Analysis of Driver Reaction State in Take-over from Automated to Manual Driving

Toshio Ito, Shibaura Institute of Technology, Japan, *tosi-ito@shibaura-it.ac.jp*, **Akihiro Abe,** Shibaura Institute of Technology, Japan, **Andrew Morris,** Loughborough University Design School, United Kingdom

ABSTRACT

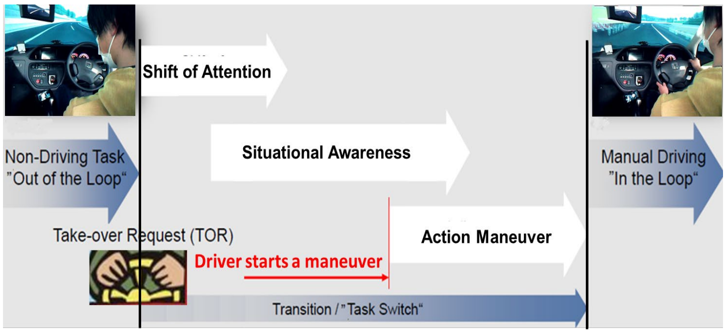
Automated driving at levels 3 normally has two kinds of take-overs; those that are planned and those in emergency situations. In the emergency case, there is concern that the awakening state of drivers is not stable and that in this situation the drivers' state involves the possibility of changing their reaction time. We classify the drivers' transition state after a take-over request (TOR) from automated driving to manual driving into three states. The states are "Shift of Attention", "Situational Awareness" and "Action Manoeuvre". This paper focuses on the drivers' sleepiness, and analyses their reaction time of the three states described above in different arousal levels by using driving simulator and brain waves. We show these three states do not change according to awakening states through experiments using a driving simulator. In our experiments, we found that the awakening state rose, the time of the Shift of Attention increased, the variability of the time in the Situational Awareness increased and the time of the Action Manoeuvre decreased. We found that these actions had been accelerated to compensate for the delay of the Shift of Attention, and most subjects finish their Action Manoeuvres within 2 seconds from the TOR regardless of arousal levels.

Keywords: automated driving, take-over, arousal level, Shift of Attention, Situational Awareness, Action Manoeuvre.

INTRODUCTION

Today, many Advanced Driver Assistance Systems (ADAS) that support various driver operations are well-developed and have been installed in vehicles. Formerly these are just "driving assistance" and only support driver operations. In other words, the driver has to monitor the HMI to ensure safety no matter what operation is supported. However, with advances in technology, future systems will involve "automated driving" and therefore, the vehicle will be able to drive by itself without the driver having to monitor the road ahead. SAE (2016) defined the relationship between the human driver and the automotive system through 6 levels from level 0 to level 5. According to this classification, level 0 involves fully 'manual operation' (No automation), level 1 is 'advanced driver support system', level 2 is 'provided with automated driving function', level 3 is 'exempted from driver's duty of forward monitoring', and level 4 and 5 systems can cope filly autonomously within most operating environments. Though level 3 systems are self-driving, they may stop if the system limits are exceeded. In this case, the system issues a TOR (take-over request) and the driver must transfer the operation from the system (It's called a take-over) and operate the vehicle manually. . That is, since the driver is not monitoring the forward direction during the automated driving, the forward direction monitoring effectively must be performed after the TOR is issued.

In a take-over, Ito (2016) divided driver behaviour into several phases. First, the driver shifts an attention to the front (Shift of Attention). Next, the driver recognizes the situation and considers what to do (Situational Awareness). Finally, the driver drives the vehicle (Action Maneuver). Abe (2018) comments that when the vehicle is on automated driving function, the human 'driver' may feel bored and drowsy as they are disengaged from the task of controlling the vehicle. Moreover, in previous research in Abe (2019), it was noted that the driver's steering operation after take-over became rough as arousal levels increased. Therefore, the driver's ability to take-over control is strongly affected by drowsiness. In general, when a driver feels drowsy, Philip (2005) showed that the response time becomes worse. However, such studies did not focus on take-over or reaction steps. The purpose of this study is therefore to clarify the effects of drowsiness on the take-over process by focusing on the driver's reaction from TOR to the end of driving operation. It is important to analyze the behaviour of the driver at Level 3, which is expected to be put into practical use in the near future, because the automated driving 'level' currently in practical use is Level 2.



