Analysis of the Color on the Tunnel Portal Based on the Drivers’ Heart Rate

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Abstract. In order to investigate the influence of the color on the tunnel portal on drivers’ heart rate under dynamic visual conditions, road experiments were carried out with different colors and at different driving speeds with the same color. PsyLAB physiological recorder was used to record the eight drivers’ heart rate under different scenes based on which the influence of the colors on the tunnel portal on drivers’ heart rate under different driving speeds was further analyzed, and the trend surface relation model among the driving speed, color and drivers’ heart rate was established. The results showed that when the value of the color was reduced, i.e. when the color brightness was increased, the drivers’ average heart rate was increased, which could improve the drivers’ attention; the driving speed was in direct proportion to the drivers’ heart rate with the same color, i.e. the faster the speed, the bigger the drivers’ average heart rate.

1. Introduction
In recent years, with the fast development of China’s tunnel construction, the traffic accident rate was also rapidly increasing, especially at the tunnel portal, often with serious injuries and casualties. According to the related data released by Norwegian highway bureau, 63.7% of the traffic accidents occurred at the tunnel portal[1]. In 2010, the number of the traffic accidents took place at the tunnel portal of a mountain highway in China accounted for 54.5% of the total number of the traffic accidents happening in that tunnel. Thus it can be concluded that the tunnel portal was the accident-prone area and great attention should be paid.

Hu[2] studied about the influence of the lighting condition on the tunnel portal on the drivers’ visual demand characteristics and the change rate of the pupil area with safe and comfortable driving. The result showed that when the speed limit was at 60 km/h at the portal, the demand for the illuminating brightness would be higher than the value in the current specification for safe and comfortable driving. Ding[3] investigated the influence of the tunnel environment on the drivers’ physiological indicators, such as the vision, heart rate etc. In terms of the landscape on the tunnel portal, Guan[4] proposed the three-level design concept and method for the factors that should be considered, i.e. the landscape elements, design principle and the landscape on the portal and the specific application of the “point”, “surface” and “line” model. Zhang[5]applied the richness of the space scenery into the landscape design on the tunnel portal and suggested “weakening the landscape design
on the portal if the space scenery was rich enough, and intensifying it if the scenery was too single”. Li[6] combined the uniqueness of the regional culture with the particularity of the landscape design on the tunnel portal, and put forward some specific requirements for the application of the regional culture in the landscape design of the tunnel portal.

From the above, it could be concluded that China has made a lot of research about the safety of the tunnel, and had achieved certain achievements. However, most of the research was about the ventilation, lighting and the transition between light and shade. And even the research about landscape on the tunnel portal was mainly about the combination of landscape with the surrounding environment and the local culture. Only little research was about the color. In the process of driving, the drivers obtained 80% of the traffic information by vision As the most perceptible part, color directly influenced the drivers’ driving behavior, thus affecting the traffic safety. Research showed that some dangerous sections of Alps was coated with red color by Sweden, and the traffic accidents on those dangerous sections decreased by 85%-90%. Thus it could be seen that proper colors could improve traffic safety. Vehicle driven on the highway was in a dynamic process. In this process, the drivers’ field of vision and sight distance were changing accordingly as the change of driving speed, making them see, notice and feel different landscape colors on the tunnel portal from the colors when they were resting. Therefore, it was of great significance and practical value to study about the landscape colors on the tunnel portal under dynamic vision from the aspect of the drivers’ physiological indexes on the basis of color psychology principle.

2. Analysis of the Color on the Tunnel Portal and Drivers’ Heart Rate

2.1. The current status of the tunnel portal color
The major material of the tunnel portal was concrete, and its color was light grey as the concrete itself, which often brought the drivers a sense of depression and was hard to be perceived by the drivers. When the drivers passed through the tunnel portal at a relatively fast speed, they could not perceive the tunnel ahead immediately and slow down accordingly, so that the probability of traffic accidents was greatly increased. Nowadays, in order to improve the drivers’ attention and avoid traffic accident at the tunnel portal, China had set up many signs and plates ahead of the tunnel and elevation markings on the tunnel portal. However, the color on the tunnel portal was also an un-negligible element. Appropriate colors could not only coordinate with the surrounding environment, but also improve the drivers’ attention and play the roles as warning, guiding and relieving.

2.2. Color and heart rate
Color was eyes’ vision to the lighting of different wavelengths. Things were distinguished from each other by their colors, and different information could be obtained. It was a physiological action. The reason why people’s behavior could be controlled by the colors was that people’s behaviour was easily controlled by their emotion, and physiological feelings could be influenced by psychological activities. According to the environment behavior theory, people’s behavior was the reflection of the cognition to the environment. The theory of planned behavior suggested that one’s behavior could be directly adjusted by his emotional attitude, standards and cognition. Different colors could produce different psychological and physiological state. Drivers’ driving behavior could be influenced by the change of their physiological status, so as to improve the traffic safety.

