making smooth communication. Therefore, it is necessary to verify whether eHMI can accurately present information on the intention of driving an automated vehicle, regardless of the person sitting at driver's seat attitude.

However, no eHMI studies exist that take into account the attitudes of person sitting at driver's seat in automated vehicles.

This study aimed to clarify how the attitude of the person in the car influences the driver's driving operation and psychological aspects, as a preliminary step to investigating a specific method for presenting information using eHMI. This study makes it possible to propose an eHMI-based information provision method that considers the attitudes of person sitting at driver's seat in automated vehicles.

2 Experiment

2.1 Purpose

This experiment supposes that a conventional vehicle is going to come out of an off-road facility onto the main line and elucidates how the attitude and gestures of a person sitting at driver's seat of a level 3 and 4 automated vehicles on the main line affect the conventional vehicle driver's conjectures on the person sitting at driver's seat expectation about next action for traffic condition.

2.2 Participants

Participants in the experiment were recruited from Kyushu University and the people in the community. The number of participants was 19 in total: 17 males and 2 females. Seventeen were university students in their 20s and two were members of the people in the community in their 60s, giving an average age of 22.4 years. All the experimental participants had a First-class driver's license (regular motor vehicles). They did not receive any financial remuneration.

This experiment was approved by the Ethical Review Committee of the Faculty of Information Science and Electrical Engineering, Kyushu University (Approval No. 2021-19). All the participants provided informed consent in accordance with the approved guidelines.

2.3 Equipment

The experiment was conducted using a driving simulator (DS). Three sets EPSON (EB-L200SW) single-throw projectors and 171-inch wall screens were used for video presentation, projecting forward and diagonally left and right CG images. The LCD resolution was 1280 x 800. Logitech G29 or Fanatec CSL DD 5Nm were used for steering and pedals. We used 13-inch and 5.5-inch monitors to present speed and other information to the participants. The program was written using Unity.

2.4 Traffic scene

We used an experimental scenario that two drivers are likely to communicate with each other about their wills to give way to the other. Participants drive a car (hereinafter, referred to as "participant's vehicle") and turn left to come out an off-road facility and enter the main line as shown in Fig. 1.

When the experimental scenario began, the participant's vehicle was in the parking lot of an off-road facility, which is 6.5 m before the stop line. Participants were instructed to pause where the tip of the participant's vehicle was at the stop line just before the sidewalk.

Two different situations were set up for the mainline vehicle: one in which the mainline vehicle stopped, assuming a traffic jam caused by a traffic signal, and the other in which the mainline vehicle slowed down to stop to yield. In the first scene, the mainline vehicle stopped 5.25 m before the merging point of the participant vehicle from the start of the experiment. In addition, the leading vehicle is stopped 10 m ahead of the mainline vehicle. In the second scene, the mainline vehicle decelerated from 40 km/h and stopped 5.25 m before the merging point of the participant's vehicle as shown in Fig. 2. Therefore, in both two scenes, the stopping position of the mainline vehicle was the same, 5.25 m, from the merging point.