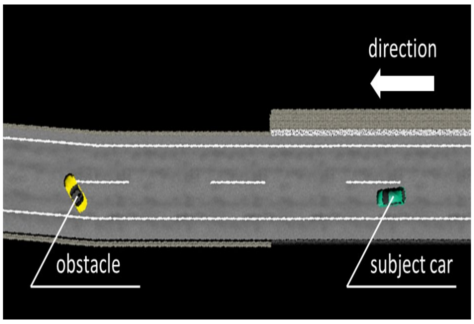


Figure 1 Phases of behaviour in take-over

Figure 2 Illustration of take-over environment

EXPERIMENT

2.1 Experiment Overview

A Take-Over Request (TOR) experiment was conducted by using a 6-axis driving simulator. In the experiment, participants experienced automated driving in a highway-like circuit (7 km per lap) over 40 minutes. During the automated driving phase, a steering wheel and throttle/brake pedals were operated automatically, and the steering wheel rotated automatically according to road layout. After this phase, an obstacle vehicle appeared in front of subject vehicle (see Figure 2). When the distance to obstacle vehicle was 90 meters, a TOR (4[kHz] intermittent sound) was provided from the driving simulator and the automated driving system stopped instantly. The driver then performed a take-over for the driving operation and avoided the collision. Each driver experienced this experiment three times.

2.2 Participants

The participants were 7 students (1 female) aged from 20 to 22 years old. All of them held a driver license. Before the experiment, they received information about the experiment and instructions regarding the function of automated driving system. The purpose of the study was withheld from them to avoid affecting the experiment results. Before the experiment started, they drove experiment course manually in order to get used to the driving simulator.

2.3 Analysis methods

Driver's arousal level was evaluated by the Facial expression evaluation developed by Kitajima (1997). This method uses driver's face video which was recorded during the experiment. After the experiment, multiple rates individually evaluated the driver's drowsiness into 5 Levels (Level 0: Does not look sleepy at all, Level 5: Looks very sleepy). Then, they compared the results with each other, and repeated the re-evaluation in mismatch section until matching.

The driver's reaction time was measured by using the facial video and operation log, and was divided into 5 phases shown in Table 1 and Figure 3. In Figure 3, the driver's eyes were closed when the TOR was provided (Phase 0). Then, the driver looked ahead of the vehicle (Phase 1), started to move his body in order to control the vehicle (Phase 2), held the steering wheel by both hands (Phase 3) and turned the steering wheel (Phase 4).

Table 1 Phases of driver's reaction

Phase	Driver's reaction	Corresponding with previous study
0	(TOR was provided)	-
1	Looking ahead	Shift of Attention
2	Starting to move	Situational Awareness
3	Holding steering wheel	Action Maneuver
4	Avoiding maneuver	

Figure 3; phases of driver's reaction (Numbers are phases shown in Table 1)

RESULTS AND DISCUSSION

3.1 Presence or absence of collision

In all experiments, there was no collision with the obstacle vehicle. All participants avoided the collision by the steering operation, and in 15 cases, (7 participants) they used brake pedal during the avoidance manoeuvre.

3.2 Arousal Level Classification

The driver's arousal level was classified by the video just before take-over occurred. Table 2 shows the classification result. There were no cases classified as Level 1, and almost half of the data (10 cases from 5 participants) were classified to Level 4.

Table 2 Result of facial expression evaluation

Sleepiness level		Number of data (Participant)
1	Not looks sleepy at all	0 (0)
2	Looks a little sleepy	2 (1)
3	Looks sleepy	6 (3)
4	Looks quite sleepy	10 (5)
5	Looks very sleepy	3 (3)

3.3 Reaction Time in Take-over

Figure 4 shows the average time of phases measured from TOR. In this experiment, "Looking ahead" was measured so short because some driver had looked in front of the vehicle before the TOR was provided. In this graph, Level 2 and 3 drivers performed a reaction quickly until "Starting to move". However, these margins disappeared when driver held steering wheel, and the final accumulated time was reversed.

Figure 4 shows that the time required for the driver to respond to take-over was less affected by arousal level. Of course, this time becomes longer if the driver falls asleep and the has to return to driving.

