# ON-ROAD ASSESSMENT OF IN-VEHICLE DRIVING WORKLOAD FOR OLDER DRIVERS: DESIGN GUIDELINES FOR INTELLIGENT VEHICLES

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**ABSTRACT**–There has been recent interest in intelligent vehicle technologies, such as advanced driver assistance systems (ADASs) or in-vehicle information systems (IVISs), that offer a significant enhancement of safety and convenience to drivers and passengers. However, the use of ADAS- and IVIS-based information devices may increase driver distraction and workload, which in turn can increase the chance of traffic accidents. The number of traffic accidents involving older drivers that are due to distraction, misjudgment, and delayed detection of danger, all of which are related to the drivers' declining physical and cognitive capabilities, has increased. Because the death rate in traffic accidents is higher when older drivers are involved, finding ways to reduce the distraction and workload of older drivers is important. This paper generalizes driver information device operations and assesses the workload while driving by means of experiments involving 40 drivers in real cars under actual road conditions. Five driving tasks (manual only, manual primarily, visual only, visual primarily, and visual-manual) and three age groups (younger (20-29 years of age), middle-aged (40-49 years of age), and older (60-69 years of age)) were considered in investigating the effect of age-related workload difference. Data were collected from 40 drivers who drove in a real car under actual road conditions. The experimental results showed that age influences driver workload while performing in-vehicle tasks.

**KEY WORDS :** Human vehicle interface (HVI), Older drivers, Driving workload, In-vehicle information system (IVIS), NASA task load index (TLX), Distraction

## 1. INTRODUCTION

There has been recent interest in intelligent vehicles that offer a significant enhancement of safety and convenience to drivers and passengers (Cena *et al*., 2005, Kim*et al*., 2010). Two types of systems have been developed for use in intelligent vehicles: advanced driver assistance systems (ADASs), which assist in safe driving, and in-vehicle information systems (IVISs), which offer many types of information to drivers (Doshi*et al*., 2009). In particular, an IVIS analyzes data on traffic, the environment, driving, and the vehicle to provide helpful information and to make driving more convenient (Jamson and Merat, 2005; Maciej and Vollrath, 2009; Vashitz *et al*., 2008). An ADAS senses the situation around the car in real time so that it can alert the driver to dangerous situations and increase driving safety (Lee and Lee, 2006).

However, the use of ADAS- and IVIS-based devices also increases driver distraction and workload, which in turn increases the chance of traffic accidents (Son *et al*.,

2010; Wang *et al*., 1996). Distraction, in particular, often occurs under a heavy driving workload due to multitasking with various electronic devices, like a cell phone or a navigation system, while driving (Horberry*et al*., 2006; Lee *et al*., 2009; Wang *et al*., 1996). According to the Road Traffic Accidents Report published by the Road Traffic Authority (ROTA) in Korea in 2005, more than 60% of the traffic accidents in Korea are related to driver error caused by distraction (Lee *et al*., 2009; Koo *et al*., 2009; ROTA, 2005). Moreover, 25% of traffic accidents in Europe are due to distraction caused by operating information devices (Wang*et al*., 1996). The 1998 statistics of the Japanese National Police Agency showed that 89% of car collision accidents were related to driver errors caused by distraction (NPA, 1998).

Many studies have investigated driver distraction and workload as the main causes of traffic accidents, focusing on the distractions related to operation of electronic devices, such as cell phones or navigation systems in intelligent vehicles. The Human Machine Interface and Safety of Traffic in Europe (HASTE) project suggested standards and methods for assessing driving distractions and workload (Anttila and Luoma, 2005). The Adaptive Integrated

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Driver-vehicle Interface (AIDE) project, which was the successor to HASTE, also includes research how to develop and assess an optimized human machine interface (HMI) system based on the condition of drivers and vehicles, focusing on ADASs and IVISs (Patten *et al*., 2006, Victor *et al*., 2005). The Safety Vehicle Using Adaptive Interface Technology (SAVE-IT) project in the U.S. is searching for ways to mitigate visual distractions, because they lead to many traffic accidents (Donmez *et al*., 2006; Vashitz *et al*., 2008). Other studies have also examined driving distraction and workload related to the operation of vehicle information devices, such as cell phones or navigation systems (Chang *et al*., 2008; Cho*et al*., 2006; Daniel*et al*., 2009; Donmez *et al*., 2006; Dressel and Atchley 2008; Lee and Cheng, 2008; Wickens and Hollands, 2002).

