TRAFFIC SAFETY ANALYSIS IN UNDERGROUND URBAN EXPRESSWAY USING A DRIVING SIMULATOR

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Abstract: This paper focuses on mental load and the deterioration of consciousness level while driving in a long urban expressway tunnel. Experiments are conducted using a fixed-base interactive driving simulator. In urban expressway tunnel, drivers might experience high mental load because of spatial pressure inside the tunnel, high traffic volume, and conflict with other vehicles at merging sections. On the other hand, monotonous visual stimulus inside the tunnel decreases the consciousness level. Hence, an analysis that considers both of these phenomena is needed and is conducted in this study. Using experiments where the relatively monotonous traffic conditions are assumed, results indicate that the driver's consciousness level can deteriorate especially when driving at basic segment between merging sections, and that of elderly drivers can deteriorate more than taxi drivers.

Key Words: urban expressway tunnel, traffic safety, consciousness level, mental load, driving simulator

1. INTRODUCTION

Underground construction is inevitable to provide a new expressway in high-density urban areas due to the existing congested surrounding environment. In tunnels, one usually drives under high mental load because of low visibility and spatial pressure. In urban expressways, there might be many conflicts with other vehicles as a result of high traffic volume and existence of merging or diverging sections. Some previous studies revealed that driving conditions, namely, monotonous visual stimulus experienced while driving inside tunnel, driving at night, and following large-sized vehicles, can result in a decreased consciousness level consequently slowing down the driver's response to surrounding traffic (Kato, 1980; Nishimura, 1993), and deteriorates the useful visual field with the prolongation of the monotonous driving task (Roge et al, 2002). Deterioration of consciousness level does not mean drowsiness but rather deterioration of brain working level. So in underground urban expressway tunnel, drivers are expected to face even higher risks under the combined pressure of two traffic conditions: driving inside a tunnel, and driving in an urban expressway.

This study focuses on deterioration of consciousness level as the first approach to traffic safety analysis in underground urban expressway. It might seem unimaginable that the driver's consciousness level can deteriorate in urban expressway tunnel because of increased mental load induced by conflicts with other vehicles. But this study hypothesizes that

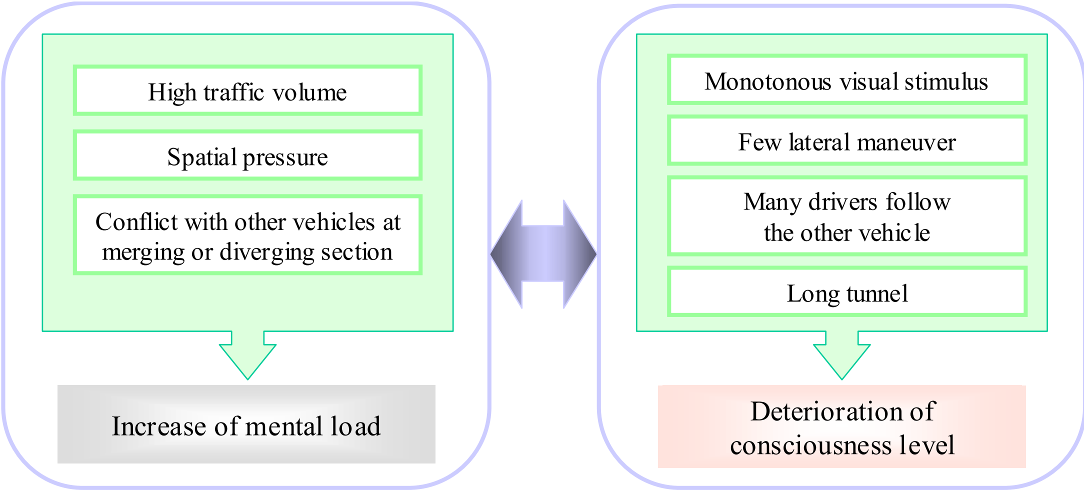


Figure 1. Traffic accident risks in underground urban expressway

consciousness level can deteriorate in some monotonous traffic condition such as following a certain vehicle along basic segments. If a driver enters a merging section with low consciousness level, the result may be an accident because the driver is not able to properly assess traffic flow disturbances and hence unable to avoid collision with surrounding vehicles. In this study, the traffic condition under which a driver's consciousness level can deteriorate is clarified by conducting experiments using the driving simulator.

2. CONSCIOUSNESS LEVEL AND MENTAL LOAD WHILE DRIVING IN LONG URBAN EXPRESSWAY TUNNEL

2.1 What is the Consciousness Level?

Consciousness level is activity level in the brain cortex and varies with internal or external factors. Sleep is treated as the lowest consciousness level. The strong triggers for lowering of the consciousness level are the circadian rhythm, fatigue, and monotonous work or stimulus; even if one is in good physical condition at the beginning of a task, monotony can make one's consciousness level low (Usaka, 1997).

2.2 Traffic Accident Risks under Low Consciousness Level

The deterioration of consciousness level dulls driver's sense of speed and stereognosis, and makes the driver unresponsive to external stimuli even if the driver's eye is wide open. Hereby, misidentifying information, misjudging, slow reaction, and operation mistake can happen, so driving under low consciousness level is considered to be highly dangerous (Yamamoto, 2000).

2.3 Consciousness Level and Mental load while Driving in Urban Expressway Tunnel

When driving inside a long urban expressway tunnel, a driver might be more nervous because of the spatial pressure by wall surface, low visibility, and many conflicts with other vehicles. In contrast, inside a tunnel, because of the lack of variation in scenery, that is, little change of visual stimulus, there is less complex sensory perception to be processed by the driver's brain. Consequently, the driver's consciousness level can deteriorate. The driver will tend to follow a certain vehicle because of the difficulty in getting the sense of speed. If the front vehicle is large-sized, the driver's visibility becomes more limited. If this kind of driving is continued, sense of speed is dulled, and the driver can get the illusion that his/her vehicle is stopping. In this state, one drives in synchrony with the front vehicle, and the brain's activity level deteriorates (Kato, 1980). In an urban expressway tunnel, if the driver follows a certain vehicle specifically along a basic segment between merging/diverging sections, factors that tend to make driver's consciousness level low can gradually have more significance than the factors that heighten the driver's mental load. Therefore, it is important to focus on time series behavior of driver's consciousness level and mental load in analyzing driving safety in long urban expressway tunnels.

