Landscape and Urban Planning xxx (xxxx) 105156

Contents lists available at ScienceDirect

Landscape and Urban Planning

journal homepage: www.elsevier.com/locate/landurbplan

Research Paper

Greener view, safer drive: Using repeated field experiments to investigate impacts of urban road landscapes on driving performance

Wenyan Xu [a,b], Jibo He [c], Lan Luo [a,b], Bin Jiang [a,b,d,*]

[a] Urban Environments & Human Health Lab, HKUrbanLabs, The University of Hong Kong, Hong Kong, China
[b] Division of Landscape Architecture, Department of Architecture, The University of Hong Kong, Hong Kong, China
[c] Department of Psychology, Tsinghua University, Beijing, China
[d] Urban Systems Institute, The University of Hong Kong, Hong Kong, China

ARTICLE INFO

Keywords:
Driving performance
Road environments
Deep learning
Real-world urban driving
Greenness

ABSTRACT

Driving in urban environments is an essential part of urban residents' daily life. We still know little about impacts of a wide range of greenness on driving performance in the real urban environments, after controlling for socioeconomic, demographic, driving record, and other environmental factors. This missing knowledge prevents policymakers and professionals from using appropriate planning and design of green landscapes to create safe driving environments for numerous urban residents. This study aimed to address this significant knowledge gap by using real-world driving experiments. Each of thirty-four residents performed seven driving tasks so 238 driving tasks were completed in total. Each task lasted one hour and followed a randomly assigned sequence. Road greenness and other environmental characteristics were analyzed using deep transfer learning semantic segmentation based on live videos (30 frames per second), which were recorded by a camera positioned to capture the driver's eye view. A serial communication technology, known as Controller Area Network bus (CANbus), was employed to continuously measure driving performance using four parameters. A series of hierarchical regression analyses yielded three major findings: First, an increased mean of greenness was associated with improved driving performance, as demonstrated by all four parameters. Second, an increased variation of greenness was also associated with better driving performance in three parameters.

Finally, the mean of greenness displayed a stronger positive relationship with driving performance than the variation of greenness in three parameters. The findings imply that both quantity and quality of green landscapes are critical for promoting driving performance in urban areas.

1. Introduction

Over the past decades, rapid urbanization has dramatically accelerated the use of motorized transport worldwide, leading to an alarming increase in road traffic injuries and fatalities (Jiang et al., 2017). According to data from the World Health Organization (WHO) (2020), road traffic crashes result in approximately 1.35 million deaths annually. Poor driving performance has been identified as a major contributing factor to traffic accidents (Rolison et al., 2018).

Urbanization has been linked to increased barren and monotonous environments, increased traffic congestion, reduced road visibility, and higher levels of air and noise pollution, all of which can negatively impact driving performance (Cabrera-Arnau et al., 2020). Furthermore, the stress and distraction associated with navigating complex urban environments can lead to impaired decision-making and reduced reaction times among drivers (Chiang et al., 2022; Jiang, He, Chen, Larsen, & Wang, 2020). As urban populations continue to expand and the demand for efficient transportation rises, it becomes increasingly crucial to find solutions to promote driving performance and safety in urban settings.

A great number of studies already found that drivers' socioeconomic and demographic factors and driving experience can impact ones driving performance. For example, driver age and gender have been proven to be highly associated with crashes and collisions (Chen & Chen, 2011; Lam, 2002; Sun et al., 2019), with young drivers tending to drive quickly and lack experience, leading to accidents (Gitelman et al., 2018; Lam, 2002), and male drivers being more likely to be involved in fatal accidents and collisions than female drivers (Benlagha & Charfeddine, 2020). Driving experience can increase the consistency of group operations and reduced the likelihood of hazard occurrence (Du et al., 2022).

* Corresponding author at: 614 Knowles Building, Pokfulam Road, The University of Hong Kong, Hong Kong, China.
E-mail address: jiangbin@hku.hk (B. Jiang).

https://doi.org/10.1016/j.landurbplan.2024.105156
Received 2 August 2023; Received in revised form 21 May 2024; Accepted 8 July 2024
0169-2046/© 20XX

In recent years, more and more studies suggested that environmental factors, including artificial and natural features, can influence drivers' driving performance (e.g., Anciaes, 2023; Cai et al., 2022; Jiang, He, Chen, & Larsen, 2021). However, due to methodological limitations of site selection (e.g., reliance on simulated driving environments), duration of driving test (e.g., short duration that cannot reflect the daily driving pattern), and measures of driving performance (e.g., reliance on self-reported or general measures), findings of previous studies provided limited support for us to understand that whether and to what extent environmental characteristics of urban roads, especially roadside landscapes, can influence common residents' driving performance in their daily urban life. To address this critical and pressing knowledge gap, we conducted this study as an initial effort.

1.1. Literature review: environmental factors of urban road and driving performance

Many studies found that artificial features within the urban road corridor, such as building facades, overpasses, vehicles, and pedestrians, can influence drivers' visual perception of urban roads, thus affecting driving performance (Choi et al., 2020). In terms of traffic signs, a study found that chevron alignment signs played a significant role in advance warnings and positive guidance, leading to a drop speed through road curves, in turn improving road driving safety (Wu et al., 2013). Researchers also found that placing over two chevrons in view around the curve could reduce driving speed (Rose & Carlson, 2005). Another study found that traffic signs carrying excessive information often causes difficulties in reading and understanding, which leads to mental fatigue and riskier driving (Lyu et al., 2017).

A handful of studies investigated impacts of roadside green landscapes on driving performance, but the findings are not highly conclusive. Some studies suggested a positive association between roadside greenness and driving performance (e.g., Song et al., 2018; Van Treese et al., 2018; Wu et al., 2020). Two studies investigated freeway landscapes: One study found that landscape conditions with moderately high level of greenness yielded the best driving performance (Jiang, He, Chen, & Larsen, 2021), and another study found that a higher dose of green landscape resulted in a shorter reaction time during an emergency incident (Chiang et al., 2022). Moreover, studies reported that the presence of roadside trees may positively perform in controlling driving speed (Van Treese et al., 2018), and enhancing the safety through providing shades for vehicles and pedestrians and reducing driver eye strain (Song et al., 2018), while the absence of trees was associated with more frequent grasps of the steering wheel, suggesting greater complexities in controlling the vehicle (Antonson et al., 2009).

However, a few other studies reported negative or neutral associations between roadside greenness and driving performance. Roadside trees are found to be visual obstacles or distractions for drivers (Calvi, 2015; Van Treese et al., 2018), and tree density affects drivers' visibility, increasing the risk of road accidents (Choi et al., 2020). Two other studies revealed no significant association between roadside vegetation density and height and decreased speed or deviations in lateral positioning (Fitzpatrick et al., 2016; Parwathaneni, 2016).

1.2. Four significant knowledge gaps

Based on the review and criticism of literature, we would point out four significant knowledge gaps.

First, Lastly, Previous studies have primarily focused on one or a few specific types of roadside landscapes, without examining sites that span a wide spectrum of greenness levels. As a result, they have been unable to depict a dose–response relationship between greenness and driving performance. The absence of this knowledge has hindered a more comprehensive and holistic understanding of the connection between these factors.

Second, although studies have found that road landscapes influenced driving performance significantly, they were mostly conducted on simulated experimental laboratory environments. Although the simulated driving study can provide a well-controlled experimental environment, it has often been criticized for lacking realism compared to real-world driving (Caird et al., 2014; Oviedo-Trespalacios et al., 2017), which may contribute to a low level of ecological validity.

Third, a few on-site experimental studies have been conducted to investigate the effects of real road environments on driving performance. However, many studies adopted short-time driving tests (e.g., 10 or 15 min) (Cassarino et al., 2019; Fitzpatrick et al., 2016), which cannot fully represent the moderate-time driving for daily commutes (around 30–60 min) (Jiang, He, Chen, & Larsen, 2021).

Lastly, a notable limitation in many studies is the lack of involvement of investigators from the fields of landscape and urban planning. This has led to the rough measurement and investigation of many landscape and architectural factors. Consequently, these studies have been unable to provide adequate suggestions for utilizing landscape and urban planning approaches to enhance driving performance.

In sum, the current knowledge is insufficient for us to understand potential impacts of curbside landscape of urban roads on driving performance in real world. As an inevitable consequence, the planning and design of those landscapes might be misled.

1.3. Central objective of the study

To address the knowledge gaps, we conducted this study as an initial exploration. The specific objective is to examine how a wide but common range of greenness along urban roads influence driving performance while controlling for socioeconomic, demographic, driving record, and other environmental factors. We also aimed to use findings from this study to support evidence-based planning and design of urban road environments to promote efficient and safe drive.

The innovative of study includes using real-world driving experiments and proposing a set of novel methods to obtain real time perception of road environment and transportation condition. Moreover, this study adopted a 60-min two-way driving task as a reasonable representation of the daily driving pattern of ordinary urban residents, as it aligns with the common driving time of residents in various countries and cities for commuting and recreational purposes (Please see Appendix A for the detailed rationale).

2. Methods

Real-world driving experiments on urban roads were employed to examine impacts of roadside greenness on driving performance (Fig. 1). Driving routes were decided after two-month site investigation and pilot study. The formal experiments were conducted from 25th November 2020 to 26th January 2021, and all participants were asked to conduct driving seven driving tasks on the planned routes. Research methods are introduced below in four parts: participants, apparatus and procedures, measurements of driving performance, and deep transfer learning for image segmentation and statistical analysis.

2.1. Participants

Forty-one healthy adult residents in Liuzhou city were recruited to participate in the experiment through a public job search website and a major social media app (WeChat). The study has received ethical approval from a university (anonymous before publication). All participants were required to meet the following criteria: (1) have a valid driving license for two or more years, (2) aged between 18 and 60 years old, (3) no diagnosis of cardiovascular diseases and mental disorders, (4) no physical disability, (5) no traumatic vehicle accident, (6) eyesight greater than 5.0 after visual correction, (7) no alcohol or caffeine

Fig. 1. Setting for the real-world driving experiments on urban roads.

intake within six hours of the experiment, (8) at least seven hours of sleep the night before the experiment, and (9) should not be or had been professional drivers, such as truck drivers, taxi drivers, or ride-hailing drivers.

