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시각적 피드백과 시각-청각적 피드백이 에코 드라이빙과 운전부하에 미치는 상대적 효과

Comparing the Effects of Visual and Visual-auditory Feedback on Eco-driving and Driving Workload

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요 약

최근 차량 내 정보 제공 장비를 통한 에코 드라이빙의 향상이 연료 효율과 안전 운전을 증가시킬 수 있다는 연구들이 보고되고 있다. 그러나 정보의 제공으로 인하여 야기될 수 있는 인지적 부하에 대한 관심은 상대적으로 적은 편이다. 본 연구는 에코 드라이빙을 향상시킴과 동시에 운전자의 운전부하를 최소화 할 수 있는 차량 내 정보 제공 장비의 특성을 확인하기 위해 두(시각vs.시청각) 피드백의 상대적인 효과 차이와 운전 중 상황의 복잡성 수준에 따른 정보 제공방식의 차이가 운전 행동과 운전부하에 미치는 효과를 알아보았다. 본 실험에는 총 38명의 운전자가 참가하였다. 연구 결과, 시각-청각 피드백의 제공이 시각적 피드백을 제공하는 조건에 비하여 에코 드라이빙을 더 향상시키며, 운전부하를 최소화하였다.

핵심어 : 에코 드라이빙, 운전부하, 시각적 피드백, 시각적-청각적 피드백

ABSTRACT

Recent studies have suggested that providing in-vehicle feedback on various driving behaviors promote eco-friendly driving behaviors. However, there was relatively little interest in cognitive overload that can be caused by the provision of information. Thus, the goal of this study was to investigate the relative effects of two types of feedback(visual feedback vs. visual-auditory feedback) to increase eco-driving performance while minimizing driving workload. Also, in this study, the complexity of the driving task was distinguished (secondary vs. tertiary task) in order to reflect the actual driving situation. The study adopted a counterbalancing design in which the two feedback types were delivered in a different order under the two different task conditions. Results showed that providing the visual-auditory feedback was more effective than the visual only feedback in both promoting eco-friendly driving behaviors and minimizing driving workload under both task conditions.

Key words : Eco-Driving, Driving Workload, Visual Feedback, Visual-Auditory Feedback

Ⅰ. Introduction

The Government of the Republic of Korea has set the national greenhouse gas reduction goal at 37% of BAU[1] in 2030 and introduces various policies to implement the policies(Ministry of Environment, 2017). Under these conditions, various solutions such as Eco-driving for greenhouse gas reduction and saving more energies are being introduced. Broadly, eco-driving is a concept that any efforts to reduce greenhouse gas emissions and fuel consumption from changing driving behaviors, machines, vehicles and transportation, but commonly it is defined as increasing fuel efficiency and reducing greenhouse gas emissions by changing driving behaviors(The Korea Transport Institute, 2009).

According to the US Energy Information Administration, transportation accounted for approximately 28% of total energy consumption in 2011, and 34% of CO2 emissions in 2009(U. EIA, 2012). To reduce fuel consumption and greenhouse gas emissions, governments and motor vehicle manufacturers have recently begun to develop eco-IVIS[2] aimed at encouraging more "eco-driving" behavior, which can potentially save up to 25% in fuel consumption(Taniguchi, 2008).

Ⅱ. IVIS for eco-driving and psychological driving workload

1. IVIS for eco-driving

Typically, eco-IVISs provide real-time in-vehicle feedback on various driving processes, such as fuel efficiency, speeding, RPM[3] episodes, and sudden acceleration or breaking. Empirical studies showed that providing in-vehicle feedback about fuel consumption and RPM episodes decreased actual fuel consumption by 5.8% on average(Beusen et al., 2009). Similarly, Boriboonsomsin et al.(2010) reported a 6% decrease in fuel consumption by implementing an eco-IVIS(Boriboonsomsin et al., 2010), and Birrell and Young(2011) also noted that using eco-IVIS promoted safe driving behaviors by reducing the time spent speeding and reducing the number of sudden accelerations(Birrell and Young, 2011).