3. INDEX TO EVALUATE DRIVER'S CONSCIOUSNESS LEVEL

3.1 Index to Evaluate Driver's Consciousness Level

Indexes to evaluate driver's consciousness level are broadly categorized into two types. The first one is subjective index such as the driver's assessment of his own condition, and the second one is objective index such as the driver's physiological data. The objective index is further categorized into two types. The first one is driving behavior index such as variance of lateral position or reaction time, and the second one is physiological index such as brain wave, skin potential level or eye movement. In this study, "(eye) blinking frequency" and "RR-interval" were selected as indexes to evaluate the driver's consciousness level because both can be measured with no expensive equipments and can be successfully recorded with small burden on the drivers. Blinking frequency is considered to be sensitive to variation in the condition that consciousness level is relatively low, like when feeling sleepy. RR-interval is considered to be sensitive to variation in the condition that his consciousness level is relatively high, such as being excited. Both measures are used complementarily.

3.2 Relation between Blinking Frequency and Consciousness Level

Blink is broadly categorized into three types. They are "physiological blink", "reflective blink", and "intentional blink". Among these blinks, frequency of "physiological blink" is correlated with consciousness level. Frequency of physiological blink is ordinarily 5-20 times a minute. The controlling nerves of physiological blink are in the hypothalamus and limbic system. The hypothalamus and limbic system are considered to have active and inhibitory effect on cerebral neocortex, and cerebral limbic system is closely related to consciousness level. When consciousness level deteriorates, neural communication channel is affected and inaccurate information is perceived, such as dryness of the eyeballs, which consequently increases blinking frequency as a physiological response. The other changes in blinking are the increase in bursting blinking frequency and the time of one blink (Tada et al, 1991).

In the experiments, the drivers' faces were recorded by video camera. After the experiments, blinking frequency was counted during video playback.

3.3 RR-interval

RR-interval is time interval between R-waves that are indicated by markedly protruding points on electrocardiographic wave. Decrease in RR-interval means the increase in heart rate. So decrease in RR-interval means high mental load. RR-interval is very sensitive to the change of mental load caused by conflict with other vehicles, or change of road structure, and so on. In this study, RR-interval is measured using a holter monitor (by Nihon Koden).

4. EXPERIMENTAL SETTING

4.1 Apparatus

A fixed-based driving simulator (DS) is developed to analyze the traffic safety in the underground expressways. For the experiments, drivers were asked to drive a virtual roadway, which has about 16km length, three-lanes, three junctions, five interchanges, and vertical slopes less than three percent. The drivers' behavioral and physiological data were collected, including driving speed, acceleration, braking, position, and RR-interval as a measure of mental load. Drivers' faces and eyes were also recorded with video camera. Surrounding

Figure 2. Fixed-based driving simulator

Figure 3. View of driving in simulator

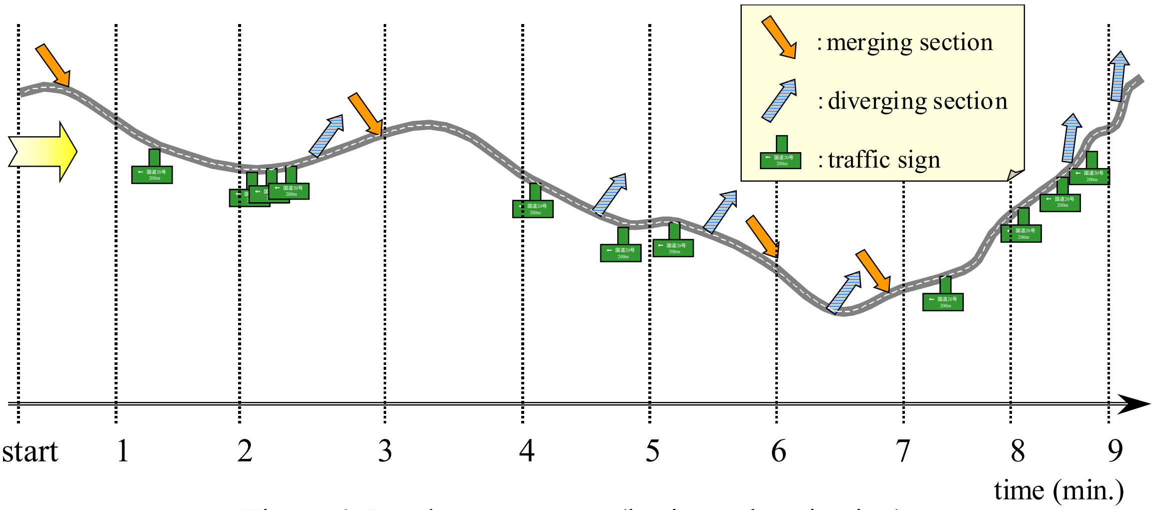


Figure 4. Roadway structure (horizontal projection)

vehicles run in response to the other vehicles. They accelerate, decelerate and change lane in order to overtake or give way. The start position, desired speed and type of vehicle were set in the experiments.

4.2 Experimented Drivers

Experiments are conducted on elderly drivers (N=10) and taxi drivers (N=9). In addition, the experiments for the verification of the DS experimental data are conducted on younger drivers (N=3). The traffic safety of elderly drivers is analyzed by comparing with taxi drivers who are experienced drivers. Table.1 shows the profile of experimented drivers.

5. VALIDATION OF DS EXPERIMENTAL DATA

5.1 Difference in Perception of Driving Speed between inside and outside Tunnel

Student drivers (N=3) were asked to drive at three recommended speeds without speed meter

Table 1. Profile of experimented drivers

ID	date	attribute	age	sex	drive frequency
O-01	18th,Dec.,2002	elderly driver	68	male	several times a week
O-02	3rd,Feb.,2003	elderly driver	66	male	several times a month
O-03	2nd,Feb.,2003	elderly driver	67	male	several times a week
O-04	25th,Dec.,2002	elderly driver	74	male	once a month
O-05	25th,Dec.,2002	elderly driver	64	male	once a week
O-06	26th,Dec.,2002	elderly driver	67	male	everyday
O-07	26th,Dec.,2002	elderly driver	75	male	everyday
O-08	9th,Jan.,2003	elderly driver	70	male	several times a week
O-09	10th,Jan.,2003	elderly driver	65	male	everyday
O-10	11th,Jan.,2003	elderly driver	75	male	several times a month
T-01	15th,Jan.,2003	taxi driver	56	male	everyday
T-02	15th,Jan.,2003	taxi driver	33	male	everyday
T-03	18th,Jan.,2003	taxi driver	46	male	several times a week
T-04	18th,Jan.,2003	taxi driver	44	male	several times a week
T-05	20th,Jan.,2003	taxi driver	53	male	everyday
T-06	20th,Jan.,2003	taxi driver	51	male	everyday
T-07	21th,Jan.,2003	taxi driver	41	male	everyday
T-08	21th,Jan.,2003	taxi driver	57	male	everyday
T-09	22th,Jan.,2003	taxi driver	41	male	everyday
S-01	20th,22th,25th, Nov.,2002	student	23	male	several times a year
S-02	21th,25th, Nov.,2002	student	22	male	several times a month
S-03	26th,Nov.,2002 2nd,Dec.,2002	student	23	male	several times a year

