Investigating the Effect of Driving Support Robot Depending on Driver Characteristics

Ryusei Kimura
ryusei_kimura@jaist.ac.jp
Japan Advanced Institute of Science Technology
Japan

Hiroto Horimoto
s2310148@jaist.ac.jp
Japan Advanced Institute of Science Technology
Japan

Takahiro Tanaka
takahiro.tanaka@mirai.nagoya-u.ac.jp
Nagoya University
Japan

Shogo Okada
okada-s@jaist.ac.jp
Japan Advanced Institute of Science Technology
Japan

ABSTRACT

Driving support robots (DSRs) can change drivers' behavior and decrease traffic accidents; however, a one-size-fits-all approach cannot change the behavior of a wide range of drivers. To develop personalized DSRs, this study analyzed the improvements in driving behavior related to speeding and sudden acceleration/deceleration resulting from interactions between humans and DSRs. We found differences in the effect of the support provided by a DSR based on driver characteristics. These results indicate that the personalization of support based on driver characteristics has the potential to improve drivers' behavior more effectively.

CCS CONCEPTS

• **Human-centered computing** → **User studies**; Ubiquitous and mobile computing.

KEYWORDS

human-robot interaction, driving support, driver characteristics, personalization

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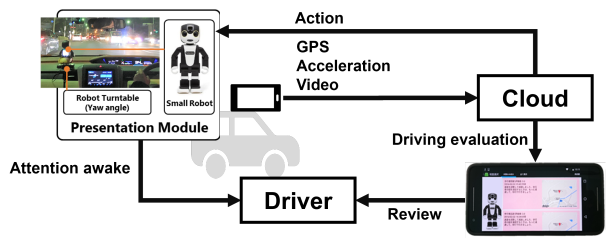

Figure 1: Overview of the driving support robots.

1 INTRODUCTION

Recently, several studies have proposed driving support robots (DSRs) to promote safe driving and reduce traffic accidents [4]. Although many effective DSRs have been proposed, most such robots support all drivers in the same way despite the various types of drivers. A one-size-fits-all approach may provide limited performance of DSRs and satisfaction for individual drivers [8]. Thus, personalized DSRs have the potential to satisfy the demands of a wide range of drivers and thus enhance their effectiveness.

We are developing a DSR that involves an assistant humanoid robot that provides feedback based on a driver's driving evaluation in situations that lead to accidents (e.g., excessive speed). The DSR system is designed to prioritize driver safety and to provide feedback to the driver through the robot's utterance in a manner that does not interfere with driving. In [7], the agent provided attention awakenings and revision suggestions regarding driving operations to ensure that drivers stop at stop signs and avoid pedestrians and parked cars. However, existing systems provide feedback to all drivers in the same manner, and differences in feedback effects resulting from differences in driver characteristics are unclear. For example, increasing the frequency of attention awakening near stop signs may be effective for careless drivers because they tend to violate stop signs.

As a first step toward the development of personalized DSRs that can provide efficient feedback in line with specific driver characteristics, the purpose of this study is to analyze the improvements in driving behavior resulting from interactions between drivers and DSRs.

Several studies have evaluated the relationships between driver characteristics and their preferences regarding or acceptance of DSR. Cramer et al. showed that drivers who scored high on locus of control tended to report that the driver should follow the robot's instructions more than those who scored low on locus of control [1]. Li et al. showed that drivers have different preferences regarding and attitudes toward in-vehicle anger intervention systems depending on their driving anger traits [5]. Miyamoto et al. found a connection between users' level of conscientiousness and

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their evaluation of the utterances of a DSR [6]. These studies have identified differences in the outcomes of interactions between drivers and DSRs depending on driver characteristics.

Regarding driver characteristics, this study uses the Driving Style Questionnaire (DSQ), which was introduced by [2] to characterize drivers in a psychological context. The ways in which drivers interact with DSRs may also be related to demographic attributes, such as gender and age. However, even if drivers are of the same gender and age, they nevertheless have different attitudes toward driving [2]. Therefore, we assume that the DSQ is more suitable for analyzing such interactions.

The preferences and acceptability demonstrated in the research mentioned above were based on a subject's response to the questions. Certainly, acceptance of a robot may improve driving, but it may not necessarily lead to actual improvement. This study analyzes the improvement in driving behavior by reference to driving data collected in the context of daily driving.

