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The effect of age, gender and roadway environment on the acceptance and effectiveness of Advanced Driver Assistance Systems

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ABSTRACT

The purpose of this paper was to investigate the effect of age, gender and roadway environment on the acceptance as well as effectiveness of the Advanced Driver Assistance Systems (ADAS). Better understanding on the age and gender differences in technology acceptance and effectiveness toward the ADAS on various roadways could help encourage drivers' use of new technology for safe driving. In this study, 52 drivers participated in on-road field experiments with or without the ADAS providing a forward collision warning and a lane departure warning. Each participant drove approximately 5.5 km of rural road (about 10 min), 6.2 km of urban road (about 25 min) and 9.6 km of highway (about 10 min). Upon completion of these driving sessions, the ADAS-supported group participants (half of all participants) responded to questionnaire. Field experiment results showed that there were significant age and gender differences in the acceptance and effectiveness of the ADAS and the roadway environment affected the effectiveness of the ADAS. Findings from this study indicated that it is essential to assess age and gender differences in effectiveness and acceptance of new in-vehicle technology for avoiding unexpected negative effects on a certain age and gender segment.

1. Introduction

With ever-increasing number of vehicles on the road, societies have faced with significant challenges in congestion, fuel consumption, emissions and traffic crashes. Among these, safety is a key area needing significant attention. A recent report from World Health Organization (2013) indicated that annually 1.24 million people die due to traffic crashes. The US alone has over 33,000 people died in motor vehicle crashes in 2012 and its cost was close to 1 trillion dollars in loss of productivity and loss of life (Rocky Mountain Insurance Information Association (RMIIA) (n.d.)). To address the safety challenge, governments, industries and non-governmental organizations have implemented many operational strategies, educational campaigns, enforcements, and technology-equipped vehicles. These include providing rational speed limit, promoting educational campaign, and implementing enforcement (Son, Fontaine, & Park, 2009), implementing variable speed limit (Lee,

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Dailey, Bared, & Park, 2013; Park & Yadlapati, 2003), establishing roadway geometry design guidelines (AASHTO, 2011), promoting educational campaign, investing advanced technologies into automobiles such as anti-lock braking system and electronic stability control.

Studies have shown that traffic crashes are mainly due to interactions among drivers, vehicles and roadways. As such, research should consider all three elements and their interactions. This research considers Advanced Driver Assistant Systems (i.e., Forward Warning System and Lane Departure Warning System) equipped in an instrumented vehicle that help assure drivers' attention. While it is important to consider age, gender and roadway conditions together, existing literature indicates studies have not considered full interactions of age, gender and roadway conditions in the evaluation of ADAS.

1.1. Effect of age, gender and roadway environment on driving behavior

Despite older drivers' diminished capacity, driving judgment increases with experience and age that may compensate for decreased capacity (Reimer et al., 2008). However, they sometimes fail with severe consequences, in situations producing very high momentary mental workload (Hakamies-Blomqvist, Mynttinen, Backman, & Mikkonen, 1999; Harms, 1991). In general, not all older drivers are unsafe, and driving capability is very important for maintaining the independence of elderly adults, especially for those who live in rural or remote area (Anstey, Wood, Lord, & Walker, 2005). However, older drivers have shown higher crash rates than other age groups except teenagers and the increased risk is associated with degradations in cognition, vision and physical functions (Anstey et al., 2005). Reimer, Mehler, Coughlin, Roy, and Dusek (2011) and Son et al. (2010) reported older drivers showed significant degradation in maintaining speed under cognitive secondary workload compared to the younger drivers, as expected based on age related declines in cognitive capacity (McDowd, Vercruyssen, & Birren, 2003; Rogers & Fisk, 2001). Lam's (2002) finding that older drivers are more likely to be susceptible to the effects of distraction than younger drivers supported age had affected the relationship between distractions and the risk of crash injury.

In gender differences, Özkan and Lajunen (2006) found that gender is influential in expressing their general driving style. Risky driving style increased as a function of masculinity and being male whereas femininity decreased risky behavior. Turner and McClure (2003) also suggested that gender and age are significantly associated with drivers' aggression and high-risk acceptance. It may be related to difference in social influence and confidence in driving skill. D'Ambrosio et al. (2008) suggested that women reported lower levels of confidence in their driving skills than men. Lesch and Hancock (2004) also indicated that age and gender had different implications on confidence and the associated performance of driving while subjects were being distracted.

Researchers have studied on the relationship between the roadway complexity and driving performance. Horberry, Anderson, Regan, Triggs, and Brown (2006) found that older drivers drove at overall lower average speed in complex road environment with larger speed variation. Son, Lee, and Kim (2011) reported that older drivers were affected by road complexity. For example, the effect of the cognitive distraction was relatively higher in an urban road than a highway.

While studies have shown effects of age, gender and roadway environment, none of these studies explored the effects of all three factors.

