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Research Article

A Sensor-Based Visual Effect Evaluation of Chevron Alignment Signs' Colors on Drivers through the Curves in Snow and Ice Environment

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The ability to quantitatively evaluate the visual feedback of drivers has been considered as the primary research for reducing crashes in snow and ice environments. Different colored Chevron alignment signs cause diverse visual effect. However, the effect of Chevrons on visual feedback and on the driving reaction while navigating curves in SI environments has not been adequately evaluated. The objective of this study is twofold: (1) an effective and long-term experiment was designed and developed to test the effect of colored Chevrons on drivers' vision and vehicle speed; (2) a new quantitative effect evaluation model is employed to measure the effect of different colors of the Chevrons. Fixation duration and pupil size were used to describe the driver's visual response, and Cohen's **d** was used to evaluate the colors' psychological effect on drivers. The results showed the following: (1) after choosing the proper color for Chevrons, drivers reduced the speed of the vehicle while approaching the curves. (2) It was easier for drivers to identify the road alignment after setting the Chevrons. (3) Cohen's **d** related to different colors of Chevrons have different effect sizes. The conclusions provide evident references for freeway warning products and the design of intelligent vehicles.

1. Introduction

Freeway traffic crashes have become a key cause of death in the population in the current years. Crash occurrence and risk are significantly influenced by adverse weather conditions, especially for the northern freeway in snow and ice (SI) environment. Meanwhile, previous freeway traffic accident reports showed that the crash rate on curves was much higher than that on straight sections. Moreover, most crashes on curves were associated with lane departure and frontal collision [1]. The detailed result shows that the accident rate at the curve section is 0.41 per million vehicle-kilometers on no-snow days, while the number rises to 5.86 on snowy days, increasing by more than 13 times [2].

Since crash risk dramatically increases when passing curves in SI environment. Chevron alignment signs are utilized as an effective measure to improve traffic safety on curves. However, the colors of the signs were only roughly studied and tested. As a result, most of the existing researches focused on blue Chevrons, but the red and green Chevrons are often what has been used in China. To correct the improper application, three questions about colored Chevrons have to be urgently addressed:

(i) How much could the Chevrons positively contribute to the freeway traffic safety?

(ii) What is the process in which the drivers as well as the vehicles are influenced by the Chevrons?

(iii) Which color is the best for Chevrons on curves in snow and ice environment to decrease the traffic accidents?

This paper reports on tests that investigated the drivers' visual and motor feedback to colored Chevrons. This study quantitatively identified the effect of the Chevrons and, then, optimized the setting of Chevrons in order to decrease the occurrence of crashes in snow and ice environment.

Figure 1: Practical application of Chevrons in China.

To alert the drivers facing existing or potential hazards, it is important to place warning signs. The Chevrons are commonly applied to guide the driving direction and to indicate changes in road alignment. However, there are differences with the color settings of the Chevrons between China and America. Based on the National Traffic Sign and Device Standards of China [3], three main standards can be found. First, the Chevrons have blue background and white symbols on the freeway, while, in the expressway system, the Chevrons have green background and white symbols. Moreover, at the central islands, channelization islands, and bridges, along with other locations, the Chevrons have red background and white symbols. As shown in Figure 1, there are some practical applications of Chevrons in China. But, in America, almost all the warning signs are yellow and black, whereas white and blue signs are generally used to inform drivers of upcoming cities and roads. Although diverse colors are chosen, there is one common concept that information delivered by signs influences drivers' control of vehicles [4].

Snow and ice environment has a tremendous detraction on the driver's vision. The drivers would be influenced by the diffused reflection effect of snow and ice and the negative effect of monotonous color background in an SI environment. As a result, driving in an SI environment could take the edge off the driver's ability to recognize the changing environment. Xing et al. (2012) reached the conclusion that the visually perceived speed by drivers in a snow and ice-covered environment was 5%–14% lower than that in an environment without snow and ice [5]. Pasetto and Barbati (2012) found that diverse brightness and light conditions of road environments weighed heavily on the driver's visual perception ability [6]. Charlton (2007) concluded that drivers were likely to make operational mistakes while passing horizontal curves, as a result of failures in concentration, misperceptions of speed and curvature, and poor lane positioning [7].

Besides, the snow around roads has high reflectance. Light reflected by the snow during shiny days could strongly irritate drivers and is prone to cause eye fatigue. Chen et al. (2015) explored the effects of road environments on driving behaviors and cognitive performance of fatigued drivers, and the conclusion showed that the drivers were likely to overestimate the distance between vehicles [8].

Road curvature has a strong correlation with the traffic incidents and easily leads to the occurrence of crashes. In order to improve traffic safety on curved roads, Yotsutsuji et al. (2014) focused on the model research of drivers' cognitions to lead-vehicle speeds on curves [9]. Compared to the text symbols, colored ones bring stronger and faster impact on human vision. In addition, cool colors, warm colors, light colors, and dark colors would arouse different emotions [10]. Carson and Mannering (2001) found that the warning signs for icy roads could be optimized by repositioning, in order to reduce the frequency and severity of ice-related accidents [11]. De La Escalera et al. (1997) also found that the traffic signs provided drivers with useful information about the road conditions, the information would then influence drivers' feedback and finally make driving safer and easier [12]. Comte and Jamson (2000) explored four speed reducing methods when passing curves. They proved that all the information provided in any format could be effective in reducing speed on horizontal curves [13].