More research into driving distraction and workload related to information devices is still required despite the work that has already been done. Previous research has focused on average people while neglecting older drivers who are the major purchasers of high-end cars equipped with high-tech devices like ADASs and IVISs (Hong and Cho, 2009; Malfetti, 1985; ROTA, 2005; ROTA, 2006). An increasing number of traffic accidents are attributed to the declining physical and cognitive abilities of older drivers. Older driver behavior, such as frontal distraction, misjudgment, and delayed danger identification, are responsible for 62.7% of traffic accidents, as shown in Figure 1 (ROTA, 2006). Because the death rate in traffic accidents is higher when older drivers are involved, finding ways to reduce the driving distraction and workload of older drivers is important (NHTSA, 2006; ROTA, 2006). Furthermore, previous research into driving distraction and workload due to the operation of electronic devices has been limited only to certain functions (Wierwille, 1993). Driving distraction and workload, however, could be effectively alleviated based on comprehensive research that generalizes the operation of various information devices.

Hence, this paper examines the operation of information devices by drivers and assesses driving workload through experiments in real cars under actual road conditions, categorizing the operation of devices into five types based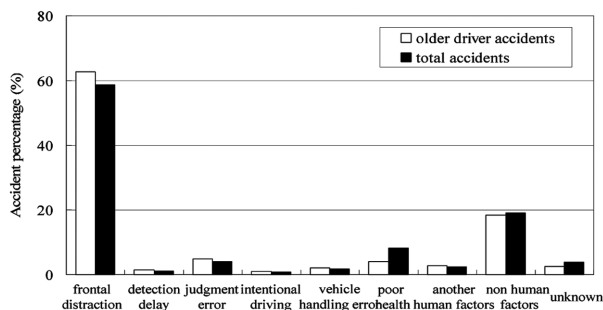 on manual and visual demands (Wierwille, 1993). The experimental results showed that age influences driver workload while performing in-vehicle tasks. This paper also provides guidelines for the design of information devices that consider possible driving workload for older drivers based on the experimental results.

The paper is structured in the following way. Section 2 describes the experimental process for assessing the driving workload of older drivers, and Section 3 analyzes and discusses the experimental results. Section 4 outlines the conclusions and makes suggestions for follow-on studies.

## 2. Experimental Method

### 2.1. Participants

Table 1 lists the details of 40 drivers who participated in this study to analyze the driving workload of older drivers caused by the operation of information devices. An equal number of males and females were selected for the younger groups to see whether the results depended on gender. The ratio of drivers in their 60s was adjusted to reflect the Korean driving population in that particular age group. The participants were selected from the group of people who drove more than twice a week and had more than three years of driving experience covering more than 30,000 km. Participants were also sufficiently healthy to drive more than three hours and did not suffer from any mental illnesses. The participants were paid for their participation; participants in their 20s received 40,000 KRW (33USD), while the others were paid 50,000 KRW (42USD).

### 2.2. Equipment

The latest Hyundai car was used in this experiment. The vehicle was selected to be unlike any vehicle the participants had driven before. Web cameras and a voice recorder were installed in the car to assess the time taken to complete the information device operation tasks. The time taken to complete a task was defined as the elapsed time from the time the researcher gave a signal to the time the



Figure 1. Distribution of older driver distractions based on the 2006 ROTA data.