1.2. Effectiveness of Advanced Driver Assistance Systems (ADAS)

Previous studies have discussed the Advanced Driver Assistance Systems (ADAS) could provide useful assistance to older drivers by supporting the difficulties resulting from limitations in motion perception, peripheral vision, selective attention and decreased speed of processing information and decision-making (Mitchell & Suen, 1997; Shaheen & Niemeier, 2001). These include electronic stability control, braking assistance, forward collision warning system, lane departure warning system, adaptive cruise control, and night vision. Among these assistance systems, forward collision warning (FCW) system is one of the most useful in-vehicle safety systems for older drivers by drawing an attention of the driver to traffic (Davidse, 2006). The acceptance of the forward collision warning was verified by a previous study through questionnaire. All older drivers answered that the system was either very useful or useful at nighttime and 63% of the older drivers said it was either very useful or useful at daytime. Almost half of the older drivers were willing to buy the system (Oxley & Mitchell, 1995). Another assistant system for compensating older drivers' diminished capability is a lane departure warning (LDW) system (Insurance Institute for Highway Safety (IIHS), 2010). Researchers have studied on the effectiveness of FCW and LDW and reported that significant improvements in driving safety behavior were observed (Ben-Yaakov, Maltz, & Shinar, 2002; Birrell, Fowkes, & Jennings, 2014; Blaschke, Breyer, Färber, Freyer, & Limbacher, 2009). However, these studies did not investigate age, gender and roadway differences in the effectiveness.

1.3. Previous findings on user acceptance of Advanced Driver Assistance Systems (ADAS)

A number of research efforts on in-vehicle technology acceptance including Advanced Driver Assistance Systems (ADAS) were conducted over last few decades. A standardized checklist for the assessment of acceptance of new in-vehicle technology was proposed by Van der Laan, Heino, and De Waard (1997) to compare the effect of new devices with other systems. Regan, Mitsopoulos, Haworth, and Young (2002) stated that usefulness, ease of use, effectiveness, affordability and social acceptance are the key components for technology acceptance. Brookhuis, van Driel, Hof, van Arem, and Hoedemaeker

(2009) assessed mental workload of drivers and acceptance of the system to understand the effects of driving with a congestion assistant system on drivers and found that the system was accepted more in fog than during normal visibility.

Venkatesh and Morris (2000) investigated gender difference in technology adoption decisions to understanding the role of social influence. Results from the study suggested that men considered perceived usefulness to a greater extent than women in making their decisions regarding the use of a new technology, but women was affected more by perceived ease of use compared with men.

Concerning older driver's acceptance, a study showed that elderly adults were willing to pay for extra technology devices and rated the assistance system higher than younger drivers who want more alerts (Oxley & Mitchell, 1995; Stevens, 2012). In a Swedish study (Viborg, 1999), similar results were found, that is, older drivers (65 year olds and older) had a more positive attitude toward the ADAS services than younger drivers (30–45 year olds). Another study (De Waard, Van der Hulst, & Brookhuis, 1999) found the same conclusion based on the results of their simulator-based study on the behavioral effects of an in-car tutoring system. The elderly adults (60–75 year olds) as well as the younger drivers (30–45 year olds) committed fewer offences when the system gave feedback messages. Interestingly, while the older drivers were pleased with the warning messages, the younger drivers disliked the system.

1.4. Research objective

As noted in earlier research findings, age, gender and roadway characteristics have effects on the ADAS' effectiveness and acceptances. However, little research has been conducted to investigate interactions among these characteristics on the effectiveness, acceptance and usefulness of the ADAS. Thus, the objective of this research is to investigate the effects of age, gender and roadway environment on the acceptance and effectiveness of the ADAS. The findings from this research would provide directions as to whether the ADAS design should accommodate age, gender and roadway environment differences or not.

2. Method

2.1. ADAS experimental design

In order to observe driver's normal driving behavior, a single blind experiment was applied in the between-subjects design. Although between-subjects factors tend to generate relatively larger error variance, the within-subjects factors are more vulnerable to participants discovering the hypothesis that may affect their driving behaviors. The participants were divided into two subgroups; one group supported by the ADAS services and the other group did not. All the participants in both groups were encouraged to drive as close as possible to their daily driving style and no constraints or penalties were used except keeping safe driving. To the ADAS supported group users, the meanings of forward collision and lane departure warning sounds were briefly introduced.

To provide the ADAS services including the forward collision warning (FCW) and the lane departure warning (LDW) features, Mobileye C2-170, an aftermarket Advanced Driver Assistance System, was used (Mobileye, 2013). As shown in Fig. 1(a), 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 (see Fig. 1(b)).

During the experiment, the FCW system monitored the roadway in front of the host vehicle and warned the driver using a beep sound when the host vehicle was approaching a preceding vehicle with a high closing rate. Different patterns of warning sounds were used depending on the approach speed, the difference in speed between the two vehicles and the distance to the preceding vehicle. The lane departure warning system monitored the position of the host vehicle within a roadway lane and warned a driver using a temporal warning sound when the vehicle was crossing a lane unintentionally, i.e. no turn signaling. The detailed warning conditions are described in Table 1 (Mobileye, 2013).

2.2. Participants

In order to investigate age and gender differences in the acceptance and effectiveness of the chosen intelligent driver warning systems, a total of 52 participants, consisted of 26 younger drivers and 26 late middle age (LMA) drivers, were recruited as shown in Table 2. Given Korean young adults typically begin driving at their early twenties; 3 years or more driving experience is generally desired. It is noted that the younger drivers' ages were specified between 25 and 35, while the late middle age drivers aged between 55 and 65 were selected instead of older drivers, in part because of the driving safety during field operational experiment.