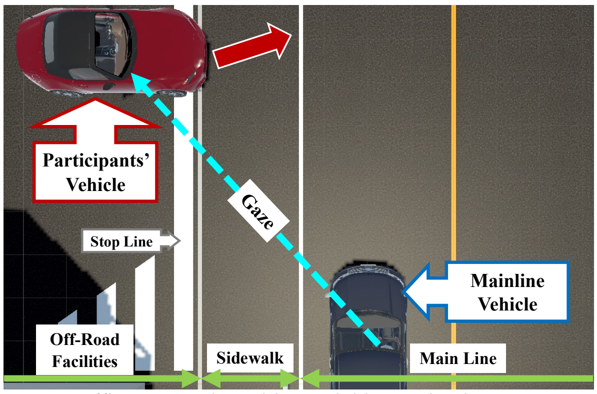

Fig. 1 Traffic scenes where drivers yield to each other

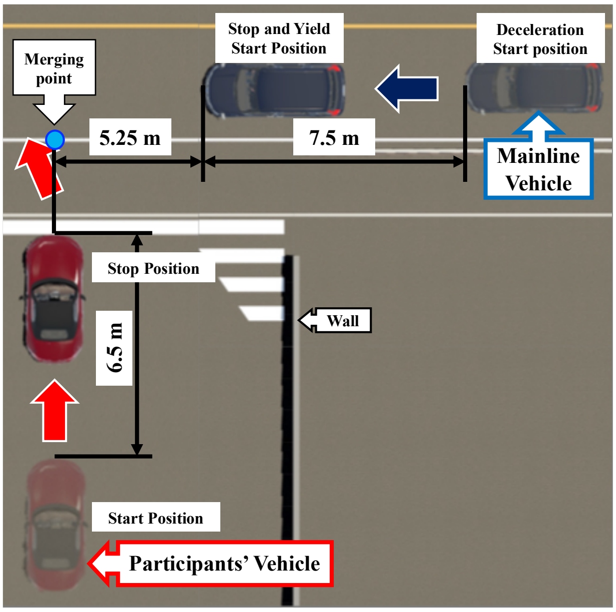

Fig. 2 Location diagram of the traffic scene

2.5 The attitudes of person sitting at driver's seat in the mainline vehicle

Based on a survey on communication when drivers give way to pedestrians trying to cross an intersection [3], we set two attitudes of the person sitting at driver's seat when we assume the person sitting at driver's seat maneuvers the steering wheel and pedals.

First, we set the "hand sign" condition of manual driving (Fig. 3) because hand signs were observed as an explicit expression of yielding intention from drivers to pedestrians although not so many drivers in the survey used hand signs.

Second, we set the "eye gaze" condition of ambiguous situations whether driving manually or using the automatic driving system, in which the person sitting at driver's seat gazes towards the participants (Fig. 4). Drives do often make eye contact with each other. "Eye gaze" of a person at driver's seat gives eye contact to participants. Not only do drivers make eye contact with each other, but they also actually communicate with each other by bowing their heads and facial expressions on the road. However, drivers seem to communicate infrequently with their facial expressions. Bowing down is often used to thank the driver for giving way. For these reasons, we did not set facial expressions or bowing down as attitude conditions for the person sitting at driver's seat. These two conditions are represented by moving the character of the person sitting at driver's seat in the simulator.

Third, as a behavior that a person sitting at driver's seat of an automated vehicle might make, we set the "smartphone gaze" condition in which the person sitting at driver's seat operates a smartphone with both hands in automatic driving system (Fig. 5). In this condition, the person sitting at driver's seat is turned downward in order to clearly indicate that person sitting at driver's seat was not gripping the steering wheel or looking at the surroundings. Steering wheel was installed in the mainline vehicle for automatic driving levels 3 and 4.

Fig. 3 The person sitting at the driver's seat is giving a hand signal to the participant. ("hand sign" condition)

Fig. 4 The person sitting at the driver's seat looks at the participant. ("eye gaze" condition)

Fig. 5 The person sitting at the driver's seat is staring at his smartphone. ("smartphone gaze" condition)

2.6 Experiment procedure

First, participants filled in an informed consent form after that we gave them an overview of the experiment. Next, we explained the experimental scenario to them and instructed them to observe the traffic environment, including the behavior of the mainline vehicle and the attitude of the person sitting at driver's seat, and merge onto the main line safely. Then, participants practiced merging only once to familiarize themselves with the operation of a vehicle on the DS.

Three conditions were set as person sitting at driver's seat factors (hereinafter, referred to as "attitudes factor"): "eye gaze," "hand sign," and "smartphone gaze" as experimental conditions to compare the influence of the attitude of person sitting at driver's seat in the mainline vehicle on participants' prediction of the person sitting at driver's seat is intentions.

Further, two conditions were set as scene factors: a scene in which the mainline vehicle is stopped, and one in which the mainline vehicle slows down and stops to give way to the participant's vehicle.

