International Journal of Intelligent Transportation Systems Research (2019) 17:18–31
https://doi.org/10.1007/s13177-018-0153-y

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Information Sharing to Improve Understanding of Proactive Steering Intervention for Elderly Drivers

Takuma Ito [1] · **Tatsuya Shino** [1] · **Minoru Kamata** [1]

Received: 28 September 2017 / Revised: 23 January 2018 / Accepted: 5 February 2018 / Published online: 15 February 2018

Abstract

In this study, we focus on the effectiveness of information sharing as a practical method for improving elderly drivers' understanding of a proactive steering intervention system that is triggered several seconds before a driver enters a dangerous situation. Because the situation of steering intervention is more complex than that of braking intervention, there are two characteristic topics to be investigated: prevention of information overload by provided visual contents, and reduction of subjective strangeness due to the steering intervention. At first, we implement four kinds of prototypes of visual content for the head-up display. After that, we investigate basic characteristics of various usages of the implemented prototype visual content using questionnaires. As a result of our experiments using a driving simulator, we confirm that information sharing using visual content is effective in improving elderly drivers' understanding of benefits, trust, and reducing the feeling of strangeness of our system. In addition, from the comparisons between single and multiple uses of visual content, we propose methods to improve them further to prevent information overload.

Keywords Elderly driver · Driving support · HMI · Proactive collision avoidance

1 Introduction

For reducing traffic accidents caused by elderly drivers, which is currently a major issue in Japan [1], more advanced safety technologies that assist such drivers are required [2–5]. To this end, our research group [6] has been developing intelligence for automated vehicles. As discussed in our previous study [7], one of the characteristics of intelligent driving assistance systems is that a vehicle intervenes proactively and performs operations on behalf of the driver. To utilize such proactive collision avoidance systems, the investigation of driver acceptance is as important as technological development. Thus, in our previous study [7], we focused on the acceptability of proactive collision avoidance systems for elderly drivers.

To this end, we implemented two simplified proactive intervention systems: proactive braking intervention and proactive steering intervention. As a result of previous experiments using a driving simulator, we confirmed basic tendencies regarding the acceptance of proactive collision avoidance systems for elderly drivers. Regarding the proactive steering intervention, many elderly drivers evaluated their acceptability of the system negatively due to uncertainty about vehicle behavior. In addition, they referred to the feeling of strangeness about the vehicle locomotion path compared to their usual driving. Thus, we discussed various approaches to improve acceptability, including improvements in vehicle controls, driver education, and development of human machine interfaces (HMIs) for improved interaction. Among the candidate approaches for improvement, in this study, we focus on technological approaches related to "information sharing." Figure 1 shows the conceptual schematic of proactive intervention system with information sharing. In contrast with existing warning systems, which aim at ensuring appropriate driver behavior, information sharing aims to provide drivers with information that enables them to accept the behavior of the proactive intervention system.

For the final goal of our study, we need to investigate many topics for designing better information-sharing systems. Thus, in this study, we first investigated the basic characteristics of information sharing, and then proposed improved means of understanding proactive steering intervention systems. Since visual and behavioral situations of steering intervention are more complex than those of braking intervention, we need to take this point into consideration.

✉ Takuma Ito
ito@iog.u–tokyo.ac.jp

[1] The University of Tokyo, 5-1-5 Kashiwanoha, Kashiwa, Chiba, Japan

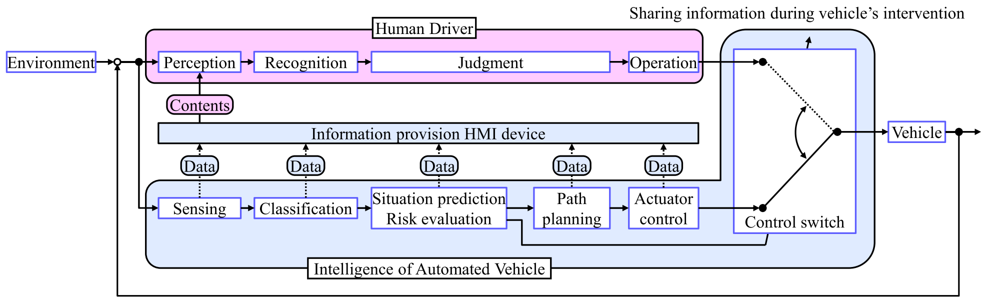

Fig. 1 Conceptual schematic of proactive intervention system with information sharing

Figure 2 shows a schematic of the research flow for proactive collision avoidance systems, as well as our position in this study. Although we previously [7] focused on two proactive collision avoidance systems, in this study, we focused only on proactive steering intervention. Figure 3 shows an overhead illustration of a situation in which proactive steering intervention occurs. This situations is one of typical situations on the community roads, where elderly drivers usually drive their vehicle. In Japan, the velocity on community roads is often regulated no more than 30 km/h [1] because probability of fatal injuries of pedestrians gets high in accordance with the impact velocity of the vehicle [9]. In this situation, a vehicle automatically detects a parked car and predicts a collision with it. To avoid this collision, the self vehicle proactively intervenes by steering with a soft yawing motion. Because our collaborator [10] was attempting to simultaneously develop a detailed vehicle control scheme for situations similar to those used in our trials, we conducted this study using simplified controls that imitated our proactive concept.

This paper is organized as follows: details of the approach of information sharing with considering the characteristic problem of steering intervention are described in the chapter 2. Detailed methods of the experiment and evaluations are described in the chapter 3. The experimental results and discussions are described in the chapter 4. And, conclusions and future works are described in the chapter 5.

2 Improving Understanding of Proactive Steering Intervention

2.1 Approach

In our previous study [7], we discussed a three-layer acceptance structure consisting of reaction, comprehension, and reflection. From the viewpoint of reactive acceptance, we confirmed some problems with proactive steering intervention, which resulted from uncertain system behavior. Furthermore, the lateral deviation for avoiding surrounding traffic participants via steering intervention may not have been in tune with the natural instinct of drivers. In other words, they may perceive the feeling of strangeness of the vehicle motion compared to their usual driving. Although these reactive aspects of the proactive steering intervention system may have reduced its acceptability for elderly drivers, these aspects are necessary for ensuring driving safety. Thus, solutions related to comprehensive acceptance, which is a higher layer than reactive acceptance, were deemed necessary.

To achieve comprehensive acceptance, it is important for drivers to perceive the system's benefits and to trust it. Thus, similar to our other previous study [8], we focused on an information-sharing approach that provides various types of information to the drivers. To be more precise, we used a head-up display as the HMI device, and discussed the information sharing based on the visual content. In this study, "information" and "content" refer to abstract discussion and implementation, respectively, to avoid confusion. The details of the concept of information sharing are described in our previous paper [8].

In contrast with the situation of braking intervention that was discussed in our previous study, the situation of steering intervention are visually and behaviorally complex. On this point, Vincent Cantin et al. [11] reported that the mental workload in the situation of overtaking was larger than in the situations of straight road and intersections. Similarly, Jessica Edquist et al. [12] reported the relations between parked vehicles and mental workload. Thus, in the situation of steering intervention, adjusting the amount of provided visual content may be more important than in the situation of braking intervention. On this point, reduction of provided visual content from a viewpoint of intent understanding and corresponding conjecture that were described in the previous paper [8] would be helpful to avoid the information overload.

