Influence of Bicolor Line Markings on Following Traffic Time Headway

Naikan Ding*1, Shunying Zhu1, Hong Wang1, Nisha Jiao2

1 School of Transportation
Wuhan University of Technology
Wuhan, Hubei, 430063, China
2 Planning Research Studio
Department of Transportation of Hubei Province,
Wuhan, Hubei, 430030, China
Correspondence: No. 1178, at Heping Avenue, Wuhan, Hubei, 430063, China;
Tel: +8615927405969; E-mail: andrei8901@gmail.com

Abstract — Car following is an important scenario in traffic operations, which is directly related to rear-end collisions. To cope with this issue, a series of bicolor line markings were designed and placed on the surface of an expressway in China, and naturalistic traffic flow data collected. Statistical analysis showed that the average time headways were increased after the implementation of the bicolor line markings, and the pattern of one yellow and one red yielded the greatest effect of time headway increase. The results suggest that the bicolor line markings could increase time headway in car-following and be beneficial in the reduction of rear-end collisions. This may provide the decision makers and engineers with a new method to increase traffic safety.

Keywords- car-following; time headways; bicolor line markings; speed perception; distance perception

I. INTRODUCTION

Car-following is a state that vehicles interact with each other, which contributes to rear-end collisions a lot as sometimes insufficient headways emerge. Time headway is an important indicator of car-following safety, which is usually defined as the time, in seconds, between two successive vehicles as they pass a point on the road way [1], and which can also be calculated as that the distance headway divided by the speed of the following vehicle. In terms of safety, time headway means the maximum time left for a driver to react to a sudden brake from its leading vehicle. According to the car-following theory [2], time headway in car-following could be greatly related to drivers’ judgments of speed and distance.

Driver’s judgments of speed and distance rely heavily on the visual information obtained [3]. Andersen et al. [4] argued that the visual information from the surrounding scene, which influenced drivers greatly, played an important role in the process of driving. Edge rate (ER) is one of such visual information, which was defined as the rate at which local discontinuities cross a fixed point of reference in the observer’s field of view [5]. Francois et al. [6] reported that edge rate, produced by textures on the ground surface, resulted in drivers’ overestimation in self-speed and consequently led to reduction in actual speed. Rakha et al. [7] designed a kind of transverse bar, and found 6km/h and 8km/h reduction on mean speed and on 85th percentile speed, respectively. In addition, Liu et al. [8] discovered that drivers experienced the greatest speed overestimation when the value of edge rate varied from 8Hz to 16Hz, which accordingly led to the greatest reduction in actual speed.

Also, the perception of distance mattered. ‘Ground Theory’, proposed by Gibson [9], predicted that when the common ground surface was disrupted, the visual system was unable to establish a reliable reference frame and consequently failed to obtain correct absolute distance. Based on the ‘ground theory’, Sinai et al. [10], Wu et al. [11], Yarbrough et al. [12] and Feria et al. [13], all reported distance underestimation from observers in conditions of ground surface with discontinuous texture. In particular, Feria et al. [13] referred this distance underestimation phenomenon as the ‘discontinuity effect’. Besides, notably, in Sinai’s experiment, a pattern of ‘grass-concrete’ (or in reverse) was presented on the ground surface to observers to intentionally form the discontinuous texture. It means that the discontinuity merely in texture itself may lead to distance underestimation from observers.

Accordingly, a simple and effective way to produce the discontinuity is to manipulate the colors of textures. That is to texture the ground surface with a pattern of alternative colors. Naturally, the following issue is to determine which colors to choose. Research showed that, on the ground surface, red was the easiest color for an observer to discover, and the orange (or yellow) came the second [14-15]. So, textures with alternative colors of red and yellow would be a worth-trying method to produce discontinuity on ground surface.

From the above, though visual information have been employed in intervening driving behaviors, it is lack of report of influence of the texture color, as an direct visual stimuli, on time headway in car-following. Given this, a series of line markings with a pattern of alternative colors of red and yellow, which is defined as ‘bicolor line markings’
in the present study, were designed and placed on the surface of a lane of an expressway in China.

