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An explanation of how the placement of traffic signs affects drivers' deceleration on curves

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ABSTRACT

Driving performance is one of the most important areas in the curve safety research because nearly all crashes on curves are associated with inappropriate driving behavior. This study developed a model to illustrate the deceleration behavior in response to the traffic sign on curves, and a simulator experiment was conducted to empirically test the model. The experiment involved three independent variables: one primary variable is the placement of the traffic sign, and two auxiliary variables are curve radius and trial number (the number of trials that the participants have conducted in the experiment). The dependent variable is the first position of releasing the accelerator pedal (FPRA). The results of the experiment showed as the same as the model indicated: when the traffic sign was placed far enough (e.g., 100 m or more) away from a curve, the FPRA was positively correlated with the placement of the traffic sign; however, when the traffic sign was placed near to the curve (e.g., 50 m or less from the beginning of the curve), the FPRA was positively correlated with the curve radius instead of the placement of the traffic sign. In addition, the more times the participants had driven in the scenario, the closer the FPRA to the beginning of the curve. These results imply that deceleration behavior is not only dependent on whether the drivers acquired the information, but also on the confidence level of such information. Moreover, the trial number is also related to the information perception, and influences the deceleration behavior.

1. Introduction

Driving on curves has been a significant global safety problem for years, with high crash frequency and severity. In recent years, many studies try to identify the inducements of the crashes on curves. Some researchers thought that drivers lacked sufficient time to handle such a complex driving task (Hummer et al., 2010), which is influenced by additional centripetal force or poor environmental conditions. Other researchers attributed speed-related collisions on curves to drivers' misperception of coming curves (Shun-Hui et al., 2008) or their underestimation of vehicle speeds (Maltz and Shinar, 2007). In addition, distraction by secondary tasks (such as cell phone calls or operating in-vehicle electronic equipment) poses a potential hazard for drivers while negotiating curves (Horberry et al., 2006). In a word, driver's inappropriate operation, which could lead to a vehicle speeding or a dangerous state, should be regarded as the root of crashes (Comte and Jamson, 2000). The best way of making curve safe is to maintain the vehicle in an appropriate state by optimizing the driver's performance. According to the cognition theory, drivers' operation should be determined by their decision system based on the acquired information (Salvucci, 2004; Ng and Chan, 2008). The key issue then exposed: how to make sure that drivers can get enough information in time to drive safely on curves?

Currently, many treatments and devices have been employed for providing sufficient information to avoid crashes, including traffic signs, pavement markings and driving assistant systems. Among them, traffic signs play important roles and are widely used in many areas (Donald, 1997; Herrstedt and Greibe, 2001). An investigation showed that crash frequency declined by an average of 30% if warning signs were set prior to dangerous curves (Elvik, 1995). The fact proves that warning signs provide drivers necessary information when they are closing to curves. Further, Lee et al. (2002) indicated that advanced warnings, compared with late warning, might be helpful for a quick reaction, and avoid collisions more effectively. Nevertheless, some other studies showed that traffic signs might be invalid under certain conditions. In Shinar's research, the installation of curve warning signs on two high crash curves failed to result in any significant change in drivers' entry speeds (Shinar et al., 1980). Also, one study reported that 90% of

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the drivers exceeded the recommended speed and over half exceeded it by 10–30 km/h (Chowdury et al., 1998). The reason of the low effectiveness is due to the overuse of the warning signs, particularly in situations of low risk (Jørgensen and Wentzel-Larsen, 1999). These inconsistent findings indicated that traffic signs are related to curve safety but how they affect driving performance needs to be further investigated.

At present, many researchers have focused on the relationship between driver behavior and the traffic signs. One study pointed out that the effect of advisory speed signs was greater than the effect of general speed signs when the reason for the limitation was apparent to drivers (Macdonald and Hoffmann, 1991). Kolisetty et al. (2006) analyzed the effects of different message signs. They found that different message signs make drivers to reduce their speed in different ways. Jørgensen and Wentzel-Larsen (1999) reported that the whole road system and warning signs had a great positive impact on driving performance. In all, researchers tried to select which kind of traffic signs might be better at certain curves, and which kind of driving performance should be encouraged. But none of them clearly explained why traffic signs made curve driving safer or how the driver responded when he saw a traffic sign on the curve. Meanwhile, a range of studies have attempted to illustrate the mechanisms of driving behavior which are influenced by traffic signs. Charlton (2007) believed that the curve driving task required drivers to spend more attention resources on collecting information, more mental resources on making decisions, but left less time on manual control. Thus if the driver want to perform well, he must properly perceive traffic objects (e.g., road signs), keep alert to make decisions, and perform at right time (Roca et al., 2012). An important consensus of mechanism research is that traffic signs helps increase curve safety mainly due to its keeping drivers alert (Carson and Mannering, 2001). Since traffic signs make drivers pay attention to the curves or give them a warning signal (Abe and Richardson, 2005), the probability of crash is therefore prominently reduced. However, more details of the mechanisms need to be further study.