Research on the design and application of Chevrons has been updated continuously. Guan et al. (2014) explored the relationship between drivers' deceleration behavior and the setting method of traffic sign on curves. The results showed that the deceleration was highly related to how much information the drivers acquired and reacted to [14]. Choi et al. (2005) analyzed the sense of stability of Chevron alignment signs on the existing freeway through a practical test. The traffic delineator was found to regulate traffic speed on curves [15]. Furthermore, Charlton (2004) found that the Chevron alignment sign is an important traffic control device for warning drivers through delineating the alignment of the curved road [16]. The Chevron alignment sign not only could expand the vision when approaching a curve but also could provide warning and guidance while navigating a curve. Meanwhile, properly spaced Chevrons can be used to guide drivers to decelerate when approaching as well as passing a curve [17]. Rose and Carlson (2005) developed a spacing chart to find the proper spacing for Chevrons on horizontal curves. The former result showed that there was an obvious deceleration of about 3 mph at night with more than two Chevrons within vision around the curve. But less obvious deceleration was observed during daylight [18]. Wu et al. (2013, 2016) and Zhao et al. (2015) conducted an experiment with a driving simulator in order to measure drivers' eye movement, operations, and changes in psychological states. Detailed comparisons were made of drivers' recognition ability, operations, and changes in psychological reactions by driving through a simulated city expressway slope with and without Chevrons. The result proved that the Chevrons would let drivers pay more attention to hazardous traffic

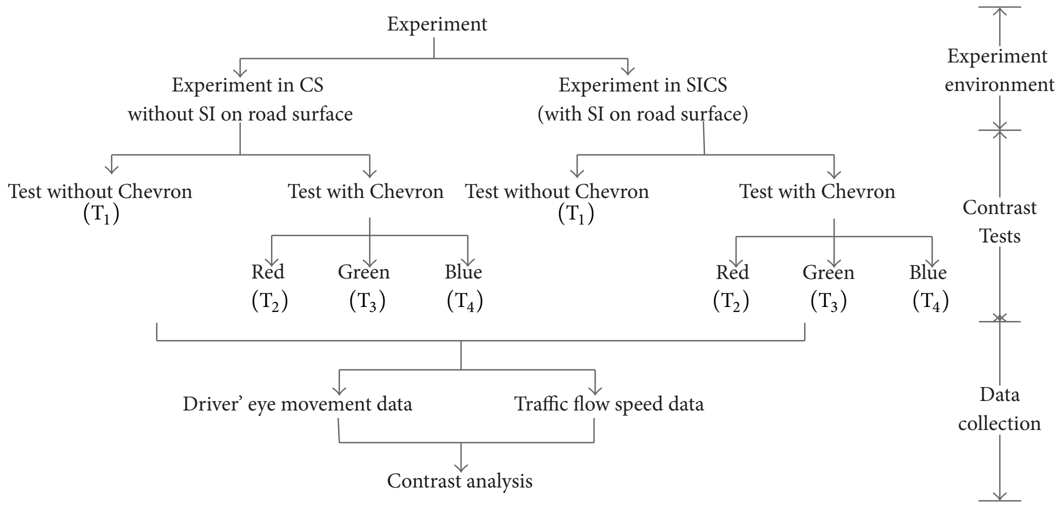


Figure 2: Flowchart of the experiment.

environments and decrease the crash risk. All these discussions lead to the common conclusion that Chevron signs can assist drivers in operating their vehicles while navigating curves [19–21].

Hardly enough attention has been given to drivers' vision feedback to colored traffic signs in existing research. Ritter et al. (1995) found that reasonable choice of color was the key to an efficient traffic sign. Moreover, the more distinctive the sign was, the rapider the drivers are able to trace information [22]. Liu et al. (2010) stated that, regardless of the traffic signs' background colors, the signs were perceived in a similar way by humans. Moreover, different contrasts between the background and foreground colors of traffic signs would make difference in cognizing [23]. Besides, the color scheme and the number of signs were significantly relevant to participants' response time to the information on the signs [24].

Thus far, although the Chevrons are able to decrease crash risk, little research has been done regarding the effect of Chevrons on visual feedback as well as driving reaction while navigating curves in a snow and ice environment, especially in the context of China. Summarizing the above discussion, only the setting method and effect of Chevrons on drivers have been analyzed, but the research results are not enough to guide the setting of Chevrons through curves in snow and ice environment. In addition, most studies on the psychological and physical effect of colored traffic signs including the Chevrons were completed by either mental questionnaire analyses or indoor simulation experiments. As a result of the color sensation and lighting condition, some results may contain a high distortion rate.

