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Impact of roadside advertisements near traffic signs on driving safety

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A R T I C L E I N F O

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Matter-Element Model
Driving Safety

A B S T R A C T

A common distraction that affects drivers on the road is billboards. It can substantially impact how well drivers manage their speed, maintain their lanes, focus their attention, and react to stressful situations. When the billboards are placed next to vital traffic signs, they negatively affect drivers, impairing their ability to recognize these signs visually and, more significantly, altering their driving behavior. In this case, the impact of billboards on drivers is mainly influenced by two critical factors: billboard size and relative position to the traffic signs. In this study, a driving simulator was used to study the influence of these two factors on drivers. For this purpose, the eye movement, EEG and driving behavior data of drivers under different combinations of these two factors were collected. The data were analyzed and comprehensively evaluated using a two-factor repeated measure variance analysis and matter-element model. The results provided three main conclusions. First, the driver's ability to recognize signs and driving behavior are significantly influenced by the size of the billboard, and the impact is higher the smaller the billboard is. Second, the relative anteroposterior position of the billboard and the signboard significantly affects how people recognize signs and behave while driving. The driver was more affected by the billboard's placement in front of the signboard. Third, the drivers were impacted by the billboard size and relative anteroposterior position between signs and billboards. However, the influence of the relative anteroposterior position was more than that of the size. Based on the study's findings, some guidelines for billboards to avoid accidents in the actual world can be developed. First, when positioning billboards around significant signs, every attempt should be made to put the billboard behind the sign so that the driver may first finish identifying the sign. Second, to minimize the impact on drivers, a large billboard (8 m x 24 m), placed as far away from the sign, should be used wherever possible. Finally, it is vital to develop uniform regulations and norms for the size standards of billboards in various settings due to the vast variations in billboard sizes used in China.

1. Introduction

According to the World Health Organization (WHO), 1.25 million people die in car collisions annually (WHO, 2017), and the

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National Highway Traffic Safety Administration (NHTSA) has confirmed that distraction by the driver accounts for 78 % of these collisions (NHTSA, 2006). This is because driving is a function that demands a high level of focus, and any distraction to the driver will affect the driving process (Green, 2002). Distractions are now a significant risk factor for fatal collisions (Sundfør et al., 2019) and injury crashes involving personal vehicles (Beanland et al., 2013). According to the Road Safety Commission (2019), distracted driving is currently acknowledged as a key contributing factor in road accidents. In the United States alone, 2,841 deaths were attributed to diverted attention (NHTSA, 2019).

Visual distraction significantly impacts drivers in road traffic and frequently results in significant accident consequences since it affects more than 80 % of the external information that people perceive. The available literature indicates that billboards, mobile phones (Ezzati Amini et al., 2023) and interior decorations (Ojstersˇek et al., 2023) are the primary information sources that create visual distraction for drivers. Roadside advertising can draw attention without the driver actively seeking it out because billboards are typically placed in the driver's central field of vision and have attractive features (colors, images, messages, etc.) that cause drivers to look away from the road (Oviedo-Trespalacios et al., 2019).In addition, much research indicated that roadside billboards adversely impact the drivers' ability to control speed, stay in the lane, allocate attention, and concentrate on stressful situations with quick response (Brome et al., 2021; Meuleners et al., 2020; Schieber et al., 2014; Shaw et al., 2019; Young et al., 2009). Many nations and territories (including Sweden, Maine, Vermont, Alaska, and Hawaii) have decided to remove billboards from their roads due to the detrimental effects of these advertisements. However, in-depth studies on the visual distraction caused by billboards on drivers can help reveal the general impact of billboards on drivers and help form accident prevention procedures and policy solutions to deal with billboard distraction in nations or regions that still use them.

Many researchers tried identifying the relationships between billboards and traffic safety to mitigate the adverse effects of billboards on road users. The results of the most recent studies on the connection between billboards and driving safety are as follows:

Some studies have investigated how drivers' decisions, driving behavior, and traffic safety are affected by roadside billboards, and they have sorted out the relationship between roadside billboards, driving behavior, and road safety (Hinton et al., 2022; Oviedo-Trespalacios et al., 2019). Some researchers used the Task Capability Interface (TCI) model to identify potential risks from billboards (Oviedo-Trespalacios et al., 2019). This model states that driving demand (i.e., lane keeping, speed control, and other driving-related subtasks) should always be less than driving ability. When the driving demand rises, the driver often reduces speed to make the driving demand less than the driving ability (Fuller, 2005). In addition, some researchers investigated how different genders and ages responded to billboards and the results showed that young drivers were more likely to be influenced than other groups (Edquist et al., 2011; Olejniczak-Serowiec et al., 2017; Oviedo-Trespalacios et al., 2019; Sheykhfard & Haghighi, 2019; Stavrinos et al., 2016; Underwood, 2007). Additionally, numerous researchers have examined the various impacts of different billboard kinds on drivers, namely static and electronic billboards, and their findings are consistent: Both static and electronic billboards will affect drivers (Edquist et al., 2011), but electronic billboards get more attention and have a more significant effect (Beijer et al., 2004; Brome et al., 2021; Crundall et al., 2006; Edquist et al., 2011; Schieber et al., 2014; Stavrinos et al., 2016). Further, many studies focused on how billboard design and contents could affect driving safety, including billboard height (Crundall et al., 2006; Topolsek et al., 2016), how the content is expressed (Marciano, 2020; Marciano & Setter, 2017), the brightness of electronic billboards' displays (Zalesinska, 2018), and billboard contents expressing various emotions (Chan & Singhal, 2013; Megias et al., 2011).

One critical factor affecting driving safety is the size of the billboard. However, an agreement has yet to be established on which billboard size is least hazardous to drivers. Zalesinska (2018) found that a driver's reaction time to obstacles is shorter when using a small billboard size than a large one, and drivers are less affected by small billboards than by huge ones. Some research shows that the impact of tiny billboards is smaller than that of huge billboards, and that the bigger the billboard, the more probable it is that the driver's attention will be drawn to it and distracted (Hughes & Cole, 1984; Wilson & Casper, 2016). However, large-sized billboards may be used, according to the research findings of other experts (Li et al., 2011). According to research by other academics, billboard size only impacts drivers' eye movements, not their driving behavior (Meng, 2015). There needs to be more than one criterion for the billboard size. For instance, the largest billboard in Queensland, Australia, is 43 m^2 (Roberts et al., 2013), whereas the largest billboard in SAN Antonio, Texas, is 63 m^2 (San Antonio, 2017).

The position of the billboard also impacts driving safety, and the position of the sign has a greater effect on drivers than the visual saliency of the billboard itself. The significance of the visual saliency would only be realized once the location criteria are satisfied (Wilson & Casper, 2016). Most current pertinent studies on the placement of billboards concentrate on the analysis of billboard placement when erected alone. For instance, according to particular research, billboards close to the road or toward the middle of the field of vision draw more attention than those closer to one side of the area (Beijer, 2002; Chattington et al., 2009). Additionally, the closer the billboard is to the road, the greater the impact on drivers' visual perception (Wilson & Casper, 2016; Zalesinska, 2018). Some studies show that billboards on curves can affect visual behavior (Beijer, 2002); Posted mounted billboards have a less noticeable effect than overhead billboards (Meuleners et al., 2020); Drivers look at billboards at street level for a more extended period than they do at higher levels (Crundall et al., 2006) and billboards ought to be kept apart from signage if the circumstances allow (Mollu et al., 2018).

However, the location of the billboard alone cannot be taken into account in many situations because the billboard may be of concern due to its proximity to other cars, traffic lights, and direction signs rather than due to its visual prominence in the surroundings (Chapman & Underwood, 1998). In addition, Schieber et al. (2014) contend that the environmental needs of the "restoration zone" (such as other signage, parking lot entrances, etc.) must be considered while placing billboards. Due to the need for both billboards and signs to occupy visual space and add some driving load, as well as the limited availability of both human visual space and driving ability at the same time, when a billboard is placed next to other significant signs, its effect on the driver will be significantly greater than if it were placed alone. This is because both would fight for scarce cognitive resources (Castro et al., 2004; Hübner & Bennemann, 1973). Due to the importance of reducing driver distraction and ensuring vehicle safety, evaluating the scenario when the billboard is placed next to the traffic sign is imperative.