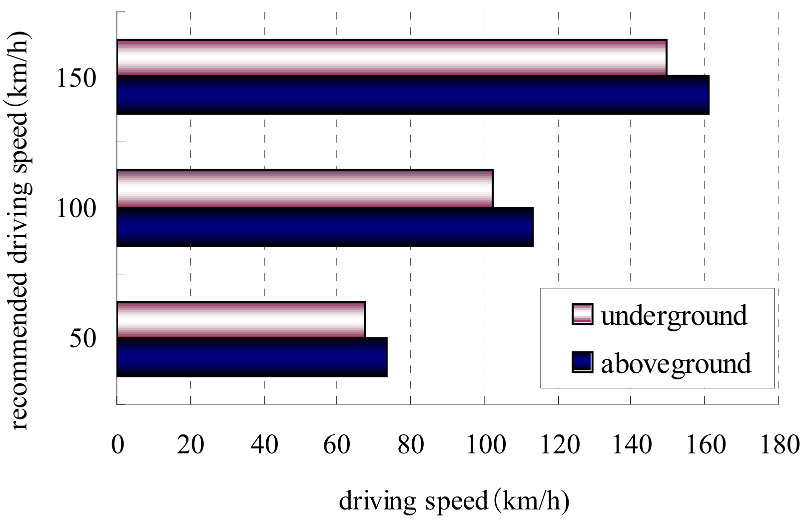


Figure 5. Driving speed in underground and aboveground DS

information. Figure 5 shows the average driving speeds of three drivers for underground (inside tunnel) and aboveground virtual driving route in the DS. For each recommended speed, the average speed when driving underground is lower than aboveground ($P<0.01$; tested by Repeated Measures ANOVA). Although the drivers intended to drive with the same speed in both sections, they actually reduced driving speed underground because they probably felt that their driving speed underground is higher than when driving aboveground. Generally, drivers feel driving faster than their actual speed inside the tunnel than outside the tunnel. This result indicates that the difference in perception of speed between driving inside and outside tunnel is reproduced in DS.

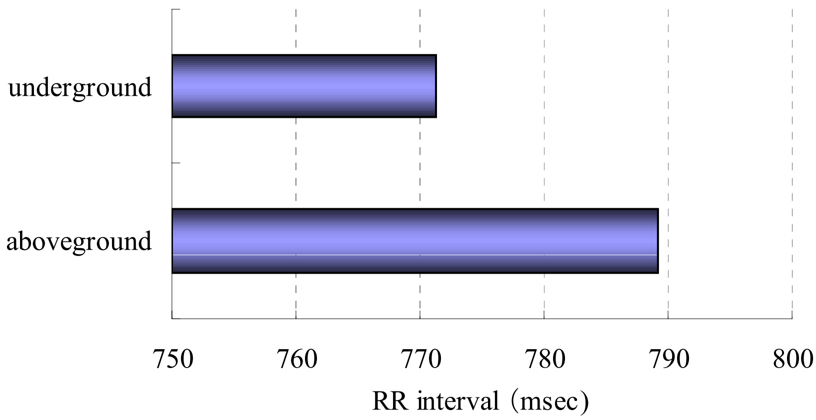


Figure 6. RR-interval in underground and aboveground DS

5.2 Difference of Mental Load between inside and outside Tunnel

Student drivers (N=3) were asked to drive five times each in both underground and aboveground DS. Figure 6 shows the average RR interval of three drivers for the underground and aboveground cases. The targeted data is the RR interval of the first 90 seconds to analyze proper mental load of drivers inside the tunnel because RR interval might vary due to deterioration of consciousness level further inside the tunnel. RR interval in underground DS was lower than that in aboveground ($P<0.01$; tested by Repeated Measures ANOVA). This indicates that drivers have more mental load underground than aboveground. The difference of mental load between inside and outside tunnel due to spatial pressure and low visibility inside tunnel is reproduced in DS.

5.3 Discussion about validation of DS experimental data

The results in section 5.1 and 5.2 show that the difference in driving speed perception and mental load between inside and outside tunnel are reproduced in DS and therefore gives reasonable validation to the simulator in comparing driver's behavior and related biological data inside and outside tunnel. However, absolute validity (numerical correspondence between the simulator and the real world) cannot be checked in these data. Previous study by the same authors (Hirata et al, 2002) revealed that driving speed at merging section was higher in the simulated road than in the real road. Also, regarding mental load, the variation trend at merging section in the simulated road was close to that in the real road, but the absolute value of mental load index differed. Because our simulator is fixed-base (no moving device) and has no peripheral vision, there is an odd feeling of driving slower than nominal speed. So subjects were required to drive a little faster in simulated road than they usually drive in actual road. Finally, drivers were not subjected to experimental traffic conditions in simulated road that required them to change lateral position frequently and the DS did not generate merging or diverging vehicles because the subjects' visual field was limited in the front monitor. Detailed traffic conditions in the experiments are discussed next.

6. ANALYSIS OF TRAFFIC SAFETY IN UNDERGROUND URBAN EXPRESSWAY

6.1 Introduction

In the experiments of this study, relatively monotonous traffic condition was assumed, where drivers followed certain vehicle in the same lane. Merging or diverging vehicles were not generated in the experiment. By changing the number, type and speed of surrounding vehicles, the effects of surrounding vehicles and roadway structure on driver's consciousness level, mental load and behavior were analyzed.

6.2 Verification Items

Specific verification items in this experiment are shown below. The detailed traffic conditions to verify those items are explained in next section.

(a) Can the driver's consciousness level deteriorate in underground urban expressway where traffic volume is high?
(b) If vehicles with same speed are always present on the side of driver, will the consciousness level hardly deteriorate due to e side vehicle pressure?
In DS experiments, consciousness level might easily deteriorate compared to experiments on real roadway. Therefore, the traffic condition in which drivers are supposed to have high mental load is added. If consciousness level deteriorates also in this condition, the possibility that the consciousness level deteriorates in underground urban expressway becomes higher.
(c) Do roadway structures such as merging or sharp curving sections have any effect on consciousness level?
(d) Are there any differences of change in the degree of consciousness level between elderly drivers and taxi drivers?
(e) Does the type of followed vehicle have any effect on consciousness level?

