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Perceived Green at Speed: A Simulated Driving Experiment Raises New Questions for Attention Restoration Theory and Stress Reduction Theory

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Abstract
Few studies have investigated the impact of landscapes on humans' mental status while they are moving at high speeds, such as driving on the freeway. This study used a simulation system to measure drivers' mental responses to six different freeway landscapes. Each of the 33 participants completed six different 90-minute simulated driving tasks in a randomly assigned sequence. The six landscape conditions consisted of an identical freeway infrastructure, with different roadside landscapes. Results show significant differences between landscape conditions and drivers' mental responses. Landscape conditions with greater greenness, in general, had a greater positive impact on drivers' mental status. The barren and tree regular landscapes yielded the worst and best results, respectively. Further, higher complexity was associated with a higher level of negative mental status. We argue that the

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speed of human's active movement should be considered as an essential factor in the Attention Restoration Theory and Stress Reduction Theory.

Keywords
freeway landscape, driving simulation, mental status, greenness, complexity, Attention Restoration Theory, Stress Reduction Theory

Introduction

Background

Extensive empirical research has shown that exposure to urban landscapes significantly impacts people's mental health. Some urban landscapes exacerbate feelings of stress, fatigue, or frustration, while other more natural landscapes improve mood and help people recover from stress and mental fatigue. One important setting that has rarely been explored is freeway landscapes, where hundreds of millions of drivers spend significant amounts of time each day (Frumkin, 2002; Wang et al., 2016).

We have little understanding of how landscapes along these freeways impact drivers' mental status. If these landscapes are associated with increased stress, fatigue, anger, and frustration, drivers who encounter these landscapes daily may be at higher risk for long-term mental and physical illness, such as cardiovascular disease, stroke, Type II diabetes, cancer, and depression (Frumkin, 2002; Jiang et al., 2014). Drivers who experience feelings of stress, fatigue, anger, and frustration are also more likely to make poor driving decisions, which can lead to violence, accidents, and even fatalities (Cunningham & Regan, 2016; Frumkin, 2002; Zhang & Chan, 2016). On the other hand, if freeway landscapes are associated with reduced stress, frustration, and fatigue, drivers may be less prone to long-term mental and physical illness and may make fewer poor driving decisions. We must understand how different types of freeway landscape settings impact mental status over extended periods of driving time so that designers can create freeway landscapes that promote safety, mental health, and well-being.

Negative Mental Status: A Significant Challenge to Health and Safety

In numerous developed regions or cities, the built environment is designed around automobile use; people rely on automobiles to get around. Driving along the freeway can cause feelings of stress, fatigue, and frustration (Knight & Riggs, 2010), and presents a major challenge to city dwellers' health and safety.

Drivers who frequently experience feelings of stress, fatigue, and frustration while driving for long periods are at greater risk for mental and physical illness, such as back pain, cardiovascular disease, and depression (Cunningham & Regan, 2016; Frumkin, 2002; Zhang & Chan, 2016). Road rage is a type of psychological stress that is strongly associated with long-distance commutes along freeways (Frumkin et al., 2004). Stress at home or work can also elicit negative moods, such as anger and frustration (Frumkin, 2002). Lengthy exposure to traffic can bring added stress, noise, and air pollution (Buckley et al., 2004; Frumkin, 2002; Grahn & Stigsdotter, 2003; Peters et al., 2004; Steptoe et al., 2000; von Klot et al., 2005), and increases the risk of heart attack (Wang et al., 2016). Time spent in traffic is positively associated with increased risk of cardiovascular disease (Peters et al., 2004; von Klot et al., 2005).

Experiencing stress, fatigue, and negative moods while driving can also lead to risky driving behaviors, poor driving performance, and even fatal traffic accidents (Beck et al., 2013; Day et al., 2012; Dula et al., 2010; Dula & Ballard, 2003; Gastaldi et al., 2014). Over 30% of road fatalities worldwide are related to drivers' negative mental state (Lal & Craig, 2001; Owen et al., 2015). Fatigue is responsible for up to 20% to 30% of road fatalities worldwide (Lal & Craig, 2001). Fatigue can impair performance on a range of cognitive and psychomotor tasks (Kaplan & Basu, 2015; Sullivan, 2015; Williamson et al., 1996).

