Study on the Influence of Anti-slipping Layer Color on Driving Safety at the Tunnel Entrance

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Abstract: In order to study the influence of anti-slipping layer color on driving safety before the tunnel entrance, based on color theory and psychology, this paper used UC-win/Road, Adobe Photoshop, and 3D Max to simulate the real scene, and 8 different color schemes were designed for anti-slipping layer paving. The analog driving device was used to simulate driving, and the eye tracker was adopted to collect the characteristic data of driver's eye movement. Through data processing, driver's pupil area change, gaze point proportion and reaction time for targets in the 8 color scheme conditions were obtained, and then the impact of different anti-slipping layers color on driver's driving safety was evaluated. The anti-slipping layer pavement schemes with different colors have different degrees of impact on driver vision, which in turn affect driving safety. According to the characteristics of optical illusion, a discontinuous multicolor anti-slipping layer pavement scheme was designed, which can provide strong guidance to improve the security of high-speed driving on Wenshan Guangnan-Nasa Expressway.

1. Introduction
With the rapid development of the transportation industry, China's highway length has increased year by year. As of the end of 2018, China's highway length had exceeded 140,000 kilometers [1]. However, with the rapid construction of expressways, the traffic accidents still frequently occur. Among them, the most serious traffic accidents often happened on expressways, causing serious property losses. According to statistics, there were more than 240,000 traffic accidents in China in 2018, causing direct property losses of nearly 1.4 billion [2]. As an important node of the expressway, the tunnel section is also a section with frequent traffic accident occurrences. Due to the generally limited speed requirements in tunnels and the “black hole effect” in the entering of tunnel [3], motor vehicles usually undergo a rapid braking process before entering the tunnel. In order to better achieve deceleration, most of the current measures are paving a multicolor anti-slipping layer on road surface before the tunnel entrance. The color of the colorful anti-slipping layer and the black asphalt pavement have a significant difference, which has a significant impact on the driver's vision. It is of great
significance to study the effect of the color of the anti-slipping layer on the driver's vision, which is conducive to improving driving safety.

Considering the visual characteristics of the human eye, different colors have different stimulating effects on the human eye, and different road colors have different effects on the driver’s vision and even psychology [4, 5]. Xu et al. [4] designed a road traffic color safety system based on color vision theory. Through model calculation and quantitative analysis, it was found that different colors have different degrees of impact on driver vision and psychology, and road surface color effects are universal for drivers. Xu et al. [6] introduced color vision from a theoretical basis, studied the influence of color on drivers’ psychological effects under different weather conditions, and proposed a design framework for the road traffic color system. Dai et al. [7] analyzed the adaptability of colored pavement to road traffic, and showed that colored pavement has a positive effect on road traffic safety, and proposed the use of colored pavement to improve safety for highway accidents. Zhang et al. [8] quantitatively studied road traffic colors, proposed an evaluation index system, constructed a traffic color evaluation model, and verified the validity and scientificity of the index system and evaluation model. A large number of studies have shown that color plays a major role in road traffic safety, and it has gradually been focused by researchers.

At present, there are few studies on the effect of road color on drivers’ vision and driving safety in front of expressway tunnel, and most researches remain on the level of theoretical and mathematical model, and there are few reports on simulation studies based on actual engineering. Therefore, based on the Guangnan-Nasa Expressway construction project in Wenshan, Yunnan, this paper used visual simulation and simulated driving to collect the driver’s visual parameters, and used eye trackers to study the impact of the anti-slipping pavement color on driving safety on the highway before the entrance of the Guangnan-Nasa Expressway Banmao Tunnel, so as to provide strong support for the research and evaluation of driving safety in the construction of engineering projects.

2. Test design

2.1 Pavement color selection

According to the construction goals, it is planned to build Guangnan-Nasa Expressway into a tourist expressway with Wenshan’s regional cultural characteristics, and at the same time, satisfying the safety of road traffic. The choice of anti-slipping pavement color before the tunnel entrance is particularly important. Reasonable color arrangement can not only play a warning role, but also show the special regional cultural color. Through extensive research work summary and consultation of experts in related fields, it was proposed to choose green(gr), yellow(ye), beige(be), earth yellow(ey), red(re), purplish blue(pb), black(bl) and multicolor combination (mc, combined by the first seven colors), a total of eight colors for the anti-slipping layer paving schemes. The selected colors include both the conventional anti-slipping layer colors and the colors with local cultural characteristics.