We conducted three experiments per condition, and participants filled a questionnaire at the end of each condition. In this questionnaire, participants answered the degree of merging smoothness, which they felt they could merge smoothly into the main line. We used a visual analog scale (VAS) to make the questionnaire. The VAS measurement was processed by measuring the position of the participants' responses, where "very smoothly" was set to 100 and "not at all smoothly" was set to 0.

2.7 Data analysis

We conducted a within-subjects analysis of variance (ANOVA). Analysis of variance was performed using the script anovakun (ver. 4.8.9) for analysis of variance, which runs on the statistical software R (ver. 4.2.2) [13]. anovakun is a commonly used tool for analysis of variance in the field of psychology [14]. This experiment was conducted on the same participants repeatedly, therefore, Mendoza's multi sample sphericity test was conducted to verify that the distribution of differences between all conditions was equal. When significant differences arose because of the sphericity test, the Greenhouse-Geisser correction for degrees of freedom was used. Multiple comparisons were made using MSRB (Modified Sequentially Rejective Bonferroni).

3 Results and discussion

3.1 Time to release the brakes

The results of the time elapsing from the time when the mainline vehicle stopped at the stop line (when gaze and hand-signaling were initiated) to when the participant released the brake are shown in Fig. 6. The mean values of the respective times for each condition were 5.85 s for the vehicle behavior stop and gaze, 5.62 s for the stop and hand sign, 5.49 s for the stop and smartphone gaze, 6.20 s for deceleration and gaze, 6.30 s for deceleration and hand sign, and 6.36 s for deceleration and smartphone gaze. Analysis using two-factor analysis of variance within participants revealed a significant difference in the main effect for the different scene factors ($F[1,56] = 14.8690$, $p = 0.0003$, $\eta_p{}^2 = 0.2098$), but meanwhile, there was no significant difference in the main effect of attitudes factor (eye gaze, hand sign, and smartphone gaze) ($F[1.55,86.91] = 0.1736$, $p = 0.7854$, $\eta_p{}^2 = 0.0031$), and in the interaction between the two factors ($F[2,112] = 1.3220$, $p = 0.2707$, $\eta_p{}^2 = 0.0231$).

Multiple comparisons revealed that the time required to release the brake was shorter in the scene where the mainline vehicle stopped than in the scene where the mainline vehicle slowed down to a stop. This suggests that the participants were observing and remembering the vehicle behavior of the mainline vehicle. Further, the participants remembered the vehicle movement history, even when the mainline vehicle stopped, and presented the intention to yield. This may have made the participants cautious about checking safety and investigating the consistency of the presented intention. In other words, as participants contextually perceive the behavior of surrounding traffic participants, they are likely to be cautious about any out-of-context behavior caused by the intent presentation.

As there was no significant difference in the timing of brake release depending on the attitude of the attitudes factor of the mainline vehicle, even if the participants perceived the intention to yield, it is reasonable to suppose that they would not immediately start entering the main line and waited a certain period to confirm whether the mainline vehicle's behavior was consistent with its intention to yield.