In this study, on-road experiments were conducted to collect vehicle and driver parameters, including speeds of the test vehicle and traffic flow, pupil size, and fixation duration, using the SMI eye-tracker system and NC200 portable traffic analyzer. The practical test vehicle was studied while passing through a common and representative curve of a freeway in China in an environment with and without snow and ice. An eye movement tracking technique was adopted to observe the driver's fixation distribution and pupil size. The NC200 portable traffic analyzer was utilized to observe the speed of the test vehicle as well as the distribution of traffic flow. A new quantitative method was then developed to evaluate the effect of colored Chevrons. In addition, different feedback of three different colors of the Chevrons in SI environment was calculated. This study provides theoretical guidance for optimizing traffic signs enabling the drivers to easily recognize road information including warning and guidance in SI environment and keep safety operation.

This paper is organized as follows: the next section provides experimental details including participants, experimental setup, data collection method, and experimental scenarios. Then, the model and statistical analysis are described, followed by the results and discussions. Conclusions and recommendations of this study are provided in the last section.

2. Experiment

The flowchart of the experiment is shown in Figure 2. A similar section of freeway was separately tested. In each test, there are two datasets with and without the colored Chevrons. Parameters, including vehicle speed, traffic flow, pupil size, and fixation duration, were measured and compared.

2.1. Experimental Scenarios. Two representatively horizontal curves located on National Rd. 302 in Jilin Province, China, were selected as the experimental road sections and are shown in Figure 3. It is worth mentioning that these two common sections of road are very similar both in shape and in visibility. These two curved sections were separately named as CS and SICS.

(i) Section 1: CS is located near Dachapeng Village. There was snow all along the roadside, but there was no snow or ice on the road surface. And the road markings could be seen clearly.

(ii) Section 2: SICS is located near West Sanjiazi Village. There was thick snow covering the road surface as well as the roadside. The road markings were not visible.

(a) (b)

Figure 3: Photos of the experimental CS (a) and SICS (b).

(a) (b)

Figure 4: SMI (a) and NC200 (b) sensors.

Both sections are two-lane freeways with one lane in each direction. Each lane is 4.5-meter-wide with a speed limit of 60 km/h. The length of the CS is 420 m, with a radius of 180 meters. The length of the SICS is 405 m, with a radius of 160 m. The surroundings of both experimental curves were covered by snow. Both curves were freeways without intersection or roadside buildings, so the experience was not impacted by the roadside traffic.

2.2. Experimental Objectives and Sensors. The objective of this experiment was twofold as followed. The experiment time was 10:00 a.m.–13:00 p.m., from Jan. 29, 2015, to Feb. 3, 2015.

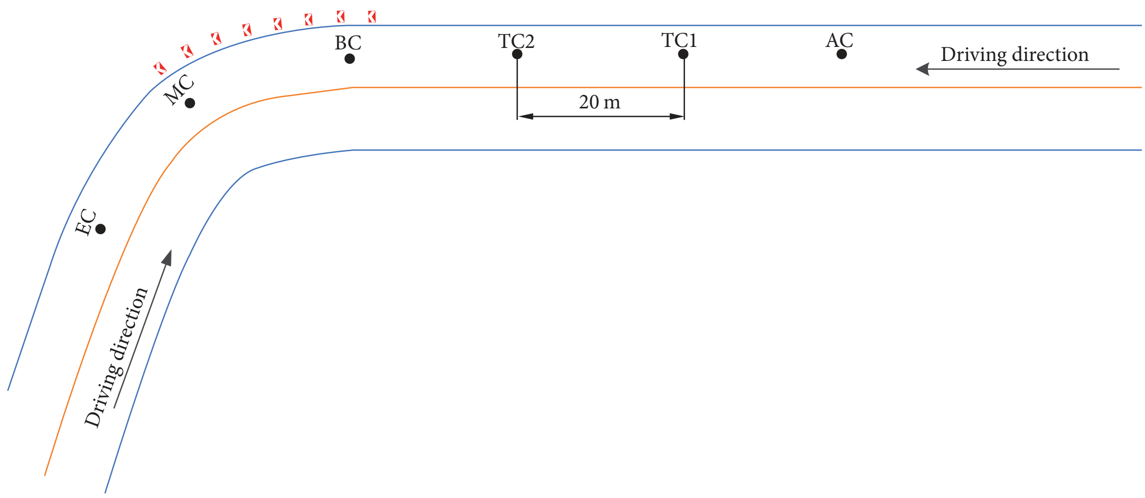
2.2.1. Objective 1: Collecting Drivers' Eye Movement. The experiment was conducted with thirteen participants between ages 24 and 35, who were asked to drive through the CS and SICS. According to the local DOT data, most drivers in this area are male and experienced. So the participants are most male drivers with over five years' driving experience. And the SMI eye-tracker (shown in Figure 4) was used to collect information of drivers' fixation distribution and changing pupil size as the vehicle passed through the two curves.

2.2.2. Objective 2: Observing Traffic Flow. The observation of traffic flow was conducted in a normal traffic environment, and all the vehicles were in free-flow running state. The traffic was mainly composed of light vehicles, especially sedans, so the influence of vehicle types could be neglected.