The driving behavior parameters, electroencephalogram (EEG) and eye movement are frequently used to assess driving safety, and the driving behavior measures are the most direct indicator of driving performance and safety (Yang et al., 2021). The EEG parameters can represent drivers' workload and emotional state. The eye movement parameters can effectively express drivers' attention allocation and detection of driving distraction state. Cai (1994) presented the matter-element (ME) model to comprehensively evaluate multiple indices using a function that transforms disparate issues and metrics into unified standards. As a result, it can more accurately capture and convey the qualitative traits and quantitative values of evaluation indicators, objectively reflect the attributes of things, and more fully capture the overall state of things. The ME model is a comprehensive evaluation model that can unify incompatible indicators and has been widely used in many fields, including traffic engineering (Xiao et al., 2018; Zhao et al., 2021). For instance, Zhao et al. used the matter-element evaluation model to thoroughly assess the lighting effect of a reflective arch in various tunnel segments and different reflective arch setting schemes by considering seven incompatible indicators, including visual indicators (pupil area), operational indicators (speed, acceleration, lateral displacement, etc.), and conscious indicators. The outcomes support the validity of the ME model. Zhao et al. (2023) also used the matter-element model to assess the health of cables. By carefully analyzing several indicators of cable health (such as current, relative temperature difference, etc.), they used the matter-element model to assess the overall state of the cable, and cables with low evaluation grades indicated the need for prompt replacement or maintenance. This study uses the ME model to thoroughly evaluate the impact of various billboard-setting scenarios on driving safety.

The above literature review shows that visual distraction caused by roadside billboards presents a potential risk to driving safety. Developing methods to cope with billboard distractions will be possible by researching how they affect drivers. Previous research on billboards and driving safety focused primarily on the impact of the billboard design features, content details, and driver's age and gender on drivers' attention distribution and driving safety when a billboard is placed alone. There needs to be more research on how drivers are affected by billboards positioned close to signs. In fact, according to the TCI theory, a billboard effect on a vehicle is stronger when it is situated close to a sign than when it is placed alone. Two crucial elements that determine a billboard's ability to distract drivers are its size and location. However, the results of recent studies on billboard size are inconclusive, and there needs to be more pertinent studies on the relative placement of billboards and signs.

By examining the effects of their size and location factors on drivers when billboards appear near signs, this study aims to compile the research evidence for the impact of billboards on drivers in complex environments. It then proposes reasonable policy and behavioral solutions and countermeasures to lessen the effects of billboards on drivers.

Fig. 1 shows the methodology used in this study. Following a literature review, two factors (size and position of the sign) that influence drivers were identified and taken as independent variables. The experiment's theme was discovered using questionnaires. After gathering data, dynamic and static scenarios that suited the needs of the investigation were created using a driving simulator, and the participants were enlisted to undergo studies after completing the necessary questionnaires. The significance of the influence of the two independent factors on the driver is then established by examining the data from the driving simulation experiment. The ultimate decision is reached when the ME model has examined all six situations.

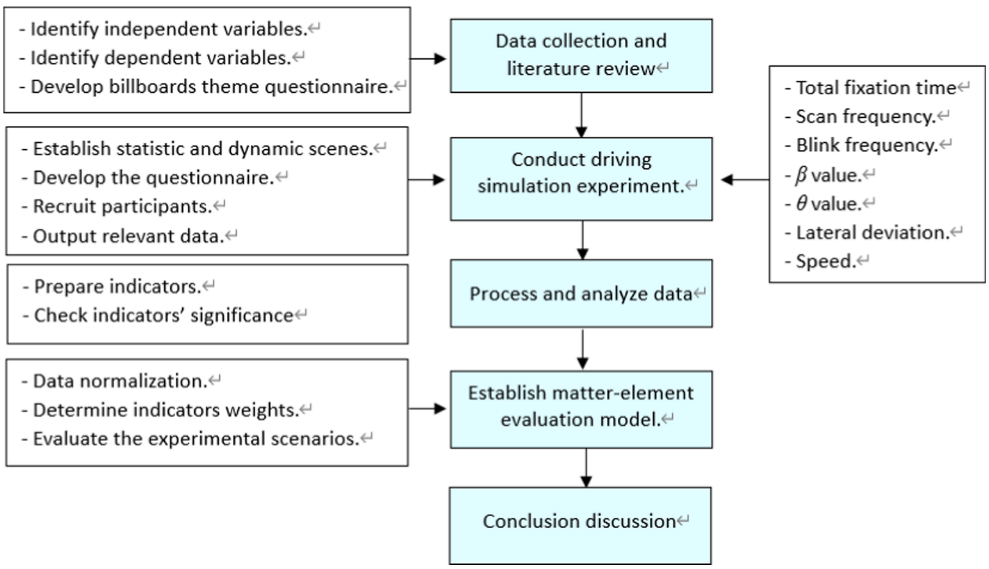


Fig. 1. Study Methodology.

2. Methodology

2.1. Variables and scenarios design

2.1.1. Experimental variables design

In this experiment, the effects of two variables on driving behavior and driving safety were examined: the billboard size and the relative position of the billboard and signboard. The visual recognition sequence of billboards and signs may affect how distracting they are, according to research by Charlton & Starkey (2011). This is because the driver experiences two states while operating a vehicle: the "monitoring process" (an unconscious mode) and the "operational process" (a conscious involvement). The variation in the order of visual recognition may cause drivers to be in various states when recognizing signs, which may affect how distracting a billboard is to them. The billboard location variables are split into two levels to reflect this distinction: the front of the sign (The driver sees the billboard first while driving) and the rear (the driver sees the traffic sign first while driving). In this experiment, the positions of the billboard and the 2 km exit warning sign represent the relative positions before and after the sign and billboard. According to the Chinese standard "Outdoor Advertising Facilities Steel Structure Technical Regulations", the billboard layout size is divided into groups of 5 m x 14 m and 6 m x 18 m. Considering the actual use of 8 m x 24 m billboards on the highway, the billboard size is divided into three levels: large (8 m x 24 m), medium (6 m x 18 m), and small (5 m x 14 m), forming 2 x 3 experimental scenarios. Table 1 shows the six experimental scenarios.

2.1.2. Control variable design

Since different billboard contents have different effects on drivers (Chan & Singhal, 2013; Maliszewski et al., 2019; Schieber et al., 2014), this study conducted 300 questionnaires on the content of billboards on Chinese freeways to bring the experiment closer to reality. As a result, the top three advertising contents on Chinese freeways are alcohol advertising, building materials advertising, and tea advertising (as shown in Fig. 2). Taking into account the poor guidance of alcohol advertising to the participants, the content of the billboard in this experiment is set as the theme of "building materials", and the content of the billboard in the six experimental scenarios is consistent, as shown in Fig. 3(a). Static billboards display the advertising content in this experiment because they make up most of the billboards on Chinese expressways. After selecting the static billboard model in the VS Design software, we added the billboard content as a texture to the model to demonstrate the static billboard's display impact.

In addition to the advertisement's content, the distance between the billboard and the sign also affects the experimental results; it is one of the critical control variables. The distance between the billboard and the sign should be greater than 100 m and less than 150 m in China to meet the requirements and make the experimental results reasonably effective (Li et al., 2013), and the final decision is to set the distance as 100 m. The advertising panel's oblique angle to the driving direction is set at 60 degrees.

The signboards of all the scenarios use guide signs that demand more cognitive resources from the driver to increase the significance of the experimental effect. The guide sign's place names count is six, as shown in Fig. 3(b). The number of six place names is the limit of the cognitive load of the guide sign, and more than six place names have a greater burden on the driver (Yang et al., 2020).

2.1.3. Experimental scenarios design

VS Design software created the simulation scenario for this experiment. The Beijing-Hong Kong-Macao Freeway from Shijiazhuang to Cixian is used as the foundation for the simulation road. The on-ramp is a single lane, and the main line's maximum design speed is 120 km/h. The design speed for the eight lanes (120 km/h) is taken as the steady traffic flow of 800 pcu/h (Li, 2012). Except for the size and position of the billboard, all other aspects of the road design in the six experimental scenarios are consistent with reality and the pertinent design guidelines. A schematic representation of the experiment's setting is shown in Fig. 4. The positions of the billboard (shown by the subscript red triangle) and the 2 km exit warning sign (indicated by the subscript green triangle) in this experiment represent the relative positions before and following the sign and billboard. Each sign and billboard value about the driving simulation experiment's beginning location is represented by its position value in the figure.

