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Research on the influence of freeway space environment on the driver's visual behavior

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Abstract. In order to understand the driver's visual behavior in different space, the Smart Eye Pro5.7 non-intrusive eye tracking instrument was used in this study to record the driver's eye movement data in three types of space environment. The main visual behavior indicator included pupil diameter, visual angle X and visual angle Y. The results showed that the driver was relaxed under open space. Through the significance statistical analysis, the space environment has significant influence on the driver's pupil diameter and visual angle. The driver's gaze position in closed space was diffuse and lower, while in open space was more uniform.

1. Introduction
The space environment is complex in mountain highway. The driver's visual behavior shifts frequently, and different space environment will gives the driver different feeling. As the principal part of the traffic system composed of person, car, road and environment, the driver plays a leading role in this system. The space environment will exert a subtle influence on people's psychology as the background of the driver's vision. The research of drivers' visual behavior has some significance to the construction of highway landscape and improvement of traffic safety. Eye tracking instrument can continuously record the driver's eye movement data, which reflect the driver's mental state and the area of interest. In the early stage, eye movement devices were mainly used in advertising, psychology, medical research, etc. With the improvement of portability and precision of eye movement devices, it have been gradually applied to the field of transportation by more scholars. Some scholars began to pay attention to the research on visual behavior characteristics of drivers. Several scholars paid attention to safety assessment (Yu et al, 2016), automatic driving (Louw and Merat, 2017), smoke (Hudák and Madlenák, 2017), the distribution of attention model (Muñoz et al, 2016), tunnel brightness (He et al, 2017), the use of mobile phones (Fitch et al, 2015), landscape color (Zhang et al, 2016), tunnel (Hu et al, 2017), traffic signs (Guo et al, 2006), road width (Yuan et al, 2011), visual intervention markings (Pan et al, 2013) and so on. There have been no studies on driver's visual behavior characteristics in the different space environment of highway. Therefore, this paper carried out a real vehicle test on the highway, and collected and analyzed the eye movement parameters of drivers such as pupil diameter, visual angle X and visual angle Y. Finally, the influence rules of different space environments on drivers' visual behavior was found out.
2. Visual behavior indicator

Smart Eye Pro5.7 non-invasive eye movement instrument can acquire many visual behavior indicators, such as visual angle, pupil diameter, fixation time and scanning angle. According to the research goal and the representativeness of indicators, pupil diameter was used as the index reflecting the driver's mental state, while visual angle X and visual angle Y as the index reflecting the driver's spatial position of attention.

2.1. Pupil diameter

The pupil changes with the external light intensity and the person's psychological state. It is generally believed that the larger the pupil is, the more nervous the person is.

2.2. Visual angle X

The visual angle X is the rotation angle of the driver's visual line to the head in the horizontal direction. It represents the space horizontal coordinate of the driver's attention in visual field.

2.3. Visual angle Y

The visual angle Y is the rotation angle of the driver's visual line to the head in the vertical direction. It represents the space position vertical coordinate of the driver's attention in visual field.

3. Structure of the trial

3.1. Trial road section

The road from Chongqing to Zunyi section of Lanhai highway in China was chosen as trial road section. The trial road section contains three types of space, which are open space, semi-closed space and closed space.

3.2. Trial driver

Considering the safety of driver and the limitation of experimental condition, a male driver who is familiar with trial road conditions and has no accident was selected as the test driver. The driver is 35 years old, and in good physical condition and mental state before the test.

3.3. Trial facility

The test car is general buick commercial vehicle. The eye tracker instruments is Smart Eye Pro5.7 non-invasive eye movement instrument.

3.4. Trial requirements

During the trial, all person in the vehicle kept quiet to avoid disturbing the driver. The driver were not informed of the purpose of the test before the test, and free to drive according to their own experience and driving habits on the premise of ensuring traffic safety and obeying traffic rules.

4. Test data analysis

This study divides the space environment into three typical space, which are open space, semi-closed space and closed space. The open space is composed of embankment and bridge road section. The semi-closed space is composed of low slope road section. The closed space is composed of high slope road section. The length of three typical space road section is about 15km.

