The Effect of Acceleration and Deceleration Information of Preceding Vehicle Group on Fuel Economy of the Following Vehicle

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Keywords: ITS, Traffic Flow, Eco-driving, Driving Simulator.

Abstract: Eco-driving and other environmentally-friendly behaviors have been gaining widespread acceptance. In order to encourage eco-driving efficiently, this study looked at the effect of preceding and pre-preceding vehicle's acceleration-deceleration information on the following vehicle's gasoline mileage. As a result, the following was found: 1. By providing information to a following vehicle, the fuel consumption rate of the following vehicle can be reduced. 2. Subjects that improved their gasoline mileage tended to value pre-preceding vehicle information more than those that worsened it. 3. With the provision of information on the pre-preceding vehicle, the following vehicles started moving earlier. 4. The pre-preceding vehicle's acceleration information caused the following vehicle to increase accelerate gradually when starting to move. Therefore, it was suggested that sharing the information on preceding and pre-preceding vehicles was effective.

1 INTRODUCTION

Recently, motivating and supporting through the provision and sharing of information have been pointed out as essential for the long-term continuation of eco-driving (Beusen et al., 2009); (Matsumoto et al., 2014); (Hao Yang and Wen-Long Jin, 2014). For this reason, systems that provide information on fuel economy to motivate drivers to change their driving behavior have been considered, and many systems including eco-drive indicators are under development. For further development of these systems, it is important to support drivers to harmonize with traffic flow by detecting not only information of one's own vehicle but also that of the preceding vehicle group (Matsumoto et al., 2011). Sato et al. tried to improve fuel economy by indicating information on acceleration/deceleration on a panel at the back of preceding vehicles to provide the information to following vehicles. The result reported that the provision of information may enable an ideal following with few needless changes in acceleration and also an improvement in fuel economy (Saito et al., 2012).

In this study, based on both these study results and trends in information technology, not only information on the acceleration/deceleration of the preceding vehicle but also that of the preceding vehicle group including the pre-preceding vehicle was presented and the effect on driving behavior, visual recognition and fuel economy was quantified.

Table 1: Display Method of Acceleration Information.

Acceleration a(m/s2)	display
0.4<=*a*	▲
-0.4<*a*<0.4Low	—
a<=-0.4	▲

2 EXPERIMENTAL OVERVIEW

2.1 Experimental Environment

As multiple subjects needed to drive in an identical driving environment, UC-win/Road (manufactured by Forum 8 Co., Ltd. and hereafter called "DS") was used to conduct the experiment in a virtual space which represented a linear road with no buildings along it. The data regarding acceleration, speed, engine speed, accelerator pedal input, brake pedal input, and the position of the vehicle were obtained

Matsumoto S..
The Effect of Acceleration and Deceleration Information of Preceding Vehicle Group on Fuel Economy of the Following Vehicle.
DOI: 10.5220/0005353700050010
In *Proceedings of the 1st International Conference on Vehicle Technology and Intelligent Transport Systems* (VEHITS-2015), pages 5-10
ISBN: 978-989-758-109-0

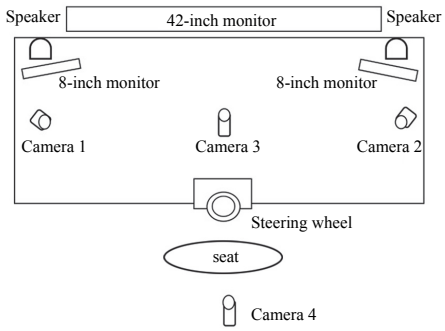

Figure 1: Experimental Equipment.

from DS as outputs. Four vehicles (hereafter called "pre-preceding vehicle", "preceding vehicle", "subject's vehicle" and "following vehicle" in order from front to back, and the front two vehicles are called "preceding vehicle group") were programmed to run on the experimental road. From the subject's vehicle, the view of the pre-preceding vehicle is blocked by the preceding vehicle. The pre-preceding vehicle was programmed to run on a low speed, mode 10, simulating driving in an urban area. The travel distance was approximately 700 m and each drive took approximately 3 minutes. Data of the vehicle driven by an average man in his twenties (having held his driver's license for 4 years and drives 3-4 times a week) following his preceding vehicle was recorded and used as the driving data for the preceding vehicle. Based on a previous study (Matsumoto et al., 2014), the following vehicle was set to follow the subject's vehicle with the same driving behavior so the inter-vehicular distance could be not too long. The brake lights of the preceding vehicle group were switched off during the experiment. If the deceleration information provided by the lighting of brake lights overlapped with the deceleration information indicated on the 8-inch monitor, the time of visual recognition may have been inaccurate.

