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Research Article

Threshold Research on Highway Length under Typical Landscape Patterns Based on Drivers' Physiological Performance

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The appropriately landscaped highway scenes may not only help improve road safety and comfort but also help protect ecological environment. Yet there is very little research data on highway length threshold with consideration of distinctive landscape patterns. Against this backdrop, the paper aims to quantitatively analyze highway landscape's effect on driving behavior based on drivers' physiological performance and quantify highway length thresholds under three typical landscape patterns, namely, "open," "semiopen," and "vertical" ones. The statistical analysis was based on data collected in a driving simulator and electrocardiograph. Specifically, vehicle-related data, ECG data, and supplemental subjective stress perception were collected. The study extracted two characteristic indices, lane deviation and LF/HF, and extrapolated the drivers' U-shaped physiological response to landscape patterns. Models on highway length were built based on LF/HF's variation trend with highway length. The results revealed that the theoretical highway length threshold tended to increase when the landscape pattern was switched to open, semiopen, and vertical ones. And the reliability and accuracy of the results were validated by questionnaires and field operational tests. Findings from this research will assist practitioners in taking active environmental countermeasures pertaining to different roadside landscape patterns.

1. Introduction

The roadside landscape, particularly those in monotonous areas, can impact driving behavior and have a restorative effect on crash reducing, speed lowering, or traffic calming in the complex driving process [1–4]. Previous research has identified that road landscape improvements along the arterial road reduced the accidents by 5% to 20% [5]. Compared to other types of landscapes, the monotonous landscape is simpler, which can be more frequently seen on highways. But a long and straight highway with monotonous landscape patterns may trigger drive fatigue, deteriorate driving alertness, and prolong cognitive information processing [6]. That may become a potential hazard to safety driving.

Then, when the monotonous landscape environment is unavoidable to travel in, what is the optimal trip length to inspire the driver's best performance? The Yerkes-Dodson law [7], an empirical law between arousal level and performance, dictates that performance increases with physiological or mental arousal, but only up to a point. When levels of arousal become too high, performance decreases. The relationship between the two variables is generally illustrated graphically as a curvilinear, inverted U-shaped curve, whose turning point is named as the critical arousal level. And studies show

that the physiological or mental arousal level has strong correlation with the trip length in transportation field. The critical trip length threshold is a criterion to assess the safety performance of roadside landscape patterns. Knowledge of the critical trip length threshold is critical to the design of roadside landscape patterns. When designing a landscape pattern, it is necessary to investigate driver's physiological performance to the landscape pattern and quantify highway length threshold under typical landscape patterns considering the drivers' physiological characteristics.

As a result of the literature review, few past studies have been found to take the aforementioned physiological performance into specific consideration when designing a roadside landscape pattern. There is also a lack of research efforts that focus on the landscape's spatial pattern heterogeneity while calculating highway length threshold. However in practice, spatially analysis of landscape patterns at various scales can help reveal driver's ergonomic response process, which is critical for accurate calculation of length threshold [8].

To address the aforementioned issues, this paper aims at quantitatively investigating the effects of roadside landscape patterns on driving behavior. Particularly, the monotonous landscape patterns were spatially classified into the open, semiopen, and vertical patterns. These patterns were commonly used on highways in China. The specific objectives are listed as follows:

(i) Extrapolate the ergonomic response mechanism to the three landscape patterns.

(ii) Quantify the respective theoretical trip length thresholds for the three landscape patterns.

(iii) Verify the simulator-based theoretical length threshold through a field driving test.

2. Literature Review

2.1. Ergonomic Response Research to Landscape Patterns. Previous studies have affirmed the landscape improvements on driver performance. Those studies were via the field tests, indoor video watching, figure-viewing, or simulator studies. Drivers explain their feelings on the viewing landscape by self-reported questionnaires, or vehicle-related data, such as crashes, violation errors, speed, wheel, and lane deviation. For instance, Parsons et al. found that those drivers who encountered natural landscape displayed a significant reduced physiological stress, compared with those drivers who viewed built settings in a self-reported figure-viewing test [9]. Antonson et al. conducted a simulator study to quantize the landscape's influence on driver performance, by measuring the objective speed, lane deviation, and questionnaire. The results showed that landscape seemed to be relevant to traffic safety [6]. Mok et al. [10] found a significant decrease in crash rate after landscape improvements on either urban arterials or state highways via before-and-after field studies. Thiffault and Bergeron [11] found that a more frequent large steering wheel movement appeared in the driving process in the monotonous road environment via a simulator study. Those findings confirm that the environmental landscape along the transportation corridors affects the operators' extrinsic performance. But few studies quantize the landscape's effect on driver's physiological performance, which is intrinsic to trigger the extrinsic performance on vehicle behaviors or self-reports.

To further quantize the landscape's effect on a driver, his/her physiological performance is detected, which is the intrinsic factor to trigger his/her self-reports or the vehicle's operational performance. Those studies were conducted via the broad usage of simulators and physiological devices. The aim was to measure drivers' physiological performance, such as the heart behavior [12], brain activity [13], eye movement [14], or face expression [15]. Among these parameters, the heart behavior measurement is more popular. It is preferred due to its relative insulation of body contact interference, and the acuity and sensitivity to any mental performance instigated by driving task and situational conditions [14]. For instance, Mehler et al. [13] used the sensitivity of heart rate to measure the mental workload and confirmed its usage in product design in a simulated driving environment. This finding inspired the usage of the heart behavior measurement in ergonomic response research on landscapes. For instance, Antonson et al. [16] investigated the effect of landscape heritage objects on driving performance in a simulator by using the heart rate index. Significant difference was found in drivers' excitement or stress, which was induced by roadside landscape. Zhao et al. [17] also used the index heart rate to investigate the monotonous landscape's effect mechanism on driving fatigue via a simulator study. A sharp decrease was found in drivers' heart rate when the trip time was prolonged to 2 hours.

And the ergonomic response to landscapes in its intrinsic pattern features has been further investigated until now. However, only a few studies have been done to give the theoretic classification on the landscape unit. For instance, Wei [18] proposed treating the landscape as consecutive dynamic units and developed several classifications on its spatial pattern, sequence array, and environmental complexity. However, in the past research, the ergonomic responses to landscape patterns were not quantified. The most recent study started to fill in this research gap. For instance, Antonson et al. [6] studied drivers' responses to those landscape units featured with different spatial patterns. And the result found that various landscape patterns affected driving behavior substantially. In particular, in the open landscape, drivers drove faster, with a larger lane deviation. Chen et al. [19] assumed that a landscape pattern in different conspicuity would bring different visual quality to drives and conducted a simulator study to verify the assumption. The results confirmed the assumption and proposed quantitative contour and size for the landscape pattern.

2.2. Critical Length Threshold Research Based on Workload. It was found that there is a lack of research on the landscape's trip length threshold. Most of the existing findings on trip length threshold were based upon the empirical analysis, without consideration of the distinctive spatial patterns of landscape unit. For instance, Zhao et al. [17] concluded that the time threshold in the monotonous landscape was 5

(a) (b)

Figure 1: Experiment devices. (a) Driving simulator. (b) Electrocardiogram.

minutes, at the speed of 60 km/h, without consideration of the landscape's spatial patterns. Wei [18] only empirically indicated that the rational length of one monotonous landscape should be referred to in their distinctive unit features. A New Zealand study [20] empirically concluded that there should be landscape stimuli every 5 minutes' length during the trip to keep drivers away from fatigue.

Despite the limited literature on the length threshold, the close connection between workload and behavior performance may provide a reference for analyzing the critical trip length. Workload response is documented for all driving experiences, though intensity varies depending on road and traffic conditions. For instance, Mehler et al. [12] examined the effect of daytime workload on drivers' physiological arousal levels and task performance. The results showed that the increased levels of workload would induce a higher physiology arousal demand and a lower task performance. Kontogiannis [21] pointed out that stressed operators could not achieve their optimal performances in complex task environments. Brookhuis and Waard [22] found that the task performance showed a downward U-shaped relationship with mental workload. Tijerina et al. [23] examined the driver response to a sudden collision under several workload levels. The results showed that drivers were sensitized to an increased driving demand. Mehler et al. [24] conducted an actual highway driving test and collected heart rate and heart rate variability under different workload levels. The results showed that the physiological measures may be most useful and complementary for detecting different aspects of workload and mental state.

3. Method

To investigate the ergonomic response to various monotonous landscape patterns, a simulator experiment was held.