Table 1. Experiment participants.

| | | Number | Age and standard deviation (yt) | Driving experiment and standard deviation (yt) |
|---|---|---|---|---|
| | Male | 5 | 27.2(0.45) | 7.0(2.35) |
| 20s | Female | 5 | 26.6(2.07) | 6.4(1.52) |
| | Total | 10 | 26.9(1.45) | 6.7(1.89) |
| | Male | 5 | 44.8(3.70) | 15.6(6.19) |
| 40s | Female | 5 | 45.4(1.85) | 14.0(5.57) |
| | Total | 10 | 45.1(2.81) | 14.8(5.61) |
| | Male | 14 | 67.6(1.95) | 29.1(9.03) |
| 60s | Female | 6 | 67.3(2.42) | 19.17(9.37) |
| | Total | 20 | 67.6(2.04) | 25.9(10.06) |

(a) Above the driver seat    (b) Center of the vehicle roof
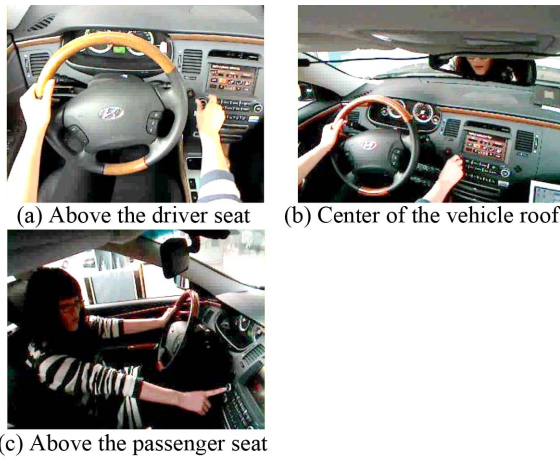


(c) Above the passenger seat

Figure 2. Images from the three positions of the webcam monitoring system.

task was completed. Three webcams (QuickCam Ultra Vision, Logitech) with a resolution of 960×720 pixels at 30 frames per s were installed above the driver and passenger seats and next to the interior light. Images were captured and sent simultaneously to a laptop computer. The images in Fig. 2 are representative of those obtained by the webcams; the cameras above the driver seat and next to the interior light showed how the drivers completed the tasks, and the camera above the passenger seat recorded the drivers' condition. The voice recorder (UP3, LG Electronics) was installed in the center of the dashboard to record any sounds made while performing the tasks.

2.3. Driving Task Classification

In-vehicle information system tasks were classified into the following groups: manual only, primarily manual, visual only, primarily visual, and combined visual and manual (Wierwille, 1993). Manual Only (M-O) tasks can be performed by one of the driver's hands without visual reference and include sounding the horn, activating the turn signal, shifting gears, or adjusting the high/low beam control. Manual Primarily (M-P) tasks require visual information to find a control and possibly determine its present setting before moving one hand to the control and adjusting it. Tasks in this group include turning on the radio, adjusting the radio volume, or adjusting the seat position. Visual Only (V-O) tasks are completely or mainly visual in terms of the resources used to accomplish them. Visual only tasks are information gathering tasks that require no manual input, such as reading the speedometer or the clock, or checking the instrument panel, current climate control setting, or map display. Visual Primarily (V-P) tasks rely heavily on vision but require some degree of manual input to obtain information. These tasks include accessing the correct format of the trip monitor display to determine the remaining number of miles and determining what station the



(a) Activating the turn signal (b) Adjusting the radio volume



(c) Reading the speedometer (d) Changing the radio station



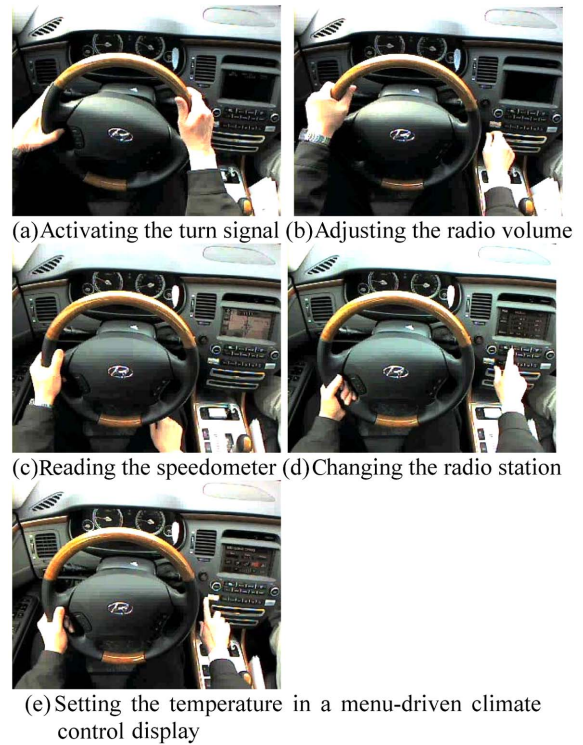(e) Setting the temperature in a menu-driven climate control display