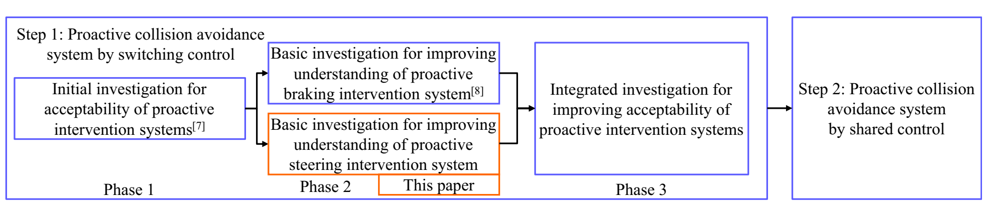

Fig. 2 Research flow to improve acceptability of proactive collision avoidance systems

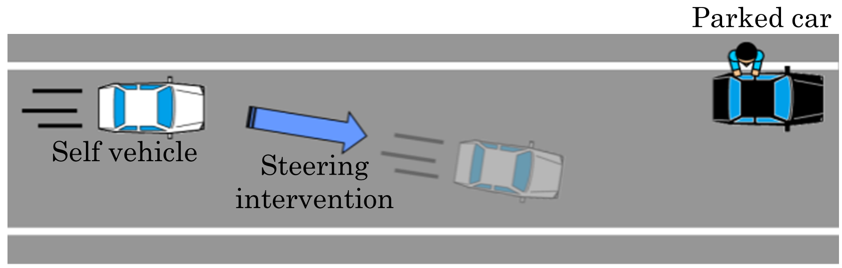

Fig. 3 Example of proactive steering intervention

In addition to the factors of the mental workload, behavioral characteristics of lateral control can affect the acceptability of the drivers. On this point, Genya Abe et al. [13] reported that characteristics of lateral control of automated vehicle in the situation of overtaking and passing other traffic participants affected the trust of the drivers. In their experiments, if the automated vehicle avoided the bicycles and scooters more gently or more hardly than the manually driving behaviors of each participant, the subjective ratings of trust were decreased. Similarly, in our previous study [7], we confirmed that some elderly drivers did not accept the steering intervention partly because of a feeling of strangeness caused by differences between the motion of the self-vehicle and what drivers anticipated. Thus, how to deal with the feeling of strangeness is a characteristic problem in the situation of steering intervention. On this point, we need to investigate basic characteristics, which were not discussed in the previous studies.

2.2 Detailed Design of Visual Content for Steering Intervention

For proactive steering intervention, information regarding when, why, and how a vehicle intervenes in vehicle control is important. In addition, unlike proactive braking intervention, a vehicle automatically approaches the opposite side of a road by proactive steering intervention; therefore, a notification confirming safe vicinity for steering intervention appears necessary. To provide this information, we designed a system to share four types of information: safety confirmation, system status, detection of surrounding traffic participants, and planned path. Regarding the design of the lower layer of visual content, we referred to ISO/IEC GUIDE 71 [14].

Figure 4 shows a schematic of the timeline of proactive steering intervention with the sharing of safety confirmation information. The schematics above the timeline show corresponding situations and examples of visual content. Unlike in several other countries, vehicles are driven on the left side of the road in Japan. Thus, as shown in Fig. 4, a vehicle drives itself on the left side. The horizontal axis indicates time, where 0.0 s is the time at which the vehicle passes through the point just beside a parked car. In this proactive steering intervention, we assume that the vehicle starts to steer 5.0 s before it passes through that point.

For sharing information of safety confirmation, we designed three types of visual content: notification of collision risk, notification of confirming safe vicinity, and completed notification of safety confirmation. Figures 5, 6, and 7 show the three types of visual content. First, an icon for the notification of collision risk is displayed 6.0 s before a vehicle starts to steer, as shown in Fig. 5. Second, an icon for the notification of confirming safe vicinity is displayed 4.0 s before steering intervention, as shown in Fig. 6. Finally, an icon for the completed notification of safety confirmation is displayed 2.0 s before steering intervention, as shown in Fig. 7. The blue characters indicates “safe” in Japanese. All three indications are displayed on the right side of a driver’s field of view. In addition, the system beeps relatively loudly to ensure that it is heard. Sounds of different notifications differ from each other to facilitate their distinction.

Figure 8 shows a schematic of proactive steering intervention with the sharing of system status information. For this information sharing, we designed two types of visual content: activation notification and remaining time of proactive steering intervention and completed notification of proactive steering intervention. Figures 9 and 10 show these types of visual content. First, an icon for activation notification and remaining time is displayed when a vehicle starts to steer automatically. During steering intervention, the length of the red sidebars decreases based on the remaining time of proactive steering intervention, as shown in Fig. 9. Finally, an icon for the completed notification of proactive steering intervention is displayed when a vehicle automatically completes the intervention, as shown in Fig. 10. These indicators are also displayed on the right side of a driver’s field of view. Similar to the previous case, the system beeps relatively loudly to ensure perception.

Figure 11 shows a schematic of proactive steering intervention with the sharing of information about the detection of surrounding traffic participants. For sharing this information, we designed only one piece of visual content: notification of traffic participants detected in the surrounding. As shown in Fig. 12, yellow rectangles are displayed at the positions of surrounding traffic participants as the notification of detection. Similar to the previous cases, the system beeps relatively loudly to ensure perception when the yellow rectangles are displayed.

Figure 13 shows a schematic of proactive steering intervention with the sharing of planned path information. For sharing this information, we designed only one piece of visual

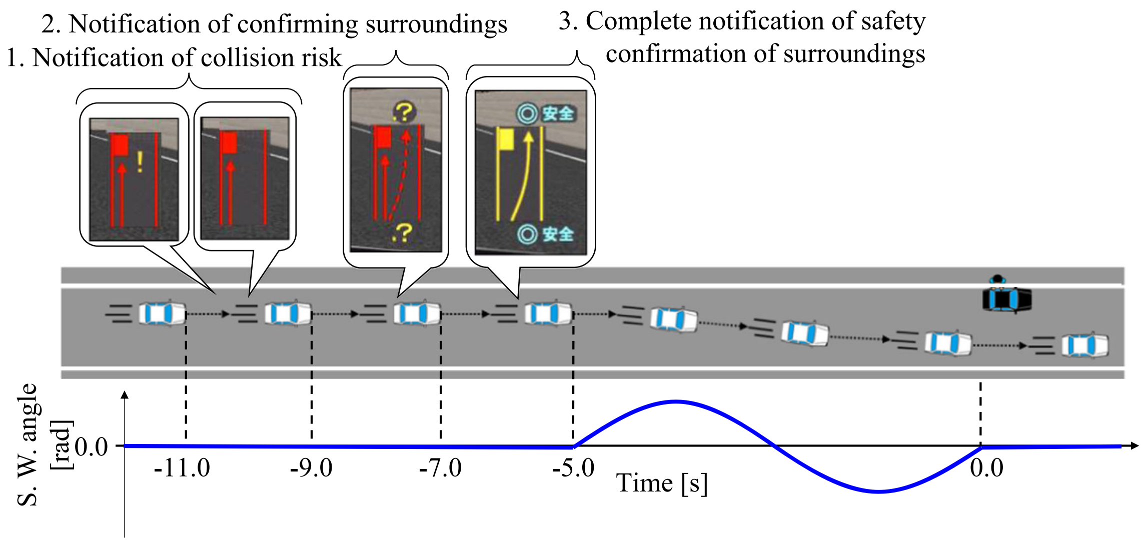

Fig. 4 Timeline of proactive steering intervention with sharing of safety confirmation information

content: planned path on which a vehicle will move automatically. As shown in Fig. 14, a blue dotted line is displayed on a road in front of a vehicle. Each dot blinks in turn so that the driver can perceive it easily. Similar to the previous cases, the system beeps relatively loudly to ensure perception when the blue dotted line is displayed.

Although the notification of safety confirmation is displayed before a vehicle starts to steer automatically, the other three types of visual content are displayed during the steering intervention. Thus, the latter can be displayed one-by-one or in a combined fashion. Therefore, it was necessary to investigate the basic characteristics of information display from the viewpoint of effectiveness including the possibility of combined use.

