Mixed Factorial Analysis of In-Vehicle Information Systems: Age, Driving Behavior, and Task Performance

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Abstract. This study conducted a driving simulation experiment using an aural, visual, or multi-modality in-vehicle information system (IVIS) to investigate the performance and emergency response of 24 younger (age: $M = 23.10$ years, $SD = 1.54$) and 24 older (age: $M = 69.21$ years, $SD = 3.05$) drivers in simple and complex road conditions. All drivers assisted by aural or multi-modality IVIS made significantly fewer errors in response to hazard warnings than those who were assisted by the visual modality system. Specifically, drivers exhibited improved performance for response time and the total number of correct turns in complex driving conditions when using multi- or aural modality IVIS; this effect is particularly salient for older drivers. The IVIS improved the safety of older drivers more than that of their younger counterparts, despite their poor vehicle control and slow response time in hazard situations.

Keywords: in-vehicle information system, age, driving simulator, driving performance, display.

1 Introduction

The number of older drivers in society has increased in conjunction with the aging population, particularly in developed countries. Previous research has shown that 20% of the population in most developed countries is older than 60 years, and that one third of the global population will be older than 60 years by 2050 [1]. In 2009, 2.45 million people (10.7% of the population) in Taiwan were older than 65 years [2], and the population of older adults will continue to increase. The United States Census Bureau forecasted that 12.3% of Taiwan's population will be older than 65 years by 2015. Furthermore, the 65+ age group in Taiwan is the fastest growing group [3]. Previous studies have recommended that the forecasted increase in the number of older drivers over the next 20 y should be addressed by designing in-vehicle human-machine interfaces [4].

Previous studies have shown that aging causes a decline in cognitive function; consequently, the operating of vehicles becomes difficult [5-7]. Furthermore, several studies have shown that older drivers are frequently involved in accidents when exposed to difficult driving conditions [8-10]. The decline in visual field in older drivers

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was the most frequent cause of traffic accidents, especially at intersections [11]. Other causes include reduced brake reaction time [8], difficulty making left-hand turns [12], and poor concentration [13-14]. The older drivers experienced difficulty driving and navigating simultaneously, and made more safety-related errors than younger drivers [15]. However, they also showed that a well-designed in-vehicle information system (IVIS) significantly improved the driving performance of older adults. Liu [16-17] reported that performance and task reaction in older drivers were worse than in younger drivers. Furthermore, traffic accidents involving older drivers were more likely to cause injury or fatality.

Visual navigation systems are a commonly used type of IVIS. Furthermore, these systems affect the concentration of drivers [18], and the drivers preferred visual navigation systems that can inform them of their current location [19]. Drivers using visual displays reduced their average glance time on the central road when using a visual display [15]. The drivers with reduced average glance time experienced a reduction in driving control performance [20], and depend on visual modality IVISs for driving-related information might experience visual overload, and compensate by driving slower and more carefully [21]. However, using visual modality displays resulted in more navigation errors than using aural modality systems [22]. Hurwitz and Wheatley [23] employed secondary tasks to compare the effect of visual and aural modality IVISs on driving performance. Their results showed visual modality IVISs caused a greater reduction in driving performance (i.e., steering wheel movement and variation of lateral speed). Aural modality IVISs are potentially superior to visual modality IVISs for presenting navigation and warning information. The audio warnings were effective in improving driver reaction times [24-25]. According to multi-resource theory, aural modality systems could improve the time-share performance in cluttered visual modality environments [26]. Therefore, multi-modal (visual and aural) IVISs could allow drivers to process additional information without increasing their sensory workload.

The current designs of in-vehicle displays are unsuitable for older drivers [27]. Advancements in system or display technologies (i.e., navigation system and IVIS) and changes in population distribution (i.e., aging population) further complicate traffic safety issues. Previous research has shown that a user-centered design of automotive human-machine interfaces such as navigation systems is crucial in addressing the increasing number of older drivers [4]. Thus, these issues require prompt investigation.