Considering these verification items, changes in consciousness level with driving time, especially at basic segment between merging sections are analyzed.

6.3 Detailed Traffic Conditions

Table 2 and Figure 7 show the detailed traffic condition on which drivers drove. There were no merging or diverging vehicles. Elderly drivers were subjected to six traffic conditions (No.1 – 6) and taxi drivers were subjected to eight (No.1 – 8). For elderly drivers, the sixth condition is set as the limit because of their virtual reality sickness and physical strength. Each experiment took around nine minutes, and after each experiment the driver took a rest for more than ten minutes. The order of traffic conditions was randomized for each driver.

Table 2. Traffic conditions of DS experiments

	Roadway structure	Traffic condition	Abbreviated name
(1)	underground	Following large-sized vehicle (no other vehicles)	"L.V."
(2)	underground	Following large-sized vehicle + passing vehicles in center lane (900vehicles/hour/lane)	"Pass"
(3)	underground	Following large-sized vehicle + side vehicles at same speed	"Side"
(4)	underground	Free driving (no other vehicles. driving at recommended speed)	"Free"
(5)	Aboveground*	Following standard-sized vehicle (no other vehicles)	"Aboveground"
(6)	underground	Following standard-sized vehicle (no other vehicles)	"S.V."
(7)	underground	Following large-sized vehicle + Stopping vehicle at first half section	"F.H."
(8)	underground	Following large-sized vehicle + Stopping vehicle at last half section	"L.H."

*aboveground : the line shape of roadway is the same as that of underground DS, and surroundings of roadway are grass field.

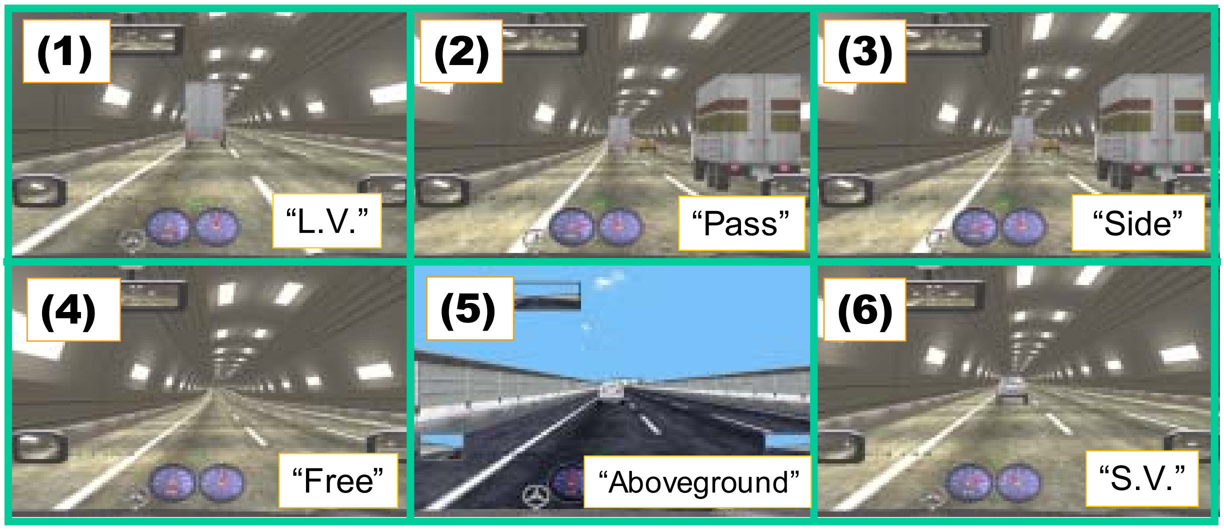


Figure 7. View of traffic condition of DS experiments

Figure 8. Pivot traffic conditions

6.4 Normalization of Blinking Frequency and RR-interval Data

Eye blinking frequency (blinks/minute) and RR interval were different among individuals. For a specific individual it was also different among experiments due to getting accustomed to driving in DS. Therefore, normalization of such data was necessary. The first 90 seconds in each experiment was the pivot condition to normalize the observed data. Figure 8 shows the pivot traffic condition. Blinking frequency was normalized by dividing the targeted blinking frequency data by the average of blinking frequencies in pivot condition of underground DS.

6.5 Analysis of Traffic Safety

6.5.1 Consciousness Level in "Pass" Condition

At first, the driver's consciousness level in "Pass" condition is analyzed to verify whether the driver's consciousness level deteriorates or not in underground urban expressway when there is a high traffic volume (verification item: 6-2 (a)).

Figure 9 shows the change of blinking frequency with driving time. The data is average of blinking frequencies of the six elderly drivers. Some elderly drivers made fewer blinking compared with normal individuals, and the data of such drivers are excluded in this analysis. As mentioned in section 3.2, increase of blinking frequency means deterioration of consciousness level. The dotted arrows point to pairs of blinking frequency levels that have