When the drivers drove fast on the highway, they needed to bear not only the physiological load on the body, but also the mental load under nervous conditions. So it was feasible to choose the drivers’ heart rate to reflect their psychological and physiological load in the process of driving. Heart rate was the beating times that the heart transferred the blood to the body in a time unit. In a calm state, the heart rate of a healthy adult was about 60-100 times/min, the average was 75 times/min, and 160 times/min at most. Besides the age, body temperature, mood and medicine etc., one’s heart rate was also closely related to the external stimulus, work intensity and his tension state. To study about the influence of the color on the tunnel portal at different speeds on the drivers’ heart rate based on the
color psychology theory could make up for the shortage of color qualitative analysis and had great significance.

3. Experimental Design Scheme

Tunnel portal color was adopted in this paper, and the often-used prohibiting and warning signs red and yellow, the green color and grey similar to the concrete were chosen as the road experiment colors (as shown in Figure 1). Since traffic accidents usually occurred at relatively fast speed and the speed of the highway tunnel was generally limited to 60-80 km/h, the speed in the experiment was selected between 60-80 km/h. The R, G, B values of the selected colors should be based on the classification standard of the roadside colors. The selected three colors were set on the tunnel portal in the same way one after another. When the drivers passed through at different speeds, observe the influence of the color on their heart rate. For easier calculation, the following formula could be used to calculate the average value of the colors:

\[ C = (65536 \times B) + (256 \times G) + (R) \]  

In the formula, R, G, B referred to the color value of red, green and blue respectively.

In order to reflect the influence of the color on the tunnel portal on the drivers’ heart rate more exactly, this experiment selected eight healthy and experienced drivers (including two female drivers) as the test objects. Of which five drivers had more than three years’ driving experience with the age between 20 and 45 years old. All the test objects were required to get enough sleep, have good mental status, drink no alcohol, coffee or medicine etc. before the test so as not to influence the physiological index.

PsyLAB physiological recorder was employed to test and record the test objects’ heart rate synchronously. This recorder could transfer the physiological and biomechanical data in real time through wireless data transmission technology. It was small in volume, convenient to carry, and had little influence on the test objects. Its recording frequency of the heart rate was 64 HZ.

To ensure the effectiveness of the experiment and reasonably analyze the influence of the color on the tunnel portal on the drivers’ heart rate, the test objects’ heart rate in the calm state and under the condition with no colors on the tunnel portal were tested respectively. After comparing with the experimental data, it could be concluded that when some appropriate colors were set on the tunnel portal, the drivers’ average heart rate was higher than that when there was no colors, which indicated that appropriate colors could improve the drivers’ heart rate to a certain extent and properly increase drivers’ tension.
4. Model Establishment and Result Analysis

4.1. Modeling of trend surface

Trend surface fitting was the most effective method for the space curved surface in mathematics. It approximately simulated the space change trend of the target parameter by the space curved surface in the form of function. Suppose at a certain speed with a certain color on the tunnel portal, the drivers’ actual observed heart rate was $z_i(x_i, y_i)$ ($i = 1, 2, \ldots, n$), and the fitting of the trend surface was $z_i(x_i, y_i)$, then the residual sum of squares $Q$ was

$$Q = \sum_{i=1}^{n} \left( z_i - z_i^* \right)^2$$

(2)

When $Q$ was the minimum, it was the fitting of the trend surface under least square. Trend surface model was employed to fit for the speed, colors and drivers’ heart rate in this paper. The fitting formula was as below:

$$z = a_0 + \sum_{i=1}^{n} (a_i \cdot x + b_i \cdot y)^i$$

(3)

In the above formula, $a_0, a_i, b_i$ were coefficients to be fitted.

4.2. Compatibility test of the trend surface model

4.2.1. $R^2$ test for the compatibility of trend surface fitting. The fitting degree coefficient of trend surface and actual surface $R^2$ was an important indicator to test the fitness of the regression model. The percentage of the total sum of square and regression sum of square of variant $Z$ was commonly used to express the goodness of fit for regression model.

$$SS_T = \sum_{i=1}^{n} (z_i - \bar{z})^2$$

(4)

$$SS_D = \sum_{i=1}^{n} (z_i - \bar{z})^2$$

(5)

$$SS_R = SS_D + SS_T$$

(6)

In the above formula, SST was the sum of squares for total; SSD was residual sum of squares, which was used to show the influence of other random factors on $z$ variation; SSR was regression sum of squares, which was used to indicate the total effects of all the independent variables on the dependent variables.

$$R^2 = \frac{SS_R}{SS_T} = 1 - \frac{SS_D}{SS_T}$$

(7)

The bigger $R^2$ was, the higher the goodness of fit of the trend surface was.

