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
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 signs 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 affects 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:

\[
\text{IF } A_{C1} \geq A_{1h} \text{ (condition 1)} \quad \text{AND } A_2 > A_3 \text{ (condition 2)} \quad \text{THEN } OC = \text{“releasing the accelerate pedal”}
\]

where \(A_{C1}\) 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 \(A_{1h}\) is the threshold value. \(A_2\) and \(A_3\) are the vehicle speed and the speed limit, respectively. \(OC\) stands for operation command.

Considering that information \(A_1\) 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 \(A_1\). 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 \(A_1\). The following formula is used to describe this generation:

\[
A_{C1} = \sum a_i \cdot w_i
\]
where $a_i$ is the confidential value of $A1$ coming from the identified object, and $w_i$ is the weight given by the memory system. The other information ($A2, A3, ..., An$) is generated in the same way.

Based the deceleration strategy, if the vehicle speed is over the speed limit the driver’s deceleration behavior is determined by $A_{C1}$. Therefore, we can infer if the environment provides enough confidence of information $A1$ for a driver, then he will release the accelerate pedal. On the opposite, if a driver release the accelerate pedal, we can assure the confidential value of the information $A1$ that he perceived must be larger than the threshold value. Thus, under condition 2, condition 1 ("$A_{C1} > A_{1th}$") should be the sufficient and necessary condition of the deceleration behavior.

Based on the above hypothesis, we conducted a curve driving experiment. Three independent variables are employed as influential factors $A_{C1}$: (a) the placement of the traffic sign ("placement"), (b) the curve radius ("radius"), and (c) the number of trials practiced ("trial number"). Different placements and radii influenced the value of $a_i$ in formula (1) when the drivers were approaching the curves. The trial number means how many times the driver has driven in the scenario, which influenced the value of $w_i$. $A2$ and $A3$ are the control information, which are designed to produce condition 2. The dependent variable is the first position of releasing the accelerator pedal (FPRA), which indicates the distance between the beginning of the curve and the point of drivers begin to release the accelerate pedal, also this value reflects the moment that $A_{C1}$ is over $A_{1th}$. If the results of the experiment are consistent with the model, it will not only offer evidence to support the model, but also an explanation of how the placements of traffic signs affect deceleration behavior on curves.

To control the conditions in this experiment, the driving simulator was used because of three main advantages: (1) ensuring the same conditions for all trials, (2) making the experiment repeatable and (3) protecting participants from risks. In addition, the experiment was designed with the following considerations:

1. The participants should be as homogeneous as possible, because individual differences (such as age, gender and education) could greatly influence drivers’ abilities (Charlton, 2004; Recarte and Nunes, 1996).
2. Other events that may lead the drivers to take an undesirable deceleration (such as adjacent vehicles, pedestrians or crossings) should be avoided. The driving environment (such as weather, landscape or roads) should be the same across all trials in the driving simulator.
3. To make sure condition 2 ($A2 > A3$) the vehicle should be able to travel at a relatively high speed before drivers reach the traffic sign or curve, and there is no option for drivers to pass the curve safely other than decrease.

More details of the experimental design will be provided in next section.

3. Methods

3.1. Participants

Thirty participants were recruited (all male, mean age 26 years, range 20–29 years) via direct contact as volunteers from Beijing University of Technology. All participants have a valid driver’s license and have been driven for an average of 3.28 years (range 2–5 years). None of the participants has color vision defects. All of them are reported to have normal or corrected-to-normal vision. To make the sample participants as homogeneous as possible, we selected only male, young, highly educated and normal drivers (in future programs, we will choose different kinds of participants). We also set driving capability as a control factor (see procedure for details).

3.2. Simulator

The AutoSim simulator system in the laboratory of the Transportation Research Center at Beijing University of Technology, shown in Fig. 2, was used in the experiment.

The hardware of the simulator system consists of a vehicle, 8 networked computers (one master computer, one that communicates with the vehicle system, and the other six that are used to compute six different real-time views), a motion control device, and other equipment (such as video and audio devices). There are three main programs for the simulation of this experiment: Evariste (used to create experimental scenarios), Simword (for controlling the scenarios) and Scancer (for collecting data and generating car motion). The frequency of data collection is 30 Hz.
3.3. Scenarios

In this experiment we designed two kinds of scenarios: one was employed in the driving capability test, as shown on the left side of Fig. 3, and the other was for the formal experiment as shown on the right side of Fig. 3. The road in the formal scenario is consisted by five curves of different radius, ranging from 20 m to 60 m, with a step of 10 m. To reduce the influence from adjacent curves, there is a straight segment before each curve (1500 m in advance of the first curve and 800 m between the remaining curves).

