Effect of Visual Distraction on Response time for Lane Change with Partially Automated Vehicle

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Abstract: The present study aims to clarify how visual distraction under partially automated driving affects the driver's subjective assessment for easy and comfort and the driver's response time in a lane change task when the driver needs to take control. We conducted an experiment on a test track using 21 participants. This experiment involved a car-following task with a lead vehicle. The study found that the response time to take control for changing lanes in the partially automated vehicle was affected by the visual task load. The drivers became to perform the visual task more often with partially automated vehicle despite the complex visual load, then response time became longer. However, the situation awareness time for the partially automated vehicle was significantly shorter than that for the manual vehicle. It is supposed that partially automated driving might handle the driver's response accurately due to trust in the systems.

1. Introduction

Drivers might change their behaviors as they integrate the advance driver assistance systems into their driving routine. This change is described as "behavioral adaptation", ([1], [2], [3], [4]). It represents a significant point of uncertainty about the efficacy of many of these systems and enhances efforts to use technology to address many safety issues ([5], [6], [7]). Based on the concept of behavioral adaptation, the present study attempts to investigate how visual distraction affects driver's human factors when the driver needs to take control from a partially automated driving system. The drivers might concentrate on secondary tasks excessively while driving the partially automated vehicle. It is found the driver's response to any sudden event to be much later in partially automated driving than in manual driving ([8], [9], [10]). However, not many papers have investigated how much the drivers concentrate on a secondary task while driving the partially automated vehicle and how the driver reacts when needing to take control in such a situation ([11], [12], [13], [14], [15], [16]).

Fundamental approaches are required to reveal how visual distractions affect the driver's resumption of control ([17], [18], [19]). The present study aims to clarify how visual distraction under partially automated driving affects the driver's subjective assessment for safe and comfort and the driver's response time in a lane change task when the driver needs to take control. We conducted an experiment on a test track using 21 participants. This experiment involved a car-following task with a lead vehicle. The drivers performed the secondary tasks in a partially automated vehicle (ACC plus lane centring system) and in a non-automated vehicle (hereinafter: "manual vehicle"). To assess the effect of visual distraction on response time in taking control, we prepared a simple visual task and a complex visual task, both of which involved a surrogate user interface. The drivers performed these tasks self-paced.

2. Methods

2.1. Test Track

The experiments were conducted at the test track of the National Institute for Land and Infrastructure Management in Tsukuba City, Japan. The track has a 2,000-m straight section within a 6,000-m oval track (Figure 1). In the first session, the participants drove the 4,000-m course in Figure 1 nine times using a manual vehicle whose advanced driver assistance system had been deactivated. After the first session, the participants drove the 4,000-m course nine times using a partially automated vehicle whose advanced driver assistance systems had been activated.

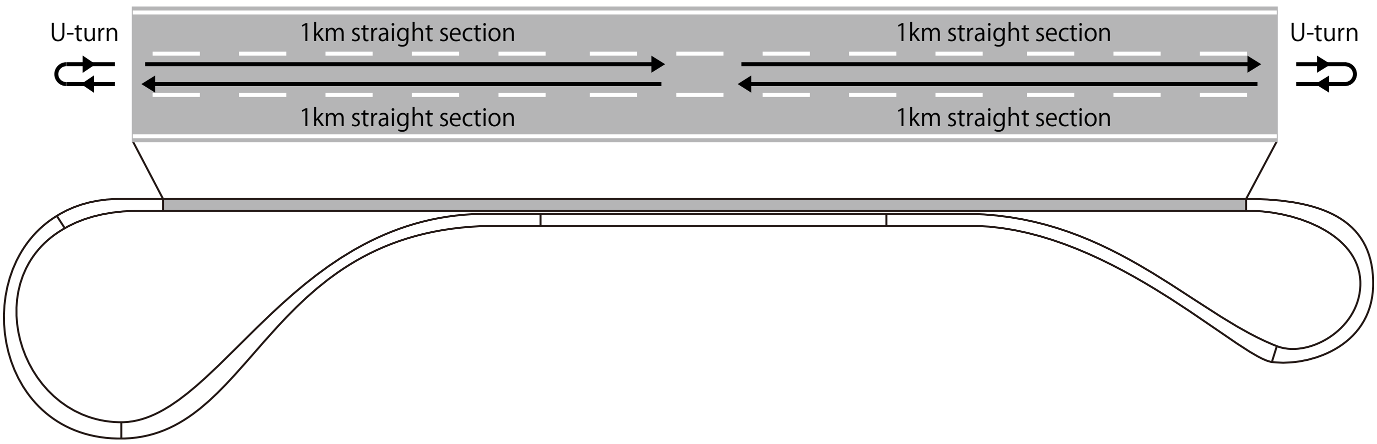


Fig. 1. *Test track of the National Institute for Land and Infrastructure Management*

2.2. Participants

Twenty-one drivers (aged 21 to 63 years, mean of 41.5 years, 11 females and 10 males) participated. They were recruited through local advertisements and were screened to ensure that they were active drivers with a valid Japanese driver's license, drove a minimum of 5,000 km per year, had normal vision and were unfamiliar with partially automated vehicles. At the beginning of the session, the experimenters spent 30 minutes explaining the schedule, the experimental overview and the secondary tasks to be performed during driving, the risks of the experiment, the cancellation policy and emergency procedures.

When the explanation was complete, the participants gave written informed consent of participation. No individual declined to participate. The research methodology was approved by Ethical Review Committee for Research with Human Subjects in Engineering Course of Hokkaido University, Japan.