2.2 Software and hardware selection

For road simulation model establishment, color anti-slipping road design, effect rendering, etc., the currently widely used virtual reality software UC-win/Road [9] and Adobe Photoshop were selected. German SMI eye tracker and Swedish Tobii eye tracker were used for the collection of drivers' visual parameters. The driving hardware system was PXN analog driving device, as shown in Fig.1.

Figure 1. Eye tracker and analog driving device
2.3 Composition of test personnel
A total of 20 driver volunteers were selected for the test, which consisted of male and female drivers. The drivers are from 22 to 40 years old, and the driving age is from 0 to 15 years.

2.4 Main test content
Based on different color anti-slipping layer sections, different scenes were simulated. The driver wore an eye tracker, and used the analog driving device to drive the car at a speed of 60 km·h⁻¹ in each scene, and the eye tracker recorded eye movement data in the field of view. Based on the dynamic clustering algorithm and the driver’s sight point, the driver’s field of view plane was divided into 6 visual areas according to the road alignment, vehicle structure characteristics and driver’s driving characteristics. The image of the driver's field of view plane is shown in Fig.2. Area 1 is the left side of the field of view, area 2 is the front left of the field of view, area 3 is the front right of the field of view, area 4 is the road surface, area 5 is the emergency lane, and area 6 is the cab area.

2.5 Data processing
The eye movement data collected by the eye tracker were processed by data processing software such as SPSS to obtain three driving safety evaluation indicators: the driver's pupil area, the proportion of the gaze point in the visual area, and the target reaction time.

2.5.1 Abnormal data removal
The Pauta judgment method [10, 11] was used to filter the data collected in the six fields of view, and the basic formula is as follows:

\[ |x_i - \bar{x}| > 3\sigma \]

Where: \( x_i \) is the sample data value, \( \bar{x} \) is the sample mean, and \( \sigma \) is the sample standard deviation.

When the difference between the value of \( x_i \) in the sample and the sample mean \( \bar{x} \) is greater than 3 times of the sample standard deviation, the data will be discarded as abnormal data, and each time the abnormal data is eliminated, the calculation will be repeated until each data is satisfied Pauta judgment method.

2.5.2 Normal distribution test
Taking the result of a driver’s red pavement driving test before a tunnel entrance as an example, after the abnormal data was removed, the pupil diameter data was tested for normal distribution. According to the normal Q-Q diagram of the pupil diameter [12], the data was basically near the straight line, indicating that the data satisfies the normal distribution.

3. Simulation scene construction and experiment
According to the requirements of Wenshan Guangnan-Nasa high-speed design file, UC-win/Road was used to stimulate the basic simulation scene, and then Adobe Photoshop and 3D Max were used to render the visual effect, so that the simulation effect can be closer to the actual road situation. Fig.3 is photos of the red and multicolor pavement schemes in 8 simulation scenarios.
During the test, the driver controlled the vehicle in the simulated scene through the analog driving device, and the eye tracker was used to record eye movement data during driving. The test photos are shown in Fig.4.

**4. Results analysis and discussion**

### 4.1 Changes in pupil area

Different road surface colors can change the driver's pupil area, which can intuitively reflect the driver's physiological and psychological state during driving, and can indirectly evaluate the effect of anti-slipping layer color on driving safety. Therefore, the pupil diameter is converted into the pupil area change rate, and the calculation formula is shown as the following.

$$
\phi = \left[ \frac{S_i - S_0}{S_0} \right] \times 100\%
$$

In the formula: $\phi$ is the change rate of pupil area (%); $S_0$ is the original pupil area (mm$^2$); $S_i$ is the pupil area after the test (mm$^2$).

The simulated driving results of 20 drivers were analyzed and processed to obtain the pupil area change rate of the eight color anti-slipping layer paving schemes, and the data results of the same scheme were averaged. The final processing results are shown in Fig.5.
It can be seen from the figure that the black pavement scheme has the lowest change rate of pupil area. The reason is that the black color and asphalt pavement is similar, making the driver's pupil shrinkage smaller during driving. The change rate of pupil area of the remaining six single-color pavement schemes is basically concentrated between 7% ~ 9%, indicating that the selected color has the effect of attracting the driver’s attention and can play a better warning role when used as an anti-slip layer pavement color, which helps to improve the safety of driving before the tunnel on the highway. In addition, the experiment also innovatively simulated the multicolor pavement scheme. In this case, the pupil area change rate of the driver reached 13%, indicating that the multicolor anti-slip layer pavement scheme has a better warning effect than the single-color pavement schemes. The effect resembles that of the three-dimensional deceleration marking line. The anti-slip deceleration belt composed of multiple colors has an optical illusion effect for the driver [13, 14], thereby playing the role of warning and controlling the speed of the vehicle.

