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An experimental study on the difference in drivers' decision-making behavior during manual and supported driving

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Abstract

The purpose of this study is to identify differences in characteristics of drivers' decision-making when driving a vehicle with manual operation or with an automatic driving assistance system by using a high fidelity driving simulator. We controlled three experimental factors. The first is driving mode as a between-participant factor: manual driving and using automatic driving systems. The automatic driving system controls the vehicle's speed while recognizing peripheral vehicles. Moreover, it controls the steering when it is necessary to change the lanes and overtake slower traffic. The participants were also instructed to intervene with the steering and pedals and bring the vehicle to safety if they felt danger. They were required to drive for a total of 40 minutes for each condition. The remaining two are within-participant factors: relative speed between lanes and distance of destination. These two factors relate to experiencing risk. The experimental results are summarized as follows. First, in the automatic driving condition, the participants tend to avoid the lane changes compared with the manual driving condition. Second, the tendency to avoid lane changes correlates with reduction of risk sensitivity. These results show that while decisions to change lanes when using driving assistance systems were more careful, the sensitivity to risk situations might be reduced.

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Keywords: Decision-making; Driver assistance systems; Driving behavior

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1. Introduction

In recent years, fully automatic vehicles are in the stage of becoming ever more practical with the development of driver assistance systems such as the adaptive cruise control and lane keeping assist. Therefore, the usage of automobile in our daily life is reaching a major turning point. However, automatic driving assistance systems are not necessarily perfect. For example, automatic driving assistance systems are difficult to cope with unexpected environmental changes. Thus, the driver needs to monitor the driving situation to interrupt the system's operation when they cannot accept the risk of the situation into which the system drives the vehicle [1]. In such situations, over-trust of driving support systems lead to serious accident. For example, automation complacency is a one of the major problems when using automation systems with high performance. If automation is highly but not perfectly reliable in supporting operators, then the operators may not monitor the automation and its information sources and hence fail to detect the occasional times when the automation fails [2-3]. To prevent such problems between drivers and automatic driving assistance systems it is necessary to understand characteristics of human driving behavior when using automatic driving assistance systems. In this study, we try to reveal how drivers' behavior changes by using automatic driving assistance systems. The nature of driving behavior when using automatic driving assistance systems is an important aspect for developing safe driver assistance systems. However, few studies focus on characteristics of driving behavior when using driving assistance systems. The purpose of this study is to identify differences in characteristics of drivers' decision-making when driving a vehicle with manual operation or with an automatic driving assistance system.

2. Method

2.1. Equipment

Our experiment used a high-fidelity driving simulator with a vehicle motion simulator called carSim (Fig. 1). The front field of view covers 180° on three screens, and the interior of the driver's area is the same as a real car.

2.2. Participants

Fifty graduates and undergraduates who had a driving license participated in the experiment. Thirteen were males and two were females. Their ages ranged from 21 to 24.

2.3. Procedure

Fig. 2 shows an overview of the experimental setting. The participants were required to drive a vehicle on a two-way highway while maintaining a speed of 100 km/h.

We controlled three experimental factors. The first is driving condition as a within-participant factor: manual driving and using driving assistance systems. In the manual-driving condition, they were required to keep the velocity of the vehicle at 100 km/h as possible as they can. On the other hand, in the supported-driving condition using driving assistance systems, the automatic driving system kept vehicle velocity on average 100 km/h. The automatic driving system controls the vehicle's speed while recognizing peripheral vehicles. Moreover, it controls the steering when it is necessary to change the lanes and overtake slower traffic. The participants were also instructed to intervene with the steering and pedals and bring the vehicle to safety if they felt danger. They were required to drive for a total of 40 minutes for each condition. The task orders were randomized between participants.

The remaining two are also within-participant factors: relative speed between lanes (20–60 km/h) and distance of destination (30–100m). These two factors relate to experiencing risk. We controlled that the velocity of surrounding vehicles on the same lane as the host vehicle were set randomly between 30 and 70 km/h (slower lane in Fig. 2), and the velocities of vehicles on the neighboring lane were set randomly between 90 and 110 km/h. After each lane changes of host vehicle, velocities of surrounding vehicles in the host vehicle's lane gradually shifted into slower range (i.e., between 30 and 70 km/h), whereas the velocities of vehicles on the neighboring lane gradually shifted in to faster range (i.e., between 90 and 110 km/h). Therefore, participants had to change the driving lane to maintain a speed of 100 km/h as the task requirement.