2.2. Apparatus and procedure

2.2.1. Site city and driving settings

A modern and international style city located in the South China was chosen to be the study site (Liuzhou City). The site city serves as a representative example of a contemporary urban area, characterized by its moderate building and population density and ordinary modern environmental features along the roads. Located within the subtropical climate region, this city maintains a constant appearance in its roadside landscapes year-round. The transportation infrastructure mainly includes a handful of urban ring roads and arterial thoroughfares, which comprise a ubiquitous traffic network found in numerous cities globally. Consequently, the outcomes of this investigation may hold a decent level of applicability and relevance to a multitude of modern urban environments worldwide.

After two-month site investigation and pilot study, seven driving routes located in the urban areas were selected and monitored via a mobile map app (Gaode Map: An app that is similar as Google Map, website: https://m.amap.com/), providing information of traffic volume and real-time tracking. Each route includes a starting point, an ending point, and one or more passing points to shape the planned route. These routes were chosen randomly across urban areas, following the four criteria: (1) no or limited construction and heavy dust pollution, (2) no severe traffic jams throughout the day, (3) exclusion of roads that are too wide or too narrow, and (4) no sighting of obvious historical and cultural features or waterbodies. Fig. 2 shows four sample photographs of each driving route.

2.2.2. Procedure of experiment

Driving is a complex behavior that accompanies multiple cognitive and information processes, and the traffic on the real road is often consistently changing conditions. These may cause interference on the research questions. To decrease these interferences, each participant completed seven planned driving routes at one-day interval; but when encountering extreme weather conditions, such as heavy rain or typhoons, the experimental date is postponed accordingly. The range for the driving experiments were wide (8:40–12:00 and 13:30–17:00) to match people's normal commuting time and avoid dining times as a part of ethical requirements. Each experiment and driving task took approximately 78 min to complete (Fig. 3).

First, participants were invited to meet the investigator at a hotel parking lot to sign the consent form and were informed of the objective of this study. They were also briefed about the whole experiment, including the one-hour driving task. Investigators tested the participants' vision using the Standard Logarithmic Visual Acuity Chart, and then instructed them to drive to the place for departure. Before the driving experiment began, each participant was instructed to get familiarized with the planned route by having a 60-min two-way driving practice, followed by a 3-min rest. In the driving phrase, participants were informed that they would be guided by the AutoNavi Voice Navigation during the 60-min back and forth trip on the assigned planed route. Investigators also emphasized that it was not compulsory to finish all planned routes to ensure participants could drive as usual without potential stress from the time constraint, limiting the possible increase of mental burden. After the 3-min rest in the car, each participant conducted the 60-min driving task (i.e., 30-min driving towards one direction and 30-min back. After the driving, each participant was asked to answer a background questionnaire to report their socioeconomic, demographic, driving record, and other background information.

2.2.3. Rules of the driving task

During the 60-min driving task, participants were asked to follow six rules: (1) Follow the planned routes and adjust the departure location only if it cannot be reached, e.g., due to road closures for repairs or traffic accidents, (2) try to drive in the right lane and avoid following cars too closely, changing lanes, or overtaking cars unless necessary, (3) keep the windows closed and set the temperature at 26 degrees Celsius, (4) refrain from listening to music, making telephone calls, engaging in conversations, or creating other noises, (5) abstain from eating food, drinking alcohol, or consuming caffeine, and (6) obey all traffic regulations and laws, including speed limits.

2.3. Measurement of driving performance

We continuously recorded the following four driving parameters using the CAN bus systems and software for measuring driving performance: mean of speed, standard deviation of speed, steering holds frequency, and steering reversal rate (Table 1). The selection of these parameters refers to parameters adopted by widely recognized studies on the similar topic (e.g., He et al., 2014; Jiang, He, Chen, & Larsen, 2021; Macdonald & Hoffmann, 1980): A higher value of steering reversal rate indicate a better driving performance while higher values of other three parameters indicate poorer driving performance.

2.4. Deep transfer learning for image segmentation

2.4.1. Real time image data

A camera was placed at eye-level where the drivers seated in the car to record out-car environmental conditions (the back camera of an Oppo Reno 2). A one-hour continuous video was recorded at a fixed angle, in color at 30 frames per second, and 1920 × 1080-pixel resolution. To decrease the data processing time while ensuring the accuracy of the image data, a frame in portable network graphics (PNG) format from each three seconds was selected using Python 3.8.8 (Chen et al., 2022).

Fig. 2. Four representative photographs of each driving route (captured during driving).

2.4.2. Deep transfer learning-based semantic segmentation

Numerous studies have utilized street view images and machine learning to audit street-level environmental features (e.g., Ma et al., 2021; Zhang et al., 2018). To obtain detailed environmental features during one-hour driving, the mean proportion of each environmental feature within the driving scene (mean of each feature within the environment of a one-hour driving) and the proportion of changes of each feature (variation of each feature within the environment of a one-hour driving) were analyzed. The environmental features were calculated by semantic segmentation analysis using the DeepLab (Ver. 3 + with the Xception_65 backbone) approach. The DeepLab is effective in producing high-quality results on the scene parsing task and achieve state-of-the-art pixel-level prediction performance on diverse datasets, including Cityscapes (Li et al., 2022; Xue et al., 2021). Through deep transfer learning, we utilized a pre-trained Cityscapes model to classify every pixel in an input image into a semantic view label, resulting in the segmentation of each photo into 19 categories of ground objects. To determine the proportion of each object in the image, we calculated the ratio of the number of pixels representing the object to the total number of pixels in the image. We measured area occupied by vertical plants with a significant 3D profile, including trees and shrubs, to describe the condition of roadside greenness for each sampled moment during the driving; We measured areas occupied by sky, buildings, roads, traffic lights, traffic signs, vehicles, and pedestrians to represent environmental and traffic conditions for each sampled moment during the driving (Fig. 4).

It is important to note that the measure of greenness counted areas occupied by both trees and shrubs because the DeepLab cannot detect

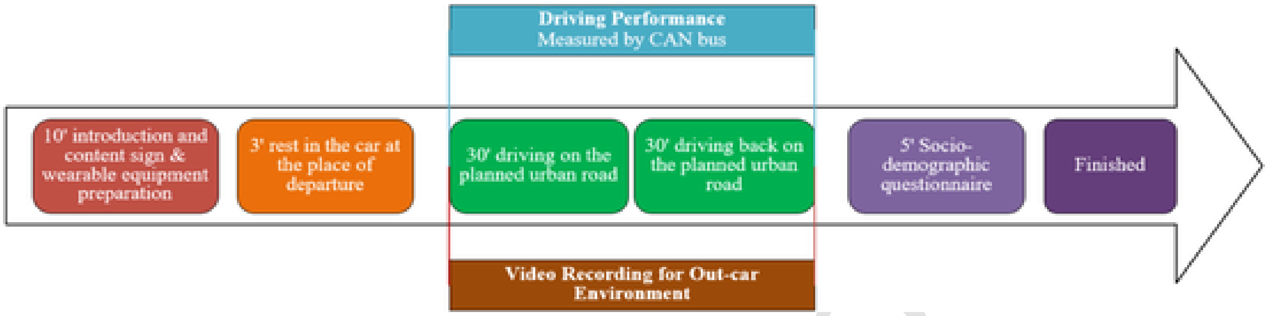

Fig. 3. Procedure of experiment.

Table 1
Driving parameters' definition and indicative meaning to driving performance.

Driving parameters	Definition	Referential meanings to driving performance
Mean of Speed (km/h)	The mean value of vehicle travelling velocity.	A higher value often means a more radical driving strategy (He et al., 2014).
Standard Deviation of Speed (km/h)	The variability of speed in vehicle travelling velocity, as indicated by its standard deviation.	A higher value means poorer control and variability of driving speed (He et al., 2014).
Steering Holds Frequency (Hz)	The number of times in a second that the steering wheel position keeps unchanged continuously for no less than 400 ms.	A higher value means a poorer control of steering position (He et al., 2014).
Steering Reversal Rate (Hz)	The number of steering reversals per second that a change of the steering wheel position larger than two degrees within the time that steering wheel velocity leaves and then returns to zero-velocity bands (Ranney et al., 2005; Tijerina et al., 1995).	A higher value means a better lane keeping performance (Jiang, He, Chen, & Larsen, 2021; Macdonald & Hoffmann, 1980)

them as two different variables although the tree seems a dominating component of roadside green landscapes (Fig. 2). Moreover, terrain was not included in the data analysis as it accounted for an extremely low proportion of the visible environmental features (mean of proportion = 0.003, see details in Appendix B). The computer for data collection and processing was a Windows 10 workstation with dual Intel Xeon E5-2690 v4 (2.6 GHz, 28 cores), Nvidia Quadro P5000 GPU, and 64 GB memory (Xue et al., 2021).

2.5. Statistical analysis

The statistical analysis included three major parts. First, descriptive statistics were used to describe the drivers' socio-economic and demographic characteristics, greenness and other environmental factors, and driving performance. Second, a correlational analysis was conducted to reveal the basic relationships among driving performance and greenness, and other environmental factors. Third, a set of three-layer hierarchical linear regression models were conducted to reveal the association between greenness and driving performance after controlling for confounding factors.

For the three-layer hierarchical regression analysis: the first model (Model 1) included the socio-economic, demographic, driving history, and behavioral factors only, the second model (Model 2) included these factors in Model 1 as well as the environmental factors except greenness, the last model (Model 3) included greenness and all factors of Model 2. The inclusive variables for all models were refined with the variance inflation factor criterion (VIF) ≥ 4 to remove multicollinearity from the regression (O'brien, 2007). The model coefficient estimates (β), standard errors (Std. Error), t-values, and p-values for coefficient estimates were reported. The statistical analysis was conducted in R Studio version 4.1.1.

