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ANALYSIS ON THE INFLUENCE OF ACCUMULATION EFFECT OF LANDSCAPE COLOR ON TRAFFIC SAFETY IN THE FOGGY SECTIONS OF EXPRESSWAYS

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ABSTRACT

The landscape color of expressways has a significant impact on a driver's visual response, thus affecting the incidence of expressways traffic accidents. Although this problem has been analyzed and discussed from different angles, there is rare quantitative analysis on the influence of accumulation effect of landscape color on the traffic safety in foggy sections of expressways. In this paper, the color combination and stroboflash of fog lamps on both sides of the road were designed from the perspective of the color research of road landscapes, and the cumulative effect of colors and stroboflash of fog lamps on the drivers' mind was also studied. Then the interactive cumulative model based on landscape color and driving time in heavy-fog environment was established. Finally, multi-group of fog-lamp colors and spacing experiment program allowing a visibility of 200–500m in fog environments was designed by using Tobii eye-movement instrument and the UC-win/Road simulation software. According to the program, simulations were performed on several drivers to test the influence of road-landscape colors in foggy environments on the drivers' visual psychology. The results of the simulation experiment showed that the colors and stroboflash of fog lamps on both sides of the road have a positive effect on the drivers' safety when the visibility range is 200–500m, and the driving speed is less than 70 km/h, in addition, the red and yellow were found to have the largest influence among all the studied colors. These results show that it is necessary to design landscape colors in the foggy sections of expressways.

KEYWORDS

Foggy sections of expressways, Road landscape, Landscape color, Cumulative effect

INTRODUCTION

When people observe objects, the primary visual reaction is caused by color. Road color is considered as one of the main influencing factors of road landscapes. Therefore, the design of road landscapes is based on several factors such as road-surface color and line trend. However, during the process of expressways-landscape design, the total design of road landscape is often emphasized, resulting in neglecting the local layout of special foggy expressways areas. The foggy sections of expressways is a serious area affected by heavy-fog weather. Moreover, secondary accidents may easily occur owing to the low visibility. So far, related studies have shown that low road visibility and high tension observed on a driver’s optic nerve in the foggy sections of expressways may produce visual fatigue, thereby resulting in traffic accidents. Thus, whether the road traffic color design can be used for reference, and how to learn from the road traffic color design and through the road landscape color matching in fog environment, to reduce the driver's visual fatigue to some extent, is a meaningful problem worthy to be discussed.

Many scholars pay significant attention to research on the traffic safety in heavy-fog environment. The analysis on influencing factors of traffic safety in heavy fog environment includes the following aspects: the formation mechanism of fog, visibility detection in the foggy sections of expressways, traffic inducement in foggy areas, information warning in foggy area, crisis principle analysis in foggy sections of expressways and etc. The traffic guidance through combing different colors of induction lamp with different driving environments was conducted in Japan. Also, a fog-area traffic-monitoring system set in the national expressway from Beijing to Zhuhai, was considered as an earlier application of a “red and yellow fog-lamp guidance system” that can be used to solve the fog-area traffic-safety problems in China [1]. Fu [2] and Jiang et al. [3] emphasized the necessity and importance of installing safety facilities in foggy areas. Qian’s [4] studies suggest that the drivers’ sight may be influenced by flicker asynchronization if fog lights were installed on both sides of the road, from the perspective of the visual psychology of the drivers. The fog lamps type selection and calculation method were established by Yang [5] from the fog lamps longitudinal and transverse location and installation height, the fog lamps engineering design theory, in view of the fog lamp brightness and diameter. Much research has been done both at home and abroad from the fog area road traffic safety guidance [6-8], however, these researches focused more from the viewpoint of security equipment and modern network technologies for building guidance systems, rather than from the perspective of landscape color or design to improve road traffic safety in foggy areas.