2.2 Provision of Information

In the preliminary study, information was provided in three steps, as shown in Table 1, based on the indication format and threshold values of acceleration obtained by the previous study (Saito et al., 2012). The configuration of experimental equipment is shown in Figure 1. Two 8-inch monitors were used in this study.

One at the left side indicated the acceleration/deceleration information of the preceding vehicle, and one at the right side indicated that of the pre-preceding vehicle, both flickering at a

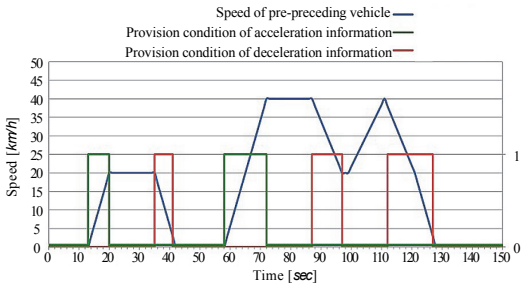

Figure 2: Swept Path and Acceleration/Deceleration Information of Pre-Preceding Vehicle.

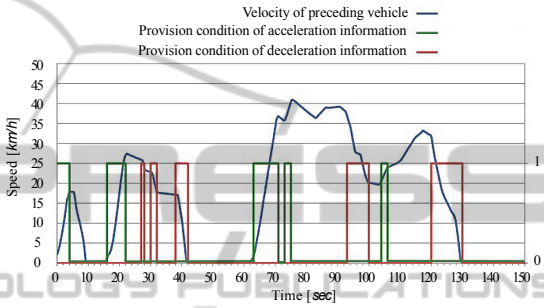

Figure 3: Swept Path and Acceleration/Deceleration Information of Preceding Vehicle.

Table 2: Attribution of Subjects

ID	*Age*	*Driving Experience*	*Driving Frequency*
A	22	2	1-2 times per week
B	34	26	almost everyday
C	22	3	1-2 times per week
D	21	3	3-4 times per week
E	22	4	1-2 times per week
F	46	25	once in a month
G	47	27	once in a month

frequency of 1 Hz. The green triangle showed the acceleration of preceding and pre-preceding vehicles. The white crossbar showed very little acceleration or deceleration, and the red triangle showed the deceleration of preceding and pre-preceding vehicles. Figure 2 and 3 shows the zone where acceleration/deceleration information of the pre-preceding and preceding vehicles is indicated. Numbers in the right axis show the information provision status; 1 represents the period of time when information is provided, and 0 represents the time when no information was provided. For the pre-preceding vehicle, the time of information provision accounted for 34.7% of the whole driving time (acceleration 40.4%, deceleration 59.6%). For the preceding vehicle, the rate was 27.3% (acceleration 43.9%, deceleration 56.1%).

2.3 Experimental Conditions

To adjust to the experimental environment, subjects practiced driving under two scenarios; with and without the provision of information. In the main experiment, each subject drove two times each under two situations; with and without the provision of information. Driving experiments were performed randomly to minimize the influence of the order. After the experiment, subjects took a questionnaire on the difference in driving with and without the provision of information.

2.4 Subject

Seven drivers (six males and one female) joined the experiment as subjects. Table 2 summarizes the attributes of each subject. Fully informed consent on the participation in the experiments was obtained from the subjects in advance, after given explanations about the following matters: 1) Disadvantages caused by the experiments 2) Consideration of privacy 3) Guarantee of their right to withdraw from the experiment. They were then given instructions as described below.

- Observe the Japanese traffic regulations.
- Drive safely.
- Follow the preceding vehicle, but do not pass the preceding vehicle group.
- Do not switch lanes.
- Do not fall too far behind the preceding vehicle.

Before driving with the provision of information, an additional instruction was given to the subjects to drive taking the acceleration/deceleration information into account where necessary. Two or three subjects drove in a day.

3 RESULT AND DISCUSSION

Under the experimental environment, the provision of information on the acceleration/deceleration of the preceding vehicle group was found to have the tendency to increase fuel economy by 2.3% on average. Therefore, the relation between the change in driving behavior after the provision of information and the increase in fuel economy was examined, based on the difference in visual recognition of acceleration information between subjects who increased the fuel economy and those who did not. Table 3 shows the fuel economy for each subject. Subjects A, B, C, D and E who

Table 3: Improvement of Fuel Economy by Subject (unit: km/l).