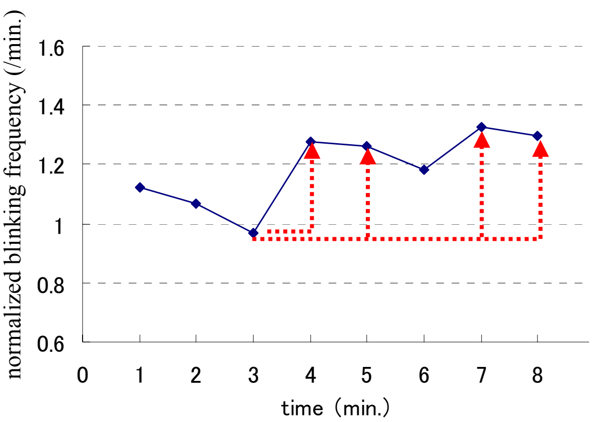


Figure 9. Blinking Frequency of elderly drivers in "Pass" condition

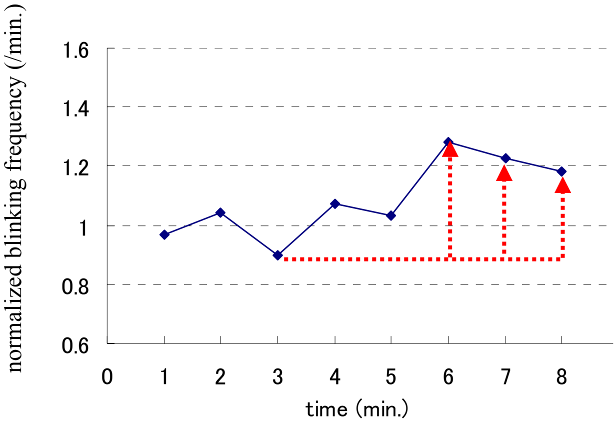


Figure 10. Blinking Frequency of taxi drivers in "Pass" condition

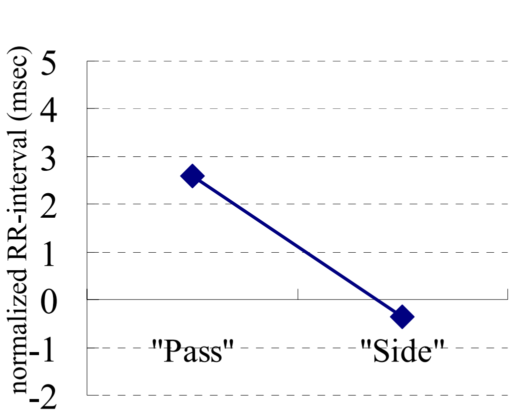


Figure 11. RR-intervals of elderly drivers in "Pass" and "Side" condition

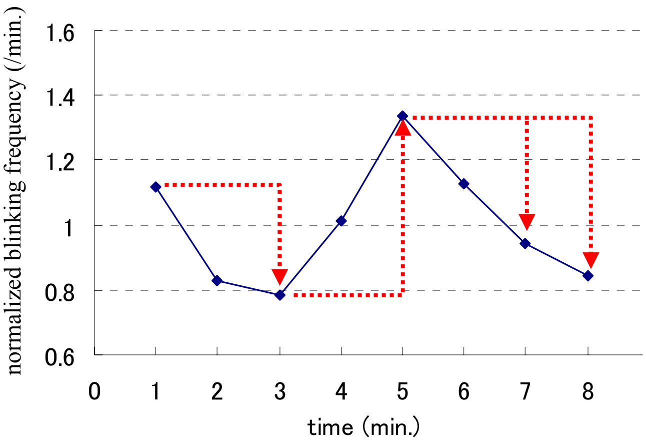


Figure 12. Blinking Frequency of elderly drivers in "Side" condition

statistically significant differences (P<0.10: tested by Least Significant Difference Method). In this figure, blinking frequency increases from 3 min. to 4 min., which means consciousness level deteriorates from 3 min. to 4 min. The section from 3 min. to 4 min. is a basic segment, around 2km long without merging or diverging sections (see Figure.4). This result indicates that consciousness level of elderly drivers might deteriorate in relatively short basic segment, which means that they enter the merging section under low consciousness level where the traffic flow might be disturbed. After 4min., low consciousness level continues.

Figure 10 shows the average change of blinking frequency for eight taxi drivers. The data for one taxi driver is excluded due to its abnormal value. Consciousness level of taxi drivers does not deteriorate from 3 min. to 4 min., but deteriorate at more latter section. This indicates that consciousness level of elderly drivers tend to deteriorate more easily than that of taxi drivers.

6.5.2 Consciousness Level in "Side" Condition

The driver's consciousness level in "Side" condition is analyzed to verify whether the consciousness level hardly deteriorates due to side vehicle pressure. (verification item: 6-2 (b)).

Figure11 shows the average of RR-intervals of elderly drivers in "Pass" and "Side" condition. RR-interval was normalized by subtracting the average of RR interval in each pivot section from targeted RR-interval. As expected, RR-interval in "Side" condition is lower than that of "Pass" condition. This means that mental load in "Side" condition is higher than in "Pass" condition. Figure 12 shows the average change of blinking frequency of the six elderly drivers.

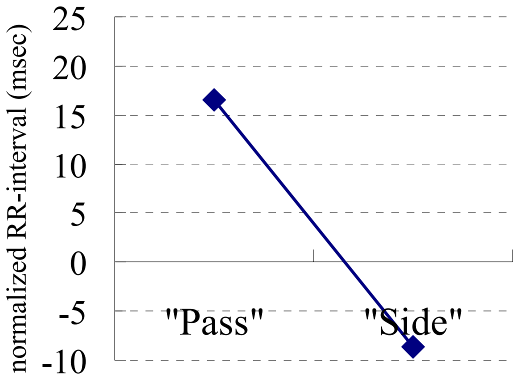


Figure 13. RR-intervals of taxi drivers in “Pass” and “Side” condition

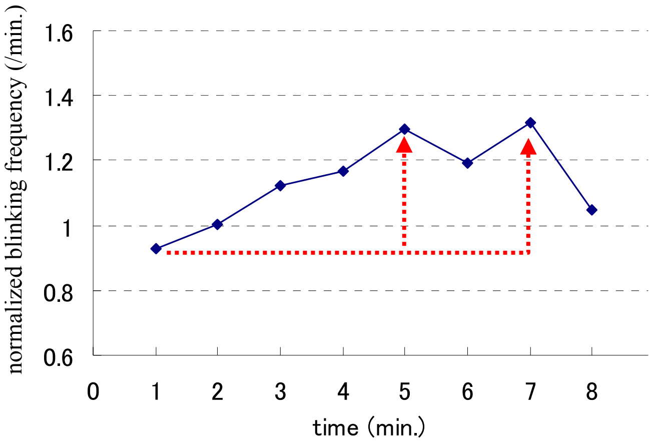


Figure 14. Blinking Frequency of taxi drivers in “Side” condition

Due to the high mental load, consciousness level ameliorated from 1min. to 3min. However, despite having high mental load, consciousness level deteriorated from 3min. to 5min., when subjects drive at basic segment. After 5min. when subjects drive into relatively hard roadway structure with sharp curves and many merging/diverging sections, consciousness level ameliorated again. The effects of both side vehicles and hard roadway structure can be considered to be the causes of this amelioration.

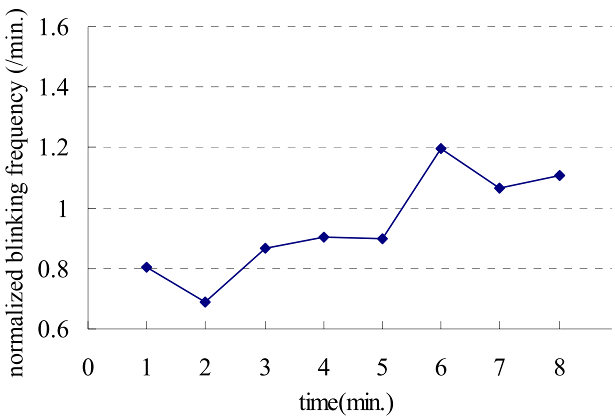
Figure 13 shows the average of RR-intervals of taxi drivers in “Pass” and “Side” condition. For taxi drivers, mental load in “Side” condition is higher than that in “Pass” condition similar to the elderly drivers. Figure 14 shows the average change of blinking frequency of eight taxi drivers. Even with high mental load, consciousness level consistently deteriorated. Compared with “Pass” condition, the deterioration rate is a bit milder. At relatively hard roadway structure, amelioration of consciousness level did not occur. These results indicate that the mental load as high as this might not affect the change of consciousness level.