2.4. Behavioral analysis

In the analysis, we focused on decision-making behavior whether or not to change the driving lane to reveal characteristics of drivers when using the automatic driving assistance system. We used a logistic regression model to distinguish whether each participant changed lanes based on two different risk factors as explanatory variables: relative speed between lanes and distance of destination. The logistic regression model is shown in the expression 1.

$$\frac{p_{\text{lane change}}}{1-p_{\text{lane change}}} = \exp\left(\beta_{\text{intercept}} + \beta_{\text{distance}} \cdot x_{\text{distance}} + \beta_{\text{speed}} \cdot x_{\text{speed}}\right) \quad (1)$$

In the expression 1, $p_{\text{lane change}}$ on the left-hand side means the probability of lane change. The variable x_{distance} and x_{speed} correspond to the risk factors: relative speed between lanes (20–60 km/h) and distance of destination (30–100m). The coefficients (β_{distance} and β_{speed}) indicate sensitivity for each risk factor related to decision of whether each participant changes the driving lane. The intercept ($\beta_{\text{intercept}}$) indicates the representative value for the tolerability of risk. In the analysis, we estimated the intercept and coefficients of the logistic regression model of each participant's decision-making in each driving condition: manual-driving and supported-driving conditions.

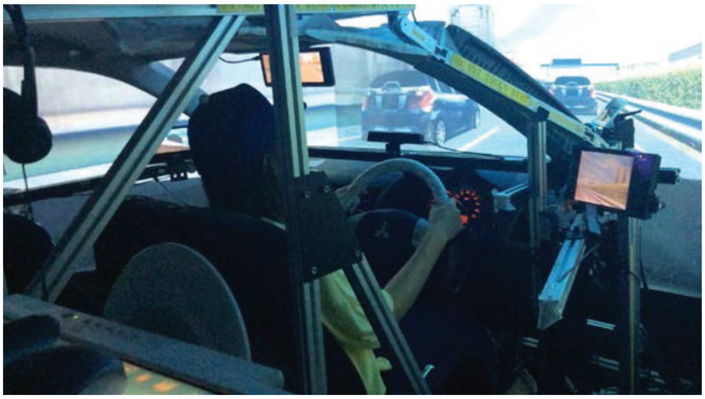


Fig. 1. Driving simulator used in the experiment.

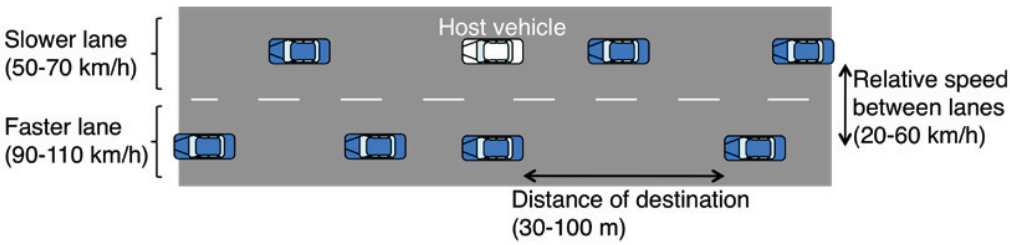


Fig. 2. Overview of the driving environment.

3. Results

We discussed how relations between decision-making in lane changing and the risk factors changed when using the automatic driving assistance system compared with manual driving. First, we depicted examples of *tolerability of risks* and *sensitivity for change of risks* when driving the vehicle with manual operation and with the automatic driving assistance system. Second, we discussed transition of each index from the manual-driving condition to the supported-driving condition and relations of them.

3.1. Overview of decision-making in lane changes

Fig. 3 shows examples of the results of decisions in lane change situations and the logistic regression of them in each driving condition. There were mainly two features in the analysis using the logistic regression. First is an odds of center of risk plane (i.e., $exp(\beta_{\text{intercept}})$), which represents tolerability of the risks in each driving condition. This participant was more careful of lane changes in the supported-driving condition than in the manual-driving condition. Second is an odds ratio of each risk factor (i.e., $exp(\beta_{\text{distance}})$ and $exp(\beta_{\text{speed}})$) as the slope of regression in each axis, which means sensitivity for the change of each risk. This participant's sensitivities for the changes of both risk factors decreased in the supported-driving condition compared with the manual-driving condition.

