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A Study on the Correlation between Driving Behavior and Driver's Take-over Time of Level 3 Automated Vehicle on Real Roads

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Abstract *- Although automated vehicles have been actively researched, they are not widely commercialized because of legal liabilities and technical issues. One of the most complex issues is the liability during the takeover of control between the vehicle and driver as there is no criterion for the time required to notify the driver when automated driving becomes impossible. In order to study the criteria, many researchers implemented a simulator environment and recruited subjects to conduct tests and study. During autonomous driving, other behaviors are made, control is switched, and the driver's responsiveness is observed. For this purpose, an automated self-driven vehicle capable of driving on a real road was implemented in order to confirm the subject's responsiveness in a real environment. In addition, a human-factor-collecting environment and a takeover alarm environment were simulated in the vehicle. Approximately 600 take-over event cases from subjects in 70 people in their 20s to 60s were collected. According to the collected and analyzed results, it was confirmed that the difference in reaction time according to the behavior was confirmed, and that age also influenced the reaction time. In addition, through the distribution of response time of drivers, it was confirmed how much in advance the situation should be informed to the driver when automated driving is not possible. Finally, considerations for the operation of automated vehicles (Lv.3) were proposed based on the obtained results.*

Keywords — *autonomous, automated vehicle, driver performance, human factors, take-over request*

I. INTRODUCTION

Today, the automated vehicle technology is rapidly developing. Most related technology developments, however, are targeted at level 4 or higher, which pertains to completely automated driving.[1] However, there are still many restrictions on commercialization at such levels. This is because the situations to which automated vehicles cannot respond to still frequently occur on roads with various variables.[2] Rapid commercialization, however, is required for the development of the technology. Automated driving should be permitted at least in some situations, and then it can be gradually expanded. For automated driving in some situations, level 3 automated driving technology is required. In level 3 automated driving, a takeover of the control from the vehicle to the driver must be performed smoothly when there are sections where the automated vehicle cannot drive itself.[3] Thus, the driver must always be ready to accept the takeover request (TOR).[4] This is the key technology of level 3. For this, research on the driver-vehicle interaction (DVI) is essential.[5]

For the smooth implementation of the relevant technology, it is important to issue the TOR to the driver using an appropriate method and at an appropriate time when automated driving becomes impossible. However, the behavior of the driver will vary in free situations, and the response time will depend on the behavior of the driver during the issuance of the TOR.[6]

For a smooth takeover, the technology to monitor the driver is essential, and the behavior of drivers must be subject to legal restrictions. Notification has to be varied depending on the driver behavior and situation, and further considering that some unskilled drivers may not respond to the situation because they could not hear the notification well.[7][8]

In this field, many researchers have performed evaluations based on virtual environments.[9] This is because evaluations in actual environments involve a complicated process of making real automated vehicles and safety issues while automated driving is tested on real roads with ordinary people. It is difficult, however, to measure the human factor of drivers in simulations because they do not drive automated vehicles the same way as conventional vehicles.[10] Therefore, measurement in a real vehicle is essential to examine driver responses in an actual environment. In this study, an environment for testing automated driving in a real vehicle with ordinary people was constructed, and the results of the test conducted with 70 people were analyzed. The driver response speed according to the non-driving related tasks (NDRTs) and age was examined.[11] Based on the results, considerations for automated vehicles (Lv. 3) were proposed.

II. TEST ENVIRONMENT CONSTRUCTION

A. Implementation of automated vehicle functions

In this study, a level 3 automated vehicle that can drive itself on highways was constructed as shown in Fig. 1. For the vehicle to travel on real roads in South Korea, it must pass the test designated by the government and receive a license for automated driving.

Fig. 1. Level 3 automated vehicle

Accordingly, preliminary tests for safety were conducted with various devices installed in the vehicle, and an automated driving license was issued after passing the final test. As ordinary people sat on the driver's seat during the test, various additional safety devices were also installed. As a test supervisor always sat on the front passenger seat, a system for monitoring the vehicle condition at any time from the front passenger seat was effected. In addition, an emergency stop button for the test supervisor was implemented to turn off the automated driving mode at any time. A mechanical emergency braking device and a speed control device were also installed in case the driver could not respond, and the test environment was constructed so that intervention in steering could be possible at any time.

B. Survey on measurement items

A survey on measurement information was conducted to determine items to be measured in the test with the real automated vehicle. The opinions of 33 organizations and 70 experts (19 companies, 14 schools, and 4 research institutes) were collected. Based on the results, items to be measured were classified as shown in Table 1. A total of 193 items were defined and the measurement environment was constructed.

