Impact of Traffic Environment and Cognitive Workload on Older Drivers' Behavior in Simulated Driving

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As the use of in-vehicle technologies became more popular, there is concern about a concomitant increase in driver distraction arising from their use. While the introduction of voice recognition systems is intended to reduce the distraction due to manual operation of these units, a significant proportion of the distraction associated with their use may arise not from the manual manipulation but rather the cognitive consequences. It is also known that the risk of inattentive driving varies with age. In this study, the impact of cognitive workload and traffic environments on older drivers' behavior was investigated in a driving simulator. To assess the impact of advancing age on driving performance degradation under a dual task condition, the performance of 63 drivers, divided into younger (20–29) and older (60–69) age groups, was evaluated. The authors also considered driving behavioral differences in the context of urban and highway driving, appropriately counterbalanced. At a specified location in the two scenarios, subjects were asked to complete a series of auditory tasks of increasing complexity. Comparisons of younger and older drivers' driving performance, including forward velocity, speed control, standard deviation of lane position and steering wheel reversal rate, were conducted. Results indicated that age and traffic environment impact both driving performance and compensatory behavior during dual task conditions.

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1. Introduction

It is known that multiple tasks, such as mobile phone use and navigation system operation, while driving cause inattentive driving and lead to increasing accidents.[1] Although all drivers are impacted by additional workload, attentional management capacity decreases with age.[2-4] Despite older drivers' diminished attentional capacity, driving judgment increases with experience and age which may compensate for decreased capacity.[5] Thus, normally, older drivers manage very well, but in situations producing very high momentary mental workload, they sometimes fail with severe consequences.[6-10] According to a study by the Road Traffic Authority, the number of traffic accidents among older drivers aged 61 or older is steadily increasing, and about 69.1% of traffic accidents are caused by inattentive driving, such as failing to look forward, judgmental error, and delayed discovery. Typical causes of this inattentive driving are the operations of convenience and information systems, such as mobile phone and navigation systems.[11,12]

The European Union HASTE (Human Machine Interaction And the Safety of Traffic in Europe) project suggested an assessment protocol for evaluating the potential distraction and effect on driving performance of an In-Vehicle Information System (IVIS)[13,14] and an AIDE (Adaptive Integrated Driver-vehicle InterfacE) research project developed methods to reduce driving workload and inattentive driving related to ADAS (Advanced Driver Assistance Systems) and IVIS (In-Vehicle Information System).[15] In the U.S., a SAVE-IT (SAfety VEhicle using adaptive Interface Technology) project developed an adaptive vehicle interface for driver workload management to minimize the safety risk of distraction and enhance crash warning system effectiveness.[16,17]

However, there are few Korean domestic studies that evaluate the driving workload and behaviors of older drivers related to various information systems, such as mobile phone and navigation systems.[18] In particular, no domestic studies can be found on the effects of audible interface systems such as a voice recognition system that enables the operation of in-vehicle systems with voice on cognitive workload and driving abilities. For the design of a safe vehicle interface, we need to understand the effects of declining cognitive abilities due to age on driving abilities.

Accordingly, this study evaluated the driving performance of younger and older drivers during single task simulated driving and in response to the added demand of an audible cognitive task as a secondary task by observing the declining driving abilities of the older drivers and their compensatory behaviors. The main goal of this study was to provide basic data on the effect of cognitive workload on older drivers' behavior in different traffic environments.

2. Method

2.1 Equipments

The experiment was conducted on the DGIST fixed-based driving simulator, which incorporated a Mercedes-Benz™ Smart car and STISIM Drive™ software (see Figure 1). Graphical updates to the virtual environment were computed using STISIM Drive™ based upon inputs recorded from the OEM accelerator, brake and steering wheel which were all augmented with tactile force feedback. The virtual roadway was displayed on a 2.5m by 2.5m wall-mounted screen at resolution of 1024 x 768. Feedback to the driver was also provided through auditory and kinetic channels. Both urban and highway settings were simulated, using only daylight and dry road conditions. Driving distance, speed, steering, throttle, and braking inputs were captured at a sampling rate of 30 Hz.

