Research on the characteristics of driver visual behavior in highway extra-long tunnel

Yunxing Yang¹, Fang Chen²*
¹China Merchants Ecological Environmental Protection Technology Co., Ltd, Chongqing 400067, China
²China Merchants Chongqing Communication Research & Design Institute Co., Ltd, Chongqing 400067, China
*Corresponding author’s e-mail: 56174286@qq.com

Abstract. In order to study the driver visual behavior in highway extra-long tunnel section, the paper used Smart Eye Pro5.7 Eye Tracking System to record the driver's eye movement data, analyzed eye movement index, such as pupil area, X sight angle, Y sight angle, percentage of fixation times, percentage of fixation time and mean fixation time. The results showed that the driver's pupil area changes rapidly to adapt brightness variation in the entrance and exit of the tunnel. After entering the tunnel, the psychological state of drivers tends to be stable, and there is a tendency of gradual relaxation. Drivers are more focused and look down.

1. Introduction
Highway tunnel section is often the point of traffic accidents. When drivers in a closed environment for a long time, easy to be nervous. The eye movement of drivers can reflect their psychological state, visual focus and attention distribution, which is of certain significance to traffic safety research. Eye tracker can record driver's eye movement data, which provides a reliable tool for driver's visual behavior research. At the early stage, eye tracker was mainly used in the research of advertising, psychology, medicine and so on. However, with the improvement of portability and collection accuracy of eye tracker, more and more scholars gradually applied it to the field of transportation. In recent years, studies on driver's visual behavior in the field of traffic safety mainly focus on autonomous driving [1], smoke environment [2], attention distribution mode [3], mobile phone use [4], sign text size [5], landscape color [6], visual intervention line [7], etc. There are few studies on driver's visual behavior in tunnel environment. Wu ling studied the changing rules of drivers' visual characteristics and the discriminant model of safety state under the long tunnel of expressway [8]. Hu yueqi studied the visual characteristics of drivers with different experiences in the environment of long tunnels on highways [9]. Shi ludan analyzed the influence of special light belt on drivers' fixation duration and pupil area changes through BP neural network [10]. Sa han analyzed drivers' eye movement rules in short tunnel, tunnel group and long tunnel [11]. These studies have their own emphasis and use different indicators. On the basis of previous studies, this paper takes the change law of drivers' visual behavior in the extra-tunnel section as the research objective, performed a real car test on the expressway, analyzes the driver's pupil change and viewpoint distribution characteristics. The research results can provide some reference for traffic safety research of tunnel section.
2. Visual behavior indicator
Smart Eye Pro5.7 non-invasive instrument can collect many indicator. According to the research goal, and referring relevant research literature, this paper selects the pupil area, X sight angle, and Y sight angle.

2.1 The pupil area
The pupil will change with the external light intensity and human psychological state. In many papers, the pupil area is regarded as an indicator reflecting the psychological state of drivers. It is generally believed that the larger the pupil is, the more nervous the subject will be.

2.2 X sight angle
X sight angle is the horizontal rotation angle of the driver's sight relative to the head, which can be understood as the spatial position coordinate of the driver's focus.

2.3 Y sight angle
Y sight angle is the vertical rotation Angle, which also can be understood as the spatial position coordinate of the driver's focus.

3. Test plan
The test section is Liang feng ya tunnel on lanhai expressway. The one-way length of the tunnel is 4100m. Smart Eye Pro5.7 non-invasive Eye tracker was adopted with a sampling frequency of 60 hz. Before the experiment, the subjects were not informed of the purpose of the experiment, and the drivers drove freely according to their driving habits. The tunnel section is divided into the entrance section, the inner section and the exit section of the tunnel.

3.1 Pupil area analysis
Basic descriptive statistics were conducted on drivers' pupil area in each section of the tunnel, and the results were shown in table 1.

| Tunnel section | Average (mm²) | Standard deviation | Median (mm) | Minimum (mm) | Maximum (mm) | Kurtosis | Skewness |
|----------------|---------------|--------------------|-------------|--------------|--------------|----------|----------|
| Entrance       | 7.07          | 1.41               | 6.79        | 2.79         | 11.48        | 0.89     | 0.41     |
| Inner          | 18.11         | 4.46               | 18.49       | 1.17         | 39.91        | 0.75     | -0.33    |
| Exit           | 5.79          | 1.90               | 5.73        | 1.73         | 14.72        | 4.73     | 1.15     |

It can be seen from table 1 that the driver's pupil area increases in the inner section of the tunnel, mainly due to the weak illumination in the tunnel, and the driver's eye adapts to the dark environment in the tunnel by dilating the pupil. It can also be seen that the standard deviation of the driver's pupil area is also large in the inner section, indicating that the pupil changes frequently and the driver is uncomfortable.

In order to deeply analyze the psychological changes of drivers in the inner section of the tunnel, the pupil area of drivers was calculated as the average pupil area in seconds, and the results were shown in figure 3.
Figure 1 Driver pupil area changes in the internal section of extra-long tunnel
As can be seen from figure 1, after entering the tunnel, the pupil area of the driver gradually enlarges and then fluctuates continuously. In the tunnel, the pupil area of the driver has an overall trend of gradually decreasing and rapidly decreases at the exit section.

In order to adapt to the sharp change of the external brightness, the pupil area of the driver at the entrance and exit of the tunnel changes rapidly, and the psychological state of driver in the tunnel tends to be stable and gradually relaxed.

3.2 Analysis of view angle distribution characteristics
In order to understand the attention distribution state of drivers in different sections of the long tunnel, the eye movement data and image data were superimposed, and the viewpoint distribution state of drivers was shown in figure 2.