2.2. Participants

The minimal sample size was determined using G*power 3.1.9.7 software to increase statistical precision. The three main parameters for calculating the minimum sample size are as follows (Almallah et al., 2021):

Table 1
Schematic diagram of experimental scenarios.

Experiment Scheme	Billboard Size	Relative Position to the Sign
1	Small	100 m Front
2	Medium	100 m Front
3	Large	100 m Front
4	Small	100 m Rear
5	Medium	100 m Rear
6	Large	100 m Rear

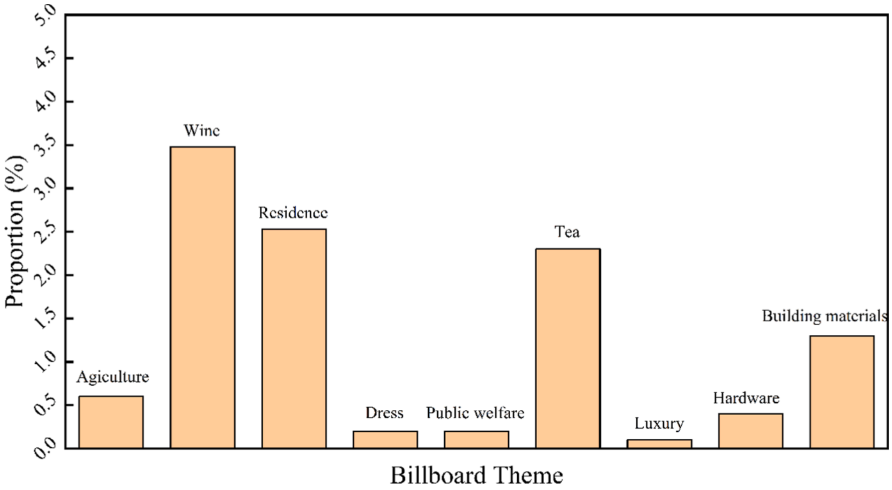


Fig. 2. Questionnaire results of billboard theme.

(a) Billboard sign (b) Guide sign

Fig. 3. Billboard and guide signs.

- α error is below 0.05 (that is, the significance level; the α error is also known as the probability of the first type of error in the statistical test, which is generally less than 0.05),
- The power of test is above 0.95 (that is, 1 - β error, β error is the probability of the second type of error in the statistical test. This test should generally be greater than 0.8), and
- The medium effect size of 0.25 (the size of the difference between the groups in the statistical test) was selected.

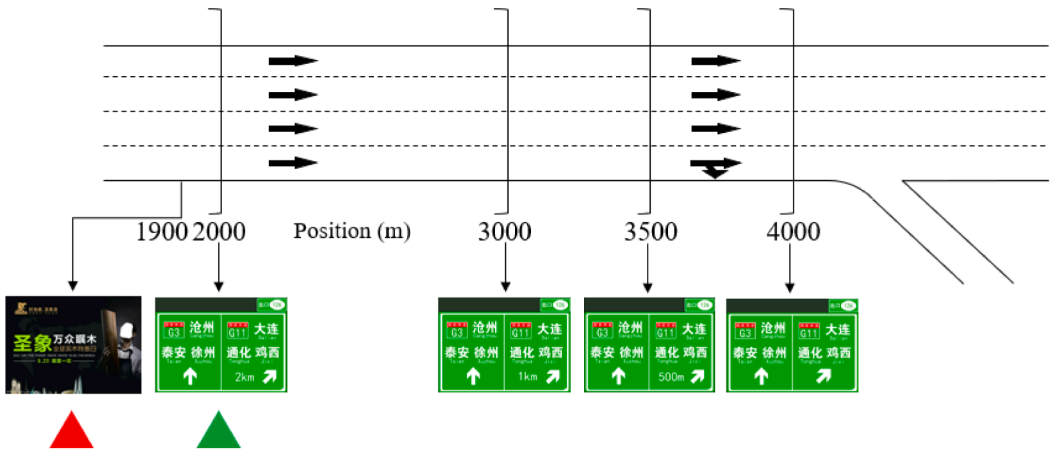
The software calculated that at least 28 individuals are required to meet the statistical effect of the aforementioned statistical precision (see Fig. 5). At last, only 32 undergraduate participants (16 males and 16 females) were engaged in the study due to the COVID-19 epidemic. All subjects had a C1 driving license and normal vision without color blindness. They ranged in age from 22 to 27 years old (mean = 25.41, standard deviation (SD) = 2.01), were between the ages of 1–6 when they began driving and had a driving distance of 5,000 km and 50,000 km. After the experiment, each participant received a reward of ¥50 and signed a declaration of voluntary participation. After that, the participants were free to pause or leave the experiment for any reason.

2.3. *Experimental equipment*

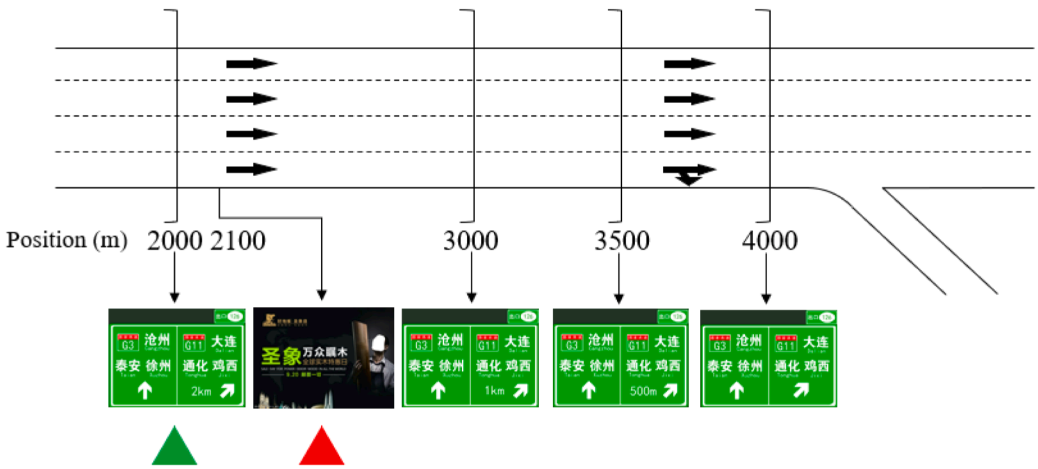
2.3.1. *DSR-1000TS2.0 driving simulation system*

The driving simulator is a dependable and efficient tool that can integrate perceptual input, cognitive processing, and behavioral output. The driving simulator has the advantage of precisely controlling experimental conditions and ensuring the participants' safety, even though it differs from the actual driving state (Blana & Golias, 2002). Driving simulators have currently been shown to be more efficient than actual driving (Meuleners & Fraser, 2015).

The cockpit, console, and display systems comprise the DSR-1000TS2.0 driving simulation used in this study. The seat, steering wheel, pedals, gear shift lever, instrument panel, ignition system, and other auto parts are all included in the cabin. Three 60-inch 4 k LCD monitors make up the display system, which offers a 120° field of view for the road. Auxiliary sound is used with the display's 30 Hz refresh rate to simulate outside and moving vehicle noises. The console also gathers experimental data from simulated driving,



(a). Billboard is positioned in front of the guide sign



(b). billboard is positioned behind the guide sign

Fig. 4. Positions of the billboards in front and behind the guide sign.

including driving behavior and vehicle dynamics parameters, such as steering wheel angle, brake pedal depth, and vehicle speed. This is in addition to the scene-switching and traffic-flow loading control functions.

2.3.2. Dikablis glasses eye tracker

The participant's pupil area, fixation times, and hotspots in their eye movement trajectories are tracked and measured using an eye tracker. The eye tracker has a sampling rate of 60 Hz and an accuracy range of 0.1°–0.3°.

2.3.3. EEG system

The Enobio wireless EEG technology, which sends 24-bit EEG data and precisely recreates the original EEG signal, makes up the EEG acquisition portion. The band sampling rate is 500 sps, the resolution is 24 bits −0.05 uv, the bandwidth is 0 ~ 250 Hz, and the noise is less than 1uvrms (0 ~ 250 Hz).

2.4. Experimental indicators

In this study, seven indicators for the drivers' eye movement, EEG, and driving performance parameters were chosen for analysis: total fixation time, saccade frequency, blink frequency, EEG β-value, EEG θ-value, lateral deviation, and average speed. Table 2 presents the definition and explanation of the proposed indicators.