II. Method and Experiment

A. Methods Overview

Two colors (yellow and red) of line markings were alternately placed just inside both edges of the slow lane of an expressway to exhibit bicolor line markings. Traffic flow data like speed, and time headway were collected at consecutive observation sections. The mean time headways collected at observation sections were compared among various layouts of the bicolor line markings.

B. Test Site

The segment of Daijiashan and Huangpi Expressway (coded S1) at Wuhan, Hubei Province, P.R. China was selected as the test site. It was a two-way-four-lane expressway and the design speed was 100km/h and the land-width was 3.75m. The exact location of the test was between K6+900 and K8+000, at which it was a flat and straight segment. In the middle part of K6+900-K8+000, a length of 300m slow lane was placed with the bicolor line markings. In addition, there was no tunnel or overpass within the test site area, nor any exposed surveillance device.

C. Design of bicolor line markings

At first, we define the sum of the length of a single marking and its adjacent interval as one unite or period of the line markings, denoted with $\lambda$. So, to examine the effect of the color of line markings alone, the period ($\lambda$) was fixed to 2m, a value at which the drivers were supposed to be most sensitive to the edge rate produced by the line markings. Then, four kinds of layout of the bicolor line markings were designed and placed on the lane, that was, group (a) (one yellow and one red), group (b) (two yellow and two red), group (c) (three yellow and three red), and group (d) (all yellow). Fig. 1 shows the design of group (a) as an example, in which 'Y' stands for yellow, 'R' stands for red, and '1Y+1R' stands for one yellow and one red, similarly hereinafter.

Since only the car-following situation was considered, those free-flow vehicles (the ones no constraints placed on the drivers by other vehicles on the road) were filtered out by a comparison between the stopping time and the time headway of vehicles. That was, if the stopping time of a vehicle was less than its time headway, then the vehicle should be defined as a free-flow vehicle, otherwise, it was in car-following. Here, the stopping time was calculated as $t = V / a$, where $t$ is the stopping time, $s$; $V$ is the instantaneous speed of a vehicle, m/s; $a$ is deceleration ($a = 2.5 \text{m/s}^2$ was suggested by AASHTO [16]). In addition, to avoid the impact of lane-change vehicles, the video clips were reviewed frame by frame to check the trajectory of each vehicle from observation section one to six. Besides, if the free-flow and/or lane-change occurred at any observation section of the six, then the vehicle was needed to be excluded. Table 1 shows the basic statistics of

Figure 1 Design of bicolor line markings and the real scene.
each group (the original condition, where no extra line marking was placed, was treated as the ‘control’, and was categorized to group (e)).

![Figure 2 Sketch of layout of NC200 traffic analyzers and cameras](image)

**Table I Descriptive statistics of time headways**

<table>
<thead>
<tr>
<th>Group</th>
<th>(a) 1Y+1R</th>
<th>(b) 2Y+2R</th>
<th>(c) 3Y+3R</th>
<th>(d) Y</th>
<th>(e) Control</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sample Size</td>
<td>122</td>
<td>105</td>
<td>101</td>
<td>114</td>
<td>110</td>
</tr>
<tr>
<td>Mean of Time</td>
<td>4.71</td>
<td>4.56</td>
<td>4.50</td>
<td>4.49</td>
<td>4.10</td>
</tr>
<tr>
<td>Headways (s)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Std. Deviation</td>
<td>1.17</td>
<td>1.02</td>
<td>1.11</td>
<td>1.04</td>
<td>0.90</td>
</tr>
<tr>
<td>Minimum Value</td>
<td>1.84</td>
<td>2.17</td>
<td>1.98</td>
<td>2.01</td>
<td>2.08</td>
</tr>
<tr>
<td>Maximum Value</td>
<td>6.78</td>
<td>6.83</td>
<td>7.36</td>
<td>6.39</td>
<td>6.83</td>
</tr>
</tbody>
</table>

a: the mean of time headways was the average of time headways that collected at all observation sections.
b: here ‘Y’ stands for all yellow in group (d).

**III. RESULTS AND DISCUSSION**

Prior to the analysis, the normality of collected data were graphically tested with a QQ plot, as depicted in Fig. 3. Fig. 3 shows that the data were largely located at the fitted line (the red solid line), and were within the corresponding 95% confidence intervals (the two red dash lines), which indicates the time headways obey the normal distribution.