A traffic flow observation experiment was performed with NC200 portable traffic analyzer (shown in Figure 4). The real-time speed of all the traffic was supposed to be observed. The devices were placed in the middle of the lane. According to the length of the curves, 5 observation points were set in SICS and 6 observation points were set in CS. Each point, as is shown in Figure 5, was spaced 20 meters from the adjacent points, recording the speeds of vehicles passing through.

2.3. Experimental Procedure

2.3.1. Experiment Design. In order to study the different impacts on traffic flow as well as drivers' vision caused by Chevrons and colors in Chevrons, a series of contrast tests were designed. In this experiment, Chevrons of three commonly applied colors (red, green, and blue) were involved. The experiment was divided into two parts as was shown in Figure 2: experiments in SICS and experiments in CS. Each part contained 4 respective tests: (T1) test without Chevrons, (T2) test with red Chevrons, (T3), test with green Chevrons, and (T4) test with blue Chevrons. According to the standard of road sign regulation in China [3], 8 Chevrons with a 2-meter height and a size of 220 mm × 400 mm board were set in the middle of the curves, separated 6 meters from the nearest ones. A brief shed was built as waiting room in order to block the drivers' vision when different Chevrons were set



AC = approach of curve
BC = beginning of curve
MC = middle of curve
EC = ending point of curve
TC1 = transition point 1 of the curve
TC2 = transition point 1 of the curve (there is no this point in C-SICS)

FIGURE 5: The speed observation point of the curve.

up along the curves. As a result, after a long waiting time, the road condition would not be remembered in each test.

2.3.2. Data Collection. For objective 1, all drivers, wearing a SMI eye-tracker, drove the test car to pass through the curves successively. Then, they would do it again after another colored set of Chevrons was set up. The drivers' eye movement, the data of the driver's eye fixation duration, and pupil size would be collected by the eye-tracker. Meanwhile, the drivers were requested to give physiological feedback.

For objective 2, when the drivers saw the Chevrons, they would adjust the speed of the vehicle. The NC200 was used to collect speed of all vehicles that passed the curves.

3. Effect Evaluation Method

3.1. Assumptions

(i) Assumption 1: the experimental environment is the same except for the traffic signs.

(ii) Assumption 2: the speed of traffic flow passing the curves in SI environment obeyed normal distribution in general.

(iii) Assumption 3: the drivers with different effect sizes would make different driving operation. This changing operation mainly depended on whether there were traffic signs on the roadside.

3.2. Effect Evaluation Model. In the single factor experiments, the mean difference is expressed as the contrast of two groups of experiments. The linear contrast function is as follows:

$$\psi = c_1\mu_1 + c_2\mu_2 + \cdots + c_j\mu_i + \cdots + c_m\mu_l, \tag{1}$$

where ψ stands for speed difference; i and j represent the indices of the experimental groups; μ_i represents the mean speed of the ith group; c_j represents a group of constants which satisfy $c_1 + c_2 + \cdots + c_m = 0$; $i = 1, 2, \ldots, l$; $j = 1, 2, \ldots, m$.

To measure the effect of Chevrons' color on drivers, variance in road condition was controlled in the experiment. The different colored Chevrons along the curves were used as the experimental variables. The experiments were divided into tests T1 to T4, T1 is expressed by μ_w (without Chevrons group), T2–T4 are expressed by μ_c (colored Chevrons group including T2: μ_r-red Chevrons, T3: μ_g-green Chevrons, and T4: μ_b-blue Chevrons) The mean difference of different Chevrons' colors is expressed as

$$\psi = \mu_c - \mu_w. \tag{2}$$

The effect size of the linear contrast, **d**, is defined as

$$\mathbf{d} = \frac{\psi}{\sigma}, \tag{3}$$

where σ is the pooled standard deviation. In calculation, ψ can be estimated by using the mean value of tests T1 to T4 in order to replace population mean. The formula to calculate σ is as follows:

$$\sigma = \sqrt{\frac{(n_w - 1) S_w^2 + (n_c - 1) S_c^2}{n_w + n_c - 2}}, \tag{4}$$

where n_w represents the number of samples without Chevrons; n_c represents the number of samples with Chevrons; S_w is the variance of samples without Chevrons; S_c is the variance of samples with Chevrons.

Therefore, the estimated value (Cohen's **d**) [25] of effect size, which represents the Chevrons' psychological effect on drivers in SI environment, can be obtained by the following expression:

$$\mathbf{d} = \frac{\overline{x}_w - \overline{x}_c}{\sigma}, \tag{5}$$

Table 1: Grades of Cohen's **d** to evaluate effect.

Cohen's **d**	Grades of effect	The significance of effect grade
d < 0.2	Light effect	Light influence on the driver's visual psychology.
0.2 < **d** < 0.8	Medium effect	Medium influence on the driver's visual psychology.
d > 0.8	Strong effect	Strong influence on the driver's visual psychology.

Table 2: Fixation duration and pupil size in each scenario.