3. Results

The results are presented in three parts. First, we present descriptive statistics of socio-demographic backgrounds of drivers. Second, the correlational scores of environmental characteristics and driving performance are reported. Third, results of hierarchical linear analysis are

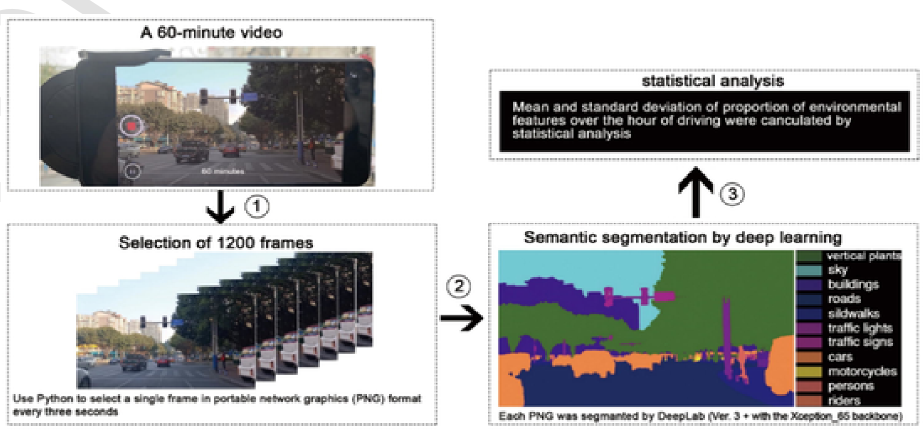

Fig. 4. Main procedure of image selection and semantic segmentation of greenness and other environmental characteristics.

presented to reveal the link between road greenness and driving performance indicated by four parameters.

3.1. Descriptive statistics of participants' socio-economic and demographic characteristics

This study recruited 41 participants and 34 of them completed all assigned experiments (16 females and 18 males). This retention rate is considered satisfactory and falls within the normal range reported in previous experimental studies investigating similar research questions (e.g., Fewtrell et al., 2008; Jiang, He, Chen, & Larsen, 2021; Kristman et al., 2004). Moreover, a priori power analysis using G*Power software (Faul et al., 2007) indicated that a sample size of 34 participants would provide sufficient statistical power (0.98) to detect medium-sized effects at an alpha level of 0.05 (Cohen, 1992; Jiang, He, Chen, & Larsen, 2021). The age of participants well reflected the age range of working population (Mean = 34.61; SD = 5.34). Most of the participants received an education at or above the level of secondary school (95.12 %). All participants held a driver license for at least two years. The mean duration of holding a driver's license was 9.72 years (SD = 5.49), while the mean duration of actual driving experience was 8.84 years (SD = 5.29). Majority of participants reported they drove at least one time each day (27 participants) and drove with a moderate or long-time duration (30 participants). Most of the participants reported they had moderate or even better driving performance (33 participants), with additional details provided in Table 2.

3.2. Descriptive statistics of greenness, other environmental features, and driving performance

Overall, the greenness (vertical plants) took high percentage of road environments (Mean = 32.13 %, SD = 5.86 %). Variation of greenness ranged from 13.11 % to 27.04 % (Mean = 18.05 %, SD = 2.64 %). Mean and variation of other environmental features can be found in Table 3. For driving performance parameters, the mean speed was 25.79 km/h, and standard deviation of speed was 16.86 km/h. Mean of steering holds frequency was 58.10 Hz and mean of steering reversal rate was 46.94 Hz.

The bivariate correlation analysis was conducted and presented in Fig. 5. The correlations between four parameters are low (0.30–0.50) or moderate (0.50—0.70), which suggests that they do not have a collinearity problem and each parameter can make a unique contribution to depict the driving performance. Similar low or moderate correlations were also evident for environmental characteristics.

3.3. Modeling association of roadside greenness on driving performance

3.3.1. Significant association between mean of greenness and driving performance after controlling for covariates

After adjusting for socio-economic demographic factors and environmental features in Model 3, the results consistently showed that a higher level of greenness (vertical plants) was significantly associated with better driving performance, as evidenced by lower driving speed (change of adjusted $R^2 = 0.02$, $\beta = -1.16$, $p < 0.001$), lower standard deviation of speed (change of adjusted $R^2 = 0.12$, $\beta = -1.42$, $p < 0.001$), lower steering holds frequency (change of adjusted $R^2 = 0.22$, $\beta = -0.66$, $p < 0.001$), and higher steering reversal rate (change of adjusted $R^2 = 0.02$, $\beta = 7.04$, $p < 0.01$; Fig. 6 and Appendix C (Tables C1–C4)).

3.3.2. Significant association between variation of greenness and driving performance after controlling for covariates

After controlling for socio-economic demographic factors and environmental features in Model 3, the results consistently showed that more variation of greenness (vertical plants) along urban roads was sig-

Table 2
Descriptive statistics of socio-economic and demographic characteristics.

Measures	N	%	Measures	N	%
Sex			**Marital status**		
Male	18	52.94 %	Divorced/Separate/Widowed	5	14.71 %
Female	16	47.06 %	Married/Cohabitation	20	58.82 %
			Never married	9	26.47 %
Age			**Family member**		
25–30	9	26.47 %	1	2	5.88 %
31–35	8	23.53 %	2	2	5.88 %
36–40	12	35.29 %	3	10	29.41 %
41–45	4	11.76 %	4	10	29.41 %
46–50	1	2.94 %	5	8	23.53 %
			6	1	2.94 %
			≥7	1	2.94 %
Education level			**Monthly household income (Chinese Yuan)**		
Primary School and below	1	2.94 %	<5000	5	14.71 %
Junior	1	2.94 %	5000–9999	13	38.24 %
Secondary School	8	23.53 %	10,000–14,999	10	29.41 %
Diploma	6	17.65 %	15,000–19,999	3	8.82 %
≥ Three-year college	18	52.94 %	20,000–24,999	1	2.94 %
			≥ 25,000	2	5.88 %
Year (s) holding a driver license (driving experience)			**How often have you been convicted of any moving violations (e.g., violations of parking or traffic lights)?**		
2–5	8	23.53 %			
6–10	13	38.24 %	0 time	15	44.12 %
11–15	7	20.59 %	1–5 times	18	52.94 %
15–20	5	14.71 %	6–10 times	1	2.94 %
>20	1	2.94 %			
Year (s) driving actually			**How often have you involved accidents in your traffic violation?**		
1–5	12	35.29 %			
6–10	10	29.41 %	0 time	30	88.24 %
11–15	9	26.47 %	1–2 times	4	11.76 %
16–20	3	8.82 %			
>20	0	0			
How often do you drive every day? (Frequency)			**Self-reported historical driving performance**		
Less than once a day	7	20.59 %			
1–2 times	17	50.00 %	bad	1	2.94 %
3–4 times	4	11.76 %	Moderate	10	29.41 %
5–6 times	2	5.88 %	good	8	23.53 %
7–8 times	1	2.94 %	Very good	13	38.24 %
More than 8 times	3	8.82 %	Extremely good	2	5.88 %
How long time do you spend on each drive on average?			**What extent of familiarity do you have to Liuzhou city roads?**		
Less than 20 min	4	11.76 %			
20–40 min	19	55.88 %	Very unfamiliar	3	8.82 %
41–60 min	8	23.53 %	Unfamiliar	14	41.18 %
61–80 min	3	8.82 %	Moderate familiar	11	32.35 %
> 80 min	0	0.00 %	Familiar	4	11.76 %
			Very familiar	2	5.88 %
How long have you driven in the last year?					
0–5000 km	3	8.82 %			
5001–10,000 km	9	26.47 %			

(continued on next page)

Table 2 (*continued*)

Measures	N	%	Measures	N	%
10,001–15,000 km	10	29.41 %			
15,001–20,000 km	1	2.94 %			
20,001–25,000 km	0	0.00 %			
>25,000 km	9	26.47 %			

Note: 1 United States Dollar = 6.51 Chinese Yuan in 01/01/2021 (https://srh.bankofchina.com/search/whpj/search_cn.jsp).

Table 3
Descriptive statistics of greenness, environmental factors, and driving performance.

	Minimum	Maximum	Mean	Std. Deviation
Environmental characteristics				
Mean of greenness (vertical plants)	19.66 %	46.11 %	32.13 %	5.86 %
Mean of sky	12.45 %	55.24 %	33.33 %	9.72 %
Mean of roads	1.16 %	23.68 %	13.10 %	6.09 %
Mean of buildings	3.65 %	22.96 %	9.87 %	4.29 %
Mean of traffic lights	0.04 %	0.16 %	0.09 %	0.02 %
Mean of traffic signs	0.33 %	0.89 %	0.52 %	0.10 %
Mean of traffic vehicles	3.49 %	14.55 %	7.35 %	1.99 %
Mean of pedestrians	0.08 %	1.55 %	0.53 %	0.36 %
Variation of greenness (vertical plants)	13.11 %	27.04 %	18.05 %	2.64 %
Variation of sky	9.66 %	23.44 %	14.62 %	2.43 %
Variation of roads	1.23 %	9.33 %	5.48 %	1.67 %
Variation of buildings	5.74 %	20.96 %	10.32 %	2.36 %
Variation of traffic lights	0.10 %	0.41 %	0.20 %	0.06 %
Variation of traffic signs	0.62 %	1.62 %	0.92 %	0.17 %
Variation of vehicles	5.38 %	25.25 %	11.68 %	2.79 %
Variation of pedestrians	0.25 %	2.87 %	1.03 %	0.48 %
Driving performance				
Mean of speed	15.13	38.57	25.79	6.67
Standard Deviation of Speed	10.04	26.41	16.86	3.59
Steering Holds Frequency	53.24	59.95	58.10	1.10
Steering Reversal Rate	0.50	255.30	46.94	41.68

nificantly associated lower standard deviation of speed (change of adjusted $R^2 = 0.02$, $\beta = -0.83$, $p < 0.001$), lower steering holds frequency (change of adjusted $R^2 = 0.14$, $\beta = -0.61$, $p < 0.001$), and higher steering reversal rate (change of adjusted $R^2 = 0.03$, $\beta = 11.58$, $p < 0.001$; see Fig. 7 & Appendix C (Tables C5–C8)).