In summary, traffic signs could reduce curve crashes by providing curve information and making drivers aware of the curve ahead, but when traffic signs are overused, their effectiveness may be declined. Thus, two meaningful points need to be further improved: how traffic sings impose their effects on drivers, and how drivers respond to the traffic signs? For this purpose, this study built a model to explain why a warning sign on curves induces a deceleration behavior and propose using the confidence of information as the input of the drivers' decision system. The study also conducted a simulator experiment to test this model. The placement of the traffic sign is employed as the major independent variable, since it is one of the most important factors to determine the place of drivers' receiving curve information. In addition, there are two auxiliary independents variables: the curve radius and the trial number. The curve radius, determining the outline of the curve, affect the driver's information perception. The trial number in the experiment affect drivers' deceleration behaviors through the drivers' memory system.

2. The model of deceleration behavior on curves

We proposed an information processing model for the deceleration behavior. In this model, a driver is regarded as an intelligent system that can respond to different external stimulus. With viewpoint of cognition theory, the driving performance is composed of a train of sequential driving-circles. Each driving-circle, from the driver's receiving an external stimulus to his producing a driving operation in response, is consisted of a set of function modules. To put the illustration and analysis clear, some rational simplification was made compared with the real driving processes. The simplified model involved three primary modules (perception, decision-making, and motion) and one auxiliary module (memory), as shown in Fig. 1.

The primary modules perform the basic function of a driving-circle, and any driving-circle should involve the three modules. In this study, the perception module refers only to the visual channel, because the relevant information only comes from the visual perception. The function of the perception module is to transform the raw visual image into meaningful information. The decision-making module is the core of the model. It determines which operation should be executed, according to its internal decision strategy and the information acquired from the perception module. The motion module manipulates the driving operation following the order of the decision-making module. The auxiliary modules make the model more variable and are able to meet complex requirements. This model employs just the memory module, and it is designed to assist the perception module for generating information. Thus the whole process of a deceleration driving-circle is stated as follows (note that period should last only milliseconds for a normal driver): (1) drives obtain traffic information perception through the perception module, (2) the decision-making module makes a judgment based on the acquired information. If the information meets the condition of deceleration strategy, the decision-making system will send a decelerating command to the motion module and (3) when receive a command from the decision-making module, the motion module will execute the deceleration operation (release the accelerate pedal). In this process, there are two sub-processes to be further specified: one is information generating procedure mentioned as the perception module, the other one is deceleration strategy, mentioned as the decision-making module.

As shown in Fig. 1, the major output parameters of the perception module to the decision module are A1, A2, and A3. A1 is the information "curve ahead," obtained from the external environment; A2 means the vehicle speed, which is acquired from the speed meter; A3 is the speed limit of the curve depending on driving experience. When the decision-making model works, it not only depends on the information itself but also whether drivers have confidence in it. In this case, the deceleration strategy can be described as follows: when the message "curve ahead" is confirmed (the confidential value being larger than its threshold value) and the vehicle speed is over the speed limit, the driver will release the accelerate pedal. Or, it can be presented as:

IF $AC_1 \geqslant A1_{th}$ (condition 1)
AND $A2 > A3$ (condition 2)
THEN OC = "releasing the accelerate pedal"

where AC_1 is the confidential value of "curve ahead" (we define the confidential value of "curve ahead" to represent the confidence of the information of "curve ahead" which the driver acquired), and $A1_{th}$ is the threshold value. A2 and A3 are the vehicle speed and the speed limit, respectively. OC stands for operation command.

Considering that information A1 is the major test condition, we take it exemplify the information generating procedure. First, the perception system will identify every object in the visual image and set each one a value (a_i) to indicate the confidence of A1. Then the memory system will set each confidential value a weight (w_i). After that, the perception system will calculate the weighted sum as the total confidence of A1. The following formula is used to describe this generation:

$$AC_1 = \sum a_i \cdot w_i \quad (1)$$