3.1. Participants. Thirty-five participants were recruited with no prior knowledge of the study. The selection criteria were as follows: healthy male or female; licensed drivers who have more than three years' experiences and drive at least 5,000 km annually; normal or corrected-to-normal vision above 1.0; dominant right-hand; beingaged 20–40 years. The age ranged was limited to 20~40 in order to mitigate the significant aesthetic difference or perception difference caused by age difference.

3.2. Apparatus

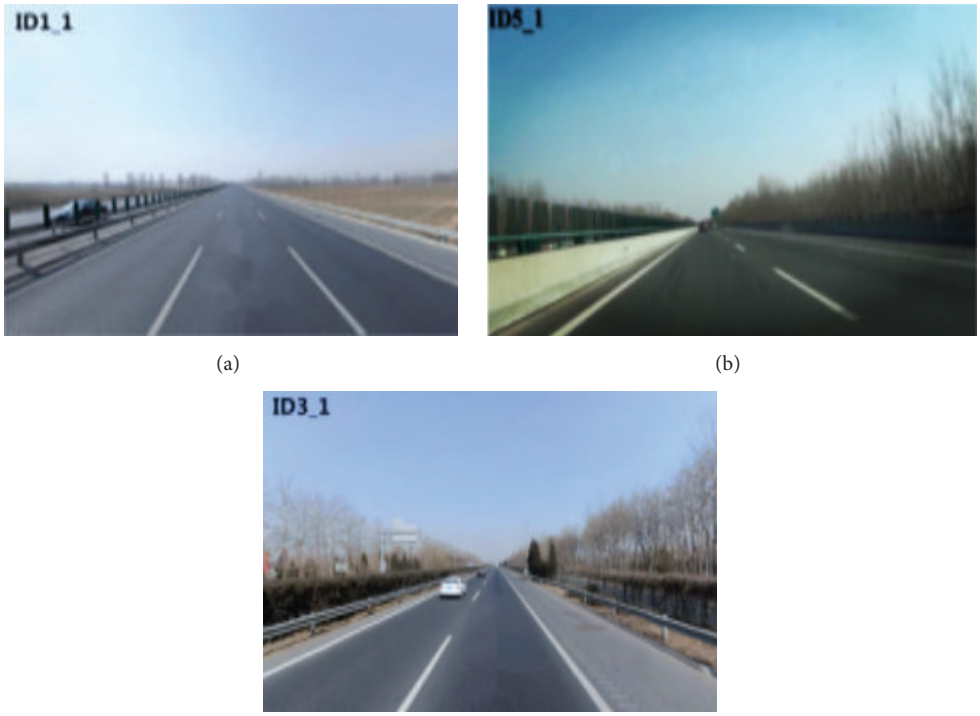
3.2.1. Driving Simulator. A simulator is often used to study driving behavior for its advantages of providing a controllable, safe, and economical virtual environment to drivers [25–27]. When the virtual landscape environment is in high fidelity compared to the real ones, no significant difference will be found [20, 21]. These findings provide reliable support to the usage of this apparatus.

The simulator used in this study is the advanced high-fidelity simulator, AutoSim AS1600, which is shown in Figure 1(a). It is a fixed-based driving simulator, composed of semiphysical facilities such as the automobile *Toyota Yaris*, with functional pedal and dashboard. It records the vehicle's key parameters in real time, such as coordination, speed, lane deviation, and brake distance. It provides realistic visual and auditory effect to individuals. Four projectors with resolution 1024 × 768 pixels print the visual scenarios on a piece of curtain 10 meters in front of the vehicle. A loudspeaker is positioned at the vehicle's ceiling to receive a driver's real-time oral feedback. The simulator is placed at a relatively isolated room. Outside the room is a main control center, where an experiment operator monitors the driving process.

3.2.2. ECG. The ECG used in this paper is a portable KF2 type device. Its picture is shown in Figure 1(b). It is used to sample and record a participant's ECG data in 256 Hz. These data include ECG diagram, heart rate, breath frequency, and body temperature. The device is bound around a participant's chest, without disturbing his/her duty performance.

3.3. Virtual Environment

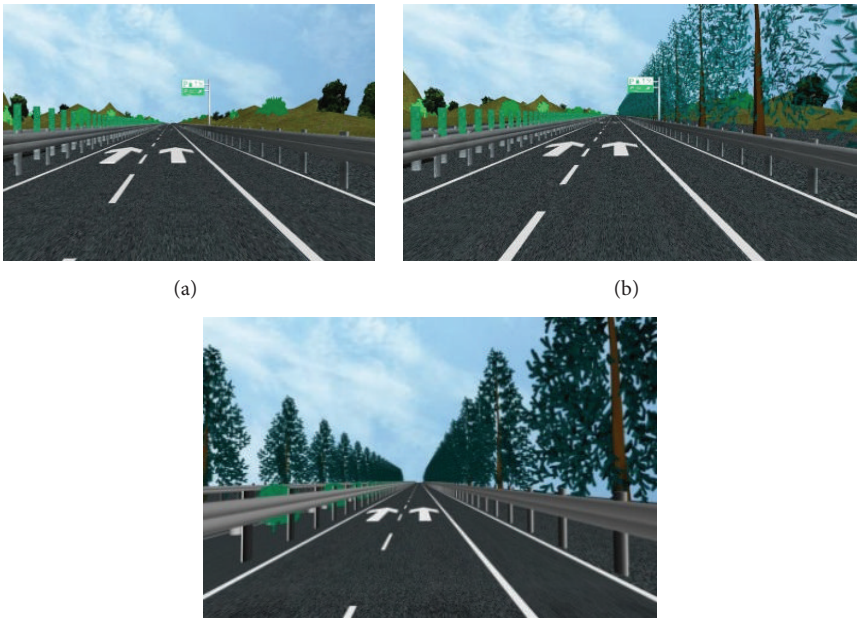
(1) Highway Design. The virtual scenarios are built by the software 3DsMAX 9.0. They are designed to reproduce the *Daguang* Highway, a toll expressway located in the southeastern part of Beijing, China. The speed limit is ranged from 50 to 100 km/h. There are four driving lanes (two in each direction) throughout. Three segments featured with typical landscape patterns are extracted, shown in Figure 2. Based on the field prototypes, three simulated highway stretches were simulated based on the three segments, shown in Figure 3. Each simulated stretch is 20 km long and 14.5 meters wide. Each lane was 3.75 meters wide, with the right shoulder 2



(a) (b)

(c)

Figure 2: Typical landscape patterns in Daguang Highway. (a) Open. (b) Semiopen. (c) Vertical.



(a) (b)

(c)

Figure 3: Typical simulated landscape patterns. (a) Open. (b) Semiopen. (c) Vertical.

meters wide. It takes 15 minutes to finish driving in one stretch with the constant speed of 80 km/h.

(2) Landscape Patterns. Distance of roadside landscape off the edge of one driving lane is set to be 5 meters. This forms a forgiven clear zone to prevent the landscape from becoming potential hazard [28]. The landscape unit is designed with tall poplar community. The poplar is generally 12 meters tall and 1 meter wide. Place the poplar community in the semiopen and vertical landscape scenarios, in order to form a dense and

forested driving scenario. More details of the three landscape patterns are given as follows:

(i) Driving vision in an open landscape is unimpeded. Drivers can see anything far and distant in this scenario.

(ii) The aforementioned poplar community is placed along one side of the highway in a semiopen landscape. The other side of the highway is featured with a broad and unimpeded vision.

(iii) The aforementioned poplar communities are placed along both sides of the highway in a vertical landscape. No additional touristic scenic or roadside facility is designed in this scenario.

3.4. Experiment Variables

3.4.1. Vehicle Operational Performance. During a test, the real-time operational SPEED and lane deviation (LD) of the vehicle are recorded by the simulator's data tracking software. Literatures have confirmed that these two indices are leading factors that are sensitive to roadside influence [29]. Speed represents the vehicle's operational stability in the driving direction. And LD refers to the vehicle's average deviation distance off the road center. It represents the vehicle's operational stability in the lateral direction. The smaller the distance LD deviates off the road center, the more stable the vehicle performs.