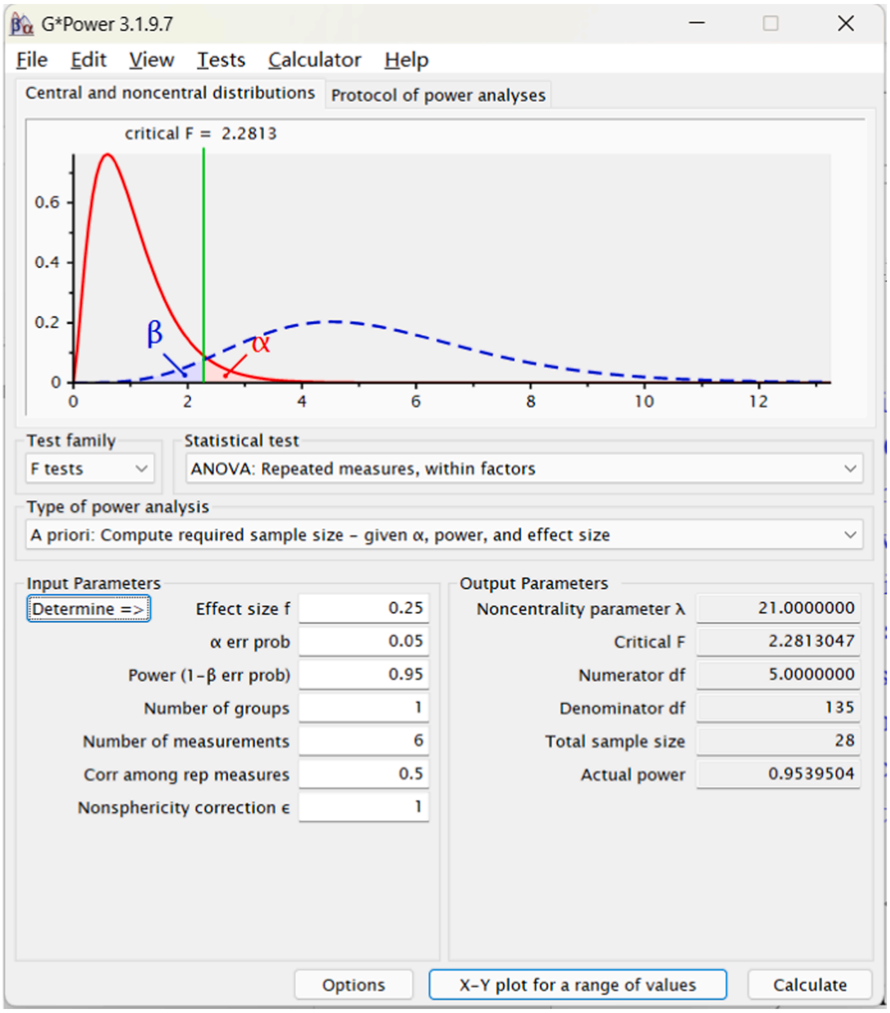


Fig. 5. Results of minimum sample size calculation.

Table 2
Indicators definition and representation content.

Category	Indicator	Unit	Indicator Definition
Eye movement Indicators	Total Fixation Time (*TFT*)	ms	The total fixation time refers to the sum of the driver 's fixation time on the guide sign for a certain period. In this study, the longer the driver 's gaze on the guide sign, the smaller the interference of the billboard.
	Scanning Frequency (*SF*)	Times/ SEC	The saccade frequency refers to the number of saccades within a unit of time for a specific area of interest. The more strongly the billboard affects the driver, the higher the saccade frequency. The saccade frequency is also highly negatively correlated with the target search efficiency.
	Blink Frequency (*BF*)	Times/ Min	Blink frequency refers to the number of blinks within a unit of time. Blink frequency can indicate a person's state of mind; it increases when people are tense and decreases when they are highly focused or relaxed.
EEG Indicators	*β-Value*	μv^2	The β-value indicates the normal and relaxed state of the driver. As the distraction effect increases, the activity of the β-value will increase (Lin et al., 2008).
	θ-Value	μv^2	The θ-value is related to attention and information processing, and it increases with the increasing working memory load and distraction effect (Lin et al., 2011).
Driving Performance Indicators	Lateral Deviation (*LD*)	m	Lateral deviation refers to the lateral offset of a driving vehicle to the road center line, and the larger the value, the worse the driver's control of the vehicle.
	Average Speed (*Speed*)	m/s	Speed refers to the average speed over some time.

2.5. Experimental procedure

The driving simulation cabin was used in this experiment. There was no outside noise interference while driving because the curtain was drawn in the testing room to block out changes in the exterior lighting environment. Before the trial, experimental roads, guide signs, and billboards were loaded. The following steps made up the bulk of the testing procedure:

1. To become accustomed to using the driving simulator, participants were trained for several minutes in a non-experimental setting before the experiment.
2. The participants were given a questionnaire to fill out with basic information and were informed of the destination of each driving experiment.
3. The participants wore study-related gear.
4. The order of the six experimental scenarios (Fig. 6) was randomized to prevent memory effects. Each participant was asked to operate a vehicle in all scenarios, and it takes about 40 to 50 min for a participant to complete the experiment. The participants may experience minor discomfort while wearing the EEG device. The trial could be stopped if the driver started to feel lightheaded or experience other uncomfortable symptoms.
5. The following person was prepared to enter the experimental area after the first had finished the experiment. This procedure persisted until all 32 volunteers had completed the scenarios.

2.6. Data processing

All experimental data were gathered between 100 m and 200 m in front of the guide sign (i.e., the position 1800 m-1900 m in Fig. 4). Among them, the TFT indicator requires creating an interest zone ((i.e. traffic sign) on the D-lab software, then manually extracting the total time the driver gazed at the interest zone. D-lab software gathers the driver's unit blink and scan times during the 1800 m–1900 m road section and uses them to compute the BF and SF indicators. Every 0.03 s, the dynamics module of the driving simulator records and exports raw driving behavior data (Speed & LD), and the final data is the driver's average value on the 1800 m–1900 m road stretch. EIC 2.0 software exports the original EEG data, which Matlab then processes. The processes techniques include filtering and re-referencing (low pass filtering, high pass filtering), ICA technology de-noising, EEG energy value data extraction (export the original data from the biosystem and import it into the EEG toolbox and then use EEG to remove the artifacts that still exists manually).

2.7. Matter-Element model

This study used three different types of data: eye movement, EEG, and driving behavior. In addition, this study used the ME model to thoroughly assess the outcomes of the six scenarios because these three sorts of data were incompatible. Cai (1994) proposed the ME model, which can standardize disparate signs and objectively assess how something looks. The following are its primary evaluation processes and duties:

Step 1: Standardize the indicator data. The standardization of data can help to intuitively compare the effect of data between various indicators. The standardization adopts the following formulas for the forward and reverse indices:

$$r_{ji}^{'} = \frac{r_{ji} - \min r_i}{\max r_i - \min r_i}(forwardindicator) \tag{1}$$

Fig. 6. Example of an experimental scenario.

$$r'_{ji} = \frac{\max r_i - r_{ji}}{\max r_i - \min r_i}(reverseindicator) \tag{2}$$

Step 2: Identify the ME model's classical field and section field. The matter element comprises things, features and feature values of things. That is, matter element = (things, feature names, and quantity values), which is recorded as R = (N, C, V). In this study, N stands for the experimental scheme, C for the experimental index, and V for the experimental indicator value, which can be expressed as:

$$R = \begin{pmatrix} N & C_1 & V_1 \\ & C_2 & V_2 \\ & \vdots & \vdots \\ & C_n & V_n \end{pmatrix} \tag{3}$$

Several levels are separated into the experimental scheme N, and matching levels are divided into the evaluation indicators C. The classical field is the value range of evaluation indicators C at various levels and is given by

$$R_i = \begin{pmatrix} N_i & C_1 & V_{i1} \\ & C_2 & V_{i2} \\ & \vdots & \vdots \\ & C_n & V_{in} \end{pmatrix} = \begin{pmatrix} N_i & C_1 & \langle a_{i1}, b_{i1} \rangle \\ & C_2 & \langle a_{i2}, b_{i2} \rangle \\ & \vdots & \vdots \\ & C_n & \langle a_{in}, b_{in} \rangle \end{pmatrix} \tag{4}$$

where N_i is the divided i evaluation grades, C_1, C_2,..., C_n refers to n evaluation indicators, Vi_1, Vi_2 Vi_n is the value range (classical field) of the ith evaluation grade corresponding to the indicators. Then, the section field is the total value range of all evaluation levels of evaluation indicator C, which is expressed as

$$R_p = (P, C, V_P) = \begin{pmatrix} P & C_1 & V_{P1} \\ & C_2 & V_{P2} \\ & \vdots & \vdots \\ & C_n & V_{Pn} \end{pmatrix} = \begin{pmatrix} P & C_1 & \langle a_{P1}, b_{P1} \rangle \\ & C_2 & \langle a_{P2}, b_{P2} \rangle \\ & \vdots & \vdots \\ & C_n & \langle a_{Pn}, b_{Pn} \rangle \end{pmatrix} \tag{5}$$

where P is the overall evaluation grade, V_{p1}, V_{p2}, ..., V_{pn} are the value range (section field) of all evaluation grades corresponding to evaluation indicators. This study uses the K-means clustering method to determine each indicator's classical and section field (Xiao et al., 2018).