6.5.3 Effect of Followed Vehicle Type: normal or heavy vehicle

To see the effect of followed vehicle type, the blinking frequency variations for “L.V.” and “S.V.” conditions are shown in Figures 15, 16, 17, and 18. The pairs of blinking frequencies that have statistically significant differences are indicated under each graph. Figures 17 and 18 shows that the number of pairs of blinking frequency levels that are significantly different is small in “S.V.” condition for both elderly and taxi driver such that the clear difference between the two conditions is difficult to deduce. However, comparing the trends in “L.V.” and “S.V.” trends of blinking frequency level changes, results imply that consciousness level deteriorates more easily in “L.V.” condition than in “S.V.” condition. As mentioned in chapter.1, a large-sized vehicle causes consciousness level deterioration of following driver, because it restricts the visual field and consequently lowers visual stimulus for the following vehicle.

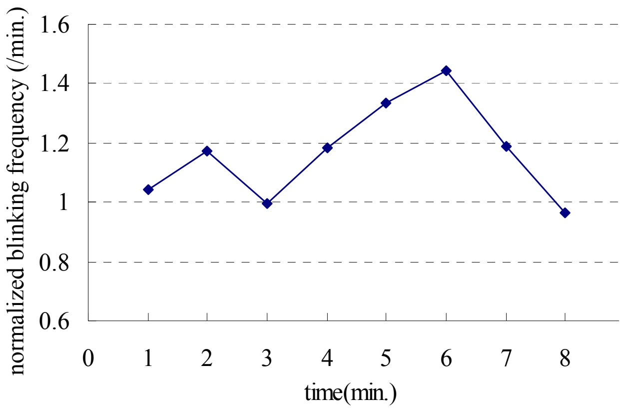
6.5.4 Comparison between inside and outside tunnel

The results of experiments in “Aboveground” condition for elderly and taxi drivers are shown in Figures 19 and 20. Compared with the results in “S.V.” condition shown in Figures 17 and 18, it can be seen that consciousness level deteriorated in “Aboveground” condition as much as in underground DS. This result might have occurred because the roadway surrounding is grass field for the “Aboveground” condition and this might have caused a monotonous visual stimulus for the driver. In real road, there are more visual variations around drivers such as buildings and mountains that provide stronger visual stimuli.



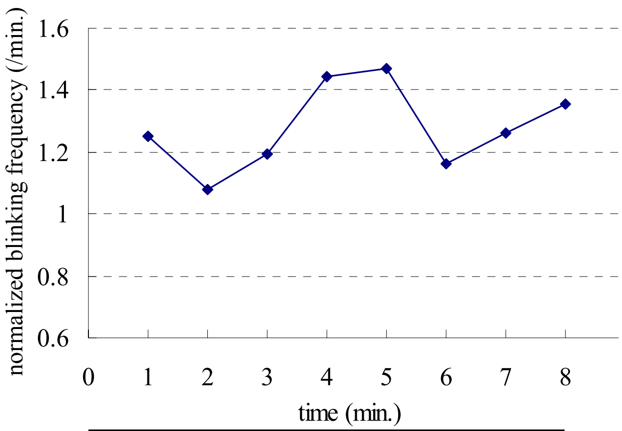
statistically significant difference (P<.10)		
1min. - 6min.	2min. - 6min.	2min. - 7min.
2min. - 8min.	3min. - 6min.	

Figure 15. Blinking Frequency of elderly drivers in "L.V." condition



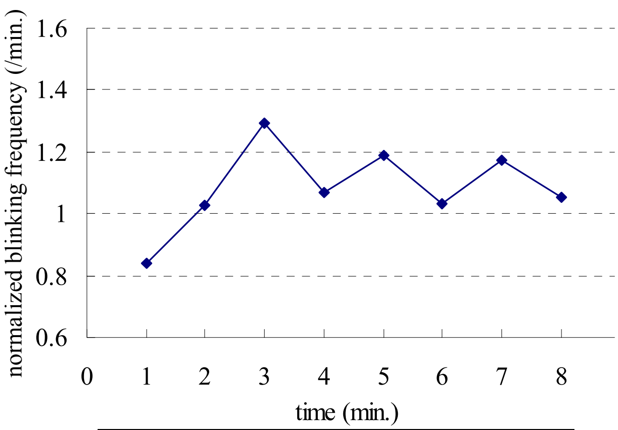
statistically significant difference (P<.10)		
1min. - 6min.	3min. - 5min.	3min. - 6min.
5min. - 8min.	6min. - 8min.	

Figure 16. Blinking Frequency of taxi drivers in "L.V." condition



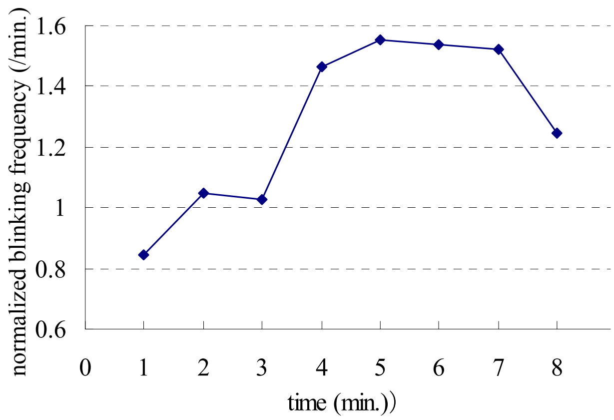
statistically significant difference (P<.10)
2min. - 4min.

