# The Effect of Edge Rate Markings on Drivers' Visual Perception During Downhill Sections of Highways

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**Abstract:** To investigate the effects of edge-rate lane markings on drivers' visual characteristics during downhill sections of expressways, field tests were conducted on three downhill sections with different gradients. Twenty-eight drivers were recruited, and a Dikablis Glasses eye tracker was used to collect four visual metrics: pupil area, fixation duration, saccade velocity, and blink rate. The results showed that after the installation of edge-rate lane markings, drivers' average pupil area decreased by 16.2%–18.1%, and blink rate increased by 8.2%–9.4%; the primary distribution range of fixation duration shortened from 400–475 ms to 375–450 ms, and the proportion of saccade velocities exceeding 50°/s increased significantly. A two-way analysis of variance revealed that the application of the markings had a significant main effect on all visual indicators ($P < 0.01$), and the downhill gradient also had a significant main effect ($P < 0.05$); however, there was no interaction between the two ($P > 0.05$). In summary, edge-rate lane markings can effectively reduce drivers' visual load on downhill sections and improve information processing efficiency. They demonstrate consistent effectiveness across different gradients and can serve as an effective measure for improving traffic safety on downhill sections of expressways.

**Keywords:** Transportation Engineering; Freeway; Edge rate markings; Downhill gradient; Visual characteristics

## 1. Introduction

Expressways have greatly improved residents' mobility and promoted rapid economic development, playing a crucial role in the modern transportation system. However, while expressways offer convenience, they also pose numerous traffic safety issues that endanger people's lives and property. Relevant studies indicate that the fatality rate per mile on expressways is approximately four times that of ordinary roads, particularly on complex sections such as downhill stretches, which has become an obstacle to the sustainable development of China's road transportation [1]. Since drivers primarily rely on visual cues to gather information while driving, the road alignment on downhill sections can alter the driver's information perception process to a certain extent, directly affecting their judgment and vehicle control [2-4]. Therefore, analyzing the patterns of changes in drivers' visual characteristics on downhill and curved sections can provide a basis for optimizing traffic safety infrastructure.

As a traffic safety facility designed based on the principles of visual perception, edge-rate markings overcome the limitations of traditional longitudinal speed-reduction markings, which focus solely on optimizing the geometric shape of the markings. By altering the number of diamond-shaped lines that pass through the periphery of a driver’s field of vision or appear intermittently within a given time frame, these markings create the illusion that the driver is accelerating, thereby prompting them to slow down voluntarily. Currently, research on the speed-reduction effectiveness of edge-rate markings is primarily conducted through simulated driving or real-vehicle testing. Zhu et al. [5] collected the measured data of Shanghai-Chengdu West Expressway in China through on-road tests, and applied the structural equation model to study the deceleration effect of edge rate marking under different driving speeds, virtual-to-actual ratios, marking angles and time frequencies. Liu Bing et al. [6] carried out real vehicle tests in the straight section of the expressway, collected the cross-section speed data of free-flow vehicles on the test section, and explored the influence of the length of the edge rate marking on the deceleration effect of the edge rate marking. Lu Nengchao [7] proposed a method to extract driving parameters such as vehicle speed, acceleration, headway and lane offset based on surveillance video. The comprehensive evaluation model was used to evaluate the effect of edge rate marking from three dimensions of effectiveness, safety and comfort.

Vision plays a central role in driving tasks, which has a decisive impact on the driving safety of vehicles. The acquisition and processing of visual information is directly reflected in the driver 's visual characteristics. Through the quantitative analysis of parameters such as gaze, saccade and blink, the change of visual load during driving can be effectively evaluated [8]. At present, scholars at home and abroad are committed to combining traffic theory with visual behavior theory to strengthen traffic safety, improve driving experience, and optimize traffic management measures. Zhang et al. [9] analyzed the eye movement behavior of drivers in the face of traffic hazards in the plateau environment through simulation experiments, and studied the influence of altitude on the driver 's perception and response. Based on simulation experiments, Xu et al. [10] analyzed the driver 's longitudinal visual search length and horizontal search angle in depth, and clarified the dynamic response characteristics of the search length and horizontal angle to the curve radius. In order to study the influence of side wall effect of urban tunnel on drivers, He et al. [11] took the visual characteristics and driving behavior of drivers as the main research objects, and found that there were significant differences in the influence of side wall effect on the attention distribution and vehicle stability of drivers in different lanes. Therefore, the effect of edge rate marking can also be evaluated by the change of driver 's visual characteristics.