2.2 Participants

To analyze the effects of cognitive workload on the driving behavior of older drivers, 61 participants were employed, as listed in Table 1. They have driven at least twice a week, had driving experience for 3 years or longer, and were able to participate in experiments for around 3 hours, including 1 hour of simulated driving. Of the 61 subjects, two male subjects in their 60s could not adapt to the environment of simulated driving and were excluded. Also, those who had illnesses, such as hypertension or diseases that required psychiatric treatment, were excluded. For compensation, 30,000 won was paid to each subject in their 20s and 50,000 won to each subject in their 60s.

Fig. 1 The DGIST Driving Simulator

2.3 Secondary Task

For the additional cognitive workload during the simulated driving, the n-back task, an auditory delayed recall task, was used.[19] The n-back was administered as a series of 30 second trials consisting of pre-recorded aural presentation of a series of single-digit numbers at an inter-stimulus interval of 2.5 seconds. With each digit presentation, the participants' task was to say out loud the "nth" stimulus back in the sequence. The task was given as a set of six trials, employing low demand in the first two trials (0-back), moderate demand in the second two trials (1-back) and high demand in the final two trials (2-back). The participants' verbal responses were recorded by using a microphone placed in the car cab.

2.4 Conditions

There were two different environment conditions, a 15km urban setting and 22km of highway. The simulated environment in both conditions consisted of two straight and level travel lanes in each direction. The urban road segments have about 30 intersections, traffic lights, and several pedestrians. Two 1km construction zones were added to increase driving workload in the urban setting. The highway was divided by an 8m landscaped median strip between opposing lanes of traffic. The environment traffic was slightly high in the urban road. The subjects performed the n-back tasks for each of these two different road settings. The order in which conditions were presented was balanced so that half of the participants drove in the urban first.

2.5 Questionnaire Data

Question wording and response categories for two questions considered in the analysis appear in Table 2.

2.6 Procedure

To analyze the effects of cognitive workload on the driving

Table 1 Distribution of Subjects by Age and Gender

Age	Gender	Mean (standard deviation)	*N*
20s	Male	25.31 (2.15)	16
	Female	25.25 (1.95)	16
Subtotal		25.28 (2.02)	32
60s	Male	65.00 (2.74)	13
	Female	64.19 (2.90)	16
Subtotal		64.55 (2.81)	29
Total		-	61

Table 2 Self-reported Items

Variable	Question Wording
Physical well-being	Think about how you feel today, how would you describe your current physical well-being? (a) Excellent, (b) Very Good, (c) Good, (d) Fair, (e) Poor
Effects of Memory Tasks	On a scale of 1 to 10 with 1 being not at all and 10 very much, on average how much do you think the number affected your driving? Please circle your response below. (1, 2, 3, … , 10)

behavior of older drivers while driving, the experimental protocol of Massachusetts Institute of Technology (MIT) was used.[9,20]

As shown in Fig. 2, the entire experimental procedure consisted of pre-experimental steps, simulated driving experiment, and post-experimental steps. The pre-experimental steps consisted of consent and overview, subject eligibility review, N-back training, simulator training, N-back pre-baseline, and pre-questionnaire. The post-experimental steps consisted of N-back post-baseline and post-questionnaire.

2.7 Performance Measures

As an indicator for estimating the reduced cognitive resource due to driving, the error rate of the n-back task was considered. Due to the fact that participants tended to give answers in similar cycles, response time was excluded from the evaluation indicators. In order to minimize the influence of individual factors, subjects underwent sufficient prior training for the n-back task before the simulated driving experiment. The error rate is a percentage of the times when subjects answer wrong numbers or give no answer to the numbers presented to them during the n-back experiment. It can be assumed that a higher error rate indicates higher cognitive workload.

For indicators of the compensatory behavior average forward velocity was used because some drivers have been observed performing compensatory behaviors, e.g., reducing their speed to manage the increasing workload.[8,9,20] Longitudinal controllability and lateral controllability were used as driving performance measures under cognitive workload, based on the assumption that accidents are prevented as long as the driver's performance is maintained above the environmental level.[21,22] The normalized average velocity and the percent coefficient of variation on velocity [(standard deviation/mean velocity) x 100%] were used for the longitudinal control ability indicator and standard deviation of lateral position and average steering wheel reversal rate which means number of steering wheel reversal counts per 100 meters were used for the lateral control ability indicator. In order to compare the forward velocity and speed variability between city and highway which have different speed limits, the normalized average and percent coefficient were used.