4.2 Gaze point proportion
The proportion of gaze points can reflect the attractiveness of each visual field to the driver’s vision, and the driver’s attention is more distributed in the road surface area, which is conducive to improving the driving safety in front of the tunnel. By calculating the ratio of the gaze point through the driver's gaze times for each field of view, the influence of the color of the pavement anti-slip layer on the driver's attention can be studied, and then the influence of the color on the driving safety can be evaluated. Fig.6 shows the average percentage of gaze points of 20 driver volunteers in 6 areas.

![Figure 6. Proportion distribution of gaze points in different regions](image)

It can be seen from Fig.6 that the difference in the gaze points of the eight paving schemes in Areas 1, 3, 5, and 6 is small, while there are significant differences in Areas 2 and 4. Since the black pavement scheme resembles the color of conventional asphalt pavement, it can be regarded as a control group, indicating that when driving on an ordinary asphalt pavement, the driver's attention is mostly focused on the left front direction of the vision and the road pavement. Compared with the black pavement scheme, the six types of anti-slip layer pavement schemes with a single color have a significant increase in the percentage of gaze points in Area 2, while the proportions of gaze points in Area 4 decrease, which is not conducive to driving safety. The reason for the analysis is that the single-color anti-slippery layer is likely to cause driver's physiological and psychological rejection and visual fatigue, reduce the driver's gaze point on the road, and turn his/her attention to the left front field of vision to find a visual sense of hierarchy. The multicolor pavement scheme accounts for more than 45% of the gaze points on the road surface, as the multicolor mixed pavement plays a visual illusion effect [13, 14], which can better attract the driver’s attention, and increase the proportion of driver’s visual gaze point on the road surface, which is helpful to remind the driver to brake and decelerate before entering the tunnel, and improve the driving safety of the tunnel section.
4.3 Reaction time
The reaction time is the time from the driver's discovery of the stimulus (the target vehicle's brake light is on) to taking braking measures. The distance of the stimulus from the driving vehicle was 50 m.

In this study, the stimulus was set in the simulation scene, the response time was measured using the data recorded by the eye tracker, and the response time of each scheme was obtained after averaging. The test results of the reaction time are shown in Table 1.

| Pavement color | gr | ye | be | ey | re | pb | bl | mc |
|----------------|----|----|----|----|----|----|----|----|
| The reaction time/s | 0.54 | 0.53 | 0.59 | 0.55 | 0.57 | 0.57 | 0.53 | 0.50 |

It can be seen from the table that the reaction time of the eight color schemes is not much different, and the overall concentration is 0.50 s ~ 0.60 s, indicating that the color of the anti-slipping layer has no significant effect on the driver's reaction time. In addition, the shortest reaction time of the multicolor scheme is only 0.50 s, which indicates that the multicolor can play a warning role, reduce the driver's reaction time, shorten the minimum safe distance of driving, and improve the driving safety in front of the tunnel.

4.4 Conclusion
This paper used UC-win/Road simulation software to build eight different color anti-slipping layer pavement schemes, studied the impact of different colors on driver vision and driving safety. For single-color paving schemes other than black, the pupil’s area change rate was basically concentrated at 7% ~ 9%, and the multicolor pupil’s area change rate reached 13%, indicating that the multicolor anti-slipping layer pavement can serve as a warning effect.

By studying the proportion of the driver’s gaze points in the 6 visual areas, it was found that the ratios of gaze points on the road surface of the 7 single colors are significantly lower than that of the multicolor anti-slipping pavement scheme, indicating that the single color is not conducive to the driver's attention, and the multicolor pavement scheme has a better effect of attracting the driver’s attention and can improve driving safety.

Through the test of the reaction time, it was found that the reaction time differences of the eight color schemes are not significant. Among them, the multicolor mixed pavement has the shortest reaction time of 0.50 s, indicating that the multicolor mixed pavement scheme can play a warning role, shorten the minimum driving safety distance, and ensure driving safety in front of the tunnel on the highway.

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