Empirical Investigation of Changes of Driving Behavior and Usability Evaluation Using an Advanced Driving Assistance System

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Abstract—**It is known that the behavior of autonomous systems affects users' cognitive and behavioral aspects; however, further examination of sequential effects is required. We manipulated instructional information as cognitive guidance and the degree of behavioral intervention implemented by an advanced driving assistance system, and then assessed usability evaluation of the system and changes in user behavior. The results show that strict intervention reduces subjective evaluations, and the absence of instructional information hinders changes in user behavior.**

Keywords-usability evaluation; behavioral change; cognitive guidance; behavioral intervention; human-system cooperation; advanced driving assistance system.

I. INTRODUCTION

Recently, many autonomous systems have become popular. They perform various tasks autonomously and often take over user activities. However, due to complexity, users cannot delegate all the activities and are often required to share activities with systems cooperatively. In automated driving, four levels of driving from no automation to full automation are defined [1]. In these levels, drivers and the system must cooperate closely.

It is known that system intervention influences user behavior in many aspects. For example, a number of behavioral changes in driving are observed when an intelligent speed adaptation system is used. A previous study reported that driver behavior shifted to both safe and risky behaviors with various systems [2].

Why do users exhibit such risky behavior against guidance provided by such systems? Cognitive factors, such as user understanding of the systems, may cause these behaviors. A "black box problem" can arise when using highly intelligent autonomous systems. With the black box problem, users cannot recognize which systems operate internally and understand what those systems are intended to do [3]. Many experiments have verified this black box problem. After observing system errors but receiving no explanation about the errors, users tend to distrust systems, which reduces their reliability [4]. Adaptive cruise control systems that share the goal or provide assistance information are more trustworthy and acceptable than those that do not share [5].

Usability questionnaires have been used to measure how users evaluate systems. Recently, a new usability questionnaire was developed to evaluate autonomous systems that perform complex information processing. This questionnaire comprises six elements, i.e., effectiveness, efficiency, satisfaction, understandability, discomfort, and motivation. The latter three elements are assumed for autonomous systems [6].

Previous research has indicated that the behavior of autonomous systems influences users' cognitive and behavioral aspects. However, further inspection is required to examine sequential effects on users' cognitive and behavioral changes while performing tasks.

In the present study, we manipulated two factors that are expected to determine the automation levels of advanced driving assistance systems, and we investigated the effects

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on users' cognitive and behavioral aspects. The first manipulated factor refers to cognitive guidance that provides instructional information concerning driving safely. The second is the levels of automation, where the high level means strict intervention with user driving behavior and the low level means moderate intervention.

We address a method for the experiment in Section 2 and the results in Section 3. Discussion and conclusion follow in Sections 4 and 5.

II. Method

A. Apparatus

We used a driving simulator equipped with a driving assistance system in an experiment (Figure 1). The driver can operate the steering wheel, the accelerator, and the brake in a same manner as an actual car. This system detects driver blind spots that can cause accidents. Such risk identifications are made based on normative behavior of expert driving instructors. The following two driving assistance stages are employed [7] [8].

1) Cognitive guidance: This provides information about the surrounding environment and gives guidance to brake or turn.

2) Behavioral intervention: This intervenes in driver braking and steering behavior when cognitive guidance does not positively affect driver behavior.

The following information is provided when cognitive guidance and behavioral intervention are performed. Three stimuli are given: a beep and notification message (e.g., "Caution: A Parked Car") as auditory stimuli; a slowdown icon, an arrow pointing to the left/right, and an LED light on the steering wheel as visual stimuli; and steering wheel and accelerator vibration as tactile stimuli.

The extent of behavioral intervention (i.e., the power of braking and steering torque) depends on the status of the car and the safety region monitored by the system. Braking intervention decelerates the car to a fixed speed when crossing an intersection and passing a parked car or a pedestrian. Steering intervention autonomously operates a steering wheel, but this torque is sufficiently small; therefore, drivers can turn the steering wheel against the system's intervention. This intervention is performed when passing a parked car or a pedestrian, but not when crossing an intersection.