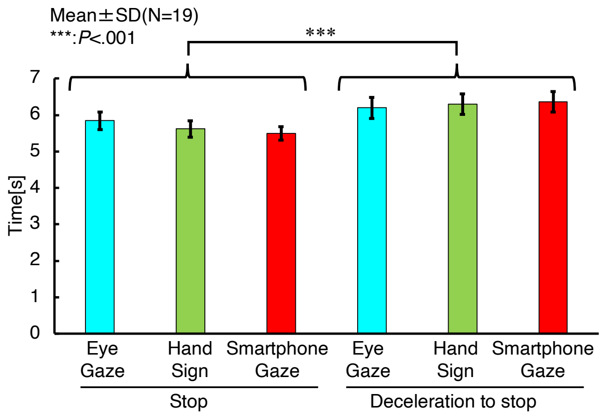

Fig. 6 Time to release the brakes

3.2 Time before the participant vehicle enters the main line

The results of the time elapsing from the time when the participant releases the brake to the time when the front of the participant's vehicle enters the main line are shown in Fig. 7. The mean values of the respective times for each condition were 8.15 s for the vehicle behavior stop and gaze, 6.07 s for the stop and hand sign, 7.32 s for the stop and smartphone gaze, 8.95 s for deceleration and gaze, 8.01 s for deceleration and hand sign, and 8.96 s for deceleration and smartphone gaze. Analysis using two-factor analysis of variance within participants revealed significant differences in the main effects for the different scene factors ($F[1,56] = 12.3892$, $p = 0.0009$, $\eta_p{}^2 = 0.1812$), and for the different attitudes factor ($F[1.56,87.08] = 16.2184$, $p = 0.0000$, $\eta_p{}^2 = 0.2246$), but no significant difference was found in the interaction between the behavior of the attitudes factor and the behavior of the mainline vehicle ($F[1.63,91.39] = 2.1667$, $p = 0.1298$, $\eta_p{}^2 = 0.0372$). Multiple comparisons revealed that the time until the participant's vehicle entered the mainline was shorter in the scene where the mainline vehicle stopped than in the scene where the mainline vehicle slowed down and stopped (Fig. 7). This may be because there was no need to check the safety of the main line in the first condition as the mainline vehicle was stopped. As for the attitudes factor, the time until the participant's vehicle entered the main line was the shortest for the hand sign, while the gaze was the longest and the smartphone gaze was somewhere in between.

The fact that the time taken to enter the main line was shorter under the condition that the mainline vehicle stopped than under the condition that it slowed down suggests that the time taken to enter the main line was shorter because the mainline vehicle had stopped and there was no need to check the safety of the main line.

This suggests that hand signs are useful to realize smooth traffic by yielding to each other. Conversely, we expected that the more information presented by the driver about the line of sight, the easier it would be for the driver to infer the intention to yield, thus, the shorter the time to enter the main line of traffic. However, the experimental results differed from our expectations, with gaze taking the longest time. We presume that this result is caused by the participants' expectation for some explicit information to be presented, as they were being watched by a person sitting at driver's seat in the mainline vehicle, and they waited while listening to the person sitting at driver's seat. Therefore, to realize smooth traffic by yielding, eye contact is considered the participants' attitude that most inhibits smooth driving operation. It is difficult to perceive the participants' intention from the mainline vehicle, thus becoming ambiguous.

Furthermore, significant differences with p-values below 0.1 were found in all conditions. This suggests that participants were concentrating on driving by keeping an eye on their surroundings, even under conditions where they were repeatedly given the right of way by the mainline vehicle.

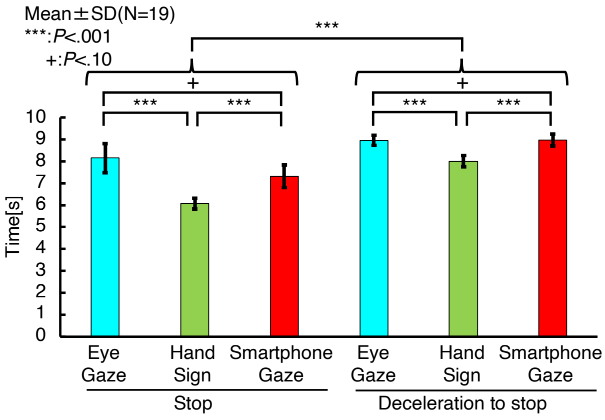

Fig. 7 Time before the participant vehicle enters the carriageway

3.3 Degree to which participants felt they were able to merge smoothly

The results of the questionnaire on "the degree to which the participants felt that they were able to merge smoothly into the main line" are shown in Fig. 8. The mean values of the respective questionnaire results for each condition were 67.67 for vehicle behavior stop and gaze, 78.35 for the stop and hand sign, 61.11 for the stop and smartphone gaze, 67.71 for deceleration and gaze, 80.07 for deceleration and hand sign, and 58.16 for deceleration and smartphone gaze. Analysis using two-factor analysis of variance within participants revealed no significant difference in the main effect for the scene factor ($F[1,56] = 0.0530$, $p = 0.8187$, $\eta_p{}^2 = 0.0009$), a significant difference in the main effect for the attitudes factor ($F[1.47,82.28] = 17.7444$, $p = 0.0000$, $\eta_p{}^2 = 0.2406$), and no significant difference in the interaction between in the behavior of the attitudes factor and the behavior of the mainline vehicle ($F[1.73,96.88] = 0.5098$, $p = 0.5757$, $\eta_p{}^2 = 0.0090$). As shown in Fig. 8, multiple comparisons found that, regardless of the mainline vehicle's behavior, the person sitting at driver's seat attitude was highest for hand signs and lowest for smartphone gaze, for the evaluation of the degree of merging smoothness.