From a behavioral psychological perspective, eco-IVIS has several advantages in effectively changing driving behaviors. First, the feedback provided by eco-IVIS is immediate. Considering that the effectiveness of feedback is much greater when it is delivered immediately after the behavior rather than delayed(Daniels and Daniels, 2004), eco-IVIS could have a large impact on driving behaviors. Second, eco-IVIS can provide feedback that does not require additional reinforcers. In general, feedback effectiveness is associated with not only the feedback itself but also positive consequences(i.e., reinforcers), such as rewards, praise, and recognition(Alavosius and Sulzer-Azaroff, 1990). However, because driving is essentially a task performed independently, it may be difficult for external parties to provide any contingent consequences. Nevertheless, drivers themselves may perceive some potential reinforcers(e.g., saving gasoline costs) from eco-IVIS even in the absence of extrinsic reinforcers(Beusen et al.,

1) BAU(Business as usual): the normal execution of standard functional operations within an organization
2) IVIS: in-vehicle information systems
3) RPM: revolutions per minute

2009; Lee et al., 2011).

2. Types of eco-IVIS and driving workload

Despite the demonstrated advantages of eco-IVIS, however, researchers have paid little attention to an increase in the driving workload when drivers interact with eco-IVIS. Since driving is a task that requires constant repetition of detection, decision-making, and judgment, providing a large amount of information through eco-IVIS often overwhelms drivers instead, overstepping the human capacity for processing information and resulting in cognitive overload. Considering that nearly 80% of crashes and 65% of near crashes can be attributed to driver distraction and overload(Klauer et al., 2006), the increase in the driving workload should be carefully considered(Jeong and Lee, 2013).

Most prior studies on eco-IVIS provided drivers with visual feedback on their driving performance(Birrell and Young, 2011; Boriboonsomsin et al., 2010), and relatively few studies examined different modality of eco-IVIS. For instance, Azzi et al.(2011) demonstrated the effectiveness of haptic on eco-driving and the results indicated that providing haptic feedback has same effects on eco-driving as visual feedback(Azzi et al., 2011).

Similarly, existing eco-IVIS systems developed by car manufacturers mainly provide visual feedback to drivers. For example, Mercedes-Benz’s Eco Display in the instrument cluster analysis individual driving styles and provides visual information on how drivers can reduce fuel consumption. Also BMW’s Eco Pro is designed for boosting more eco-friendly behaviors by adjusting engine efficiency and provides visual information to drivers how further they can drive more from saving energy consumption on the dash board.

One advantage of visual feedback is that it can provide the same amount of information much faster than auditory feedback. For example, whereas auditory information must be provided in a particular sequence, visual feedback can provide several pieces of information on a screen at the same time. However, considering that drivers largely rely on vision for driving-related information, more visual information from eco-IVIS can lead to attentional overload(Liu, 2001), and providing multimodal feedback can reduce visual distraction while driving(Jamson et al., 2015).

According to multiple resource theory, to the extent that two or more tasks involve the same modality, a person’s workload will increase due to the increased demand for common perceptual resources(Wickens, 2002). However, if information is given across multiple modalities, the demand for perceptual resources will be distributed in a way that minimizes the increasing workload. The meta-analysis by Burke supported this assertion by showing that multimodal feedback(e.g., visual-auditory feedback) was more effective than single-modal feedback(e.g., visual feedback only) in terms of both performance and workload(Klauer et al., 2006).

However, most prior studies on eco-driving have merely focused on improving the participants’ driving performance, paying little attention to the different types of feedback that can enhance performance without significantly increasing workload. Therefore, the present study examines the relative effects of two in-vehicle feedback types, visual and visual-auditory, on eco-driving and workload. Furthermore, considering the recent increase in the use of HMI[4](e.g., navigation, entertainment system, safety guidance) systems in vehicles(Rouzikhah

4) HMI: human machine interface

et al., 2013), the study also attempted to investigate the effects of using an in-vehicle HMI system in addition to the eco-IVIS. Thus, the effects of the eco-IVIS only(secondary task condition) and both the eco-IVIS and a navigation system(tertiary task condition) on eco-driving performance and mental workload were compared.