Table 1. Measurement environment

No.	Classification	Data Count
1	Subject Basic Information	107
2	Driver input and environment monitoring	37
3	Vehicle Behavior Monitoring	17
4	External environment monitoring	20
5	Control switch monitoring	12
	Total	193

C. Implementation of a TOR alarm environment

A test environment in which alarms can be issued by combining the visual, auditory, and tactile senses was implemented for the TOR to the test subject (driver) during automated driving. For the visual alarm, a five-inch display was implemented next to the navigation system as shown in Fig. 2. The speakers in the vehicle were used as the auditory alarm. For the tactile alarm, two haptic motors were embedded in the seat around the position of the thighs and vibration was generated through pulse width modulation(PWM) control.

Fig. 2. The visual alarm

Three types of visual information (Take over, Ready, and AutoDrive On) for notifying a takeover were implemented as shown in Fig. 3. For the auditory information, the notification selected through a survey on various existing notifications was used.[12] As shown in Fig. 4, a signal with two audible frequencies 880 and 1,760 Hz were reproduced four times at 50 and 30 ms intervals, respectively. It was reproduced three times at a magnitude of 65 db for 3 s and ten times at 75 db for 5 s. The tactile sense was not applied in the test.

Fig. 3. Three types of visual information

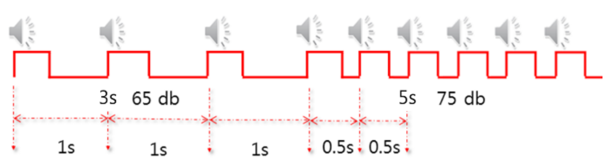

Fig. 4. The auditory information

D. Implementation of test subject measurement environment

Table 2. Response measurement environment

No.	Parameter	Acquisition Tool
1	Time to react to alert	Camera/ Pupil diameter
2	Time to regain control	Pedal Input/ FSR/ Steering Torque/ Steering Angle
3	Performance	
4	Method used to regain control/cancel automation	
5	Time to release control of steering	FSR/ Steering Torque
6	Time to resume non-driving task	FSR/ Steering Torque/ Eyetracker
7	Driving-related Glance	Eyetracker
8	Non-driving-related Glance	
9	Visually engaged in a Non-driving-related Task	
10	Holding Device-not visually engaged in a Non-driving-related Task	

To measure the responses of the test subjects, an environment was constructed as shown in Table 2. Basically, the input values of the steering torque, brake, and accelerator pedals of the driver obtained from the CAN of the vehicle were used. In addition, an FSR sensor was mounted on the steering wheel and pedal effort sensors were mounted on the pedals to detect even the slight responses of the driver as shown in Fig. 5.[13] An eye tracker was used to measure the gaze and heading angle of the driver, and the gaze of the driver was tracked using the eye tracker and a scene cam.[14] A sound level meter was placed to measure the magnitude of the sound heard by the driver, and the electrocardiogram (ECG) was measured to examine the biosignal response of the driver.[15] In addition, the pedal control and behavior of the driver were captured and stored using a camera to be referred to after testing. Temperature, humidity, and CO2 sensors were installed to measure the driving environment.

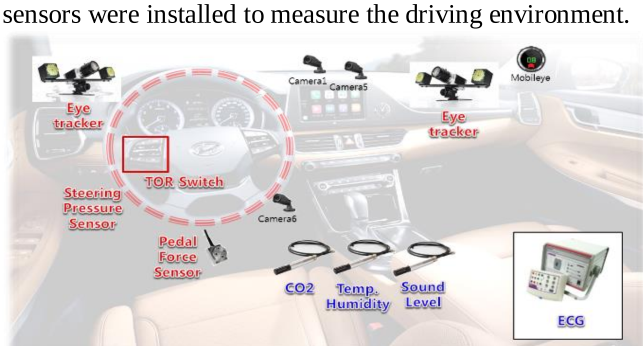

Fig. 5. Response measurement environment

E. Data acquisition environments

As it is difficult to control the surrounding environment for the test with real vehicles unlike in simulations, an environment for measuring as many surrounding environments and test conditions as possible was constructed to be used for further analysis as shown in Fig. 6.