Then, the time headways of each group were analyzed in a one-way ANOVA with repeated measures. The main effect was found to be significant (F(4, 546)=5.03, p<0.001) (see Fig. 4), the mean time headways were 4.71s (MSE=0.11), 4.56s (MSE=0.10), 4.50s (MSE=0.11), and 4.49s (MSE=0.10) for the conditions of ‘1Y+1R’, ‘2Y+2R’, ‘3Y+3R’, and ‘Y’, which increased by 0.61s (14.9%), 0.46s (11.2%), 0.40s (9.8%), and 0.39s (9.5%), respectively, as compared with the control. In addition, the post hoc comparisons were conducted by a Tukey’s HSD test. It showed significant differences at pairwise comparisons between ‘1Y+1R’ and ‘Y’ (p<0.05), ‘1Y+1R’ and control (p<0.001), ‘2Y+2R’ and control (p<0.05), ‘3Y+3R’ and ‘Y’, which increased by 0.61s (14.9%), 0.46s (11.2%), 0.40s (9.8%), and 0.39s (9.5%), respectively, as compared with the control. In addition, the post hoc comparisons were conducted by a Tukey’s HSD test. It showed significant differences at pairwise comparisons between ‘1Y+1R’ and ‘Y’ (p<0.05), ‘1Y+1R’ and control (p<0.001), ‘2Y+2R’ and control (p<0.05), ‘3Y+3R’ and ‘Y’, which increased by 0.61s (14.9%), 0.46s (11.2%), 0.40s (9.8%), and 0.39s (9.5%), respectively, as compared with the control. In addition, the post hoc comparisons were conducted by a Tukey’s HSD test. It showed significant differences at pairwise comparisons between ‘1Y+1R’ and ‘Y’ (p<0.05), ‘1Y+1R’ and control (p<0.001), ‘2Y+2R’ and control (p<0.05), ‘3Y+3R’ and ‘Y’, which increased by 0.61s (14.9%), 0.46s (11.2%), 0.40s (9.8%), and 0.39s (9.5%), respectively, as compared with the control.

![Figure 3 QQ plot of time headways](image)
In general, the results above suggest that the time headways were increased after the implementation of bicolor line markings. This phenomenon could be interpreted from the perspective of driver’s perception of speed and distance. As introduced at the beginning of this paper, the effect of edge rate would be produced and acted on drivers since the bicolor line markings were placed on the lane with a constant interval (\( \lambda = 2m \)). As reported by Francois et al. [6] and Liu et al. [8], this effect would consequently lead to a reduction in actual speed. Specifically, Liu et al. [8] attributed this speed reduction to the deceleration from drivers, who were exposed to the bicolor line markings. Besides, from the perspective of distance perception, the ‘discontinuity effect’ could be produced by the bicolor line markings, which induced an underestimation in distance headway from drivers (Sinai et al. [10], Wu et al. [11], Yarbrough et al. [12], and Feria et al. [13]). But for safety, the drivers would increase its following distance in case of a suddenly brake from the leading driver. Consequently, the time headway increased since the distance headway increased and the speed of the following vehicle reduced.

In particular, the post hoc comparisons indicates that the condition of ‘1Y+1R’ was witnessed the greatest increase in time headway as compared with the condition of ‘1’ (p<0.05), and the control (p<0.001). It means that the drivers would experience the strongest overestimation in speed and underestimation in distance, because a more frequent alternation in colors may enhance the effects of edge rate and ‘discontinuity’.

IV. Conclusions

In the present study, a series of patterns of bicolor line markings were designed and placed on an expressway in China. Naturalistic traffic flow data from field observations showed that the time headways were increased after the implementation of the bicolor line markings, and the greatest increase was seen in the condition of ‘1Y+1R’, as there may be a relative stronger effect of edge rate and ‘discontinuity’ produced. The results suggest that this pattern of bicolor line markings could be beneficial to the improvement of traffic safety by reduce the rear-end collisions. A near future research would be focused on a variety of patterns of this kind of bicolor or even tricolor line markings that could influence driving behavior better. Nevertheless, this study is yet to be further verified with traffic flow data on other roadways.

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