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Modeling the influence of Chevron alignment sign on young male driver performance: A driving simulator study

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ABSTRACT

In China, the Chevron alignment sign on highways is a vertical rectangle with a white arrow and border on a blue background, which differs from its counterpart in other countries. Moreover, little research has been devoted to the effectiveness of China's Chevron signs; there is still no practical method to quantitatively describe the impact of Chevron signs on driver performance in roadway curves. In this paper, a driving simulator experiment collected data on the driving performance of 30 young male drivers as they navigated on 29 different horizontal curves under different conditions (presence of Chevron signs, curve radius and curve direction). To address the heterogeneity issue in the data, three models were estimated and tested: a pooled data linear regression model, a fixed effects model, and a random effects model. According to the Hausman Test and Akaike Information Criterion (AIC), the random effects model offers the best fit. The current study explores the relationship between driver performance (i.e., vehicle speed and lane position) and horizontal curves with respect to the horizontal curvature, presence of Chevron signs, and curve direction. This study lays a foundation for developing procedures and guidelines that would allow more uniform and efficient deployment of Chevron signs on China's highways.

1. Introduction

As an important element of curve delineation devices, the Chevron alignment sign has been widely applied in curves to serve two main purposes: (1) provide better visibility and guidance when approaching and negotiating a curve; (2) encourage drivers to reduce speed going into and through a curve (Srinivasan et al., 2010). Thus, the vehicle speed and lateral placement were most commonly used to reflect the effectiveness of Chevrons in curves; in most previous studies, Chevrons have been determined to be effective in reducing vehicle speed and maintaining a reasonable and stable lane position (e.g., Rose and Carlson, 2005; Re et al., 2010).

In the U.S., the Chevron alignment sign described in the Manual on Uniform Traffic Control Devices (MUTCD) is a vertical rectangle with a black arrow on a yellow background and no border (see Fig. 1(a)) (Federal Highway Administration, 2009). Researchers in the U.S. conducted numerous studies, including both driving simulations and field experiments, to evaluate the effectiveness of American Chevron alignment signs on speed reduction and vehicle position (e.g., Jennings and Demetsky, 1985; Zador et al., 1987; Zwahlen, 1993). Given the results of these research studies, it can be determined that Chevrons in the U.S. do cause some reduction in speed as well as speed variance. Additionally, Chevrons in the U.S. do encourage drivers to keep a more proper and stable lane position while negotiating a curve. Meanwhile, the guidelines for placing and maintaining Chevrons on curves have also been systematically developed (Rose and Carlson, 2005). These study results have provided a foundation for uniform and detailed guidelines for using Chevrons in the MUTCD, and thus provide good guidance for designers and engineers implementing Chevrons in the U.S.

However, unlike in other countries, the Chevron alignment sign on highways defined in *China National Standards of Road Traffic Signs (GB5768.2-2009)* is rectangular-shaped with a white arrow and border on a blue background (see Fig. 1(b)). In the past, the effect of China's Chevrons on driving behavior was seldom studied and few studies have evaluated the effectiveness of China's Chevrons on vehicle speed and lane position. Scant existing research on Chevron alignment signs in China focuses primarily on determining the optimal spacing of Chevrons on curves (e.g., Zhao et al., 1998; Huang, 2004; Peng, 2007). To our knowledge, these study results were mainly based on theoretical calculations from the aspect of vehicle

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(a) Chevron alignment sign in the U.S. (b) Chevron alignment sign in China

Fig. 1. Chevron alignment signs in China vs. in the U.S.

physical properties, rather than the characteristics of driver performance on curves under the influence of Chevrons. Meanwhile, the guidance for placing Chevrons is too vague, offering no clear and specific requirements for using Chevrons under various traffic, roadway and environmental conditions (National Standards of the People's Republic of China, 2009).

To systematically estimate the effectiveness of Chevrons, determine the influence mechanism of Chevrons and then develop more practicable guidelines for the use of Chevrons on China's highways, our research group has conducted a series of experiments since 2011. First, as a pilot study, the Si-fang Interchange of the Fourth Ring Road in Beijing was selected as the study site for simulated daytime scenarios. We analyzed the effect of China's Chevrons on drivers' eye movements, driving performance (steering, braking, and letting off the accelerator), vehicle operations (speed and lateral placement) and stress (heart rate) in given road conditions, based on a driving simulator study (Wu et al., 2013, 2012). The results show that drivers pay more attention to the roadside near Chevrons; they are also more relaxed, tending to drop their speed more when Chevrons are present (Wu et al., 2013). However, we did not find a significant effect of Chevrons on average driving speed (Wu et al., 2012). A serious limitation of the study is that the experimental data was likely affected by the confounding factors involved. In this study, Chevrons were placed near the guardrail along the left-hand edge of the paved road surface. A significant interaction has been found between the guardrail and roadway geometry, affecting both driving and perceived speed (Ben-Bassat and Shinar, 2011).