This driving assistance system provides information about potential risks and encourages drivers to change behavior if necessary. Assistance (i.e., cognitive guidance and behavioral intervention) is not provided when driving safely. From an educational prospective, if drivers understand the system's intent, they are expected to adopt safer driving behaviors.

B. Data

In the experiment, we collected the following data.

- *Usability evaluations:* A usability evaluation questionnaire measured six elements, i.e., effectiveness, efficiency, satisfaction, understandability, comfort, and motivation. Each element has three questions rated on a five-point scale.
- *Behavioral changes:* The driving behavior before and after run with the assistance system was measured to confirm its educational effect.

C. Procedure

We manipulated the following two factors of the system's behavior.

1) Cognitive guidance: Two cases were considered, i.e., whether or not the system provides instructual information.

2) Behavioral intervention: Two cases were considered, i.e., the system intervenes in driver behavior moderately (minimum system intervention) or strictly (active intervention).

Three experimental conditions were employed based on the above settings. A total of 89 participants were assigned to one of the three conditions.

- *Moderate assistance without cognitive guidance (MOD w/o GUD):* The system intervenes moderately without cognitive guidance.
- *Moderate assistance with cognitive guidance (MOD w/ GUD):* The system intervenes moderately with cognitive guidance.
- *Strict assistance with cognitive guidance (STR w/ GUD):* The system intervenes strictly with cognitive guidance.

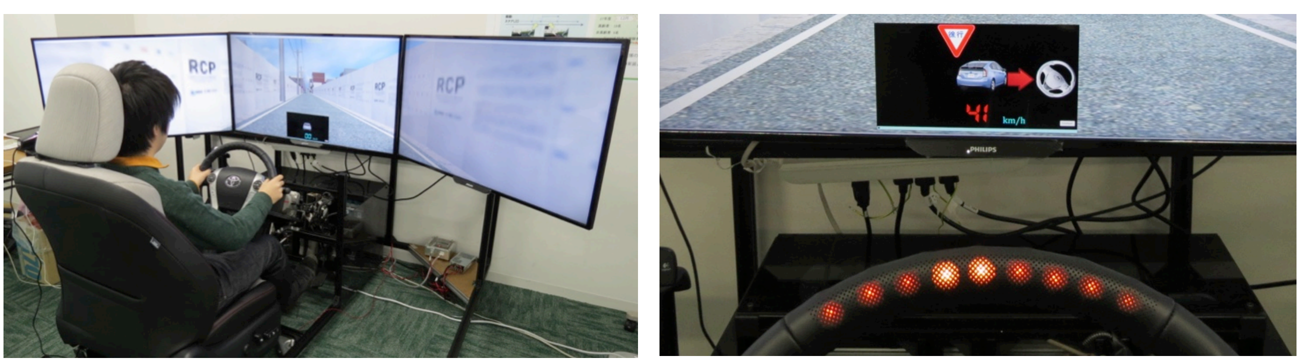

Figure 1. Driving simulator used in the experiment (left). The system autonomously provides various information for cognitive guidance (right).

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The length of the driving course used in the experiment was approximately 500 meters, and the same course was used in all trials. Participants were required to drive the course while passing a parked car, at an intersection without a traffic signal, and beside a pedestrian.

The flow of the experiment was as follows.

- *Practice run (two times):* To understand the driving simulator, participants were allowed to drive without assistance.
- *Pre-run (three times):* To measure the initial driving behavior without assistance, participants drove the course.
- *Practice run with assistance (two times):* To understand the assistance, participants were allowed to drive the course under one of the three conditions mentioned above.
- *Run with assistance (three times):* For training, participants drove the course in the same manner as the preceding practice run.
- *Usability evaluation:* Participants answered a questionnaire (18 questions).
- *Post-run (three times):* Participants drove the course in the same manner as the initial pre-run.