3.2. Differences of decision-making in lane changes between the manual and supported driving conditions

To reveal differences of decision-making in lane change situations between the manual and supported driving conditions, we calculated both the ratio of tolerability of the risks and the ratio of sensitivity for the change of each risk. The correlation between the transitions of sensitivity for the change of the risk factors (relative speed and distance of destination) is shown in Fig. 4. A correlation analysis showed a significant correlation (r = -.80, p < .01).

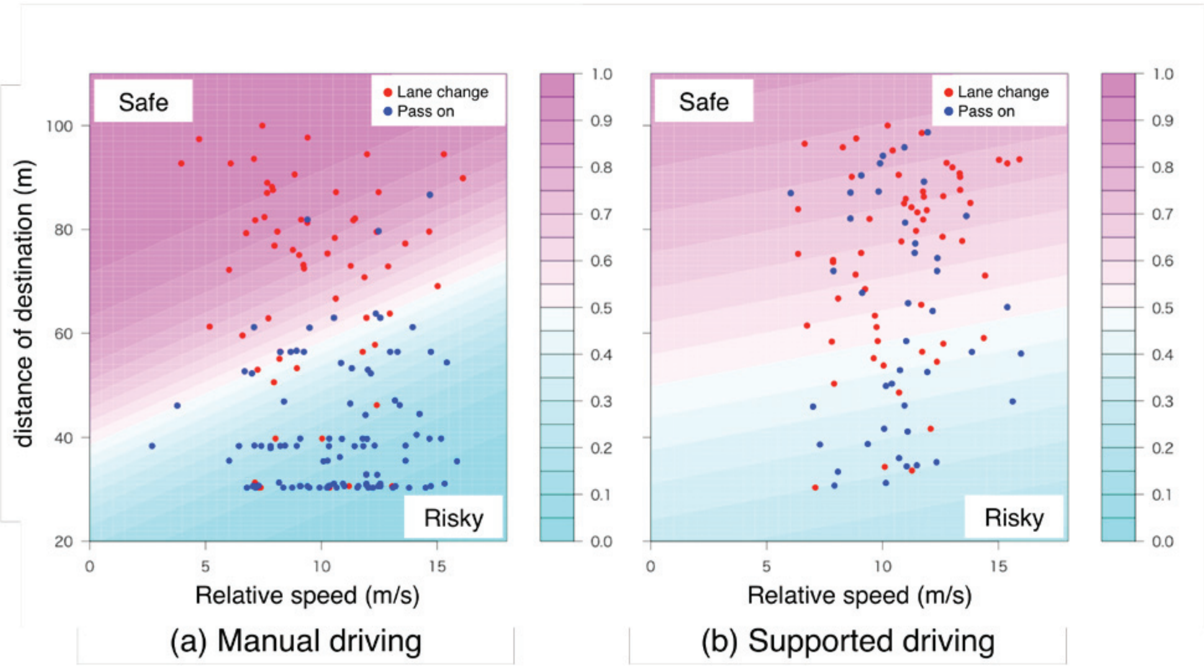


Fig. 3. Examples of decision boundaries on risk plane. *Note*. In the manual-driving (a) and supported-driving (b) conditions, situations when the participant executed lane changes and when he did not are depicted as red and blue points, respectively. The results of logistic regression are shown as the color contours.

Fig. 5 shows correlations between the transition of tolerability of the risks and the transition of sensitivity for change of each risk. There were two characteristic tendencies. First is that the transition of tolerability of the risks in many of the participants decreased from the manual-driving condition to the supported-driving condition. In the supported-driving condition, they tended to avoid the lane changes compared with the manual driving condition. Second is that there were significant correlations between the transition of tolerability of the risks and the transition of sensitivity for change of each risk factor (vs. relative speed: $r = .64$, $p < .01$; vs. destination of distance: $r = .67$, $p < .01$).