3.3.3. *Modeling association of both mean and variation of greenness and driving performance after controlling for covariates*

We further considered effects of both the mean and variation of roadside greenness (vertical plants) on driving performance in this last step of analysis. After adjusting for socio-economic and demographic characteristics and other environmental features, the result in Fig. 8 and Appendix C (Tables C9–C12) showed that mean of greenness was significantly and negatively associated with standard deviation of speed (change of adjusted $R^2 = 0.07$, $\beta = -1.16$, $p < 0.001$), and steering hold frequency (change of adjusted $R^2 = 0.24$, $\beta = -0.68$, $p < 0.001$), and positively associated with steering reversal rate (change of adjusted $R^2 = 0.02$, $\beta = 9.21$, $p < 0.01$). Overall, a higher proportion of greenness contributed to better driving performance.

4. Discussions

4.1. *Summary of major findings*

The aim of this study was to investigate the effects of roadside green landscapes on driving performance on urban roads. Using on-site driving experiments and deep learning analysis of environmental factors, this study found that a higher mean of greenness (vertical plants) was associated with a better driving performance indicated by all four parameters. Meanwhile, a higher variation of greenness was associated with a better driving performance indicated by three parameters. Furthermore, an integrated analysis revealed that the effect of mean of greenness was stronger than the effect of variation of greenness.

It is crucial to emphasize that the interpretations and discussions of our findings pertain to a moderately wide range of mean and variation in proportion of greenness, which could potentially represent the greenness of urban roads in numerous contemporary cities worldwide. Consequently, these insights may not be relevant for urban roads exhibiting exceedingly low or high levels of mean and variation in greenness. In the subsequent section, we delve into the interpretation of these findings, put forward recommendations for road landscape planning and design, and ultimately examine the limitations while offering suggestions for future research.

4.2. *A higher level of greenness linked to a better driving performance?*

4.2.1. *Why a higher mean of greenness may promote driving performance*

In this study, possible positive effects of greenness on driving performance are implied by the observed increased steering reversal rate, and decreased speed, speed variability, and steering holds frequency. These findings were supported by findings and discussions of previous studies although their specific site conditions and driving tasks were different. For example, (Calvi, 2015) found visual perception of a lower density roadside greenness was associated a poorer control of vehicle. Similarly, Jiang, He, Chen, and Larsen (2021) found that greenness was positively associated with a better driving performance indicated by objective parameters. In another study, Chiang et al. (2022) found that a higher mean of greenness was associated with a better driving performance indicated by the drivers' better attention capability and shorter response time.

There are three potential explanations for why a higher mean of greenness may contribute to a better driving performance on urban roads. First, the presence of greenery along urban roads may improve overall cognitive functioning, leading to safer and more efficient driving. Greenness can serve as a soft fascination to restore directed attention, enabling drivers to briefly shift their attention away from the road, thereby reducing fatigue or monotony, potentially leading to shorter reaction times for safe driving (Chiang et al., 2022). Second, the visual contact with greenery consumes our involuntary attention, thereby helping to restore directed attention according to Attention Restoration Theory (Kaplan & Kaplan, 1989; Kaplan, 1995).

On the contrary, environments with minimal or no greenery in urbanized areas tend to consume a significant portion of our directed attention (Chang et al., 2008; Hartig et al., 2003). Driving on urban roads with many vehicles, pedestrians, traffic signals, and other artificial features demand and consume more directed attention. Green trees provide a visual buffer for artificial streetscapes, which can lead to more positive mental responses (Chiang et al., 2022). Therefore, green landscapes may partially contribute to better driving performance by restoring our directed attention under complex driving tasks (Jiang, He, Chen, & Larsen, 2021).

Lastly, studies have shown that exposure to natural scenery could lower heart rate, blood pressure, and stress hormone levels (Ulrich et al., 1991; Ulrich, 1981), thereby contributing to a more relaxed and focused state of mind. Concerning driving tasks, the presence of greenery provides a more visually appealing environment, leading to a reduction in stress and anxiety levels while driving (Ulrich et al., 1991; Ulrich, 1981), thus inducing attractive driving experience (Wu et al., 2020), and reducing the likelihood of road rage and aggressive driving behaviors.

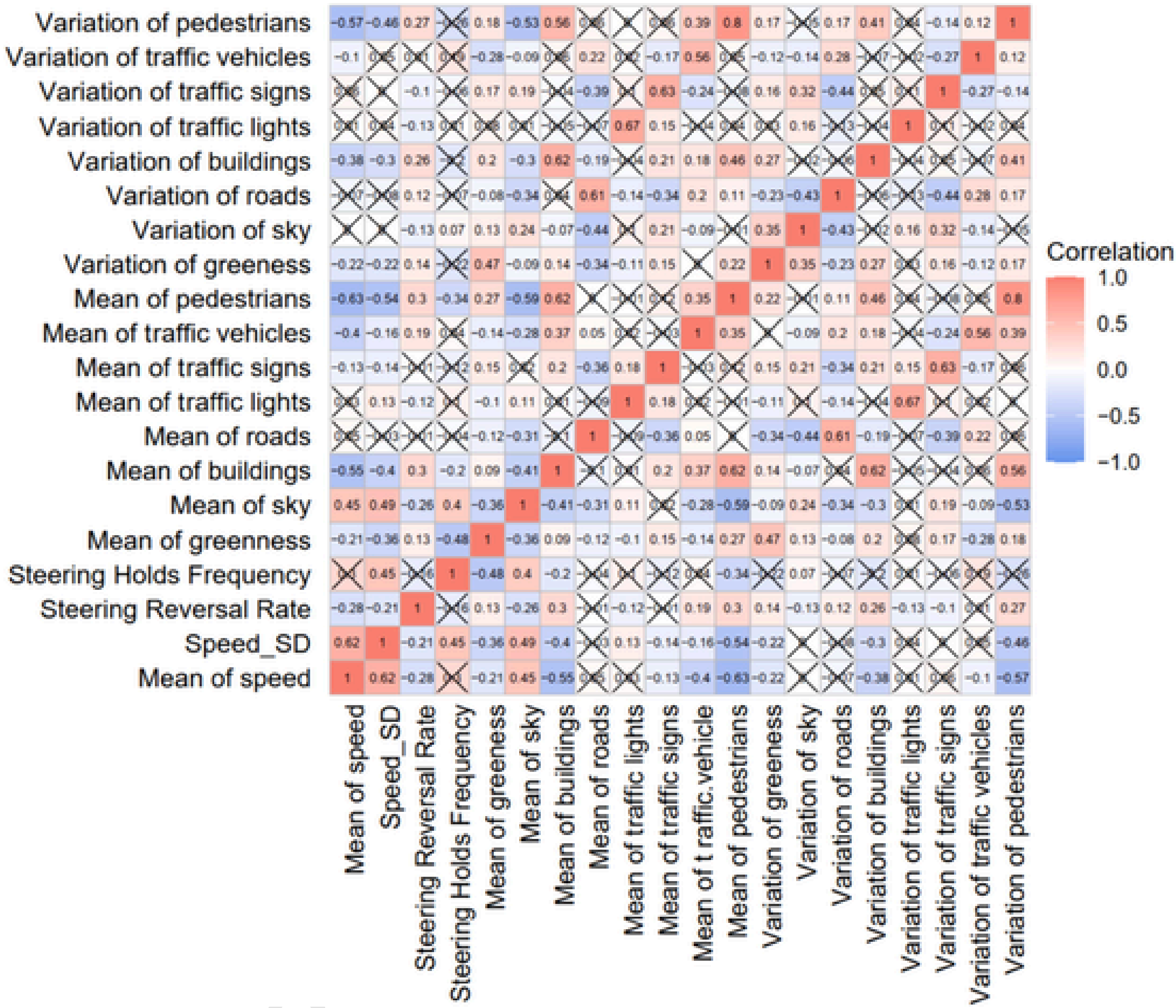

Fig. 5. Correlation analysis between driving performance parameters and environmental factors. The X indicates non-significant correlation ($p \geq 0.05$).

4.2.2. Why a higher variation of greenness may promote driving performance

The current study concludes that variation of roadside greenness can promote driving performance. The arousal theory may provide a reasonable interpretation of the findings. The arousal theory suggests that performance is poor when arousal is either too weak or very strong (see Davies & Parasuraman, 1982), similar to the explanation with reference to the Yerkes and Dodson Law (Yerkes and Dodson, 1908). A moderate level of mental arousal can ensure optimal performance (Bracha, 2004), which corresponds to better task performance by restricting the allocation of attention to focus on the most emergent information (Hanoch & Vitouch, 2004).

In this study, we can make two specific interpretations: First, a higher variation of greenness can induce a relatively higher arousal status, while a higher mean of greenness makes drivers more relaxed, in turn inducing a low arousal status, therefore, the higher variation of greenness may strike a balance between drivers' low and high arousal status, in which drivers maintain the optimal level of arousal, and in turn, optimal performance in complex driving tasks. This trade-off effect between mean and variation of greenness has been found and well interpreted in previous studies (Jiang, He, Chen, & Larsen, 2021; Jiang, He, Chen, Larsen, & Wang, 2020).

Second, more variations, or changes in greenness along urban roads improve driving performance by decreasing drivers' fatigue arising in a monotonous environment. A higher variation of landscape scenes can reduce physiological and psychological fatigue caused by monotonous and unchangeable environments (Korpela & Ylen, 2007; Nordh et al., 2009), which may also contribute to improving driving performance.