The participants have been driving for at least three years, have driven more than twice a week, and their health condition was self-reported to be adequate to participate in this field operational test. They brought a valid driver's license and did not drink any alcoholic beverage within 24 h. Half of participants, i.e., 26 younger and LMA drivers were supported by the ADAS (i.e., the forward collision warning and the lane departure warning systems) during their experiments, but the others were not supported as a control group.

(a) The ADAS Attachment (b) Folded Unit for Non-Supported Group

Fig. 1. The experimental setup of ADAS system.

Table 1
Warning condition for forward collision and lane departure.

Services	Min. speed for activation (km/h)	Time-to-collision (or crossing) (s)	Warning sound	
			Level (dB)	Duration (s)
FCW				
Warning level 1	30	$TTC \geqslant 1.0$	–	–
Warning level 2	30	$1.0 > TTC > 0.6$	75	0.80
Warning level 3	30	$TTC \leqslant 0.6$	85	1.00
LDW	55	$TTC \leqslant 0.5$	75	1.25

Table 2
Participants overview.

		N	Age	
			Younger	Late Middle Age (LMA)
Gender	Total	52	26	26
	Male	26	27.5(2.9)	60.7(1.9)
	Female	26	30.5(3.1)	57.1(2.1)

Note. Average age with standard deviation in parentheses.

2.3. Field experimental setup

An instrumented passenger car designed by DGIST was used to collect the drivers' behavioral data, in-vehicle data and environmental factors based on synchronized master time (Park & Son, 2010). The DGIST instrumented car consists of six video cameras; two cameras for monitoring drivers' physical interaction and four cameras for monitoring traffic environment in terms of front, rear, left and right side views. One driver-monitoring camera for a driver's face was located beside of the rearview mirror, and the other for the cockpit was located beneath the center of the roof. Two cameras for monitoring the left and right blind spots were attached under the side view mirrors, and two cameras for forward and rear view were attached on the top of front and rear windshields. High speed and low speed CAN loggers were used to monitor vehicle speed, steering wheel angle, and so on. The Mobileye advanced driver assistance system was used to record lane position and headway as well as to alert forward collision and lane departure. The DGIST-designed monitoring software was separately running on two Microsoft windows-based PCs. All data was synchronized with the master time that was transmitted by the monitoring software at every 10 ms.

2.4. Procedure

As shown in Fig. 2, the overall experiment procedure consists of three sessions: pre-experiment, main experiment, and post-experiment. In the pre-experiment session, following informed consent, participants completed safety questionnaire to ensure their ability for safe driving. After completing a pre-experimental questionnaire, participants spent about 20 min for adapting on the instrumented car by driving on a rural road and an urban road. Then, the main driving experiment session began once a participant was confident in driving the test vehicle safely. In the main experiment session, each participant drove on a pre-defined driving road that contained 5.5 km of rural road (about 10 min) with one lane per direction, 6.2 km of urban road (about 25 min) with two to four lanes per direction and 9.6 km of highway (about 10 min) with divided

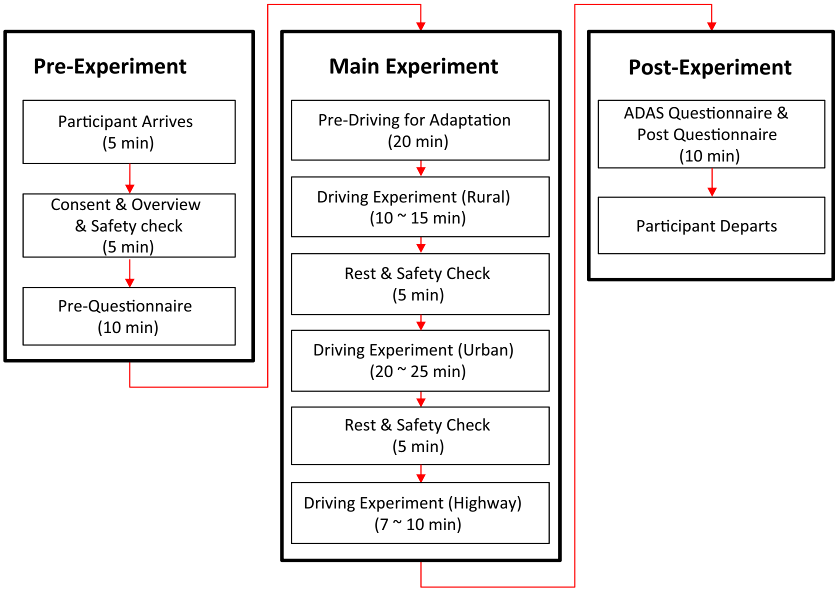


Fig. 2. Overall experimental procedure.

Fig. 3. Typical traffic scenes.

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. After completing the main driving experiment, each participant responded to the ADAS and post-experimental surveys.

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. Fig. 3 shows typical traffic situations on each road segment during the experiments. It is expected that the order effect due to the sequence of three roadway types would be relatively small as driving workload was kept low.