3.4.2. Physiological Performance. ECG indices, namely, heart rate (HR) and heart rate variability (HRV), are extracted from the KF2 device. They are two typical types of intrinsic physiological data to measure the physical workload or mental stress. HR index is calculated by the heartbeat intervals. It is sensitive to human's physiological performance and can be used to measure the physical workload. HRV is measured by the variation in the time interval between heartbeats [30]. It will decrease when individuals experience heavy mental stress or physical fatigue [31]. HRV presents an interaction effect balanced by the individual's sympathetic nervous system (SNS) and parasympathetic nervous system (PSNS). When an individual is in an intense workout, emotional strain, or elevated anxiety, SNS activity will take a dominant advantage over PSNS activity by enhancing the heartbeat frequency. The low frequency value LF will increase as well, which contributes to SNS activity. Besides, when an individual takes a rest, PSNS activity will take a dominant advantage over SNS activity. The high frequency value HF will increase as well, which contributes to PSNS activity. Increased SNS activity or decreased PSNS activity will result in HRV's drop, which is related to the respiratory sinus arrhythmia. Thus, HRV can be an effective indicator to indicate the individual's physiological performance [32]. One key ECG index to explain the physiological performance is the index LF/HF, which refers to a balanced state between SNS and PSNS. It is the ratio of low frequency (LF) to high frequency (HF). Previous research has highlighted that an overall increase of LF/HF is positively correlated to SNS activity and negatively correlated to PSNS activity, showing an individual may be stuck in an adverse environment or emotional strain [33–35].

3.5. Questionnaires

3.5.1. Fidelity Questionnaire. To ensure the validity of data obtained from the simulator experiment, it is necessary to evaluate the fidelity of the experimental device or virtual environment. The 5-point Likert scale serves for the fidelity evaluation, which is ranged from "not at all" (+1) to "very much" (+5). Specific components of the experiment devices contain the accelerator, brake pedal, shift gears, steering wheel, seat, and mirrors. Specific components of the virtual environment contain the traffic signs, traffic lines, landscape, pavement, and highway linearity design.

So the fidelity questionnaire is developed, which is comprised of two special issues. The 5-point Likert scale is used in these two issues. Details are given below:

(i) The 1st issue tests the fidelity of the experimental device by one question, "How realistic did you feel like each component of the experiment devices, such as the accelerator, brake pedal, shift gears, steering wheel, seat, and mirrors respectively?"

(ii) The 2nd issue tests the fidelity of the virtual environment by one question "How realistic did you feel like each component of the virtual environment, such as the traffic signs, traffic lines, landscape, pavement, and highway linearity design respectively?"

3.5.2. Stress Perception Questionnaire. If the highway is too long with too monotonous surroundings, the driver becomes stressed easily. Besides, Bear et al. [34] indicated that physiological performance had strong correlation with mental status. So it is necessary to evaluate the most undesirable scenario which triggers high mental stress and to evaluate the perceived stress of a participant in order to validate his/her physiological performance. Finally, it is necessary to evaluate a participant's most desired length thresholds in the three scenarios in order to validate the theoretical length thresholds from the simulator experiment.

Hence, the stress perception questionnaire is developed. A participant is asked to evaluate the subjective attitude towards the aforementioned questions based on his/her retrospective driving experiences in the three scenarios. The questionnaire is comprised of three special issues. The 5-point Likert scale is also used in the first two issues. Details are given below:

(i) The 1st issue tests the most undesirable scenario among the three by one question, "In which scenario did you want to end the traveling as quickly as possible?"

(ii) The 2nd issue tests the perceived stress by one question, "Tell how strong you felt depressed in each scenario?" The experiment operator asks this question every four kilometers during the participant's travelling.

(iii) The 3rd issue tests the longest highway length in the participant's desire by one question, "Compared with the trip length in the simulated highway stretch, what's the longest length you expect to travel in the real field?" Specific length is given according to this question.

3.6. Procedure. The experiment was held on the date May 21st to May 31st in the simulator lab, positioned in Beijing University of Technology. Two experimental periods were selected due to the active physical performance of an individual, 9:00~12:00 am and 2:00~5:00 pm [27]. The temperature in the lab was 23°C. The inner environment was kept quiet to prevent the participant from being disturbed by the external environment.

A participant was asked to sleep adequately and not to consume any irritant such as tobacco, alcohol, or caffeine two hours before the appointed experiment time. During the participant's experiment time, the staff introduced the specific procedure, such as instrument operation or questionnaire filling, to ensure the participant's knowledge of experiment process. Then, a 15-minute training practice was arranged on a neutral 10 km straight rural road. The participant could drive as usual to get familiar with the simulator and the virtual environment. After 10 minutes' rest, the participant wore the portable ECG around his/her chest and was seated for 15 minutes till he/she returned to calmness.

In the formal experiment, the speed limit was 80 km/h. And every participant was asked to, respectively, finish the drive task in the open, semiopen, or vertical scenarios once. Sequences of the three scenarios were arranged randomly to minimize the potential learning effect. The experiment staff recorded the experiment variables in real time. After each task, the participant took a 3 min necessary break to recover his/her mental or physical status. After whole completion of all tasks, the participant was guided to remove the ECG and complete the questionnaires.

3.7. Statistics. The first step was to use the 3σ rule, a simple filtering rule widely substantiated by statistics, to filter those outliers beyond a normal distribution.

All valid data on thirty participants' operational performance were collected during the tests. Those indices were speed, LD, HR, and LF/HF. A highway section was divided into twenty intervals. And each interval section was one kilometer. The study calculated the average value of an index in every interval and finished analysis of the remaining data in the same way. Descriptive analysis and statistical variance analysis of each index grouped by three scenarios were performed by SPSS, by using the F test and repeated measures ANOVA (ANOVA: analysis of variance). The level of statistical significance was defined as $p < 0.05$ or $p < 0.01$. One index was extracted as characteristic index if it had significant difference among three scenarios. Besides, results of the questionnaires were analyzed as well to supplement the objective analysis of these indices.

Table 1: Analysis of the participants' basic data.

Gender	Number	Proportion (%)	Mean age	Mean driving experience
Male	16	53.3	27.12 ± 2.41	4.00 ± 0.31
Female	14	46.7	25.92 ± 2.75	3.83 ± 0.87
Total	30	100.0	26.56 ± 2.11	3.92 ± 0.49

4. Results

4.1. Fidelity Questionnaire Evaluation. The fidelity of the experiment device or virtual environment was firstly analyzed. The fidelity figure was shown in Figure 4. Average scores for the experiment devices' components were as follows: the accelerator 4.87 ± 0.85, brake pedal 4.93 ± 0.29, shift gears 4.85 ± 0.87, steering wheel 4.80 ± 1.29, seat 4.89 ± 0.69, and mirrors 4.81 ± 0.68. Average scores for the virtual environment's components were as follows: traffic signs 4.85± 0.51, traffic lines 4.80 ± 0.86, landscape 4.81 ± 0.99, pavement 4.83 ± 0.59, and highway linearity design 4.87 ± 0.95. Both the experiment devices and the virtual environment had been found to have high fidelity, which served as reliable tools to support the reliability of experiment data.

4.2. Analysis of Participants. Thirty-five participants took part in the tests. Four participants had to abort the predriving test due to the acute simulator nausea. One participant quit the driving, because he was disturbed by the cellphone given in the experiment. Finally, thirty participants (16 males and 14 females) completed the driving test. Their basic data were shown in Table 1. Their average age was 26.56±2.10 years, and their average driving experience was 3.92 ± 0.49 years. The proportion of male participants among all the participants was 53.3%. The male participants' average age was 27.12 ± 2.41 years, with their average driving experience 4.00 ± 0.31 years. The proportion of female participants among all the participants was 46.7%. The female participants' average age was 25.92 ± 2.75 years, with their average driving experience 3.83 ± 0.87 years.

A significance test was conducted for driving-experience differences between the male and female participants. And the result was $F(1, 28) = 0.86$, $p = 0.36 > 0.05$. Another significance test was conducted for age differences between the male and female drivers. And the result was $F(1, 28) = 2.54$, $p = 0.12 > 0.05$. Thus, no significant differences were found within gender group of drivers.

4.3. Analysis of Vehicle Operational Performance

4.3.1. SPEED. Table 2 presented the average values of SPEED among three landscape patterns. It is found that all the three scenarios yielded SPEED close to or even above the limit speed 80 km/h.

The repeated measures ANOVA was conducted to analyze the statistical difference of SPEED variance grouped by three scenarios. SPEED's Mauchly's Test of Sphericity gave a Sig.