2 DATASET AND DRIVING SUPPORT ROBOTS

2.1 Dataset

In this paper, we use a dataset shared by the Institutes of Innovation for Future Society of Nagoya University. The dataset includes 5578 driving sessions obtained from 50 drivers who drive regularly and range in age from their 20s to 60s. Driving data were collected in the context of daily driving, and the driving environment, such as route, time, and frequency of driving differed for each driver. The DSR detailed in Section 2.2 was attached to the front of the driver while driving. Global positioning system (GPS) data, acceleration, and video of the front of the car were recorded using a smartphone (AQUOS sense2 SH-M08). We excluded data for cases in which the driving distance was less than 1 km, the driving time was less than 3 minutes, or some parts were missing. After this preprocessing, 4087 driving data remained.

Nagoya University's ethics committee approved the experimental plan for collecting the driving data with support from the DSR after making a judgment regarding driver safety. All participants with a Japanese driving license provided informed consent regarding their participation in the experiments.

2.2 Driving support robots

This study uses a compact communication robot (RoBoHoN, Sharp Co., Ltd) that is customized for our study as a DSR. Figure 1 shows an overview of the DSR system. The robot provides two types of support, namely, an attention awakening and a review of driving.

The former type of support is provided during driving and aims to revise dangerous driving behavior. This support aims to promote exact stopping at stop signs and to prevent sudden acceleration/deceleration and speeding. These types of supports were generated based on an instruction set developed by professional driving instructors. This study focuses on the effect of support on the prevention of nonsafe driving behavior such as sudden acceleration/deceleration and speeding. Sudden acceleration/deceleration is detected based on acceleration data. When the acceleration or deceleration exceeds 1.3G, the robot notifies the driver of the sudden acceleration/deceleration by saying "Wow. Oops." and making a motion. Speeding is detected using the speed of the car and the legal speed limit on roads obtained based on GPS and map data. Additionally, the robot suggests speed reduction via both voice and motion when the speed exceeds the legal speed limit by 15 km/h. After expressing a warning, the robot does not issue another warning regarding speeding for approximately five minutes to avoid bothering the driver.

The latter type of support is provided to drivers after each driving session via a smartphone. The application evaluates the driver's driving behaviors and offers reviews of good and bad scenes to the driver. The feedback consists of an evaluation value, advice comments, a map based on GPS data, and a recorded movie. The details of this review support are described in [7].

2.3 Driving Style Questionnaire

To investigate the effect of support by DSR (Section 2.2) in accordance with each driver's characteristics, we asked the drivers to complete the DSQ questionnaire to characterize their attitudes toward driving. The DSQ includes eight items scored on a scale ranging from 1 to 4. Each item is associated with two questions, and their mean value represents the score for the item. Scores for negative-form questions are reversed to calculate the item scores. All DSQ items and questions are listed in Table 1. The DSQ focuses on the attitudes, orientations, and ways of thinking associated with daily driving rather than actual driving behavior [2]. Thus, we assume that the DSQ is related to the acceptability of the support provided by the driver robot. Moreover, in [3], it is indicated that the DSQ score can be automatically estimated based on driving data. Such automatic estimation of driver characteristics facilitates personalization without the administration of burdensome questionnaires. We confirmed that the DSQ item scores attained by the subjects were widely distributed.

3 ANALYSIS AND RESULTS

We analyzed the effect of supportive feedback from the DSR for each DSQ characteristic. For this purpose, we focused on whether drivers changed (revised) their driving behavior after they received feedback from the DSR.

3.1 Long-term improvement in driving behavior

We evaluated the long-term improvement in driving behaviors. As the performance indexes of each session of driving, we counted the number of speeding instances or sudden acceleration/deceleration events per mile. Then, we sorted these indexes by date of driving and calculated the Pearson correlation coefficient (r) between the sorted indexes and the number of sessions of driving for each driver. When r is small (negative), the number of speeding instances or sudden acceleration/deceleration events per mile tends to decrease, and driving behavior is regarded as having improved. Finally, we compared the results between the high-DSQ group, in which drivers scored greater than or equal to the median score, and the low-DSQ group, in which drivers scored less than the median score. We conducted the Wilcoxon one-sample signed rank test for r values for each group and the Mann-Whitney U test for the comparison of r values among groups. Table 2 shows the p-values for these tests. The underlined p-values are less than 0.05.

Table 1: DSQ items and questions associated with each item.