The traffic sign installed in all scenarios is shown on the right side of Fig. 4. Each curve has its own speed limit. The speed limits are 20 kph, 30 kph, 40 kph, 50 kph and 60 kph respect to the radii of 20–60 m, which acquire by using the auto-run function of the simulator system. The placement of the traffic signs before the curves have five levels: 0 m, 50 m, 100 m, 200 m and 400 m away from the beginning of the curve (symbolized as P0, P50, P100, P200 and P400 respectively in later text), as shown on the left in Fig. 4. There are five formal scenarios, and a participant drive only one of them.

All of the formal scenarios are of the same road shown in Fig. 2. The only difference among the scenarios is the placement of the traffic signs. For each radius of the curve, the 5 placements are randomly distributed across 5 scenarios. Table 1 shows the results and the distribution of the 5 levels of placement. The first column of the table is for the 5 radii of the curves. The other 5 columns, A–E, represent five different scenarios in the experiment, with the placement of the traffic sign before each curve. For example, in scenario B, the traffic sign was installed 100 m in advance of the curve with a radius of 20 m, 50 m and 60 m, 200 m in advance of the curve with a radius of 30 m, at the beginning of the curve with a radius of 40 m.

Other conditions were controlled to make drivers to follow the designed patterns when they approached the curves. A one-way rural road (width 3.5 m) was used in this experiment to eradicate other options. There was no other traffic flow in the scenario to make sure participants’ driving performance would not be influenced by other vehicles.

3.4. Procedure

This experiment possesses two phases: the driving capability test and the formal experiment. Each participant was asked to drive three times along the capability test scenario, and the average speed for each trial was calculated (m/s). The driving performance for each participant was measured by the difference between the maximum average speed and minimum average speed, which reflected the speed-control capability on straight roadways of the participant, denoted as $S$. The participants were classified into three levels (low level: $S \geq 6$, middle level: $3 < S < 6$, high: $S \leq 3$) so that each level had ten participants. Then we randomly picked two participants from each of the three levels to compose a new group of six participants (two were with low level driving capacity, two with middle and two with high). In this way, thirty participants were assigned to five groups, and each group corresponded to one formal scenario.

The formal experiment is composed by three main steps. The first step was to introduce the participants that their task was to drive the simulator car from the starting point to the ending point as quickly as possible. They were also informed that there would be traffic signs before the curves, but they were not given any other information about the scenarios (such as the curve’s radius, length of the straight segment, and position of the traffic sign). This helped to make sure that the participants conformed to the curve decision strategy (maintaining high speed before curves and decelerating their cars to enter the curves), but they got no hint about deceleration. The second step is the practice drive step. The participants drove in the test scenario to warm up (5–10 min) in order to avoid mistakes caused by bad driving state. The third step is the formal experiment step. Each participant drove through the scenario 5 trials. The participant had an inter-trial break of 2 min after each trial. The simulator recorded the driving data from the beginning to the end of the experiment.

4. Results

To explore how AC1 influences the FPRA, the three independent variables (placement, radius, and trial number) were conducted by running the three-way ANOVA test. Based on the results ($F(4596) = $
17.01, p < 0.01 as placement, F(4596) = 3.69, p < 0.01 as radius, and F(4596) = 3.58, p < 0.01 as trial number), all the three independent variables had a significant influence on the FPRA, as their p-values were all smaller than 0.01.

4.1. The influence of the placement of traffic sign and curve radius

The average FPRA of each placement is shown in Fig. 5, across all radii and trials. The x-axis is the placement of traffic signs before curves with the five values mentioned above (i.e., 0 m, 50 m, 100 m, 200 m, and 400 m), and the y-axis is the average FPRA across all radii and trials. As Fig. 5 shows, the FPRA emerges two different patterns of variation: when the traffic sign is placed equal or over 100 m away from the curve (P100, P200 and P400) the FPRA is positive correlation with the placement; however we fail to point out an apparent increase comparing the FPRA at P0 with P50. The following analyses just focus on the reasons for the above phenomenon.

Based on the two patterns of FPRA, we divided the five placements into two groups to analyze the relationship between the effect of placement and of radius, and employed a two-way ANOVA test. Group-PA involved P0 and P50, because these two placements did not make apparent changes in FPRA. Group-PB involved P100, P200, and P400, for each placement had a different FPRA. The results of the ANOVA test showed that different radii resulted in apparent effects on FPRA, (F(4236) = 3.55, p < 0.01) in Group-PA, but no effect was presented on the placement (F(1149) = 0.41, p = 0.52). In contrast, for Group-PB, different placements resulted in significant effects on FPRA, (F(2298) = 22.5, p < 0.01), but the effect of radius made no significant difference (F(4356) = 1.84, p = 0.12). Further, we draw the average FPRA across all placements and trials in Fig. 6. In Group-PA the average FPRA increases with the radius; however we did not figure out any regular pattern in Group-PB.