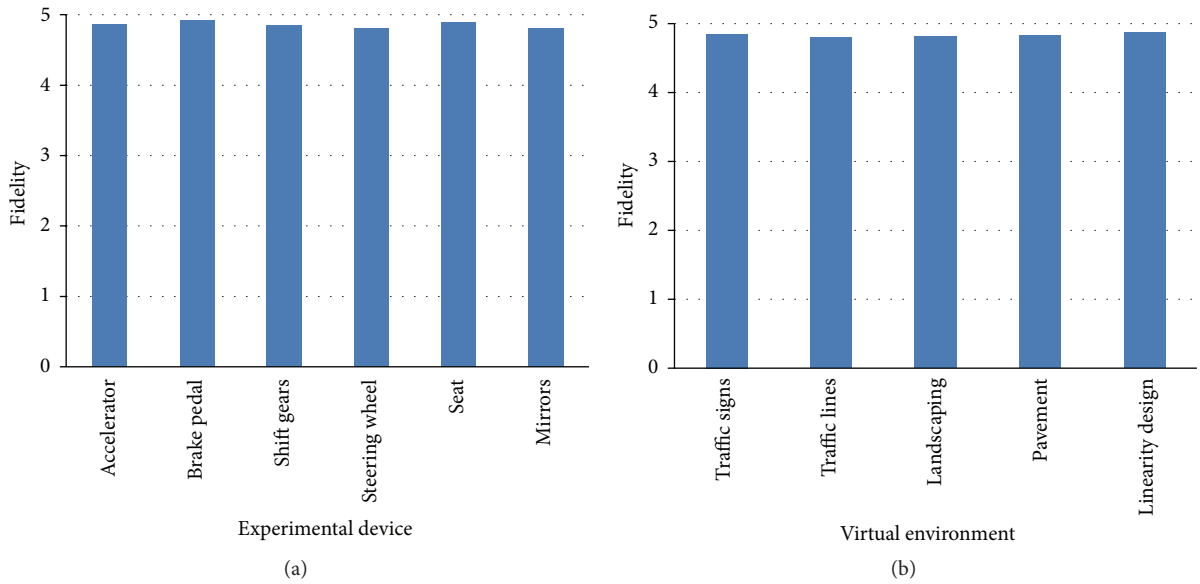


Figure 4: Fidelity evaluation results. (a) Experimental device. (b) Virtual environment.

Table 2: Descriptive statistics of key indices.

Landscape pattern	Vehicle's performance		ECG indices	
	SPEED mean (km/h)	LD mean (m)	HR mean (beat/min)	LF/HF mean
Open	81.49 ± 3.52	0.74 ± 0.12	78.26 ± 3.52	2.57 ± 0.55
Semiopen	81.27 ± 3.90	0.18 ± 0.08	77.71 ± 7.30	2.55 ± 0.54
Vertical	81.16 ± 3.94	0.10 ± 0.04	78.11 ± 3.15	2.38 ± 0.39

figure of 0.00 [$\chi^2(2) = 11.59$, $p < 0.05$], throwing some doubt on the sphericity assumption. So results from the fitting model of multivariate analysis of variance (MANOVA) were adopted to test within-subject effects. A Sig. figure of 0.33 [$F(2, 370) = 1.12$, $p > 0.05$] was given in Pilla's trace test, showing no statistically significant difference in SPEED among the three landscape patterns.

No significance difference in SPEED was found because the experimental instruction did not allow participants to drive above 80 km/h in each scenario. SPEED could not be considered as characteristic index in this study. But the result testified the confirmation that driving in the long and straight highway may trigger fast driving or speeding behavior to some extent.

4.3.2. LD. Table 2 showed the average values of LD among three landscape patterns. It is found that the average LD was highest in the open pattern (0.74 ± 0.12 meters) and lowest in the vertical pattern (0.10 ± 0.04 meters).

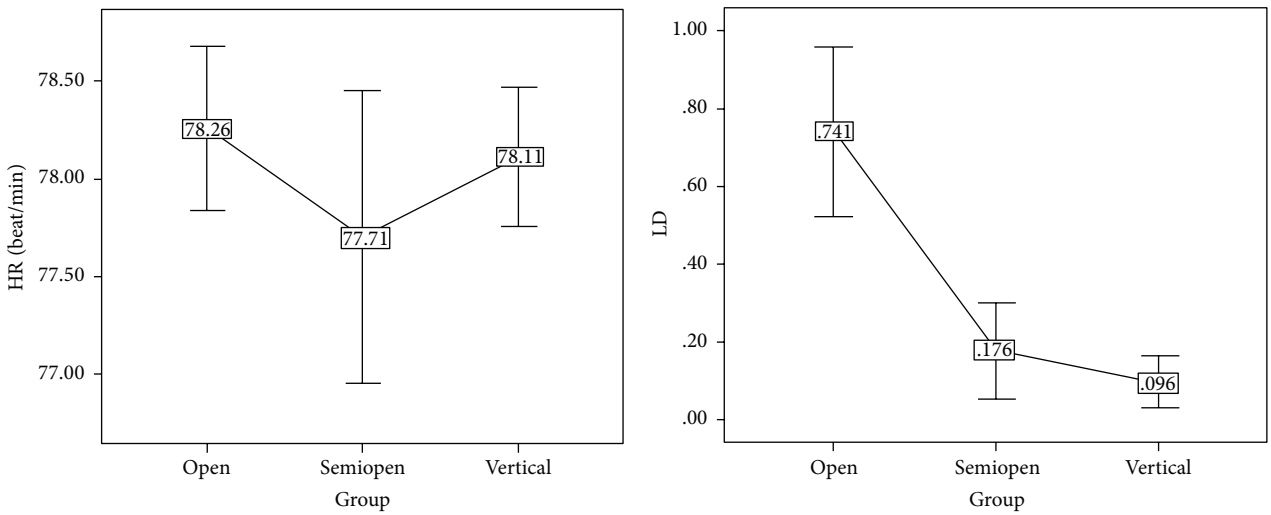
The repeated measures ANOVA was conducted to analyze the statistical difference of LD variance grouped by three scenarios. LD's Mauchly's Test of Sphericity gave a Sig. figure of 0.49 [$\chi^2(2) = 1.42$, $p > 0.05$], suggesting the sphericity was an acceptable assumption. So results from ANOVA fitting model were adopted to test the within-subjects effects. A Sig. figure of 0.00 [$F(2, 360) = 297.55$, $p < 0.05$] was given in the assumed sphericity, showing a statistically significant difference in LD among the three landscape patterns.

Multiple comparisons of LD were carried out to further understand the significant effect of landscape patterns on LD. The comparison results showed that the open scenario's LD was significantly different from the semiopen scenario's LD ($p = 0.00 < 0.05$) and from the vertical scenario's LD ($p = 0.00 < 0.05$). However, no significant difference was found between the semiopen and the vertical ones ($p = 0.45 > 0.05$). LD's error bar chart presented in Figure 5(a) testified the result.

Thus, a statistically significant difference was found only between the open scenario and the other two scenarios, showing the open scenario was more probable to induce higher lane deviation and inferior driving stability than the other two types. So LD was labeled as characteristic index in this study.

4.4. Analysis of Physiological Performance

4.4.1. Correlation Analysis. Correlation analysis of ECG indices was carried out, respectively, in each scenario. The output Table 3 provided the results of Pearson correlation matrix and associated significance tests. It was found that LF/HF was highly correlated with LF ($r > 0.70$) and with HF ($r > 0.70$). And LF was modestly correlated with HF ($r >$



(a) LD (b) HR

Figure 5: Error bar chart of LD (a) and HR (b).

Table 3: Correlation analysis of ECG indices in each scenario.

Landscape pattern	Indices	LF	HF	LF/HF	HR
Open	LF	1.00	—	—	—
	HF	.54**	1.00	—	—
	LF/HF	.73**	−.75**	1.00	—
	HR	−.29**	−.15**	.09	1.00
Semiopen	LF	1.00	—	—	—
	HF	.53**	1.00	—	—
	LF/HF	.74**	−.73**	1.00	—
	HR	.28**	.07**	.20**	1.00
Vertical	LF	1.00	—	—	—
	HF	.54**	1.00	—	—
	LF/HF	.76**	−.75**	1.00	—
	HR	.32**	.31**	.33**	1.00

** Significant at the 0.01 level.

0.50). Neither of these indices LF, HF, or LF/HF, reached high correlation with the index HR ($r < 0.40$). All the correlation was statistically significant at the 0.01 level. The descriptive statistics and significance tests of these indices were further performed, in order to extract characteristic ECG indices in the three scenarios.