2.3. Partially Automated Vehicle

Adaptive Cruise Control (ACC) and Lane Keeping Assist System (LKAS) were installed in the partially automated vehicle. ACC maintains a constant vehicle speed and a set following interval behind a vehicle detected ahead, and if the detected vehicle slows to a stop, the system decelerates and stops the experimental vehicle without the driver having to keep a foot on the brake or the accelerator. LKAS provides assistance to keep the vehicle in the center of the lane by using the front sensor camera when the lane has detectable lane markers on both sides. The system applies torque to the steering to keep the vehicle between the left-lane line and the right-lane line. The applied torque increases as the vehicle approaches either of the lane lines. However, the driver needs to hold the steering control in this system.

2.4. Primary Driving Task

We selected a car-following task in which the lead vehicle's speed changed according to a predefined rhythm. The lead vehicle slowed to 65 km/h and sped up to 70 km/h. The frequency of the speed cycle was approximately 0.05 Hz. Also, we selected the license plate of the leading car as an appropriate visual target for the participants to maintain about 40m of headway (approximately 2 seconds) while following the leading vehicle. In case of the manual driving, participants were required to follow a lead vehicle whose speed changed on the test track's 2.0-km straight section.

2.5. Two Secondary Tasks

During the primary driving task, the drivers performed the simple or the complex visual task shown in Figure 2, at their own pace. An 8-inch touch screen (Century LCD-8000) was used in this experiment. The position of the touch screen was the same as the car navigation system. We did not re-adjust the screen position for each participant. Also, software that presents the simple visual task and the complex visual task on the screen recorded the start and finishing time for each visual task and the number of correct answers during each run.

The Simple Visual Task: The participants were required to view a single-digit numeral on the screen. While viewing it, the participants were to touch the same single-digit numeral from the five other numerals shown on the screen (Figure 2(A)). Cognitive, visual and manual distractions can occur during such a secondary search task while the driver is following a lead vehicle and maintaining the lateral position. However, these distractions are simple and light for drivers.

The Complex Visual Task: The participants were required to view one short word on the screen at a time. The word was of five, six or seven Japanese hiragana characters. While viewing that word, the participants were to tap all the characters of the presented word with their index finger on the screen (Figure 2(B)). The participants had to select the correct characters from among the 48 phonetic Japanese hiragana characters, which places a complex visual load on the participants rather than the simple visual task. Cognitive, visual and manual distractions can occur during such a secondary search task while the driver is following the lead vehicle and maintaining a lateral position in case of the manual driving.

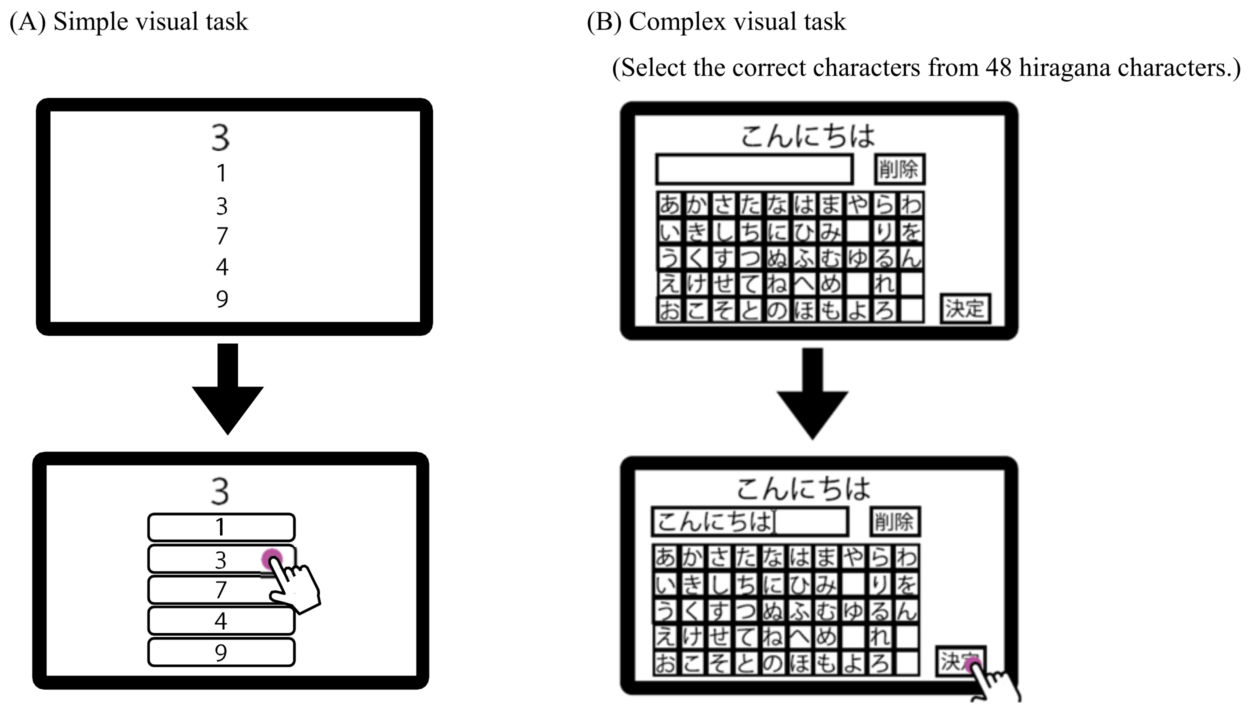


Fig. 2. *The two self-paced secondary tasks, which the drivers performed during the primary task*

2.6. Lane Change Task

While performing the primary task, the drivers were suddenly required to change lanes as soon as possible after noticing the left-turn signal of the lead vehicle. The left-turn signal of the lead vehicle was intended to simulate the situation in which a lead vehicle stops due to abnormal conditions and a following vehicle has to change lanes to avoid that vehicle. To ensure safety, however, the lead vehicle did not stop but maintained its speed after signaling the turn. Figure 3 shows this lane change task step by step. In the first step, the lead vehicle signals a left turn. Before signaling a right turn, the driver must check the surroundings by using the side and rear-view mirrors, determine the gap to enter and ensure nothing is in the way. The gap distance of the following vehicle was approximately 40 meters, and the gap was maintained during run. In the second step, the driver must move into the right lane as soon as possible after noticing the left-turn signal of the lead vehicle.