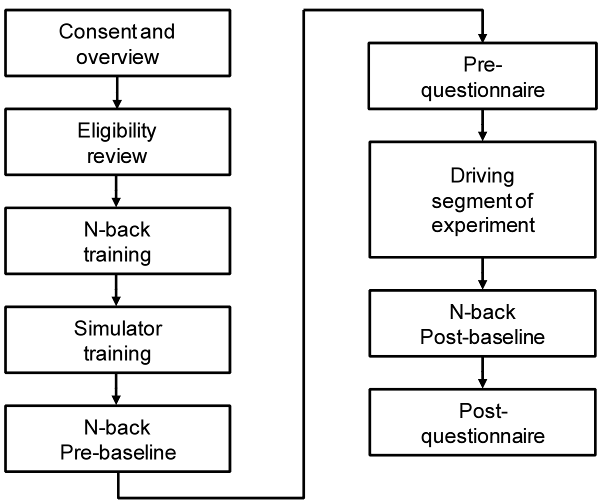

Fig. 2 Flowchart of Experimental Protocol

2.8 Analysis Method

SPSS version 14.0 was used to analyze the cognitive workload and driving performance in terms of the two independent variables of age and traffic environment. For the dual task management ability, an ANOVA analysis was conducted with the average n-back score of the pre-baseline and post-baseline and the n-back scores from the urban and highway driving. For the driving performance, a MANOVA analysis was conducted with forward velocity, longitudinal control, and lateral control from the periods of before, during, and following the n-back tasks.

3. Results

3.1 Self-Ratings

The two age groups reported almost same well-being ratings with reporting scoring of 3.0 and 2.9 for the younger and older groups (lower scores indicate more positive well-being ratings), so there was no significant difference (F(1,114)=0.014, P < 0.907). This result indicate the individual health conditions between 20s and 60s were almost same.

According to the self-rating of the effects of n-back tasks, the 20s group was affected slightly high with scoring 6.93 and 6.58 for the 20s and the 60s. But there is no significant difference was found (F(1,114)=0.385, P=0.538). This result indicates that both ages were affected by n-back tasks and it is consistent with cognitive task and driving performance results below.

3.2 Cognitive Task Performance

For the indicator for evaluating reduced cognitive resource due to driving, the error rates of the n-back task were used. Table 3 shows the average error rates before and after the simulated driving experiment as non-driving condition and the average error rates of the 0-back, 1-back and 2-back tasks during driving in urban and highway sections.

In the urban section, The n-back experiment showed a statistically significant difference in age (F(1,114)=88.836, P=0.000), but no significant difference was found in gender (F(1,114)=1.103, P=0.296). The n-back results showed significant differences between when the subjects were driving and when they were not driving (F(1,114)=7.390, P=0.008). The error rate during driving increased by 4.79% among subjects in their 20s and 12.32% among subjects in their 60s compared to when they were not

Table 3 Secondary Task Error Scores

Age Group	Non-driving	Dual task	
		Urban	Highway
20s	4.43 (6.77)	9.22 (9.42)	7.60 (9.98)
60s	29.81 (24.56)	42.13 (21.51)	33.67 (22.22)

1) Note: mean (standard deviation)

2) Significance Probability (* *p*<.05, ** *p*<.001)

	Age	Gender	Workload
Urban	**	-	*
Highway	**	-	-

driving. In the highway section, the n-back experiment showed a statistically significant difference in age ($F(1,114)=68.800$, $P=0.000$), but no significant difference was found in gender ($F(1,114)=2.808$, $P=0.097$). However, the n-back results did not show a significant difference between when the subjects were driving and when they were not driving ($F(1,114)= 1.283$, $P=0.260$). This result seems to be related to the different level of cognitive workloads were required in different traffic environments and the compensatory behaviors of lowering speed. In other words, the drivers seemed to minimize cognitive workload from driving and tried to focus on the n-back task by reducing speed sufficiently in the highway section, which has a lower driving workload than the urban section. As a result, they maintained a similar cognitive ability to the non-driving condition, and the difference in error rates between the existence and no existence of dual task was not high. For the 60s group, the average speed during the n-back task decreased by 9.5% in the highway section, whereas it decreased by 7.0% in the urban section. The error rate in the highway section increased by 3.17% among the 20s and 3.86% among 60s during the simulated driving compared to non-driving. Thus, it can be suggested that the increase in error rate was lower in the highway compared to the urban section.