Curve environment	Chevrons tests (T1–T4)	Fixation duration (second)		Pupil size (pixel)	
		AVG	SD	AVG	SD
CS	Without Chevrons	0.543	0.457	31.196	1.001
	Red Chevrons	0.558	0.390	31.303	1.547
	Green Chevrons	0.277	0.241	33.452	2.382
	Blue Chevrons	0.334	0.256	30.285	1.398
SICS	Without Chevrons	0.352	0.199	36.736	2.196
	Red Chevrons	0.427	0.246	34.055	1.347
	Green Chevrons	0.348	0.273	34.355	2.500
	Blue Chevrons	0.345	0.215	37.179	1.948

where $\overline{x}_w$ is the mean speed of samples without Chevrons and $\overline{x}_c$ is the mean speed of samples with Chevrons.

3.3. Large Sample Evaluation Method. Effect evaluation model can indicate the correlative degree of variables. However, there is little relation between effect evaluation model and sample size. Combined with pretest and posttest design, the model used Cohen's **d** to measure the difference between the different tests (T1 to T4). Cohen's **d** is defined as the difference between the two means divided by the standard deviation of a sample. Also, Cohen's **d** represents the correlation degree of variables. Psychological Cohen's **d** is often used to evaluate the colored signs' psychological effect. Cohen's **d** uses the standard deviation unit to express effect size. Thus, **d** = 1.0 means the difference between the mean values of the tests of samples is 1 SD (standard deviation). Cohen and Jacob studied the size of effect [25], and Cohen's **d** values are divided into three grades (see Table 1).

4. Results and Discussion

4.1. Eye Movements Analysis

4.1.1. Descriptive Statistics. After the experiment for objective 1, the data from the SMI eye-tracker is used in the following analysis. Table 2 presents a summary of the average fixation duration (FD_AVG), standard deviation of fixation duration (FD_SD), average pupil size (PS_AVG), and standard deviation of pupil size (PS_SD) in different scenarios.

4.1.2. Fixation Duration. The first analysis compares the drivers' fixation duration approaching the curve in tests T1–T4. As is shown in Table 2, both in CS and in SICS, the FD_AVG value of sections with green (0.277 and 0.348) and blue (0.334 and 0.345) Chevrons is lower than that without Chevrons (0.543 and 0.352), while the FD_AVG with red Chevrons (0.558 and 0.427) is higher. The drivers' FD_AVG values in CS are all bigger than that in SICS. Drivers find it easier to identify the road alignment with setting of Chevrons; as a result, the fixation duration is reduced. Moreover, different colored signs produce different visual effects, and red is commonly considered as prohibition or warning, and the drivers easily pay more attention to it.

4.1.3. Pupil Size. In this study, drivers' pupil size is creatively utilized as a corresponding variable with fixation duration. These two variables are supplemental to each other and are enrolled in one function. The percentage of fixation duration is shown as follows:

$$f_a = \left(\frac{\sum_a^{a-1} t_x}{\sum_B^A t_x} \right) \times 100\%, \quad (6)$$

where f_a is the percentage of fixation duration when $a - 1 < x \leq a$; x is pupil size; t_x is the corresponding fixation duration of x; A and B are the boundary of pupil size distribution. Here $A = 24$ and $B = 44$.

Fixation duration characteristics of pupil size in different environments are shown in Figure 6. Combining the values in Table 2, the drivers' average pupil size in SICS was larger than that in CS. Because the very similar environments and road condition were controlled, it is found that drivers are more likely affected by the SI environment than by the CS environment. Also, drivers show a greater mental load staring at the target in SI environment than in CS environment.

The PS_AVG values in CS with the setting of blue Chevrons (30.285) are smaller than that without Chevrons (31.196), while the PS_AVG values with red (31.303) and green (33.452) Chevrons are larger than that without Chevrons. But the opposite results are found when passing through SICS, and the PS_AVG values with blue Chevrons (37.179) are larger than that without Chevrons (36.736), while the PS_AVG