4.1. Analysis of pupil diameter

In order to analyze the differences of drivers' mental states in three typical space, we performed a descriptive statistical analysis of the pupil diameter, and the result was shown in table 1.
Table 1. Statistics of pupil diameter in three typical space.

| Section       | Average (mm) | Standard deviation | Median (mm) | Minimum (mm) | Maximum (mm) | Kurtosis | Skewness |
|---------------|--------------|--------------------|-------------|--------------|--------------|----------|----------|
| Closed space  | 2.83         | 0.38               | 2.84        | 0.71         | 5.37         | 2.65     | -0.20    |
| Semi-closed space | 2.83     | 0.32               | 2.84        | 1.00         | 6.02         | 6.45     | 0.05     |
| Open space    | 2.54         | 0.29               | 2.52        | 0.74         | 6.00         | 13.27    | 1.22     |

It can be seen from table 1 that the driver's pupil diameter average and standard deviation in the open space is smaller than other space, indicating that the driver's mental state is calm and relaxed. In order to compare the difference of pupil diameter in three typical space, we performed the significance statistical analysis of driver's pupil diameter. The eye movement data of each trial section were divided into ten samples averagely. Then the mean of each sample of driver's pupil diameter was calculated. The result was shown in table 2. One-way ANOVA was conducted for the pupil diameter in three typical space environments to compare the difference of pupil diameter in three typical space environments.

Table 2 Sectional mean statistics of pupil diameter in three typical space.

| Segment section number | Closed space(mm) | Semi-closed space(mm) | Open space(mm) |
|------------------------|-------------------|-----------------------|----------------|
| 1                      | 2.91              | 2.78                  | 2.57           |
| 2                      | 2.94              | 2.88                  | 2.46           |
| 3                      | 2.78              | 2.80                  | 2.50           |
| 4                      | 2.87              | 2.69                  | 2.51           |
| 5                      | 2.75              | 2.79                  | 2.61           |
| 6                      | 3.00              | 2.98                  | 2.54           |
| 7                      | 2.88              | 2.94                  | 2.62           |
| 8                      | 2.75              | 2.85                  | 2.64           |
| 9                      | 2.66              | 2.92                  | 2.56           |
| 10                     | 2.72              | 2.92                  | 2.48           |

The prerequisite of ANOVA is independence, normality and homogeneity of variance. Since the experimental data of the three space segments are independent and have no influence on each other. The normality and homogeneity of variance were tested.

4.1.1. Normality test. The Kolmogorov-Smirnov test method was used to test the normality of ten samples of the three typical space segments. The result was shown in table 3.

Table 3 The pupil diameter normal test in three typical space.

| Space type         | Single sample Kolmogorov-Smirnov test | Kolmogorov-Smirnov Z | P       |
|--------------------|---------------------------------------|----------------------|---------|
| Closed space       |                                       | 0.508                | 0.908   |
| Semi-closed space  |                                       | 0.516                | 0.953   |
| Open space         |                                       | 0.472                | 0.979   |

It can be seen from table 3 that the test probability P value of the pupil diameter of drivers in three typical space is higher than the significance level of 0.05. So it can be considered that the distribution of the pupil diameter of drivers in each typical space segment satisfies normality.
4.1.2. **Homogeneity test of variance.** The correlation probability P of driver's pupil diameter is 0.08, which is greater than significance level 0.05. Therefore, it can be considered that the total variance of the three typical space segments is the same with homogeneity of variance.

4.1.3. **One-way analysis of variance.** One-way anova was used to the driver's pupil diameter respectively. The F statistic is 35.703, and P value is 0.00, which smaller than the significance level, indicating that the space environment had a significant impact on the driver's pupil diameter at the significance level of 0.05.

4.2. **Analysis of visual angle distribution characteristics**

In order to explore the distribution of drivers' visual angle in three typical space sections, we used AutoCAD to draw the driver's visual angle distribution overall diagram. The result was shown in figure 1.

![Figure 1](image)

Figure 1 The driver's visual angle distribution overall diagram in three typical space. (a) closed space, (b) semi-closed space and (c) open space.

Figure 1 illustrated that drivers' visual angle in three typical space are mainly distributed in the middle region. Drivers' visual angle in the closed space were scattered and slanted, while those in the open space were evenly distributed. In order to quantitatively analyze the differences of drivers' visual angle in three typical space, we performed a descriptive statistical analysis of drivers' visual angle, as shown in table 4.

| Space type     | Visual angle | Average (°) | Standard deviation | Median (°) | Minimum (°) | Maximum (°) | Kurtosis | Skewness |
|---------------|--------------|-------------|--------------------|------------|-------------|-------------|----------|----------|
| Closed space  | X            | -5.95       | 7.27               | -5.05      | -49.63      | 59.45       | 8.91     | -0.14    |
|               | Y            | -5.51       | 6.33               | -5.43      | -34.21      | 15.42       | 1.21     | -0.62    |
| Semi-closed space | X         | 0.12        | 7.34               | -1.29      | -50.48      | 69.82       | 15.15    | 1.78     |
|               | Y            | -12.00      | 5.49               | -11.16     | -46.42      | 24.37       | 6.28     | -1.71    |
| Open space    | X            | -2.36       | 6.01               | -2.44      | -48.46      | 48.04       | 14.38    | -0.05    |
|               | Y            | -11.21      | 5.67               | -11.02     | -43.96      | 11.88       | 2.29     | -0.68    |