In the research of the color effect on visual psychology of drivers, Wang et al. [9] used MRI (Magnetic Resonance Imaging) to detect features of color and motion perception in the brain, thus improving the understanding of brain structure and functions of human color perception and motion perception. Yuan and Hu [10] introduced some information on the application of color to landscapes. Zhang et al. [11] discussed some aspects of color psychology and analyzed the application to traffic security considering factors such as the colors of road and accessory facilities, traffic-sign color, vehicle color, the colors of pedestrian clothes, and the road landscape. By using methods from safety psychology, color psychology, and qualitative analysis, Yuan et al. [12] and Lee et al. [13] analyzed the influence of vehicle colors on traffic safety and drivers’ reaction and proposed ideas for safe color design as well as principles, system, and steps for safe vehicle-color design. Li [14] and Siogkas et al. [15] introduced the functions of color, environment and people for protecting traffic safety in view of urban traffic and provided basic research for the design of urban-traffic safety colors. Based on the different psychological effects brought by color vision and visibility research under different weather conditions, Xu et al. [16] proposed the design framework for a road-traffic color system. Zhang et al. [17] studied urban road-traffic colors, proposed an assessment indicator system for such colors and created an evaluation and optimization model. Dai and Deng [18] believed colored pavement promotes the safety of road traffic suggested the use of colored pavement to promote traffic safety in highways. Shen et al. [19] analyzed the influence of colors on road-traffic safety and preliminarily discussed colors and color combinations in traffic systems. Wang et al. [20] studied the influence of roadside landscape colors in highways on the heart rate of drivers. By improving the light and dark adaptability of portal, Zhang et al. [21] improved the safety of road sections through planting plants separately with three colors in different sections and speed cutting signal, put forward some color treatment measure in walls of tunnels, and integrated portal safety and functions of landscape effectively. Tao et al. [22] simulated different colors in tunnel portals using an eye tracker and the 3D-MAX software and analyzed the influence of landscape colors in tunnel portals on the drivers’ heart rate.

Above papers focus on the influence of colors on road traffic safety, however, not involving the influence of colors on the visual psychology of drivers resulting from the cumulative effect of low visibility and dull road landscapes in heavy-fog environments where the drivers' visual range is limited. With large national territorial area, complex network environment and wide range of the foggy sections of expressways in China, it is necessary to study the influence of the cumulative effect of road landscape colors in the foggy sections on visual psychology of drivers.

In this study, the color combination and stroboflash of roadside fog lamps from the point of view of landscape colors in road were designed, the research drivers' mental cumulative effect caused by colors and stroboflash of fog lamps was analyzed, traffic safety guidance in fog environment was proposed and the simulation experiment using eye tracker and UC-win/Road simulation software was done. The main goal is to assess the influence of colors and stroboflash of roadside fog lamps on the driving safety.

2. THE APPLICATION OF COLORS IN THE FIELD OF ROAD TRAFFIC

2.1. The influence of colors on road traffic safety

As we all know, in the field of traffic safety, color is the preliminary information perceived by vision and directly affects traffic safety. The comparison of the attention of human eye to color and to shape is shown in Figure 1. The figure tells us: at first view, people pay 80% attention to color; 2 minutes later, the attention paid to shape increases to 20% while that of to color decreases to 60%; 4 minutes later, people pay 50% attention to shape; 5 minutes later, the influence of color decreases to 50% [23]. Therefore, color is the most easily perceived information, which directly influences operations of drivers and driving safety.

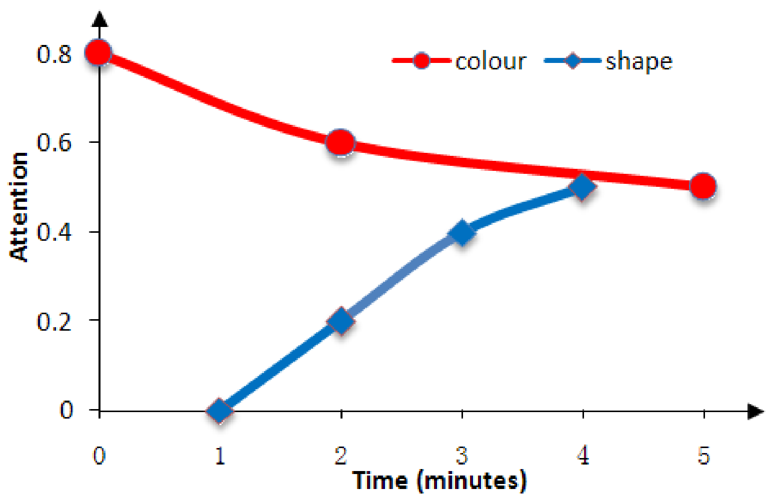

Fig. 1 - The Comparison of the attention of human eye to color and to shape

2.2. Color selection in road traffic

According to the theory of color vision [24], red, yellow, and green, which are highly related to human vision and mental reaction, are always used as signals in the traffic field. The human retina contains one type of rod photoreceptor cells and three types of cone photoreceptor cells. The rod photoreceptor cells are most sensitive to yellow light, whereas the three types of cone

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photoreceptor cells are separately most sensitive to red, green, and blue. Red and green are most easily distinguished by human beings because of this vision structure. Although yellow and blue are also easily distinguished, our eyes distinguish red and green better because there are relative fewer photoreceptor cells which are sensitive to blue and yellow lights. The psychological impact of common colors on people is shown in Table 1 [12]. It can be seen that colors may show active and drastic meanings; to express a hot or drastic meaning, red is the best choice, and yellow ranks the second; Green implies coldness and calmness. Therefore, red light is used as the forbidding signal in traffic engineering, yellow is used as the warning signal and green is used as the passing signal.