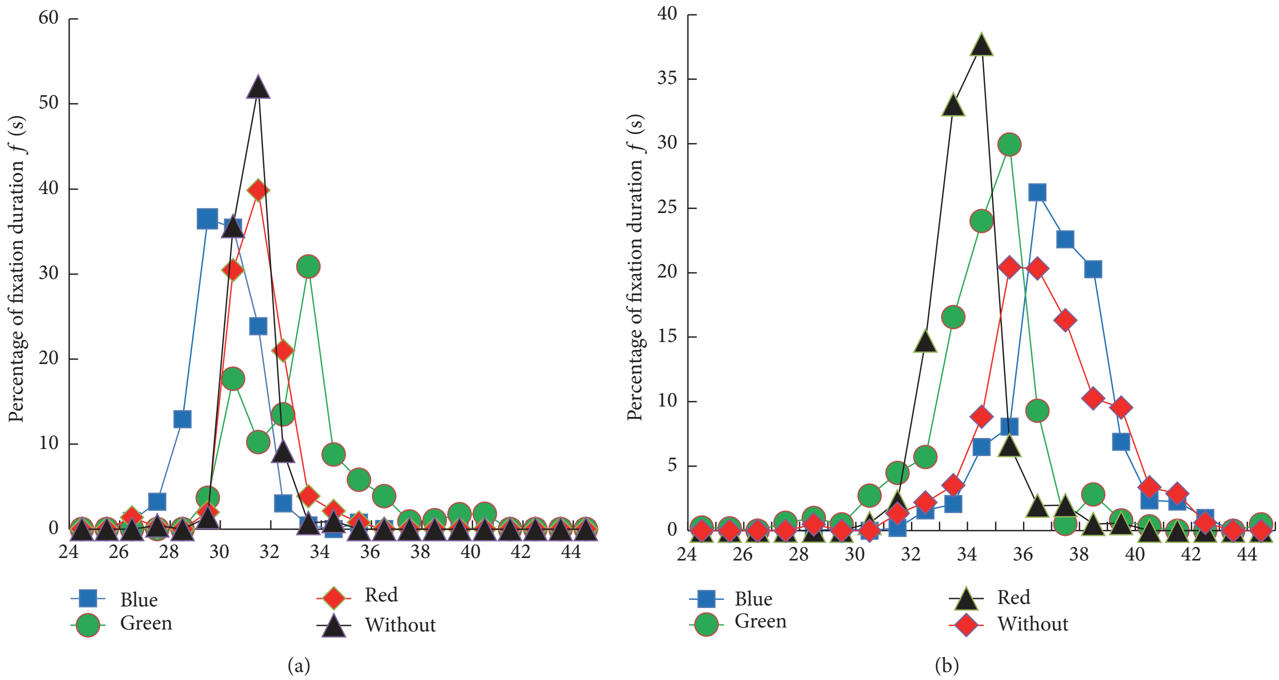


Figure 6: Fixation duration characteristics of pupil size in different environments.

Table 3: Evaluation of effect and speed distribution.

Curve environment	Chevrons tests (T1–T4) μ	Mean speed $\overline{x}$ (km/h)	Standard deviation S	Sample size n	Mean speed difference ψ	Pooled standard deviation σ	Effect size **d**	Effect evaluation
CS	Without	65.31	12.815	120	—	—	—	—
	Red	60.50	10.049	120	4.81	11.515	0.418	Medium
	Green	60.06	10.975	120	5.25	11.930	0.440	Medium
	Blue	62.39	10.020	120	2.92	11.502	0.254	Medium
SICS	Without	38.50	10.301	100	—	—	—	—
	Red	33.32	5.389	100	5.18	8.220	0.630	Medium
	Green	35.86	8.702	100	2.64	9.535	0.277	Medium
	Blue	37.81	10.155	100	0.69	10.228	0.067	Small

values with red (34.055) and green Chevrons (34.355) are smaller than that without Chevrons (36.736). The ability of visual recognition is different in different environments. In this study, this ability shows a visibly better result in CS environment. Furthermore, as a result of contrast tests of T2 to T4, the different colors of Chevrons, combined with ambient color, also have an effect on the driver's identification abilities.

4.2. Feedback of Driving Operation. In order to confirm the effect of the Chevrons, the feedback of driving operation is analyzed by the change of vehicle speed in different scenarios. The detailed methodology is explained in Section 2.1. The results will be discussed in three aspects as follows.

4.2.1. General Results in SI Environment. The analysis of the Chevrons' influence on the traffic with CS and SICS was analyzed. Based on the speed data recorded by NC200, the effects shown in different tests were presented in Table 3.

From Table 3, the results revealed a significant interaction between the different Chevrons and the speeds of passage through curves. The driving speed was significantly lower with Chevrons along the curves. Meanwhile, different colors showed significantly different feedback on drivers' operation. There are some common results of speed distribution for both CS and SICS: the red Chevrons and green Chevrons produced the most significant effect, and blue Chevrons produced the lightest effect. Under the condition of CS, Cohen's **d** values of all the colors indicated medium effect; meanwhile, the values of the green Chevrons and red Chevrons (>0.4) are greater than that of blue Chevrons (0.254). Under the condition of SICS, blue Chevrons had the smallest effect size (0.067).

After comparison in Table 3, the speed distribution of traffic flow under the condition of CS is higher than that in SICS. And the Chevrons were proven to be highly effective on feedback of speed. However, under the condition of SICS, the average traffic flow speed is smaller. And the red Chevrons,