Table 4 illustrated that drivers' visual angle X is 0.12 °. The visual focus is in centre right position. The standard deviation of the driver's visual angle X in the open space is 6.01, which is smaller than other space, indicating that the change of the driver's visual angle in the horizontal direction is smaller.
than other space. Similar to the analysis of pupil diameter, the driver's visual angle data of three typical space were divided into ten samples averagely. The result was shown in table 5. Through the one-way ANOVA of visual angle in three typical space environment, the differences of visual angle in three typical space environment were compared.

Table 5 Sectional mean statistics of visual angle in three typical space.

| Serial number | Closed space | Semi-closed space | Open space |
|---------------|--------------|-------------------|------------|
|               | Visual angle X(°) | Visual angle Y(°) | Visual angle X(°) | Visual angle Y(°) | Visual angle X(°) | Visual angle Y(°) |
| 1             | -7.11         | -5.85             | 0.23        | -11.23          | -3.96            | -16.00           |
| 2             | -7.37         | -5.32             | 2.22        | -13.04          | -1.65            | -13.64           |
| 3             | -7.94         | -2.16             | 0.64        | -10.86          | -2.15            | -12.91           |
| 4             | -8.39         | -3.45             | -1.34       | -10.43          | -1.19            | -11.39           |
| 5             | -4.98         | -6.74             | 1.47        | -12.54          | -1.44            | -11.75           |
| 6             | -5.87         | -8.28             | 5.50        | -13.30          | -4.35            | -9.77            |
| 7             | -6.25         | -6.05             | -0.75       | -12.51          | -2.88            | -10.84           |
| 8             | -10.19        | -3.34             | -0.47       | -12.18          | -3.02            | -10.22           |
| 9             | -10.69        | -11.96            | -0.02       | -12.42          | -2.73            | -8.69            |
| 10            | -6.60         | -5.30             | -0.38       | -13.11          | -1.88            | -9.34            |

4.2.1. Normality test. Kolmogorov-Smirnov test was used to test the normality of drivers' visual angle at different sections of road. The result was shown in table 6. It can be seen from the table that the test probability P of drivers' visual angle X and visual angle Y of each section is greater than the significance level of 0.05. So it can be considered that drivers' visual angle of each section conform to the normal distribution.

Table 6 The visual angle normal test in three typical space.

| Space type      | Single sample Kolmogorov-Smirnov test | Single sample Kolmogorov-Smirnov test |
|-----------------|---------------------------------------|---------------------------------------|
|                 | Kolmogorov-Smirnov Z | P                                      |
| Closed space    | Visual angle X       | 0.434 | 0.992 |
|                 | Visual angle Y       | 0.552 | 0.921 |
| Semi-closed space | Visual angle X       | 0.678 | 0.748 |
|                 | Visual angle Y       | 0.649 | 0.794 |
| Open space      | Visual angle X       | 0.439 | 0.356 |
|                 | Visual angle Y       | 0.466 | 0.982 |

4.2.2. Homogeneity test of variance. The homogeneity test of variance was tested by LSD test. The test result showed that the concomitant probability P_X from the visual angle X is 0.395, and the concomitant probability P_Y from the visual angle Y is 0.170, both of which were greater than the significance level 0.05. Therefore, the overall variance of each group was considered to be equal. It has homogeneity of variance, meeting the prerequisites for variance test.

4.2.3. One-way analysis of variance. One-way ANOVA was used for the driver's visual angle respectively. The F statistics of the visual angle X is 61.72, and the P value is 0.00; the F statistics of the visual angle Y is 26.15, and the P value is 0.00, both of which were less than the significance level, indicating that the space environment had a significant impact on the driver's visual angle at the significance level of 0.05.

5. Conclusions

In this paper, the eye movement data of drivers in three typical space sections was obtained through the real vehicle test on highway. The influence law of space environment on drivers' visual behaviour...
was obtained through the significance analysis. The main results obtained from the study are as follows:

- The pupil diameter can represent the psychological state of the driver. The visual angle X and the visual angle Y can represent the attention position of the driver.
- The psychological state of drivers in open space is calm and relaxed. Through the significance analysis, the space environment has a significant influence on the driver's pupil diameter.
- Drivers' gaze position in the three typical space are mainly distributed in the middle region. Drivers' gaze position in the closed space are relatively scattered, and in the open space are evenly distributed. The visual angle of the driver in the closed space is higher than other space. Through the significance analysis, the space environment has a significant impact on the driver's visual angle.

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