3 Experiments

To investigate the strangeness of the locomotion path of the proactive steering intervention and the effectiveness of information sharing, we conducted driving simulator experiments. The following protocols were approved by the institutional review board for human studies of the School of Engineering at the University of Tokyo. Written informed consent was obtained from all participants.

3.1 Experimental Participants

In our study, we recruited 15 healthy elderly drivers who were 65 to 75 years old (M = 70.1 years; SD = 3.0 years) as participants. They had a driving license for a period between 18 and 58 years (M = 46.3 years; SD = 9.9 years.) Their average frequency of driving was 4.8 days per week. They participated in another experiment [8] that was conducted simultaneously with this experiment.

3.2 Characteristics Investigation

Because our previous study [7] revealed that characteristics of individual elderly drivers affected their evaluations of proactive collision avoidance systems, we investigated each participant's individual characteristics. The methods that were used to that end are as follows:

Fig. 5 Visual content for notification of collision risk

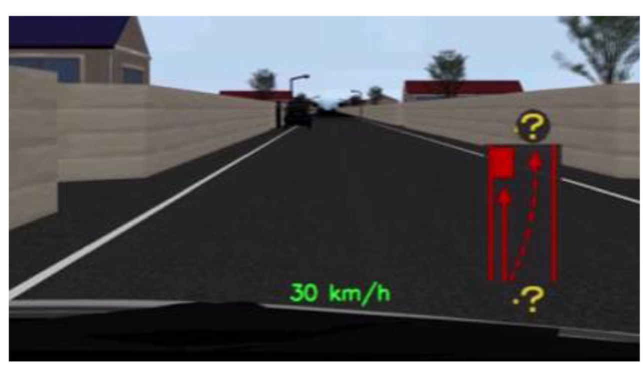

Fig. 6 Visual content for notification of confirming safe vicinity

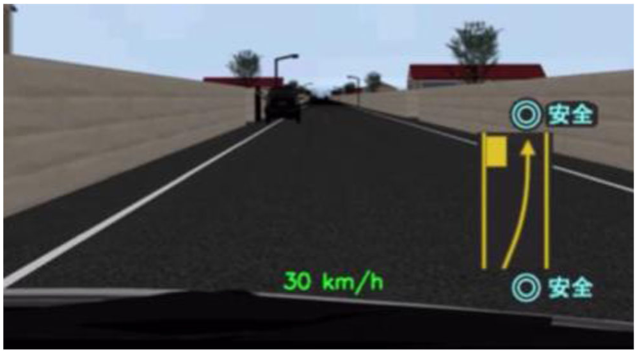

Fig. 7 Visual content for completed notification of safety confirmation

- DSQ: Driving style questionnaire [15]
- WSQ: Workload sensitivity questionnaire [16]

In this study, we used these questionnaire as a secondary resource to interpret the mechanisms of refusal.

3.3 Experimental Scenarios

This experiment contained three parts as follows. All parts were conducted using a driving simulator. The details of the simulator were described in our previous paper [8].

1. Measurement of lateral deviation during manual driving by each participant between the self vehicle and the parked car while passing the parked car.
2. Investigation of the basic characteristics of information sharing with each visual content component during proactive steering intervention based on the measured lateral deviation of each participant.
3. Investigation of proactive steering intervention on the basis of the measured lateral deviation with some offset.

The first part of the experiment involved measurement of the naturalistic lateral deviation between the self vehicle and the parked car when the former passes the latter during manual driving. For avoiding the parked car as shown in Fig. 3, we measured the lateral deviation of each participant during his/her maneuver to avoid the parked car. Figure 15 shows a conceptual schematic of the measurement. First, the participants drove on a practice course to adjust themselves to the driving simulator. Then, they drove on a measurement course to avoid a parked car. On the basis of the results of three trials, we calculated average values for each participant. By referring to their respective measured values, we determined the steering angle of proactive steering intervention for replicating the participants' usual driving behavior, which was applied in the second and third phases of the experiment.

The second part of the experiment was the investigation of basic characteristics of information sharing using various types of visual content during proactive steering intervention. To investigate the basic characteristics of visual content, the effectiveness of combining multiple visual content components, and the effects of reducing a few components, we set up our experimental conditions as summarized in Table 1. For example, the visual content components shown in Figs. 9, 10, and 12 were displayed in condition e. For investigating the visual content during steering intervention, we set up the conditions for single-use as well as combined use. Only one type of visual content was employed under conditions a, b, c, and d, whereas multiple types of visual content were employed under the other conditions. Regarding the order of our experiments, first, the participants experienced proactive steering intervention without sharing of any information about the experimental course. Thereafter, they experienced proactive steering intervention with information about conditions a-h in the given order.

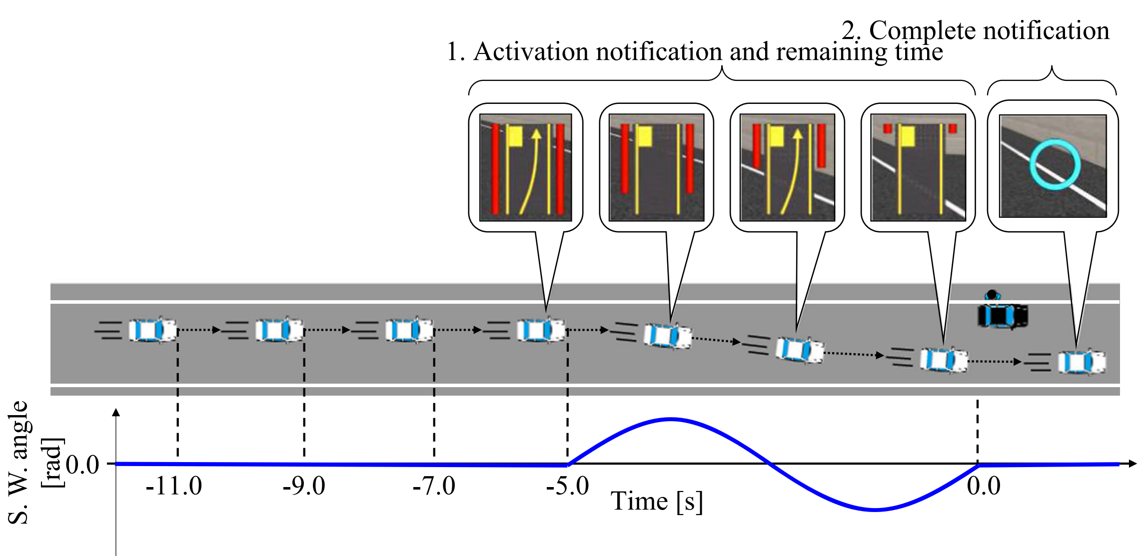

Fig. 8 Timeline of proactive steering intervention with sharing of system status information

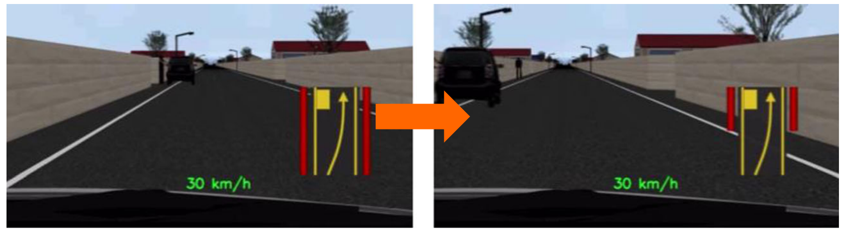

Fig. 9 Visual content for activation notification and remaining time of proactive steering intervention

Figure 16 shows an overhead view of the experimental course. This course contained four proactive steering intervention situations, as shown in Fig. 3. When the vehicle arrived at the position at which the time to collision with a parked car was 5.0 s, the vehicle started to intervene proactively and steer automatically. The amplitude of the sine wave-shaped steering input generated by the proactive steering system was set up based on the measured lateral deviation of each participant. Thus, the locomotion path via steering intervention was unique for each participant. To set up the basis of evaluation and reduce the order effect, visual content was not displayed in the first and third situations, whereas it was displayed in the second and fourth situations, as shown in Fig. 16. In addition, evaluations were conducted based on the comparison with the condition without information sharing.