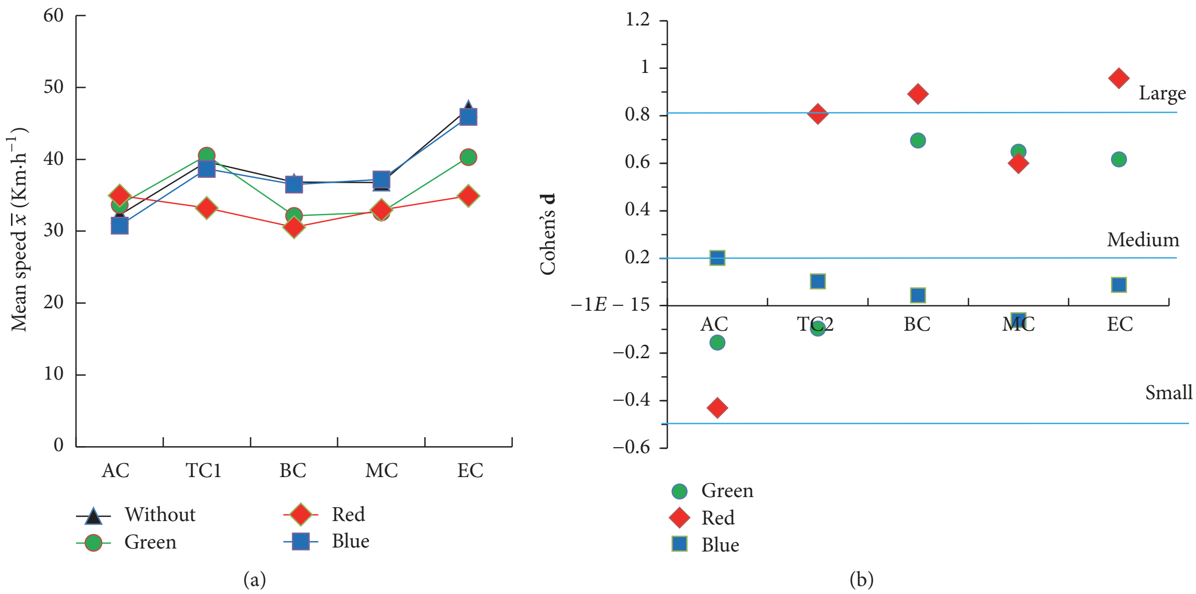


FIGURE 7: Mean speed (a) and effect sizes (b) obtained at observation points on SICS.

as the connotation of hazard warning, show the biggest effect size as 0.630.

4.2.2. Driver Performance in SICS. In the process of driving along the curve in SI environment, the Chevrons' effect on the drivers was time-varying and distance-varying. According to what they saw, the drivers made different feedback in their driving operation. The mean speed of traffic flow and effect sizes obtained from the observations points in SICS are shown in Figure 7.

Figure 7 shows that the Chevrons with different colors resulted in different mean speeds in SICS. Red Chevrons, green Chevrons, and blue Chevrons had different effects on improving the safety driving operation. The red Chevrons led the distinct mean speed changes. The green Chevrons resulted in a significant reduction compared to normal traffic flow speed. The blue Chevrons led the comparatively light mean speed changes. Moreover, by analysis of effect sizes at all the five observation points as shown in Figure 7, red Chevrons produced relatively large effect sizes at distances of 20 m, 40 m, and 80 m from the curve entrance. However, the effect sizes produced by the blue Chevrons were smaller. In general, the red Chevrons and the green Chevrons produced larger effect sizes (around 0.8), while blue Chevrons produced unobvious and small effect sizes (less than 0.2).

Under the condition of SICS, the drivers drove conservatively at a low speed; as a result, they could recognize the Chevrons earlier than the drivers keeping fast speed. Therefore, they would pay more attention to the Chevrons for a longer time. Meanwhile, the Chevrons had an obvious effect on the drivers. Due to the weak visibility and warning effect, blue Chevrons were unlikely to have a noticeable effect. In conclusion, the effect of the red and green Chevrons in the SICS will be better.

4.2.3. Driver Performance in CS. In the process of passing through the curve in CS, the Chevrons produced different effect sizes at the observation points. The mean speed of traffic flow and effect sizes are shown in Figure 8. Although there was no snow or ice on the road surface, there was snow all along the roadside.

As is shown in Figure 8, with the road surface in dry condition, the trend of speed measured at all the observation points was almost the same. There are a common rise at TC1, TC2, and EC and fall at BC and MC. Almost all the values with the Chevrons in whichever color are lower than that without the Chevrons. This means the mean speed of traffic flow decreases visibly after setting the Chevrons. The mean speeds with the red Chevrons, the green Chevrons, and the blue Chevrons are slightly different from each other, and such difference can be ignored. Figure 8 shows that the Chevrons' effect sizes at the observation points were generally within 0.2–0.8, presenting a stable distribution. The effect sizes show that all the Chevrons with the three colors had a basically medium effect under the condition of CS, while, after a detailed comparison, blue Chevrons have a slightly weaker effect than the red Chevrons and green Chevrons. However, the effect sizes caused by red Chevrons and green Chevrons at the same observation points differ from each other.

Because of the good condition of freeway in CS, the traffic flow speed was high. However, the snow roadside still had influence on drivers, reflecting vehicle speed and effect size. According to Figure 8, the speed influence could be explained as follows. When approaching the curve, the drivers were confident enough to accelerate a little to see the curve information clearly. Then they slowed down actively once being stimulated by the Chevrons as soon as they saw the information. Finally, they speeded up again to pass through the curve.