These two papers stated above illustrated the need to explore the effectiveness of China's Chevrons on highways. However, these study results were based on a given roadway condition. It was still unclear if the roadway geometries played a role in determining the effects of Chevron alignment signs. Thus, based on the same driving simulator platform, 12 horizontal curves in the simulated scenario were designed to accommodate variations in Chevron presence (with or without), curve radius (sharp, moderate, or flat) and curve direction (left or right). Then, the effectiveness of Chevrons on horizontal curves with different roadway geometry conditions was analyzed. First, the effectiveness of Chevrons on driver performance was thoroughly explored (Zhao et al., 2015). The results showed that Chevrons had a significant effect on speed reduction, and this function was not significantly affected by curve radius but was statistically affected by curve direction. Meanwhile, we also found a significant effect of Chevrons in encouraging participants to drive the vehicle with a more proper lane position in the first half of curves; this function was slightly affected by curve radius. Meanwhile, Chevrons helped keep drivers in a more stable lane position; this effect was also statistically significant in the second half of curves.

Meanwhile, we also analyzed the influence of China's Chevron alignment signs on driver stress in curves of various roadway geometries, through comparing drivers' heart rate in different curve conditions (Zhao et al., 2014). The study results indicated that in a sharp-radius curve, the effect of Chevrons on drivers' heart rate was significant, and their heart rate was relatively low when Chevrons were present.

In addition, the effect of China's Chevrons on drivers' perceived safe speed, including both the main effect of Chevrons and the interaction between Chevrons and curve roadway geometries, was also discussed (Wu et al., 2015). In this paper, we found that China's Chevrons made drivers evaluate a higher safe speed for sharp curves, as compared with the absence of Chevrons. China's Chevrons fail to convey to drivers critical information about sharpness of curves.

Summarizing the above discussion, the influence of China's Chevrons has been deeply analyzed in our previous studies. But until now, there has been no method to quantitatively describe the effects of Chevron alignment signs in various roadway conditions; furthermore, it is unclear how the parameters of driver performance can be predicted. Thus, based on our previous study findings, the current study aimed at establishing a regression model to predict and estimate driver performance on curves with different roadway geometries, under the effect of Chevrons. The vehicle speed and lane position were selected as the indexes to reflect Chevrons' effectiveness; the Chevron presence, curve radius and curve direction were defined as independent variables. This study contributes to knowledge of driver performance on different roadway geometry curves under the influence of Chevrons; therefore it provides a good reference for field crews deciding whether it is necessary to implement Chevron alignment signs on various curves from the aspect of driving safety. These study results lay a foundation for more uniform and efficient Chevron use on China's highways.

2. Methods

2.1. Participants

A total of 36 healthy young male drivers participated in our driving simulator study. Participants were recruited by announcement and each of them has a Chinese class B driver's license. Their age was between 20 and 34 years (AVG = 24.8, SD = 3.66); having 2–8 years (AVG = 3.4, SD = 1.63) driving experience. All participants provided a written informed consent before joining in the experiment. After complementing the driving task, each participant was offered China Yuan (CNY) 100 cash as reward.

To explain briefly, the homogeneous sample of subjects selected intends to minimize any bias attributable to sample heterogeneity, as numerous studies have demonstrated that driving performance was most affected by age and by gender (e.g., Calvi et al., 2012). Meanwhile, due to the high resource demands, it is common for simulator studies to have a small sample size. Examples include: a study of effect of shoulder width, guardrail and roadway geometry on driver perception and behavior, with 22 participants (Ben-Bassat and Shinar, 2011); research into the influence of roadside infrastructure including guardrails, trees and barriers on vehicle speed and lateral positioning, also with 22 participants (van der Horst and de Ridder, 2007); research examining how travel lane width, edge line striping, and shoulder width affect driver errors on two-lane rural roads, with 36 participants (Chrysler and Williams, 2005); a study aiming at exploring driver lateral position, speed and deceleration on deceleration lanes, with 30 participants (Calvi et al., 2012).