Figure 17. Blinking Frequency of elderly drivers in "S.V." condition



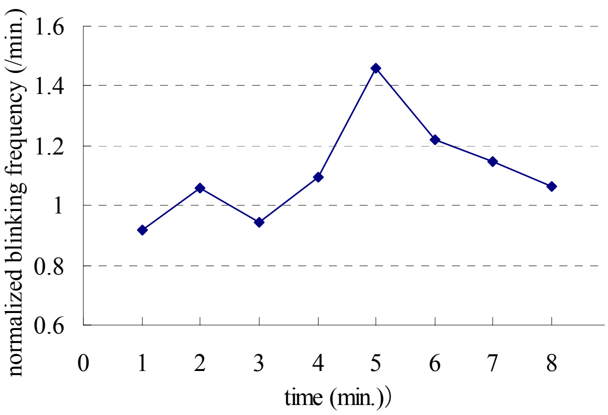
statistically significant difference (P<.10)
1min. - 3min.

Figure 18. Blinking Frequency of taxi drivers in "S.V." condition



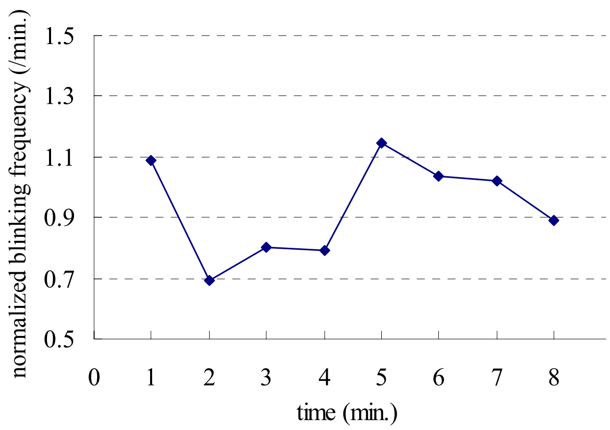
statistically significant difference (P<.10)			
1min. - 4min.	1min. - 5min.	1min. - 6min.	1min. - 7min.
1min. - 8min.	2min. - 4min.	2min. - 5min.	2min. - 6min.
2min. - 7min.	3min. - 4min.	3min. - 5min.	3min. - 6min.
3min. - 7min.			

Figure 19. Blinking Frequency of elderly drivers in "Aboveground" condition



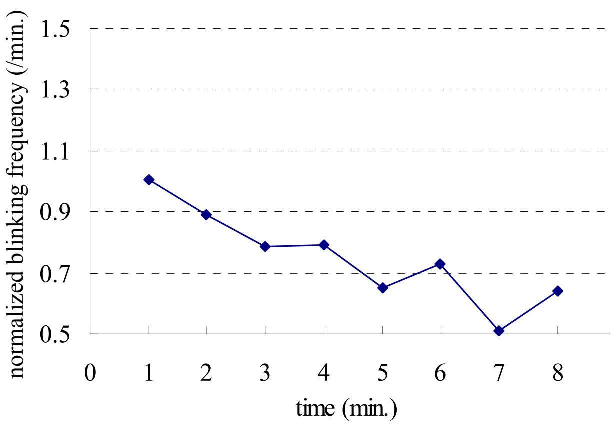
statistically significant difference (P<.10)	
1min. - 5min.	3min. - 5min.

Figure 20. Blinking Frequency of taxi drivers in "Aboveground" condition



statistically significant difference (P<.10)		
1min. - 2min.	1min. - 4min.	2min. - 5min.
2min. - 6min.	2min. - 7min.	3min. - 5min.
4min. - 5min.		

Figure 21. Blinking Frequency of elderly drivers in “Free” condition



statistically significant difference (P<.10)			
1min. - 3min.	1min. - 4min.	1min. - 5min.	1min. - 6min.
1min. - 7min.	1min. - 8min.	2min. - 5min.	2min. - 7min.
3min. - 7min.	4min. - 7min.		

Figure 22. Blinking Frequency of taxi drivers in “Free” condition

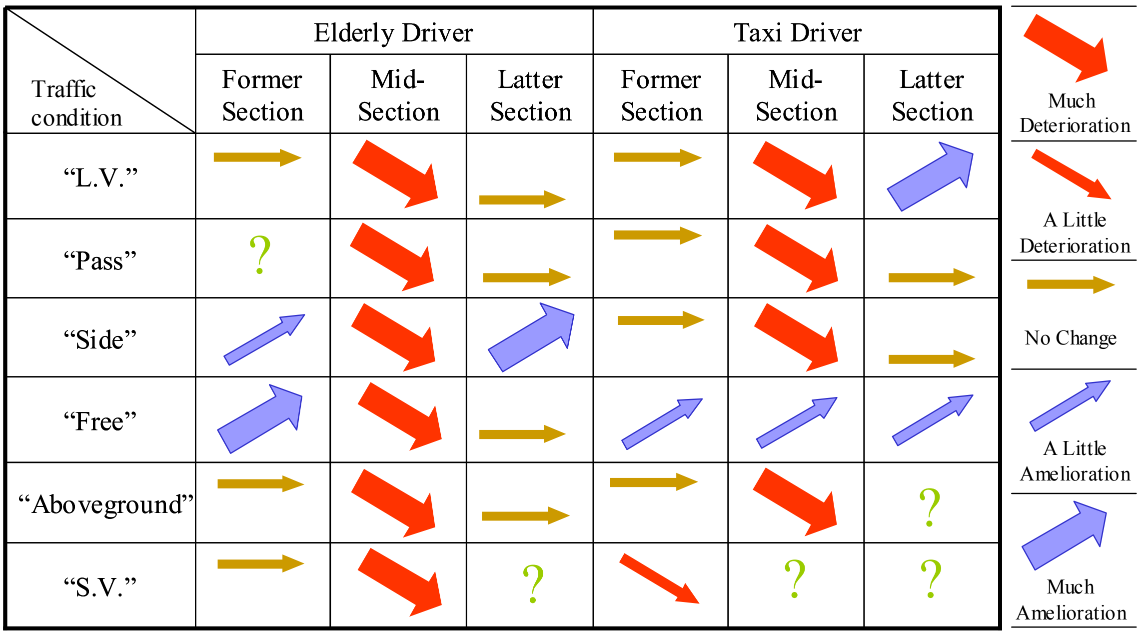


Figure 23. Change of consciousness level for all traffic conditions

6.5.5 Following or Not Following

The results of experiments in “Free” condition for elderly and taxi drivers are shown in Figures 21 and 22. For both elderly and taxi drivers in “Free” condition, consciousness level tended to ameliorate. Consciousness level remained high because drivers needed to control their driving speed by themselves without following any other vehicles. Following another vehicle seems to cause deterioration of consciousness level.

Figure 23 shows the summary of consciousness level variations in all conditions as reference.