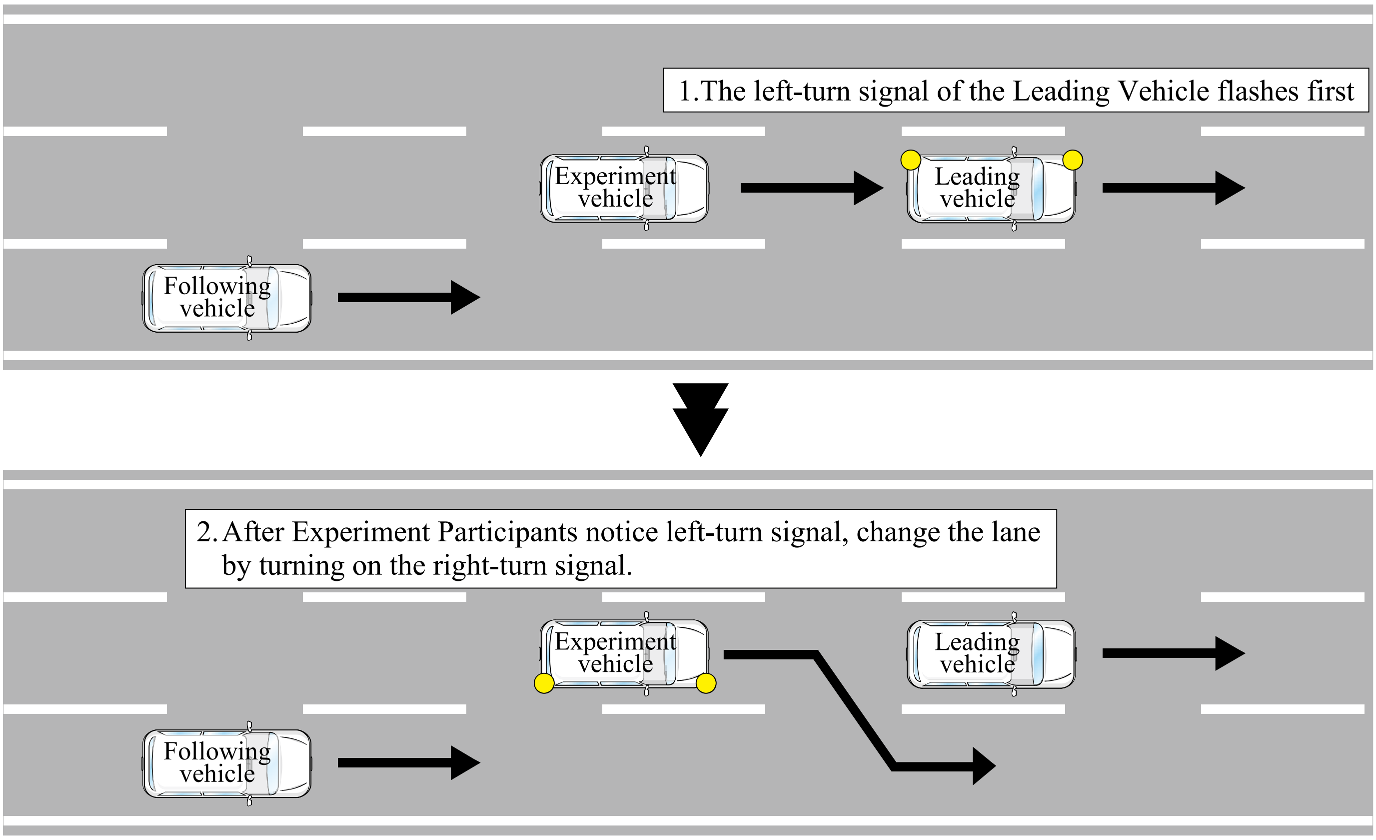


Fig. 3. *The lane change task*

2.7. Measuring the Response Time

When the lane change task started, we recorded the driver's response time using the devices described below. We defined two response times shown in Figure 4. The first refers to the lag between when the lead vehicle signalized a left turn and when the participants signalized a right turn. The second refers to the lag between when the participants looked from the secondary task screen back to the road ahead until the participants signalized for a lane change.

To record these two response times, the experimental vehicles (the manual vehicle and the partially automated vehicle) and the lead vehicle were installed with the Video-VBOX-Pro (20Hz, RACELOGIC), which records controller area network (CAN) signals from an OBD-2 port, and with the RTK-GPS (R330 GNSS Receiver, Hemisphere). The RTK-GPS recorded the location and the speed of the vehicle in real-time using GNSS. The sampling and output rate of the system is 20Hz, and the system has a margin of error of plus or minus 3 cm each for the longitudinal and lateral positions. The sampling rate was 20 Hz. Also, a small static on-board video camera installed on the dashboard was used to record the driver's viewing direction. We measured the driver's behavior and the vehicle behavior during the lane change task using CAN signals, RTK-GPS and a small on-board video camera.