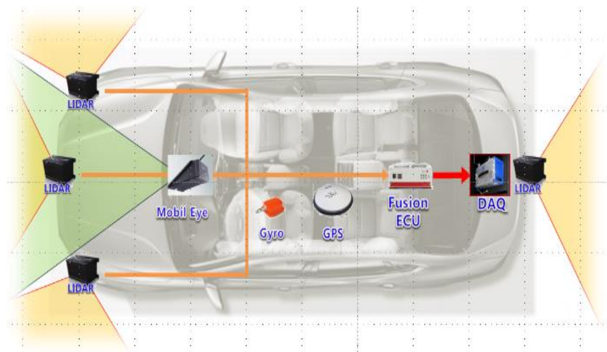

Fig. 6. Sensor data acquisition environment

LIDAR sensor was placed at surrounding positions to collect information on nearby vehicles, and the vehicle location and behavior information were measured using a GPS and gyro sensors. Moreover, various image data were acquired, and a system for synchronizing and storing all these signals was constructed.

III. TEST SCENARIO DESIGN

A. Test and course design

The purpose of the test is to accurately measure the response time of the drivers when the TOR was sent while they are performing various actions during automated driving. Therefore, highway sections with as many straight lines as possible were selected to increase the concentration of the test subjects on NDRTs. In addition, proper bifurcations existed and some planned TORs were included. In the total section of 114 km, approximately 94 km were highways. The test course was selected such that the total driving time could be approximately 1 h and 30 min.

B. NDRT selection and course application

Based on survey literature[16], priority tasks were selected as shown in Table 3, and NDRTs were applied during the test.

Among them, tasks, such as listening to music, were replaced with 1-back, a representative controlled NDRT, and used as the difficulty baseline of the tasks. The test scenario was constructed so that the selected NDRTs could be performed 17 times while driving in the test course and that 12 TOR events (two IC entries, four bifurcation entries, three lane instabilities, and three system failures) could occur.

Table 3. Specified NDRT based on workload V-A-C-P. (Vision, Auditory, Cognition, Psychomotor)

	Category	V	A	C	P
1	Sending a text	■		■	■
2	Eating/Drinking	■		■	■
3	Talking on the phone		■	■	△
4	Having a conversation with passenger		■	■	
5	Watching a video	■	■	■	△
6	Keeping an eye on the road	■		■	
7	1-back		■	■	

C. Test process design

The test was conducted in the sequence shown in Fig. 7. Questionnaires[17] for driver disposition analysis were filled in before the test, and questionnaires on the difficulties of the NDRTs related to the test were completed after the test. After the test, the driving capability and physical reaction speed of each test subject were measured using the driving capability measurement instrument. The total test time required was 2 h and 30 min. In this study, basic data, such as the genders and ages of the drivers, and only the results of the difficulties of NDRTs shown in Table 4 among the questionnaire contents were utilized.

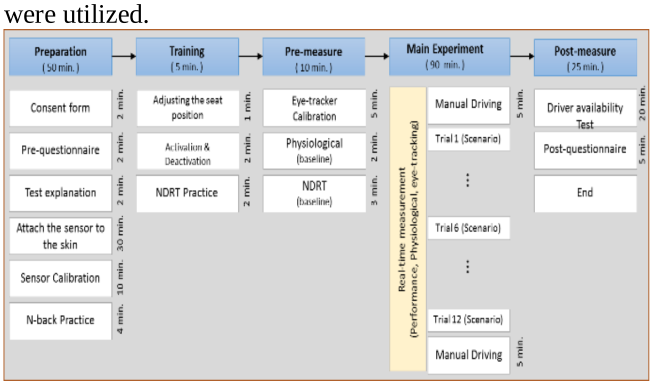

Fig. 7. Test process

Table 4. Utilized questionnaire contents

Utilized contents
How old are you?
What is your gender?
Which task was most disturbed when switching control? Number them in order. Talking on the phone ( ) Sending a text ( ) Watching a video ( ) 1-Back ( ) Eating ( ) Keeping an eye on forward road ( )

IV. TEST RESURTS

A. Test procedure

The test was conducted with 70 people as shown in Table 5. The total driving distance was 7,980 km, and 700 Take-over event cases occurred during the driving time of 105 h. 563 cases were used for the analysis.

B. Test results

For the test data analysis, the questionnaires on the difficulties of the NDRTs were analyzed first. When the difficulties were surveyed as shown in Table 4, the rankings were obtained as shown in Table 6. Many people answered that 'Sending a text' was the most difficult, and the actual response time was the slowest. It was found that the response time increased equally for the same difficulties when the TOR was received..

