Short- and Long-Term Effects of an Advanced Driving Assistance System on Driving Behavior and Usability Evaluation

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***Abstract*—In recent times, advanced driving assistance systems have become popular, and drivers have had more opportunities to interact with the system continually. Although the majority of earlier studies compared driving behaviors with and without systems or before and after using systems, the effect of the system has not been verified from a long-term perspective. Therefore, the present study investigates both short- and long-term effects of driving assistance systems on drivers' behaviors and usability evaluations. The results found two types of transition patterns in driving behavior and one stable pattern in usability evaluations. This indicates that there are non-uniform effects of a single driving assistance system, depending on the kinds of risk objects and driving behaviors.**

Keywords-short-term effect; long-term effect; driving behavior; usability; advanced driving assistance system.

I. INTRODUCTION

There are two popular measures to encourage drivers to adopt safer behaviors: educational measures and engineering measures [1]. Engineering measures include advanced driving assistance systems, while educational measures include driver training and safety education. As an example of engineering measures, a head-up display system provides visual guidance to drivers on the immediate required behavior. In recent times, such systems are known to directly intervene in driver behavior—for example, emergency brake systems, which decelerate a car in danger of collision with others.

Several educational measures have proven beneficial in the long term [2]. However, the effect of engineering measures, especially that of an advanced driving assistance system, is yet to be proven because of its short duration in use.

Many studies have compared driving behaviors with and without systems or before and after using systems. It is known that driver behavior shifted to both safe and risky behaviors based on the authority bestowed by intelligent speed adaptation systems after using the system [3].

As driving assistance systems become popular, drivers have more opportunities to interact with the system continually. Therefore, it is essential to consider both the short-term and long-term effects of the systems. For example, drivers' behaviors appeared to improve for six months following brief exposure to the system [4]. However, the longer the drivers interacted with the intelligent speed adaptation system, the more frequently they overrode it [5].

A few earlier studies show that subjective evaluations toward systems is related to changes in driving behaviors [6]. Similarly, from a long-term perspective, some drivers barely trusted and accepted an adaptive cruise control system when they were provided incomplete information [7]. These studies reveal the importance of measuring subjective evaluations to encourage drivers to change their driving behaviors appropriately.

Therefore, it is essential to consider both the short- and long-term effects of an advanced driving assistance system. The present study empirically verifies the effects of the system on drivers' behaviors and usability evaluations from short- and long-term perspective.

The changes in speed, margin, and evaluation scores immediately after driving with assistances are defined as "short-term effects," while the changes after one week of driving with assistances are defined as "long-term effects." If drivers can comprehend the system's intention immediately after initially driving with assistances, their driving behaviors would improve on day 1 and no changes would be observed thereafter. If drivers understand the system's intention gradually, their driving behaviors would improve gradually week after week.

Section 2 describes the experimental method and Section 3 describes the results of the experiment. In Section 4, we discuss the short- and long-term effects of an advanced driving assistance system.

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Figure 1. Driving simulator used in the experiment.

TABLE I. THR NUMBER OF RISK OBJECTS IN COURSES

Running	Intersections		Parked Cars		Pedestrians		Others
	High risk	***Low risk***	***High risk***	***Low risk***	***High risk***	***Low risk***	
Practice Running	4	2					
Pre- and Post-Running	4	2	1	1	1	1	
Running with Assistance							
Parked Cars (High Risk)	2	1	2				
Parked Cars (Low Risk)	2	1		2			
Pedestrians (High Risk)	2	1			2		
Pedestrians (Low Risk)	2	1				2	
Filler (Parked Cars)	2	1					2 (Parked cars in the opposite lane)
Filler (Pedestrians)	2	1					2 (Pedestrians in the opposite lane)

II. METHOD

A. Apparatus

We used a driving simulator equipped with a driving assistance system in an experiment (Figure 1). This system detects the potential risks that may lead to accidents, such as drivers' blind spots. Such risks are identified based on the normative behaviors of expert driving instructors. The following two driving assistance stages are employed [8] [9]:

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

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

The following information is provided when cognitive guidance is given and behavioral interventions are performed. Three stimuli are provided: a beep and notification message (e.g., "Caution! A parked car") as the 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 scope of the 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 occurs when passing a parked car and a pedestrian but not when crossing an intersection.