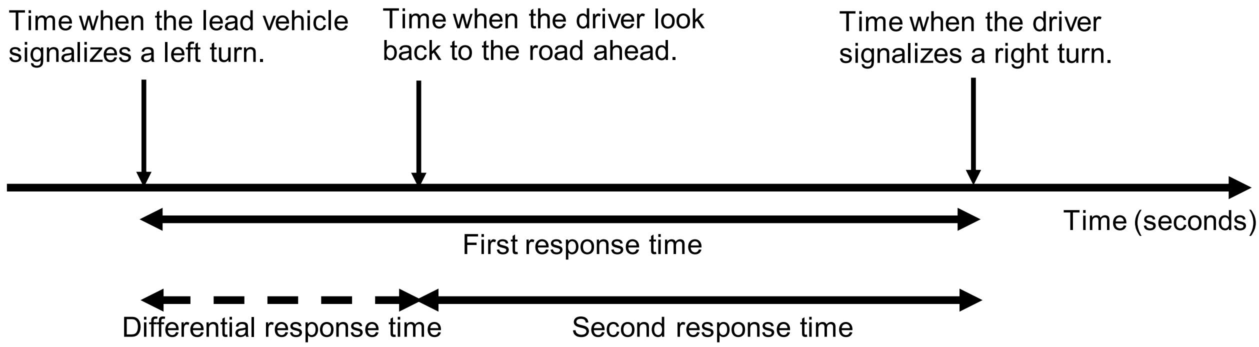


Fig. 4. *Measured two response times*

2.8. Five Subjective Assessment Items

There were five subjective assessment items (Figure 5); assessment of ease and comfort of the simple and complex visual task while driving the manual and the partially automated vehicle, assessment of dependence of the ACC while driving the partially automated vehicle, assessment of dependence of the LKAS while driving the partially automated vehicle and assessment of convenience of the partially automated vehicle. The participants evaluated each of Q1 and Q2 subjective assessment items on a scale of one to nine (Figure 4) after finishing the first session. Also, the participants evaluated each of the five subjective assessments after finishing the second session. Performance of the simple and complex visual task was subjectively assessed with respect to the easy and comfort with which the task was performed. The task was performed while theparticipants followed the lead vehicle in the manual vehicle or in the partiality automated vehicle. The Q3 was to evaluate dependence on the ACC, and the Q4 was to evaluate dependence on the LKAS. The Q5 was to evaluate whether the participants found it comfort to drive using the advanced driver assistance systems even while performing the visual tasks.

Q1: While you driving the test section, how easy was it to perform the simple visual task?

Hard | | | | | | | | | Easy

While you were driving the test section, how easy was it to perform the complex visual task?

Hard | | | | | | | | | Easy

Q2: While you were driving the test section, how comfort was it to perform the simple visual task?

Discomfort | | | | | | | | | Comfort

While you were driving the test section, how comfort was it to perform the complex visual task?

Discomfort | | | | | | | | | Comfort

Q3: While you were driving the test section, how heavily did you depend on the ACC?

Not heavily | | | | | | | | | Heavily

Q4: While you were driving the test section, how heavily did you depend on the LKAS?

Not heavily | | | | | | | | | Heavily

Q5: How comfort was it to drive the test section using the advanced driver assistance systems?

Discomfort | | | | | | | | | Comfort

Fig. 5. *The five subjective assessment questions*

2.9. Experimental Design

There were two independent variables: the vehicle type (manual vehicle and partially automated vehicle), and the secondary task condition (the primary task alone (the baseline condition), the simple visual task and the complex visual task). The participants were self-paced in performing each of the two visual tasks during each run. Also, each participant performed the lane change task twice for each of the three secondary task conditions. In addition, we randomly assigned the lane change task to each of 21 participants during the run.

Each participant used the manual vehicle for the first session and the partially automated vehicle for the second session. The participants went around the 4km-course nine times in the manual vehicle and nine times in the partially automated vehicle. We divided the 4km course into four 1km straight sections shown in Figure 1. This gave us 36 1km sections in all. Three secondary task conditions were randomly assigned to each of the 36 1km straight sections. Under each of three secondary task conditions, we randomly assigned the lane change task to the 12 1km sections per each of three secondary task.

2.10. Experimental Procedure

At the beginning of the session, we briefly explained the experimental overview. After that, we explained the car-following task, the two visual tasks, the lane change task and how to drive the partially automated vehicle. Also, we explained that the lane change task was the first priority. We told them that they should stop the secondary task when they notice the lane change task as soon as possible.

The participants were instructed on how to perform details of the lane change task. They moved into the right lane as soon as possible after noticing that the lead vehicle was signaling a left turn. Before signaling a right turn, they need to check the gap with the following vehicle coming from the rear left by using their side and rearview mirrors shown in Figure 3. Also, we told them that the lead vehicle does not stop and maintained the same speed after signaling the turn. After changing lanes, they need to return to the left lane and resume following the lead vehicle. In addition, we explained the five subjective questions. The whole process for these explanations took about 30 minutes.

After all the explanations, the participants went to the starting area of the test track, and adjusted the seat and the steering wheel. They were instructed on how to complete the two visual tasks in detail. After that, they had a training session. Before the first session in the manual vehicle, they drove the 4km course four times. They familiarized themselves with the primary car-following task, the secondary visual tasks and the lane change task. Following that, the participants performed the first session. It took about 30 minutes per each participant. There was a 10-minute break, and then the participants drove the 4km course five times in the partially automated vehicle. It was thought that the participants need more times to familiar with the operation of the ACC and the LKAS than those to become familiar with the manual vehicle. The participants then performed the second session. It took about 30 minutes per each participant. The whole process including the first and the second sessions and breaks took about 90 minutes per participant.