2.5. Questionnaire

Four questionnaires were developed for this study including pre- and post-experimental questionnaire, safety questionnaire, and ADAS questionnaire. The pre-experimental questionnaire comprised of 48 questions to examine a participant's health information, recent behaviors related to eating, drinking and sleeping, driving history and attitude, demographic information, and perceived stress scale. The post-experimental questionnaire had 8 questions to survey perceived stress scale after the experiment and effects of sensor equipment. Prior to each driving task (see the details in Fig. 2), participants were confirmed their confidence of safe driving through safety check questionnaire that consisted of 6 questions for examining experiment induced stress and alertness.

The ADAS questionnaire contained 12 questions, i.e., 6 items each for FCW and LDW, to analyze user acceptance and willingness to pay. As described in Table 3, four user acceptance questions, i.e., 'safe', 'unpleasant', 'desirable' and 'annoying', were selected from the nine items in the usability scale of Van der Laan et al. (1997) by combining similar words when translated to Korean in one word, e.g., 'likeable' was merge into 'desirable.' To emphasize the safety feature of the ADAS, 'useful' and 'effective' were translated to 'safe;' Among the four components, 'safe' and 'desirable' indicated positive responses, while 'unpleasant' and 'annoying' were negative ones. 7-point Likert type scales were used for this study. The ADAS supported group was asked to answer the ADAS questionnaire after completing the driving experiment with the ADAS services.

Table 3
Questionnaire items used to analyze user acceptance.

1	Did you feel safe driving with the forward collision warning system (or the lane departure warning system) compared to driving without it?								
	Very unsafe	1	2	3	4	5	6	7	Very safe
2	Would you desire to drive with the forward collision warning system (or the lane departure warning system)?								
	Very undesirable	1	2	3	4	5	6	7	Very desirable
3	Did you feel unpleasant driving with the forward collision warning system (or the lane departure warning system) compared to driving without it?								
	Very unpleasant	1	2	3	4	5	6	7	Very pleasant
4	Did you feel annoying driving with the forward collision warning system (or the lane departure warning system) compared to driving without it?								
	Very annoying	1	2	3	4	5	6	7	Very comfortable

2.6. User Acceptance Model for the ADAS

To measure user acceptance, this study examined the Technology Acceptance Model (TAM) in which quantifies computer-related technology acceptance behaviors (A), i.e., attitude toward using it by adding perceived usefulness (U) and perceived ease of use (EOU) (Davis, Bagozzi, & Warshaw, 1989):

$$A = U + EOU \tag{1}$$

This study revised TAM to consider four-attitudinal questions including ‘safe,’ ‘desirable,’ ‘pleasant,’ and ‘comfort.’ The proposed acceptance model quantifies the usefulness (U) using ‘safe’ and ‘desirable’ measured from participant’s response to questionnaire.

$$U = (S_{safe} + S_{desirable})/2 \tag{2}$$

where S_{safe} is the subjective score of safety and $S_{desirable}$ is the subjective score of desire.

The ease of use (EOU) term is related to ‘pleasant’ and ‘comfort’ in the ADAS questionnaire of this study because the only use case of the warning systems is to accept the warning.

$$EOU = ((S_{pleasant}) + (S_{comfort}))/2 \tag{3}$$

where $S_{pleasant}$ is the subjective score of pleasant and $S_{comfort}$ is the subjective score of comfort.

Finally, the user acceptance of the ADAS is expressed as the average of the usefulness and the ease of use. For intuitive interpretation of acceptance value, the average acceptance value was divided by the rating scale of the ADAS questionnaire, i.e. 7 points:

$$A = ((U + EOU)/(2 \times C_{RatingScale})) \times 100(\%) \tag{4}$$

where $C_{RatingScale}$ is the subjective rating scale, i.e., 7 points.

Eq. (4) describes that the user acceptance increases as the usefulness and the ease of use become higher.

2.7. Measures of effectiveness and analysis

To assess the effectiveness of the ADAS, five dependent variables that are commonly used in measuring driving performances and four independent variables (i.e., age, gender, roadway and ADAS support) were selected.

In order to analyze the drivers’ behavioral changes by the FCW system, three commonly used measures, i.e., the average forward collision warning counts (FCWC) at the level 3, the average time headway (TH), which calculated when a car in path was detected within a 2.5 s headway, and the percentage of the journey that the participants spent travelling closer than 1.5 s (PJ1.5), were selected (Ben-Yaakov et al., 2002; Birrell et al., 2014). The ADAS provided the FCWC and TH via CAN bus, and the percent journey 1.5 s was calculated using the TH. To assess the impacts of the LDW system, the average lane departure warning counts (LDWC) and the standard deviation of lane position (SDLP) were used (Birrell et al., 2014; Blaschke et al., 2009; Östlund et al., 2004). The LDWC was calculated by counting the number of lane excursion without turn signaling. The SDLP was calculated from 0.1 Hz high pass filtered lateral position data and lane changes were removed using the AIDE project guidelines (Östlund et al., 2004). The five variables were calculated by road segments based on geometric and environmental characteristics such as road slope and traffic flow, and aggregated into each road section. The overall road had three sections consisted of highway, urban and rural areas.