To sum up, highway traffic safety measures are very important to ensure the safety of drivers. This paper will deeply discuss the application of edge rate marking in the downhill section of expressway, analyze its specific influence mechanism on driver 's visual characteristics, and consider the influence of downhill slope in the process, and explore whether there is an interaction effect between them.

## 2. Experimental Design

### *2.1 Experimental Road Section*

Based on the project, this paper selects some sections of the Ezhou-Xianning Expressway (Exian Expressway) in Hubei Province as the research object. The design speed of E-Xian Expressway is 100 km / h. The minimum radius of horizontal curve is generally 1500 meters. The minimum vertical curve radius is 12000 meters for convex type and 10000 meters for concave type. The maximum longitudinal slope design value is controlled at 3 %. The two-way six-lane standard with subgrade width of 33.5 meters is adopted from the starting point to Changgang section, and the two-way four-lane standard with subgrade width of 26 meters is adopted from Changgang to the end point. Considering the operability of the road test and the difficulty of obtaining the test data, after the field survey of the E-Xian Expressway, three downhill sections were finally selected. The specific information of the road section is shown in Table 1.

**Table 1:** Basic Details of Downhill Test Section.

| Serial number | Road pile number | Design speed (km/h) | Line shape | Gradient (%) | Direction |
|---|---|---|---|---|---|
| 1 | K83 | 100 | downhill section | 1.5 | E-Xian |
| 2 | K85 | 100 | downhill section | 1.0 | E-Xian |
| 3 | K100 | 100 | downhill section | 0.5 | Xian-E |

### *2.2 Edge Rate Marking Laying Scheme*

After selecting the test section on the road, the next step is to determine the laying scheme of the edge rate marking. The laying form of the marking will directly affect its effect on the driver 's visual characteristics. The laying scheme of the edge rate markings in this paper (including the color, period length and geometric design parameters of the markings) is shown in Table 2 and Figure 1.

**Table 2:** Design Parameters of Asymmetric Edge Rate Marking of Downhill Test Section.

| Serial number | Lateral width | Longitudinal length | Periodic length | Angle | Color |
|---|---|---|---|---|---|
| 1 | 30cm | 50cm | 2m | 135° | white |
| 2 | 30cm | 50cm | 2m | 135° | white |
| 3 | 30cm | 50cm | 2m | 135° | white |

**Figure 1:** Laying on the Downhill Section Edge Rate Marking Line.

### *2.3 Test equipment and participants*

#### *2.3.1 Test Equipment*

(1) Test vehicle

This experimental vehicle selects the five cars of Volkswagen Tanyue, as shown in Figure 2. The test vehicle has good performance and spacious interior space. It has a large market share in China and meets the test requirements.

**Figure 2:** Test Vehicle.

(2) Dikablis Glasses Eye Tracker

The spectacle eye tracker is widely used in the collection of driver's eye movement data in real environment or simulated scene because of its simple operation, accurate stability and ergonomic design characteristics. In this experiment, Dikablis Glasses eye tracker was used to track the driver 's eye movement during driving, and the collected data were recorded and analyzed in real time with the help of D-Lab3.6 software on the laptop, as shown in Fig.3.

**Figure 3:** Dikablis Glasses Eye Tracker.

(3) Other equipment

Laptop, large capacity battery, record board, etc.

### *2.3.2 Test Personnel*

In this study, under the premise of considering the factors such as age, occupation and gender of drivers, the number of drivers needed to be recruited is calculated according to the parameters such as expected variance, target confidence and error range [12], and the calculation formula is as follows (1).

$$n = \frac{Z^2\sigma^2}{E^2} \tag{1}$$

In the formula: n is the required sample size; z is the standard normal distribution statistics; the standard deviation of the sample; e is the maximum allowable error. Usually, a 10 % significance level is selected to reflect the 90 % confidence level of the unknown parameters. When the confidence level is 90 %, Z = 1.25. The value range of standard deviation is 0.25 to 0.5, which is set to 0.35 considering the experimental cost. The maximum allowable error E is 10 %.

According to Formula (1), it is determined that 20 drivers need to be recruited. In order to ensure the redundancy of test conditions, 28 drivers were recruited from universities and society to participate in the experiment. There were 20 males and 8 females, aged between 23 and 50 years.

### *2.4 Test Steps*

The specific steps of this experiment are as follows:

(1) Scene survey screening. The preliminary survey of the test section is carried out to obtain information such as road environment and determine the test scene.