Tab. 1 - The psychological impact of common colors on people (modified from Ouyang et al. [25])

Color	Anger	Vigilance	Power	Enthusiasm	Exciting	Warmth	Quiet	Hope	Distance	Cold	Relaxed	Heavy
Red	△	△		△	△	△						△
Orange		△	△		△	△						
Yellow				△	△	△					△	
Green							△	△	△	△		
Blue									△	△		△
Purple									△	△		△
White											△	
Black												△

Note: "△" in the table refers to the existence of certain psychological effect or association.

At present, as to the urban road landscape design in China, people tend to focus on road structure and solving of traffic capacity, while regard road landscape design as an independent issue, which separates road landscape design, road geographical environment, road linear programming and road natures. There are few researches on special landscape design aiming at local regions with special linear structure, special climate characteristics or other special geographical features. With the improvement of national expressways system, in 2014, the Ministry of Public Security (MPS) of China showed that there are 1468 road sections in expressways with more than 3 foggy periods every year, and multiple vehicle rear-end and secondary accidents are typical features of accidents in fog sections. It is in urgent need to improve driving safety in the foggy sections of expressways. Installing induction fog lamps is one of solutions to improve driving safety in fog sections at present. However, when setting fog lamps, engineers only analyze installation interval from engineering perspective. This paper aims at setting fog lamps and designing landscape colors in a fog section from perspectives of road landscape design and visual psychology of drivers. It can be seen from Figure 2, that there is a certain linear relation between pupil area and driving speed. Figure 3 shows drivers' distances of visual cognition on different colors at night. It can be seen from Figure 3, that drivers have different distances of visual cognition on different colors. Fog environment brings low visibility. The moving distances of visual cognition on green and black are the most short among several colors. Unfortunately, black, grey and green are three dominant tones in fog sections. Therefore, it is necessary to design landscape colors in the foggy sections of expressways.

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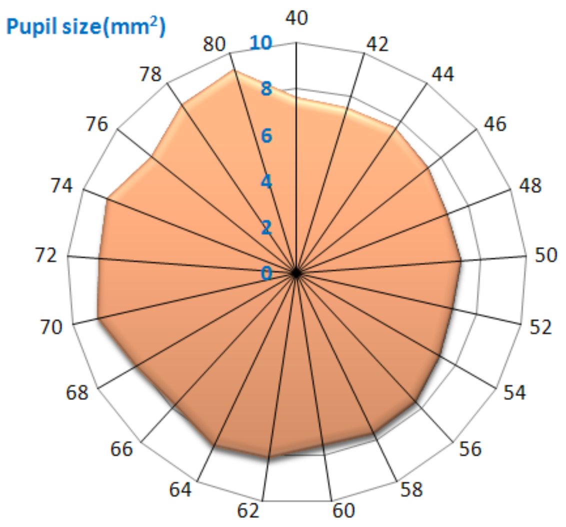

Fig. 2 - The relationship between the pupil area of the human eye and the driving speed

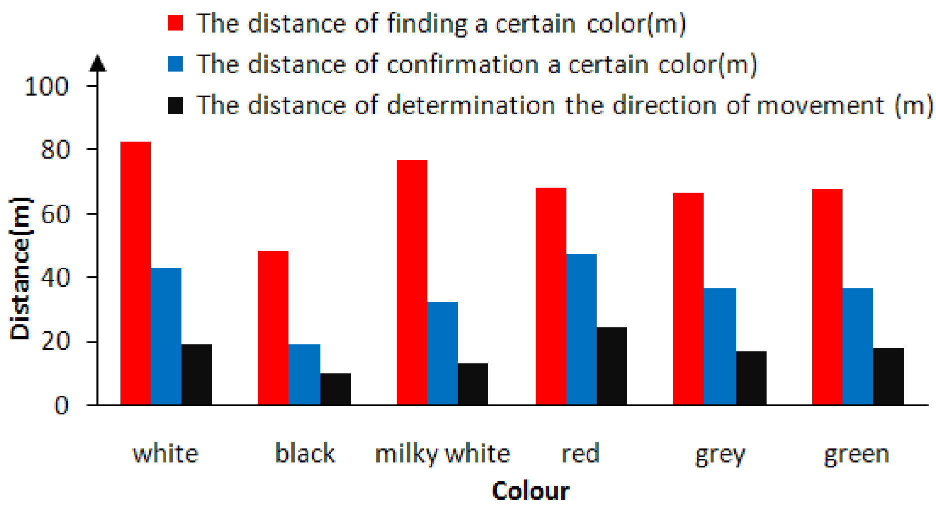

Fig. 3 - The comparison of the visual cognition distance of different colors at night

3. ANALYSIS OF THE CUMULATIVE EFFECT OF HEAVY FOG ENVIRONMENT AND LANDSCAPE COLORS

The cumulative effects can be regarded as the superposition or reduction effect of factors with same or different natures based on spatial and temporal scale (Li et al. [26]). The cumulative effect model includes three parts: the cumulative source, the cumulative approach and the cumulative effect. The cumulative source is divided into the single project cumulative source and the multi-project cumulative source. The cumulative approach contains addition function and interaction function. The cumulative effects are shown in following Table 2.