4.4.2. HR. Table 2 showed the average values of HR among three landscape patterns. It is found that the average HR values were all close to 78 beat/min.

The repeated measures ANOVA was conducted to analyze the statistical difference of HR variance grouped by three scenarios. HR's Mauchly's Test of Sphericity gave a Sig. figure of 0.00 [$\chi^2(2) = 109.23$, $p < 0.05$], throwing some doubt on the sphericity assumption. So results from MANOVA fitting model were adopted to test within-subject effects. A Sig. figure of 0.11 [$F(2, 247) = 2.25$, $p > 0.05$] was given in Pilla's trace test, showing no statistically significant difference in HR among the three landscape patterns. HR's error bar chart presented in Figure 5(b) testified the result. Based on the aforementioned theory that HR quantifies the physical workload of an individual, it is indicated that the participants in the study were not associated with significant difference in physical workload in three landscape patterns. So HR was not extracted as characteristic index due to its insensitivity to the given landscape patterns.

4.4.3. LF/HF. Table 2 showed the average values of LF/HF among three landscape patterns. It is found that the average LF/HF was highest in the open pattern (2.57±0.55) and lowest in the vertical pattern (2.38 ± 0.39).

The repeated measures ANOVA was conducted to analyze the statistical difference of LF/HF variance grouped by three scenarios. LF/HF's Mauchly's Test of Sphericity gave a Sig. figure of 0.18 [$\chi^2(2) = 3.45$, $p > 0.05$], suggesting the sphericity was an acceptable assumption. So results from ANOVA fitting model were adopted to test the within-subjects effects. A Sig. figure of 0.04 [$F(2, 360) = 3.27$, $p < 0.05$] was given in the assumed sphericity, showing a statistically significant difference in LF/HF among the three landscape patterns.

Multiple comparisons of LF/HFs were carried out to further understand the significant effect of landscape patterns on the participant's LF/HF. The comparison results showed that a statistically significant difference was found only between the open and vertical scenarios ($p = 0.01 < 0.05$). No significance was found between the open and semiopen scenarios ($p = 0.06 > 0.05$) or between the semiopen and vertical scenarios ($p = 0.41 > 0.05$). LF/HF's error bar chart presented in Figure 6 testified the result. It is obvious that the value of LF/HF in the open scenario was significantly higher than that in the vertical scenario. Thus, the index LF/HF was labeled as characteristic in this study.

The aforementioned theory indicates that when an individual is in an intense workout, emotional strain, or elevated

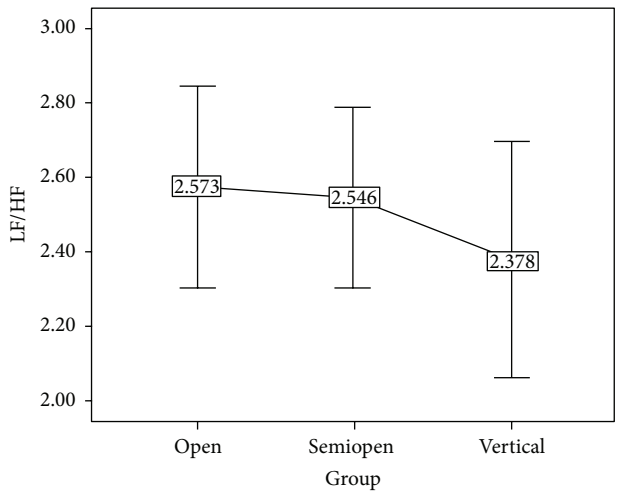


Figure 6: LF/HF's error bar chart.

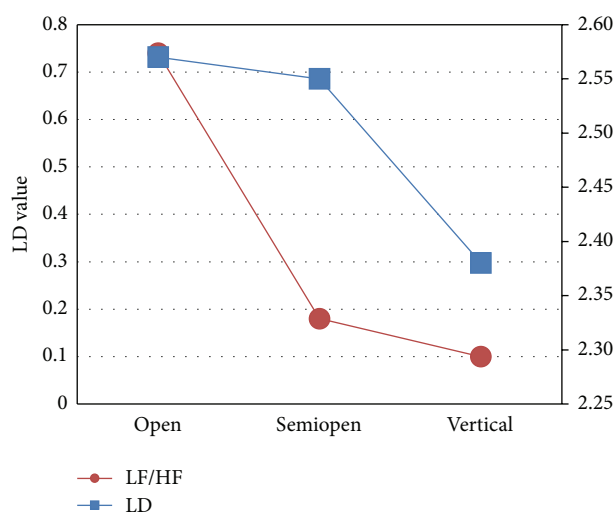


Figure 7: Relationship between LF/HF and LD.

state anxiety, SNS takes a dominant advantage over the PSNS, accompanied with the rising LF/HF and the enhanced SNS activity. So the participants in the open scenario were more probable to be stuck into negative driving mood and to suffer with stronger mental stress in the open scenario than the other two types.

4.5. Interaction Relationship Analysis. In the open and vertical scenarios, the variation trends of the characteristic indices LD and LF/HF were compared, as was shown in Figure 7.

It was found that, no matter in the open or vertical scenario, LF/HF was in proportion to LD. From Table 4, it was found that LF/HF was highly correlated with LD ($r \geqslant 0.75$), which was statistically significant at the 0.01 level. The most probable explanation was that the intrinsic physiological index LF/HF was better at measuring mental stress than LD, the extrinsic representation for vehicle performance. LF/HF was the characteristic and intrinsic index to evaluate driving behavior.

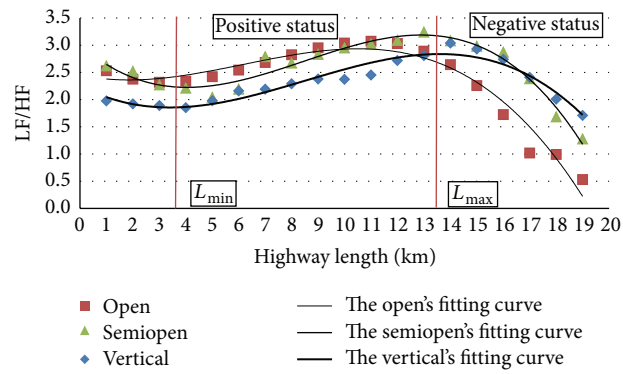


Figure 8: U-shaped relationship between LF/HF and highway length under each landscape pattern.

Table 4: Correlation analysis of LF/HF and LD.

Landscape pattern	Correlation
Open scenario	.80**
Semiopen scenario	.75**
Vertical scenario	.79**

**Significant at the 0.01 level.

5. Modeling Building

Highway length threshold in each scenario was further explored based on landscapes' effect on physiological index LF/HF.

5.1. Physiological Response to Monotonous Highway. Firstly, the participants' physiological response to highway scenario was extrapolated according to LF/HF's variation trend with highway trip length, which is shown in Figure 8.

In this figure, the fitting curve of LF/HF ratio displayed a U-shape trend to trip length. To understand the U-shape curve, several key elements were defined as follows:

(i) $F(L)$ was defined as the value of LF/HF ratio with respect to trip length L.

(ii) $L_{\min}$ was defined as the very highway length to reach the point $F_{\min}$, which was the minimum value of LF/HF.

(iii) $L_{\max}$ was defined as the very highway length to reach the point $F_{\max}$, which was the maximum value of LF/HF.

The vertical scenario's two extreme values, $L_{\min}$ and $L_{\max}$, were labeled in Figure 8, for instance. In the length interval $[0, L_{\min}]$, the participant was mainly influenced by the vehicle-starting process, but not the roadside landscape in each scenario. Due to this, the data in this period was filtered. Thus, the valid variation trend of LF/HF was explained as follows:

(i) In the length interval $[L_{\min}, L_{\max}]$, an increase occurred in LF/HF along with the driving task. This phenomenon indicated that the landscape brought

Table 5: Polynomial coefficients q_i and fitting degree R^2 of the curves in the simulator test.

Landscape pattern	Polynomial coefficient				Adjusted R^2
	q_1	q_2	q_3	q_4	
Open	-1.80×10^{-3}	3.30×10^{-2}	1.03×10^{-1}	2.45	0.95
Semiopen	-2.80×10^{-3}	7.10×10^{-2}	4.36×10^{-1}	3.02	0.95
Vertical	-1.90×10^{-3}	4.70×10^{-2}	2.58×10^{-1}	2.26	0.92

Table 6: Highway's concluded length thresholds.