This driving assistance system provides information about the potential risks and encourages drivers to change their behaviors if necessary. No assistance (i.e., cognitive guidance and behavioral intervention) is provided in the case of safe driving. From an educational perspective, if the drivers understand the system's intention, they are expected to adopt safer driving behaviors than before.

B. Course Settings

Approximately 1,400 meters is used as the length of the driving course utilized in the experiment. Although the course includes some intersections, participants are required to drive straight at all intersections.

Intersections without signals, parked cars, and pedestrians are arranged on the course as the risk objects, which the system can detect. Each risk object is of two different kinds, depending on their risk level.

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- *Intersections:* The size of blind spots can be controlled by the height of fences near intersections—that is, high-risk intersections with high fences and low-risk intersections with low fences.
- *Parked cars:* The size of blind spots can be controlled by the size of parked cars—that is, high-risk parked trucks and low-risk parked compact cars.
- *Pedestrians:* The level of risk can be controlled by the direction of pedestrians—that is, high-risk pedestrians in the same direction as the car and low-risk pedestrians in the direction facing to the car.

The system provides more assistance toward the high-risk objects than toward low-risk objects because the system determines the amount of assistance based on the risk levels. If drivers understand the relationship between risk levels and the amount of assistance, they may adopt safer behavior by themselves.

C. Procedure

Eighteen drivers participated in four 90-minute experiments spanning four weeks, with a one-week interval between experiments. Ethic approval was granted by the Nagoya University Institute of Innovation for Future Society Ethics Committee and participants were provided with an informed consent form.

All four experiments were conducted according to the following procedure. Table 1 shows the number of the risk objects arranged in each running.

- *Practice running:* Participants were allowed to drive the course once without assistance to understand the driving simulator.
- *Pre-running:* Participants drove the course twice to measure the initial driving behavior without assistances. The course included each of two kinds of risk objects for intersections, parked cars, and pedestrians.
- *Instruction:* Participants were informed that the system encourages drivers to adopt safer driving behaviors with cognitive guidance and behavioral interventions. Participants also watched a movie on the assistances provided by the system.
- *Pre-evaluation:* Participants answered a usability questionnaire prior to using the system. This questionnaire measured six elements: effectiveness, efficiency, satisfaction, understandability, comfort, and motivation. Each element has three questions rated on a five-point scale [10].
- *Running with assistance:* During training, participants drove the six courses with assistances. To encourage participants to understand the relationship between the risk levels and the amount of assistance, either parked cars or pedestrians were arranged in each running. Two filler runnings were included in the six courses to inform participants that the system does not provide assistances unnecessarily for objects with extremely low risk. In this running, the number of intersections was reduced to half, as the length of the course was set to half the normal length. The order of the six courses was counterbalanced with a Latin square.
- *Post-running:* Participants drove the course twice, similarly as in the initial pre-running.
- *Post-evaluation:* Participants answered a usability questionnaire after using the system, similarly as in the initial pre-evaluation.