III. RESULTS

We excluded nine participants who experienced carsickness during the experiment. Therefore, 80 participants were analyzed. We conducted two examinations focusing on (1) the differences between MOD w/ GUD and MOD w/o GUD to investigate the effect of cognitive guidance, and (2) the differences between MOD w/ GUD and STR w/ GUD to investigate the effect of behavioral intervention.

A. Usability Evaluation

Figure 2 shows the usability evaluation for each condition. We conducted a between-participant ANOVA with one factor (condition: MOD w/o GUD, MOD w/ GUD, and STR w/ GUD) for the evaluation score for each of the six elements.

The results show significant main effects for efficiency, understandability, and comfort ($F(2, 77) = 6.81$, $p < .005$; $F(2, 77) = 4.85$, $p < .05$; $F(2, 77) = 3.22$, $p < .05$, respectively), and a marginal effect for motivation ($F(2, 77) = 3.03$, $p = .054$). No significant main effects were found for effectiveness and satisfaction ($F(2, 77) = 1.79$, *n.s.*; $F(2, 77) = 1.26$, *n.s.,* respectively). Ryan's analysis for efficiency, understandability, and comfort showed the scores in MOD w/ GUD were higher than those in STR w/ GUD ($t(50) = 3.47$, $p < .001$; $t(50) = 3.11$, $p < .005$; $t(50) = 2.54$, $p < .05$, respectively). There was no significant difference between MOD w/o GUD and MOD w/ GUD (all *p*s > .10).

As a result, we found that a system that intervenes strictly in user behavior reduces driver evaluation of efficiency, understandability, and comfort. However, there was no significant difference between the MOD w/ GUD and MOD w/o GUD conditions, indicating that cognitive guidance did not affect usability.

B. Behavioral Changes

Driving with the assistance system is expected to encourage drivers to adopt safer driving behaviors. We analyzed changes in driving behavior before and after using the assistance system. We used a 100-meter interval, including an intersection, for the former analysis, and a five-meter interval, including a parked car, for the latter analysis because the system was most likely to offer assistance in these intervals.

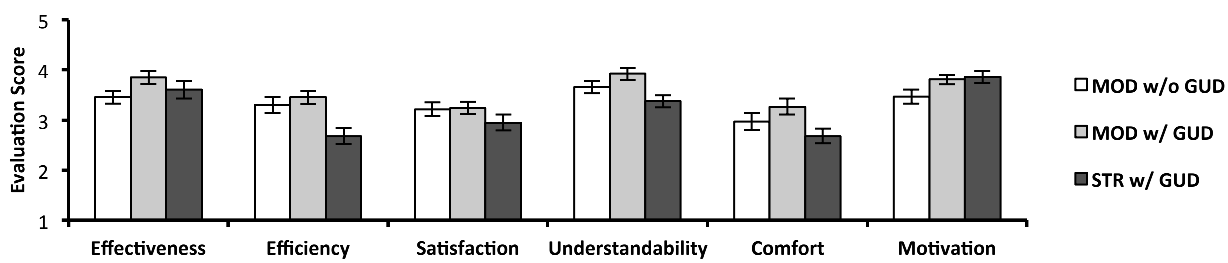

Figure 2. Mean of the usability evaluation of the driving assistance system. The error bar represents the standard error of the mean.

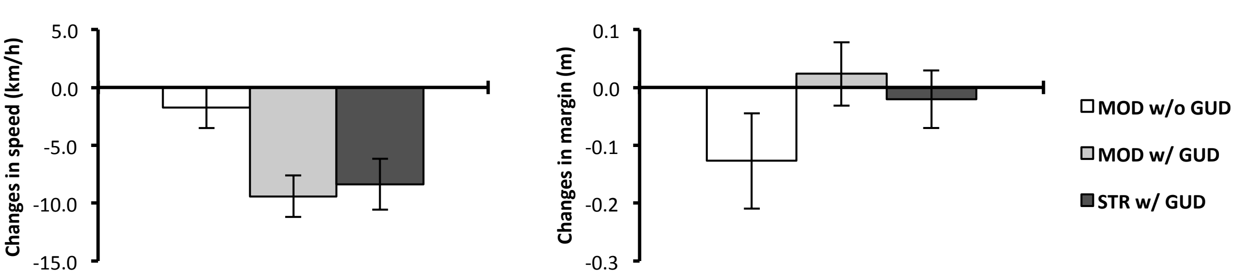

Figure 3. Changes in speed (left) and margin (right) between the pre-run and the post-run.