Figure 3. Photographs of the in-vehicle information tasks used to assess the driving workload.

radio is on when the display initially shows the time. Finally, Visual-Manual (V-M) tasks feature interactive visual and manual demands where the driver gathers information and uses it for making additional manual inputs, or the driver makes manual inputs sequentially to access desired information. These tasks include manually turning the radio to a specified frequency, operating a cellular telephone, making mirror adjustments, and finding the correct page in a menu-driven display to adjust a specific quantity on the display. The five tasks chosen are shown in Fig. 3: activating the turn signal (M-O), adjusting the radio volume (M-P), reading the speedometer (V-O), changing the radio station (V-P), and setting the correct temperature in a menu-driven climate control display (V-M).

2.4. Road Experiments

Figure 4 shows the route in Daegu chosen for the road experiments. A city route was chosen instead of a highway route because of the greater workload related to device operation on congested roads and the increased possibility of traffic accidents. The route was limited to 30 km to avoid a long drive that would add to the driving workload. Each participant drove from the lab (a) to a point about 5 km outside the city, then made a U-turn(b) and drove another 25 km in the city, ending up at the lab again (c-d-e-a). The width of the road varied from 4 to 10 lanes. Participants were told not to exceed 70 km/h while driving.
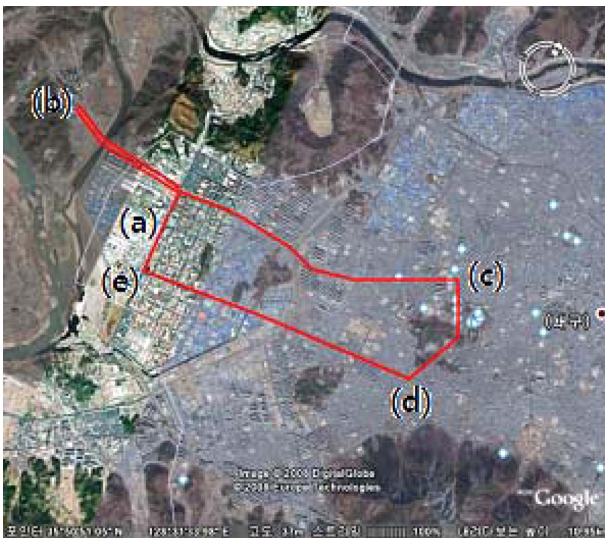
Figure 4. Route for the road experiments in Daegu.

## 2.5. Procedure

Figure 5 shows the experimental procedure, which consisted of phases before driving, the road experiment, and phases after driving. The 70-min pre-driving phase included obtaining driver consent, providing an overview, reviewing subject eligibility, administering a questionnaire, and training. First, the participants were provided with a description of the experiment and eligibility was confirmed, and they were then requested to read and sign an informed consent form (Son *et al*., 2010). The participants completed a questionnaire in Korean, and they were presented with the vehicle and five tasks. Following the familiarization period, participant drove about 5 km
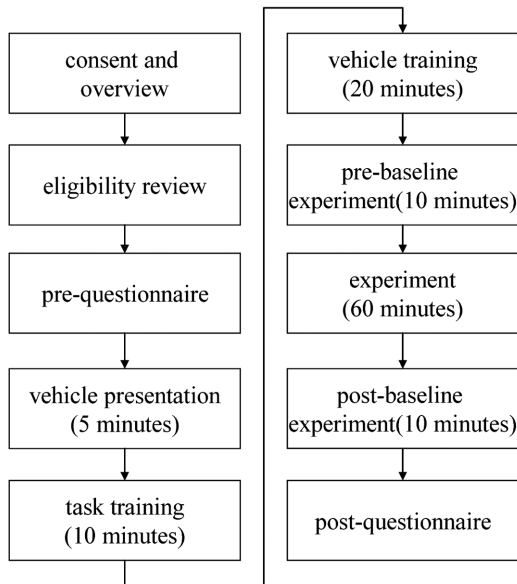