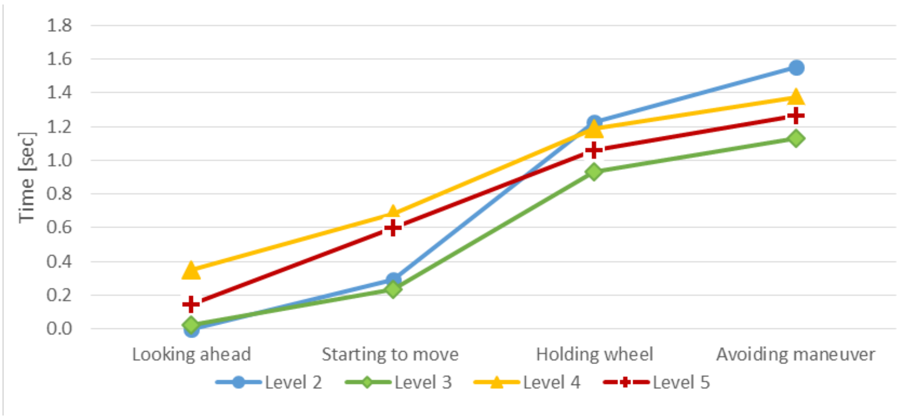


Figure 4; Average of accumulated time from TOR sounds

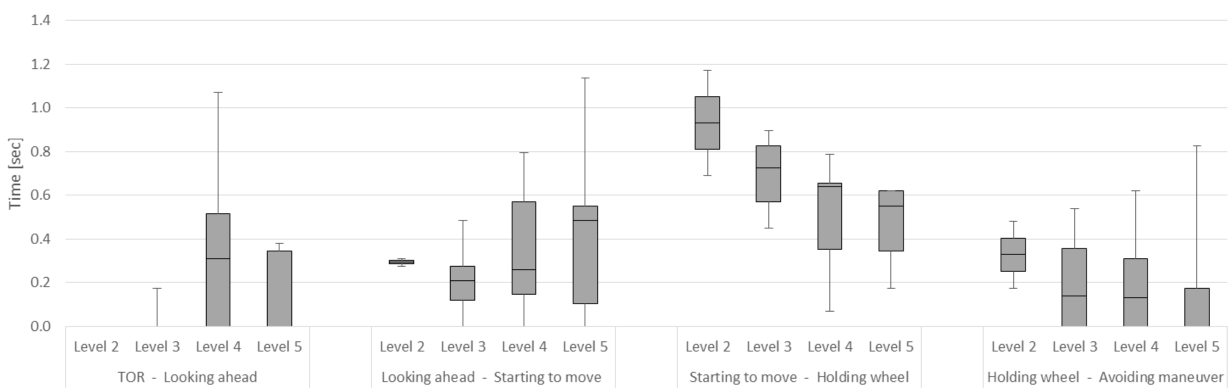


Figure 5 Time between reaction phases

Next, we focused on the distribution of the times between reaction phases. Figure 5 shows the different tendency between the before and after “Starting to move”. Before the body movement, Levels 4 and 5 driver’s reaction time was the same or longer than other levels. However, after this, the driver’s movement became faster. In particular, some drivers rotated steering wheel at the same time as he/she held it.

We suggest that the driver who experienced sleepiness didn't focus his/her attention on the surrounding environment. Therefore, time for "Shift of Attention" was longer than usual. The driver also needs to recognize what is happened, but this takes time because of sleepiness. After that, the driver tries to control the vehicle in a hurry in order to make up for lost time. As a result, he/she can start to manoeuvre earlier than usual. However, this is a trade-off of the time for a safety check. If there is less time for safety check, the driver may take inappropriate actions such as dangerous lane changing manoeuvres or sudden braking.

3.4 Maximum Difference of Brake Operation

As mentioned previously, the driver’s steering operation becomes inconsistent when the driver is in a ‘sleepy’ condition. To assess the effect of sleepiness on brake operation, we analysed the maximum difference of the brake operation for the driver who used the brake pedal during avoidance. The sampling frequency of brake operation was 0.01 second. According to the results shown in Figure 6, the brake operation became inconsistent gradually when the driver’s drowsiness was raised. It is considered that individual differences affected the results because these data vary widely.