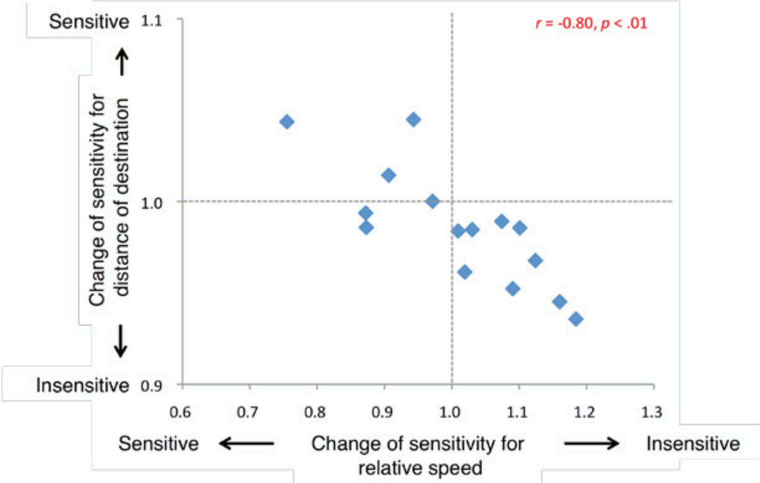
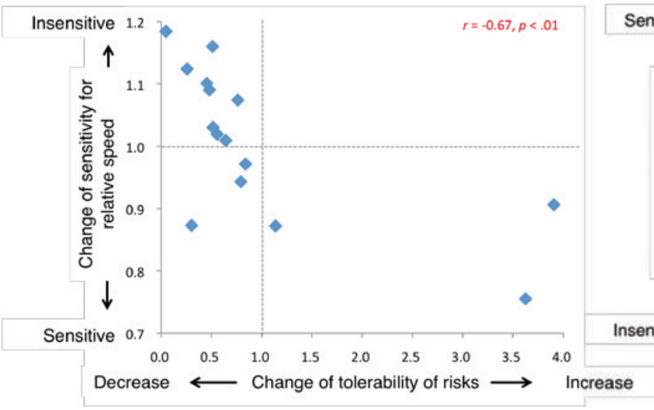
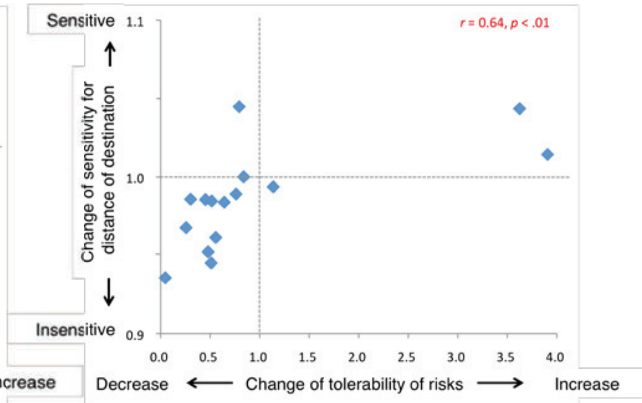


Fig. 4. Correlations between the transitions of sensitivity for change of both risk factors. The horizontal axis shows the ratio of odds ratio of the relative speed (transition of the sensitivity for change of relative speed). The vertical axis shows the ratio of odds ratio of the distance of destination (transition of the sensitivity for distance of destination). If the sensitivity for change of the relative speed increased in the supported-driving condition compared with the manual-driving condition, the transition of the sensitivity for the relative speed becomes less than one. On the other hand, if the sensitivity for change of the distance of destination increases in the supported-driving condition compared with the manual-driving condition, the transition of the sensitivity for the distance of destination becomes greater than one.



(a) Correlation with relative speed



(b) Correlation with distance of destination

Fig. 5. Correlations between the transitions of the tolerability of the risks and the transitions of the sensitivity for change of both risk factors. *Note*. (a) The correlation between the transitions of the tolerability of the risks and the transitions of the sensitivity for the relative speed. (b) The correlation between the transitions of the tolerability of the risks and the change of the sensitivity for the distance of destination. If the tolerability of the risks decreases in the supported-driving condition compared with the manual-driving condition, transitions of the tolerability of the risks become less than one.

4. Conclusion

In the study, we proposed a methodology for detecting changes in drivers' decision-making behavior and also discuss differences of such behavior between when driving manually or with driver assistance systems.

The experimental results are summarized as follows. First, in the supported-driving condition, the participants tend to avoid the lane changes compared with the manual-driving condition. The participants who reduced sensitivity for change of relative speed when using the automatic driving assistance system compared with manual driving tended to reduce their sensitivity for change of distance of destination. Second, the tendency to avoid lane changes correlates with reduction of risk sensitivity. These results show that while decisions to change lanes when using driving assistance systems were more careful, the sensitivity to risk situations might be reduced.

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