Figure 5. Experimental procedure used to assess the driving workload.

outside the city for vehicle training and assessed the five tasks without driving as a pre-baseline of the time required to complete the task. The 30-km drive experiment took about 60 minutes. The five tasks were assigned to the participants at certain points along the route, and the National Aeronautics and Space Administration task load index (NASA-TLX) questionnaire composed of random for counterbalancing was completed by each participant after the driving experiment (Yu and Park, 1998). Each road experiment took about 1 hr. The 10-minute post-driving phase included post-baseline experiment and administering a questionnaire about the mental state and stress of the participants. Hence, the complete experiment required about 3 hr per participant. The experiments were conducted twice a day starting at 11 A.M. and 2 P.M. to avoid periods of major road congestion.

## 2.6. Analysis Method

Subjective and objective performance indices were chosen to analyze the driving workload due to the operation of information devices. The NASA-TLX was used as a subjective performance index; it is one of the most representative methods used to assess driving workload (Hart and Staveland, 1988). NASA-TLX was developed by NASA in the early 1980s and is a well-known subjective assessment tool for measuring the difficulty of work. NASA-TLX randomly allocates points in the range 0-100 for six items, including mental demand, physical demand, temporal demand, effort, performance, and frustration, and it quantifies the difficulty of work in general by calculating an average value (Hart, 1998; Yu and Park, 1998; Wickens and Hollands, 2002). The NASA-TLX questionnaire was completed by each participant after the driving experiment.

The time required to complete the tasks was used as the objective performance index because driving workload is normally defined as the ratio of the time taken to complete a task to the given mission time (Chang *et al*., 2008; Liu and Wickens, 1994; Pierre *et al*., 2005; Wickens and Hollands, 2002). The tasks were assigned to the participants at certain points along the route, and the drivers were told to complete the tasks while observing the speed limit and driving a certain lane so that the road conditions would not affect the result. The time taken to complete the tasks was measured by the webcams and the voice recorder.

The SPSS Version 14 software package was used to analyze driving workload differences among age groups. An MANOVA analysis was conducted on the independent variables and reciprocal action between the subjective and objective performance indices for the tasks, depending on age and gender. The level of statistical significance was set at $\alpha = 0.05$.

## 3. RESULT AND DISCUSSION

Figure 6 shows the NASA-TLX score as a function of driver age for driving workload related to information
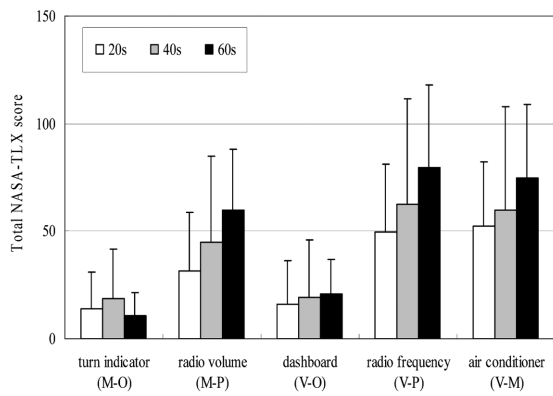
Figure 6. NASA-TLX task assessment results by age group for five in-vehicle tasks.

device operation while driving. The drivers were asked to give their scores subjectively without any criteria. The drivers gave themselves the highest scores for the V-M task and recorded higher scores for the M-P and V-P tasks than for the M-O and V-O tasks. In addition, the drivers gave themselves higher scores for the visual tasks than for the manual tasks. The drivers recorded higher scores for the V-P and V-M tasks, which required the difficult process of obtaining visual signs, because visual information is the most important while driving. The standard deviation of the drivers' NASA-TLX scores was high because the subjective driving workload experienced by drivers varied from one individual to another. The NASA-TLX score of older drivers was 1.90 times higher for the M-P task and 0.74 times higher for the M-O task than that of drivers in their 20s. The older drivers gave themselves low scores for relatively easy tasks and recorded scores 1.34 times higher for the M-P task and 0.56 times higher for the M-O task than the drivers in their 40s.