Step 3: Determine the weight coefficient of the evaluation indicators. The Shannon entropy, which measures the quantity of information in data using probability theory, was suggested to measure ambiguous information (Shannon, 1948). The entropy weight method determines the weight because the experimental data are all quantitative. The pertinent equation is as follows:

$$W_i = \frac{1 - H_i}{n - \sum_{i=1}^{n} H_i} \tag{6}$$

where H_i represents the information entropy of the ith indicator data.

Step 4: Calculate the correlation function. Correlation function K_{ij} reflects the closeness between the matter element to be evaluated and the classical field:

$$K_{ij} = \begin{cases} \dfrac{-\rho(V_i, V_{ij})}{|V_{ij}|}, & V_i \in V_{ij} \\ \dfrac{\rho(V_i, V_{ij})}{\rho(V_i, V_{ip}) - \rho(V_i, V_{ij})}, & V_i \notin V_{ij} \end{cases} \tag{7}$$

where,

$$\rho(V_i, V_{ij}) = \left| V_i - \frac{a_{ij} + b_{ij}}{2} \right| + \frac{a_{ij} - b_{ij}}{2} \tag{8}$$

$$|V_{ij}| = |b_{ij} - a_{ij}| \tag{9}$$

$$\rho(V_i, V_{ip}) = \left| V_i - \frac{a_{ip} + b_{ip}}{2} \right| + \frac{a_{ip} - b_{ip}}{2} \tag{10}$$

where a_{ij} and b_{ij} is the endpoint value of $V_{ij} = [a_{ij}, b_{ij}]$, a_{ip} and b_{ip} is the endpoint value of $V_{ip} = [a_{ip}, b_{ip}]$.

Step 5: Calculate the correlation degree between the matter element to be evaluated and each grade, and determine the final evaluation grade. The correlation degree between the matter elements to be evaluated and the various levels is computed using the correlation function K_{ij} and evaluation index weight W_i mentioned above:

$$K_j(P) = \sum_{i=1}^{n} W_i K_{ij} \tag{11}$$

The final evaluation level is the one with the highest correlation rate:

$$K_{j0}(P) = \max_{j \in \{1,2,\cdots,m\}} K_j(P) \tag{12}$$

where $K_{j0}(P)$ is the comprehensive correlation degree of the evaluation grade, j_0 is the result of the evaluation grade, and m represents the number of levels.

3. Data analysis

Following initial data processing and testing, the 7 data items from 32 subjects across 6 scenarios were reliable and used in the ensuing two-factor repeated measurement analysis of variance and ME model. The two-factor repeated measurement analysis of variance was conducted using the SPSS 26.0 program. Almost each data set passed the normality test and did not contain any outliers, according to the findings of the data outliers and normality tests. Next, the sphericity hypothesis was examined using Mauchly's Test of Sphericity. The significance-test results were based on the Sig value, where the *LD* indicator was corrected using the greenhouse method. The Sig value under the sphericity hypothesis was used to identify interaction because all interaction terms for all indicators in this experiment satisfied the sphericity hypothesis. Since the billboard relative position variable only has two levels, verifying its sphericity is unnecessary. The hypothesis sphericity test of the advertising size variable and the interaction of the two variables and the interaction test are shown in Table 3. Note that *size* represents the advertising specification variable, and *position* represents the relative position variable.

3.1. Eye movement data analysis

3.1.1. Total fixation time

As can be seen in Tables 3 and 4, there is no interaction between the two variables ($F = 0.916$; $P = 0.405$), but both variables' within-subjects effects are significant ($F = 12.407$, $P < 0.001$; $F = 45.816$, $P < 0.001$). The Within-Subject Effects test reveals that both variables significantly affect the total fixation time. The paired test indicates a substantial difference between small and large-sized billboards (Mean Difference (MD) = -30.344, $P < 0.001$), but not between small and medium-sized ones (MD = -3.750, $P = 1.000$). The driver's total fixation time is smaller when the billboard is in front of the sign rather than behind it (MD = –33.854, $P < 0.001$). Overall, the driver's total fixation time increases when the billboard size increases, as shown in Fig. 7(a).

3.1.2. Scanning frequency

Tables 3 and 4 show that the billboard size and relative position substantially impact the saccade frequency ($F = 4.595$, $P = 0.014$; $F = 11.004$, $P = 0.002$), although there is no interaction between the two factors ($F = 0.052$, $P = 0.949$). The drivers' saccade frequency in various situations exhibits a law of decreasing frequency with increasing billboard size. Additionally, the frequency of drivers' saccades is much higher in the small-size billboard scenario than in the medium-size and large-size billboard scenarios (MD = 0.085, $P = 0.050$; MD = 0.097, $P = 0.015$). The drivers' saccade frequency in the front of the billboard scenario is significantly higher than that in the rear (MD = 0.09, $P = 0.002$), as shown in Fig. 7(b).

3.1.3. Blink frequency

Tables 3 and 4 also demonstrate that the blink frequency indicator's two variables do not interact ($F = 0.131$, $P = 0.878$). However, when the driver identifies the billboard and the signboard simultaneously, the two factors substantially impact the blink frequency, according to the Within-Subject Effects test of the two variables ($F = 25.976$, $P < 0.001$; $F = 94.988$, $P < 0.001$). The paired comparison showed that the blink frequency of the small and medium billboard scenarios is significantly greater than that of large ones (MD = 4.115, $P < 0.001$; MD = 3.101, $P < 0.001$). The drivers' blink frequency is also considerably higher in the scenarios in front of the sign

Table 3
Sphericity test results and interaction test results.

Indicator	Mauchily's Test of Sphericity		Two-Variable Interaction Test	
	Inspection item	Sig.	F	Sig
TFT	*Size*	0.787		
	*Size*Position*	0.149	0.916	0.405
SF	*Size*	0.422		
	*Size*Position*	0.236	0.052	0.949
BF	*Size*	0.848		
	*Size*Position*	0.228	0.131	0.878
β-Value	*Size*	0.885		
	*Size*Position*	0.098	0.372	0.691
Θ-Value	*Size*	0.724		
	*Size*Position*	0.353	1.319	0.275
LD	*Size*	0.018		
	*Size*Position*	0.078	0.002	0.998
Speed	*Size*	0.441		
	*Size*Position*	0.933	0.015	0.985

Table 4a
Within-subject effect of eye movement and EEG parameters.

Test of Within-Subjects Effects						
Indicator	Variable	Variable Level	Mean	F	Sig. [a]	η^2
TFT	*Size*	Small	818.875	12.407	0.001*	0.286
		Medium	822.625			
		Large	849.219			
	Position	Front	813.313	45.816	0.001*	0.596
		Rear	847.167			
SF	*Size*	Small	0.710	4.595	0.014*	0.129
		Medium	0.625			
		Large	0.612			
	Position	Front	0.694	11.004	0.002*	0.262
		Rear	0.604			
BF	*Size*	Small	26.647	25.976	0.001*	0.456
		Medium	25.633			
		Large	22.532			
	Position	Front	26.966	94.988	0.001*	0.754
		Rear	22.909			
β-Value	*Size*	Small	248.717	10.711	0.001*	0.257
		Medium	241.741			
		Large	216.071			
	Position	Front	263.312	99.374	0.001*	0.762
		Rear	207.707			
θ-Value	*Size*	Small	348.553	13.066	0.001*	0.297
		Medium	329.012			
		Large	302.772			
	Position	Front	351.355	35.734	0.001*	0.535
		Rear	302.203			

[a] An asterisk indicates that the variable is statistically significant.