To set up the same initial position of the self vehicle relative to the parked car in each steering intervention situation, the participants were instructed to basically drive on the left side of the road and return to the left side after each steering intervention. In addition, to control the initial steering intervention situation precisely, we gradually adjusted the position of the self vehicle independent of the driver operation. This adjustment was performed very gradually such that the participants did not notice it before the main steering intervention.

The third part of the experiment was an investigation of the proactive steering intervention based on the measured lateral deviation with some offset. To investigate the feeling of strangeness toward the locomotion path of proactive steering intervention, we set up four conditions: leftward offset of 0.4 m, leftward offset of 0.2 m, rightward offset of 0.2 m, and rightward offset of 0.4 m. Figure 17 shows a conceptual schematic of the locomotion path with an offset from the base condition. The base condition reproduces the average lateral deviation of each participant. In this part, no visual content was provided.

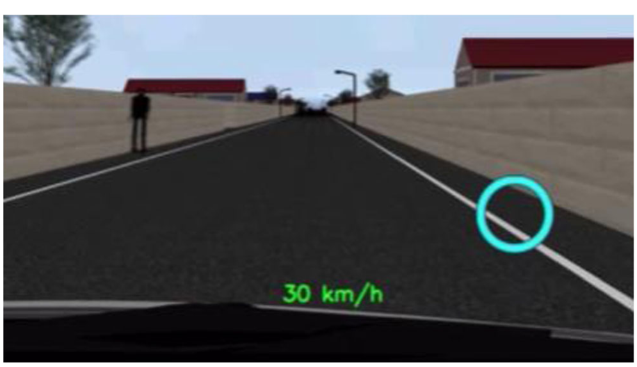

Fig. 10 Visual content for completed notification of proactive steering intervention

3.4 Instructions

Before starting the evaluation, we explained the concepts and behaviors of proactive steering intervention. Then, we explained that the system displays varied information during the steering intervention. In addition, we showed some visual content as examples. These examples contained the visual content in condition h, where the maximum visual content was displayed, and the visual content in conditions a, b, c, and d, where the minimum visual content was displayed. By showing these examples before the actual experience, we aimed to not change the evaluation standards of the participants during the experiment. However, we did not explain the meaning of each visual content.

Regarding the experimental course, we explained the situations in detail. In the experimental course, we instructed the participants to operate mainly the steering wheel. As for the acceleration pedal, we set special setup that the velocity of the vehicle was limited not more than 30 km/h, which is one of the regulated velocity on the community roads in Japan, for making the participants concentrate on the steering operation. We explained the participants about this special setup, and instructed them to keep pressing the acceleration pedal. In addition, we instructed the participants to return to the left side of the lane after overtaking the parked car.

3.5 Evaluation Method

For subjective evaluations, after the completion of each trial on the driving simulator, the participants filled out questionnaires to evaluate the systems that they had experienced. On the basis of the results of our previous study [7], we asked the following questions in the given topic areas:

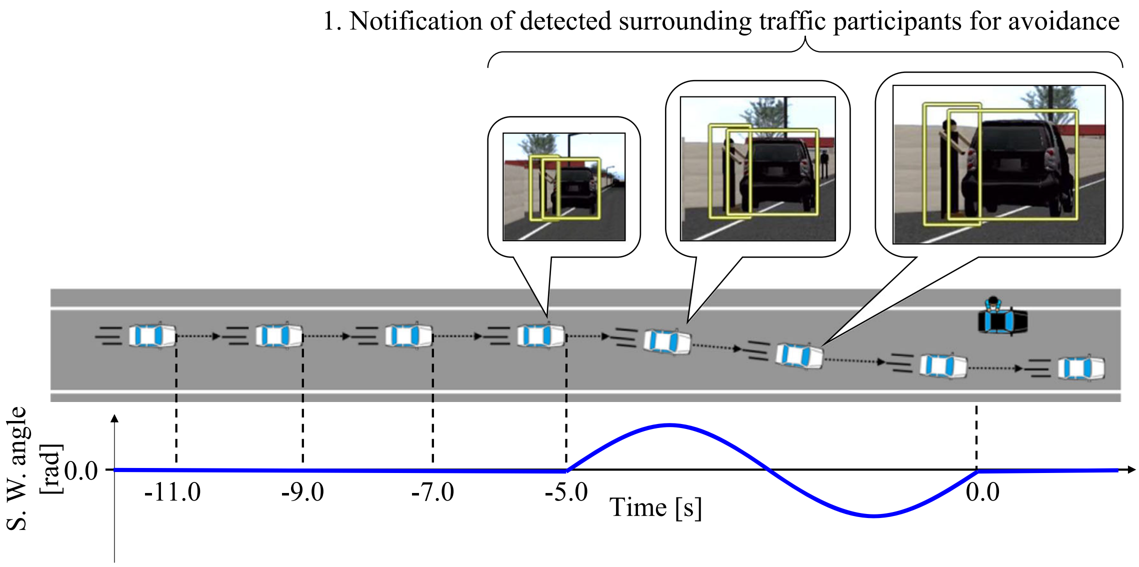

Fig. 11 Timeline of proactive steering intervention with sharing of information about detection of surrounding traffic participant

- Perception of the meaning of provided visual content: "Compared to the condition without information, to what degree did you better notice the following topics?"
- Topics regarding safe confirmation
  - Safe confirmation
- Topics regarding system status
  - Start timing
  - Status of activation
  - End timing
  - Automated steering
- Topics regarding detected traffic participants
  - Reason of system activation
  - Detected danger

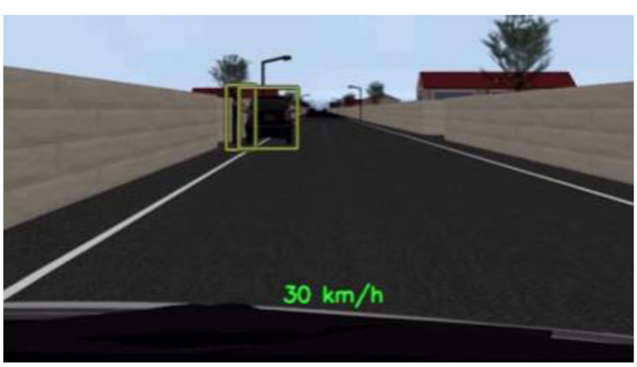

Fig. 12 Visual content for notification of detection of surrounding traffic participants

- Topics regarding planned path
  - Planned path
- Necessity of safety confirmation: "To what degree did you need safety confirmation before steering intervention?"
- Perception of disturbance by information sharing: "Compared to the condition without information, to what degree did you feel that the system disturbed you while driving?"
- Perception of the benefits of the system with information sharing: "Compared to the condition without information, to what degree did you feel that the system could realize the following?"
  - Avoid a dangerous situation
  - Reduce the number of traffic accidents
  - Decrease your driving workload
- Sense of trust in the system through information sharing: "Compared to the condition without information, to what degree did you feel distrust in the automatic vehicle control system?"
- Perception of the strangeness of locomotion path with lateral offset
  - "Compared to the base condition, to what degree did you feel the strangeness in the locomotion path?"
  - "To what degree did you feel that some types of visual content reduced your feeling of strangeness?"