According to the model mentioned in Section 2, we obtain there are two main reasons for the above results: first, both of the traffic sign and the curve outline can influence the value of AC1; second, the operation of releasing accelerator pedal is conduced by the condition “AC1 ≥ A1th”. Whichever makes AC1 over A1th it will impose no influence. Specifically, when the traffic sign is settled at or over 100 m, the drivers perceived the traffic sign earlier than the curve. In this case, the first time when AC1 is over A1th, it is mainly triggered by the traffic sign, and will result in the FPRA’s changing with the placement of the traffic sign. And when the traffic sign is settled at or less than 50 m, the drivers perceived the curve earlier than the traffic sign. Thus the first time when AC1 is over A1th, is mainly triggered by the curve outline, and result in the FPRA’s changing with the radius of the curve.

The details of how the traffic sign and the curve outline influence the value of AC1 is explained by expanding formula (1) as follows:

\[ AC_1 = \sum a_t \cdot w_t = a_t(p_t) \cdot w_t + a_t(w_t) \cdot w_r + \sum_j \alpha_j \cdot w_j \]  

(2)

Here, \( p_t \) means the distance from the driver to the traffic sign at one point, and \( p_r \) means the distance from the driver to the beginning of the curve. The symbols \( a_t(p_t) \) is a decreasing function of \( p_t \) which represents the confidential value for information A1 of the traffic sign, and the symbols \( a_t(p_r) \) is a decreasing function of \( p_r \) which represents the confidential value for information A1 of the curve. This is in line with our driving knowledge, as a driver is getting closer to an object (such as the traffic sign and the curve), he will be more confident about the information conveyed it. The symbols of \( w_t \) and \( w_r \) are the weights given by the memory system to the traffic sign and the curve outline, respectively. The third term \((\sum_{j=1}^{\alpha} \alpha_j \cdot w_j)\) represents the influence of other objects. In that the other objects were controlled stable in this experiment, the third term will be ignored in the following analysis.

Based on the model, we can infer that AC1 is approximately equal to the threshold value at the point of FPRA. The reason is simple, because after the point of FPRA the drivers maintain the state of releasing the accelerate pedal which reflects “AC1 ≥ A1th”, and before the point of FPRA the drivers do not release the accelerate pedal which reflects the “AC1 < A1th”, so the point of FPRA means the balance point. Thus the AC1 should have the same value at the five points of FPRA which are corresponding to the five different placements of the traffic signs in Fig. 5 equaling to the A1th.

In Fig. 7 it shows the \( p_t \) and \( p_r \) at the point of FPRA which is corresponding to the five different placements of traffic signs. The x-axis is the placements of traffic signs before curves, with the five value points previously mentioned (0 m, 50 m, 100 m, 200 m, and 400 m), and the y-axis refers to the distance (m) from the drivers to the objects (traffic sign or the beginning of the curve). As Fig. 7 shows the \( p_t \) is increasing with the placement of traffic sign, and this variation reflects that the \( a_t \) is decreasing with the placement of traffic sign. Meanwhile, the \( p_r \) is decreasing with the placement of traffic sign, and this variation reflects that the \( a_t \) is increasing with the placement of traffic sign. According to the formula (2) AC1 is influenced by the weight sum of \( a_t \) and \( a_r \), so that the variation trend of \( a_t \) and \( a_r \) is reverse if we want to keep AC1 at a certain value. All these result in when AC1 is at a certain value (equal to A1th at the point of FPRA), we can see the confidence of A1 from the traffic sign \( a_t \) become smaller and the confidence of A1 from the curve \( a_r \) become larger, with the traffic sign is settled near to the beginning of the curve.