Table 4b
Paired test of eye movement and EEG parameters.

Paired Test					
Indicator	Pair	Mean Difference	Sig. [a]	95 % CI	
				LB	UB
TFT	S & M	−3.750	1.000	−21.535	14.035
	S & L	−30.344	0.001*	−46.941	−13.747
	M & L	−26.594	0.001*	−42.594	−10.594
	F & R	−33.854	0.001*	−44.055	−23.653
SF	S & M	0.085	0.050*	−0.0002	0.170
	S & L	0.097	0.015*	0.016	0.179
	M & L	0.012	1.000	−0.086	0.110
	F & R	0.090	0.002*	0.035	0.146
BF	S & M	1.014	0.245	−0.412	2.440
	S & L	4.115	0.001*	2.581	5.648
	M & L	3.101	0.001*	1.546	4.655
	F & R	4.057	0.001*	3.208	4.906
β-Value	S & M	6.976	1.000	−12.250	26.203
	S & L	32.646	0.001*	13.432	51.860
	M & L	25.669	0.003*	7.734	43.605
	F & R	55.605	0.001*	44.229	66.982
θ-Value	S & M	19.541	0.076	−1.530	40.613
	S & L	45.780	0.001*	21.915	69.646
	M & L	26.239	0.022*	3.031	49.447
	F & R	49.152	0.001*	32.382	65.922

[a] An asterisk indicates that the variable is statistically significant.

than it is in the scenarios behind the sign (MD = 4.057, P < 0.001) at the same time, as shown in Fig. 7(c).

3.2. EEG data analysis

3.2.1. β-value

There is no interaction between the two factors (F = 0.372, P = 0.691), as shown in Tables 3 and 4. However, the two variables substantially impact the *β-value* in the within-subjects effects (F = 10.711, P < 0.001; F = 99.374, P < 0.001). The paired comparison

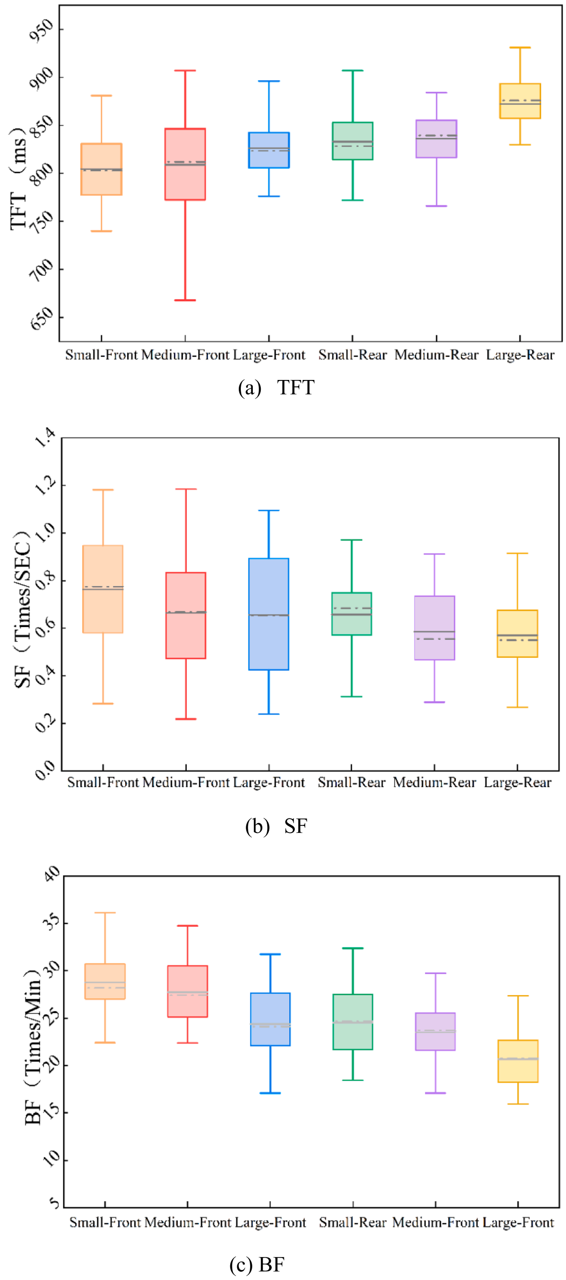


Fig. 7. Boxplot of eye movement data in different scenarios.

test reveals that the *β-value* is considerably higher when the drivers are exposed to small and medium-sized billboards than large billboards (MD = 32.646, P < 0.001; MD = 25.669, P = 0.003). In addition, the EEG *β* value decreases as the billboard size increases. The *β-value* in the scenario in front of the sign is significantly greater than in the scenario behind the sign (MD = 55.605, P < 0.001), as shown in Fig. 8(a).

3.2.2. *θ-value*

There is no interaction between the two factors (F = 1.319, P = 0.275), as indicated in Tables 3 and 4, but the within-subjects effects test reveals that the two variables significantly affect the *θ-value* (F = 13.066, P < 0.001; F = 35.734, P < 0.001). According to the paired-comparison test, the *θ-value* is significantly higher for small and medium-sized billboards than for large billboards (MD = 45.780, P < 0.001 ; MD = 26.239, P = 0.022), and it decreases as the size of the billboard increases. In addition, the *θ-value* when the billboard is in front of the sign is significantly greater than when it is behind (MD = 49.152, P < 0.001), as shown in Fig. 8(b).

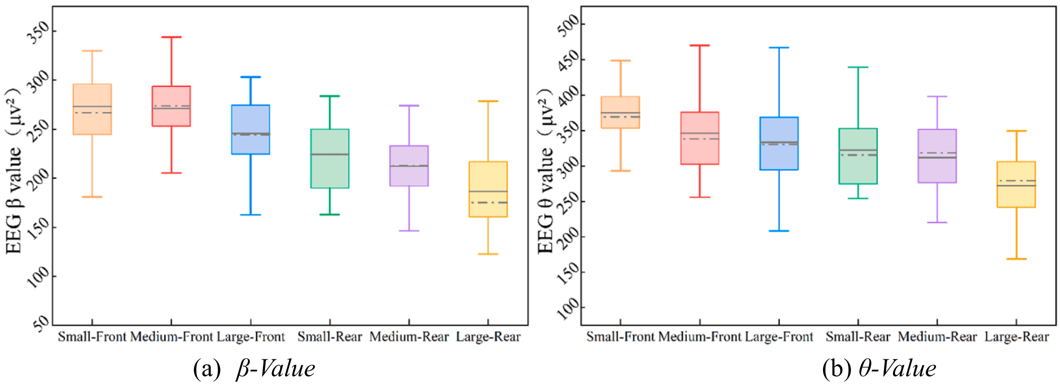


Fig. 8. Boxplot of EEG data in different scenarios.

3.3. Driving performance analysis

3.3.1. Lateral deviation

There is no interaction between the two variables (F = 0.002, P = 0.998), and no discernible impact on lateral deviation (F = 0.330, P = 0.675; F = 1.085, P = 0.306), as indicated in Tables 3 and 5. The table shows, however, that the drivers all experienced a significant lateral deviation (the minimum is 1.644) and that the lateral deviation brought on by the billboard placed in front of the sign is greater.

3.3.2. Speed and deviation

There is no interaction between the two factors (F = 0.015, P = 0.985), as indicated in Tables 3 and 5. However, the position variable significantly affects the speed in the within-subjects effects test (F = 9.590, P = 0.004). The speed when the billboard is set in front of the sign is greater than the speed of the driver when the billboard is set behind the sign. Fig. 9 shows the changes in speed in the 1500–2100 m segment.

4. Evaluation results of ME model

4.1. The calculation results of each step

Step 1 Results: Different dimensional indicator data were transformed into dimensionless data between 0 and 1. The original indicator data is better when the value is close to 1. The effect is better when the speed indication is neither large nor small. As a result, the speed indication is not used in ME model evaluation. Instead, the evaluation data was produced from the 32 participants' averages of their other factors. The outcomes of standardizing several metrics for each of the six situations are shown in Table 6.

Step 2 Results: Five levels were used in this study: Excellent (E), Great (G), Fair (F), Poor (P), and Worst (W). Table 7 displays the K-means clustering method's results for each indicator's classical and section field.