Regarding no significant differences observed in the scene factors, although the mainline vehicle's behavior indicates that it is "yielding," it is still necessary to confirm the intention of the person sitting at driver's seat by observing their attitudes and body language. Thus, this did not affect the "smoothness" of the scene.

The fact that the hand sign was the most highly rated was thought to be caused by the fact that the hand sign was such a clear indication that it obviated the need for the participant to check whether it was OK to merge. Conversely, the reason for the lowest evaluation for smartphone gaze may be that, unlike the other conditions, the person sitting at driver's seat did not seem to notice the participant's presence and could not initiate communication. Therefore, it is presumed that the participant must drive while observing the mainline vehicle's behavior carefully.

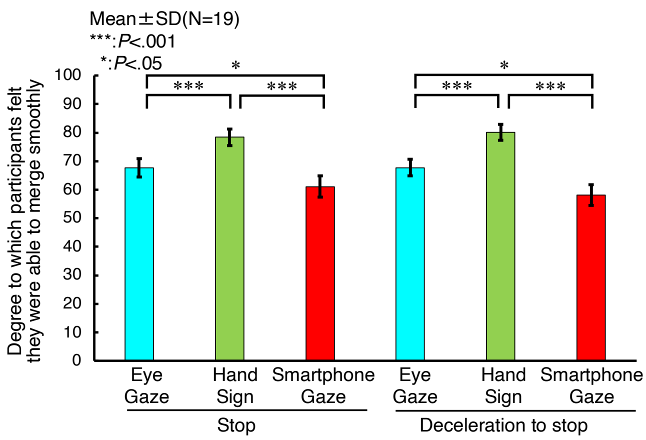

Fig. 8 Degree to which participants felt they were able to merge smoothly

3.4 Summary of results

The most significant results of the present experiments are summarized in the Table 1.

Table. 1 Table of particularly significant results.

Assessment items	Main Results
Time to release the brakes.	There was no significant difference in the main effect of attitudes factor (eye gaze, hand sign, and smartphone gaze).
Time before the person sitting at driver's seat vehicle enters the roadway.	As for the attitudes factor, the time until the participant's vehicle entered the main line was the shortest for the hand sign.
Degree to which they felt they were able to merge smoothly.	The person sitting at driver's seat attitude was lowest for smartphone gaze for the evaluation of the degree of merging smoothness.

4 Comprehensive discussions

The evaluation of the time that the participant took for the front of the participant's vehicle to enter the main line and the "degree to which the participants felt that they were able to merge smoothly into the main line" indicated that the condition in which the attitudes factor of the mainline vehicle was hand-signaling was the smoothest to enter the main line in comparison with the other conditions. This result can be attributed to successfully presenting a clear "intention to yield" from the person sitting at driver's seat to the driver. Additionally, we presume that the result that the time until the front of the participant's vehicle entered the main line became the shortest was due to the driver's abbreviation of confirmation for whether their intention to yield, which was predicted from the behavior of the mainline vehicle, was correct.

Although the time taken for the front of the participant's vehicle to enter the main line of the eye gaze condition was longer than the time of the smartphone gaze condition, the rating of the eye gaze condition in the degree of merging smoothness was rated higher than that of the smartphone gaze condition. This result indicates that the participant's evaluation of the degree of merging smoothness did not consider "how smoothly they were able to merge into the main line without taking too much time," and the rating was not as high when the participant's attention was focused on the person sitting at driver's seat in the mainline vehicle or when a hand sign indicated the person sitting at driver's seat intention to yield. The state in which the person sitting at driver's seat intention to merge into the main line is presented by hand signs and in which others approve of the series of procedures when the participant merges into the main line may influence the evaluation of "smooth merging."