Landscape pattern	Designed highway length (km)	Theoretical length threshold (km)	Expected length threshold (km)	Field length threshold (km)
Open	20	**10.38**	**11.02**	**11.00**
Semisopen	20	**12.87**	**13.68**	**13.70**
Vertical	20	**13.01**	**14.08**	**13.79**

positive effect to enhance SNS activity of a participant, who was then in positive mental state. And the period of positive effect extended to length $L_{\max}$, where LF/HF had reached its peak, and SNS activity had reached its highest level.

(ii) In the length interval $[L_{\max}, 20]$, a sharp drop occurred in LF/HF along with the driving task. This phenomenon indicated that the excessive monotony of the landscape suppressed SNS activity and enhanced PSNS activity, which exerted negative effect to the participants.

Thus, the theoretical highway length threshold in the simulated scenario was concluded to be $L_{\max}$. Within this threshold, the landscape could bring positive stimulus to drivers.

5.2. Model Building on Highway Length. Models on highway length were built based on landscapes' effect on physiological index LF/HF. Select several curves to fit for the scatter distribution of LF/HF to trip length, such as quadratic polynomial, cubic polynomial, linear, exponential curve, negative exponential curve, and logarithmic curve. The results showed that the cubic polynomial best fitted for LF/HF's curve. And its goodness of fitting R^2 was the highest and ranged from 0.92 to 0.95. The fitting curve's function was presented in (1), with its polynomial coefficients and adjusted R^2 shown in Table 5:

$$F(L) = q_1 L^3 + q_2 L^2 + q_3 L + q_4, \quad (1)$$

where L is the trip length in the landscape scenario, with its unit km; $F(L)$ is the LF/HF ratio with respect to the trip length L; q_i is the ith polynomial coefficient of the parameter L in jth power ($i = 1, 2, 3, 4$, and $j = 4-i$); R^2 is the adjusted goodness of fitting.

As was discussed in the above section, the critical trip length threshold was concluded to be the value $L_{\max}$. And $L_{\max}$ was calculated based on the derivation of $F(L)$, with its function shown in

$$\frac{d(F(L))}{dL} = 0, \quad L > 0. \quad (2)$$

The results of theoretical highway length threshold $L_{\max}$ were shown in Table 6.

ANOVA and significance test for $L_{\max}$ in three scenarios were performed. It was found that a statistically significant difference existed in $L_{\max}$ among the three landscape patterns $[F(2, 87) = 441.22,\ p = 0.00 < 0.05]$. By further performing multiple comparisons of $L_{\max}$, it was found that the open scenario's $L_{\max}$ was significantly smaller than the value in the semiopen scenario ($p = 0.00 < 0.05$) and smaller than the value in the vertical scenario ($p = 0.00 < 0.05$). However, no significant difference was found between the semiopen and vertical scenarios ($p = 0.64 > 0.05$).

5.3. Evaluation on Expected Highway Length Threshold

5.3.1. Stress Response to Monotonous Highway. The aforementioned theory indicates that an increase of LF/HF is in proportion to stress loading. So in the highly automated driving scenarios, the main output was the participants' stress strain towards the monotonous highway. In the stress perception questionnaire, each issue had been scored on the same Likert scale ranging from one to five. Stress variation with the trip length was analyzed in order to quantify the subjective stress response to monotonous highway.

The 1st issue ranked the most undesirable scenario among the three scenarios. Of the thirty participants, 40%, 31%, and 29% were eager to fast end the traveling in the open, semiopen, and vertical scenarios, respectively. And the scoring scale representing the subjective desire to end the test was ranged from +4 (fairly) to +5 (strongly). This finding explained that travelling in one monotonous landscape for twenty kilometers could induce drivers' strong desire to drive fast, much in line with the statistical result of operational speed. The higher ratio in the open pattern testified that the open scenario was more probable to induce mental stress to drivers than the other two types.

The 2nd issue in the questionnaire showed that 43.2%, 29.3%, and 27.5% of the thirty participants, respectively, showed that they had felt depressed in the open, semiopen, and vertical scenarios. The higher ratio in the open pattern

showed the open scenario was associated with higher probability to induce negative moods than the other ones. And the depressed degrees in these three scenarios were, respectively, quantized as 3.3 ± 1.8, 2.6 ± 1.7, and 2.4 ± 1.6. The stress variation trend with the trip in each scenario was depicted in Figure 9.

In the open scenario, it was during the period of 9~12 km that the depressed degree rose sharply to 3.5, indicating the stress was fairly strong. In the semiopen and vertical scenarios; it was during the period of 13~16 km that the depressed degree soared to points above 3.8 points, indicating the stress was fairly strong.

All the theoretical length thresholds in the models lied in the point when the participants felt strong stress scored from 3.8 to 4.0 points. The open scenario's theoretical length was the shortest, because the strong stress occurred the earliest among the three scenarios. The result verified that the subjective stress response was much in line with the physiological response to monotonous highway. And the subjective stress response to monotonous highway testified that the open scenario was more probable to bring negative effect on drivers.

5.3.2. Expected Highway Length. The 3rd issue in the questionnaire evaluated the expected highway length threshold for each single landscape. The statistics results showed that 85.9% of the thirty participants considered that the 20-kilometer-length highway was too long and too monotonous to travel in. The expected average length threshold was, respectively, 11.02 km, 13.68 km, and 14.08 km for the open, semiopen, and vertical scenarios. The results were shown in Table 6. Comparing the theoretical length thresholds with the expected ones and calculating the precision rates, the results showed that the theoretical length thresholds in the models had precision rates valued as 99.2%, 94.1%, and 92.4%, all higher than 90%. Thus, the model results had high reliabilities.

5.4. Model Validation. In order to verify the theoretical length threshold gotten from simulator study, a field driving test was carried out accordingly.

5.4.1. Field Test Design. The highway scene was the prototype of the simulator scenario, namely, Daguang Highway. The highway stretches with typical open, semiopen, and vertical landscape patterns were chosen for the field test. The instrumental vehicle in the field was *Buick Excelle*, similar to the vehicle type *Toyota Yaris* in the simulator. Six participants who were randomly chosen from the simulator test participated in the field test held on the date July 7th to July 11th, 2015. The traffic flow was low and the weather was sunny. The field procedure was the same as that in the simulator. The characteristic index LF/HF was measured by KF2 ECG device in real time. The variation trend of LF/HF collected in the field test was compared with that obtained in the simulator. LF/HF's correlation in and out of the simulator was analyzed as well.

Table 7: Correlation analysis of the evaluation indices in each scenario.

Evaluation index	Landscape pattern	Correlation coefficient
Indoor and outdoor LF/HF	open	.77**
	Semiopen	.83**
	Vertical	.78**

**Significant at the 0.01 level.

Table 8: Descriptive analysis of the evaluation indices in each scenario.

Evaluation index	Landscape pattern	Field test	Indoor test
LF/HF	Open	3.24 ± 0.71	2.53 ± 0.55
	Semiopen	3.34 ± 0.56	2.51 ± 0.53
	Vertical	3.21 ± 0.59	2.37 ± 0.37

5.4.2. Data Analysis and Results. In all the three landscape patterns, the following comparisons were made:

(i) The average value of LF/HF obtained in the simulator was highly and significantly correlated with the value obtained in the field. In the open, semiopen, and vertical scenarios, the respective correlation coefficients were 0.77, 0.83, and 0.78. The result was shown in Table 7.

(ii) Compared with the average value of LF/HF in the simulator, a clear increase was found in the average value of LF/HF in the field. The result was shown in Table 8.

(iii) The variation trend of LF/HF in the field test presented relative consensus with that in the simulator study. The result was shown in Figure 10.

In a conclusion, comparison of LF/HF made in the simulator and field tests presented convincing evidence for the validity and reliability of the simulator results.

Three cubic polynomial curves were chosen to fit for LF/HF's variation trends in the field test. Specific polynomial coefficients q_i and fitting degree R^2 of the curves were given in Table 9. The highway length threshold under each field scenario was deducted based on the derivation of each cubic polynomial. The field length thresholds were, respectively, 11.00, 13.70, and 13.79 km for the open, semiopen, and vertical scenarios. The results were shown in Table 6. The multiple of the field threshold to the theoretical one was 1.06 in each scenario. Field validation survey showed the validity and reliability of the theoretical highway length threshold obtained from the simulator.