2 Methods

2.1 Participants

Twenty-four older adults (20 men, 4 women; age: M = 69.21 years, SD = 3.05) and 24 students (12 men, 12 women; age: M = 23.10 years, SD = 1.54) were recruited as the older and younger driver groups in this study. All participants met the following requirements to qualify for this study: 1) have held a valid driver's license for at least 1 year; 2) have driven at least 5000 km per year; 3) have achieved a minimum visual acuity test score of 0.5 or 0.8 for the older or younger groups, respectively; 4) have passed the Ishihara color blindness test; and 5) have no hearing impairments. Participants were compensated with US$30.

2.2 Apparatus

This study employed the interactive STI® high-fidelity driving simulator developed by Systems Technology Inc. (Hawthorne, CA, USA). The simulated vehicle (VOLVO 340 DL) was fitted with standard automotive displays and controls (i.e., steering wheel, brakes, and an accelerator) and an automatic transmission system. Driving scenarios were projected onto a 100 in aluminum concave Mocom Power Screen® (width = 200 cm, height = 150 cm, curvature = 900 cm, brightness = 20 gains) situated 3.1 m in front of the driver. The simulation audio was broadcast using stereo amplifiers in vehicle cab.

Driving-related information such as vehicle speed and task instructions were projected onto an approximate 15 in heads-up display (HUD, width = 32 cm, height = 22 cm, resolution = 700 × 600 dpi, icon size = 10 x 10 cm2 ~1.8 degrees) situated 2.9 m directly in front of the driver. The vertical projection angle was maintained between 6° and 12° below the driver's horizontal line of vision. Audio information or warnings were generated using the simulation software and a trained female assistant speaking at approximately 150 words per minute. The multi-modal IVIS provided audio and visual information.

2.3 Experimental Design

The following three factors were involved in this mixed-factorial experiment: age (younger versus older groups; inter-participants), driving load (high versus low; individual participants), and IVIS modality (aural-, visual-, and multi-modality; inter-participant). Variables were assigned randomly to participants, but were counterbalanced to prevent any pattern learning or order effect. Dependent variables based on objective and subjective measures are detailed in the following section.

The simulated driving environment scenarios were developed using STI scenario definition language version 8.0 and categorized as low and high load conditions. The driving load condition was manipulated using the factors discussed by Liu and Wen [28]. The high (low) driving load environment was configured as follows: lane width = 3.6 m (4.1 m); speed limit = 90 km/h (60 km/h); number of intersections = 120 (40); and density of roadside buildings = 20 buildings/min (2 buildings/2 min). Each scenario required approximately 20 min to complete.

2.4 Tasks

Driving Task. All participants were instructed to complete the simulated driving course while adhering to all traffic rules and driving safely.

Navigation Task. Navigation task-related information was displayed on the HUD. The visual display interface shown in Fig. 1 was designed and employed according to the layout proposed by Liu and Wen (2004). Audio navigation information was used to ensure that participants received the messages clearly (volume loudness = approximately 75 dB). Participants were requested to follow the system's route guidance information. Because the simulator could not simulate actual turning, participants were instructed to say the name of the road and the direction in which they wanted to turn, and to turn on the left- or right-turning signal as if they were about to turn. Each driving scenario included 20 turns.

Emergency Response Task. The system periodically (approximately 2 min) issued a road danger warning (e.g., road construction or watch for pedestrians) and vehicle monitoring information (e.g., insufficient tire pressure and engine temperature too high). This information was presented for approximately 3 s before disappearing. The participants were instructed to verbally inform the experimenter which type of danger (i.e., road or vehicle) they considered. Each driving scenario included eight warnings (four of each danger type).

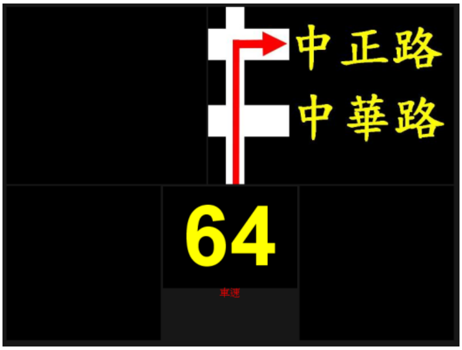

Fig. 1. Example of navigation information on the visual display. Speedometer (64 km/h) and navigation information were displayed. Descriptions of navigation information contained street name before the turn, name of street to turn into, and turning direction (e.g., right-hand turn).