Tab. 2 - The function of the cumulative effect

Accumulative source	Accumulative way	Accumulative effect
Single source	Plus	Single source superposition
	Interactive	Single source interactive superposition
Multi source	Plus	Multi - source superposition
	Interactive	Multi- source interactive superposition

As shown in Figure 4, without being effectively planned, the accumulation of all factors of landscapes in expressways, including dull colors, unscientific lines, scrambled landscape, and low visibility, will make drivers more tired and increase the risk of road traffic. In the heavy fog environment, low road visibility, increased slippery index in the foggy sections and accumulation of multiple factors will result in a threshold value accumulation effect. To be specific, when the accumulated results of multiple factors exceed certain threshold, the quantitative accumulation leads to qualitative transformation, as shown in Figure 5. The various elements of the driving environment of expressways contain: people, vehicle and road. The elements of road include: visibility, road landscape, the shape of the line, and road slippery index and so on. These factors may bring interactive and cumulative effect to the driver, and then delivered to the vehicle and traffic safety. When the cumulative effect reaches a certain threshold value, it has an impact on traffic safety.

Fig. 4 - Expressways heavy fog environment

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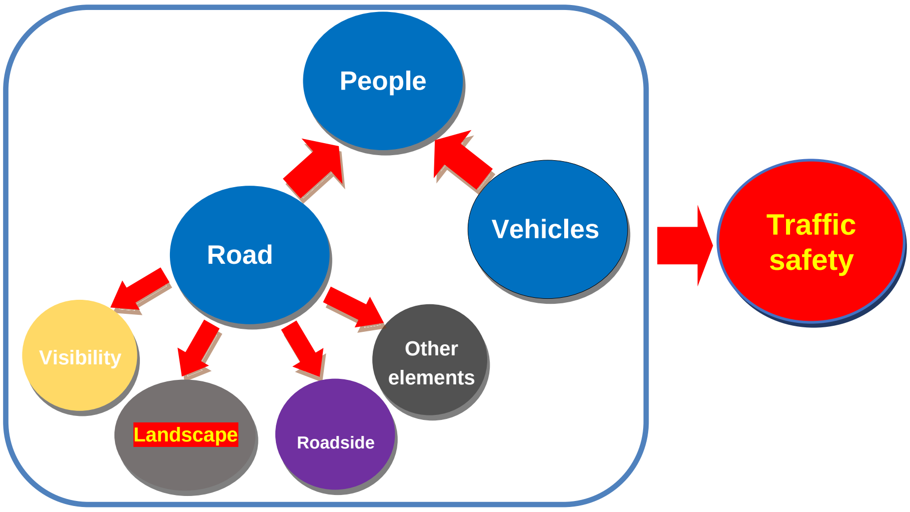

Fig. 5 - The synergistic accumulation of the influencing factors of traffic safety in the foggy sections of expressways

Based on the cumulative effect and according to Figure 5, the following cumulative model can be got,

$$AF = \beta_{xt} RAF + \beta_{yt} PAF + \beta_{zt} VAF \tag{1}$$

AF means the cumulative effect value; RAF means the cumulative source; PAF means the cumulative source of driver; VAF means the cumulative source of vehicle; β_{xt}, β_{yt} and β_{zt} means the cumulative effect index, and in general, $\beta_{xt} + \beta_{yt} + \beta_{zt} = 1$.

$$\begin{cases} \beta_{xt}, \beta_{yt}, \beta_{zt} > 0 \\ \beta_{xt}, \beta_{yt}, \beta_{zt} = 0 \\ \beta_{xt}, \beta_{yt}, \beta_{zt} < 0 \end{cases} \tag{2}$$

In formula (2), $\beta_{xt}, \beta_{yt}, \beta_{zt} > 0$ means positive cumulating. $\beta_{xt}, \beta_{yt}, \beta_{zt} = 0$ means no cumulating. $\beta_{xt}, \beta_{yt}, \beta_{zt} < 0$ means reversed cumulating.