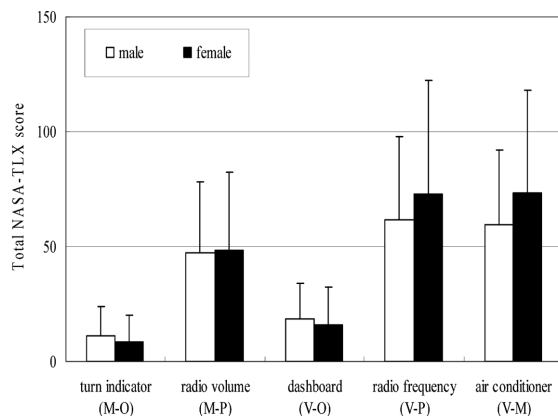Figure 7 shows the NASA-TLX score differences of the drivers based on gender. Because female drivers tended to be less skilled in driving than male drivers, they gave themselves higher scores for the V-P and V-M tasks, which were relatively more difficult. The standard variation of the female drivers' NASA-TLX scores was also higher because the subjective difficulty of tasks varied according to the driving proficiency of each driver. The NASA-TLX scores for female drivers were 1.23 higher for the V-M task and 0.75 times higher for the M-O task than those of male drivers. The female drivers gave themselves low scores for relatively easy tasks. However, the difference of the NASA-TLX scores by gender was smaller than the difference by age group, showing that the results were more affected by the age of the drivers than their gender. The NASA-TLX test results show that statistically significant differences by age ($F_{(2, 159)} = 4.79$, $p = 0.010$), gender ($F_{(1, 159)} = 7.974$, $p = 0.005$), and task ($F_{(4, 159)} = 21.317$, $p = 0.00$) but not for age*gender ($F_{(2, 159)} = 1.327$, $p = 0.268$), age*task ($F_{(8, 159)} = 0.668$, $p = 0.719$), gender*task ($F_{(4, 159)} = 1.565$, $p = 0.186$), or age* gender*task ($F_{(8, 159)} = 0.643$, $p = 0.741$).

Figure 8 shows the time required to complete the tasks depending on the age of the drivers. Like the NASA-TLX test results, the drivers used the most time performing the V-M task and required more time for the M-P and V-P tasks than for the M-O and V-O tasks. More precisely, it took 3.55 times longer to complete the M-P task than the M-O task and 2.47 times longer to complete the V-P task than the V-O task. They took more time to finish visual tasks than manual tasks, i.e., 3.20 times longer to complete the V-O task than the M-O task and 2.22 times longer to complete the V-P task than the M-P task. For reference purposes, they also took 1.11 times longer to complete the V-M task than the V-P task. The standard deviation of the times required to complete the tasks for a given age of driver was lower than the results of the NASA-TLX test, showing that the driving workload experienced by drivers was not significantly different for drivers in the same age group. On average, older drivers required 3.79 s (maximum 8.35 s for V-M, minimum 0.2 s for M-O) longer than



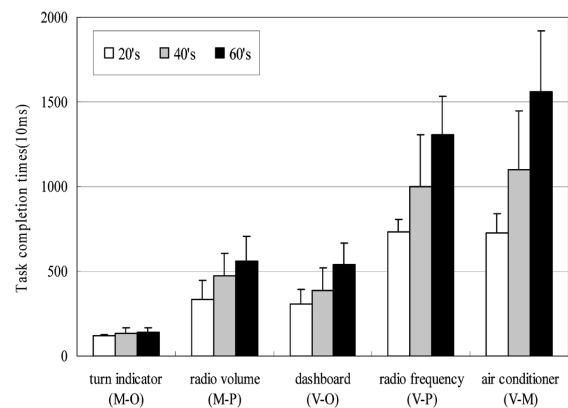Figure 7. NASA-TLX task assessment results by gender for five in-vehicle tasks.



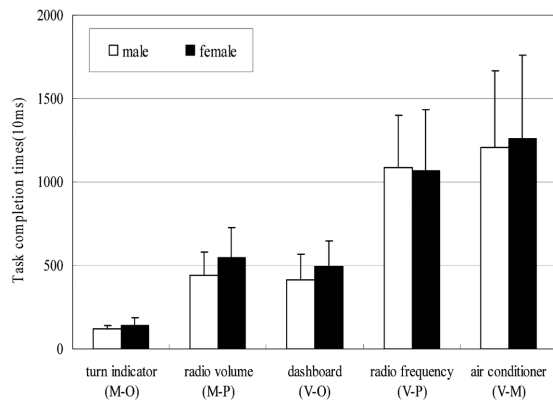Figure 8. Task completion times by age group for five in-vehicle tasks.