Stress and rage also lead to poor driving decisions, such as overtaking other cars in a reckless manner, speeding, and running red lights. Over 60% of participants in a nationwide survey in the US admitted that they had lost their temper during driving, leading them to speed along the freeway on occasion (Hennessy & Wiesenthal, 1997). Stress is common for drivers who commute daily, particularly when traffic is disorderly or congested, and can also cause poor decision-making and high risk of fatal collisions (Frumkin et al., 2004). Drivers may also experience negative thoughts and feelings, such as anger, related to specific situations they encounter. Drivers experiencing negative moods are often aggressive and impatient (Nesbit et al., 2007), which can lead to reckless and risky driving behaviors, such as speeding, weaving, and tailgating (Frumkin et al., 2004).

Theoretical Pathways: Impacts of Green Landscapes on Mental Status

Mitigating drivers' negative mental status, including fatigue, stress, and negative mood, is a practical approach to promoting drivers' health and well-being and enhancing roadway safety. One promising way to mitigate drivers' negative mental status is to expose them to green landscapes (de Kort et al., 2006; Grahn & Stigsdotter, 2003; Suppakittpaisarn et al., 2018). Environmental Psychology theories, including Attention Restoration Theory (ART) (Kaplan & Kaplan, 1989) and Stress Reduction Theory (SRT) (Ulrich, 1981; Ulrich et al., 1991) have suggested that green landscapes can facilitate restoration from mental fatigue, stress, and negative moods.

ART posits that green landscapes restore our ability to pay attention and recover from mental fatigue. Mentally-demanding tasks require us to direct our attention and inhibit distractions. The ability to direct attention to mentally-demanding tasks is crucial for keeping us productive at work and safe on the road. Unfortunately, our ability to direct our attention to these tasks fatigues, and we become competitive, rash, uncooperative, and irritable (Kaplan & Kaplan, 1989, pp. 179–182). However, our directed attention is restored when we expose ourselves to green landscapes. Natural landscape elements such as trees, water, and sunsets are "softly fascinating." They capture our involuntary attention and require little mental effort to process, allowing our directed attention to rest and recover (Kaplan, 1995). Restorative landscapes do not have to be large or extensive; nearby or small-scale nature in neighborhoods or urban parks can provide restorative effects as well.

Stress Reduction Theory posits that exposure to nature promotes stress recovery (Ulrich et al., 1991). According to Ulrich (1991), positive psychophysiological responses to unthreatening natural settings are deeply rooted in humans' genes, based on millions of years of evolution. Following a stressful experience, exposure to unthreatening natural settings has a calming effect. This emotional response is immediate, unconscious, and spontaneous, and is accompanied by increased positive feelings and reduced levels of arousal. Ulrich argues that we don't have a similar capacity to recover from stress in artificial settings since humans' capacity to recover from stress has evolved primarily in natural settings.

A great deal of empirical research has supported these theories. In general, this research suggests that a higher level of greenness is often associated with a higher level of mental restoration.

Beyond Greenness: Impacts of Complexity of Landscape Settings on Mental Status

Besides greenness, landscape complexity also significantly impacts people's mental states. The perception of landscape complexity is often associated with higher species diversity and naturalism. Walker's Hedgehog Theory (1980) suggests that the relationship between complexity of information and mental status or preference can be best described by a U-shaped dose-response curve where zero indicates a neutral hedonic response. Preference responses are below zero when complexity is low because the subject is bored or displeased with the lack of complexity. When complexity reaches a moderate level, the subject gains the highest level of pleasure or preference. When complexity is too high, pleasure or preference declines once again, because the participant is overwhelmed by the amount of information presented or how chaotic it feels.