Ⅲ. Research method

1. Participants and Settings

Thirty-eight adults(26 males, 12 females) participated in the study. Their mean age was 27(SD=2.5), and the average number of months of driving experience was 69(SD=28.4). A Chevrolet Spark 2005 was used in the study, with an official fuel efficiency of 13.3 km/l. During the study, the participants drove on the roads and highways of the capital city of South Korea, for a total of 20.7km and an average driving time of 32(SD=4) minutes.

In order to control the external environment that can directly influence the dependent variables of the study(see 2.2. dependent variables and measurement), the experiment took place during non-rush hours between 10am and 4pm on the same driving course of total 20.7km only on non-rainy (or non-snowy) days. Also, we did not carry out experiments on days when there were unusually more vehicles on the road due to accidents, breakdowns, and construction work.

2. Dependent variables and measurement

The dependent variables included objective eco-driving behaviors and subjective ratings of workload. Three types of driving performance were assessed for this study: the mean fuel efficiency, the frequency of excessive RPM episodes, and the percentage of speeding time. Mean fuel efficiency was defined as the average kilometers driven per one liter of gas. An excessive RPM episode was defined as a time when the engine exceeded 3000RPM, which indicated extreme acceleration. These two variables were automatically recorded using a EW200BT device connected with an OBD-II cable. Lastly, speeding was defined as exceeding the posted speed limit of any road, and the time percentage of speeding was obtained using the following formula:[(speeding time / total driving time) × 100]. To measure the percentage of time speeding, a research assistant sat in the back of the car and recorded the duration of time that a driver exceeded the legal limit. The average speed limit of the roads and highways driven in the study was 72.1km/h.

The Driver Activity Load Index(DALI[5]) was used to rate the participants' subjective ratings of driving workload(Pauzié, 2000). The level of driver's workload is linked to the difficulty of the task he experienced, and to his choice of strategies between the effort and performance trade-off(Zeitlin, 1995). DALI is a revised version of the NASA-TLX[6], which measures mental workload generally. While the method of scoring and the anchors of the survey items remained the same as in the NASA-TLX, the content of the DALI is more specific to the driving task and measures six factors: effort of attention, visual demand, auditory demand, temporal demand, interference, and

5) DALI: the driver activity load index
6) NASA-TLX: nasa's task load index

situational stress. To determine the overall DALI score, each participant performed a total of fifteen pair-wise comparisons between the six factors to assign a weight to each factor. Next, they rated the perceived magnitude of the workload for each factor on a scale from 0 to 100 after completing a given driving task. Based on the responses to the pair-wise comparisons, the ratings that were deemed more important were given more weight, and the weighted ratings for each factor were computed by multiplying them together. The sum of all weighted ratings was then divided by 15(the total number of pair-wise comparisons) to obtain an overall workload score(range=0 to 100).

3. Independent variables and procedure

There were two independent variables in the current study: the type of in-vehicle feedback and the task condition. For the type of feedback, visual feedback and visual-auditory feedback were compared; specifically, the sole difference was whether feedback information on driving performance was given only visually, or both visually and aurally. In addition, the study attempted to compare the relative effects of the two driving task conditions, secondary task and tertiary task conditions, on the driving workload. In the secondary task condition, the car was equipped with the eco-IVIS only, whereas in the tertiary task condition, it was equipped with both the navigation system and the eco-IVIS. The study adopted an ABC/ACB counterbalancing design whereby a within-group factor was feedback type and a between-groups factor was task condition. Thus, after the baseline, the participants who were assigned to the secondary task condition completed the driving with visual feedback, followed by visual-auditory feedback. On the contrary, participants who were assigned to the tertiary task condition completed the visual-auditory feedback phase first. Each experimental phase was carried out for one week.