	ID	*Information not Provided*	*Information Provided*
improvement group	A	8.0	8.4(+5.6%)
	B	8.0	8.2(+2.0%)
	C	7.9	8.4(+5.9%)
	D	7.9	8.3(+4.9%)
	E	8.1	8.4(+1.0%)
reduction group	F	8.4	8.3(-1.0%)
	G	8.1	7.7(-4.7%)

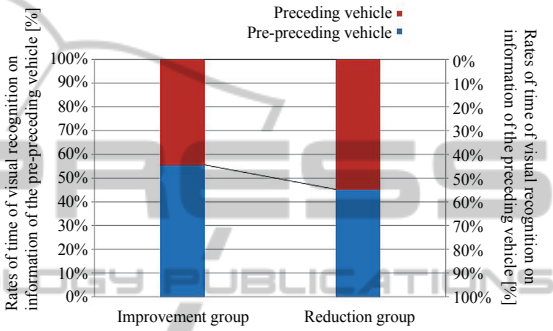

Figure 4: Rates of Time of Visual Recognition on Preceding Vehicle Group.

increased the fuel economy were classified as "elevation group", and subjects F and G who reduced the fuel economy were classified as "reduction group". The figure parenthesis shows the increase-decrease rate of fuel economy, using the rate with no provision of information as the standard. Firstly, Figure 4 shows the rate of time of visual recognition on acceleration/deceleration information of the preceding vehicle group. The rates of time of visual recognition on pre-preceding and preceding vehicles were 56% and 44% respectively in the elevation group, whereas the rates in the reduction group were 45% and 54%, respectively. Therefore, it was found that the elevation group tended to visually recognize the acceleration information of the pre-preceding vehicle more frequently, compared to the reduction group. Figure 6 shows the result of the questionnaire on degree of references of pre-preceding and preceding vehicles. For all subjects, the average rates of references of pre-preceding and preceding vehicles were 40% and 60%, respectively. However, the rate of references of acceleration information for pre-preceding vehicles was higher than the average rate of 40% for four subjects out of five in the elevation group. In contrast, both subjects in the reduction group answered that they referred more to acceleration information of preceding

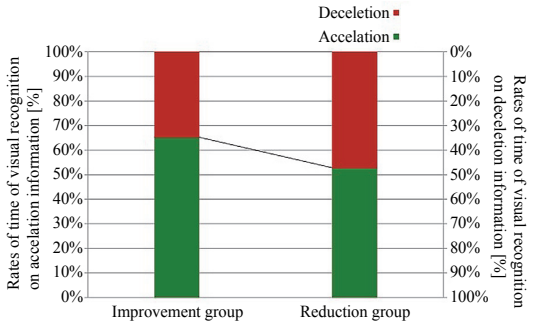

Figure 5: Rates of Time of Visual Recognition on Acceleration/Deceleration Information of the Pre-Preceding Vehicle.

vehicle, and the rate was higher than the average of 60%.

Secondly, Figure 5 shows the rates of time of visual recognition of acceleration/deceleration information of the pre-preceding vehicle. As a result, the rates in the elevation group were 65% for acceleration information and 35% for deceleration. This shows that they put more emphasis on acceleration information, compared to the reduction group.

According to "10 tips for fuel-conserving Eco Driving" by the Eco-Drive Promotion Council, soft starts with gentle acceleration called "e-start" improve fuel economy by approximately 10%, and in an urban area, driving without excessive accelerating reduces the fuel economy by approximately 2% (The Eco-Drive Promotion Council, 2013). Therefore in this study, specific differences in the ways of accelerating at the start time, when the improvement of fuel economy is highly expected, were analyzed.

Firstly, in order to find out the timing when the acceleration information of the pre-preceding vehicle is frequently recognized, the recognition times of all subjects for every second (hereafter called "overall recognition time") were compiled and plotted as shown in Figure 7. The summary indicates that in the three second period after the 14 and 61 second mark, which coincide with the time of the start of the pre-preceding vehicles, the visual recognition increased. These periods are the time when the acceleration information of the pre-preceding vehicle is provided, and account for 64.1% of the overall visual recognition time.

