Effect of advanced driver assistance systems on driving style and fuel economy

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Abstract

It is known that driving style is highly correlated with safety and fuel economy. In general, drivers who have moderate driving style shows safer driving behavior than aggressive drivers, and they may achieve higher fuel efficiency than their aggressive counterpart. Some previous studies found forward collision warning systems supported to change driving style toward safer behavior. However, their potential benefit of improving fuel economy was not clearly evaluated.

This paper aims to analyze the effect of the advanced driver assistance systems (ADAS) on driving style and fuel economy using field operational test data from 52 participants. A half of participants were supported by ADAS and the others were not supported. Each participant drove approximately 5.5 km of rural road (about 10 minutes), 6.2 km of urban road (about 25 minutes) and 9.6 km of highway (about 10 minutes). The results suggested that there has been significant interaction between ADAS and gender on driving style, and consequently ADAS supported younger male drivers' improvement in fuel efficiency was observed.

Keywords: Fuel Efficiency, Driving Style, Forward Collision Warning (FCW), Field Operational Test (FOT), Advanced Driver Assistance Systems (ADAS)

Introduction

A recent report from World Health Organization indicated that annually 1.24 million people die due to traffic crashes [1]. Thus, governments, industries and non-governmental organizations have implemented many operational strategies, educational campaigns, enforcements, and technology-equipped vehicles. In the technology-equipped vehicle perspective, numerous studies have reported positive effects of the Advanced Driver Assistance Systems (ADAS) on safer driving style. Results from the studies suggested that meaningful improvements in driving safety behavior were observed [2-5]. For example, Son et al. suggested that the ADAS supported male drivers significantly increased the time headway safety margin [2].

On the other hand, it is known that driving style is highly correlated with fuel efficiency as well as driving safety. Thus, it was expected that the ADAS-induced changes in driving style could affect fuel efficiency. Cleaves *et al*. found that the fuel consumption varies according to driving pattern and suggest the eco driving style [6]. Klunder *et al*. also suggested that changing driving style may increase the fuel efficiency up to 20% with relatively lower cost comparing with other factors [7]. Birrell *et al.* successfully demonstrated real-world improvements in fuel efficiency and safe driving behavior when using an in-vehicle eco driving application [3].

The objective of this research is to investigate the effects of the ADAS on driving safety behavior and fuel efficiency. The interaction effect among age, gender and roadway environment was also considered.

Method

Participants

As shown in Table 1, 52 drivers were participated and they met the following criteria: drive on average more than twice a week for three years or longer, be in self-reported good health to participate in the three-hour driving experiment, and free from major medical conditions. The younger drivers' ages were ranged from 25 to 35, and late middle ages were from 55 to 65.

Experimental setup

The on-road driving experiment was conducted in an instrumented passenger car (engine displacement: 3,300cc) which was designed to collect driving information (vehicle speed, engine speed, engine load, steering wheel angle, real-time fuel consumption, etc.), GPS, driver's eye movement (gaze position, blinking, etc), physiological data (electrocardiogram, skin conductance level, etc), and videos for driver views (driver's face and pedal behavior) and surroundings views (front, back, left and right sides) [8].

Table 1. Participants overview

	Younger		Late middle age	
Gender	Male	Female	Male	Female
# Subject	13	13	13	13
Age*	27.54 (2.90)	30.46 (3.10)	60.69 (1.89)	57.08 (2.06)

* Note. Means with standard deviations

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All data was synchronized with the master time that was transmitted by the monitoring software at every 10ms. The vehicle running information including fuel consumption was collected from CAN communication data.

To provide the ADAS services, Mobileye C2-170, an aftermarket Advanced Driver Assistance System, was used [9]. The ADAS display unit was attached on the upper left corner of the windshield to minimize visual obstruction. Consequently, the audible warning was a primary form of the ADAS alert. When the ADAS was not used for the experiment, i.e. non-supported group, the display unit was off and folded.

Procedure and road condition

An experimental procedure was designed and conducted to analyze the effect of the ADAS on driving styles and fuel efficiency. The overall experiment procedure consists of two sessions: pre-experiment and main experiment. In the pre-experiment session, following informed consent, participants completed safety questionnaire to ensure their ability for safe driving. Then, participants spent about 20 minutes for adapting on the instrumented car by driving on a rural road and an urban road.

The main driving experiment session began when a participant was confident in driving the instrumented vehicle safely. In the main experiment session, each participant drove on a pre-defined driving road that contained approximately 5.5 km of rural road (about 10 minutes) with one lane per direction, 6.2 km of urban road (about 25 minutes) with two to four lanes per direction, and 9.6 km of highway (about 10 minutes) with divided two lanes per direction. The posted speed limits of the rural road, the urban road and the highway were 70 km/h, 60 km/h and 100 km/h, respectively.

To help participants keep their own driving style, the experiments were conducted at off-peak time, i.e., 11:00 to 11:30 in the morning and 3:30 to 4:00 in the afternoon, under relatively low traffic condition. Typical traffic situations on each road segment during the experiments were shown in Fig. 1.

Driving style measures and analysis

Human factors in driving can be classified into two separate components, i.e., driving skills (or driving performance) and driving style (or driver behavior) [10]. Driving style refers to the ways drivers choose to habitually drive, for example, the choice of driving speed, habitual level of general attentiveness, and gap acceptance [11]. In this perspective, the time headway and the average speed were considered to analyze the effect of driving behaviors on the fuel efficiency.