2.5 Procedure

Prior to the experiment, all participants were prescreened to ensure they met the discussed requirements to qualify for this study. The purpose of the experiment was subsequently explained to each participant. After signing an informed consent form, the participants were provided approximately 10 min of driving practice in the simulator to become familiar with the simulator controls and the IVIS modalities. The experiment was conducted following the practice process. During the experiment, participants were allowed a 5-min break between driving loads. All experiments took approximately 60 min.

2.6 Data Collection and Analysis

The dependent measures for assessing the impact of age and IVIS modality display on driving behavior and performance are detailed as follows: 1) driving behaviors (variation in lateral speed, ft/s; mean and variation of longitudinal speed, ft/s); and 2) accuracy when performing specific navigation and emergency response tasks.

Analysis of variance (ANOVA) was performed on the obtained data using SPSS version 19.0, and post hoc analyses were conducting using the Tukey method. The level of significance for all analyses was $\alpha < .05$.

3 Results

3.1 Navigation and Emergency Response Performances

Results show that driving load [$F(1,42) = 14.141$, $p = .001$], age [$F(1,42) = 16.915$, $p = .000$], and visual modality [$F(2,42) = 24.549$, $p = .000$] have a significant effect on navigation and emergency response performance. Two interactions of modality type × driving load [$F(2,42) = 5.551$, $p = .007$] and modality type × age ($F(2,42) = 7.853$, $p = .001$) also have a significant effect on navigation accuracy and emergency response tasks. Post hoc analyses show that the drivers had lower task accuracy in high driving load conditions (96.875%) than in low conditions (98.363%); furthermore, older drivers (96.057%) had worse performance than younger drivers (99.182%). The visual modality IVIS also achieved the lowest task accuracy (93.862%) and had a significant difference between aural and multi-modality IVISs. The difference in rating between the aural (99.330%) and multi-modality (99.665%) IVIS is non-significant.

Within the younger driver group, the differences in performance for navigation and emergency response task performance between high and low load conditions were non-significant [$F(1,21) = 3.723$, $p = .067$]. However, there is a significant difference among visual, aural, and multi-modality IVISs [$F(2,21) = 18.021$, $p = .000$]. Post hoc analyses show that the worst performance of navigation and emergency response tasks occurred using the visual-modality IVIS (97.545%), whereas performances using aural and multi-modality IVISs achieved perfect scores. Among the older driver group, there is a significant difference between high and low driving load conditions [$F(1,21) = 10.43$, $p = .004$]. These drivers had lower task accuracy in high driving load conditions (94.940%) than in low load conditions (97.173%). Visual modality IVIS (90.179%) resulted in significantly lower task accuracy than when identical data presented using the aural (98.661%) or multi-modality (99.330%) ISIVs [$F(2,21) = 16.060$, $p = .000$).

3.2 Driving Performance: Mean Speed

Because the participants were instructed to adhere to the speed limit to complete the high and low driving load condition experiments, this analysis is discussed separately by dividing the data into two conditions. The low load condition results show that the impact of age [$F(1,42) = 0.786$, $p = .380$] and IVIS modality type [$F(2,42) = 0.921$, p = .406] on mean speed is non-significant. Furthermore, two interactions of display modality × age show no significant effect on mean speed.

The high driving load condition results show that the impact of age on mean speed is non-significant [F(1,42) = 0.194, p = .662], whereas the effect of modality type on mean speed is significant [F(2,42) = 16.109, p = .000]. Two interactions of display modality × age had a significant effect on mean speed [F(1,42) = 6.084, p= .005]. Further analyses shows no significant difference for the mean speed of younger drivers [(F(2,21) = 2.466, p = .109] among the three discussed IVIS modalities; however, the difference in mean speed among older drivers is significant [F(2,21) = 13.904, p = .000]. The visual modality IVIS has the lowest mean speed (78.947 ft/s); furthermore, the difference in mean speed between aural (82.458 ft/s) and multi-modality (82.028 ft/s) IVISs is non-significant.