4.2.2. Significance $F$ test for the compatibility of trend surface fitting. $F$ test for the compatibility of trend surface fitting was the significance testing of the total regression model of the trend surface. The exact computing method was as follows:

$$F = \frac{SS_R/p}{SS_D/(n-p-1)}$$

(8)

In the formula, $p$ was the freedom degree of the regression sum of squares; $n-p-1$ was the freedom degree of the residual sum of squares.
4.3. Model calculations

After comparing the original experimental data, 21 sets of data were selected to quantitatively analyze the relationship of the driving speed, the average value of the color on the tunnel portal and the drivers’ average heart rate. Part of the experimental sample data was obtained as shown in table 1.

| Driving Speed (km/h) | Average Value of Colors | Average Heart Rate (Times/min) |
|----------------------|-------------------------|-------------------------------|
| 60                   | 1778908                 | 78.03                         |
| 61                   | 3380637                 | 76.1                          |
| 62                   | 3805902                 | 77.12                         |
| 63                   | 4786904                 | 76.76                         |
| 64                   | 1387252                 | 75.17                         |
| 65                   | 2637052                 | 76.23                         |
| 66                   | 1802801                 | 74.38                         |
| 67                   | 2987798                 | 74.43                         |
| 68                   | 2263842                 | 71.52                         |
| 69                   | 2372487                 | 73.57                         |
| 70                   | 1431295                 | 69.98                         |

The data in table 1 showed that there was great difference in the order of magnitudes of driving speed, the average value of the color on the tunnel portal and the drivers’ average heart rate. Many problems may be caused if the above three were fitted directly. Therefore, the sample data was processed with variation method in this paper. The exact computing formula was as follows:

\[
\bar{x}_i = \frac{x_i - \min(x_i)}{\max(x_i) - \min(x_i)}
\]  

(9)

In the above formula, \(x_i\) was the value of number \(i\). Suppose the driving speed was independent variable \(x\), the average value of the color on the tunnel portal was independent variable \(y\), and drivers’ average heart rate was dependent variable \(z\), the following scatter diagram could be established by Matlab after the normalization processing of the sample data as shown in Figure 2.

Figure 2. Scatter diagram among driving velocity, color and drivers’ average heart rate

According to the data in Table 1, the trend surface relationship model among the driving speed, the average value of the color on the tunnel portal and drivers’ average heart rate was established as below:

\[
z = 0.9206 - 1.5162x + 0.5314y - 0.0871xy + 0.6059x^2 - 0.4970y^2
\]  

(10)
When the driving speed and average value of the color on the tunnel portal in table 1 was applied into the formula (10), the predicted value of the drivers' heart rate could be obtained. The comparison result of the measured and predicted values of the drivers' heart rate was showed that there was only small difference between the measured and predicted values of the drivers' heart rate. After calculations, the secondary trend surface the fitting coefficient R2 was 0.76, which showed that the fitting effect of the trend surface was quite good. There is a significant difference from drivers' heart rate (P<0.05), which showed that the tunnel portal color effect of the drivers' heart rate was obviously.

4.4. Test Result Analysis
The trend surface diagram among the driving speed, the average value of the color on the tunnel portal and the drivers' average heart rate was established in Matlab in accordance with the fitting formula (10) as shown in Figure 3.

According to Figure 3, as the increase of the driving speed, the drivers' average heart rate increased rapidly and the drivers got much more nervous than they were in the calm state, so that the traffic accidents were prone to take place at the tunnel portal; as the increase of the value of the color, the drivers' average heart rate showed a downward trend, i.e., to set some proper colors on the tunnel portal could improve the drivers' attention to a certain extent and reduce the probabilities of the traffic accidents.

5. Conclusions
Through the analysis of the drivers' average heart rate when they were in the calm state, when there was no color and some colors set on the tunnel portal, it showed that to set some appropriate colors on the tunnel portal could increase the drivers' heart rate to a certain extent and properly improve drivers' tension.

The value of the color on the tunnel portal had an inverse relationship with the drivers' average heart rate, i.e., as the decrease of the color value, the drivers' heart rate kept increasing, however, the increase rate was very slow, which indicated that to properly increase the brightness of the colors on the tunnel portal could somewhat increase the drivers' tension and improve their attention so as to avoid the happening of the traffic accidents.

It was suggested that besides setting up signs & plates and elevation markings on the tunnel portal to remind the drivers, proper bright could also be set in accordance with the color psychology theory to change the current simple color and improve the drivers’ attention through the conversion of the colors, so that the probabilities of the traffic accidents could be reduced.
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