Step 3 Results: Table 7 displays the weight value for each indicator as determined by the entropy weight technique.

Step 4 Results: Fig. 10 shows the six scenarios' most appropriate levels and correlation values for various indicators.

Step 5 Results: The final evaluation grade of each scenario and its correlation with each level are shown in Table 8 below.

Table 5
Within-subject effect and value of lateral deviation and speed.

Within-Subjects Effects Test					Lateral Deviation Value		
Indicator	source	F	Sig. [a]	η^2	Scenario	Mean	SD
LD	*Size*	0.330	0.675	0.011	1	1.791	0.480
					2	1.716	0.549
					3	1.717	0.433
	Position	1.085	0.306	0.034	4	1.710	0.403
					5	1.644	0.763
					6	1.646	0.438
Speed	*Size*	1.314	0.276	0.041	1	117.9	9.930
					2	115.7	8.992
					3	114.8	9.134
	Position	9.590	0.004*	0.236	4	114.1	8.669
					5	112.4	9.261
					6	111.3	9.356

[a] An asterisk indicates that the variable is statistically significant.

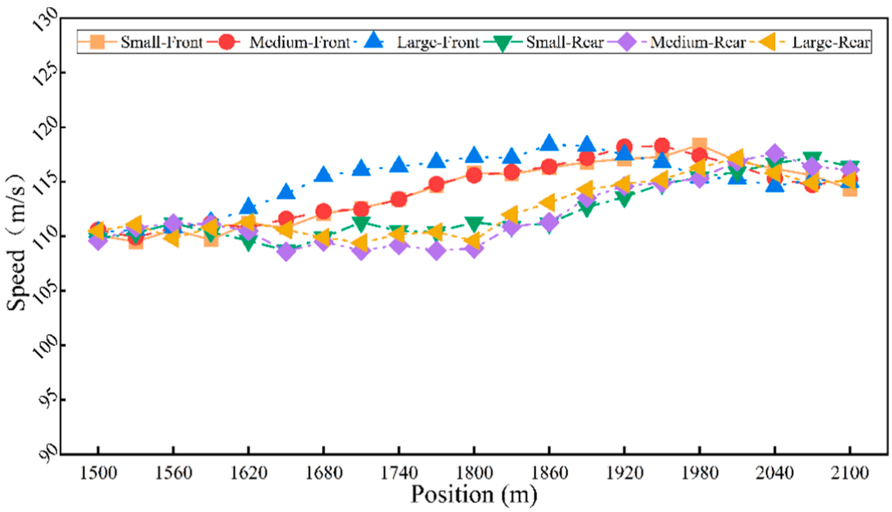


Fig. 9. Speed variation in different scenarios.

Table 6
Standardization results of indicator data.

Indicator	Set in Front			Set at Rear		
	Small Size	Medium Sze	Large Size	Small Size	Medium Size	Large size
TFT	0.519	0.536	0.602	0.628	0.639	0.776
SF	0.433	0.534	0.543	0.542	0.616	0.631
BF	0.364	0.414	0.581	0.574	0.624	0.764
β	0.490	0.496	0.583	0.655	0.696	0.783
θ	0.317	0.412	0.454	0.490	0.525	0.657
LD	0.551	0.573	0.573	0.575	0.595	0.594

Table 7
Weights and division of classical and sectional fields of each indicator.

Indicator	Classical Field Value					Segment Field	Weight
	Worst	Poor	Fair	Good	Excellent		
TFT	[0–0.184]	[0.184–0.451]	[0.451–0.591]	[0.591–0.740]	[0.740–1]	[0–1]	0.217
SF	[0–0.200]	[0.200–0.393]	[0.393–0.574]	[0.574–0.759]	[0.759–1]	[0–1]	0.118
BF	[0–0.291]	[0.291–0.471]	[0.471–0.603]	[0.603–0.766]	[0.766–1]	[0–1]	0.168
β	[0–0.265]	[0.265–0.475]	[0.475–0.604]	[0.604–0.752]	[0.752–1]	[0–1]	0.231
θ	[0–0.217]	[0.217–0.388]	[0.388–0.536]	[0.536–0.707]	[0.707–1]	[0–1]	0.143
LD	[0–0.364]	[0.366–0.520]	[0.520–0.645]	[0.645–0.781]	[0.781–1]	[0–1]	0.123

4.2. Comprehensive evaluation analysis

As shown in Table 8, the value range of correlation degree between experimental scenarios and each evaluation level is (-1, 1), and the final evaluation level is the evaluation level corresponding to the highest correlation degree value among all evaluation levels. The closer a value is to 1, the stronger the correlation is with the final evaluation level when the correlation degree of the last evaluation level is (0,1). When the correlation degree of the final evaluation level is (-1, 0), the closer the value is to 0, the closer it is to the ultimate evaluation level. Still, it needs to be set up to the evaluation level. When two scenarios are evaluated at the same evaluation level, their relative benefits and drawbacks are assessed about their relative separation from the evaluation level's surrounding level. For example, the Medium-Rear and Large-Rear scenarios are both in the "G" level. However, the Large-Rear scenario is superior to the Medium-Rear scenario because it is closer to the "E" level and farther from the "F" level. The order of the six scenarios is Large-Rear > Medium-Rear > Small-Rear > Large-Front > Medium-Front > Small-Front.

5. Discussion

When billboards appear near signs, drivers' attention will be diverted by billboards, putting their safety at risk. In this case, the

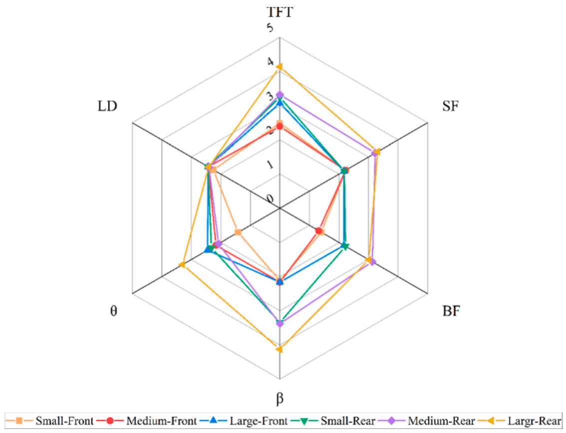


Fig. 10. Correlation level of different indicators of 6 scenes.

Table 8
Correlation between the scheme and evaluation grade and final evaluation grade.

Alternative	Correlation Degree of Alternatives					Evaluation Level of Alternatives
	Excellent	Good	Fair	Poor	Worst	
Small-Front	−0.408	−0.247	0.125	0.076	−0.302	F
Medium-Front	−0.360	−0.177	0.204	−0.039	−0.341	F
Large-Front	−0.303	−0.051	0.196	−0.203	−0.420	F
Small-Rear	−0.275	0.085	0.107	−0.250	−0.450	F
Medium-Rear	−0.240	0.189	−0.040	−0.315	−0.498	G
Large-Rear	−0.062	0.007	−0.274	−0.485	−0.621	G

visual impact of billboards and their position are the two key variables that cause drivers to get distracted. Even though these two factors have been the subject of several studies, most required that the billboard be erected separately. In agreement with Schieber et al. (2014), Chapman and Underwood (1998) claim that the billboard appears to draw attention due to its proximity to other vehicles, traffic lights, and direction signs. Information about road traffic is frequently provided through traffic signs. The effect that billboards have on drivers is especially significant when they are placed close to traffic signs. In this study, a driving simulator, an eye tracker, and an electroencephalograph were used to gather pertinent data to analyze the effects of billboard size and relative position to the traffic signs on the drivers' ability to see traffic signs and their driving behavior. In the end, SPSS analysis was performed on 7 data items collected from 32 subjects across 6 different scenarios. All of these data were valid following preliminary testing. The P-value of 0.05 was employed as the significance threshold in SPSS data analysis. The two variables significantly affect drivers' total fixation time on the guidance sign, blink frequency, saccade frequency, EEG, and average speed, according to the SPSS data analysis. There is a chance of false positives in the significance conclusions of the Speed and SF indicators if family-wise error is considered and the P-value is corrected using the Bonferroni method. Still, this chance is small because the law reflected in the significance conclusions of the Speed and SF indicators follows the law of other significance indicators. That is, the larger billboards and the fact that they are mounted behind the signs make it easier for the driver to maintain concentration and control of the car. Although the lateral deviation indicator for different levels of variables does not significantly change, the lateral deviation value for each scenario is greater than 1.6 m. According to the paired comparison test, there is always a significant difference between different billboard sizes. The six scenarios' impacts on drivers were ranked after the results of the ME model were thoroughly reviewed.