3. Results

3.1. Results of the Five Subjective Assessment Responses

Figure 6 shows the subjective assessments of how easy it was to perform the simple visual task and the complex visual task. Figures 6(A) and 6(B) show the results of subjective assessment for the respective tasks. The vertical axis indicates the number of drivers choosing a given value on the nine-point scale shown by the horizontal axis. The large value of the horizontal score means that the drivers felt easy to

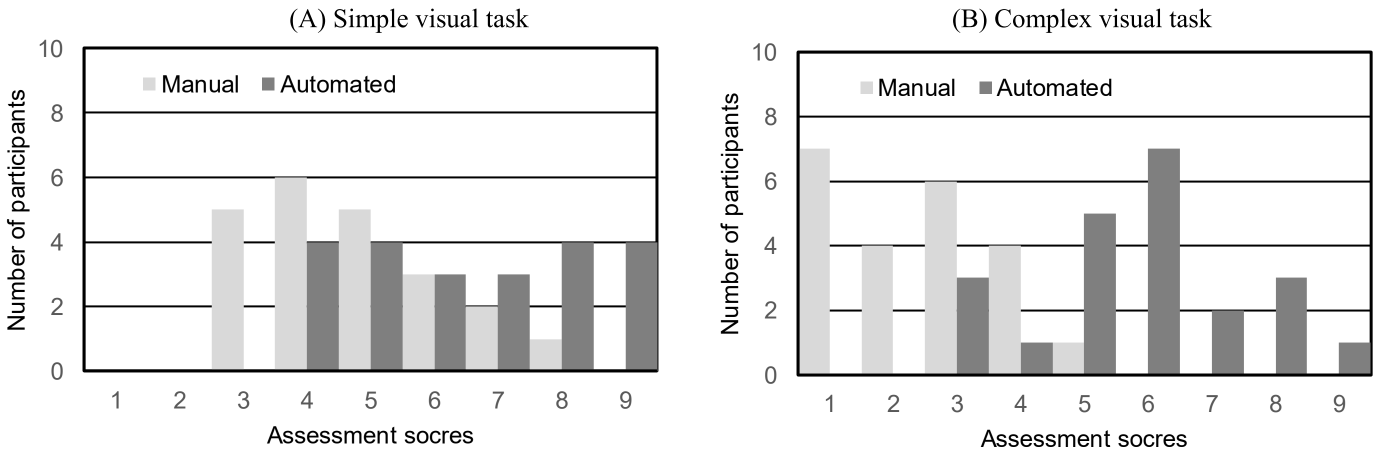


Fig. 6. *Subjective assessments of how easy it was to perform the simple and the complex visual tasks.*

perform the visual task. Within-subjects ANOVA was conducted to evaluate the effect of the two independent variables on the mean of subjective assessment scale for easy. The interaction between the secondary task and the vehicle type ($F(1, 79)=5.37$, $p<0.05$) was found to have a significant effect on the mean of the subjective assessment scale for easy. There was significant mean difference in subjective assessment score for easy among the partially automated vehicle and the manual vehicle under the complex visual task. However, there was not significant difference in subjective assessment score for safe under the simple visual task. The number of drivers who had high evaluation scores increased in case of the partially automated vehicle. This tendency was particularly notable for the complex visual task.

Figure 7 shows the subjective assessments of how comfort it was to perform the simple and the complex visual tasks. The large value of the horizontal score means that the drivers felt comfort to perform the visual task. The scores given by the most number of drivers were less than 5 point for both of the simple and complex visual task in case of the manual vehicle. In contrast, the scores given by the most number of drivers were over 5 point in case of the partially automated vehicle. A few drivers gave low scores of less than 5 even for the partially automated vehicle. Within-subjects ANOVA was conducted to evaluate the effect of the two independent variables on the subjective assessment score for comfort. There was no interaction effect between the secondary tasks and the vehicle. Vehicle type ($F(1,79)=99.8$, $p<0.01$) and secondary task ($F(1,79)=10.5$, $p<0.01$) had a significant effect on mean subjective assessment score for comfort. The operation of the secondary task under partially automated vehicle was significantly comfort rather than that under manual vehicle. Also, the operation of the simple visual task was significantly more comfort than that of the complex visual task.