Figure 9. Task completion times by gender for five in-vehicle tasks.

drivers in their 20s, and 2.04 s (maximum 4.58 s for V-M, minimum 0.05 s for M-O) longer than drivers in their 40s. In particular, older drivers required far more time to complete V-P and V-M tasks, which were relatively more difficult; they spent 13.08 s and 15.60 s, respectively, on these tasks.

Figure 9 shows the time required to complete the tasks depending on the gender of the drivers. Female drivers spent 1.25 times longer completing the M-P task and 1.19 times longer completing the V-O task than male drivers. There were no significant differences for other tasks. The time taken to complete the task showed statistically significant differences by age (F(2, 168) = 79.291, p = 0.000), gender (F(1, 168) = 21.750, p = 0.000), task (F(4, 168) = 193.740, p = 0.000), and age*task (F(8, 168) = 10.686, p = 0.000) but not by age*gender (F(2, 168) = 1.822, p = 0.165), gender*task (F(4, 168) = 1.619, p = 0.172), or age* gender*task (F(8, 168) = 0.689, p = 0.701).

The results of the in-vehicle experiments indicated that older drivers experienced more driving workload when operating information devices than did younger drivers; they took 3.79 s longer to complete the tasks on average, with a maximum of 8.35 s longer for the difficult V-P task, which indicates that older drivers are more likely to be involved in traffic accidents due to the high driving workload when they operate information devices while driving. Moreover, compared to the other drivers, older drivers had more difficulty completing the V-P and V-M tasks, which were relatively more complicated; they required 3.96 times longer to complete the V-O task than the M-O task, 2.33 times longer to complete the V-P task than the M-P task, and 1.19 times longer to complete the V-M task than the V-P task. A number of older drivers even abandoned some of the more complicated device operation tasks so that they could concentrate on driving.

According to the standards for preventing distraction due to the operation of information devices published by the National Highway Traffic Safety Administration (Bischoff,

2007; Li *et al.*, 2002), operating a device should require less than 2 s and the total visual task time should not exceed 15 s to prevent traffic accidents related to distracted driving (Bischoff, 2007; Li *et al.*, 2002). Moreover, it is recommended that drivers should not glance at the device more than 10 times. However, older drivers spent 13.08 s and 15.60 s to complete the V-P and V-M tasks, respectively, which indicates that they are more likely to be involved in traffic accidents when they operate these devices while driving. Therefore, to reduce the driving distraction of older drivers, the interface of these devices should be modified so that the V-P and V-M tasks require less than 15 s to complete.

## 4. SUMMARY AND CONCLUSION

This study measured the driving workload of drivers, including older drivers, through in-vehicle experiments after generalizing information device operations. It categorized the device operations into five tasks based on visual and manual demands and assessed the workload while completing these tasks in a car during actual road tests. Distraction guidelines were included and can be used for designing information devices by considering the driving workload and distraction of older drivers. The conclusions of this study are as follows.

First, older drivers showed statistically significant differences in the NASA-TLX scores and the time to complete the tasks. However, there were no significant differences in the time based on the gender of the drivers.

Second, older drivers needed more time to finish the tasks than did drivers in their 20s; older drivers spent 3.79 s longer on average to complete a given task and 8.35 s longer on the most difficult task, which indicates that, when designing the user interface of information devices for intelligent vehicles, it must be taken into consideration that older drivers need more time to operate the devices, such as navigational devices or the radio, than do younger drivers.

Third, older drivers tend to exceed the distraction guideline values when they complete relatively complicated tasks. Because greater distraction leads to more accidents, methods of reducing distraction for older drivers are required when designing information devices for intelligent vehicles.

Follow-up studies are required to set standards for quantifying the driving workload and distraction of older drivers using the driving performance. In addition, follow-up research is required on methods of applying the results of the driving workload analysis to the design of information devices for intelligent vehicles.

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