3.3 Driving Performance by Cognitive Workload

To analyze the effects of the complexity of traffic environment and cognitive workload on driving performance, this study evaluated forward velocity, longitudinal control ability, and lateral control ability. Under the cognitive workload condition, the effect of gender on driving performance was found to show a statistically significant difference only for lateral control.

3.3.1 Forward Velocity

To observe the compensatory behaviors under cognitive workload conditions by age, forward velocity was used as an evaluation indicator. In order to compare the forward velocity in the urban and highway sections, the normalized mean velocity divided by the speed limit (60 km/h in the urban section, 100 km/h in the highway section) was used. The results for forward velocity are shown in Fig. 3.

Forward velocity did not show a statistically significant difference by age ($F(1,354)=1.235$, $P=0.267$) or by environments between urban and highway sections ($F(1,354)=2.038$, $P=0.154$). However, it showed a significant difference among before, during, and after the n-back task ($F(2,354)=9.439$, $P=0.000$). The forward velocity also showed a statistically significant difference by age*environment interaction ($F(1,354)=17.843$, $P=0.000$).

As shown in Fig. 3, the forward velocity decreased during the n-back task and recovered after the n-back task. This tendency was clearer in the highway section. When comparing the forward velocity between without and with the n-back task, it decreased by 5.7% for the 20s groups and by 9.5% for the 60s group during the n-back task in the highway section, whereas in the urban section, it decreased by 2.5% and 7.0%, respectively. This result shows that a secondary task has a higher influence on the primary task (driving) in the highway section. As mentioned in 3.2 regarding the compensatory behaviors of lowering speed under cognitive workload, the reason for this result seems to be that the subjects concentrated on the n-back task more in the highway section, which has a lower driving workload compared to the urban section. The result also shows that the interaction between age and environment was significantly different. The reason seems to be that the 20s group could keep their speed relatively high because of their sufficient cognitive capability. However, it is unclear that there is no difference between before and during in the young drivers for the urban section. It can be argued that the 60s group (21.5 years) had more driving experience than the 20s group (4.9 years) and the younger driver moderated the speed at the beginning of complex driving environment.

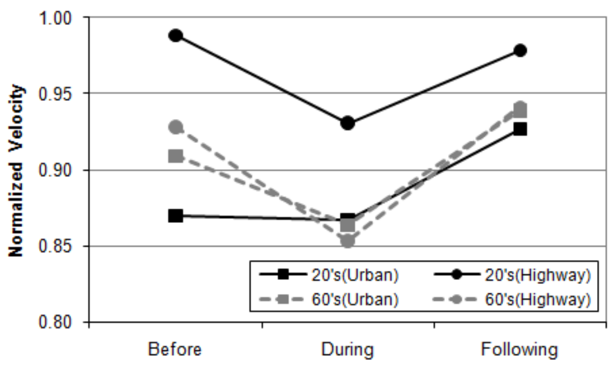

Fig. 3 Normalized Velocities by Age and Environment

3.3.2 Longitudinal Control

For the evaluation indicator of driver's longitudinal control ability, the coefficient of variation on velocity [(standard deviation/mean velocity) X 100] was used. As shown in Fig. 4, the results showed a statistically significant difference by age ($F(1,354)=24.978$, $P=0.000$), but no significant difference was found by the environment between urban and highway sections or by the existence of a dual task ($F(1,354)=2.346$, $P=0.097$).