3. Results

The data were analyzed with several statistics including reliability analysis, descriptive statistics, a two-way ANOVA for the user acceptance analysis, and a mixed ANOVA for the effectiveness analysis. This study used the SPSS version 17. A

Greenhouse-Geisser correction was applied for models that violated the sphericity assumption (Reimer, Mehler, Wang, & Coughlin, 2012).

3.1. Age and gender differences in ADAS acceptance

Reliability analysis on the user acceptance indicated that Cronbach's alpha reliability coefficients for the FCW and LDW subscale were 0.744 and 0.910, respectively. Thus, the reliability of the FCW and LDW user acceptance is considered satisfactory (Van der Laan et al., 1997). The normality of the user acceptance for the FCW and LDW calculated by the proposed acceptance Eq. (4) was accepted, i.e., $p = .156$ for the FCW and $p = .200$ for the LDW (Shapiro–Wilk test). While the sample size is fairly small, the statistics on the alpha reliability and normality support the data is valid for the analysis conducted in this paper. However, it would be desirable to increase sample size to ensure the findings are consistent.

The overall acceptance results of the FCW and LDW were described in Table 4. The user acceptance of the FCW was subjected to a two-way analysis of variance having two levels of age (younger and late middle age) and gender. The main effect on gender yielded an F ratio of $F(1,22) = 6.490$, $p < .05$, indicating that the mean acceptance score of the FCW was significantly higher in the male participants ($M = 78.8$, SD = 0.14) than the female participants ($M = 64.6$, SD = 0.14). The interaction effect was not significant, $F(1,22) = 0.599$, $p > .05$. In the comparison of the LDW acceptance, the mean acceptance of the LMA was relatively higher than the younger participants, but it was not statistically significant ($F(1,22) = 2.620$, $p = .120$).

3.2. Effectiveness of the forward collision warning

Table 5 shows the descriptive statistics of the effectiveness variables for the FCW, while Table 6 shows the statistical analyses results based on the data observed from FCW. As shown in Table 6, a mixed ANOVA yielded a main effect for the age ($p < .05$), but the main effects of the ADAS and the gender were not significant. The interaction effect between age and gender was significant on PJ1.5 ($p < .05$), indicating that the age effect was greater in female participants than in male as shown in Fig. 4. The interaction effect between gender and ADAS 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.

A mixed ANOVA indicated that the roadway environment has a main effect (see details in Table 6), suggesting that the average time headway (TH) was significantly larger for highway and rural ($M = 1.75$, SD = 0.24 and $M = 1.43$, SD = 0.29) than

Table 4
Results of age and gender differences in user acceptance of the ADAS.

	FCW				LDW			
	Mean(S.D)	*F*	d.f.	*p*	Mean(S.D)	*F*	d.f.	*p*
Age		0.086	1,22	0.770		2.620	1,22	0.120
Younger	71.4(0.16)				64.0(0.21)			
LMA	72.0(0.15)				75.0(0.14)			
Gender		6.490	1,22	**0.018**[*]		1.601	1,22	0.219
Male	78.8(0.14)				73.6(0.20)			
Female	64.6(0.14)				65.4(0.18)			
Age × gender	71.7(0.16)	0.599	1,22	0.447	69.5(0.19)	0.038	1,22	0.848

[*] $p < .05$.

Table 5
Results for the effectiveness measures of the FCWC by age, gender and roadway.

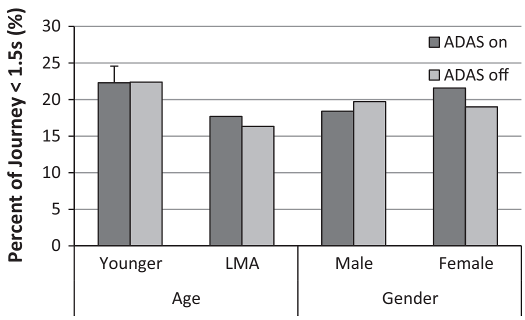
	Experimental (FCW: On)			Control (FCW: Off)		
	FCWC (times)	TH (s)	PJ1.5 (%)	FCWC (times)	TH (s)	PJ1.5 (%)
Age						
Younger	0.18(0.39)	1.36(0.37)	22.30(16.46)	0.33(0.81)	1.35(0.39)	22.39(16.05)
LMA	0.28(0.76)	1.41(0.41)	17.70(15.18)	0.44(1.33)	1.39(0.43)	16.34(15.68)
Gender						
Male	0.23(0.71)	1.45(0.40)	18.41(15.19)	0.33(1.20)	1.36(0.40)	19.72(16.34)
Female	0.23(0.48)	1.31(0.37)	21.58(16.63)	0.44(1.10)	1.38(0.43)	19.00(15.95)
Road						
Highway	0.04(0.20)	1.75(0.22)	10.86(10.48)	0.00(0.00)	1.75(0.26)	12.07(10.66)
Rural	0.12(0.33)	1.44(0.27)	10.92(7.42)	0.08(0.39)	1.41(0.30)	8.35(5.02)
Urban	0.54(0.90)	0.96(0.11)	38.22(9.80)	1.08(1.67)	0.95(0.14)	37.66(11.17)
Total	0.23(0.60)	1.38(0.39)	20.00(15.90)	0.38(1.10)	1.37(0.41)	19.36(16.05)

Note. Average with standard deviation in parentheses.