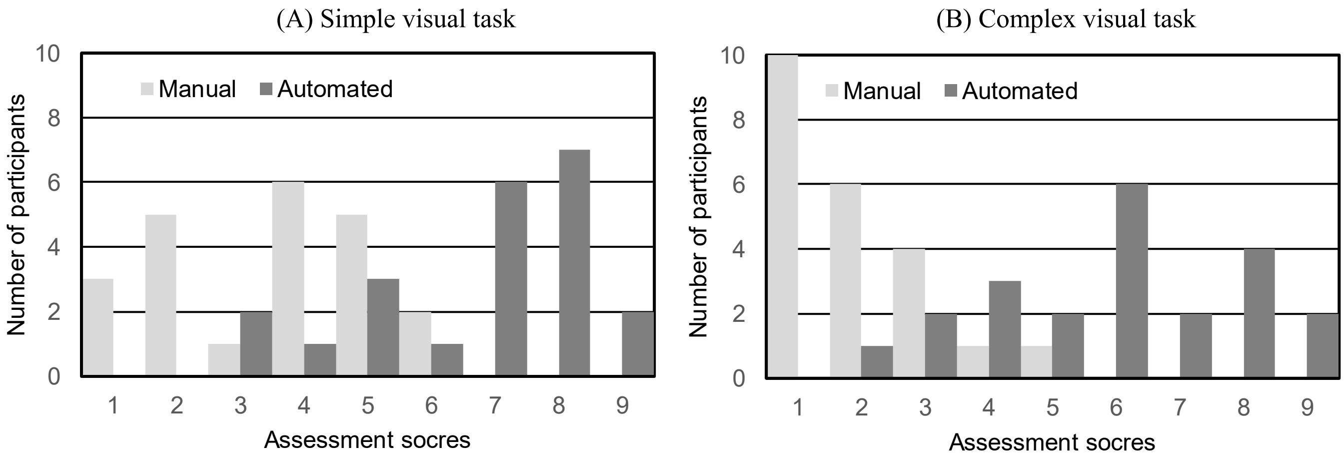


Fig. 7. *Subjective assessments of how comfort it was to perform the simple and the complex visual tasks.*

Figures 8(A) and 8(B) show the subjective assessments of dependence on ACC and LKAS, respectively. The vertical axis indicates the number of drivers choosing a given value on the nine-point scale shown by the horizontal axis. The large value of the horizontal score means that the drivers depended on the ACC and LKAS. The most number of drivers selected high evaluation scores, and this means the most drivers depended on these systems. Figure 9 shows evaluating results whether the drivers could drive comfortably using the advanced driver assistance systems despite performing the visual tasks. The most drivers selected high evaluation scores.

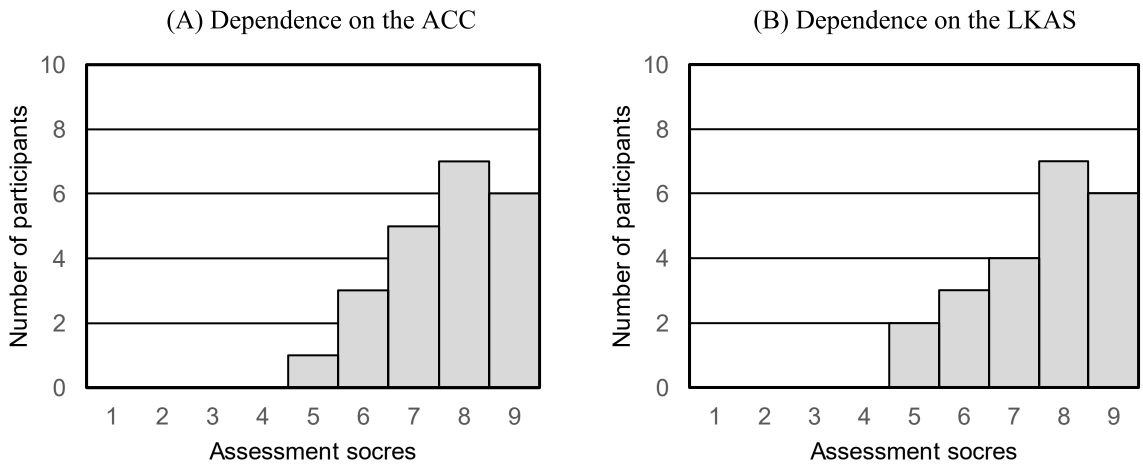


Fig. 8. *Subjective assessments of dependence on ACC and LKAS, respectively.*

3.2. Analysis of Display Viewing Time

We analysed data of the 14 participants in terms of the display viewing time and the response time. We were unable to record data for the other 7 participants due to sunlight effects on the camera and the mis-operation of the data measuring system.

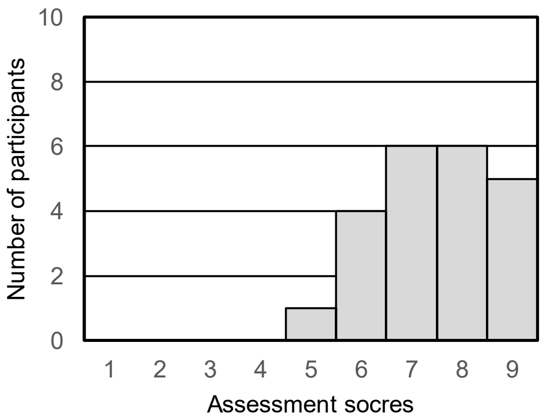


Fig. 9. *Results of whether the participants were able to drive comfort using the advanced driver assistance systems despite performing the visual tasks*

A small static on-board video camera installed on the dashboard was used to record the viewing time per glance at the display. We measured the display viewing time for the runs with the lane change task. Also, we recorded the display viewing time from 5 seconds before the drivers initiated the left-turn signal to 20 seconds after the drivers initiated the left-turn signal. After the experiments, the experimenter recorded the time codes for when the drivers started and ended each glance at the display on a sheet by advancing the video image frame by frame.