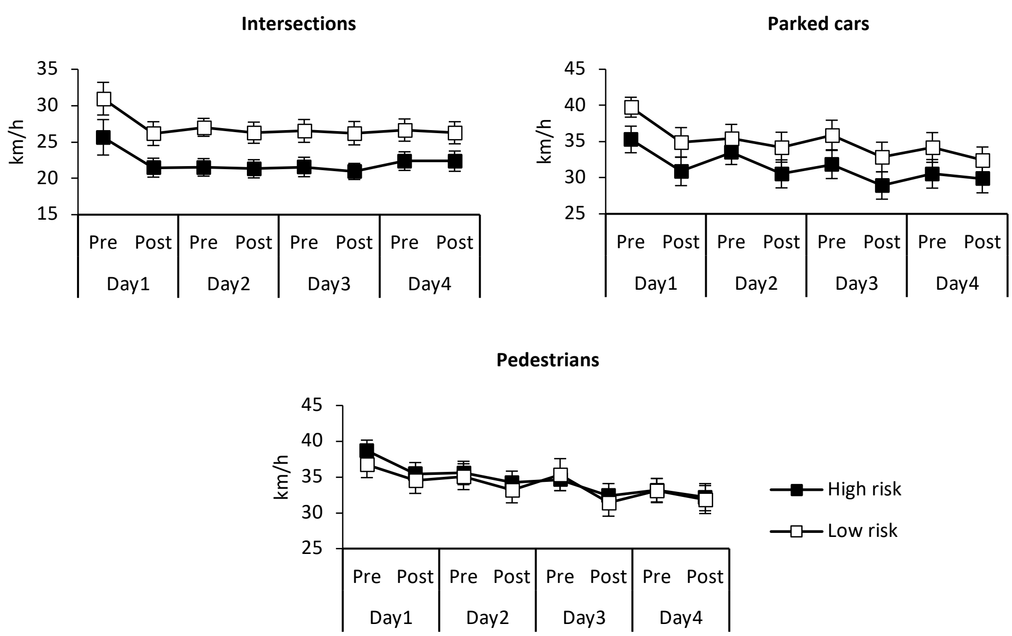

Figure 2. Transition of speed. The error bars represent the standard error of the mean.

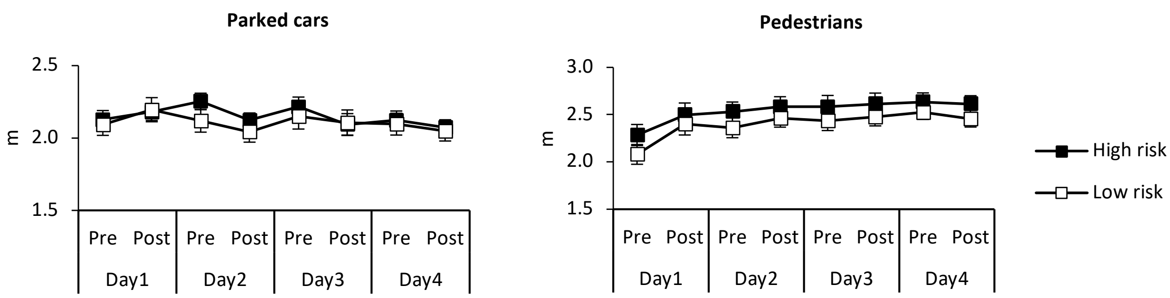

Figure 3. Transition of margin. The error bars represent the standard error of the mean.

TABLE II. SUMMARY OF ANOVA RESULTS FOR SPEED

Objects	Risk	Day (1/2/3/4)			Running (Pre/Post)		Day × Running			Effect Type
		F	*p*	*Significant pairs*	*F*	*p*	*F*	*p*	*Significant pairs*	
Intersections	High	2.98	**0.039***	1-2, 1-3	4.06	**0.059+**	4.46	**0.007***	Day1: pre-post Pre: 1-2, 1-3, 1-4	Initial short-term
	Low	2.24	**0.094+**		9.25	**0.007***	5.04	**0.003***	Day1: pre-post Pre: 1-2, 1-3, 1-4	Initial short-term
Parked Cars	High	2.21	**0.098+**		21.90	**0.001***	1.55	0.21		Short- and long-term
	Low	3.63	**0.018***	1-3, 1-4	15.93	**0.001***	1.45	0.23		Short- and long-term
Pedestrians	High	5.67	**0.002***	1-3, 1-4	11.99	**0.003***	0.85	0.47		Short- and long-term
	Low	1.89	0.14		9.34	**0.007***	0.90	0.44		Short- and long-term

*: $p < .05$, +: $p < .10$

TABLE III. SUMMARY OF ANOVA RESULTS FOR MARGIN

Objects	Risk	Day (1/2/3/4)			Running (Pre/Post)		Day × Running			Effect Type
		F	*p*	*Significant pairs*	*F*	*p*	*F*	*p*	*Significant pairs*	
Parked Cars	High	2.01	0.12		7.15	**0.016***	4.80	**0.005***	Day2, 3: pre-post Pre: 1-2, 2-4	Others
	Low	0.85	0.47		0.28	0.60	2.11	0.11		Others
Pedestrians	High	4.88	**0.004***	1-2, 1-3, 1-4	2.36	0.14	2.74	**0.052+**	Day1: pre-post Pre: 1-2, 1-3, 1-4	Initial short-term
	Low	6.12	**0.001***	1-2, 1-3, 1-4	7.09	**0.016***	5.03	**0.003***	Day1: pre-post Pre: 1-2, 1-3, 1-4	Initial short-term

*: $p < .05$, +: $p < .10$

III. RESULTS

All 18 participants of mean age 30.5 years were analyzed. The standard deviation of age was 10.1 years. We conducted 4 (Day factor: 1/2/3/4) × 2 (Running factor: pre/post) ANOVAs for the following analyses.