(2) Basic information collection of participants. Collect the basic information of the driver participating in the test. Through the questionnaire, the basic conditions of the driver 's age, driving experience, occupation, cumulative mileage and psychological state are recorded in detail, so as to ensure that the selected test subjects meet the requirements.

(3) Test time selection. The meteorological conditions on the day of the test were confirmed by weather forecast before the test. If the forecast shows that there is rainfall, the test arrangement on the day is canceled. If the weather is good, two road tests are arranged from 8:00 a.m.to 10:00 a.m. and from 3:00 p.m.to 5:00 p.m.

(4) Installation and commissioning of test equipment. Before the test, the driver is clearly informed of the start and end point of the test, the test equipment is installed and debugged and calibrated. The eye tracker is worn by the driver, and the five-point calibration method (5-point) is used to calibrate the eye tracker, so that it can accurately capture the driver 's eye movement behavior.

## 3. Visual Characteristic Index Analysis

### *3.1 Pupil Area*

In order to explore the change rule of pupil area of drivers on downhill sections with different slopes before and after the laying of edge rate markings, the average pupil area of all drivers was counted and the Shapiro-Wilk normal distribution test was carried out. The test results show that the driver 's average pupil area data satisfies normality($P > 0.05$). The comparison results of the average pupil area before and after the marking of the downhill sections with different slopes are shown in Figure 4.

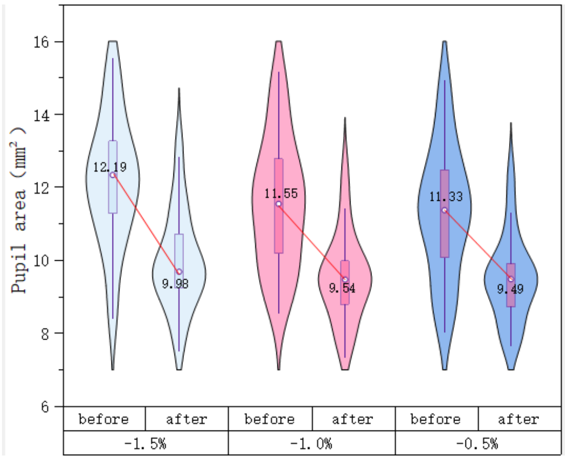



**Figure 4:** The Average Pupil Area of the Driver Before and After the Marking of the Downhill Section of Different Slopes.

It can be seen from Fig.4 that after the edge rate marking is laid, the average pupil area of the driver on the downhill section of different slopes shows a downward trend. Among them, the average pupil area of-1.5 % downhill section decreased from 12.19 mm 2 before laying to 9.98 mm 2, with a decrease of 18.1 %. The mean value of-1.0% downhill section decreased from 11.55 mm 2 to 9.54 mm 2, with a decrease of 17.4 %. The average value of -0.5% downhill section decreased from 11.33 mm 2 to 9.49 mm 2, with a decrease of 16.2 %. Further analysis shows that the dispersion degree of the mean pupil area of each downhill section also decreases after the marking is laid. In the downhill sections of-1.5%, -1.0 % and-0.5%, the standard deviation decreased from 1.75, 1.78 and 1.79 mm 2 to 1.35, 1.22 and 1.18 mm 2, respectively. The above analysis results show that the edge rate marking laid on the downhill section can effectively reduce the pupil area of the driver when driving on its road section, and effectively reduce the individual differences between different drivers. This shows that the edge rate marking laid on the downhill section enhances the driver 's perception of their own speed by providing visual guidance, thereby reducing the cognitive load and psychological tension in driving.

In order to further study the influence of the laying of the edge rate marking on the pupil area of the driver in the downhill section, and consider the effect of the slope of the road section, the two-factor analysis of variance is used for testing. The results are shown in Table 3. The results of two-way analysis of variance showed that the effect of marking on the pupil area of the driver showed a significant difference ($F = 72.692$, $P < 0.001$). The slope of the road also showed a significant difference in the pupil area of the driver ($F = 3.046$, $P < 0.050$), and there was no interaction between the two on the pupil area ($F = 0.191$, $P > 0.050$). According to the effect index of partial $\eta^2$, when driving on the downhill section, the influence of the marking laying on the driver 's pupil area is much higher than that of the downhill slope, which is the more important factor affecting the driver 's visual load.