Figure 2 The driver's viewpoint distribution overall diagram in the extra-long tunnel. (a) entrance section, (b) inner section and (c) exit section.

In order to make a comparative analysis of the difference in the distribution of drivers' viewpoints, descriptive statistics are made from the X sight angle and Y sight angle of drivers. The statistical results are shown in table 2.
Table 2 Descriptive statistics of sight angle in the extra-long tunnel (unit:°)

| Tunnel section | Average | Standard deviation | Median | Minimum | Maximum | Kurtosis | Skewness |
|----------------|---------|--------------------|--------|---------|---------|----------|----------|
| Entrance       | X -0.48 | 5.76               | -1.05  | -1.87   | 50.83   | -44.52   | 5.47     |
|                | Y -6.39 | 4.21               | -5.89  | -43.01  | 1.56    | 29.38    | -4.18    |
| Inner          | X -0.94 | 4.30               | -1.54  | -13.98  | 29.65   | 7.60     | 1.89     |
|                | Y -13.55| 3.58               | -14.32 | -30.87  | 10.07   | 4.08     | 1.19     |
| Exit           | X -2.35 | 5.61               | -1.24  | -13.21  | 8.24    | -0.95    | -0.23    |
|                | Y -7.37 | 2.58               | -7.04  | -15.24  | 1.00    | 1.62     | -0.13    |

As can be seen from the figure 2 and table 2, the driver's Y sight angle in the inner section is -13.55 °, the driver's attention is low. The X sight angle is -0.94 °, which is right in the middle. The driver's X sight angle is -2.35 °, which is located in the centre-left area. Compared with the standard deviation of the X sight angle, the inner section of the tunnel is smaller than the other sections, indicating that the viewpoint changes less in the horizontal direction and the attention is more focused.

In order to understand the distribution of drivers’ viewpoints in the visual space of the extra-long tunnel, the X sight angle and Y sight angle of drivers are divided into 20 ranges on average. The results are shown in figure 3 and figure 4.

Figure 3 The driver's X sight angle distribution in the extra-long tunnel.
Figure 4 The driver's Y sight angle distribution in the extra-long tunnel.

As can see from figure 3 and figure 4, the driver's X sight angle in entrance section is distributed in the range of -10~ 5 °. The driver's X sight angle in inner section distributed in the range of -10~ 10 °, but most distributed in the range of -5~ 0 °. The driver's X sight angle in exit section distributed in the range of -15~ 10 °, but the distribution is uniform. The driver's Y sight angle in entrance section is distributed in the range of -10~0°. The driver's Y sight angle in inner section distributed in the range of -20~ -5 °. The driver's Y sight angle in exit section distributed in the range of -15 ~ 0 °, but focus on -10 ~ -5 °, indicated that the attention of the driver in the inner section of the tunnel is more concentrated and downward.

4. Conclusions
In this paper, the visual behavior characteristics of the drivers were obtained by using the eye movement device to carry out a real car test in the extra-long tunnel of the expressway. The main results obtained from the study are as follows:

- In the entrance and exit sections of the tunnel, in order to adapt to the sharp changes in the external brightness, the driver's pupil area changes rapidly. After entering the tunnel, the driver's psychological state tends to be stable and tends to relax gradually.
- In the inner section of the tunnel, the driver's viewpoint changes less in the horizontal direction and his attention is more concentrated.
- The driver's Y sight angle in inner section mainly distributed in the range of -20 ~ -10 °, the driver's attention is low.

Acknowledgments
This research work was sponsored by the Project of the National Natural Science Foundation of China [Grant No.51608470].

References
[1] Tyron L, natasha M. (2017) Are you in the loop? Using gaze dispersion to understand driver visual attention during vehicle automation. Transportation Research Part C: Emerging Technologies, 76: 35-50.
[2] Martin H, radovan M. (2017) The Research of Driver Distraction by Visual Smog on Selected Road Stretch in Slovakia. Procedia Engineering, 178: 472-479.
[3] Mauricio M, bryan R, joonbum L, et al. (2016) Distinguishing patterns in drivers’ visual attention allocation using Hidden Markov Models. Transportation Research Part F: Traffic Psychology and Behaviour, 43:90-103.

[4] Gregory M. F, Paul R. Bartholomew, Richard J. Hanowski, Miguel A. Perez. (2015) Drivers' visual behavior when using handheld and hands-free cell phones. Journal of Safety Research, 54:105.e29-108.

[5] YUAN W, FU R, MA Y, GUO Y S. (2011) Effects of Vehicle Speed and Traffic Sign Text Height on Drivers’Visual Search Patterns. Journal of Traffic and Transportation Engineering, 11(1):119-126.

[6] ZHANG G M, ZHU S L,.QI C H. (2016)Effects Analysis of Monotonous Roadside Landscape Color on the Driver’s Eye Movement Indicators. Science Technology and Engineering, 16(18):284-289.

[7] PAN X D, XU M. (2013) Influences of Visual Intervention Markings on Driving Behavior. Journal of Wuhan University of Technology(Transportation Science & Engineering), 37(6):1163-1166.

[8] WU L, LIU H X, ZHU T, XU Y. (2016) Research on driver visual characteristics and safe state discriminate model on highway super long tunnel. Highway, 1:138-143.

[9] HU Y Q, LIU H X, ZHU T , XU Y. (2017) Research on visual characteristics of drivers driving through extremely long expressway tunnel.China Safety Science Journal, 27(6):31-36.

[10] SHI L D. Study on the driver's eye movement fixation characters at highway super long tunnel section. Xi’an: Chang’an University,2011.

[11] HAN Sa. Study on the driver's eye movement characters of tunnel section in mountainous freeway. Xi’an: Chang’an University,2008.