Baseline. During the baseline, three driving behaviors and workload were measured prior to the implementation of the eco-IVIS. Before starting the baseline drive, the participants were given 5 minutes to become familiar with the car. Nineteen participants engaged in the secondary task condition, and the other half participated in the tertiary task condition. In the secondary task condition, the research assistants provided a detailed description of the entire driving course, whereas in the tertiary task condition, the participants were provided with no information about the driving course but were able to use the navigation tool. All of the participants drove the same driving course. Immediately after completing the baseline drive, the participants completed the DALI questionnaire.

Visual feedback phase. Before starting the feedback phases, the participants were taught how to interpret the visual or visual-auditory feedback provided by the eco-IVIS. In the visual feedback phase, the participants received only visual feedback while driving the same course they drove during baseline. The EW200BT was used to visually show information about speeding, excessive RPM episodes, and fuel efficiency in real time throughout the course of driving <Fig. 1>. For speeding, if the participant exceeded the speed limit, the bars and the current speed (displayed as a number) on the left side of the screen turned red. Similarly, when the instant RPM number exceeded 3000, the color of the RPM bars on the top right turned red. The information about mean fuel efficiency was delivered on the bottom left of the screen. All other experimental procedures were the same as in the baseline. The participants completed the DALI questionnaire upon completing the driving task.

Visual-auditory feedback phase. In the visual-auditory feedback phase, the participants were asked to engage in the same driving task, but with the additional auditory feedback. Auditory feedback was provided in the following ways: when their driving speed exceeded the legal limit, the participants heard, “Please slow down”; when the instant RPM exceeded 3000, they heard, “Please accelerate slowly.” Since information about fuel efficiency could not be given aurally, feedback on fuel efficiency was only provided visually.

〈Fig. 1〉 Interface providing visual feedback

4. Interobserver Agreement (IOA)[7)]

To assess interobserver agreement(IOA) on the time spent speeding, two research assistants independently observed 46% of the total driving tasks. The IOA was obtained by comparing the speeding time observed by two research assistants using the following formula:[IOA = Smaller speeding time / Larger speeding time × 100]. The mean IOA for speeding time was 92%. The IOA for the remaining two behaviors(i.e., frequency of excessive RPM, mean fuel efficiency) were not assessed because they were automatically recorded by the in-vehicle measurement system.

Ⅳ. Results

1. Driving performance

<Table 1> illustrates the average fuel efficiency, percentage of speeding time, and frequency of excessive RPM. To assess the significance of the mean differences across the experimental conditions, a repeated measures of ANOVA[8)] was conducted.

〈Table 1〉 Means and standard deviations of eco-driving variables

	Variable	Baseline	Visual	Visual-auditory
Secondary Task	Fuel efficiency (km/l)	*M*=6.88 (*SD*=0.54)	*M*=7.84 (*SD*=0.40)	*M*=8.16 (*SD*=0.38)
	Frequency of excessive RPM episodes	*M*=23.05 (*SD*=15.19)	*M*=4.74 (*SD*=2.84)	*M*=2.74 (*SD*=3.40)
	Percentage of speeding time	5.49 (*SD*=3.88)	1.44 (*SD*=1.27)	1.77 (1.64)
	Variable	Baseline	Visual-auditory	Visual
Tertiary Task	Fuel efficiency (km/l)	*M*=6.70 (*SD*=0.46)	*M*=8.32 (*SD*=0.40)	*M*=7.96 (*SD*=0.50)
	Frequency of excessive RPM episodes	*M*=22.37 (*SD*=12.23)	*M*=2.21 (*SD*=1.62)	*M*=4.11 (*SD*=3.50)
	Percentage of speeding time	*M*=6.87 (*SD*=4.33)	*M*=3.68 (*SD*=7.54)	*M*=1.17 (*SD*=1.15)

7) IOA: Interobserver Agreement
8) ANOVA: analysis of variance

〈Table 2〉 Pair-wise comparisons of each experimental phase for both the secondary and tertiary task conditions