The resulting graph shows that the variation in velocity was generally higher in the urban section than in the highway section. This indicates that longitudinal control is more difficult in the urban section. The 60s group exhibited increasing speed variation during

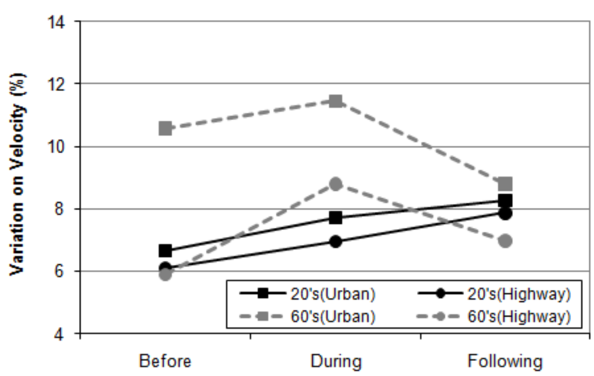

Fig. 4 Percent Coefficient of Variation on Velocity by Age and Environment

the n-back task but the variation was decreased again after the n-back task. For the 20s group, on the other hand, although speed variation increased during the n-back task, it did not decrease after the n-back task. It seems that the 20s group had sufficient cognitive management ability even when driving and their speed control ability was not greatly affected by the traffic environment and cognitive workload under a dual task condition.

In contrast, the results of the 60s group show that the variation in speed control between without and with the n-back task increased by 15.4% in the urban section and 26.8% in the highway section. This suggested that the longitudinal control ability of the 60s group is highly affected by cognitive workload and the environment.

3.3.3 Lateral Control

For the evaluation indicator of lateral control, the standard deviation of the lane position and the steering wheel reversal rate[25] were used. The analysis results of the standard deviation of lane position are shown in Fig. 5. Statistically significant differences were found by age ($F(1,354)=6.438$, $P=0.012$), environment ($F(1,354)=11.332$, $P=0.001$), and between the existence and no existence of the n-back task ($F(1,354)=7.518$, $P=0.001$).

As shown in Fig. 5, the variation in the lane position decreases during the n-back task and increases again after the experiment-back task. If we compare the standard deviation of lane position between without and with the n-back, it decreased by 27.7% for the 20s group and by 47.6% for the 60s group during the n-back task in

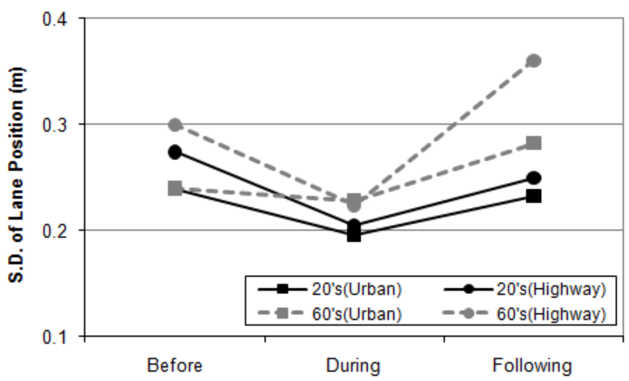

Fig. 5 Standard Deviation of Lane Position by Age and Environment

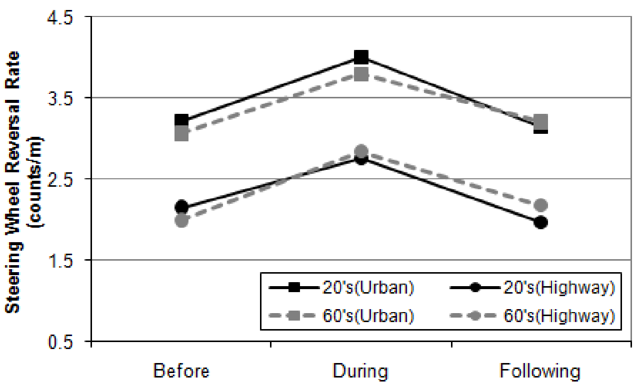

Fig. 6 Steering Wheel Reversal Rate by Age and Environment

the highway section, whereas in the urban section, it decreased by 20.6% and 14.3%, respectively. The result seems to indicate the subjects' lateral control ability increased under a cognitive workload.