In this paper, RAF means the cumulative source of road, and β_{xt} means the cumulative coefficient of road. β_{xt} is determined by the visibility cumulative coefficient β_{vaf}, the cumulative coefficient of landscape color β_{lcaf}, and the cumulative coefficients of other factors β_{oaf} .The value model of the cumulative coefficient of road β_{xt} is as follows:

$$\beta_{xt} = \delta_v t_v \beta_{vaf} + \delta_l t_l \beta_{lcaf} + \delta_o t_0 \beta_{oaf} \quad (3)$$

δ_v, δ_l and δ_o means the value coefficients and t_v, t_l and t_0 means the action time of the cumulative coefficients.

In this paper, β_{yt} the cumulative coefficient of PAF can be measured by mental tension index of a driver. In experiment, the mental tension index of a driver refers to pupil area of the driver tested by eye tracker. At the same time, in the heavy fog environment, the driving time of drivers influences their mental tension indexes to some extent. Therefore, the value model of β_{yt} is as follows:

$$\beta_{yt} = \delta_t \Delta T \beta_{taf} + \delta_p t_p \beta_{paf} \quad (4)$$

As to the cumulative impact value of *VAF*, we mainly consider the speed of vehicles, and cumulative indexes in different speeds. The interactive cumulative model based on landscape color and driving time can be derived by formula 1, 3 and 4.

$$AF = (\delta_v t_v \beta_{vaf} + \delta_l t_l \beta_{lcaf} + \delta_o t_0 \beta_{oaf})RAF + (\delta_t \Delta T \beta_{taf} + \delta_p t_p \beta_{paf})PAF + \beta_{zt} VAF \quad (5)$$

In formula 5, ΔT means the absolute driving time of driver in heavy fog environment. β_{taf} means the cumulative coefficient of absolute driving time ΔT in heavy fog environment. β_{paf} means the cumulative coefficient of mental tension index within absolute driving time in heavy fog environment. δ_t and δ_p means the value coefficients.

After simplifying formula 5, we can get formula 6:

$$AF = RAF \cdot \sum \delta_{RAF} t_{RAF} \beta_{RAF} + PAF \cdot \sum \delta_{PAF} t_{PAF} \beta_{PAF} + \beta_{zt} VAF \quad (6)$$

δ_{RAF} is the cumulative value coefficient of RAF; t_{RAF} is the cumulative action time of *RAF*; β_{RAF} is the cumulative coefficient of RAF; β_{PAF} is the cumulative value coefficient of PAF; t_{PAF} is the cumulative action time of *PAF*; β_{PAF} is the cumulative coefficient of PAF.

4. THE SIMULATION EXPERIMENT ON LANDSCAPE COLOR SELECTION IN FOG AREA OF EXPRESSWAYS

4.1. The scheme of simulation experiment

According to the viewpoint of Gao et al. [27], the driving speed should be limited to 80 km/h when the visibility level in the foggy sections of expressways is between 200 m~500 m. This speed is the crest speed of most road sections. In this environment, the outline and linear shape of road, whose influence on driver decreases gradually along with the decreasing of visibility, influence traffic safety in the heavy fog environment. In this research, the software called UC-win/Road (version 4.0) was used to simulate the heavy fog environment with visibility of 200m~500m. According to the actual device using standards, induced lights are set in fog section with the interval of 30m. Scenes were simulated according to different road landscape formed under the opening and closing conditions of fog lamps. We made simulation experiment to multiple drivers with Tobii Eye Tracker by comparing different vehicle models, driving speeds and time.

Six drivers with good health and proficient driving skill were selected in this experiment. See Table 3 for information of drivers. To optimize the experiment and decrease influences of other physiological factors on driving status, participants are required to sleep well before and keep good mental state in the experiment without drinking wine, coffee or taking medicine.

Tab. 3 - Some information about drivers in the experiment

Sex	Age	Driving Experience	Health Condition	Familiarity	Career
Man	26	2	Good	Unfamiliar	Student
	31	6			Teacher
	37	8			Doctor
	43	18			Driver
Woman	28	4	Good	Unfamiliar	Student
	33	5			Teacher

4.2. The experimental process

Before the experiment, firstly install and debug Tobii eye tracker, prepare driving simulation video, and request drivers to respectively see driving simulation videos with different colors and intervals. During the experiment, the eye tracker will record the variable parameters of drivers' fixation points in three-dimensional space in real time, record simulation video and drivers' facial expressions, and provide basis for data analysis and dealing in the future. To ensure the effectiveness of date, other influencing factors must be eliminated. Drivers will be required to be tested again one week later. After removing abnormal data, the mean values of two experiment data are regarded as the results of the change of the driver's visual indicator.