Every questionnaire was accompanied by a nine-grade answer sheet. In the measurements of feeling of disturbance, the grades of the answers indicated the following degrees:

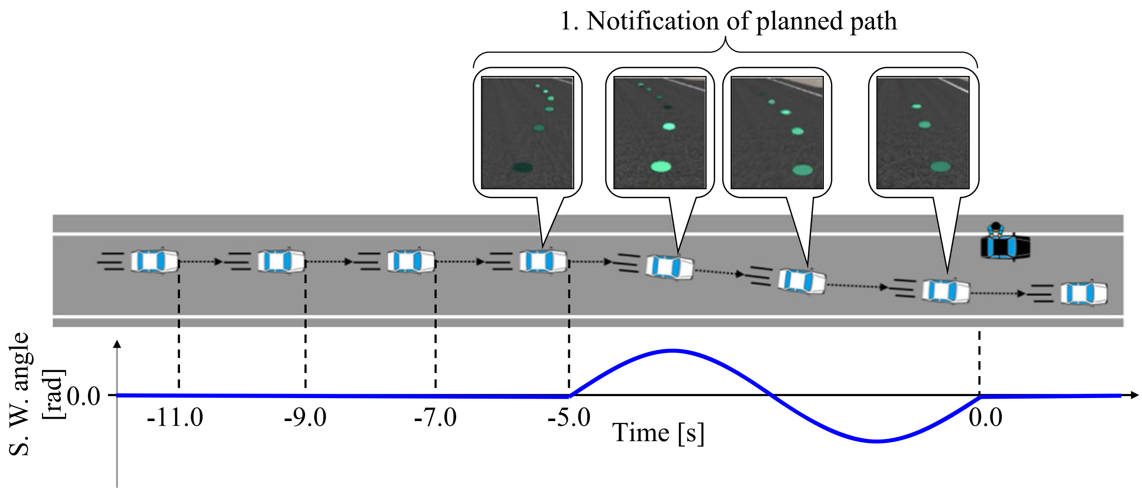

Fig. 13 Timeline of proactive steering intervention with sharing of planned path information

- Grade 9: No disturbance
- Grade 7: Negligible disturbance and no difficulty in driving
- Grade 5: Slight disturbance, but no difficulty in driving.
- Grade 3: Experienced disturbance that caused slight difficulty in driving
- Grade 1: Experienced disturbance that caused substantial difficulty in driving

Because the sensitivity of the evaluation was different for each participant, the results did not have precise quantitative meaning. An important point in this study was whether the participants experienced difficulty in driving due to the provided visual content. In other words, we focused on whether the evaluation results were greater or less than Grade 5. In addition, regarding the perception of strangeness, we asked questions similar to the above ones, replacing "disturbance" with "strangeness."

For the other questionnaire components, the grades of the answers indicated the following:

- Grade 9: Felt substantially
- Grade 7: Felt moderately

Fig. 14 Visual content for notification of planned path for steering intervention

- Grade 5: Felt the same as if no information had been provided
- Grade 3: Did not feel much
- Grade 1: Did not feel at all

Regarding the sense of trust, the evaluation grades were used inversely; Grade 9 indicates "Did not feel distrust at all", and Grade 1 indicates "Felt distrust substantially." The key point in these results was whether each participant responded positively, neutrally, or negatively. In other words, we focused on whether the evaluation results were more than, equal to, or less than Grade 5.

4 Results

4.1 Lateral Deviation when Avoiding Parked Car

Table 2 presents the evaluation results of the lateral deviation between the self vehicle and the parked car. The first row indicates the average lateral deviation, which was measured in the first part of the experiment, by each participant during manual driving. The lower rows in the table indicate the feeling of strangeness toward steering intervention, which was measured in the third part. Larger values indicate a lower perception of strangeness. Blue, green, and red colored cells indicate evaluations less than, equal to, and greater than Grade 5, respectively.

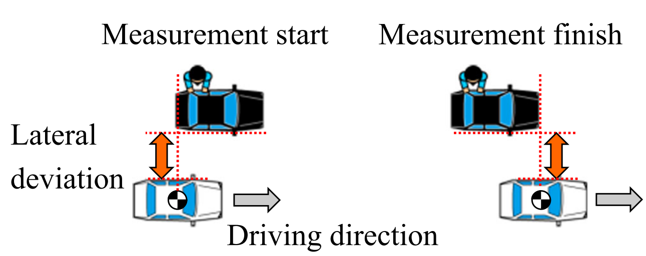

Fig. 15 Schematic depicting the measurement of the naturalistic lateral deviation between the self vehicle and the parked car

Table 1 Summary of experimental conditions

Contents		Experiment condition							
		a	b	c	d	e	f	g	h
Before intervention	Safety confirmation	O							
During intervention	System Status		O			O		O	O
	Detected traffic participants			O		O	O		O
	Planned Path				O		O	O	O

As is evident from the table, there are various tendencies in the perception of proactive steering intervention. Some participants perceived the strangeness of proactive steering intervention with some offset, whereas others did not. In addition, in terms of the perception of strangeness, some participants perceived on both sides, while others perceived it on only one side. Considering these results, the perception of strangeness may be one of the reasons for the refusal of proactive steering intervention in our previous study [7].

Regarding the evaluation results without an offset, no participant perceived the strangeness to be too much to drive, although some participants answered Grade 5, which indicates a slight feeling of strangeness but no difficulty in driving. The evaluations of proactive steering intervention in the second part were conducted using these values for each participant.

4.2 Evaluation of Safety Confirmation

Table 3 summarizes the evaluation results of measuring perception and necessity of safety confirmation. The upper row indicates the meaning perception of provided visual content by intent understanding. Larger values indicate a better understanding of the meaning. As is evident from the table, we confirmed good results of intent understanding. Regarding the neutral evaluation results, participant 1 commented that an icon with characters is slightly difficult to understand. On this point, the improvement of the implementation of the visual content components will be necessary. The lower row indicates the evaluation results of the necessity of the notification of safety confirmation. Basically we confirmed positive evaluation results although a few participants gave neutral evaluations.

4.3 Intent Understanding of Single Visual Content

In this study, we designed the intent of visual content as follows:

- Intent of visual content providing system status information: Start timing, status of activation, end timing, and automated steering.
- Intent of visual content providing information about detected traffic participants: Reason for system activation and detected danger.
- Intent of visual content providing information of planned path: Planned path.

Thus, if the participants perceived the intended meaning of the information shared in the given visual content, we considered that they perceived the meaning through intent understanding. On the contrary, if they perceived a non-intended meaning of the information shared in the visual content, we considered that they perceived the meaning through a corresponding conjecture.

Table 4 summarizes the results of an evaluation of participants' perceptions of the meaning of single visual content by intent understanding. Larger values indicate better understanding of the meaning. As is evident from the table, we confirmed good results in terms of intent understanding on the whole. Regarding the reason for system activation, because participant 5 commented that he did not understand the reason for the intervention instead of a warning, it can be inferred that this is not a problem of the implementation of visual content but a problem of instruction. Thus, we need to better instruct a user about the system concept. Regarding the end timing, participant 5 commented that he was unsure as to when he should return to actively driving a vehicle after the

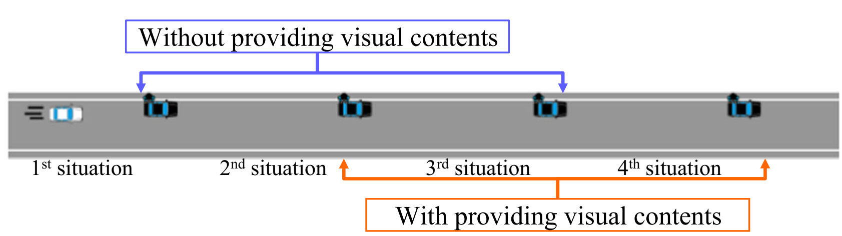

Fig. 16 Overhead view of experimental course

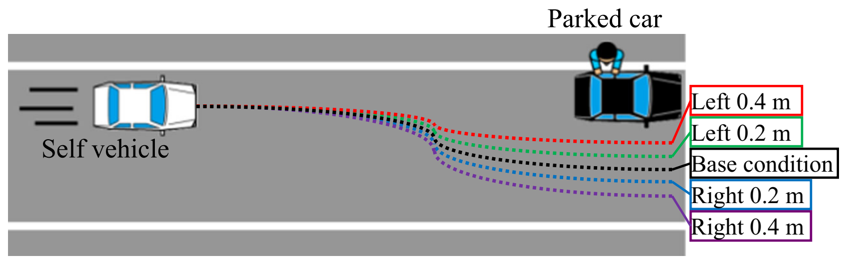

Fig. 17 Schematic of locomotion path of steering intervention with lateral offset

intervention. Thus, improvement in visual content implementation is necessary in this regard.