Therefore, the time between the starts of the pre-preceding vehicle and subject's vehicle (hereafter called "starting time difference") was examined. The result is shown in Figure 8. When the information was provided, the starting time difference was

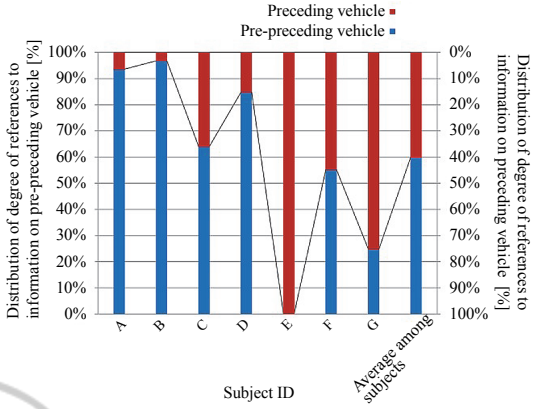

Figure 6: Result of the Questionnaire on Degree of References to Acceleration/Deceleration Information of Preceding Vehicle Group.

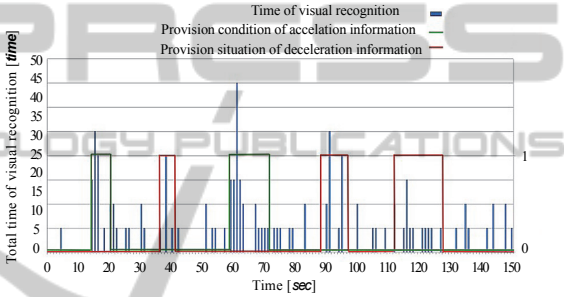

Figure 7: Relation Between Provision Condition of Acceleration/Deceleration Information and Total Time of Visual Recognition.

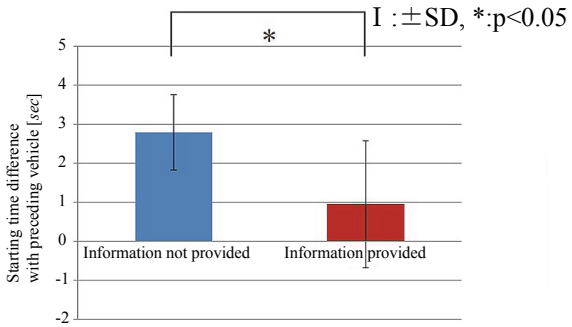

Figure 8: Starting Time Difference with Preceding Vehicle.

shorter by 1.9 seconds compared to that of travels without the provision of information ($p<0.05$). This means that the time difference was further shortened by approximately one second, compared to the result of the previous study by Sato et al. (Saito et al., 2012) in which the start time difference among subject's vehicle and preceding vehicle was shortened by one second when

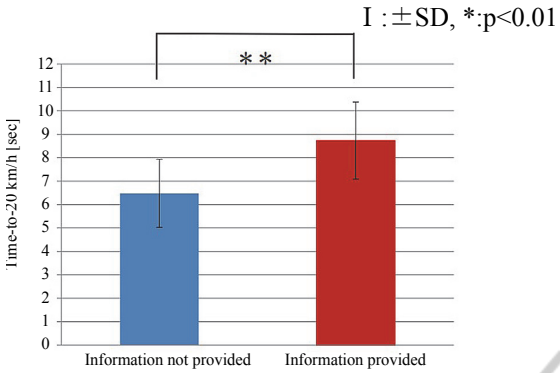

Figure 9: Time-to-20 km/h.

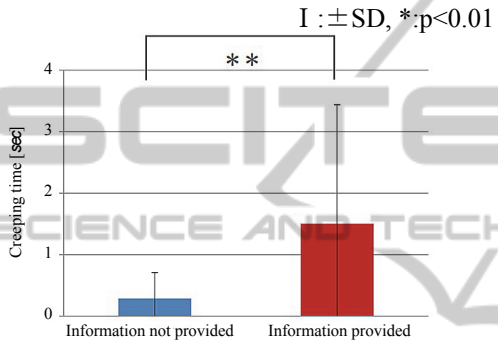

Figure 10: Creeping Time.

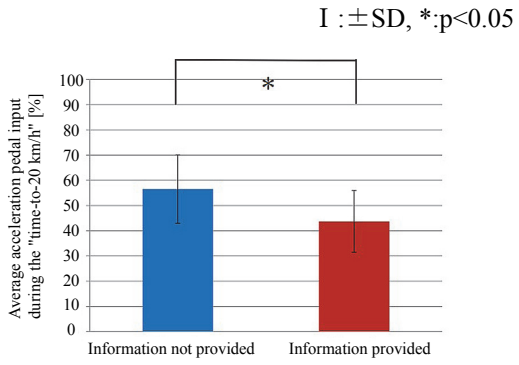

Figure 11: Average Acceleration Pedal Input During the "Time-to-20 km/h".