Additionally, under the smartphone gaze condition, it was more difficult for the driver to merge quickly and smoothly—specifically regarding both the results of the driver's operation and subjective evaluation—rather than when a hand sign presented the driver's intention. Therefore, the driver observed the attitude of the vehicle occupants and used it as a reference in judging their behavior. Thus, in a traffic environment where manual and automatic driving are mixed, it is necessary to prevent the driver from seeing what is happening inside the automatic vehicle. And/or the indicator which shows in automatic operation is useful.

Regarding the scene factor, the data showed that the time until the start of the driving operation necessary for merging was longer in the scene where the mainline vehicle decelerated to a stop than in the scene where the mainline vehicle stopped. Therefore, as in a previous study [4], the vehicle behavior presenting the intention to yield is considered to have a strong influence on the driving operation receiving the intention to yield. Nevertheless, as no significant differences were found in the subjective evaluation, the vehicle behavior and the attitude and communication of the surrounding traffic participants are considered to be evaluated together in terms of "smoothness" and "a feeling of security."

A particularly interesting point throughout the experiment is that, from the perspective of realizing smooth traffic, the eye gaze condition was the worst compared with other attitudes factor conditions. Nonetheless, the driver's subjective evaluation was lower for the smartphone gaze condition than for the eye gaze condition. It is challenging to conduct an appropriate assessment using only the quantitative evaluation method of the driver's driving operation to realize a safe, secure, and comfortable traffic environment. This is because, quantitative indicators, such as "reaction time for the presentation of the intention to yield," which have been used in many conventional studies, do not consider the psychological aspects of traffic participants. Therefore, it is deemed necessary to use more multifaceted evaluation methods in future studies of information presentation by eHMI.

The study was conducted in a setting where level 3 and 4 automated vehicles were assumed. The results of the experiment showed that manual drivers paid more attention to the attitude of the person sitting in the driver's seat. Therefore, even in the case of level 5, drivers in the surrounding traffic environment may still pay attention to the attitude of the person sitting in the front seat. Therefore, it is necessary for the eHMI to present information on the fact that the vehicle is an "automatic vehicle" and information on the intention to yield, such as "after you", from the automatic vehicle.

Currently, not much experimental psychological research on communication between human drivers and automated driving systems has not been considered in Japan. On the other hand, studies have already started in the Netherlands [5] and Germany [6]. As automated vehicles should follow the traffic rules of the country in which they are traveling and the human drivers' driving styles are different among countries, the results of this study may be applicable in some countries, but not in the other countries which have different traffic rules and driving styles. Therefore, it is necessary to conduct similar experiments with this research method in each country henceforth.

5 Conclusion

This study examined how the attitudes and gestures of a person sitting at driver's seat in an automated vehicle on the main line affect the human driver's inference of the person sitting at driver's seat intention and the driver's maneuvers when merging into the main line. The following three results were obtained.

1. The smoothest possible merge to the main line can be achieved when the person sitting at driver's seat of the mainline vehicle performs the hand sign.
2. If the person sitting at driver's seat of the mainline vehicle is looking at the driver, the merge into the main line may be delayed more than in other conditions.
3. If the person sitting at driver's seat in the mainline vehicle are gazing at their smartphones, many drivers feel that they cannot communicate well or merge smoothly.

Therefore, for a safe, secure, and comfortable traffic environment, it is necessary to present specific and clear information from an automated driving system by using eHMI.

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7 Abbreviations

SAE: Society of Automotive Engineers; eHMI: External Human Machine Interface; ADS: Automated Driving System; DS: Driving Simulator; CG: Computer Graphics; VAS: Visual Analog Scale; MSRB: Modified Sequentially Rejective Bonferroni;

8 Declarations

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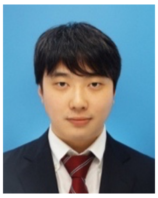

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