6. Conclusions and Discussions

Transportation environmentalists have long considered the landscape as an effective tool in optimizing travel behavior. Analysis results from landscape's effect on drivers testify the confirmation. And the concluded highway length thresholds

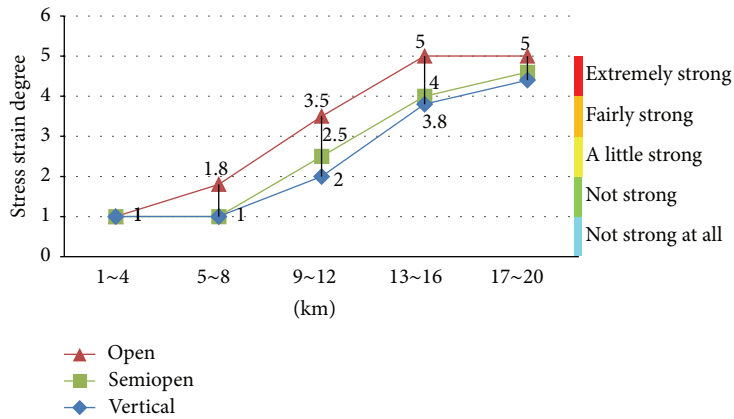


Figure 9: Stress variation trend with the trip length in each scenario.

Table 9: Polynomial coefficients q_i and fitting degree R^2 of the curves in the field test.

Landscape pattern	Polynomial coefficient				Adjusted R^2
	q_1'	q_2'	q_3'	q_4'	
Open	-3.10×10^{-3}	7.23×10^{-2}	-3.74×10^{-1}	3.44	0.95
Semiopen	-3.30×10^{-3}	8.8×10^{-2}	-5.53×10^{-1}	3.57	0.94
Vertical	-2.60×10^{-3}	6.35×10^{-2}	-3.29×10^{-1}	3.39	0.97

have been testified to be valid and reliable in this paper. The main findings in this study are as follows:

(i) Certain landscape, though monotonous, can affect drivers positively by reducing mental fatigue within specific length threshold.

(ii) Different spatial patterns influence driver behavior significantly. Drivers tend to drive faster, deviate larger from the center of the lane, and have heavier stress when driving in the open landscape.

(iii) The semiopen and vertical patterns can lower the speed, provide superior visual guidance, and relieve the drive stress significantly compared to the open landscape.

(iv) The aforementioned mechanism does not apply when the highway length is beyond its threshold. Obviously, not every length extension in the monotonous landscape will enhance the positive mental state, unless the trip length is within certain threshold.

(v) The theoretical highway thresholds are, respectively, 10.38, 12.87, and 13.01 km in the simulator, much in line with the expected ones evaluated in the simulator test. The field highway thresholds are, respectively, 11.00, 13.70, and 13.79 in the field, 1.06 multiples of those in the simulator tests.

Each landscape pattern has its own advantage when being considered in the environmental design. The conclusions in this study can guide practitioners in designing optimum highway length to trigger the drivers' positive mood. Pertaining to different roadside landscape patterns, the length threshold should be different. The length threshold in the open pattern should be the shortest, no more than 11 km. It is identified in this study that the open landscape pattern gives intense stimulus to drivers within length threshold. Thus, it can be the best transition after long-hours' tedious driving. And the length threshold in the vertical pattern can be a little longer, but still no more than 14 km. The vertical pattern is found to be the most stable one, with the smallest deviation in speed, LD, or stress. It has great regulating function on mental calmness.

Several limitations and future research ideas must be mentioned as follows:

(i) The conclusion can only apply to the Daguang Highway of Beijing, a 2-lane urban expressway with a constant speed limit of 80 km/h. The key indices (the lane deviation or the operational speed) may have potential relationships with some other effect variables not considered in this paper, such as the lane width, lane lines, and road geometric design. We will carry out further researches to verify the effect of these variables to the experimental results.

(ii) All test participants are healthy volunteers aged between 20 and 40, who are the representative population driving in China. However, the gross driving population also includes the young or older drivers, who will be considered in future research.

(iii) In the semiopen scenario, its LF/HF value had no significant difference with that in the open scenario. And its LD had no significant difference with that in the vertical scenario. The variation trend of the indices in this scenario had changed randomly and

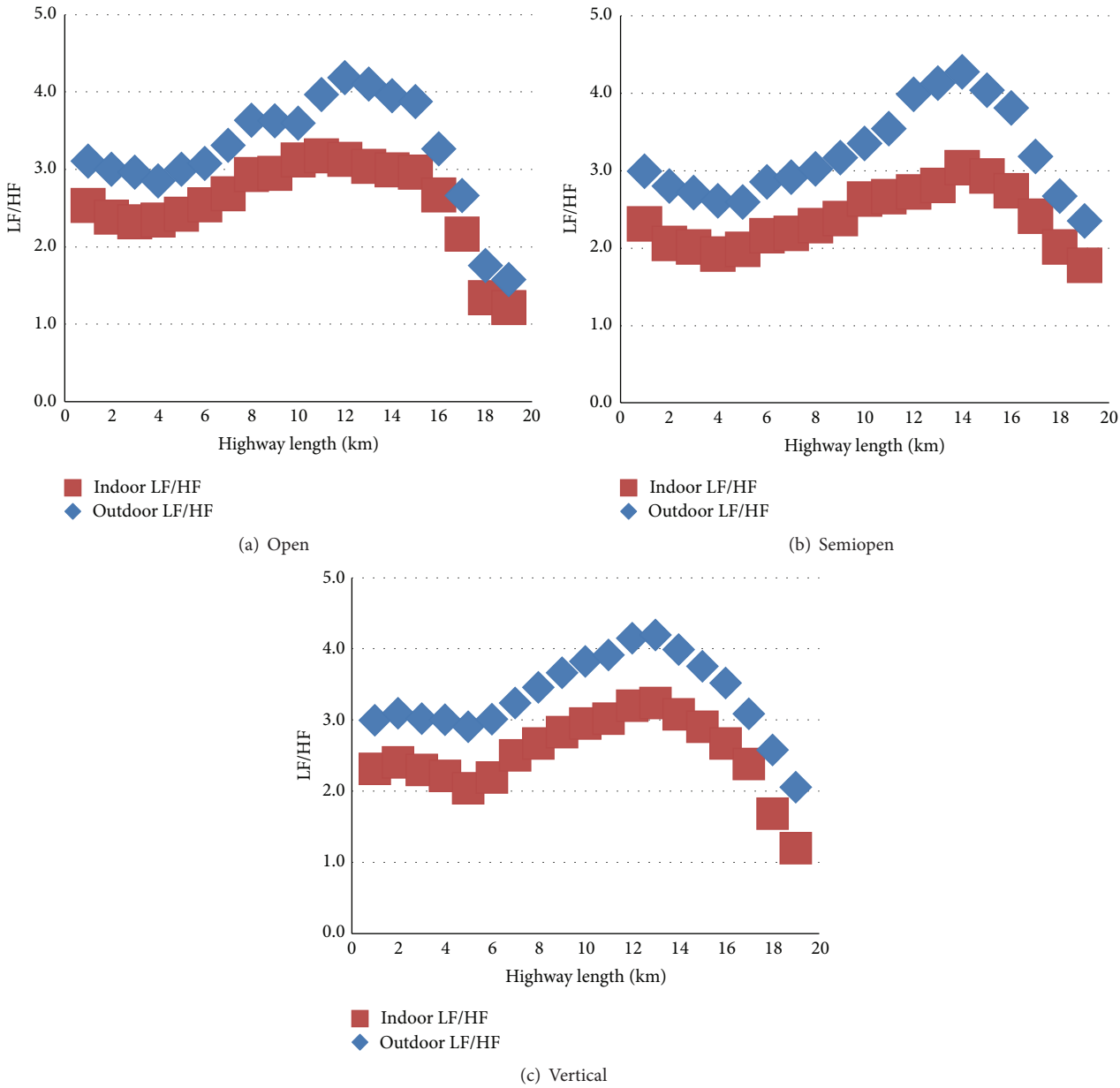


Figure 10: Scatter distribution of LF/HF in the real and simulated vertical scenario.

unstably. The rule behind the semiopen scenario is not easy to grasp or evaluate, which will not be further discussed in this study. But because of its strong compatibility and plasticity to the natural landscape, it deserves further discussion and exploration.

(iv) The highway length may be highly correlated with the visual quality of natural landscape. When the visual quality of natural landscape is low, the length threshold is recommended to be used. However, when the visual quality of natural landscape is high, the length threshold may be not suitable to use. So the aspect deserves in-depth exploration.