Table 6
Analysis of variance table for the FCWC dependent measures.

	d.f.	F-ratio		
		FCWC (times)	TH (s)	PJ1.5 (%)
Between subjects effects				
ADAS	1,44	1.096	0.040	0.349
Age	1,44	0.691	1.962	**10.000**[**]
Gender	1,44	0.160	2.666	0.457
ADAS × age	1,44	0.001	0.123	0.132
ADAS × gender	1,44	0.213	**6.042**[*]	1.841
Age × gender	1,44	3.644	3.983	**8.653**[**]
ADAS × age × gender	1,44	1.517	0.578	0.009
Within subjects effects				
Road	2,88	**14.286**[***]	**163.985**[***]	**228.013**[***]
Road × ADAS	2,88	1.842	0.042	0.723
Road × gender	2,88	0.148	**4.018**[*]	0.256
Road × age × gender	2,88	2.467	0.703	**2.501**[†]

[***] $p < .001$.
[**] $p < .01$.
[*] $p < .05$.
[†] $p < .1$.



Note. Error bars represent the standard error of the mean data

Fig. 4. Comparison of percent of journey <1.5 s by age and gender on ADAS.

for urban (M = 0.95, SD = 0.13). Consequently, the FCW count and the PJ1.5 were significantly lower for highway and rural (M = 11.46, SD = 10.48 and M = 9.63, SD = 6.41) than for urban (M = 37.94, SD = 10.40). As shown in Fig. 5, the interaction effect between roadway and gender was significant on TH ($p < .05$). Contrasts revealed that the gender effect was greater on a rural road than an urban road ($F(1,44) = 7.064$, r = .37). The interaction effect among age, gender and roadway environment also showed a strong trend on PJ1.5 ($p < .1$). Contrast revealed that the age and gender interaction effect was significantly greater on the rural road than that of the urban road environment ($F(1,44) = 6.076$, r = .35).

3.3. Effectiveness of the lane departure warning

As shown in Tables 7 and 8, a mixed ANOVA yielded that a main effect for gender ($p < .05$) was significant on the lane departure warning count (LDWC) and the standard deviation of lane position (SDLP), indicating that the average LDWC was significantly higher for male (M = 1.85 times, SD = 2.30) than female (M = 1.14 times, SD = 1.34) and the average SDLP was significantly higher for female (M = 0.29 m, SD = 0.10) than male (M = 0.27 m, SD = 0.10). The main effect of the age was also significant on the SDLP ($p < .05$), indicating that the average SDLP was significantly higher for younger age group (M = 0.29 m, SD = 0.11) than late middle age group (M = 0.27 m, SD = 0.09). Although the interaction effects were not significant, a strong interaction between ADAS and gender was observed on LDWC ($p < .1$), indicating that the gender effect was greater in the ADAS supported condition than in the non-supported condition as shown in Fig. 6.

A mixed ANOVA identified a main effect on the roadway environment (see details in Table 8). The LDWC was significantly higher for highway (M = 2.38 times, SD = 2.54) than rural (M = 0.63 times, SD = 0.99), $F(1,44) = 23.471$, r = .59. The SDLP was significantly larger for rural (M = 0.36 m, SD = 0.06) than for highway (M = 0.16 m, SD = 0.05), $F(1,44) = 334.978$, r = .94. The interaction effects were not significant ($p > .5$).

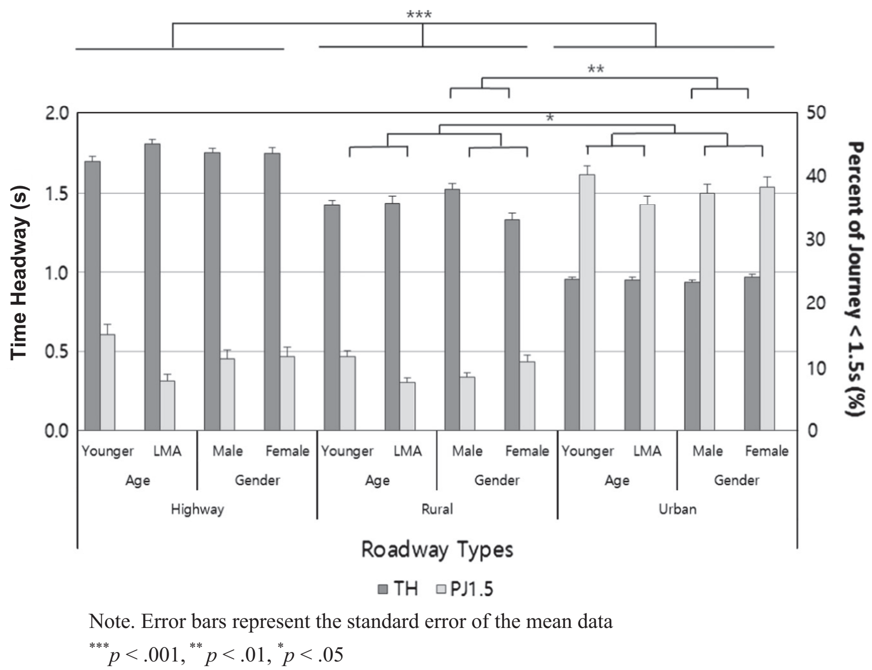


Fig. 5. Comparison of percent of journey <1.5 s by age and gender on road.