The ADAS provided the time headway via CAN bus, and the vehicle speed and the fuel consumption were received from the engine management system of the instrumented vehicle. The three variables were averaged across roadway types

(a) Rural road

(b) Urban road

(c) Highway

Figure 1. Typical traffic scenes

Results

A mixed ANOVA (analysis of variance) were conducted to analyze drivers' behavioral changes and the effects of improvements in fuel efficiency. Table 2 shows the descriptive statistics of the driving style variables and fuel efficiency, while the statistical analyses results was described in Table 3.

As shown in Table 3, a mixed ANOVA yielded a main effect for the gender ($p < .05$) was significant on the fuel efficiency, but the main effects of the ADAS and the age were not significant. The interaction effect among ADAS, age and gender was significant on fuel efficiency ($p < .05$), indicating that the gender effect was greater in male participants than in female.

For driver behavior measures, the interaction effect between ADAS and gender was also significant on the average time headway (TH) ($p < .05$), indicating the gender effect was greater in the ADAS supported condition than in the non-supported condition

Table 2. Effects of the FCW on drivers' behavior and fuel efficiency by age, gender and roadway

		Experimental (FCW: On/Off)		
		Fuel Efficiency (km/*l*)	TH (sec)	Speed (kph)
ADAS ON	AGE			
	Younger	8.49 (1.48)	1.36 (0.37)	51.33 (27.77)
	LMA	8.67 (1.47)	1.41 (0.41)	49.82 (26.71)
	GENDER			
	Male	8.54 (1.56)	1.45 (0.40)	50.79 (27.53)
	Female	8.62 (1.38)	1.31 (0.37)	50.37 (26.98)
	ROAD			
	Highway	10.17 (0.58)	1.75 (0.22)	85.82 (3.47)
	Rural	8.73 (0.60)	1.44 (0.27)	44.83 (3.30)
	Urban	6.85 (0.46)	0.96 (0.11)	21.09 (2.34)
ADAS OFF	AGE			
	Younger	8.52 (1.40)	1.35 (0.39)	52.64 (29.72)
	LMA	8.72 (1.63)	1.39 (0.43)	48.49 (25.91)
	GENDER			
	Male	8.41 (1.50)	1.36 (0.40)	50.62 (28.54)
	Female	8.83 (1.51)	1.38 (0.43)	50.51 (27.36)
	ROAD			
	Highway	10.22 (0.84)	1.75 (0.26)	86.43 (6.98)
	Rural	8.73 (0.48)	1.41 (0.30)	44.47 (4.79)
	Urban	6.90 (0.58)	0.95 (0.14)	20.81 (2.71)

Note. Average with standard deviation in parentheses

Table 3. ANOVA table for drivers' behavior and fuel efficiency

	df	F-ratio		
		Fuel Efficiency (km/*l*)	TH (sec)	Speed (kph)
Between Subjects Effects				
ADAS	1,44	0.157	0.04	0.002
Age	1,44	3.686	1.962	**17.99*****
Gender	1,44	**5.68***	2.666	0.31
ADAS x Age	1,44	0.072	0.123	4.073
ADAS x Gender	1,44	2.99	**6.042***	0.008
Age x Gender	1,44	0.869	3.983	0.091
ADAS x Age x Gender	1,44	**6.762****	0.578	1.42
Within Subjects Effects				
Road	2,88	**163.985*****	**596.709*****	**4551.849*****
Road x ADAS	2,88	0.042	0.091	0.253
Road x Age	2,88	1.018	**4.199***	**9.78*****
Road x Gender	2,88	**4.018***	0.179	1.562
Road x ADAS x Age	2,88	1.133	**3.296***	**3.585***
Road x ADAS x Gender	2,88	0.093	0.368	0.456
Road x Age x Gender	2,88	0.703	2.405	1.318
Road x ADAS x Age x Gender	2,88	0.423	0.643	1.284

$^{***}p < .001$, $^{**}p < .01$, $^{*}p < .05$

A mixed ANOVA indicated that the roadway environment has a significant main effect (see details in Table 3) on the fuel efficiency, suggesting that the fuel efficiency was significantly higher for highway than for rural and urban.

Although the interaction effects among ADAS, roadway and age were significant on the time headway ($p < .05$) and the average speed ($p < .05$), there was no significant interaction effect on fuel efficiency.

Discussion and Conclusions

Results from this study did not suggest that the ADAS gave a positive effect on the overall fuel efficiency. However, the interaction effect among the ADAS, gender and age was significant on the fuel efficiency, indicating that the younger male drivers have shown improvement in fuel efficiency under the ADAS supported condition.

The positive effect on the younger male drivers was contributed by the increased mean headway of the ADAS supported male drivers. There have been a few studies investigating drivers' behaviors on maintaining time headways. Without the ADAS or a smart warning system, a study found that participants spent an average of 6.61% of the entire journey under 1.5s [3]. Another study found that drivers spent 42.2% of their driving time at headways less than 1s [5]. This large variation between these two studies could have been stemmed from the roadway environment factors such as traffic density and posted speed limit.

As this study found that the gender difference in the effect of the FCW was significant on fuel efficiency, the parameters of the ADAS such as a forward collision warning threshold, need to be set by considering gender characteristics to improve the safety and fuel economy.

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