4.3. Analysis of experimental results

Figure 6 shows the sensitivity of different participants with different driving speeds in a fog environment with visibility of 200m~500m. It can be known from Figure 6 that, drivers have the highest sensitivity on color when the driving speed is 40km/h. Later, their sensitivity on color decreases along with the increasing of driving speed.

To better show the influences of colors on drivers' pupil area under different driving speeds, the changing conditions of the influences of colors on drivers' pupil area in the speed of 40 km/h-80 km/h in fog environment with visibility of 200 m~500 m are shown in Figure 7 and Figure 8.

It can be seen from the pupil area change rates in different speeds from Figure 6 to Figure 8, the change rates of drivers' pupil area under different colors increase along with the increasing of driving speed, while it keeps stable when driving speed is from 62 km/h-80 km/h. It can be known from the relation of drivers' psychological states and change rates of pupil area that, when the driving speed is 40km/h, drivers are comfortable when seeing colors, except red and yellow, or combination of colors. Drivers are out of the demarcation points of tension and comfort when seeing colors of red and yellow. Along with the increasing of driving speed, both red and yellow make drivers nervous, and have obvious influence on increasing rate of pupil area. Other colors or combination of colors make drivers comfortable. The reasons for the above phenomenon is that, color is the main influencing factor of change rate of pupil area when the driving speed is low, while color and driving speed, which increase change rate of pupil area, jointly influence pupil area and change rates when driving speed increases. When driving speed increases to certain value, the influence of color and speed on change rates of pupil area keeps stable, and the change rates keep stable too. Therefore, the drivers' psychological states are jointly influenced by road colors and driving speeds.

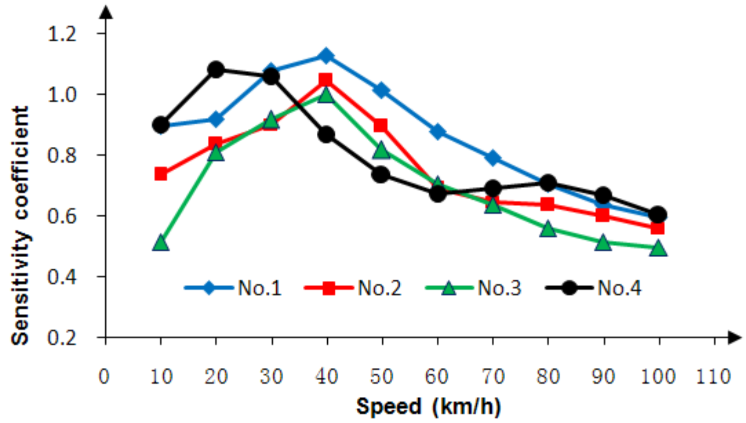

Fig. 6 - The sensitivity of the driver to color in different speeds

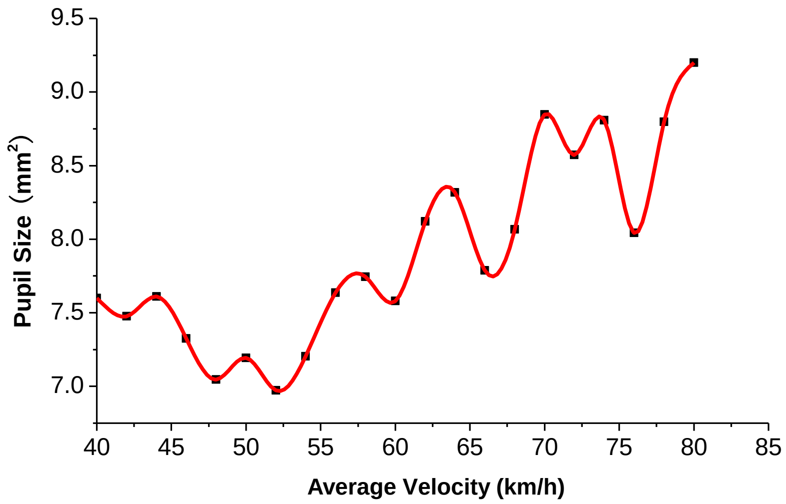

Fig. 7 - The relationship between the human eye's pupil area and the driving speed