Table 7
Results for the effectiveness measures of the LDW by age, gender and roadway.

	Experimental (LDW: On)		Control (LDW: Off)	
	LDWC (times)	SDLP (m)	LDWC (times)	SDLP (m)
Age				
Younger	1.38(1.62)	0.30(0.11)	1.79(2.33)	0.28(0.11)
LMA	1.28(1.56)	0.27(0.10)	1.51(2.05)	0.27(0.09)
Gender				
Male	1.38(1.82)	0.27(0.11)	2.31(2.64)	0.27(0.09)
Female	1.28(1.32)	0.29(0.10)	1.00(1.36)	0.28(0.10)
Road				
Highway	1.96(2.24)	0.16(0.04)	2.81(2.79)	0.16(0.05)
Rural	0.69(0.97)	0.37(0.05)	0.58(1.03)	0.35(0.06)
Urban	1.35(0.94)	0.32(0.05)	1.58(1.81)	0.32(0.04)
Total	1.33(1.58)	0.28(0.10)	1.65(2.19)	0.28(0.10)

4. Discussion

4.1. Age and gender difference in the acceptance

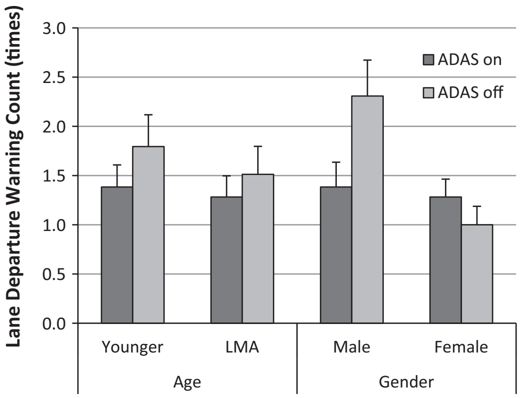
This study results showed that the difference in acceptance of the FCW by gender was statistically significant. Male drivers showed higher acceptance on the FCW than female drivers. The result may relate to gender difference in risk-taking behavior. As indicated by Turner and McClure (2003), gender is significantly associated with driver aggression and a high-risk acceptance. In addition, Özkan and Lajunen (2006) suggested that risky driving style increased as a function of masculinity whereas it decreased as a function of femininity. This means male drivers may experience dangerous driving situations more often than female drivers and the perceived usefulness on the FCW of male is greater than female. This is also supported by Venkatesh and Morris (2000) whom found that men consider perceived usefulness to a greater extent than women in making their decisions regarding the new technology acceptance. These factors likely resulted in male drivers rating higher scores on the ADAS acceptance than those of female drivers.

Although the main effect on the age factor was not significant, an apparent trend of age difference in the acceptance of the LDW was observed. Older drivers showed higher acceptance on the LDW than younger drivers. This finding is consistent with the findings of previous studies, and supported that older drivers rated the assistance system higher than younger drivers (Oxley & Mitchell, 1995; Stevens, 2012) and older drivers had a more positive attitude toward the ADAS services than younger drivers (Viborg, 1999).

Table 8
Analysis of variance table for the LDW dependent measures.

	d.f.	*F*-ratio	
		LDWC (times)	SDLP (m)
Between subjects effects			
ADAS	1,44	0.956	0.677
Age	1,44	0.514	**5.577**[*]
Gender	1,44	**4.575**[*]	**4.069**[*]
ADAS × age	1,44	0.187	2.472
ADAS × gender	1,44	**3.439**[†]	0.287
Age × gender	1,44	0.071	0.032
ADAS × age × gender	1,44	0.330	0.556
Within subjects effects			
Road	2,88	**15.715**[***]	**225.473**[***]
Road × ADAS	2,88	1.035	0.448
Road × gender	2,88	1.138	0.035
Road × age × gender	2,88	1.202	2.321

[***] $p < .001$.
[*] $p < .05$.
[†] $p < .1$.



Note. Error bars represent the standard error of the mean data

Fig. 6. Comparison of lane departure warning count by age and gender on ADAS.

The acceptance difference between the FCW and the LDW may have originated from the difference of the effectiveness while experiencing the ADAS. The effectiveness differences are discussed in the following section.

4.2. Effects of age, gender and roadway on the effectiveness of the FCW

While this study results did not show the main effect on the effectiveness of the FCW system, the interaction effect between gender and the FCW assistance was significant on the average time headway. The male drivers kept higher time headways than female drivers under the FCW supported condition. The FCW-supported male drivers' mean headway for entire journey increased by 6.6% to 1.45 s compared with 1.36 s in the control condition (Table 5). In addition to a significant difference in time headway, the percent of journey closer than 1.5 s was significantly impacted by age. The younger participants spent 22.34% of their driving time at headways of less than 1.5 s. This was 31.3% higher than in the LMA group, which was 17.02%.