Figure 10 shows the results for mean and standard deviation of display viewing time per glance for the simple and complex visual tasks as a function of manual automated vehicle versus partially automated vehicle. Within-subjects ANOVA was conducted to evaluate the effect of the two visual tasks and the two vehicle types on mean display viewing time per glance. There was no interaction between visual task and vehicle type. Visual task ($F(1,287)=8.90$, $p<0.01$) and vehicle type ($F(1,287)=11.7$, $p<0.01$) had significant

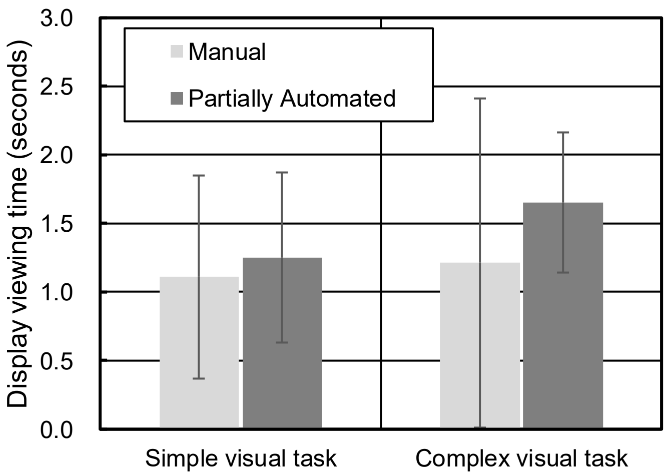
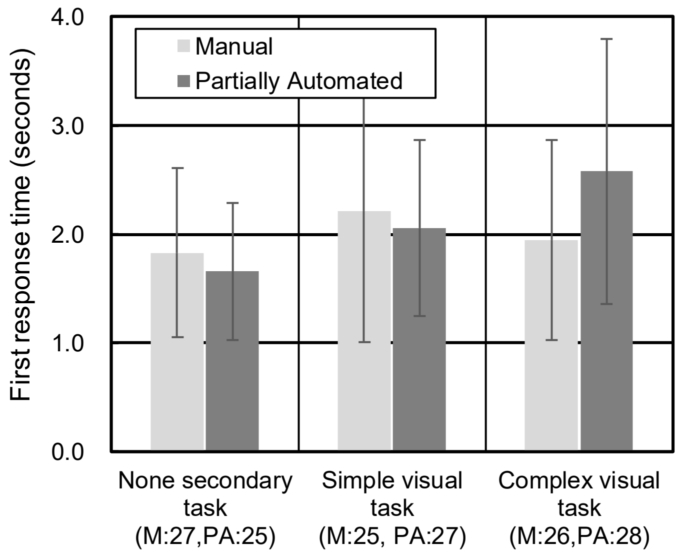


Fig.10. *Display viewing time as a function of the two visual tasks and the two types of experimental vehicle*

effects on mean display viewing time. The mean for the partially automated vehicle was significantly greater than that for the manual vehicle. Also, the mean for the complex visual task was significantly greater than that for the simple visual task.

3.3. First Response Times

Figure 11 shows the mean and standard deviation of first response time when the drivers performed the lane-change task under the three secondary task conditions in the manual vehicle and in the partially automated vehicle. Within-subjects ANOVA was conducted to evaluate the effect of the secondary task and the vehicle type on the mean of the first response time. The secondary task includes the baseline condition and the two visual tasks. The interaction between the secondary task and the vehicle type ($F(2, 139)=5.21$, $p<0.01$) was found to have a significant effect on the mean of the first response time. The first response times for the partially automated vehicle under the baseline condition and the simple visual task were shorter than those for the manual vehicle. However, the first response time was longer for the partially automated vehicle under the complex visual task than for the manual vehicle under the complex visual task.

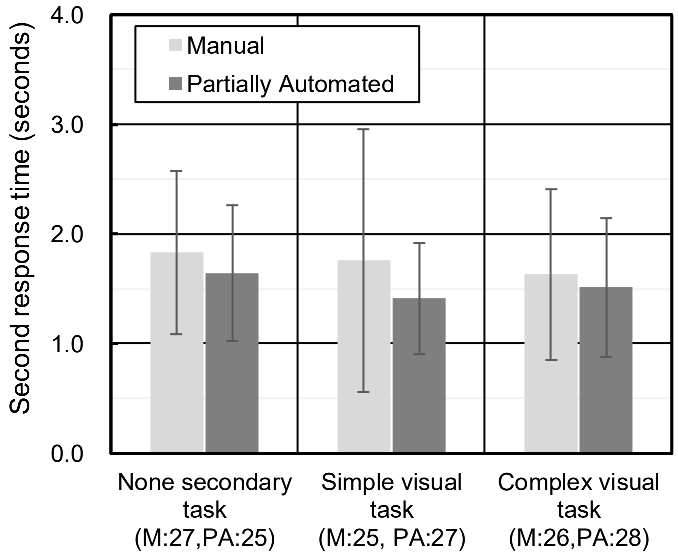


Note: Number shown in parentheses is number of data for each vehicle.

Fig. 11. *First response time as a function of the secondary task and the vehicle type*

3.4. Second Response Time

Figure 12 shows the results for mean and standard deviation of the secondary response time when the drivers performed the lane change task under the three secondary task conditions in the manual vehicle and the partially automated vehicle. Within-subjects ANOVA was conducted to evaluate the effect of the three secondary tasks and the vehicle type on the second response time. There was no interaction effect between the secondary tasks and the vehicle. Only vehicle type ($F(1,139)=5.64$, $p<0.05$) had a significant effect on the mean of the second response time. The second response time for the partially automated vehicle was significantly shorter than that for the manual vehicle. In addition, we performed a post hoc test to analyse the effect of the three secondary tasks on the mean of second response time. The mean second response time during the two visual tasks was significantly shorter than that of the baseline condition. There was no significant difference in the second response time between the complex and simple visual task conditions.