Conflict of Interests

The authors declare that there is no conflict of interests regarding the publication of this paper

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References

[1] A. Amekudzi, M. Smith, S. R. Brodie, J. Fischer, and C. Ross, "Impact of environmental justice on transportation," *Transportation Research Record*, vol. 2320, pp. 1–9, 2012.

[2] J. Lu, L. Yuan, and Q. Ge, "Development of a model for freeway green landscape evaluation," *Journal of Transportation Research Record*, vol. 2025, pp. 68–71, 2008.

[3] E. Shay and A. J. Khattak, "Automobiles, trips, and neighborhood type," *Journal of Transportation Research Record*, vol. 2010, pp. 73–82, 2007.

[4] R. Naderi, B. S. Kweon, and P. Maghelal, "Simulating impacts of curb-side trees on driver performance and perceptions," in *Proceedings of the 85th Annual Meeting of the Transportation Research Board*, pp. 1–23, Washington, DC, USA, January 2006.

[5] N. J. Rosenblatt, "Landscape design in the clear zone: effect of landscape variables on pedestrian health and driver safety," *Journal of Transportation Research Record*, vol. 1851, pp. 119–130, 2003.

[6] H. Antonson, S. Mårdh, M. Wiklund, and G. Blomqvist, "Effect of surrounding landscape on driving behaviour: a driving simulator study," *Journal of Environmental Psychology*, vol. 29, no. 4, pp. 493–502, 2009.

[7] R. M. Yerkes and J. D. Dodson, "The relation of strength of stimulus to rapidity of habit-formation," *Journal of Comparative Neurology and Psychology*, vol. 18, no. 5, pp. 459–482, 1908.

[8] P. G. Spooner, I. D. Lunt, and S. V. Briggs, "Spatial analysis of anthropogenic disturbance regimes and roadside shrubs in a fragmented agricultural landscape," *Applied Vegetation Science*, vol. 7, no. 1, pp. 61–70, 2004.

[9] R. Parsons, L. G. Tassinary, R. S. Ulrich, M. R. Hebl, and M. Grossman-Alexander, "The view from the road: implications for stress recovery and immunization," *Journal of Environmental Psychology*, vol. 18, no. 2, pp. 113–140, 1998.

[10] J.-H. Mok, H. C. Landphair, and J. R. Naderi, "Landscape improvement impacts on roadside safety in Texas," *Landscape and Urban Planning*, vol. 78, no. 3, pp. 263–274, 2006.

[11] P. Thiffault and J. Bergeron, "Monotony of road environment and driver fatigue: a simulator study," *Accident Analysis and Prevention*, vol. 35, no. 3, pp. 381–391, 2003.

[12] B. Mehler, B. Reimer, L. A. D'Ambrosio, A. Pina, and J. F. Coughlin, "An evaluation of time of day influences on simulated driving performance and physiological arousal," in *Proceedings of the 89th Annual Meeting of the Transportation Research Board on Traffic and Transport Planning*, pp. 1–15, Transportation Research Board of the National Academies, Washington, DC, USA, January 2010.

[13] B. Mehler, B. Reimer, J. F. Coughlin, and J. A. Dusek, "Impact of incremental increases in cognitive workload on physiological arousal and performance in young adult drivers," *Journal of Transportation Research Record*, vol. 2138, pp. 6–12, 2010.

[14] K. A. Brookhuis and D. W. Dick, "Measuring physiology in simulators," in *Safety and Human Factors*, CD-ROM, pp. 1–10, Transportation Research Board of the National Academies, Washington, DC, USA, 2011.

[15] H. Cai and Y. Lin, "Modeling of operators' emotion and task performance in a virtual driving environment," *International Journal of Human-Computer Studies*, vol. 69, no. 9, pp. 571–586, 2011.

[16] H. Antonson, C. Ahlström, S. Mårdh, G. Blomqvist, and M. Wiklund, "Landscape heritage objects' effect on driving: a combined driving simulator and questionnaire study," *Accident Analysis & Prevention*, vol. 62, pp. 168–177, 2014.

[17] X. Zhao, K. Mao, J. Rong, and J. Ma, "A study of the relationship between driver fatigue and monotonous road environment," in *Proceedings of the 91st Annual Meeting of the Transportation Research Board on Safety and Human Factors*, CD-ROM, pp. 1–14, Transportation Research Board of the National Academies, Washington, DC, USA, January 2012.

[18] Z. Wei, *Research on highway landscape design theory [Ph.D. thesis]*, Beijing University of Technology, Beijing, China, 2005.

[19] X. Chen, Z. Wei, X. Zhao, M. Hao, and T. Zhang, "Conspicuity research on the highway roadside objects: a simulator study," *Discrete Dynamics in Nature and Society*, vol. 2014, Article ID 864791, 9 pages, 2014.

[20] Transit New Zealand National Office, *Guidelines for Highway Landscaping*, Debbie Firestone, 2003.

[21] T. Kontogiannis, "Stress and operator decision making in coping with emergencies," *International Journal of Human-Computer Studies*, vol. 45, no. 1, pp. 75–104, 1996.

[22] K. A. Brookhuis and D. Waard, *Assessment of Drivers' Workload: Performance, Subjective and Physiological Indices*, edited by: P. Hancock, P. Desmond, Lawrence Erlbaum Associates, Mahwah, NJ, USA, 2001.

[23] L. Tijerina, M. Blommer, R. Curry et al., "Simulator study of effects of alternative distraction mitigation strategies in driver workload manager," *Transportation Research Record*, vol. 2248, pp. 81–86, 2011.

[24] B. Mehler, B. Reimer, and Y. Wang, "A comparison of heart rate and heart rate variability indices in distinguishing single-task driving and driving under secondary cognitive workload," in *Proceedings of the 6th International Driving Symposium on Human Factors in Driver Assessment, Training and Vehicle Design*, pp. 590–597, Lake Tahoe, Calif, USA, June 2011.

[25] J. D. Lee, D. V. McGehee, J. L. Brown et al., "Matching simulator characteristics to highway design Problems," *Journal of Transportation Research Record*, vol. 2248, pp. 53–60, 2011.

[26] G. J. Allen and B. Mike, "Physical fidelity of driving simulators," in *Safety and Human Factors*, CD-ROM, pp. 1–24, Transportation Research Board of the National Academies, Washington, DC, USA, 2011.

[27] J.-M. Auberlet, F. Rosey, F. Anceaux et al., "The impact of perceptual treatments on driver's behavior: from driving simulator studies to field tests-first results," *Accident Analysis & Prevention*, vol. 45, pp. 91–98, 2012.

[28] C. Zhao, M. Zhao, J. Liu, and C. Zheng, "Electroencephalogram and electrocardiograph assessment of mental fatigue in a driving simulator," *Accident Analysis & Prevention*, vol. 45, pp. 83–90, 2012.

[29] R. van der Horst and S. de Ridder, "Influence of roadside infrastructure on driving behavior: driving simulator study," *Transportation Research Record*, vol. 2018, pp. 36–44, 2008.

[30] Z.-D. Zhu, Y.-C. Lu, C.-H. Fu, and T. Xu, "Research on the safety audit methods for two-lane highway based on HRV," *Mathematical Problems in Engineering*, vol. 2014, Article ID 308028, 6 pages, 2014.

[31] J. F. Brosschot, E. van Dijk, and J. F. Thayer, "Daily worry is related to low heart rate variability during waking and the subsequent nocturnal sleep period," *International Journal of Psychophysiology*, vol. 63, no. 1, pp. 39–47, 2007.

[32] Y. J. Li, H. Yan, W. Chen et al., "Different characteristics of heart rate variability in mental and physical fatigue states," *Space Medicine & Medical Engineering*, vol. 23, no. 3, pp. 157–162, 2010.

[33] K. Zuzewicz, A. Saulewicz, M. Konarska, and Z. Kaczorowski, "Heart rate variability and motion sickness during forklift simulator driving," *International Journal of Occupational Safety and Ergonomics*, vol. 17, no. 4, pp. 403–410, 2011.

[34] M. F. Bear, B. W. Connors, and M. A. Paradiso, *Neuroseience. Exploring the Brain*, Lippincott Williams & Wilkins, Baltimore, Md, USA, 2001.

[35] P. Nickel and F. Nachreiner, "Sensitivity and diagnosticity of the 0.1-Hz component of heart rate variability as an indicator of mental workload," *Human Factors*, vol. 45, no. 4, pp. 575–590, 2003.