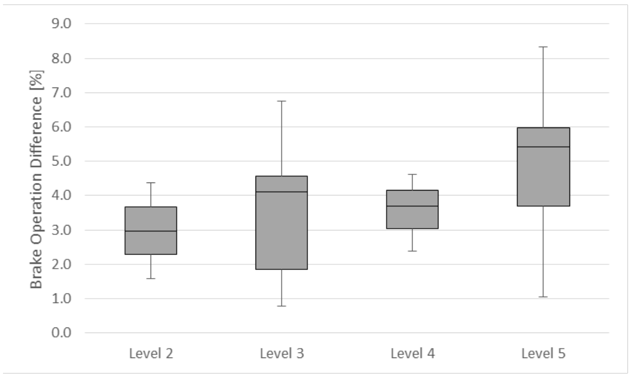


Figure6; Maximum difference of brake operation

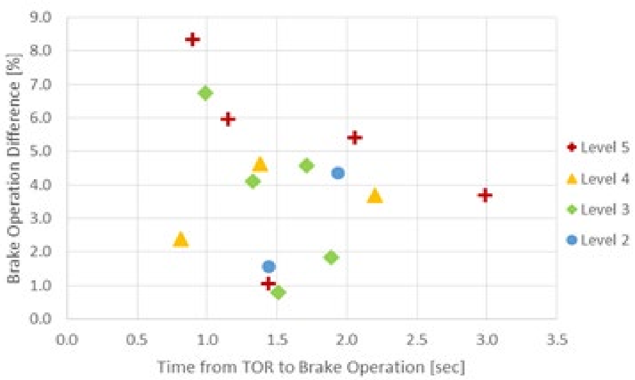


Figure 7; Relationship between the time using brake pedal and maximum difference value

The next result shown in Figure 7 is the comparison between “time from TOR to brake operation” and “maximum difference of brake operation”. The worst values for each axis are at level 5. However, there is not an obvious tendency. It seems that inconsistent brake operation is not caused by the delay in response.

CONCLUSION

This study focuses on the driver's behaviour during the transition from automated driving to manual driving. Seven students were tested in a driving simulator and their responses were analyzed by reaction stage. The results showed that "Situational Awareness" and "Shift in Attention" took longer when arousal levels were high. However, subsequent behaviour "Action Manoeuvre" was shorter than normal. This is considered to be a compensation action for response delay, however may cause insufficient safety confirmation or improper operation. Drowsiness of the driver not only affects the steering operation but also causes inconsistent braking operation. The cause appears to be more than a delay in response, and further studies are needed to identify the cause. Therefore, in the case of automated driving with at least one take-over, it is necessary to monitor the arousal level when the driver does not monitor the vehicle in the forward direction during the automated driving, and therefore a mechanism to eliminate the drowsiness of the driver is required depending on the situation of the driver. In future studies of this subject matter, additional experiments will be conducted for other participants to improve reliability. The authors will also develop a system that can manage driver drowsiness for safe automated driving.

REFERENCES

SAE (2016). Taxonomy and Definitions for Terms Related to Driving Automation Systems for On-Road Motor Vehicles, SAE J3016-201609

Ito, T., Takata, A., and Oosawa, K. (2016) Time Required for Take-over from Automated to Manual Driving, SAE Technical Paper 2016-01-0158

Abe, A. & Ito, T. (2018). Study on Effective Tasks for Keeping Driver’s Arousal Level in Automated Driving. In Proceedings 25th World Congress on ITS, Copenhagen. ERTICO (ITS Europe).

Abe, A. & Ito, T. (2019). Driver State and Driving Maneuver Analysis in Take-over from Automated to Manual Driving. In Proceedings 26th World Congress on ITS, Singapore. ITS Singapore.

Philip, P., Sagaspe, P., Taillard, J., Valtat, C., Moore, N., Akerstedt, T., Charles, A. & Bioulac, B. (2005). Fatigue, Sleepiness, and Performance in Simulated Versus Real Driving Conditions. Sleep, Vol.28, Issue 12, pp.1511-1516.

Kitajima, H., Numata, N., Yamamoto, K. & Goi, Y. (1997). Prediction of Automobile Driver Sleepiness (1st Report, Rating of Sleepiness Based on Facial Expression and Examination of Effective Predictor Indexes of Sleepiness). In Proceedings Transaction of the Japan Society of Mechanical Engineers. C, Vol.63, No.613, pp.3059-3066.