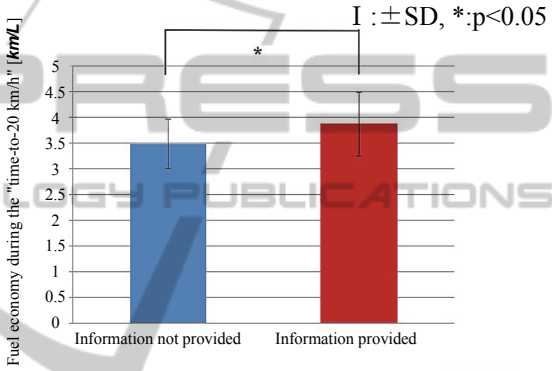

Figure 12: Fuel Economy During the "Time-to-20 km/h".

acceleration/deceleration information was provided. Therefore, it is expected that the operation in the entire traffic flow may be more efficient with the provision of information on both preceding and pre-preceding vehicles, as opposed to the provision of information on the preceding vehicle only.

Secondly, the changes in driving behavior at the startup were analyzed. Eco-driving at the startup includes a soft start with gentle acceleration, called an “e-start”, and a start using the creep phenomenon. To make the "e-start", it is recommended to start moving at a speed of approximately 20 km/h in 5 seconds (The Eco-Drive Promotion Council, 2013). This speed was used as a reference in examining the time from the start until the velocity reached the speed of 20 km/h (hereafter called "time-to-20 km/h") to evaluate the slow movement of vehicles at the start. The result is shown in Figure 9. In total the provision of information extended the "time-to-20 km/h" by 2.1 seconds ($p<0.01$). The average acceleration pedal input during the "time-to-20 km/h" was also examined. As shown in Figure 11, the average accelerate- on pedal input when information was provided was reduced by 22.6% compared to that when there was no information provided ($p<0.05$).

The time from the start until the acceleration pedal was depressed was defined as the "creeping time", and the creeping times for each travel are shown in Figure 10. In this experimental scenario, each trial run has two timings for starting, which come at approximately 14 and 61 seconds after the start of the experiment.

However, if either of the starts was made after an imperfect stop (as in the second travel by subject A, first and second travels by subject B, and first travel by subject F), those travels were excluded from the analysis. As a result, among 24 starts in the travels under information provision, 16 starts were made by creeping after visually recognizing the information on a pre-preceding vehicle. The creeping time was extended by 13 seconds on average ($p<0.01$).

Subsequently, the effect on fuel economy, given by the change in driving behavior under information provision in accelerating area was evaluated. Fuel economy at the time-to-20 km/h in each travel was calculated, and the results are shown in Figure 12.

Information provision improved the fuel economy at the time-to-20 km/h by 7.3% ($p<0.05$). This value is relatively similar to the value of the

fuel consumption reduced by the e-start, which is approximately 10% (The Eco-Drive Promotion Council, 2013), indicating that fuel economy can be comparatively improved solely by the effect of information provision without the necessity of imposing rigorous driving rules.

4 CONCLUSIONS

Recently, many studies have been conducted to assist drivers by providing information on fuel economy of the preceding vehicle as well as safety. However, it has been pointed out that providing information on the vehicle running ahead of the preceding vehicle is also necessary (Hao Yang and Wen-Long Jin, 2014).

Therefore, this study used DS to give a quantitative evaluation of the influence of providing drivers with information on the acceleration/deceleration of the preceding vehicle and the pre-preceding vehicle simultaneously, on fuel economy, visual recognition behaviors and driving behaviors.

As a result, the possibility of an improvement in fuel economy with this information provision was indicated. Additionally, subjects who improved their fuel economy tended to visually recognize the acceleration information of the pre-preceding vehicle more frequently compared to those who reduced their fuel economy. In particular, visual recognition of acceleration information of the pre-preceding vehicle led to earlier detection of the timing to start moving, by approximately 1.9 seconds. Additionally, provision of acceleration information at start-up was confirmed to change the driving behavior to be similar to that of eco-driving, such as an increase in creeping time and a decrease in acceleration pedal input. From above, the effectiveness of provision of information on acceleration/deceleration of a preceding vehicle group to a following vehicle was indicated.

Issues in the future are to enhance data reliability with a larger number of test subjects, and to clarify further the influence of information of the acceleration of preceding and pre-preceding vehicles provided individually on the fuel economy and driving behaviors.

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