	DSQ Item	Question
(1)	Confidence in driving skill	I am not skillful at changing lane in congestion. I have confidence in sensing the width of car.
(2)	Hesitation for driving	I use bus or train rather than car when there is no large difference in time required. I choose a well arranged wide road with traffic lights instead of a narrow back road.
(3)	Impatience in driving	I keep a sufficient distance to the lead vehicle without minding another car cutting in. I want to go ahead as much as possible, even if I need to change my lane.
(4)	Methodical driving	I surely drive slowly at the small intersection, or securely stop at the stop line. I confirm safety when changing lane or strating at intersection.
(5)	Preparatory maneuvers at traffic signals	I change speed far in advance depending on traffic signal ahead. I control speed not to stop at the red signal.
(6)	Importance of automobile for self-expression	I consider cars are just a means for transportation and am satisfied if they run. I consider car as a status symbol (I like to have a good looking car).
(7)	Moodiness in driving	I can not concentrate on driving when troubled. I drive carelessly or at high speed depending on the state of mind.
(8)	Anxiety about traffic accidents	I am always in fear of hitting a pedestrian. I am worried about meeting a traffic accident.

DSQ item	Speeding					Sudden acc/dec				
	High		Low		Diff	High		Low		Diff
	r	p	r	p	p	r	p	r	p	p
Confidence in driving skill	0.027	0.374	-0.029	0.814	0.980	-0.133	0.014	-0.124	0.068	0.910
Hesitation for driving	0.096	0.003	-0.160	0.064	0.003	-0.092	0.052	-0.207	0.008	0.434
Impatience in driving	-0.039	0.627	0.079	0.020	0.115	-0.128	0.016	-0.134	0.073	0.991
Methodical driving	0.004	0.538	0.031	0.575	0.731	-0.180	0.001	0.021	0.831	0.122
Preparatory maneuvers at traffic signals	-0.007	0.751	0.082	0.176	0.639	-0.121	0.010	-0.167	0.074	0.702
Importance of automobile for self-expression	0.021	0.501	-0.007	0.507	0.849	-0.070	0.096	-0.241	0.005	0.132
Moodiness in driving	0.032	0.260	-0.016	0.756	0.140	-0.134	0.017	-0.125	0.083	1.000
Anxiety about traffic accidents	0.035	0.106	-0.017	0.744	0.274	-0.207	0.004	-0.043	0.179	0.104

Table 2: Wilcoxon one-sample signed-rank test's p-values for each group and Mann-Whitney U test's p-values for comparing groups.

As a result of the analysis, for speeding, in the high group for "hesitation for driving" and the low group for "impatience in driving", the mean values of r were significantly different from zero. Moreover, we found a significant difference in the mean values of r between the high and low groups for "hesitation for driving". Figure 2 shows boxplots of the r values for the high and low groups for "hesitation for driving". We found that the high groups did not tend to decrease their speeding, while the low groups did tend to decrease their speeding.

Regarding sudden acceleration/deceleration, in the eight high groups and the two low groups, a significant difference from zero was observed. However, we could not find DSQ items that exhibited significant differences between the mean values of r of the high and low groups. Most r values were smaller than those for speeding, and their signs were negative, except that of the low group for "methodical driving".

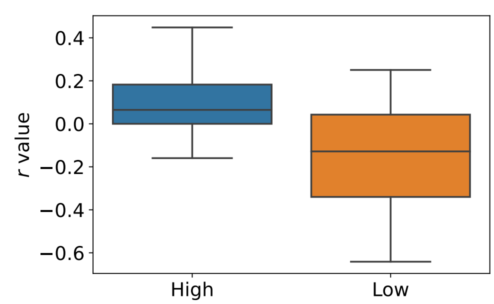

Figure 2: Boxplots of r values of the speeding performance for the high and low groups of "hesitation for driving".

3.2 Temporal improvement in driving behavior

Changes in driving behavior immediately after receiving support from the DSR indicate that temporal improvement in driving behavior is caused by the DSR and that the interaction between the

DSQ item	μ_{high}	μ_{low}	Diff (p)
Confidence in driving skill	7.200	13.152	0.004
Hesitation for driving	8.068	10.752	0.213
Impatience in driving	8.910	9.225	0.573
Methodical driving	9.230	8.457	0.618
Preparatory maneuvers at traffic signals	8.795	10.114	1.000
Importance of automobile for self-expression	9.145	8.804	0.732
Moodiness in driving	9.710	8.057	0.875
Anxiety about traffic accidents	9.861	8.064	0.390

Table 3: The average number of seconds of speeding after receiving support and Mann-Whitney U test's p-values for the comparison across groups.