The analysis results of the steering wheel reversal rate shows in Fig. 6. Statistically significant differences were found by environment ($F(1,354)=124.875$, $P=0.000$) and the secondary workload ($F(1,354)= 25.046$, $P=0.000$), but there was no difference by age ($F(1,354)=0.094$, $P=0.759$). The reversal rates were increased while the secondary tasks were added. This result suggests that high values of the steering wheel reversal rate mean high driving workload. This relationship is consistent with Macdonald's study.[25]

According to those results, two evaluation indicators of the lateral control ability showed opposite results. The standard deviation of lane position indicated an improved lateral controllability under a cognitive workload, whereas the steering wheel reversal rates indicated a poor lateral controllability under the workload. In the discussion, it will be considered which indicator is better for evaluating an effect of cognitive workload.

4. Discussion

4.1 Effects of cognitive workload

The lower average velocities adopted by both age groups for the cognitive workload conditions were a compensatory strategy to increase safety margins for errors when they were overloaded.[10,23] This was more pronounced for the 60s group, because an individual's capacity to manage multiple tasks simultaneously generally decreases with age.[2,3] This finding is compatible with previous studies, which were done by McDowd[2] et al., Rogers and Fisk,[3] showing that older drivers have less total capacity for engaging in secondary tasks.

In this study, four evaluation indicators for the cognitive workload were used. For the longitudinal control ability, the forward velocity could indicate the cognitive workload well whereas the velocity variation did not provide clear clues for the cognitive workload by the 20s. As mentioned in the driver workload metrics project final report, the cognitive distraction effects are very subtle and are not monolithic.[24]

However, the lateral control ability measures including the standard deviation of lane position and the steering wheel reversal rate were more indicative for the cognitive workload, but the values of each measure have opposite meanings. In order to judge which value is true, we can use the self-ratings of the effects of the cognitive workload. The average score was 6.75 out of 10. This suggests that the participants thought they were affected by the n-back tasks and the values of the steering wheel reversal rate were more appropriate for the cognitive workload indicator.

4.2 Effects of environmental complexity

The 60s group drove slower than the 20s group under highway condition. When mental workload demands increased with the introduction of the n-back task, all participants as a group showed a reduction in highway driving speed. In the urban driving conditions, the older drivers again showed the marked drop in driving speed in response to the dual task condition. However, in contrast with the highway environment, the older participants drove at a higher rate of speed than their younger cohort during the initial and the rest of the urban driving environments, even with the marked drop that occurred during the dual task.

In longitudinal control ability, the 20s group exhibited constant speed control ability regardless of traffic environment, whereas the 60s group showed considerably lower speed control ability in the urban driving condition. This finding is compatible with Horberry's study which found that the younger group deviated less from the speed limit than older group.[10] The reason for this is that the older drivers depend on such compensatory behavior as reducing speed when the road situation becomes complex.

4.3 Age-related effects

The performance errors on the n-back task were higher for older participants in the non-driving assessment and increased markedly during driving. As would be expected based on age related declines in cognitive capacity,[2,3] older group had significantly more difficulty with the cognitive task under both non-driving and driving conditions.

The ability to manage varying levels of cognitive workload is an essential aspect of safe driving. When demands on attention are high relative to available resources, one compensatory strategy for increasing safety margins is to moderate driving speed.[24] This strategy is more pronounced for the 60s group, because an older driver's capacity to manage multiple tasks simultaneously is decreased with age. This strategy makes differences in longitudinal control ability by age. It was shown that the longitudinal control ability of the 60s group is highly affected by cognitive workload and the environment.

There was no notable difference in the steering wheel reversal rate, which is more appropriate for the cognitive workload indicator in the lateral control ability.

5. Conclusions

This study intended to observe the declining driving abilities of older drivers and their compensatory behaviors, and provide basic data on the effect of cognitive workload on older drivers' behavior in different traffic environments. For this purpose, a simulated driving experiment with drivers of ages in their 20s and 60s was conducted, and the following conclusions can be made:

Firstly, the older drivers showed a greater decline in cognitive resource under a dual task condition compared to the younger drivers. A comparison between simulated driving and non-driving conditions found that the effect of the cognitive workload was not high in the highway section but it was high in the urban section for the older drivers. That is, the older drivers were more vulnerable to a complex road environment. This result is compatible with Horberry's study which found that drivers over the age of 60 appear to attempt to compensate for the effects of the secondary tasks by driving more cautiously than younger drivers in the complex environment.