A. Driving Behaviors

Figure 2 shows the transitions in speed when crossing an intersection and passing a parked car or a pedestrian, and Figure 3 shows the transitions of the margin between the car and a parked car or a pedestrian. We can find two types of transition patterns in speed and margin: "initial short-term effect" and "short- and long-term effects."

1) Initial short-term effect: On day 1, short-term effects from pre- to post-running were observed, and no changes were observed thereafter. This effect appeared for speed when crossing an intersection and for margin when passing by a pedestrian. Statistically, there were significant interactions between day factor and running factor and significant differences between pre-running on day 1 and the other three pre-runnings (Tables 2 and 3).

2) Short- and long-term effects: The short-term effects between pre- and post-running as well as the long-term effects between days appeared simultaneously. Therefore, driving behavior improved gradually over four weeks. This effect appeared for speed when passing by a parked car and a pedestiran. Statistically, there were significant main effects

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of both day facror and running factor and no significant interaction (Table 2).

These transition patterns depended on the kinds of risk objects and driving behavior, regardless of the risk levels. The margin when passing by a parked car did not conform to these two patterns (Table 3).

B. *Usability Evaluations*

Figure 4 shows the transition of usability scores. We found that each of the scores is not fluctuating, with small variances. However, the ANOVA results show significant main effects for some elements. First, significant main effect of day factor for efficiency was observed ($F(3, 51) = 4.89, p < 0.005, \eta^2 = 0.05$). The score on day 1 was significantly lower than that on the other three days (day 1-2: $t(35) = 2.06, p < 0.05$; day 1-3: $t(35) = 3.50, p < 0.001$; day 1-4: $t(35) = 3.09, p < 0.005$). Second, a marginally significant main effect of running factor for understandability indicates that participants comprehend the system more in post-running than in pre-running ($F(1, 17) = 3.46, p < 0.10, \eta^2 = 0.01$). However, subjective evaluations were stable because both effect sizes were extremely small.

IV. DISCUSSION AND CONCLUSION

The present study empirically confirmed the short- and long-term effects of an advanced driving assistance system on drivers' behaviors and usability evaluations. As a result, we found two types of transition patterns in driving behaviors and one stable pattern in usability evaluations.

The first pattern in driving behavior, in which changes between pre- and post-running on day 1 and no changes following day 1 are observed, is interpreted as the initial short-term effect. This pattern appears for speed when crossing an intersection and for margin when passing by a pedestrian. Drivers adequately understand the potential risks immediately after an initial driving session with assistances and remember them until the next week.

The second pattern, in which changes between pre- and post-running on each day and changes between days are observed, is interpreted as the short- and long-term effects. In other words, changes between pre- and post-running on each day disappear in pre-running in the following week. This pattern appears for speed when passing by a parked car and a pedestrian. Although drivers could not adequately understand potential risks after their initial driving session with assistances, they gradually comprehend the risks after repeated runnings with assistances.