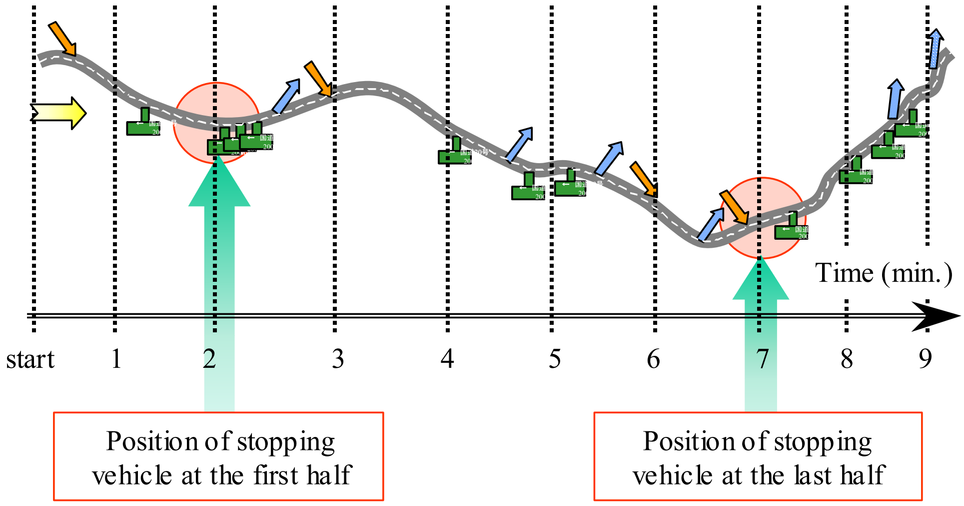


Figure 24. Position of stopping vehicle

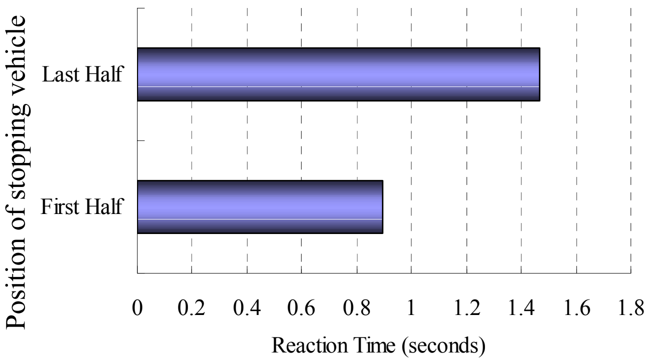


Figure 25. Reaction time to the stopping vehicle

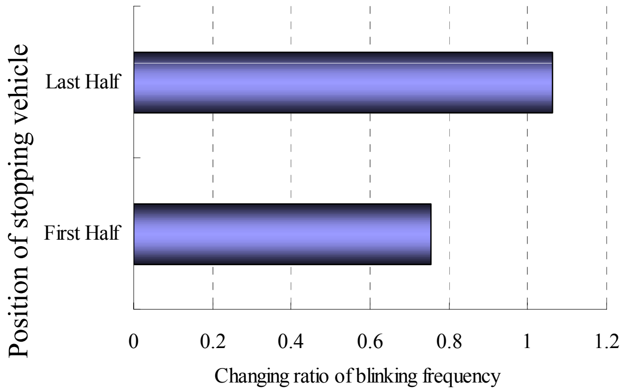


Figure 26. Changing ratio of blinking frequency

6.5.6 Reaction Time to Stopping Vehicle

In this section, the reaction time to stopping vehicle is analyzed. Since the correlation between reaction time and consciousness level is considered to be high, the reaction time is reliable as an index of consciousness level. Comparing reaction time and blinking frequency, the reliability of blinking frequency is also checked.

The positions of stopping vehicle were at the first half and the last half of roadway, and both are along straight sections (shown in Figure 24). These two experiments were randomly conducted on five taxi drivers among the eight traffic conditions (Table 2). The traffic conditions of “F.H.” and “L.H.” condition are the same as “L.V.” condition except for the generated stopping vehicle. Drivers were not informed about the existence of a stopping vehicle. Reaction time and Changing ratio of blinking frequency are defined as follow.

a) Reaction time: time from when followed car starts to decelerate due to stopping vehicle to when driver starts to brake.
b) Changing ratio of blinking frequency: ratio of blinking frequency in the first one minute to that in one minute just before driver starts to brake.

Figure 25 shows the average reaction time of five taxi drivers (the other drivers are excluded because some did not brake or followed the stopped car with unexpected manner.). Reaction time at the last half is longer than that at the first half ($P<0.10$; tested by Repeated Measures

ANOVA). Considering each individual, this result is true for four of five subjects. These observed reaction times imply that consciousness level might deteriorate with driving time. Figure 26 shows the average changing ratio of blinking frequency. The changing ratio at the last half is bigger than that at the first half ($P<0.15$; tested by Repeated Measures ANOVA). Considering each individual, this result is again true for four of five subjects. Although the level of difference is not significant, these observed blinking frequencies also imply that consciousness level might deteriorate with driving time. These results suggest that there is correlation between reaction time and blinking frequency. Therefore, blinking frequency can be considered to be a reliable index of consciousness level.

6.5.5 Summary of analysis result

The summary of results from experiments in this chapter is mentioned below.

In the “Pass” condition, which is the case most similar to real traffic flow in urban expressway, the driver’s consciousness level deteriorated while driving along a 2km basic segment between merging/diverging sections.

Especially for elderly drivers, in the “Side” condition, which is the case that induced much mental load, driver’s consciousness level also deteriorated along the same 2km basic segment.

Following a vehicle, especially large-sized, caused more deterioration of consciousness level.

In addition to blinking frequency, the deterioration of consciousness level with driving time can be verified also by reaction time to stopping vehicle.

Consciousness level of elderly drivers might deteriorate more easily than that of taxi drivers.

These results indicate that at basic segment between merging/diverging sections in underground urban expressway, driver’s consciousness level can deteriorate, and enter merging section at a low consciousness level, where the traffic flow might be disturbed. This driving situation can be considered extremely dangerous.

7. CONCLUSION

In underground urban expressway, there are several traffic accident risks. In this paper, deterioration of driver’s consciousness level is especially analyzed through DS experiments conducted on elderly drivers and taxi drivers. Results of analyses indicated that at basic segment between merging/diverging sections in underground urban expressway, the driver’s consciousness level could significantly deteriorate especially for elderly drivers as compared to taxi drivers. For future study, the merging and diverging vehicles should be explicitly demonstrated in DS experiments and mental load and consciousness level under more conflicts with other vehicles must be analyzed. It is also necessary to analyze in more detail index of consciousness level that is more reliable and have higher time resolution.

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