4.2.3. A buffer effect: Another pathway to explain why greenness can promote driving performance

Urban road corridors often feature a vast array and diversity of artificial features (e.g., colors, forms, objects, lights, and sounds), resulting from the high density of various buildings, constructions, commercial screens and posters, and human activities (Zhang et al., 2016). Green landscapes, especially trees and shrubs with a significant vertical and 3D profile, along urban roads can function as an effective buffer, mitigating drivers' multisensory exposure to a great load of artificial stimuli

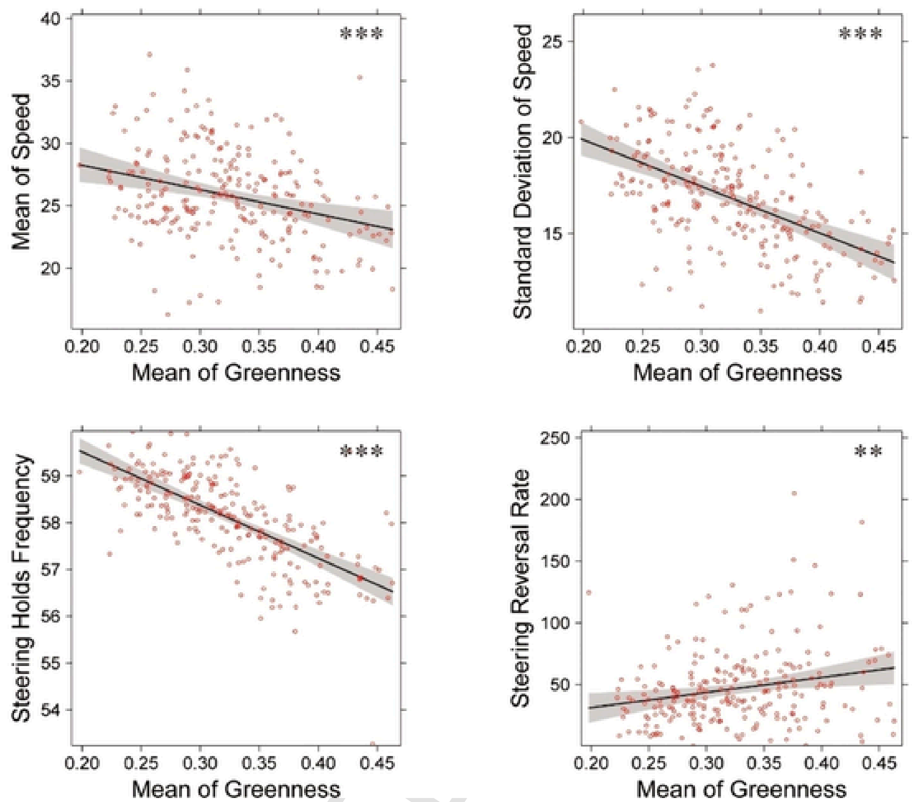

Fig. 6. Plot of the associations between mean of roadside greenness (vertical plants) and driving performance parameters after controlling for covariates. Note: ^{ns}p = non-sig, $^{*}p < 0.05$, $^{**}p < 0.01$, $^{***}p < 0.001$.

and information produced by the urban environments (Ma et al., 2020). This, in turn, may help reduce the considerable mental arousal, fatigue, stress, and negative emotions. This buffer effect not only encompasses a full obstruction of artificial stimuli, but also involves softening and diluting the impacts of those stimuli on drivers' perceptions.

In the context of this study, according to Kaplan's attention restoration theory (1995), urban road corridors dominated by artificial features may lead to heightened mental arousal and substantial consumption of directed attention, a limited resource that requires effort and can become fatigued with overuse, consequently impairing driving performance. Researchers have discovered that an increased quantity and variety of artificial features entail more information to process, necessitating drivers to be more attentive to their surroundings and generating decreased cognitive capabilities and directed attention (Edquist et al., 2012; Kaplan, 1995; Ulrich et al., 1991) and increased negative emotions and mental stress (Bratman et al., 2012; Grassini et al., 2019; Luo & Jiang, 2022; Qin et al., 2020; Wolf, 2006). As a collective consequence, they may contribute to a decline in driving performance.

4.3. Strengths and original contributions

The present study makes significant contributions to the existing body of knowledge by providing solid evidence that greater greenness along urban roads can positively influence driving performance. It is distinguished by several key strengths that enable multiple original contributions.

Firstly, the study investigated urban road sites spanning a moderately wide spectrum of greenness levels, in contrast to previous studies predominantly focused on one or a few specific green settings. This design offers a unique advantage by revealing a holistic dose–response relationship, aiding comprehensive understanding of the link between greenness and driving performance. Encompassing diverse greenness levels allows the findings to be more generalizable across urban roads with quite different levels of greenness (Hartig et al., 2014).

Additionally, the study not only considered the quantity (mean value) of roadside landscapes, which has been the primary focus in most previous studies, but also emphasized the significance of diversity (variation value) within these landscapes. This aspect has been considerably less explored in the existing literature (Dean et al., 2011; Fuller et al., 2007). The findings reveal that the variability of green landscapes positively contributes to improving driving performance. By adopting this multidimensional approach to greenness, the study provides nuanced insights into both quantitative and qualitative impacts of green landscapes on human well-being.

The targeted study design, focusing on the driving patterns of ordinary urban residents, enhances the external validity of the findings (Fisher et al., 2016; Gong et al., 2016). The one-hour, two-way driving experiment was designed to mimic the daily commuting patterns of typical urban residents, further bolstering the ecological validity of the study (Stavrinos et al., 2013; Walshe et al., 2017). Moreover, the deliberate restriction of driving environments to urban roads minimizes potential bias arising from fundamental differences in various road types, such as freeways, highways, suburban roads, or rural roads (Aldred et al., 2017; Kaplan et al., 2015). By controlling for these factors, the study can provide more reliable and generalizable insights into the impact of green viewing environments on driving performance in urban settings (Park et al., 2018; Tarko et al., 2017).

A notable strength of this study is the use of real-world driving experiments, unlike most prior studies that relied on simulated driving environments. While simulated studies offer advantages such as a high level of control over variables and the ability to establish causal relationships, they also face the risk of low ecological validity, as driving activities on real urban roads differ significantly from those conducted in laboratory settings (Caird et al., 2014; Oviedo-Trespalacios et al.,

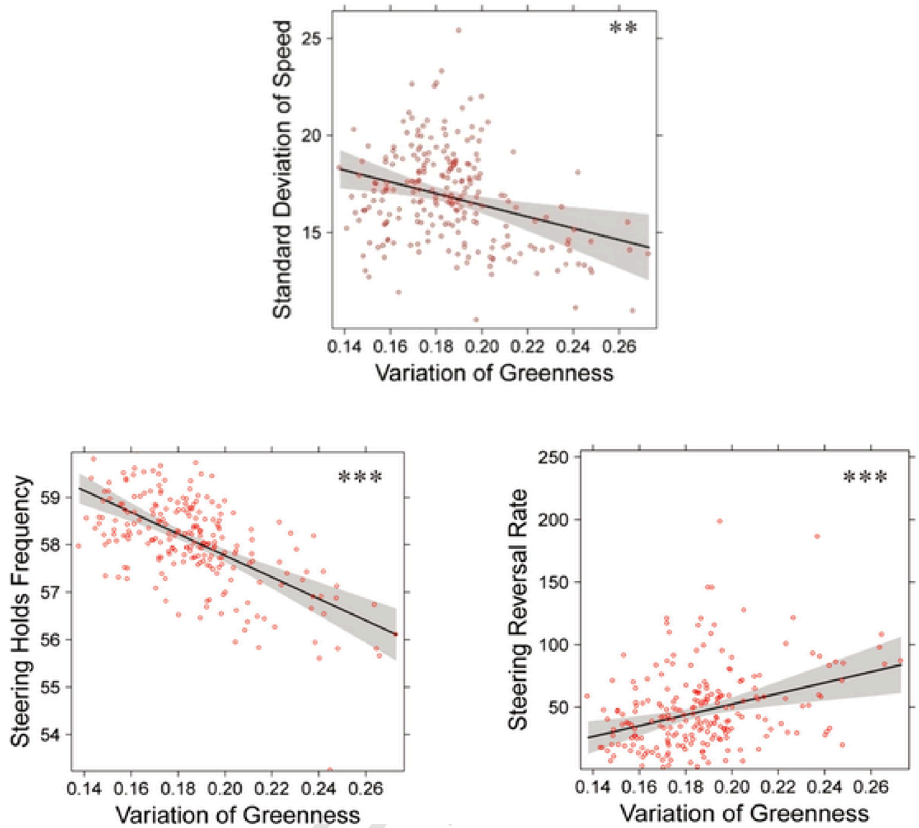

Fig. 7. Plot of the three significant associations between variation of roadside greenness (vertical plants) and driving performance parameters after controlling for covariates. Note: ^{ns} p = non-sig, *p < 0.05, **p < 0.01, ***p < 0.001.

2017). In real urban environments, traffic conditions, road users, and landscapes are complex and dynamic, resulting in a greater number of variables to consider and higher levels of psychological and physical challenges compared to driving in a simulator. Furthermore, participants in real-world driving experiments are more likely to exhibit natural behaviors, as their physical and psychological senses of driving in a real vehicle differ substantially from driving in a simulated environment, and they are less aware of being observed or studied.

Lastly, real-world driving experiments offer the opportunity to collect rich, real-time information about road environments and employ deep-learning methods for semantic segmentation analysis. The video records, in conjunction with measurements of driving activities, generate a substantial number of photographs (30 frames per second) capturing the out-car environments. This enables researchers to extract more detailed information about visual exposure to green landscapes and other environmental features from the driver's perspective, potentially leading to novel insights and methodological advancements in environmental exposure assessments.

4.4. Implications for landscape planning and design

Based on major findings of this study, we propose two sets of suggestions for landscape planning and design.

Policymakers, planners, and designers should enhance awareness that the quantity of green landscapes significantly impacts driving performance through multiple pathways. Incorporating more plants, especially vertical greenery with substantial 3D profiles (Jiang, He, Chen, & Larsen, 2021), is necessary and critical to improve the driving experience and potentially enhance safety. The central objective should be promoting drivers' visual exposure to green landscapes while driving. Therefore, it is crucial to adopt the driver's visual perspective and provide ample greenness at eye-level while in the vehicle (James et al., 2015; Jiang et al., 2017). Specific suggestions include: 1) Designers should consider roadside greenery from the driver's viewpoint by sitting in a moving vehicle; the data collection and analysis methods used in this study can support this practice. 2) Increase tree species with large canopies while balancing shade and natural light. 3) Incorporate more green spaces like urban parks and pocket gardens with substantial tree canopy coverage along road corridors. 4) Enhance vertical greenery development on building facades and facilities along roads. 5) Widen curbside spaces for plantings, including between pedestrian pathways and vehicle lanes, pathways and roadside buildings, and median strips. 6) Reduce unnecessary vehicle lanes and allocate more space for plants, while ensuring they do not impede visual perception and cognitive comprehension of traffic conditions (Luo, 2019).