Secondly, when cognitive workload increased due to dual tasks, all drivers tried to ensure the cognitive ability by reducing speed, and the tendency was more visible among the 60s age group. As a result, the longitudinal control ability of the older drivers declined considerably. Because such excessive compensatory behavior can interfere with traffic flow and safe driving, the interfaces of in-vehicle devices that older drivers have to operate while driving need to be designed so that they are less complex and easier to use for safe driving.

Thirdly, both the 20s group and the 60s group showed improved in lane keeping performance under a dual task condition, but the steering performance was decreased with showing more correction movements. As mentioned in 4.1, the steering wheel reversal rate is more intuitive measure for evaluating the cognitive workload.

Based on the above results, we found that older drivers show different cognitive resource management and driving performance compared to younger drivers. Thus, in-vehicle interfaces need to be designed in consideration of these characteristics of the older drivers. Even if voice recognition technology allows drivers to keep looking forward, their situational awareness may decline due to the cognitive workload. This study did not consider the difficulty in the use of audible interface, the correlations between the difficulty and the N-back task, and the comparison of driving performance between simulated driving and actual driving. These issues will be considered in the future studies.

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REFERENCES

1. Stutts, J. C. and Hunter, W. W., "Driver inattention, driver distraction and traffic crashes," Institute of Transportation Engineers Journal, Vol. 73, No. 7, pp. 34-45, 2003.
2. McDowd, J. M., Vercruyssen, M. and Birren, J. E., "Aging, Divided Attention, and Dual-task Performance, in: Damos, D. L. (Ed.), Multiple-Task Performance," Taylor & Francis Ltd., pp. 387-414, 1991.
3. Rogers, W. A. and Fisk, A. D., "Understanding the Role of Attention in Cognitive Aging Research, in: Birren, J. E. and Schaie, K. W. (Eds.), Handbook of the Psychology of Aging," Elsevier Science, pp. 267-287, 2001.

4. Coughlin, J. F. and Reimer, B., "New Demands from an Older Population: An Integrated Approach to Defining the Future of Older Driver Safety," Proc. of SAE Convergence Conference, Paper No. 2006-21-0008, 2006.

5. Reimer, B., Mehler, B., Coughlin, J. F., Wang, Y., D'Ambrosio, L. A., Roy, N., Long, J., Bell, A., Wood, D. and Dusek, J. A., "A comparison of the effect of a low to moderately demanding cognitive task on simulated driving performance and heart rate in middle aged and young adult drivers," Proc. Int. Conf. Cyberworlds, pp. 493-500, 2008.

6. Reimer, B., "Cognitive Task Complexity and the Impact on Drivers' Visual Tunneling," Transportation Research Record, Vol. 2138, pp. 13-19, 2009.

7. Hakamies-Blomqvist, L., Mynttinen, S., Backman, M. and Mikkonen, V., "Age-related differences in driving: Are older drivers more serial?" International Journal of Behavioral Development, Vol. 23, No. 3, pp. 575-589, 1999.

8. Harms, L., "Variation in drivers' cognitive load: Effects of driving through village areas and rural junctions," Ergonomics, Vol. 34, No. 2, pp. 151-160, 1991.

9. Son, J., Reimer, B., Mehler, B., Pohlmeyer, A. E., Godfrey, K. M., Orszulak, J., Long, J., Kim, M. H., Lee, Y. T. and Coughlin, J. F., "Age and cross-cultural comparison of drivers' cognitive workload and performance in simulated urban driving," International Journal of Automotive Technology, Vol. 11, No. 4, pp. 533-539, 2010.

10. Horberry, T., Anderson, J., Regan, M. A., Triggs, T. J. and Brown, J., "Driver distraction: The effects of concurrent in-vehicle tasks, road environment complexity and age on driving performance," Accident Analysis and Prevention, Vol. 38, No. 1, pp. 185-191, 2006.