3.3 Driving Performance: Variation in Lateral Speed

The results show that driving load [F(1,42) = 16.972, p = .000], age [F(1,42) = 10.793, p = .002], and modality type [F(2,42) = 4.672, p = .015] have a significant impact on variation in lateral speed. Performance of lateral speed variation for low load conditions (0.545 ft/s) was better than for high load conditions (0.976 ft/s); furthermore, variation in lateral speed was greater for older drivers (1.201 ft/s) than for

Table 1. Effects of age, driving load, modality type on driving performance

Performance measures	Variables			*p*-value
	Age			
	Younger		Older	
Accuracy of navigation and emergency response (%)	99.182		96.057	.000
Variance in lateral speed (ft/sec)	0.433		0.515	.002
	Driving load			
	Low load		High load	
Accuracy of navigation and emergency response (%)	98.363		96.875	.001
Variance in lateral speed (m/sec)	0.320		0.629	.000
	Modality type			
	Visual	Aural	Multi-modality	
Accuracy of navigation and emergency response (%)	93.862A[a]	99.330B	99.665B	.000
Variance in lateral speed (m/sec)	1.339A	0.443B	0.500B	.015

[a]Values with the same letter are not significantly different.

younger drivers (0.320 ft/s). In addition, the use of the visual modality IVIS resulted in the greatest variation in lateral speed (1.339 ft/s); furthermore, the difference in lateral speed variation between the aural (0.500 ft/s) and multi-modality IVISs (0.443 ft/s) is non-significant. Two interactions of driving load × age show a significant effect on variation in lateral speed.

The variation in lateral speed for the younger driver group under low driving load conditions (0.413 ft/s) and in high load conditions (0.227 ft/s) is significant [$F(1,21) = 16.389$, $p = .001$]. Participants using the visual modality IVIS show the greatest variance in lateral speed (0.444 ft/s), whereas the difference between aural (0.291ft/s) and multi-modality (0.226 ft/s) IVISs is significant [$F(2,21) = 3.587$, $p = .046$].

The variation in lateral speed results is similar to that of the older driver group. There is a significant difference between high (1.538 ft/s) and low (.864 ft/s) driving load conditions. Experiments with the visual modality IVIS (2.234 ft/s) produced significantly higher variances in lateral speed than experiments using identical data on the aural (0.709 ft/s) and multi-modality (0.659 ft/s) TVISs [$F(2,21) = 3.78$, $p = .040$].

4 Discussion

The analyzed results in this study show that age has an effect on behavior while driving (Table 1); furthermore, an inverse relationship between driver age and driving performance was observed. Extant research has indicated that driving-related information from IVISs might cause difficulties for older drivers [4], [15-17], [27]. This study provides additional evidence that supports the assertion that older adults experience greater difficulty than their younger counterparts in processing driving-related information by IVIS, especially in high driving load conditions. This result indicates that IVIS user interfaces should be designed in ways that do not increase the workload of older drivers; furthermore, all information should be presented as simply as possible. Consequently, the older adult demographic warrants particular attention in IVIS design because the number of older drivers continues to increase.

All drivers' aural or multi-modality IVIS made significantly fewer errors in responding to hazard warnings than those of using only the visual modality IVIS. Specifically, driving performance, response time, and response accuracy were better in high load driving conditions when drivers used aural and multi-modality IVISs. This effect is particularly salient for older drivers. The experimental results are consistent with those of previous studies that stated that using only visual modality IVISs might cause distraction, visual overload, increased reaction time, and reduced glance time on the central road and driving controls [15],[18],[20-25].

This study supports the assertions made by [21], [29] that drivers who are highly dependent on visual modality IVISs for driving-related information might experience visual overload; consequently, they tend to compensate by driving slower and more carefully. Although IVIS modality type had no significant impact on mean speed in low driving load conditions, the opposite was true in high driving load conditions. Both age groups performed better when using the multi-modality IVIS; this finding was especially noticeable for older drivers. For older drivers, using the visual modality IVIS resulted in the slowest mean speed; furthermore, the use of aural and multi-modality IVISs significantly decreased mean speed.

In summary, this study shows that using IVISs while driving causes few negative effects in the older driver group, especially in high driving load conditions. Aural and multi-modality IVISs are suitable for providing warning information because they promote quick driver responses and enhance the information processing capabilities of older drivers. In this study, although drivers using the visual modality IVIS performed poorly in the majority of tasks, older drivers, to some extent, might benefit from IVISs similar to younger drivers.

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