The variation of roadside greenness emerges as the second crucial aspect. Specific suggestions may include: 1) It is essential to avoid monotonous road environments, even when the road is characterized by a moderately high or high level of greenness. A diverse and engaging landscape can better support driving performance by maintaining driver interest and attention. 2) Cultivating trees or shrubs in naturalistic configurations, which mimic nature's intrinsic irregularity and clustering patterns, may yield substantial improvements in driving performance compared to regular planting patterns (Jiang, He, Chen, & Larsen, 2021). By emulating the inherent randomness and heterogeneity found in natural environments, these arrangements can provide a more engaging visual experience for drivers. 3) Diversifying vertical plant species, shapes, sizes, and ages of plants along roadsides can contribute to heightened variation in greenness levels over time (Tribot et al., 2018). By incorporating a mix of plant characteristics, roadside greenery can evolve and change throughout the seasons, offering drivers a dynamic and visually appealing environment that promotes bet-

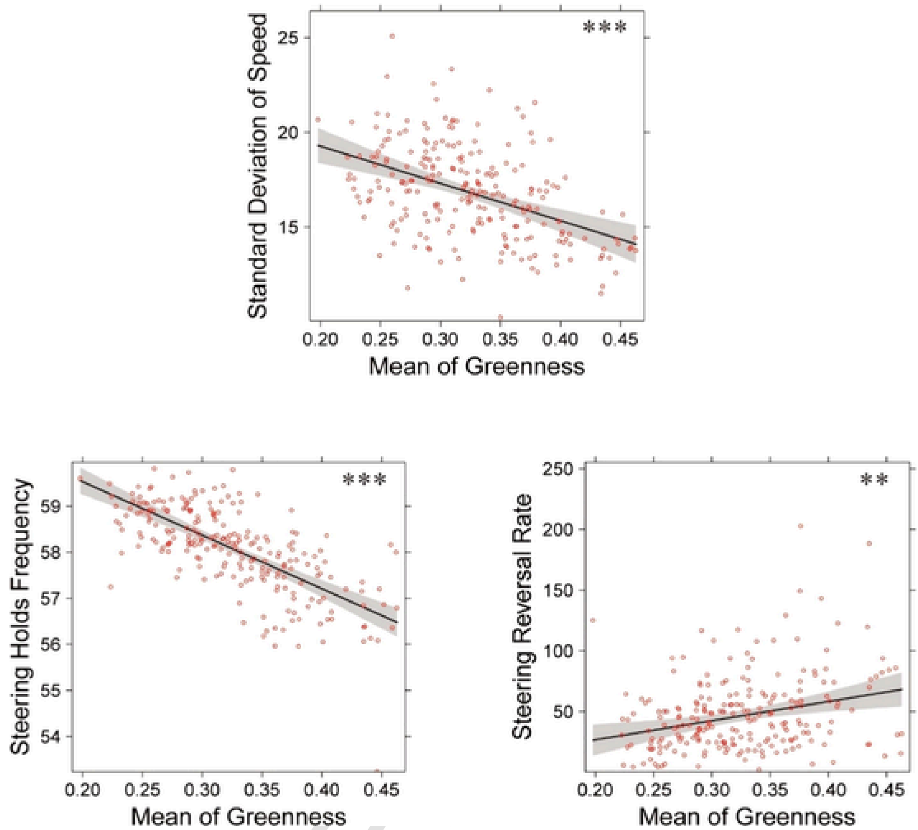

Fig. 8. Plot of the three significant associations between mean of roadside greenness (vertical plants) and driving performance parameters after controlling for covariates. Note: ^{ns}p = non-sig, $*p < 0.05$, $**p < 0.01$, $***p < 0.001$.

ter driving performance. 4) Nevertheless, it might be crucial to avoid an excessively high level of variation, as driving environments with overly complex landscape information may pose a risk of impeding driving performance (Jiang, He, Chen, & Larsen, 2021). Careful consideration should be given to balancing the complexity of landscape features in order to provide a stimulating yet manageable environment for drivers, ensuring that the benefits of green landscapes are not overshadowed by potential distractions or cognitive overload.

4.5. Limitations and suggestions for future studies

A single study may not be able to examine all possible conditions and factors, and this study is no exception. We acknowledge the limitations of this study and present them below, with the aim of providing valuable suggestions for future research endeavors.

First, it is crucial to acknowledge that this study was conducted in a specific modern city, and the replication of this study in other modern cities is necessary to further verify and generalize the findings (Cohen & Crabtree, 2008; Yin, 2012). While we selected an ordinary city with international-style road settings and a wide but common range of greenness to maximize the representativeness of our findings, it is possible that urban road settings in different cities still have many differences, such as variations in prevalent plant species, climate conditions, zoning regulations, and driving regulations. Thus, we strongly encourage future research to validate our findings across a more diverse range of regions and cities throughout different seasons, which will contribute to a more comprehensive understanding of the impact of green landscapes on driving performance in various urban contexts (Birenboim et al., 2019; Park et al., 2018).

Second, previous research has shown that the road environments had long-term impacts on driving performance and drivers' health and well-being (Du et al., 2015; Lal & Craig, 2001). However, the present study does not examine the long-term effect. Future research could consider adopting a cohort study or natural experiment design to investigate the effect over a longer period of daily life, such as several weeks or months (Gong et al., 2016). While controlling for numerous variables during an extended period may pose a challenge, this approach could provide valuable insights into the potential long-lasting effects of green landscapes on drivers' behavior and cognitive functioning, thereby contributing to a more comprehensive understanding of this topic (Ulrich et al., 1991; Van den Berg et al., 2014).

Third, as proposed in the Discussion section, the buffering capacity of green landscapes on artificial features in urban road corridors may provide a plausible explanation for the positive impact of greenness on driving performance (Kaplan, 1995; Ulrich, 1979). Although the current study controlled for many artificial elements as covariates in the statistical analysis, such as building facades, road surfaces, vehicles, and other man-made facilities, future studies could benefit from establishing a more robust control of a greater variety of artificial features. With the ongoing advancements in deep learning techniques that can be applied in urban studies (Helbich et al., 2019), it is anticipated that the proportion and configuration of artificial features can be more accurately detected and controlled, thereby strengthening the validity of findings.

Fourth, a notable limitation of the present study is the inability to differentiate between tree and shrub segments within the vast number of images analyzed, due to technical constraints. This common challenge may be overcome through the continued advancement of deep learning technology. Although it can be qualitatively observed that the proportion of trees is much larger than that of shrubs, suggesting that trees may play a more substantial role in the influence of green landscapes on driving performance. This assertion echoes findings of some relevant studies (Jiang, He, Chen, & Larsen, 2021; Tomao et al., 2018). However, it should only be considered as a hypothesis and further investigation is needed to provide empirical evidence in support of this claim.

Fifth, although the study accounted for certain contextual elements, such as traffic density, weather conditions, and time of day, a more comprehensive approach could involve exploring the concurrent influence of multiple contextual factors. Future research endeavors could delve into the intricate interplay between the amalgamated effects of these variables and the presence of roadside greenery, elucidating their collective resonance on driving proficiency. Unraveling these intricate dynamics would provide a better understanding of the dynamic relationship between road greenness and driving behavior in urban environments.

Sixth, driving performance is dependent on multisensory information, such as auditory, olfactory, and tactile inputs, which have been evidenced to have a significant influence on driving performance (Meng & Spence, 2015; Spence & Ho, 2008; Xu et al., 2024). Furthermore, the visual impact of the road environment may interact with other sensory modalities, potentially playing a cooperative role in driving performance (Gueguen et al., 2012). Although this study adopted the within-subject method and driving rules (e.g., same vehicle was used for all experiments, windows were required to be closed; temperature inside the vehicle was remained same; no food, drink, and music display were allowed during driving), which may largely reduce the variations of multisensory stimuli, we strongly suggest future studies should further investigate multisensory perception and the interactions between multiple senses during driving.

Lastly, the roads in this study encompass a moderately wide but not theoretically full range of mean and variation in greenness. Although this range may offer a reasonable representation of greenness for urban roads in numerous contemporary cities worldwide, it implies that the findings of linear associations and interpretations may not be applicable for urban roads with excessively lower or higher greenness. We recommend that future studies explore a more comprehensive range of greenness to further enhance our understanding of its impacts on driving performance within the context of urban roads.

5. Conclusion

This study employed real driving experiments to examine the impacts of a moderately wide and common range of greenness along urban roads on the driving performance of ordinary urban residents. The findings reveal that a greater dose of green landscapes along urban roads leads to improved driving performance, with both the mean and variation of greenness proving benefits. These findings strongly suggest that society should be aware that both the quantity and quality of green landscapes along urban roads can significantly influence driving performance. By providing concrete scientific evidence, we are positive that this study can support the development of safer, more enjoyable, and environmentally friendly urban driving experiences for numerous urban residents.

Uncited references

Donovan et al. (2013), Jiang et al. (2014), Mok et al. (2006), Parsons et al. (1998), Shamsul et al. (2014), Wang and Pei (2014).

CRediT authorship contribution statement

Wenyan Xu: Writing – review & editing, Writing – original draft, Visualization, Software, Methodology, Investigation, Formal analysis, Data curation, Conceptualization. **Jibo He:** Resources, Methodology, Funding acquisition. **Lan Luo:** Writing – review & editing. **Bin Jiang:** Writing – review & editing, Supervision, Resources, Project administration, Funding acquisition, Conceptualization.

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.

Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.landurbplan.2024.105156.

References

Aldred, R., Woodcock, J., & Goodman, A. (2017). *Does more cycling mean more diversity in cycling? Transport Reviews*, *37*(1), 28–44.