4.4 Corresponding Conjecture of Single Visual Content

Table 5 summarizes the results of an evaluation of participants' perceptions of the meaning of single visual content by corresponding conjecture. Similar to our results of intent understanding, we confirmed relatively good results, as is evident from the table. Thus, we can reduce the visual content using the mechanism of corresponding conjecture if we need to reduce visual content.

4.5 Intent Understanding of Multiple Visual Content Components

Table 6 summarizes the results of evaluating participants' perceptions of the meaning of multiple visual content components. Although we confirmed relatively good results, participant 4 answered negatively on many questions, as is evident from the table. Regarding these negative evaluations, he commented that simultaneously displaying multiple visual content components prevented him from understanding their meaning. Especially, the horizontal arrangement of multiple visual content components made the perception of the meaning more difficult.

To further investigate the results of multiple visual content components, we focused on driver characteristics of participant 4. Figure 18 shows his DSQ and WSQ scores. The areas colored in blue indicate scores within one standard deviation of the average value. The average value and standard deviation were based on the original study of DSQ [15] and WSQ [16]. As is evident from the figure, his scores of "Anxiety about traffic accidents" in DSQ and "Awareness of traffic situation" and "Recognition of road environment" in WSQ were higher than one standard deviation above the average value. Considering these tendencies, he may have worried about the great variety of visual content provided; furthermore, this may have affected his evaluation.

Although the purpose of information sharing is not to make users behave appropriately based on a perfect understanding of the provided visual content but to help them accept system behavior through a gradual understanding of the system, this result indicates that too much variety in visual content may not be suitable for this purpose, as discussed in the section 2.1. Therefore, we need to reduce unnecessary visual content by utilizing the mechanism of corresponding conjecture.

Table 2 Evaluation results of lateral deviation between the self vehicle and parked car

		Participant ID														
		1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
Lateral deviation of manual driving [m]		1.3	1.7	1.6	1.3	1.3	1.4	1.7	1.5	1.2	1.8	1.5	1.2	1.6	2.2	1.3
Feeling of strangeness	Left 0.4 m	4	9	5	7	3	3	7	9	7	6	3	7	7	7	3
	Left 0.2 m	5	9	6	7	3	7	5	7	7	8	9	7	7	7	3
	Without offset	5	9	5	5	9	5	7	7	8	5	5	7	7	7	9
	Right 0.2 m	7	9	9	3	3	4	5	8	5	8	7	7	7	3	3
	Right 0.4 m	5	9	5	1	1	1	5	5	7	3	2	7	7	3	3

4.6 Corresponding Conjecture of Multiple Visual Content Components

Table 7 summarizes the results of evaluating participants' perceptions of the meaning of multiple visual content components by corresponding conjecture. We confirmed positive evaluations for all patterns of the components. Thus, similar to the acknowledgment of a single visual content component, we confirmed that we could reduce unnecessary visual content by employing the concept of corresponding conjecture.

4.7 Comparison of Feeling of Disturbance from Visual Content

Table 8 summarizes the results of an evaluation of drivers' feelings of disturbance while driving. Larger values in the table indicate fewer disturbances. As is evident from the table, some patterns of the combined use of multiple visual content components has some neutral and negative evaluations. From the perspective of disturbance, providing too much variety of visual content can possibly have a negative effect. The combined use of visual content pertaining to detected traffic

Table 3 Evaluation results of meaning perception and necessity of safety confirmation.

	Particpant ID														
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
Intent understanding	5	9	7	9	5	8	8	8	9	9	8	8	8	7	9
Necessity	5	9	5	7	9	9	9	7	9	9	9	7	9	7	9

Table 4 Evaluation results of meaning perception single visual content by intent understanding

Contents	Intent	Particpant ID														
		1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
System status	Start timing	7	7	7	9	7	7	8	9	9	9	8	9	9	7	9
	Status of activation	7	7	7	9	7	7	9	9	9	9	8	9	8	7	9
	End timing	7	7	7	9	3	7	8	9	9	8	7	9	9	7	9
	Automated steering	7	9	7	9	7	7	8	9	9	9	8	9	9	7	9
Detected traffic participants	Reason of system activation	6	9	7	9	3	7	7	8	9	8	8	9	9	7	9
	Detected danger	7	9	9	9	7	8	7	8	9	9	8	9	9	7	9
Planned path	Planned path	9	9	9	9	7	9	8	9	9	9	9	9	8	7	9

participants and planned path (D + P) was positively evaluated compared to other combined uses.

4.8 Feeling of Benefit from Use of Single Visual Content

To examine the benefits felt by participants in detail, we asked questions regarding three benefits of the system: avoiding danger, reduction in the number of traffic accidents, and decrease in driving workload. Avoiding dangers and reducing the number of traffic accidents are the actual purposes of the proactive collision avoidance system, whereas decreasing driving workload is not an intended purpose.

Table 9 summarizes the results of evaluating drivers' perceptions of benefits of being provided with a single visual content component. As in the results presented above, larger values indicate better benefit perception. Regarding benefits of avoiding dangers and reducing the number of traffic accidents, all participants answered positively to varying degrees.

Regarding the benefit of decreasing driving workload, we found relatively numerous negative evaluations, although this benefit was not our intended purpose. The participants who answered negatively may have considered the provided visual content as additional mental workload. On the contrary, the participants who answered positively may have perceived the benefit of decreasing driving workload as an indirect result of the other benefits.

Table 5 Evaluation results of meaning perception single visual content by corresponding conjecture

Contents	Corresponding conjecture	Particpant ID														
		1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
System status	Reason of system activation	7	9	7	9	7	7	9	9	9	7	9	8	9	7	9
Planned path		7	9	9	9	9	8	7	9	9	8	8	9	9	7	9
System status	Detected danger	7	9	7	8	7	8	9	9	9	9	8	8	8	7	9
Planned path		5	9	9	9	7	8	9	7	9	7	8	9	9	7	9
System status	Planned path	7	9	7	7	7	8	8	9	9	7	8	9	9	7	9
Detected traffic participants		7	9	7	9	7	8	8	7	9	6	7	9	9	7	9
Detected traffic participants	Start timing	7	7	7	9	7	7	8	8	9	7	8	9	9	7	9
Planned path		9	7	9	9	7	9	8	9	9	9	8	9	9	7	9
Detected traffic participants	Status of activation	6	7	7	9	7	7	9	8	9	7	8	9	9	7	9
Planned path		7	7	9	9	9	9	9	9	9	9	8	9	8	7	9
Detected traffic participants	End timing	3	7	7	9	7	8	7	8	9	6	8	9	9	7	9
Planned path		9	7	7	9	7	9	8	9	9	8	8	9	9	7	9
Detected traffic participants	Automated steering	7	9	7	9	7	7	7	7	9	7	8	9	9	7	9
Planned path		9	9	9	8	7	9	7	9	9	9	8	9	9	7	8