	Variable	Comparison	MD[4]	SE[5]	*P*
Secondary task	Fuel efficiency (km/l)	a[1] vs. b[2]	-0.96	0.17	0.000
		a vs. c[3]	-1.28	0.10	0.000
		b vs. c	-0.32	0.15	0.045
	Frequency of excessive RPM episodes	a vs. b	18.32	3.55	0.000
		a vs. c	20.32	3.29	0.000
		b vs. c	2.00	0.90	0.039
	Percentage of speeding time	a vs. b	4.05	0.93	0.000
		a vs. c	3.72	1.00	0.002
		b vs. c	-0.33	0.41	0.432
Tertiary Task	Fuel efficiency (km/l)	a vs. b	-1.63	0.13	0.000
		a vs. c	-1.26	0.15	0.000
		b vs. c	0.36	0.15	0.022
	Frequency of excessive RPM episodes	a vs. b	20.16	2.75	0.000
		a vs. c	18.26	2.91	0.000
		b vs. c	-1.90	0.87	0.042
	Percentage of speeding time	a vs. b	3.20	2.17	0.158
		a vs. c	5.71	0.96	0.000
		b vs. c	2.51	1.68	0.152

Note. 1): a=baseline phase, 2) b=visual feedback phase, 3)c=visual-auditory feedback phase, 4) Mean Difference, 5) Standard Error

The results showed significant mean differences on fuel efficiency in both the secondary task($F(2,36)=42.65$, $P<0.001$) and in the tertiary task($F(2,36)=70.74$, $P<0.001$). In addition, the pair-wise comparisons revealed that when the participants were provided with either type of feedback(visual or visual-auditory), fuel efficiency in both task conditions was significantly higher than in the baseline<Table 2>. Further, the mean fuel efficiency in the visual-auditory feedback phase was significantly higher than in the visual feedback phase in both task conditions.

Similarly, the significant main effect of feedback type was found for the mean frequency of excessive RPM episodes in both the secondary task($F(1.10,19.71)=30.97$, $P<0.001$) and the tertiary task($F(1.14,20.47)=44.45$, $P<0.001$) conditions. The pair-wise comparisons revealed that providing feedback produced fewer episodes of excessive RPM compared with the baseline in both task conditions. In addition, visual-auditory feedback was found to produce fewer episodes of excessive RPM compared with visual feedback in both task conditions.

With respect to the speeding time, a significant main effect across the three experimental phases was also found both in the secondary task($F(1.27,22.78)=14.87$, $P<0.001$) and in the tertiary task($F(1.25,22.53)=5.82$, $P<0.05$) conditions. The pair-wise comparisons for the percentage of speeding time revealed that providing both types of feedback resulted in significantly less speeding behavior in both task conditions, with an exception where visual-auditory feedback provided in the tertiary task condition did not result in a significant decrease of speeding. On the other hand, between the feedback types, there were no significant differences in the percentage of speeding time in both task conditions.

2. Driving workload

<Table 3> illustrates the means and the standard deviations of the DALI scores across the three experimental phases in the secondary and tertiary task conditions. While the total DALI score increased from the baseline when visual or visual-auditory feedback was delivered, the visual-auditory feedback resulted in the highest DALI in both task conditions.

The ANOVA results showed a significant in the secondary task condition($F(2,36)=10.50$, $P<0.001$), and a moderate main effect in the tertiary task condition($F(2,36)=2.95$, $P<0.10$). When the total DALI scores were compared between the three experimental phases in the two task conditions<Table 4>, the total DALI scores in both feedback phases were significantly higher than those in the baseline, with the exception of a moderate difference between the baseline and visual feedback phase in the tertiary task condition($P<0.1$). However, the study found no significant differences in workload between visual and visual-auditory feedback in both task conditions.