Anciaes, P. (2023). *Effects of the roadside visual environment on driver wellbeing and behaviour – A systematic review. Transport Reviews*, *43*(4), 571–598. https://doi.org/10.1080/01441647.2022.2133189.

Antonson, H., Mårdh, S., Wiklund, M., & Blomqvist, G. (2009). *Effect of surrounding landscape on driving behaviour: A driving simulator study. Journal of Environmental Psychology*, *29*(4), 493–502. https://doi.org/10.1016/j.jenvp.2009.03.005.

Benlagha, N., & Charfeddine, L. (2020). *Risk factors of road accident severity and the development of a new system for prevention: New insights from China. Accident Analysis & Prevention*, *136*, 105411. https://doi.org/10.1016/j.aap.2019.105411.

Birenboim, A., Dijst, M., Ettema, D., & Scheepers, F.E. (2019). *Streetscape biodiversity and the role of biophilic design in enhancing mental health and physiological restoration in the city. Landscape and Urban Planning*, *190*, 103595.

Bracha, H.S. (2004). *Freeze, flight, fight, fright, faint: Adaptationist perspectives on the acute stress response spectrum. CNS spectrums*, *9*(9), 679–685.

Bratman, G.N., Hamilton, J.P., & Daily, G.C. (2012). *The impacts of nature experience on human cognitive function and mental health. Annals of the New York Academy of Sciences*, *1249*, 118–136. https://doi.org/10.1111/j.1749-6632.2011.06400.x.

Cabrera-Arnau, C., Prieto Curiel, R., & Bishop, S.R. (2020). *Uncovering the behaviour of road accidents in urban areas. Royal Society Open Science*, *7*(4), 191739. https://doi.org/10.1098/rsos.191739.

Cai, Q., Abdel-Aty, M., Zheng, O., & Wu, Y. (2022). *Applying machine learning and google street view to explore effects of drivers' visual environment on traffic safety. Transportation Research Part C: Emerging Technologies*, *135*, 103541.

Caird, J.K., Johnston, K.A., Willness, C.R., Asbridge, M., & Steel, P. (2014). *A meta-analysis of the effects of texting on driving. Accident Analysis & Prevention*, *71*, 311–318.

Calvi, A. (2015). *Does roadside vegetation affect driving performance?: Driving simulator study on the effects of trees on drivers' speed and lateral position. Transportation Research Record*, *2518*(1), 1–8. https://doi.org/10.3141/2518-01.

Cassarino, M., Maisto, M., Esposito, Y., Guerrero, D., Chan, J. S., & Setti, A. (2019). Testing Attention Restoration in a Virtual Reality Driving Simulator. *10*(250). https://doi.org/10.3389/fpsyg.2019.00250.

Chang, C., Hammitt, W.E., Chen, P., Machnik, L., & Su, W. (2008). *Psychophysiological responses and restorative values of natural environments in Taiwan. Landscape and Urban Planning*, *85*(2), 79–84.

Chen, F., & Chen, S. (2011). *Injury severities of truck drivers in single- and multi-vehicle accidents on rural highways. Accident Analysis & Prevention*, *43*(5), 1677–1688. https://doi.org/10.1016/j.aap.2011.03.026.

Chiang, Y.-C., Ke, R.-A., Li, D., & Weng, P.-Y. (2022). *Greening and safety: The influence of road greenness on driver's attention and emergency reaction time. Environment and Behavior*. https://doi.org/10.1177/00139165221147627.

Choi, K., Byun, G., Kim, A., & Kim, Y. (2020). *Drivers' visual perception quantification using 3D mobile sensor data for road safety. Sensors*, *20*(10), 2763.

Cohen, J. (1992). *A power primer. Psychological Bulletin*, *112*(1), 155–159. https://doi.org/10.1037/0033-2909.112.1.155.

Cohen, D., & Crabtree, B. (2008). *Evaluative criteria for qualitative research in health care: Controversies and recommendations. The Annals of Family Medicine*, *6*(4), 331–339.

Davies, D.R., & Parasuraman, R. (1982). *The psychology of vigilance*. Academic Press.

Dean, J., van Dooren, K., & Weinstein, P. (2011). *Does biodiversity improve mental health in urban settings? Medical Hypotheses*, *76*(6), 877–880. https://doi.org/10.1016/j.mehy.2011.02.040.

Donovan, G.H., Butry, D.T., Michael, Y.L., Prestemon, J.P., Liebhold, A.M., Gatziolis, D., & Mao, M.Y. (2013). *The relationship between trees and human health: Evidence from the spread of the emerald ash borer. American Journal of Preventive Medicine*, *44*(2), 139–145.

Du, H., Zhao, X., Zhang, X., Zhang, Y., & Rong, J. (2015). *Effects of fatigue on driving performance under different roadway geometries: A simulator study. Traffic Injury Prevention*, *16*(5), 468–473. https://doi.org/10.1080/15389588.2014.971155.

Du, Y., Zhi, J.y., & He, S.j. (2022). *Impact of experience on visual behavior and driving*