11. Wang, J., Knipling, R. R. and Goodman, M. J., "The role of inattention in crashes; new statistics from the 1995 crashworthiness data system (CDS)," 40th Annual Proceedings: Association for the Advancement of Automotive Medicine, pp. 377-392, 1996.

12. Stutts, J. C., Reinfurt, D. W., Staplin, L. and Rodgman, E. A., "The role driver distraction in traffic crashes," Report Prepared for AAA Foundation for Traffic Safety, 2003.

13. Anttila, V. and Luoma, J., "Surrogate in-vehicle information systems and driver behaviour in an urban environment: A field study on the effects of visual and cognitive load," Transportation Research Part F: Traffic Psychology and Behavior, Vol. 8, No. 2, pp. 121-133, 2005.

14. Merat, N., Anttila, V. and Luoma, J., "Comparing the driving performance of average and older drivers: The effect of surrogate in-vehicle information systems," Transportation Research Part F: Traffic Psychology and Behavior, Vol. 8, No. 2, pp. 147-166, 2005.

15. Patten, C. J. D., Kircher, A., Östlund, J., Nilsson, L. and Svenson, O., "Driver experience and cognitive workload in different traffic environments," Accident Analysis & Prevention, Vol. 38, No. 5, pp. 887-894, 2006.

16. Donmez, B., Boyle, L. N., Lee, J. and McGehee, D. V., "Drivers' attitudes toward imperfect distraction mitigation strategies," Transportation Research Part F: Traffic Psychology and Behavior, Vol. 9, No. 6, pp. 387-398, 2006.

17. Dingus, T. A., Klauer, S. G., Neale, V. L., Petersen, A., Lee, S. E., Sudweeks, J., Perez, M. A., Hankey, J., Ramsey, D., Gupta, S., Bucher, C., Doerzaph, Z. R., Jermeland, J. and Knipling, R. R., "The 100-car naturalistic driving study," Report No. DOT HS 810 593, NHTSA, 2006.

18. Koo, T.-Y., Park, K.-J., Kim, B.-Y., Kim, H.-J. and Suh, M.-W., "A study on driver's workload of telematics using a driving simulator: A comparison among information modalities," Int. J. Precis. Eng. Manuf., Vol. 10, No. 3, pp. 59-63, 2009.

19. Zeitlin, L. R., "Subsidiary task measures of driver mental workload: A long-term field study," Transportation Research Record, Vol. 1403, pp. 23-27, 1993.

20. Reimer, B., Mehler, B., Son, J., Pohlmeyer, A. E., Orszulak, J., Long, J. and Coughlin, J. F., "A cross cultural comparison of younger and older adults' simulated highway driving performance under single and dual task conditions," Proc. of the 5th International Symposium on Human Factors in Driver Assessment, Training and Vehicle Design, 2009.

21. Roskam, A. J., Brookhuis, K. A., Waard, D., Carsten, O. M. J., Read, L., Jamson, S., Ostlund, J., Bolling, A., Nilsson, L., Anttila, V., Hoedemaeker, M., Janssen, W. H., Harbluk, J., Johansson, E., Tevell, M., Santos, J., Fowkes, M., Engstroem, J. and Victor, T., "HASTE Deliverable 1: Development of experimental protocol," Report of European Project HASTE (Human machine interface And the Safety of Traffic in Europe), 2002.

22. Michon, J. A., "A critical view of driver behaviour models. What do we know, what should we do? in: Evans, L. and Schwing, R. C. (Eds.), Human Behaviour and Traffic Safety," Plenum Press, pp. 485-520, 1985.

23. Haigney, D. E., Taylor, R. G. and Westerman, S. J., "Concurrent mobile (cellular) phone use and driving performance: task demand characteristics and compensatory processes," Transportation Research Part F, Vol. 3, pp. 113-121, 2000.

24. Angell, J. A., Austria, P. A., Kochhar, D., Tijerina, L., Biever, W., Diptiman, T., Hogsett, J. and Kiger, S., "Driver Workload Metrics Task 2 Final Report," NHTSA, Report No. DOT HS 810 635, 2006.

25. Macdonald, W. A. and Hoffmann, E. R., "Review of relationships between steering wheel reversal rate and driving task demand," Human Factors, Vol. 22, No. 6, pp. 733-739, 1980.