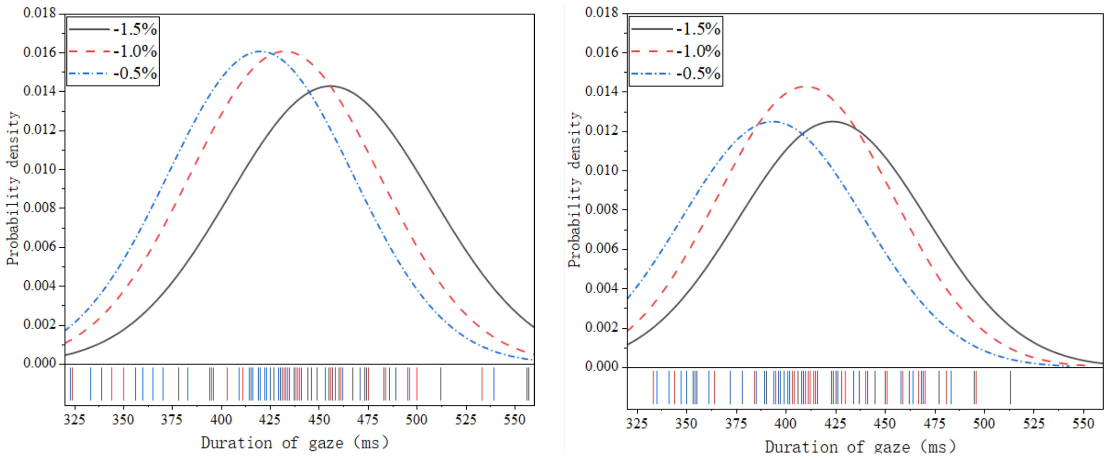
**Table 3:** Variance Analysis Results of Average Pupil Area of Drivers in Downhill Section.

| Source of Variation | Type III Sum of Squares | df | Mean Square | F | P | Partial $\eta^2$ |
|---|---|---|---|---|---|---|
| Curve radius | 14.384 | 2 | 7.192 | 3.046 | <0.050 | 0.036 |

| | | | | | | |
|---|---|---|---|---|---|---|
| Pavement marking | 171.619 | 1 | 171.619 | 72.692 | <0.001 | 0.310 |
| Curve radius × Pavement marking | 0.904 | 2 | 0.452 | 0.191 | >0.050 | 0.002 |

### *3.2 Fixation Duration*

The average fixation duration of all drivers before and after the edge rate marking of different slope sections was counted and the Shapiro-Wilk normal distribution test was performed. The test results show that the driver 's average fixation duration data satisfies normality ($P>0.05$). The probability density distribution of the average fixation duration of the downhill section of different slopes before and after the marking is shown in Figure 5.




(a) Before the marking line is laid (b) After the marking line is laid

**Figure 5:** Probability Density Distribution of Driver 's Average Fixation Duration at Different Slopes.

It can be seen from Fig.5 that before the edge rate marking is laid, the average fixation duration of the drivers on each downhill section is mainly distributed in 400-475ms, and the average fixation duration corresponding to the peak value of the probability density distribution curve of the-1.5 % downhill section is slightly higher than that of the other two sections. After the edge rate marking is laid, the probability density distribution of the average fixation duration of drivers on each downhill section shows a trend of shifting to the left, and the main distribution interval shrinks to 375-450 ms. In addition, the long tail part of the probability density distribution curve is significantly shortened, especially the average fixation duration probability above 500 ms is close to zero. This shows that the edge rate marking laid on the downhill section effectively improves the efficiency of visual information collection and processing of each driver on the downhill section by providing visual guidance, thereby shortening the duration of their fixation.

In order to further study the influence of the laying of the downhill edge rate marking on the driver 's fixation duration, and consider the effect of the road slope, a two-factor analysis of variance was used for testing. The results are shown in Table 4. The results of two-way analysis of variance showed that the effect of marking on the fixation duration of the driver showed a significant difference ($F = 13.335$, $P < 0.001$). The slope of the road also showed a significant difference in the fixation duration of the driver ($F = 6.903$, $P < 0.050$), and there was no interaction between the two ($F = 0.125$, $P > 0.050$). According to the effect index of partial η2, it can be seen that when driving on the downhill section, the two factors of marking laying and downhill slope will have a certain degree of influence on the driver 's fixation duration.