performance of high-speed train drivers. *Scientific Reports*, *12*, 5956. https://doi.org/10.1038/s41598-022-10055-9.
Edquist, J., Rudin-Brown, C.M., & Lenné, M.G. (2012). *The effects of on-street parking and road environment visual complexity on travel speed and reaction time. Accident Analysis & Prevention*, *45*, 759–765.
Fisher, D.L., Caird, J.K., Horrey, W.J., & Trick, L.M. (2016). *Handbook of teen and novice drivers: Research, practice, policy, and directions*. CRC Press.
Fitzpatrick, C.D., Samuel, S., & Knodler, M.A. (2016). *Evaluating the effect of vegetation and clear zone width on driver behavior using a driving simulator*. *Transportation Research Part F: Traffic Psychology and Behaviour*, *42*, 80–89. https://doi.org/10.1016/j.trf.2016.07.002.
Fuller, R.A., Irvine, K.N., Devine-Wright, P., Warren, P.H., & Gaston, K.J. (2007). *Psychological benefits of greenspace increase with biodiversity*. *Biology Letters*, *3*(4), 390–394. https://doi.org/10.1098/rsbl.2007.0149.
Gitelman, V., Bekhor, S., Doveh, E., Pesahov, F., Carmel, R., & Morik, S. (2018). *Exploring relationships between driving events identified by in-vehicle data recorders, infrastructure characteristics and road crashes*. *Transportation Research Part C: Emerging Technologies*, *91*, 156–175. https://doi.org/10.1016/j.trc.2018.04.003.
Gong, Y., Palmer, S., Gallacher, J., Marsden, T., & Fone, D. (2016). *A systematic review of the relationship between objective measurements of the urban environment and psychological distress*. *Environment International*, *96*, 48–57.
Grassini, S., Revonsuo, A., Castellotti, S., Petrizzo, I., Benedetti, V., & Koivisto, M. (2019). *Processing of natural scenery is associated with lower attentional and cognitive load compared with urban ones*. *Journal of Environmental Psychology*, *62*, 1–11.
Gueguen, N., Meineri, S., Eyssartier, C., & Bonnefond, J. (2012). *The effect of plant odors on the evaluation of environmental quality and human behavior: An experimental study with passersby*. *Journal of Environmental Psychology*, *32*(3), 207–211.
Hanoch, Y., & Vitouch, O. (2004). *When less is more: Information, emotional arousal and the ecological reframing of the Yerkes-Dodson law. Theory & Psychology*, *14*(4), 427–452.
Hartig, T., Evans, G.W., Jamner, L.D., Davis, D.S., & Gärling, T. (2003). *Tracking restoration in natural and urban field settings*. *Journal of Environmental Psychology*, *23*(2), 109–123.
Hartig, T., Mitchell, R., de Vries, S., & Frumkin, H. (2014). *Nature and health. Annual Review of Public Health*, *35*, 207–228.
Helbich, M., Yao, Y., Liu, Y., Zhang, J., Liu, P., & Wang, R. (2019). *Using deep learning to examine street view green and blue spaces and their associations with geriatric depression in Beijing, China*. *Environment International*, *126*, 107–117. https://doi.org/10.1016/j.envint.2019.02.013.
James, P., Banay, R.F., Hart, J.E., & Laden, F. (2015). *A review of the health benefits of greenness*. *Current Epidemiology Reports*, *2*(2), 131–142.
Jiang, B., Chang, C.Y., & Sullivan, W.C. (2014). *A dose of nature: Tree cover, stress reduction, and gender differences. Landscape and urban planning*, *132*, 26–36.
Jiang, B., He, J., Chen, J., & Larsen, L. (2021). *Moderate is optimal: A simulated driving experiment reveals freeway landscape matters for driving performance*. *Urban Forestry & Urban Greening*, *58*, 126976. https://doi.org/10.1016/j.ufug.2021.126976.
Jiang, B., He, J., Chen, J., Larsen, L., & Wang, H. (2020). *Perceived green at speed: A simulated driving experiment raises new questions for attention restoration theory and stress reduction theory*. *Environment and Behavior*. https://doi.org/10.1177/0013916520947111.
Jiang, B., Liang, S., Peng, Z.-R., Cong, H., Levy, M., Cheng, Q., … Remais, J.V. (2017). *Transport and public health in China: The road to a healthy future. The Lancet*, *390*(10104), 1781–1791.
Kaplan, S. (1995). *The restorative benefits of nature: Toward an integrative framework*. *Journal of Environmental Psychology*, *15*(3), 169–182. https://doi.org/10.1016/0272-4944(95)90001-2.
Kaplan, S., Basford, L.E., Ho, C., & Reed, M. (2015). *Effects of visual and cognitive distractions on lane change test performance. Accident Analysis & Prevention*, *77*, 149–155.
Kaplan, R., & Kaplan, S. (1989). *The experience of nature: A psychological perspective*. Cambridge University Press.
Korpela, K.M., & Ylen, M. (2007). *Perceived health is associated with visiting natural favourite places in the vicinity. Health & Place*, *13*(1), 138–151.
Lal, S.K., & Craig, A. (2001). *A critical review of the psychophysiology of driver fatigue*. *Biological Psychology*, *55*(3), 173–194. https://doi.org/10.1016/s0301-0511(00)00085-5.
Lam, L.T. (2002). *Distractions and the risk of car crash injury: The effect of drivers' age*. *Journal of Safety Research*, *33*(3), 411–419. https://doi.org/10.1016/S0022-4375(02)00034-8.
Li, M., Xue, F., Wu, Y., & Yeh, A.G. (2022). *A room with a view: Automatic assessment of window views for high-rise high-density areas using City Information Models and deep transfer learning. Landscape and Urban Planning*, *226*, 104505.
Luo, Y. (2019). *From transportation infrastructure to green infrastructure–adaptable future roads in autonomous urbanism. Landscape Architecture Frontiers*, *7*(2), 92–99.
Luo, L., & Jiang, B. (2022). *From oppressiveness to stress: A development of Stress Reduction Theory in the context of contemporary high-density city*. *Journal of Environmental Psychology*, *84*, 101883.
Lyu, N., Xie, L., Wu, C., Fu, Q., & Deng, C. (2017). *Driver's cognitive workload and driving performance under traffic sign information exposure in complex environments: A case study of the highways in China*. *International Journal of Environmental Research and Public Health*, *14*(2), 203. https://www.mdpi.com/1660-4601/14/2/203.
Ma, B., Hauer, R.J., & Xu, C.-Y. (2020). *Effects of design proportion and distribution of color in urban and suburban green space planning to visual aesthetics quality*. *Forests*, *11*(3), 278. https://doi.org/10.3390/f11030278.
Ma, X., Ma, C., Wu, C., Xi, Y., Yang, R., Peng, N., … Ren, F. (2021). *Measuring human perceptions of streetscapes to better inform urban renewal: A perspective of scene semantic parsing. Cities*, *110*, 103086.
Macdonald, W.A., & Hoffmann, E.R. (1980). *Review of relationships between steering wheel reversal rate and driving task demand. Human Factors*, *22*(6), 733–739.
Meng, F., & Spence, C. (2015). *Tactile warning signals for in-vehicle systems. Accident Analysis & Prevention*, *75*, 333–346.
Mok, J.-H., Landphair, H.C., & Naderi, J.R. (2006). *Landscape improvement impacts on roadside safety in Texas. Landscape and Urban Planning*, *78*, 263–274.
Nordh, H., Hartig, T., Hagerhall, C., & Fry, G. (2009). *Components of small urban parks that predict the possibility for restoration. Urban Forestry & Urban Greening*, *8*(4), 225–235.
O'brien, R.M. (2007). *A caution regarding rules of thumb for variance inflation factors. Quality & Quantity*, *41*(5), 673–690.
Oviedo-Trespalacios, O., Haque, M.M., King, M., & Washington, S. (2017). *Effects of road infrastructure and traffic complexity in speed adaptation behaviour of distracted drivers. Accident Analysis & Prevention*, *101*, 67–77.
Park, S., Lee, S., & Kang, S. (2018). *The effects of the density of urban green on driving stress. International Journal of Environmental Research and Public Health*, *15*(12), 2829.
Parsons, R., Tassinary, L.G., Ulrich, R.S., Hebl, M.R., & Grossman-Alexander, M. (1998). *The view from the road: Implications for stress recovery and immunization. Journal of Environmental Psychology*, *18*(2), 113–140.
Parwathaneni, R. (2016). *Effect of roadside vegetation on driver behavior*. Cleveland State University.
Qin, X., Zhang, N., Zhang, W., & Meitner, M. (2020). *How does tunnel interior color environment influence driving behavior? Quantitative analysis and assessment experiment*. *Tunnelling and Underground Space Technology*, *98*, 103320. https://doi.org/10.1016/j.tust.2020.103320.
Ranney, T.A., Harbluk, J.L., & Noy, Y.I. (2005). *Effects of voice technology on test track driving performance: Implications for driver distraction. Human Factors*, *47*(2), 439–454.
Rolison, J.J., Regev, S., Moutari, S., & Feeney, A. (2018). *What are the factors that contribute to road accidents? An assessment of law enforcement views, ordinary drivers' opinions, and road accident records*. *Accident Analysis & Prevention*, *115*, 11–24. https://doi.org/10.1016/j.aap.2018.02.025.
Rose, E.R., & Carlson, P.J. (2005). *Spacing chevrons on horizontal curves. Transportation Research Record*, *1918*(1), 84–91.
Shamsul, B., Khairunnisa, S., Ng, Y., & Irwan Syah, M. (2014). *Stress; the vulnerability and association with driving performance. American Journal of Applied Sciences*, *11*(3), 448–454.
Song, X.P., Tan, P.Y., Edwards, P., & Richards, D. (2018). *The economic benefits and costs of trees in urban forest stewardship: A systematic review*. *Urban Forestry & Urban Greening*, *29*, 162–170. https://doi.org/10.1016/j.ufug.2017.11.017.
Spence, C., & Ho, C. (2008). *Multisensory warning signals for event perception and safe driving. Theoretical Issues in Ergonomics Science*, *9*(6), 523–554.
Stavrinos, D., McManus, B., Mrug, S., Heaton, K., Gresham, B., Albright, M.G., … White, D.M. (2013). *Adolescent driving behavior before and after licensure: A naturalistic study. American Journal of Preventive Medicine*, *45*(4), 395–400.
Sun, L.-L., Liu, D., Chen, T., & He, M.-T. (2019). *Analysis on the accident casualties influenced by several economic factors based on the traffic-related data in China from 2004 to 2016*. *Chinese Journal of Traumatology*, *22*(2), 75–79. https://doi.org/10.1016/j.cjtee.2019.02.002.
Tarko, A., Davis, G., Saunier, N., Sayed, T., & Washington, S. (2017). *Surrogate measures of safety. Analytical Techniques for Public Safety*, *1*, 1–16.
Tijerina, L., Kiger, S. M., Rockwell, T. H., & Tornow, C. (1995). Workload assessment of in-cab text message system and cellular phone use by heavy vehicle drivers on the road. In *Proceedings of the Human Factors and Ergonomics Society Annual Meeting* (Vol. 39, No. 17, pp. 1117-1121). Sage CA: Los Angeles, CA: SAGE Publications.
Tomao, A., Secondi, L., Carrus, G., Corona, P., Portoghesi, L., & Agrimi, M. (2018). *Restorative urban forests: Exploring the relationships between forest stand structure, perceived restorativeness and benefits gained by visitors to coastal Pinus pinea forests*. *Ecological Indicators*, *90*, 594–605. https://doi.org/10.1016/j.ecolind.2018.03.051.
Tribot, A.-S., Deter, J., & Mouquet, N. (2018). *Integrating the aesthetic value of landscapes and biological diversity*. *Proceedings of the Royal Society B: Biological Sciences*, *285*, 20180971. https://doi.org/10.1098/rspb.2018.0971.
Ulrich, R.S. (1979). *Visual landscapes and psychological well-being. Landscape Research*, *4*(1), 17–23.
Ulrich, R.S. (1981). *Natural versus urban scenes: Some psychophysiological effects. Environment and Behavior*, *13*(5), 523–556.
Ulrich, R.S., Simons, R.F., Losito, B.D., Fiorito, E., Miles, M.A., & Zelson, M. (1991). *Stress recovery during exposure to natural and urban environments. Journal of Environmental Psychology*, *11*(3), 201–230.
Van den Berg, A.E., Jorgensen, A., & Wilson, E.R. (2014). *Evaluating restoration in urban green spaces: Does setting type make a difference? Landscape and Urban Planning*, *127*, 173–181.
Van Treese, J., Koeser, A.K., Fitzpatrick, G.E., Olexa, M.T., & Allen, E.J. (2018). *Drivers' risk perception of roadside trees. Arboricultural Journal*, *40*(3), 153–161.
Walshe, E.A., Winston, F.K., & Romer, D. (2017). *Effects of a naturalistic parent-implemented driving intervention for teens with ADHD. Prevention Science*, *18*(8), 986–996.
Wang, L., & Pei, Y. (2014). *The impact of continuous driving time and rest time on commercial drivers' driving performance and recovery*. *Journal of Safety Research*, *50*, 11–15. https://doi.org/10.1016/j.jsr.2014.01.003.
WHO. (2020). *China: Road traffic accidennts*. Retrieved May 20 2023 from https://www.worldlifeexpectancy.com/china-road-traffic-accidents.
Wolf, K.L. (2006). *Roadside urban trees-balancing safety and community values. Arborist News*, *15*(6), 56–58.
Wu, J., Cheng, L., Chu, S., Xia, N., & Li, M. (2020). *A green view index for urban transportation: How much greenery do we view while moving around in cities? International Journal of Sustainable Transportation*, *14*(12), 972–989.

Wu, Y., Zhao, X., Rong, J., & Ma, J. (2013). *Effects of chevron alignment signs on driver eye movements, driving performance, and stress. Transportation Research Record, 2365*(1), 10–16.
Xu, W., Wang, H., Su, H., Sullivan, W.C., Lin, G.S., Pryor, M., & Jiang, B. (2024). *Impacts of sights and sounds on anxiety relief in the high-density city*. *Landscape and Urban Planning, 241*. https://doi.org/10.1016/j.landurbplan.2023.104927.
Xue, F., Li, X., Lu, W., Webster, C.J., Chen, Z., & Lin, L. (2021). *Big data-driven pedestrian analytics: Unsupervised clustering and relational query based on tencent street view photographs. ISPRS International Journal of Geo-Information, 10*(8), 561.
Yin, R.K. (2012). *Applications of case study research*. Sage Publications.
Zhang, F., Zhou, B., Liu, L., Liu, Y., Fung, H.H., Lin, H., & Ratti, C. (2018). *Measuring human perceptions of a large-scale urban region using machine learning. Landscape and Urban Planning, 180*, 148–160.
Zhang, G., Zhu, S., & Qi, C. (2016). *Effects analysis of monotonous roadside landscape color on the driver's eye movement indicators. Science Technology and Engineering, 16*(18), 284–289.