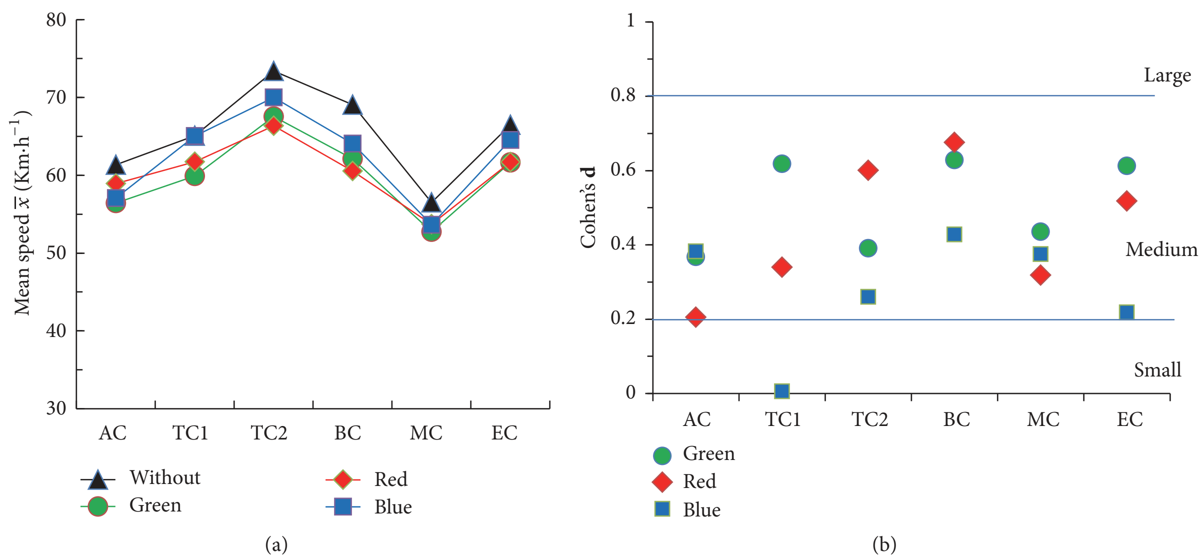


FIGURE 8: Mean speed (a) and effect sizes (b) obtained at observation points on CS.

By considering the actual application of the Chevrons in CS environment, the green Chevrons should be used in freeway ramp due to the higher speed. The blue Chevrons should be used on the general road due to the low speed. The red Chevrons would better be used as a warning sign in some special sections. The recommended setting method of the Chevron alignment signs in this paper is the same as China Standards [3].

5. Conclusion

The existent studies investigated the effect of Chinese Chevron alignment signs along the curves on two-lane rural freeways. Moreover, most studies were based on the driving simulation experiments. This paper contributed to developing and applying a new basic method on the multisensors. The contrast test environments without and with Chevrons were set on the actual road in dry and SI road conditions. The vehicle test was carried out in all the scenarios to research the influence of the Chevrons on drivers with snow covering the roadside. Moreover, this study did further research on effects of the colors of traffic signs on drivers, and the conclusions were helpful in providing a theoretical foundation for safety design of colors in traffic environment.

In an environment with snow covering the roadside, the significant effect of Chevrons on drivers' feedback is found through the contrast analysis of Chevrons' guiding effect and colors' psychological effect. Chevrons along the side of freeway curves could enhance the signs' effect on drivers as well as reduce the speed of traffic flow. As a result, setting of proper Chevrons improves driving safety passing through the curves in dry condition or SI condition.

There was a lower traffic flow speed with Chevrons along the road than without Chevrons. Meanwhile, the function of Chevrons on speed reduction was significantly affected by the Chevrons' color. All three colors can attract drivers' attention on roadside information along the curves and effectively guide them into making a correct response to the roads' alignment. Besides, the Chevrons play a significant role in encouraging drivers to reduce their speed, and this effect was sensitive to Chevrons' color. It was caused according to the drivers' special visual field. Since the Chevrons prevent excessive speeds and encourage drivers to pay more attention to curves, Chevrons appear to bring great benefit in reducing traffic crashes on curves.

With different road surface conditions, the driver's visual recognition ability is not the same. Generally, they have a better version in CS. Meanwhile, the contrast between Chevrons' color and environmental color also affects the driver's identification. Drivers find it easier to identify the road alignment when Chevrons were set as a result of the decrease of fixation duration. Because red is commonly used as warning, the driver will pay more attention to identify signs in red. The Chevrons' psychological effect was different with different kinds of road surface in SI environment. Cohen's **d** values for CS were within 0.2–0.5, which indicated medium effect. Significant difference was observed between the effect of different colors on drivers for SICS. The red Chevrons produced the greatest effect, followed by the green Chevrons. The blue Chevrons had the weakest effect. Therefore, proper color is both supplementary and complementary in setting the Chevrons on curves. Trade-off colored Chevrons are recommended in SICS regarding future Chevron sign implementation on roadways in harsh winter areas to improve driver visibility and traffic safety.

Conflicts of Interest

The authors declare that there are no conflicts of interest regarding the publication of this paper.

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