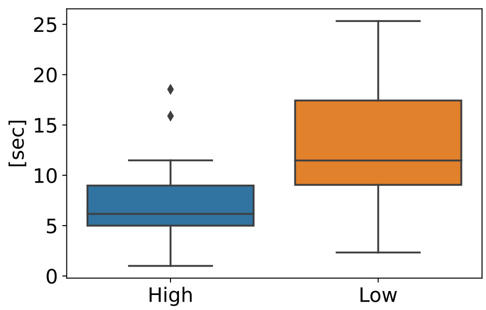

Figure 3: Boxplots of the mean duration of speeding after receiving support for the high and low groups for "confidence in driving skill".

DSR and the driver is successful. Hence, we focused on the temporal improvement in driving behavior, which refers to the duration of speeding after receiving support. If drivers accept the warning regarding their speeding, they attempt to reduce their speed to comply with the speed limit. As described in Section 2.2, the DSR does not warn drivers again for five minutes after conveying the initial warning. Thus, we use the first speeding data regarding each driving session for which a warning must be provided.

We performed the Mann-Whitney U test to compare the mean duration of speeding after receiving support across groups. Table 3 shows the average number of seconds of speeding after receiving support for the high- and low-DSQ groups and the tests' p-values. The underlined p-values are less than 0.05. We found significant differences only in the comparison of the high and low groups for "confidence in driving skill". Figure 3 shows boxplots of the mean values of the average number of seconds of speeding in the high and low groups for "confidence in driving skill". The mean value associated with the high groups for "confidence in driving skill" was smaller than the mean value associated with the low groups.

4 DISCUSSION

The results of the experiment showed that the degree of improvement in driving behavior due to the DSR varies depending on the DSQ item.

Regarding long-term improvement in speeding, the difference in improvement between the high and low group for "hesitation for driving" was most significant. The mean r value for the low group for "hesitation for driving" was negative, while that of the high group for "hesitation for driving" was positive; that is, their driving behavior did not improve. Thus, there is room for improvement in the driving behavior of the high group for "hesitation for driving", and adapting the support provided based on the driver's level of "hesitation for driving" seems to be effective. One possible reason for this result is that drivers who exhibit a high level of "hesitation for driving" tend to hesitate not only to drive but also to use the DSR.

Regarding long-term improvement in sudden acceleration/deceleration, no significant differences were observed between groups with high and low DSQ scores. This result suggests that the support was effective for most of the groups. On the other hand, the mean r value of the low group for "methodical driving" was positive; that is, their driving behavior did not improve. This result indicates the presence of a group whose driving is difficult to improve. Drivers in the low group for "methodical driving" might not have paid attention to the robot's support or might have ignored the support provided by smartphone. Improving the driving behavior of drivers who ignore support is difficult. Increasing the frequency of support is a simple solution to this problem, but if drivers feel uncomfortable with the robot, they will stop using the robot. The group associated with the lowest r value was the group of drivers who exhibited high levels of "anxiety about traffic accidents". Since their driving behavior is influenced by their mood and is prone to fluctuation, support from the robot or smartphone may have helped them become aware of their unconscious driving behavior resulting from their mood.

Regarding temporal improvement in speeding, that is the duration of speeding after receiving support from the robot, the difference between the high and low groups for "confidence in driving skill" was most significant. Hence, specific support is needed for drivers who exhibit a low level of "confidence in driving skill" to improve their driving behavior. It is possible that one's driving skills lead to a margin of acceptance of support.

Furthermore, based on the results of the analysis of long-term improvement, support for sudden acceleration/deceleration is more effective than support for speeding. While speeding can easily be confirmed by glancing at the speedometer, sudden acceleration/deceleration is more difficult to be aware of. In other words, the driver may consciously cause speeding and unconsciously cause sudden acceleration/deceleration. We predict that support from a robot or a smartphone is more likely to improve unconscious driving behavior by helping drivers become aware of it.

5 CONCLUSION

In this work, we investigated the varying effects of the support provided by a driving support robot (DSR) based on differing driver characteristics. We analyzed long-term and temporal improvements in the driving behavior associated with speeding and sudden acceleration/deceleration. The results revealed that the effect of support depends on drivers' scores on the DSQ scale and highlighted the importance of providing personalized support to change driving behavior more effectively. In future work, we must explore why these differences occurred and propose personalized support for drivers whose driving behavior did not improve.

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