〈Table 3〉 Means and standard deviations of DALI scores

	Secondary task			Tertiary task		
	Baseline phase	Visual feedback phase	Visual-auditory feedback phase	Baseline phase	Visual feedback phase	Visual-auditory feedback phase
EA	*M*=55.00 (*SD*=23.21)	*M*=72.37 (*SD*=17.82)	*M*=67.67 (*SD*=22.26)	*M*=70.79 (*SD*=21.81)	*M*=73.68 (*SD*=19.64)	*M*=77.63 (*SD*=15.58)
VD	*M*=62.11 (*SD*=24.46)	*M*=77.11 (*SD*=22.44)	*M*=72.89 (*SD*=16.10)	*M*=77.11 (*SD*=16.86)	*M*=81.32 (*SD*=18.55)	*M*=86.05 (*SD*=15.14)
AD	*M*=36.32 (*SD*=22.54)	*M*=32.63 (*SD*=18.51)	*M*=60.53 (*SD*=25.16)	*M*=51.32 (*SD*=22.54)	*M*=61.05 (*SD*=18.90)	*M*=45.26 (*SD*=17.99)
TD	*M*=24.21 (*SD*=20.16)	*M*=28.21 (*SD*=20.50)	*M*=36.84 (*SD*=26.05)	*M*=34.47 (*SD*=29.24)	*M*=26.05 (*SD*=19.33)	*M*=39.74 (*SD*=23.12)
IF	*M*=26.84 (*SD*=21.81)	*M*=50.53 (*SD*=28.52)	*M*=53.42 (*SD*=28.09)	*M*=19.21 (*SD*=20.50)	*M*=31.31 (*SD*=19.50)	*M*=32.90 (*SD*=29.72)
SS	*M*=37.89 (*SD*=28.05)	*M*=55.79 (*SD*=29.40)	*M*=55.00 (*SD*=29.48)	*M*=30.00 (*SD*=27.88)	*M*=39.21 (*SD*=27.60)	*M*=35.00 (*SD*=29.72)
Total	*M*=45.02 (*SD*=18.64)	*M*=63.48 (*SD*=11.20)	*M*=65.52 (*SD*=14.63)	*M*=55.86 (*SD*=13.36)	*M*=65.98 (*SD*=13.80)	*M*=63.97 (*SD*=11.34)

Note. EA=effort of attention; VD=visual demand; AD=auditory demand; TD=temporal demand; IF=interference; SS=situational stress; Total=total DALI score

〈Table 4〉 Pair-wise comparisons of each experimental phase for total DALI scores

	Variable	Comparison	MD[4]	SE[5]	P
Secondary Task	Total DALI Score	a[1] vs. b[2]	-18.46	4.79	0.001
		a vs. c[3]	-20.51	5.58	0.002
		b vs. c	-2.05	4.34	0.643
Tertiary Task	Total DALI Score	a vs. b	-8.11	4.50	0.088
		a vs. c	-10.12	3.80	0.016
		b vs. c	-2.01	4.86	0.684

Note. 1): a=baseline phase, 2) b=visual feedback phase, 3)c=visual-auditory feedback phase, 4) Mean Difference, 5) Standard Error

The total DALI scores in the two task conditions in each experimental phase were also compared. The mean baseline DALI score in the tertiary task condition was significantly higher than that in the secondary task condition($t(36)=-2.06$, $P<0.05$). However, the scores in both visual($t(36)=-0.13$, $p>0.05$) and visual-auditory feedback($t(36)=-0.10$, $P>0.05$) phases showed no significant differences.

Ⅴ. Discussion and Conclusion

1. Driving performance

The present study demonstrated positive effects of in-vehicle feedback system on eco-driving. While both visual and visual-auditory feedback had considerable effects in increasing the fuel efficiency and decreasing the RPM episodes and speeding time, adding the auditory feedback to the visual feedback did produce further increases in the fuel efficiency and decreases in the excessive RPM episodes. However, the visual-auditory feedback did not have greater advantages in reducing speeding time compared to the visual only feedback. Despite this, the study still suggests the superior effects of the visual-auditory feedback over the visual only feedback on several grounds. According to Young et al.(2011), decreasing excessive RPM episodes is critical in decreasing fuel consumption. The results clearly showed that the visual-auditory feedback was more effective than the visual feedback in decreasing excessive RPM episodes. More importantly, the present study also demonstrated that the clear advantage of the visual-auditory feedback over the visual feedback in increasing fuel efficiency, which can be a more direct contributing factor to fuel saving.