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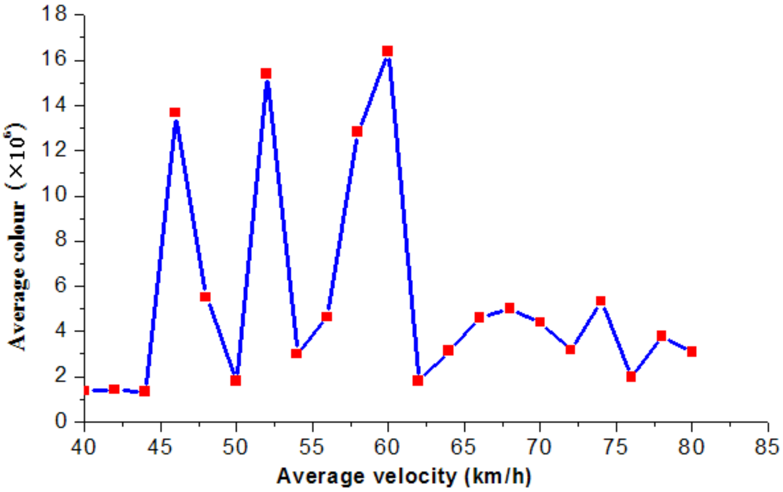

Fig. 8 - The relationship between driving speed and average color

It can be seen from Figure 9 that drivers drive slower when fog lamps are open. It costs them more time to pass fog section when fog lamps are open. On the surface, drivers drive more efficiently when fog lamps are closed. However, from Figure 9, the driving speed range is 80 km/h~200 km/h when fog lamps are closed, which is faster than threshold value of driving speed in fog environment and is an improper driving speed. When fog lamps are open, the driving speed range is 60 km/h~100 km/h, which is a range of normal speed.

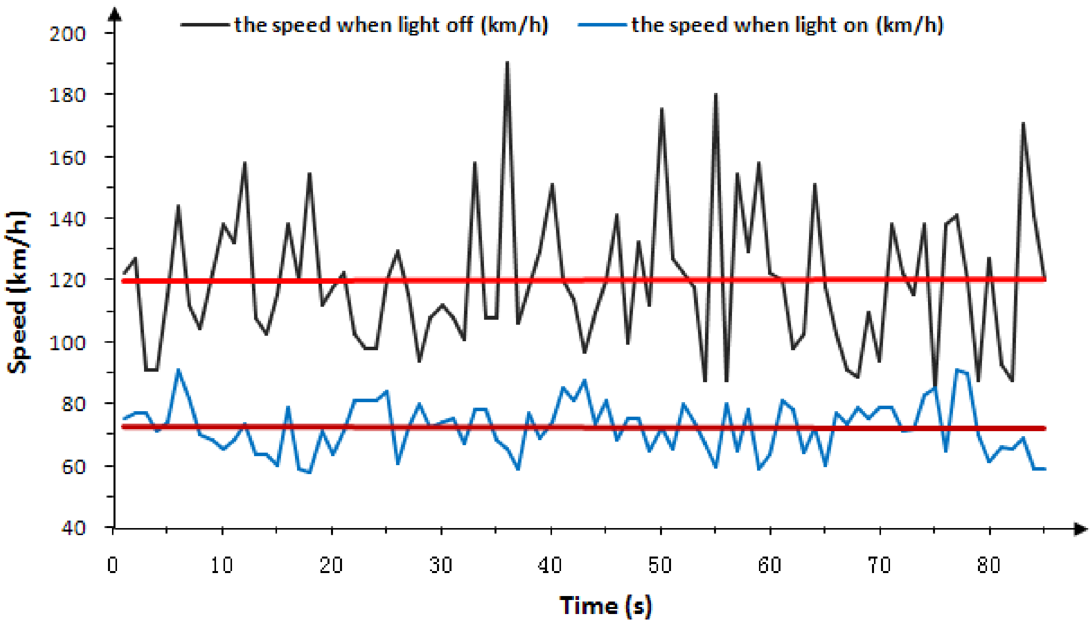

Fig. 9 - Contrast the two speed of induction lamp open and closed

The drivers' field of view decreases when speed increases. Their long apparent distance point extends forward with the rising of speed, while valid field of view narrows. The dynamic long apparent distance point refers to the distance from the longest point saw by driver to eyes of driver

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during high speed driving. Not everything within dynamic field of view draws attention of drivers. Traffic environment in dynamic long apparent distance point does not influence driving behavior because there is an alertness distance, which is shorter than long apparent distance, of drivers within the dynamic apparent distance. The alertness distance refers to the distance in which drivers will be drew attention by obstacles or other influencing factors, and take relevant operations. It is showed by this experiment that drivers' controlling on speed is mainly influenced by long apparent distance point and alertness distance, which is specifically showed in Figure 10. From Figure 10, we can find that traffic accidents in the foggy sections of expressways happen more frequently when there is no color induction in fog environment.