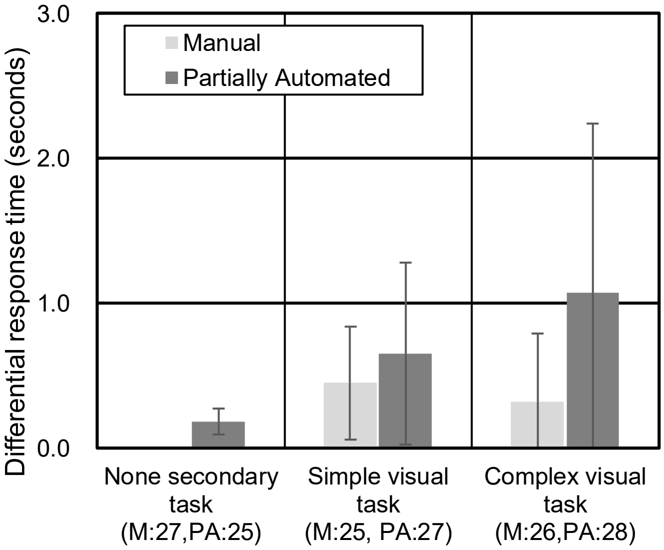
Note: Number shown in parentheses is number of data for each vehicle.

Fig. 12. *Second response time as a function of the secondary task and the vehicle type*

3.5. Difference in response time between the first and the second response times

Figure 13 shows the mean and standard deviation of “difference in response time between the first and the second response times” (hereinafter, differential response time) shown in Figure 4. Mean differential response time for none secondary task was zero seconds. Then, within-subjects ANOVA except none secondary task condition was conducted to evaluate the effect of the secondary task and the vehicle type on the mean of differential response time. The interaction between the secondary task and the vehicle type ($F(1, 89)=4.61$, $p<0.05$) was found to have a significant effect on the mean of the differential response time. The mean differential response time for the partially automated vehicle under the simple visual task was longer than that for the manual vehicle. Under the complex visual task, the mean differential response time for the manual vehicle became shorter than that under the simple visual task. However, this tendency was opposite for the partially automated vehicle. The differential response time increased largely under the complex visual task.

Thus, we examined the mean differential response time among the two secondary task conditions for each of the two vehicles. The secondary task in the manual vehicle did not have significant difference in the mean differential response time. The secondary task in the partially automated vehicle did not have significant difference in the mean differential response time. Also, we examined the mean differential response time between the two vehicles for each of the two secondary task conditions. There was not significant difference in the mean differential response time among the two vehicles in case of the simple visual task. However, there was significant difference in the mean differential response time among the two vehicles in case of the complex visual task. The mean differential response time with the partially automated vehicle was significantly longer than that with the manual vehicle.



Note: Number shown in parentheses is number of data for each vehicle.

Fig. 13. *Differential response time as a function of the secondary task and the vehicle type*

4. Discussions

On the test track, we simulated a situation in which the drivers were required to take control of driving when the advanced driver assistance systems were unable to handle a sudden situation under performing the secondary visual tasks. The drivers spent more time performing the secondary task when driving the partially automated vehicle despite facing the sudden situation than performing that when driving the manual vehicle. In self-paced visual tasks, many other researchers reported that the driver tends to focus more on the secondary task when driving a vehicle with advance driver assistance systems than when driving a manual vehicle ([11], [12], [13], [14], [15], [16]). The present study indicated that the mean of viewing time per glance at the screen under the complex visual task was 0.4 seconds greater in the partially automated vehicle than in manual vehicle. Mean viewing times recorded in the present study under partially automated vehicle were around 1.5 seconds. Authors indicated that 90% of single viewing time was less than 1.5 seconds in driving during visual task under the distracted driving [20]. This is thought to be not over safe driving.

Also, the results of the five subjective assessment responses indicated that the drivers felt easy despite the complex visual task when they drove the partially automated vehicle. Differences in evaluation of easy and comfort of performing the second tasks between the manual vehicle condition and the partially automated vehicle condition were significantly greater when they performed the complex visual task than when they performed the simple visual task. In addition, most drivers depended on the ACC and the LKAS, and regarded the partially automated driving as convenient.

The present study measured the response time to take control during performing complex and simple secondary visual tasks. We measured two types of response time when the drivers performed lane change. It is supposed that the first response time includes perception time and situational awareness time. The differential response time could be regarded as perception time. Because, the differential response time corresponds to the lag back to the road ahead from the secondary task screen. Also, the second response time could be regarded as situational awareness time. During the second response time, the drivers must check the surroundings, and determine to move into the right lane as soon as possible.

The differential response time for the complex visual task in the partially automated vehicle shown in Figure 13 was significantly greater than that in the manual vehicle. It is supposed that the drivers might have chosen to focus excessively on the complex visual task because of relying heavily on partially automated driving. In contrast, the second response time for the partially automated vehicle was significantly shorter than that for the manual vehicle shown in Figure 12. The partially automated vehicle might accelerate driver's situation awareness due to trust in vehicle behaviour controlled by the system.

5. Conclusions

The study found that the response time to take control for changing lanes in the partially automated vehicle was affected by the secondary visual task load. The drivers became to perform the secondary visual task more often with partially automated vehicle despite the complex visual load, then perception time became longer. It is assumed that the drivers spend longer glances on the visual task during the automated condition, because they trust the ACC and the LKAS. They know that it is safer to do so in automation than when not automated. Also, the situation awareness time for the partially automated vehicle was significantly shorter than that for the manual vehicle. It is supposed that partially automated driving might handle the driver's response accurately due to trust in the systems. Then, it might be required to install the human machine interface to increase the driver's trust for automated vehicle regardless of normal and abnormal situations.

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