Figure 3 shows changes in average speed when crossing an intersection from the pre-run to post-run, and changes in average margin between the car and a parked car. A positive value indicates that the value for the post-run is higher than that of the pre-run. If drivers follow the guidance of the system, changes in speed are expected to be negative and those in margin are expected to be positive.

An ANOVA for changes in speed indicates a significant main effect ($F(2, 77) = 4.61$, $p < .05$). Ryan's analysis showed the changes in MOD w/ GUD are greater than that in in MOD w/o GUD ($t(52) = 2.78$, $p < .01$), but there is no significant difference between MOD w/ GUD and STR w/ GUD ($t(50) = 0.37$, *n.s.*). Similarly, the results for changes in margin showed a significant main effect ($F(2, 77) = 4.98$, $p < .01$). Ryan's analysis showed a significant difference between MOD w/o GUD and MOD w/ GUD ($t(52) = 3.05$, $p < .005$), but not between MOD w/ GUD and STR w/ GUD ($t(50) = 0.86$, *n.s.*).

The results reveals that behavioral intervention without instructional information decreases behavioral changes for both braking and steering operations compared to when intervention is performed with instructional information. A surprising result is that the margin in the post-run was significantly smaller than that in the pre-run in the MOD w/o GUD condition ($t(27) = 13.75$, $p < .001$), meaning that participants who were not provided instructional information adopted risker behavior against the behavioral guidance offered by the system. The experimental results also show that, despite strict assistance, behavioral improvements in both braking and steering operations for the STR w/ GUD condition were comparable to those for the MOD w/ GUD condition.

IV. Discussion

In this study, we manipulated instructional information provided by an assistance system as cognitive guidance and the degree of behavioral intervention. In an experiment, we verified that an advanced driving assistance system affects usability evaluations and behavioral changes.

The results showed the following findings. First, the degree of behavioral intervention has a significant effect on user subjective evaluations of the system; however, it does not affect behavioral changes significantly. The evaluation scores for efficiency, understandability, and comfort with the STR w/ GUD condition were substantially less than those for the MOD w/ GUD condition. This implies that strict intervention implemented by autonomous systems makes users uncomfortable and causes disinterest in understanding the system. In addition, we found no significant differences in behavioral changes between the MOD w/ GUD and STR w/ GUD conditions. It is assumed that users do not intend to accept all interventions provided by the system due to discomfort with the systems.

Second, the information provided by autonomous systems has a significant effect on users' behavioral changes but does not have significant effect on their subjective evaluations. The results showed no differences between the MOD w/o GUD and MOD w/ GUD conditions for all usability elements. It was surprising that cognitive guidance did not influence subjective evaluations of the system. Even in such a case, improvements to behavioral changes in the MOD w/o GUD condition were significantly smaller than those of the MOD w/ GUD condition. This indicates that the absence of instructional information provided by autonomous systems reduces educational effects and, in some cases, hinders user behavior improvements. It is likely that users cannot distinguish their own behavior and normative behavior guided by an assistance system if the system does not explicitly identify the differences.

For future research, we will consider how different environments affect drivers' usability and behavior, and what drivers understand about the assistance system.

V. Conclusion

We investigated how the behavior of autonomous systems affects users relative to cognitive and behavioral aspects. The results showed that the strict intervention reduces subjective evaluations, and the absence of instructional information hinders behavioral changes.

Acknowledgment

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