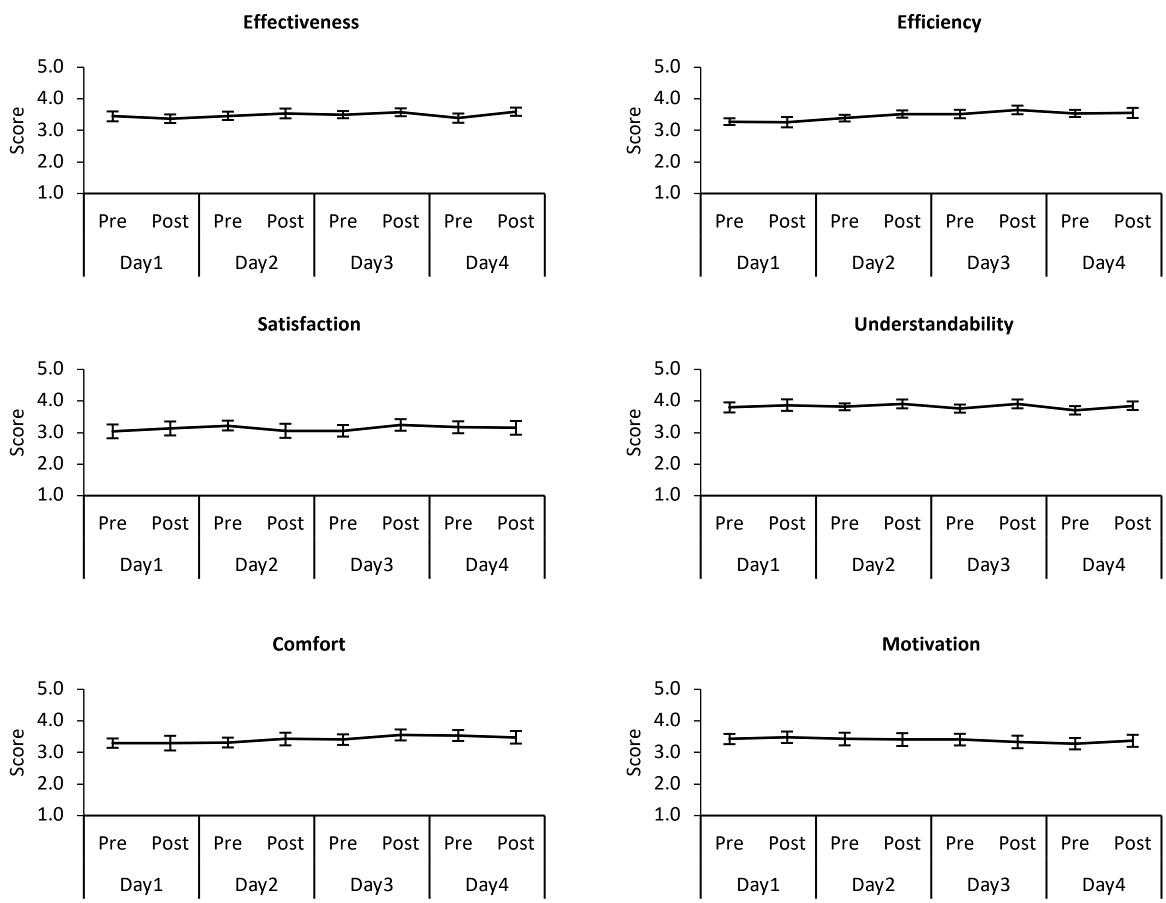

Figure 4. Transition of usability evaluation scores. The error bars represent the standard error of the mean.

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What determines the type of effect that appears in driving behaviors? The study results indicate that the factor is the combination of risk objects (i.e., an intersection, a parked car, or a pedestrian) and driving behaviors (i.e., speed or margin), regardless of risk levels (i.e., high risk or low risk).

There is no steering intervention when crossing an intersection, unlike when passing by a parked car and a pedestrian. Similarly, drivers are prone to experience sudden slowdowns prompted by the system because the risk level of intersections is higher than the risk levels of parked cars and pedestrians. Such salient experiences of slowdowns in an intersection encourage drivers to learn the potential risks well, which could appear as the initial short-term effect in driving behaviors. The number of intersections is likely to influence the type of effect because more intersections are arranged than parked cars and pedestrians.

Both braking and steering interventions are conducted when passing by a parked car and a pedestrian. A pedestrian is the only object that moves autonomously in courses, unlike a parked car. Moreover, previous research using the same driving assistance system shows that the change in margin between the car and a pedestrian after running with assistances was larger than that in the margin between the car and a parked car [6] [11]. Therefore, drivers could easily understand the potential risks that a pedestrian might run right in front of the car. Drivers might increase the margin between the car and a pedestrian, which could appear as the initial short-term effect in driving behaviors.

The present study revealed that there is no uniform effect of a single driving assistance system and it depends on the kinds of risk objects and driving behaviors. Although we used only engineering measures in the experiment, it would be more beneficial to use both engineering and educational measures, such as training, in order to encourage drivers to adopt safer behaviors in real life.

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