**Table 4:** Variance Analysis Results of Driver 's Average Fixation Duration in Downhill Section.

| Source of Variation | Type III Sum of Squares | df | Mean Square | F | P | Partial $\eta^2$ |
|---|---|---|---|---|---|---|
| Curve radius | 31306.750 | 2 | 15653.375 | 6.903 | <0.050 | 0.079 |
| Pavement marking | 30241.167 | 1 | 30241.167 | 13.335 | <0.001 | 0.076 |
| Curve radius × Pavement marking | 568.440 | 2 | 284.220 | 0.125 | >0.050 | 0.002 |

### *3.3 Scan Speed*

The average saccade speed of all drivers before and after the edge rate marking of different slope sections was counted and the Shapiro-Wilk normal distribution test was carried out. The test results show that the driver 's average saccade speed data satisfies normality (P>0.05). The ratio of the average saccade speed of the downhill section of different slopes before and after the marking line is laid is shown in Figure 6.

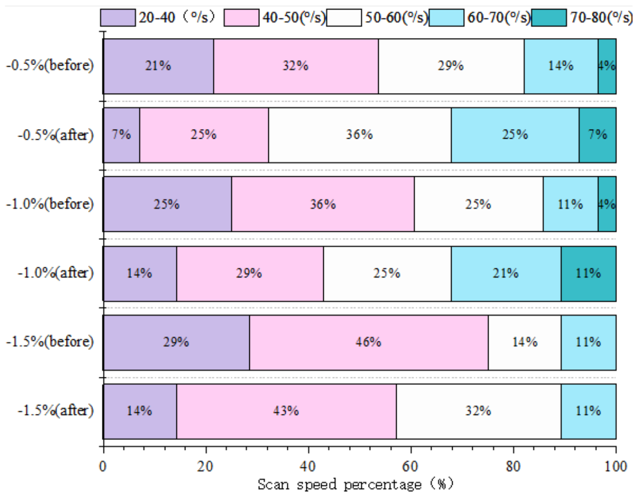



**Figure 6:** The Average Saccade Speed Ratio of Drivers at Different Slopes.

It can be seen from Fig.6 that before the edge rate marking is laid, the average saccade speed of the driver on the downhill section of different slopes has a high proportion in the range of 20-40, especially in the downhill section of-1.5 %, with a proportion of 29 %. After the marking was laid, the proportion of the average saccade speed in the range of 20-40 and 40-50 on each slope section decreased, while the proportion of the average saccade speed above 50 increased. For example, in the downhill section of-0.5 %, the proportion of saccade speed in the range of 50-60 increased from 29 % to 36 %, while the proportion in the range of 60-70 increased from 14 % to 25 %. This shows that the laying of the edge rate marking on the downhill section can effectively reduce the difficulty of obtaining information during the driver 's scanning process, thereby improving the scanning speed.

In order to further study the influence of the laying of the downhill edge rate marking on the driver 's saccade speed, and consider the effect of the road slope, a two-factor analysis of variance was used for testing. The results are shown in Table 5. The results of two-way analysis of variance showed that the effect of marking on the driver 's saccade speed showed a significant difference (F = 9.357, P <

0.010). The slope of the road also showed a significant difference in the effect of the driver 's saccade speed ($F = 3.372$, $P < 0.050$), and there was no interaction between the two on the average saccade speed ($F = 0.108$, $P > 0.050$). According to the effect index of partial η2, when driving on the downhill section, the marking laying and the downhill slope have a certain degree of influence on the driver 's saccade speed.

**Table 5:** Analysis of Variance Results of Driver 's Average Saccade Speed in Downhill Section.

| Source of Variation | Type III Sum of Squares | df | Mean Square | F | P | Partial $\eta^2$ |
|---|---|---|---|---|---|---|
| Curve radius | 706.172 | 2 | 353.086 | 3.372 | <0.050 | 0.040 |
| Pavement marking | 979.717 | 1 | 979.717 | 9.357 | <0.010 | 0.055 |
| Curve radius × Pavement marking | 22.544 | 2 | 11.272 | 0.108 | >0.050 | 0.001 |

### *3.4 Blink Frequency*

The average blink frequency of all drivers before and after the edge rate marking of different slope sections was counted and the Shapiro-Wilk normal distribution test was performed. The test results show that the driver 's average blink frequency data satisfies normality ( ). The comparison results of the average blink frequency of the downhill sections with different slopes before and after the marking are shown in Figure 7.