2. Driving workload

With respect to workload, the results from the current study revealed that the total workload significantly increased when either type of feedback was provided in both secondary and tertiary task conditions. However, there were no significant differences in the total workload between visual and visual-auditory feedback. These results support Multiple-resource theory that asserts providing information across different sensory modalities can minimize overall workload build-up, because the workload can be distributed across the different sensory modalities. Specifically, the results of the secondary task condition showed the increase in visual demand when the visual feedback was provided. When the visual-auditory feedback was provided, however, visual demand rather decreased while auditory demand increased<Table 3>. The same opposite trend was found in the tertiary task condition. Thus, adding the auditory feedback to the visual feedback did not result in a significant increase in the overall workload.

When the two task conditions(secondary task group vs. tertiary task group) were compared during the baseline phase, the participants in the tertiary task condition perceived a higher workload compared to those in the secondary task condition. This finding is consistent with the previous studies demonstrating the increase of driver workload when using navigation systems. However, the mean total DALI scores were not significantly different between the two task conditions in both feedback phases, despite the fact that more driving-related information was provided in the tertiary task condition. Thus, adding the navigation system to the eco-IVIS did not further increase driver workload.

3. Conclusions and limitation

The data presented in the current study suggests that providing visual-auditory feedback through the eco-IVIS, compared to visual only feedback, is a more effective way in terms of both promoting eco-friendly driving behaviors and maintaining driving workload minimal. Based on the results of this study, IT/SW engineers related to automobiles are able to consider how to maximize the driving performance along with considering minimizing the human cognitive overload[9] when designing IVIS and dashboard. Future researches need to develop better human-machine technology to maximize human performance through collaboration works between IT/SW engineers and psychologists.

However, there are several limitations in the present study and caution is warranted. One of the limitation is the fact that all of the three driving performance might have been influenced by traffic conditions. Although we chose non-rush hours for the experimental sessions throughout the experiment, traffic conditions could not be identical across all the experimental conditions. Furthermore, the driving time for each experimental session was relatively short, which was only 32 minutes on average; such a short driving time suggests that the traffic conditions might have exerted a large influence on the driving performance. Another limitation of this study is length of driving time to fully demonstrate drivers' workload while driving. In this study, the average driving distance for each participant was 20.7km to complete driving course in average which might not sufficient to demonstrate changing of drivers' workload. Considering that driving distraction would be evoked when overstepping the human capacity of processing from large amount of information by Eco-IVIS or long time of driving, future study needs to be conducted in highways or express ways with longer length of experiment time. Therefore, future studies need to be conducted in more controlled settings. Another limitation of this study is the fact that there was no auditory feedback provided concerning fuel efficiency. Since fuel efficiency tends to be an indicator that is most reflective of fuel saving, drivers could have paid greater attention to fuel efficiency than to other information provided as feedback. Therefore, the absence of auditory feedback on fuel efficiency could have made the drivers depend more on the visual feedback. Also the eco-IVIS in this study was designed to deliver informative feedback only. Prior study of using auditory feedback to promote eco-driving suggested that level of eco-driving performance could vary depending on the different contents of feedback(Joo and Lee, 2014). Similarly, studies from the field of behavior analysis emphasized that feedback contents need to be considered since the effectiveness of feedback can be changed depending on its different contents such as positive feedback or negative feedback. Thus future studies need to examine which contents of feedback is more effective on driving performance.

Lastly, because the participants used the car designated for an experimental purpose, they may have not been as motivated to decrease fuel consumption. Future studies that look at drivers' behavioral changes in daily lives would be necessary to further demonstrate the relationship between feedback and eco-driving behavior.

Also, in this study, we examined the relative effects of different types of feedback mechanisms provided from particular in-vehicle information system, the various ways to deliver information such as different types of contents, frequency, design, and salience might not be sufficiently considered. Thus future studies need to be considered various characteristics of delivering information to change driving behaviors.

9) Human cognitive overload: workload, disturbance and drowsiness

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