Table 6 Evaluation results of meaning perception multiple visual content components by intent understanding

Contents	Intent	Particpant ID														
		1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
S D	Start timing	7	7	9	7	7	7	7	8	9	8	8	9	9	7	9
S P		9	7	7	3	9	8	8	7	9	8	7	9	9	7	9
S D P		9	7	9	9	9	7	8	9	9	8	8	9	9	7	9
S D	Status of activation	7	7	9	7	7	7	8	9	9	8	8	9	9	7	8
S P		9	7	7	3	9	8	9	7	9	8	7	9	9	7	9
S D P		9	7	9	3	9	8	9	9	9	8	8	9	9	7	9
S D	End timing	7	9	7	3	7	7	8	8	9	8	7	9	9	7	9
S P		9	9	7	7	7	8	9	7	9	9	8	9	9	7	9
S D P		9	9	9	1	9	7	9	9	9	8	7	9	9	7	9
S D	Automated steering	7	9	9	7	7	7	9	8	9	8	8	9	9	7	9
S P		7	9	9	3	9	8	9	7	9	8	8	9	9	7	9
S D P		8	9	9	1	9	8	9	9	9	9	7	9	9	7	9
S D	Reason of system activation	7	9	7	3	7	7	8	9	9	8	8	9	9	7	9
D P		7	9	9	9	7	7	8	9	9	8	8	9	9	7	9
S D P		6	9	9	1	7	7	8	9	9	8	8	9	9	7	9
S D	Detected danger	9	9	9	3	7	7	8	9	9	8	8	9	9	7	9
D P		8	9	9	9	9	7	8	7	9	8	9	9	9	7	9
S D P		7	9	9	3	7	7	9	9	9	8	8	9	9	7	9
D P	Planned path	9	9	9	9	7	8	9	9	9	9	9	9	9	7	9
S P		9	9	9	3	9	8	9	8	9	7	7	9	9	7	9
S D P		9	9	9	1	9	8	9	9	9	9	8	9	9	7	9

4.9 Feeling of Benefits from Multiple Visual Content Components

Table 10 summarizes the results of evaluating participants' perceptions of benefits provided with multiple visual content components. In contrast to the single visual content component results, participant 4 answered negatively for some conditions. Because he answered negatively for the perceptions of the meaning of multiple visual content components, not perceiving the

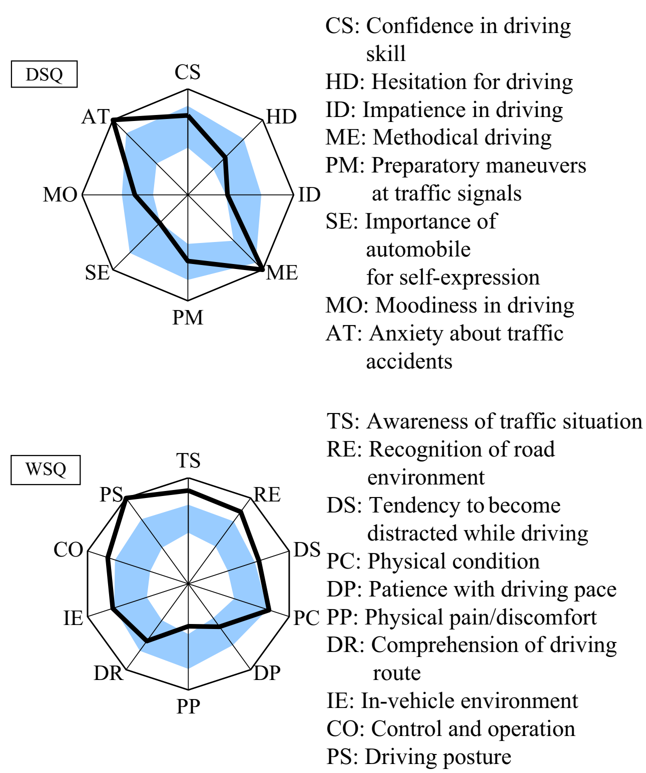

Fig. 18 DSQ and WSQ scores of participant 4

Table 7 Evaluation results of meaning perception multiple visual content components by corresponding conjecture

Contents	Corresponding conjecture	Particpant ID														
		1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
S D	Planned path	9	9	7	7	9	7	9	8	9	9	7	9	8	7	9
D P	Start timing	9	7	7	9	9	7	8	9	9	9	9	9	9	7	9
D P	Status of activation	9	7	7	9	7	8	9	9	9	9	9	9	9	7	9
D P	End timing	9	9	7	9	9	7	9	9	9	9	8	9	9	7	8
D P	Automated steering	7	9	9	9	9	7	9	9	9	8	8	9	9	7	9
S P	Reason of system activation	6	9	9	7	7	7	8	8	9	8	7	9	9	7	9
S P	Detected danger	6	9	9	7	9	7	9	8	9	8	7	9	9	7	9

meaning may be the reason for him not feeling the benefits. From the viewpoint of benefit perception, we confirmed the need to improve the implementation of visual content. On this point, given that the combined use of visual content about detected traffic participants and planned path (D + P) was positively evaluated compared to other combined uses, modifying this combined use can allow for enhancing users' perception of the benefits.

Regarding benefits of decreasing driving workload, some participants provided negative evaluations, similar to the results for only one visual content component.

4.10 Comparison of Feeling of Trust among Visual Content

Table 11 summarizes the results of evaluating participants' feelings of trust in the system. Larger values indicate better trust. As is evident from the table, although many participants answered positively, some participants answered neutrally and negatively. Regarding participant 4, because he answered negatively only for the combined use of multiple visual content components, not perceiving the meaning of the provided visual content may be the reason for negative evaluations of feeling trust. Participant 7 commented that the uncertainty of vehicle locomotion made him distrust the system. On the basis of his evaluation results and comments, he may have preferred a simple provision of the visual content of the planned path. Concerning these points, we need to modify the implementation of the combined use of multiple visual content components.

Table 8 Evaluation results of feeling disturbance while driving

Contents	Variety	Participant ID														
		1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
S	Single	8	9	7	5	7	7	7	9	8	7	8	8	9	7	9
D	Single	6	9	7	9	7	9	7	8	9	8	8	9	9	7	9
P	Single	8	9	9	9	5	9	7	8	8	8	9	9	9	7	9
S D	Double	5	9	9	5	9	5	5	8	8	7	7	9	9	7	9
D P	Double	8	9	7	9	9	7	7	9	8	8	8	9	9	7	9
S P	Double	5	9	9	3	9	8	7	8	9	5	7	9	9	7	9
S D P	Triple	8	9	7	2	9	5	7	8	9	5	8	9	9	7	9

Table 9 Evaluation results of perceived benefits by only one visual content component

Contents	Benefit	Participant ID														
		1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
S	Avoiding dangers	7	9	7	9	7	6	9	8	9	9	8	8	9	7	9
D		6	9	7	9	9	8	8	7	9	6	8	8	9	7	9
P		7	9	9	8	7	8	9	7	9	9	8	9	8	7	9
S	Reduction of the number of traffic accidents	6	9	7	9	9	8	9	8	9	9	8	9	9	8	9
D		7	9	7	9	9	8	9	7	9	7	8	9	9	7	9
P		7	9	9	9	9	9	9	7	9	9	7	9	9	8	9
S	Decrease of driving workload	7	7	7	9	7	7	3	1	9	8	7	8	9	7	8
D		7	9	3	9	7	8	3	7	9	7	7	9	9	3	9
P		7	9	7	8	7	8	8	3	9	8	7	9	1	3	9

4.11 Reduction of Perceived Strangeness by the Provision of Visual Content

Table 12 shows the evaluation results of the possibility of reducing the strangeness by displaying visual content. This table indicates the evaluation results under the condition where the participants felt considerable strangeness that was expressed as the value less than 5 in Table 2. The cells with diagonal indicates the conditions in which the evaluations of the participants were equal to or more than 5 in Table 2. In Table 12, larger values indicate less strangeness. As is evident in Table 12, although some participants answered neutrally and negatively for some conditions, many participants answered positively. Thus, displaying visual content can possibly reduce the perception of strangeness of proactive steering intervention, although there may be limitations for too much lateral deviations from their basic locomotion path.