Table 5. Driver distribution

		Gender	
		Male	**Female**
Age	20s	7	7
	30s	7	7
	40s	7	7
	50s	6	7
	60s	7	8
Total		34	36

Table 6. Questionnaire ranking and response time

ID	**NDRTs**	**Survey Rank. (Avg.)**	**Response time[s]**	
			Avg.	**Std.**
A	Sending a text	1(2.4)	3.6	1.5
B	Talking on the phone	2(2.5)	2.7	1.8
C	Watching a video	3(2.6)	2.6	1.4
D	1-back	4(3.5)	2.3	1.3
E	Eating	5(4.2)	2.5	1.1
F	Eating and talking with passenger		2.0	0.7
G	Keeping an eye on forward road	6(5.7)	1.8	0.9

Next, the TOR speed by age group was analyzed. Table 7 shows the event case distribution and response speed of all age groups. There was no significant difference in the response speeds between the subjects in their 20s and 30s; however, it began to slow down for the subjects in their 40s. The subjects in their 60s exhibited significantly low reaction speeds.

The correlation analysis for the NDRTs and age group and gender distributions exhibited the correlation coefficient,(R2), as shown in Table 8, confirming that both have strong positive correlations. It was also confirmed that there was no difference in response time according to Gender.

Table 7. Distribution of response time by Gender

Age group	Response time[s]				TOR Event case	
	Avg.		Std.			
	Male	FeMale	Male	Female	Male	Female
20s	2.3	2.1	0.8	0.9	33	44
30s	2.1	2.3	0.7	1.1	62	76
40s	2.5	2.5	1.0	1.4	63	63
50s	2.7	2.6	1.8	1.5	56	58
60s	3.2	3.1	2.0	2.1	58	50
Total	**2.6**	**2.5**	**1.5**	**1.5**	**272**	**291**

Table 8. Correlation analysis

Correlation coefficient	**R2**
NDRTs VS Response time	0.913
Age Group VS Response time	0.950
Gender VS Response time	0.033

V. DISCUSSION

Table 9 shows the event case distribution for each NDRT, and the maximum response time for each distribution can be seen. Through this result, the time required to notify the driver of a necessary takeover is cautiously proposed as at least 6 s. This takeover time includes more than 99% of drivers who can respond in most NDRT situations during automated driving.

Table 9. Distribution of response time by NDRTs

ID	TOR Event Case	The maximum response time for each distribution[s]			
		75%	90%	95%	99%
A	75	4.1	5.1	7.4	8.1
B	110	3.2	4.4	5.5	10.6
C	122	3.1	4.0	5.3	8.2
D	121	2.8	3.4	3.9	8.5
E	57	2.9	3.8	4.2	6.7
F	25	2.6	3.0	3.2	3.5
G	53	2.2	2.5	3.1	5.8

Table 10. Distribution of response time by Age group

Age group	Response time[s]		TOR case	The maximum response time for each distribution[s]			
	Avg.	Std.		75%	90%	95%	99%
20s	2.2	0.9	77	2.6	3.7	4.0	4.6
30s	2.2	0.9	138	2.8	3.6	4.0	4.5
40s	2.5	1.2	126	3.0	3.9	5.1	7.9
50s	2.7	1.6	114	3.2	4.5	5.9	9.3
60s	3.2	2.0	108	4.1	5.6	7.6	10.3
Total	2.6	1.5	563	-	-	-	-

Table 10 shows the finding that the reaction became slower as the age of the driver increased means that the reaction time may increase as the driving capability or the motor nerve function decreases. Therefore, a separate license for driving automated vehicles (lv. 3) is required and this license must be issued only to drivers who meet specific criteria. This indicates a need for an evaluation device that can distinguish the capability to drive such vehicles, rather than simply placing limits depending on the age..

VI. CONCLUSION

In this study, efforts were made to measure the response time of drivers while driving an automated vehicle (lv. 3) in an actual environment. An environment for testing on a real road was constructed, and the test was conducted with ordinary people to analyze the response time according to NDRTs and ages.[18] Based on the test results, Factors influencing the driver's response time were verified. In this study, responses to visual and auditory notifications were investigated, and responses to the tactile sense were not considered. Moreover, as it was difficult for the drivers to recognize the visual notification device because it was located next to the navigation system, the results are significant only as to the effects of the auditory notification. To address this problem, the position of the visual notification has been changed and placed to the dashboard, and tests are being conducted by adding biosignals such as brain waves. In the course of this study, survey data for identifying the disposition of each test subject were collected and a test to measure the driving capability was conducted[19], but these information were not be dealt with in this study.[20] Such data will be used to present more in-depth research results in a future study.