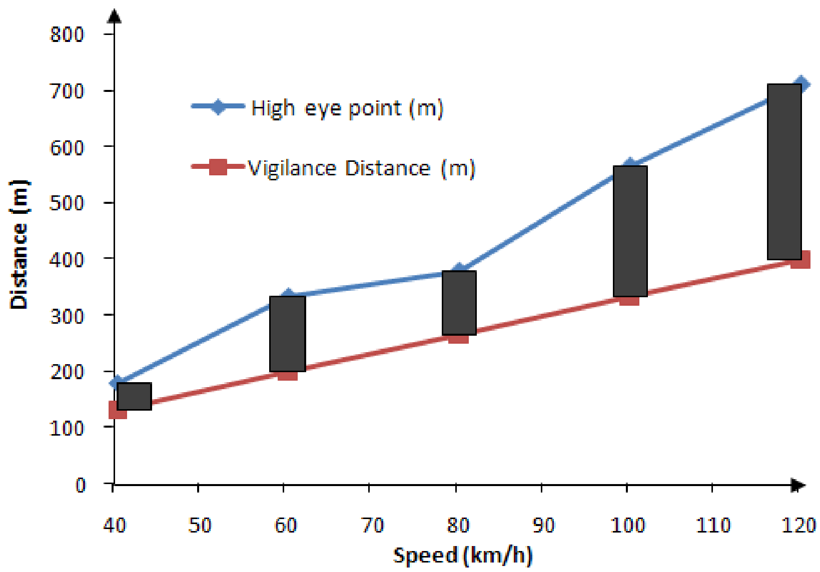

Fig. 10 - The influence relation about speed, high eye point and the warning distance

4.4. Curve fitting of cumulative effect model

To better analyze date, the following fitted curve is got by verifying with cumulative effect model created in previous section and giving curve fitting to cumulative effect function:

$$\begin{cases} y_1 = 0.0336x_1^4 - 0.6588x_1^3 + 3.1799x_1^2 + 6.6584x_1 - 1.0667 \\ y_2 = 0.0196x_2^4 - 0.2997x_2^3 + 0.1919x_2^2 + 14.369x_2 - 9.8219 \\ y_3 = 0.0196x_3^4 - 0.2997x_3^3 + 0.1919x_3^2 + 14.369x_3 - 9.8219 \\ y_4 = 0.0113x_4^4 - 0.1282x_4^3 - 0.7854x_4^2 + 15.994x_4 - 9.0046 \end{cases} \tag{7}$$

R^2-the test of goodness of fit of the model, are separately 0.9948, 0.99, 0.99 and 0.9706, which shows that the landscape colors formed by open and closed fog lamps influence drivers' driving speed and pupil area to some extent.

5. CONCLUSIONS

When the visibility in the foggy sections of highway is less than 500m, the sight of the driver will be seriously affected, although the meteorological department would issue yellow warning of disaster, but often still cannot prevent a lot of serious traffic accidents. In view of this problem, although many scholars have analyzed and discussed from different angles, there is rare quantitative analysis on the influence of accumulation effect of landscape color on the traffic safety in the foggy sections of expressways. Therefore, according to the model derivation and simulation experiment analysis, the following conclusions are obtained.

(1) Drivers are very sensitive to the color of road landscapes, which has an impact on road-traffic safety. In the fog environment with visibility of 200m-500m, when the road landscape color is yellow, the pupil area of the driver through the fog area is the largest, followed by red. At the same driving speed, the influence sequence of colors on the driver's pupil area is yellow > Red> yellow-white> red-white> orange> white.

(2) Based on the cumulative effects of the fog environment and the landscape color of expressways, the interactive cumulative model based on landscape color and driving time in heavy fog environment was deduced. Because multiple influencing parameters including the speed of the vehicle, the cumulative index under different speeds, the cumulative value coefficient, the accumulated time, the cumulative coefficient and the cumulative action time were considered in the proposed model, so the model is more close to the real scene of the highway traffic in fog environment.

(3) By using the Tobii eye tracker and UC-win / Road simulation software, multi-group of the fog lamp color and spacing experiment program with 200m-500m visibility in fog environment was designed, and according to the program, the simulation experiments on several drivers were carried out to test the influence of road landscape color in fog environment on drivers' visual psychology. The simulation experiment results show that the smaller the driving speed, the greater the visual impact of the road landscape color on the driver; with the increment of the driving speed, the pupil area also shows a growing trend, this indicates that the driver's psychological stress levels is proportionate to the driving speed; while when the driving speed exceeds 70km/h, the influence of color on change rate of pupil area tends to be stable, and the landscape color has relative lesser influence on the visual psychology of the driver at this time.

(4) Based on the interactive cumulative model and simulation experimental data analysis, we can see that in the fog environment with visibility between 200m and 500m, the red and yellow have a great influence on the visual psychology of the driver, and along with the increasing of the driving speed, the visual psychological effects of these two kinds of color on the driver is more significant than the other colors. Thus, the installation of red and yellow fog lights on both sides of the road can effectively alleviate the psychological tension of the driver in the heavy fog environment.

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