4.2. The influence of the trial number

The \( w_t \) in formula (1) and (2) also affects the confidence value for information A1, and it can be influenced by trial number. As the experiment was designed, each participant was asked to drive
five times, which were marked as lap1, lap2, lap3, lap4, and lap5. Based on degree of familiarity with the scenario, we divided the five trial numbers into two levels: level-L1 only included lap1, when the drivers first drove and knew nothing about the scenario; level-L2 included lap2 through lap5, and the drivers became familiar with the scenario as the trial number increased. This grouping result is in accordance with the post-hoc test. In addition, for the post-hoc test, the five placements were divided into four levels: P0 and P50 as level-P1, P100 as level-P2, P200 as level-P3, and P400 as level-P4. Thus, we could divide the FPRAs into eight groups on the basis of the combinations with different levels of placement and trial number (4 × 2). To clearly see how the trial number affects the FPRA, we employed the rank order of the FPRA to replace its absolute value for analysis. The calculation process is as follows: first, calculate the rank value of each FPRA using the “Van Der Wacerden” test; second, calculate the rank mean for each group; finally, order the groups by increasing rank. The difference between each adjacent rank order is significant according to the Kruskal–Wallis test. So the group with a smaller number of the rank order means that its average FPRA is small and also indicates that the place where the driver began releasing the accelerator pedal was near the beginning of the curve.

Fig. 8 shows the rank order of the eight groups as described above. The x-axis is the level of placement, and the y-axis represents the rank order. The left pillars filled with diagonal lines represent the rank order of the placements within level-L1, and gray pillars on the right represent the rank order within level-L2. One interesting finding is that the FPRAs with different placements under level-L1 are all larger than those under level-L2. This means the FPRA will get closer to the beginning of the curve as the trial number increases, regardless of the placement of the traffic sign. Another finding is that the order of level-P2 is larger than level-P3 under level-L1, but in contrast, the order of level-P3 is larger than level-P2 under level-L2. This indicates that in lap1, the role of the memory module was not significant, but with an increasing trial number, \( w_t \) shows a steady influence on the FPRA. This phenomenon is caused by repeated driving in the same scenario, which could establish a fixed relationship between the traffic sign and the information it represents.

5. Conclusions and discussion

Driving through curves has been a significant global safety issue for years. Driver’s inappropriate operation should be regarded as the root of these crashes. However, though traffic signs have warned of these curves, about 90% of drivers still exceeded the suggested speeds (Chowdury et al., 1998). Towards the goal of alerting the drivers when approaching a curve so that they would decelerate to the suggested speed, this study proposed a model of the information processes while the drivers are approaching the curve. It is the central idea that drivers will prevent the speed of the vehicles from exceeding limitation when the alert curve ahead is strong enough. Guided by this model, we conducted a curve driving experiment to test this hypothesis. The major findings of the experiment are:

(1) Based on the model, this paper gives a well explanation of how the placement of traffic sign affects the drivers’ deceleration operation on curves. The core idea of the model is that drivers’ deceleration strategy is dependent on the confidence of the acquired information. If the driver has sufficient confidence of the information A1 (“curve ahead”) under condition 2 (\( A_2 > A_3 \)), then he should release the accelerator pedal.

(2) In this experiment, there are two sources (traffic sign and curve outline) of information A1, and the sum of their confidence of the information A1 determines whether “\( A_{C1} > A_{1th} \)”. This is embodied in the two patterns of the FPRA variation: when the traffic sign is placed far enough away from the curve (P100, P200 and P400) the FPRA increase with the distance between the traffic sign and the beginning of the curve; but when the placement of the traffic sign is close to the curve (P0, P50), the FPRA increase with the curve radius instead.

(3) The placement, radius, and trial number all impose influence on FPRA. The drivers get information of the first two factors from the visual stimulus. Therefore, the placement, radius are the factors affecting A1. Meanwhile, the trial number reflects the participants’ experience and familiarity with the scenarios in this experiment, which should affect the memory. It is reasonable to suppose that the placement and radius affect \( \alpha_t \) and \( \alpha_r \) and trial number are \( w_t \) and \( w_r \) in formula (2).

In summary, the experiment of this study shows the effects of placement, radius, and trial number on FPRA, provides sufficient evidence supporting the information processing model of deceleration behavior on curves, and offers clues for how the placement of traffic signs affects deceleration behavior on curves. Although we illustrated why drivers might decelerate before curves and how to induce a deceleration behavior based on the schematic model we proposed, it was only a static and simplified description. The results of this experiment are based on the average of a specific group of participants. Driving performance is far more complicated in our daily life, both the drivers’ reactions and the surroundings. If we want to discuss more kinds of drivers and different environments, the structure of the model will correspondingly more
complex and elaborate, because largely extended modules could describe more complex driving performance. Further study we will also do some field studies to explore more evidence of these findings.

In a driving simulator research, the driving environment in virtual scenario could be maintained at the same level during the whole experiment, in order to avoid the confounding effects of unexpected events which happen stochastically on field tests. Thus, results based on driving simulator research will be more obvious and clear. In future research, field study will also be performed to explore more evidence of the findings in this paper.

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