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REFERENCES

[1] Society of Automotive Engineers, (2018), J3016 - Taxonomy and Definitions for Terms Related to On-Road Motor Vehicle Automated Driving Systems

[2] C.Jeong et al., Comparison of Driving Characteristics between Drivers in Korea and in the United States of America based on Driver-Vehicle Interaction Field Database. Int. J. Automotive Technology 1, 1, (2012), 101−112.

[3] Merat, N.; Jamson, A.H.; Lai, F.C.H.; Daly, M.; Carsten, O.M.J. Transition to manual: Driver behaviour when resuming control from a highly automated vehicle. Transp. Res. Part F Traffic Psychol. Behav. 27, (2014), 274–282, doi:10.1016/j.trf.2014.09.005

[4] Zeeb, K.; Buchner, A.; Schrauf, M. What determines the take-over time? An integrated model approach of driver take-over after automated driving. Accid. Anal. Prev.,78, (2015), 212–221, doi:10.1016/j.aap.2015.02.023

[5] Blanco et al., Human Factors Evaluation of Level 2 and Level 3 Automated Driving Concepts,(2015).

[6] Eriksson, A.; Stanton, N.A. Takeover Time in Highly Automated Vehicles: Noncritical Transitions to and from Manual Control. Hum. Factors, 59, (2017), 689–705, doi:10.1177/0018720816685832.

[7] Kwon, D.; Jung, E.S. Effects of Modalities of Non-driving Related Tasks on Driver"s Stress and Driving Performance during Autonomous Driving. Ergon. Soc. Korea, 38, (2019), 265–277.

[8] Kim, Y.W.; Yoon, S.H.; Ji, Y.G. The effect of cognitive attributes of non-driving related tasks on the takeover performance. 2019

[9] J. Son et al., Age and cross-cultural comparison of drivers' cognitive workload and performance in simulated urban driving, Int. J. Automotive Technology, 11, 4, (2010), 533-539.

[10] Eriksson, A.; Banks, V.A.; Stanton, N.A. Transition to manual: Comparing simulator with on-road control transitions. Accid. Anal. Prev. (2017), 102, 227–234, doi:10.1016/j.aap.2017.03.011

[11] Daesub Yoon et al., The measurement of drivers' workload and criterion, the Industry Source Technology Development Project, (2009~2014),the Ministry of Knowledge Economy

[12] J. Lee, J.H.Yang, Analysis of Driver's EEG Given Take Over Alarm in SAE Lelev 3 Automated Driving in a Simulated Environment, , Int. J. Automotive Technology. ,(2019)

[13] Ahlstrom, C.; Kircher, K.; Kircher, A. Considerations when calculating percent road centre from eye movement data in driver distraction monitoring. Proc. Fifth Int. Driv. Symp. Hum. Factors Driv. Assessment, Train. Veh. Des. (2009).

[14] Merat, N.; Jamson, A.H.; Lai, F.C.H.; Daly, M.; Carsten, O.M.J. Transition to manual: Driver behaviour when resuming control from a highly automated vehicle. Transp. Res. Part F Traffic Psychol. Behav. (2014), 27, 274–282, doi:10.1016/j.trf.2014.09.005

[15] Wandtner, B.; Schmidt, G.; Schoemig, N.; Kunde, W. Non-driving related tasks in highly automated driving - Effects of task modalities and cognitive workload on take-over performance. In Proceedings of the AmE 2018 - Automotive meets Electronics; 9th GMM-Symposium; (2018); pp. 1–6.

[16] Kyriakidis et al, Public opinion on automated driving: Results of an international questionnaire among 5,000 respondents. Transportation Research Part F: Traffic Psychology and Behaviour, 32, (2015), 127–140.

[17] French D et al., Decision making style, driving style and self-reported involvement in road traffic accidents. Ergonomics 36, (1993), 627-644.

[18] M. H. Kim, J. Son, On-road assessment of in-vehicle driving workload for older drivers: design guidelines for intelligent vehicles, Int. J. Automotive Technology, 12, 2, (2011), 265-272.

[19] West R et al., Direct observation of driving, self-reports of driver behaviour and accident involvement. Ergonomics 36, (1993). 557-567.

[20] West R et al., Decision making, personality and driving style as correlates of individual accident risk, Contractor report 309, (1992), Transport Research Laboratory.