There have been a few studies investigating drivers' behaviors on maintaining time headways. Without the FCW or a smart warning system, a study found that participants spent an average of 6.61% of the entire journey under 1.5 s (Birrell et al., 2014). Another study found that drivers spent 42.2% of their driving time at headways less than 1 s (Ben-Yaakov et al., 2002). This large variation between these two studies could have been stemmed from the roadway environment factors such traffic density and posted speed limit. Specifically, Birrell et al. (2014) conducted their field operational test on a motorway (approximately 11–12 min), an urban section (approximately 8 min) and an inter-urban section (approximately 18 min) at off-peak hours. The experiment of Ben-Yaakov et al. (2002) took place on a six-lane divided highway in a late afternoon for approximately 15 min.

The present study found that the main effect of roadway types on the percent of journey closer than 1.5 s was significant, which was not addressed in the previous studies. The percent of journey times closer than 1.5 s varied by roadway types, i.e., 11.5% on the highway, 9.6% on the rural road and 38.0% on the urban roadway.

Finally, female drivers' behavior changes need to be discussed as their driving behaviors became much less safe under the FCW-supported condition. . Their average time headway was decreased by 5.1% to 1.31 s compared with 1.38 s for the non-supported control group of female drivers. The female drivers' unexpected driving behaviors could be due to the fact that women's accuracy level would be decreased with increasing speeds as they overestimate speeds with increasing speeds (Taieb-Maimon & Shinar, 2001). The FCW system used in this study generated a warning when the time headway was lower than 1.0 s. This may mislead the female drivers' perceived safe headway toward shorter, i.e. below 1.5 s which was still higher than the lowest warning level.

As this study found that the gender difference in the effectiveness of the FCW was significant, the safety parameters of the FCW, such as a forward collision warning threshold, should be set by considering gender characteristics.

4.3. Effects of age, gender and roadway on the effectiveness of the LDW

Although no significant difference was shown with the main effect of the LDW system on the number of lane departure warning and the standard deviation of lane position, overall number of lane departure warning was decreased (Table 7). The results from the previous research on the effectiveness of the LDW system were mixed. Blaschke et al. (2009) suggested that the LDW systems have been effective in reducing lane deviations. However, Birrell et al. (2014) reported that no significance was observed with reducing lane deviation and explained that the effect of the LDW system on the lane deviation was not distinctive without performing secondary tasks to manipulate an infotainment system, such as radio sound settings and destination. The present study was consistent with the results from the latter study. Insurance Institute for Highway Safety (IIHS). (2012) also reported that the lane departure warning systems from premium luxury vehicles were associated with higher claim rates under both collision and property damage liability (PDL) coverage. The report explained this counterintuitive results with the fact that crashes in which vehicles drift off the road are not common even though they account for a large proportion of fatal crashes and lane departure warning would be irrelevant to about 97 percent of police reported crashes. Although it was not clear to explain the reason why the systems seem to increase claim rates, it could support that the effectiveness of the LDW was not significant.

On the other hand, this study results showed a main effect of age was significant on the standard deviation of lane position (SDLP). The younger drivers showed higher lane deviation of 0.29 m compared with 0.27 m in the late middle age group. The age difference in the lane deviation could be explained with the fact that the lane deviation was highly correlated with the eye-off-road times (Son & Park, 2012) and the older drivers checked the mirrors less frequently than the younger drivers (Holland & Rabbitt, 1994; Lee, Cameron, & Lee, 2003).

The results of this study also showed a significant main effect of gender and a trend in the interaction between gender and the LDW support. As noted, the female drivers showed lower number of the lane departure warnings than the male drivers in general. However, the female drivers' number of warning was significantly increased by 28% to 1.28 times compared with 1.00 time in the non-supported female group. The reason could be the gender difference in the confidence level on their driving skills. Because women had lower confidence level in their driving skills than men (D'Ambrosio et al., 2008), they were easily affected by the LDW warning.

4.4. Conclusions

This study investigated the acceptance and the effectiveness of the ADAS through on-road field operational tests using three factors including gender, age and roadway environment. The female and the younger drivers showed the lowest acceptance, whereas the male and the late middle age drivers were more likely to accept the ADAS systems. For the effectiveness perspective, the FCW significantly impacted on the time headway safety margin of the male drivers. However, it affected the time headway of the female drivers toward more dangerous conditions. The effectiveness of the LDW was mixed between genders. The male drivers showed an improvement in their lane departure, while the female drivers who rated near-lowest acceptance showed the opposite effectiveness. It can be concluded that it is essential to assess age and gender differences in the effectiveness and the acceptance of new in-vehicle technology for avoiding unexpected negative impacts on a certain age and gender segment and for providing proper recommendations to set the safety parameters by considering gender characteristics. It is also important to consider adjusting settings, if needed, based on the roadway types and possibly traffic conditions.

5. Limitations and future work

While this research successfully quantified the effectiveness and acceptance on the Advanced Driving Assistance Systems, it only considered two age groups. Given some of advanced driver assistance systems are more attractive to older drivers over 70s and no drivers in their 40s were considered in this research, future research should consider recruiting the entire age group to ensure whether the findings are consistent with those of this paper.

It is recommended that future research evaluate these advanced driver assistance systems for longer duration of time (e.g., one year or so) to see if the acceptance and effectiveness on these ADAS changes over time. It is also recommended that future research evaluate these advanced driver assistance systems combined with various driving assistance systems such as adaptive cruise control system, lane keeping system and automated driving system.

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