5.1. Billboard size

This study draws a reasonably consistent result from the experimental data of drivers exposed to various billboard sizes: when the billboard is placed near the sign, the larger the billboard size, the less disturbance to drivers. The following elements, in particular, represent this conclusion: In the billboard greater size scenario, the driver's fixation time on the guide sign is longer, their blink and saccade frequency are lower, their β and θ*-values* were lower, while in the smaller-size scenario, the driver's indicator is poorer. This experimental finding differs from the finding by (Hughes & Cole, 1984; Wilson & Casper, 2016; Zalesinska, 2018) but supports those of (Li et al., 2011), who asserted that billboard settings should be large.

In this experiment, when a billboard is placed next to a traffic sign, the impact of large-size billboards on drivers is less than that of small-size billboards, possibly because billboards of different sizes provide different recognition distances to drivers. The larger the size of the billboard, the farther away the driver can recognize the billboard (Costa et al., 2019). As a result, drivers are less affected when they recognize the guide sign because they are more aware of the large-size billboards and have even finished doing so before they recognize the guide sign. However, the recognition distance of the small-size billboards is shorter, making the road sections that recognize small-size billboards more coincident with those that recognize guide signs. The impact of the billboards and signs competing for the drivers' limited recognition resources is also more apparent (Hübner & Bennemann, 1973), which worsens the driver's indicators in situations with small-size billboards. So, to avoid impairing driver's visual recognition of the sign and ability to control safe driving due to the unclear identification of the small billboard, the driver should consciously divert his attention to the sign when he comes across one while driving.

5.2. Billboard position

The effects of the relative positions of billboards and signs on several indicators in this investigation are similarly consistent: when a billboard is placed next to a traffic sign, the total fixation duration, saccade frequency, blink frequency, β and θ-*values*, and lateral deviation values are better in the scenario behind the billboard is positioned in the sign. The cause might have something to do with the order in which drivers notice signs and billboards. The "monitoring process" (unconscious mode) and the "operational process" (conscious involvement), according to Charlton & Starkey (2011), affect the driving state. Unconscious processes need less cognitive effort, but "operational processes" demand more mental effort. If there is a billboard in front of a guide sign, the driver will initially use some of his cognitive resources to notice the billboard before recognizing the guide sign. Continuing to see the guidance sign exerts a heavier load because the driver is in the "operation process" condition. The driver is in the 'monitoring mode' of the surrounding environment before the guide sign is recognized, and the recognition load is low if the billboard is placed behind the guide sign. The impact on the driver is lessened since by the time the billboard reappears, the driver has fully or partially recognized the guide sign.

5.3. Speed indicator

Surprisingly, the circumstance that this experiment's speed indicator reflects might not match what other indications show. The TCI model predicts that as the driving demand rises, the driver will slow down to ensure it is lower than the driving ability (Edquist et al., 2012), and the speed will decrease as the driving demand rises (Fuller, 2011). According to the TCI hypothesis, the driver's driving demand or load is higher in the study's large-size billboard scenarios and scenarios where the billboard is positioned behind the guide sign since they involve slower driving speeds. The eye movement and EEG data, however, indicated that large billboards behind the guide signs had less impact on drivers, contradicting the findings of the speed indicator under the TCI theory. In contrast to the TCI model's view that slower speeds represented a more significant burden on drivers, some studies also made the case that slower average speeds meant safer driving (Meuleners et al., 2020). From this perspective, the experiment's speed indicator made sense with other indicators. Since the *Speed* indicator can represent contradictory circumstances from different perspectives, it was not chosen for the thorough evaluation in this paper.

5.4. Matter-element model evaluation

After thoroughly evaluating all relevant factors, the six scenarios' influence on the driver is found in the following order: Large-Rear, Medium-Rear, Small-Rear, Large-Front, Medium-Front, and Small-Front. When the billboard is placed on the same side as the guide sign, the impact of the large-size billboard on the driver is always less than the small-size billboard. We can see that the comprehensive evaluation results of the three scenarios placed behind the guide sign are in the top three of the six scenarios, while those of the three scenarios placed in front of the guide sign are in the bottom three. The research conclusion by Wilson & Casper (2016) that the impact of the location of billboards on drivers is stronger than the visual salience of billboards themselves is supported by this finding, which shows that the effect of the relative location of billboards and signs on drivers is stronger than the impact of the size of billboards on drivers. Therefore, based on the thorough analysis, we can take the following conclusion: First, more than the size of the billboard, the relative position of the signboard and the billboard has a greater impact on the driver; Second, the driver is less affected by the billboard placed behind the sign than by the one placed in front of them. Third, the larger the billboard size, the smaller the impact on the driver.

Several valuable recommendations for preventing accidents based on the overview of the prior literature and the findings of this study can be summarized. First, billboards should be kept as far away from signs as feasible because their proximity to them would cause additional driving distractions for drivers (Mollu et al., 2018). Second, when planning the actual placement of the billboard, if it is difficult to avoid having one placed next to the sign, make sure it is placed after the sign and choose a huge billboard (8 m x 24 m). Finally, suppose the drivers discover a small billboard close to the sign or the billboard is set in front of the sign. In that case, they should consciously focus on the sign while slowing down and maintaining the vehicle's lateral stability. This would ensure smooth visual recognition of the sign and the safe control of the vehicle.

6. Conclusions

This study conducted a driving simulation experiment and collected participant eye movement, EEG, and driving performance data to examine the impact of billboard size and its relative position on drivers when billboards are positioned close to significant signs. Based on this study, the following conclusions were drawn:

1. When the billboards and signs appear close together, the billboard size significantly influences the driver's ability to recognize the signs and the driving behavior, and the impact is higher for the smaller billboards. In addition, the billboard relative position significantly affects how the drivers recognize the signs and behave while driving. The driver is more affected by the billboard's placement in front of the signboard.
2. The ME model results show that when the billboards and signs appear next to one another, although the drivers will be impacted by the billboard size and relative position, the influence of the relative position is greater.
3. The study clarified the effects of the billboard size and the billboard front and back positions on the drivers. The findings suggest that when a billboard is placed close to a sign, it should be placed behind it by first considering their relative positions. Second, we should make an effort to select large-scale billboards. To lessen the impact of visual signs, try to position the billboard as far away from the sign as possible. The driver should remain alert and focus on the sign while slowing down and maintaining the stability of the vehicle's lateral displacement if they are distracted by the billboard when recognizing the sign, particularly if the billboard is blurred due to its size and location. The findings of this study are expected to help formulate pertinent legislation and offer recommendations for placing billboards in complex traffic conditions.
4. This study has three limitations. First, this study's sample size and age range were constrained by the COVID-19 outbreak in China, which resulted in the recruitment of just 32 university students. Although the minimal sample size requirement was satisfied, increasing the sample size could still lessen the likelihood of false positives brought on by family-wise error, improving the scientific rigor of the findings. The age range of the subjects in this study ranged from 22 to 27 years due to the recruitment of college students, and there is a lack of participation from other age groups, so the research findings from this experiment may only apply to Chinese college students. Therefore, to make this study more inclusive, recruiting more subjects and broadening their age distribution is essential. Second, out of the 32 participants, 16 were males and 16 were females, which is not representative of the gender distribution of the driving population in China. The effect of billboards on drivers can be further examined from the perspective of different gender ratios. Third, this study only considered the location between a single billboard and a single sign. However, more complex issues could arise in real-world situations, such as billboard placement in areas with many billboards and signs. Future studies might examine how to lessen billboards' effect in such circumstances.

Ethical statement.

This research complied with the American Psychological Association Code of Ethics and was approved by the Institutional Review Board, College of Civil Engineering at Fuzhou University. All participants signed the informed consent.

CRediT authorship contribution statement

Yanqun Yang: Conceptualization, Funding acquisition, Supervision. **Xianhui Liu:** Writing – original draft, Methodology, Project administration. **Said M. Easa:** Writing – review & editing, Validation, Supervision. **Lina Huang:** Writing – review & editing. **Xinyi Zheng:** Writing – review & editing, Supervision, Validation.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Data availability

Data will be made available on request.

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