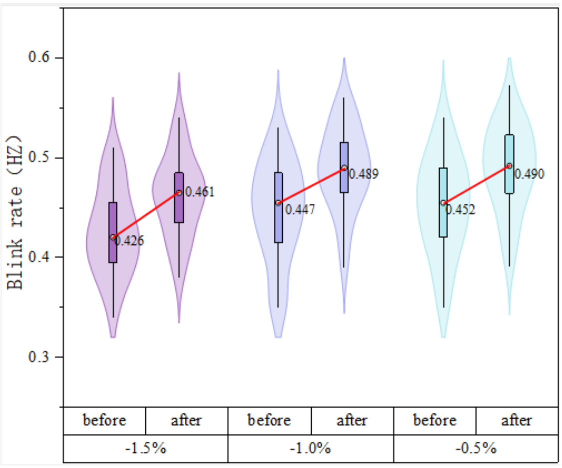



**Figure 7:** Average Blink Frequency of Drivers Before and After Marking on Different Slopes.

It can be seen from Figure 7 that after the edge rate marking is laid, the average blink frequency of drivers on each downhill section shows an upward trend. Among them, the average blink frequency of-1.5 % downhill section increased from 0.426 HZ before laying to 0.461 HZ, an increase of 8.2%; the average value of-1.0 % downhill section increased from 0.447HZ to 0.489HZ, with an increase of 9.4 %. The average value of-0.5 % downhill section increased from 0.452HZ to 0.490HZ, with an increase of 8.4 %. In addition, the standard deviation also decreased, which decreased from 0.044 to 0.040 in the-1.5 % downhill section, from 0.051 to 0.042 in the-1.0 % downhill section, and from 0.050 to 0.044 in the-0.5 % downhill section, indicating that the individual differences were reduced. The above phenomena show that the edge rate marking laid on the downhill section can reduce the visual load of the driver during driving, thereby increasing the blink frequency.

In order to further study the influence of the laying of the downhill edge rate marking on the driver 's blink frequency, and consider the effect of the road slope, a two-factor analysis of variance was used for testing. The results are shown in Table 6. The results of two-way analysis of variance showed that there was a significant difference in the influence of marking laying on the blink frequency of drivers ( $F = 31.075$, $P < 0.001$ ), and the slope of road section also had a significant difference in the influence of the blink frequency of drivers ( $F = 6.216$, $P < 0.050$ ), and there was no interaction between the two on the blink frequency ( $F = 0.087$, $P > 0.050$ ). According to the effect index of partial η2, when driving on the downhill section, the influence of the marking laying on the driver 's blink frequency is higher than that of the downhill slope, which is the more important factor affecting the driver 's visual load.

**Table 6:** Variance Analysis Results of Driver 's Average Blink Frequency in Downhill Section.

| Source of Variation | Type III Sum of Squares | df | Mean Square | F | P | Partial $\eta^2$ |
|---|---|---|---|---|---|---|
| Curve radius | 0.026 | 2 | 0.013 | 6.216 | <0.010 | 0.071 |
| Pavement marking | 0.064 | 1 | 0.064 | 31.075 | <0.001 | 0.167 |
| Curve radius × Pavement marking | 0.000 | 2 | 0.000 | 0.087 | >0.050 | 0.001 |

## 4. Conclusion

In this study, the downhill sections of three different slopes of the E-Xian Expressway were used as test scenarios. The visual characteristics data of 28 drivers were collected through real vehicle tests. The changes of the driver's visual characteristics before and after the edge rate marking were systematically analyzed. The two-factor analysis of variance was used to explore whether there was an interaction effect between the marking laying and the downhill slope on the above indicators. The main conclusions are as follows:

(1) The edge rate marking significantly improves the driver's visual characteristics in the downhill section. After the marking is laid, the average pupil area of the driver decreases by 16.2% -18.1%, and the blink frequency increases by 8.2% -9.4%. The main distribution interval of fixation duration was shortened from 400-475 ms to 375-450 ms, and the proportion of saccade speed in the range of more than 50°/s was significantly increased. It shows that the edge rate marking can effectively reduce the driver 's visual load and improve the efficiency of visual information processing.

(2) Two-way analysis of variance showed that marking had a significant main effect on all visual indicators (pupil area: $F=72.692$, $P<0.001$; blink frequency: $F =31.075$, $P<0.001$; fixation duration: $F = 13.335$, $P < 0.001$; saccade speed: $F = 9.357$, $P < 0.010$), downhill slope also had a significant main effect on each index $P < 0.05$). However, there was no interaction between the marking and the slope ($P > 0.05$), indicating that the deceleration and visual guidance effects of the edge rate marking on the downhill sections of different slopes were consistent and robust.

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