4.12 Summary of Results for Improving Visual Content

We summarize our experimental results as follows:

- Almost half of the participants felt strangeness to varying degrees regarding the lateral deviation due to proactive

Table 10 Evaluation results of perceived benefits by multiple visual content components

Contents	Benefit	Participant ID														
		1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
S D	Avoiding dangers	7	9	9	3	9	8	9	7	9	8	8	9	9	7	9
D P		7	9	7	9	7	8	9	7	9	9	8	9	9	7	9
S P		7	9	9	3	9	8	9	6	9	8	7	9	9	7	9
S D P		7	9	9	3	7	7	9	7	9	8	8	9	7	7	9
S D	Reduction of the number of traffic	6	9	9	3	7	8	9	7	9	9	8	9	9	7	9
D P		7	9	7	9	9	8	9	7	9	9	8	9	9	7	9
S P		7	9	9	7	7	8	9	7	9	8	7	9	9	7	9
S D P		7	9	9	3	9	8	9	7	9	8	8	9	9	7	9
S D	Decrease of driving workload	7	9	7	3	7	7	3	6	9	8	7	9	9	3	9
D P		7	9	7	9	9	3	3	6	9	9	8	9	9	3	9
S P		7	9	3	3	9	3	3	8	9	8	7	9	9	3	9
S D P		7	9	9	3	9	3	5	7	9	8	8	9	9	3	9

Table 11 Evaluation results of feeling trust in the system

		Participant ID														
Variety	Contents	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
Single	S	7	9	7	9	5	7	3	9	9	7	7	8	9	7	9
	D	5	9	5	9	5	6	3	7	8	7	7	8	9	7	9
	P	8	9	5	9	5	8	7	8	8	8	7	8	9	7	9
Double	S D	6	9	7	3	7	7	3	8	8	8	8	9	9	7	9
	D P	7	9	5	9	9	7	3	9	8	8	8	9	9	7	9
	S P	6	9	7	3	7	7	5	9	8	8	7	9	9	7	9
Triple	S D P	6	9	7	3	9	7	5	9	9	8	8	9	9	7	9

steering intervention between the self vehicle and a parked car due to the lateral offset.

- All participants evaluated neutrally or positively for the necessity of safety confirmation before proactive steering intervention.
- The meaning of a single piece of provided content could be interpreted via intent understanding in this study. In visual content showing the system status including the end timing, some improvements in implementation were deemed necessary.
- The single visual content component may be partially interpreted also as non-intended meanings via corresponding conjecture.
- Although the combined use of multiple visual content components could convey the meaning to almost all participants, one participant, whose DSQ and WSQ scores regarding the perception of traffic environment were higher than average evaluated negatively due to information overload.
- Simultaneously providing various visual content components creates the possibility of disturbing users while driving.
- Although providing visual content basically could make users feel benefits of the system, information overload prevented them from perceiving the benefits.
- Providing various visual content components could basically make users trust the system. Regarding negative evaluations for the combined use of multiple visual content components, modification for simplifying visual content for a planned path can possibly improve the current evaluations.
- Displaying visual content can possibly reduce the feeling of strangeness between a user's natural driving and proactive steering intervention.

As discussed in our previous study [8], we need to improve the bad evaluations rather than the average and best evaluations. On the basis of our experimental results, the strength of visual stimulation due to the combined use of multiple visual content components appears to be the main factor of negative evaluations in some topics; however, the combined use of moderately adjusted multiple visual content components can possibly lead to the perception of benefits and generate trust. Thus, we need to weaken the stimulation for some components for improving the problems confirmed in the experiments.

Table 12 Evaluation results of reducing strangeness by displaying visual content

		Participant ID							
		1	4	5	6	10	11	14	15
Reduction of strangeness feeling	Left 0.4 m	7		7	8		5		9
	Left 0.2 m			7					8
	Right 0.2 m		5	9	5			5	7
	Right 0.4 m		7	9	3	9	5	7	7

Furthermore, weakening the stimulation provided by visual content components of system status appears preferable because visual content components of planned path and those of detected traffic participants can convey the meaning of necessary information via intent understanding and corresponding conjecture. Improving the visual content in this regard would improve the drivers' perceptions of benefits, build trust in the system, and reduce the feelings of disturbance and strangeness. Moreover, it would improve the acceptability of proactive steering intervention for elderly drivers.

5 Conclusions

To improve understanding of proactive steering intervention systems, we focused on information-sharing methods that provide drivers with internal data about control systems. First, we designed four types of visual content: safety confirmation information, system status, detection of surrounding traffic participants, and planned path. Next, we conducted driving simulator experiments to investigate basic characteristics of visual content prototypes. The important points evident from the experimental results are as follows:

- Information sharing helped elderly drivers understand the behavior of the proactive steering system.
- The design of visual content based on corresponding conjecture will contribute to the reduction of unnecessary visual content.

In addition, a means of improving visual content based on the experimental results was proposed.

Because this study was conducted as an initial basic investigation, it is necessary to investigate the effectiveness of moderate adjustments to visual content based on the results of this study to further improve acceptability. Furthermore, in this study, although it was assumed that an intelligent automated vehicle would perform exactly as expected, such systems sometimes fail to behave as expected in real-world situations. Thus, it is necessary to investigate characteristics of false alarms. Moreover, information sharing during steering intervention can be applied for other situations, such as lane keeping on curve road section. In such case, optimization of visual contents for the corresponding situations would be necessary. These tasks are our next steps in this field of research.

Acknowledgements This research has been conducted as a part of the research project "Autonomous Driving System to Enhance Safe and Secured Traffic Society for Elderly Drivers" granted by Japan Science and Technology Agency (JST), S-Innovation (Strategic Promotion of Innovative Research and Development).

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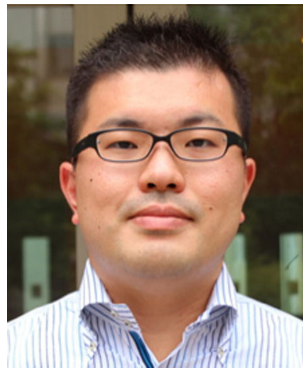
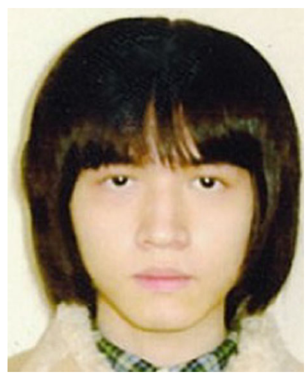


Takuma Ito is a project researcher at Institute of Gerontology, The University of Tokyo, Japan. He received his Doctor of Engineering degree from The University of Tokyo in 2012. His research interests are autonomous vehicles and human machine interactions.



Tatsuya Shino received his Master of Engineering degree from The University of Tokyo in 2014. His research interest is advanced driving assistance system.

Minoru Kamata is a professor at The University of Tokyo in Japan. He received his Doctor of Engineering degree from The University of Tokyo in 1987 in the field of mechanical engineering. His research interests are advanced driver assistance systems for enhancing active safety and assistive technology for elderly and disabled.