Similarly, Cognitive Load Theory (Sweller, 1988) suggests that people's cognitive capacity to process simultaneous information (such as environmental stimuli) is limited. Extraneous cognitive load causes a loss of directed attention and accelerated negative emotions (Ayres & Paas, 2012; Plass & Kalyuga, 2019). Thus, an environment high in complexity (such as one with lots of visitors or visual stimuli) elicits negative mental responses. Research has found that landscape settings high in visual complexity also elicit a strong sense of unpredictability (Yang et al., 2013) and lack of guardianship (Jiang et al., 2017, 2018). Those perceptions may make people feel less in control of their environment and more vulnerable to danger, which might lead to other negative mental responses (Kaplan & Berman, 2010; Lal & Craig, 2001).

Significant Knowledge Gaps

Together, the theories mentioned above suggest that greenness and landscape complexity significantly impact mental responses. These theories have been supported by empirical research in many urban environments, such as schools, streets, parks, communities, and gardens. Only a few studies have examined the impact of freeway landscapes on drivers' mental status (Antonson et al., 2009; Oron-Gilad & Ronen, 2007; Thiffault & Bergeron, 2003; Wang et al., 2016). Freeway landscapes are often regarded as a decorative addition without measurable practical function. We do not know whether and to what extent freeway landscapes impact drivers' mental status, which is a significant knowledge gap considering that there are hundreds of millions of people who drive along freeways daily.

In particular, we do not know how the amount of greenness impacts drivers' mental status. Most studies exploring this issue have compared landscapes with or without roadside trees (e.g., Antonson et al., 2009; Fitzpatrick et al., 2014; Parsons et al., 1998). We do not know how drivers will respond to less prominent roadside vegetation, such as turf and shrubs, which are not as visually-dominant and do not provide as much greenery but might be more restorative than barren landscapes. We also do not know how freeway landscapes with different levels of landscape complexity influence drivers' mental status. Will drivers respond more positively to landscapes that are perceived as less complex, such as landscapes with orderly, single-species plantings? Or will they respond more positively to plantings perceived as more complex, with multiple species, planted in a more random fashion?

Finally, past studies have explored how drivers respond to roadside landscapes during a relatively short time (around 30–40 minutes) (e.g., Antonson et al., 2009, 2014). Many freeway drivers spend much longer time periods on the road (Wang et al., 2016). We do not know how drivers respond to different freeway landscapes over an extended time period.

These knowledge gaps prevent developers, managers, and designers of transportation infrastructure from creating evidence-based landscape designs that improve the mental status and health of hundreds of millions of people worldwide who frequently commute long distances along freeways.

To test drivers' responses to different types of landscapes, we exposed participants to a simulated 90-minute freeway driving experience. We used advanced virtual reality techniques to simulate a driving scenario (Seen et al., 2010; Sung et al., 2005), and exposed drivers to one of six types of freeway landscape conditions: *barren*, *turf*, *shrub-regular*, *shrub-random*, *tree-regular*, and *tree-random*. During and after the driving task, we asked participants to report their mental status. The study was approved by the Human Research Ethics Committee at the University of Hong Kong.

Methods

Experimental Design

To examine how different freeway landscapes impact drivers' mental status, we created six different landscape conditions on the same virtual freeway. For the driving conditions, we built 3D models in Esri CityEngine® (2015), with AutoCAD 2016, Rhinoceros 5, and Grasshopper (0.9.0076) as auxiliary. Then we exported the 3D models into OpenDS 4.5 (Green et al., 2014; Math et al., 2012), an open-source driving simulation software, using Blender plugins (version 2.78c) for conversion. The freeway infrastructure is identical for each driving condition. We configured six types of roadside landscape conditions into the models: *barren*, *turf*, *shrub-regular*, *shrub-random*, *tree-regular*, and *tree-random* (Figures 1 and 2).

The simulated loop freeway for all conditions is 40,500 m long, with slight curves, and is based on typical urban freeways in large international cities, with skyscrapers and multi-story commercial and residential buildings on both sides of the road.

The width of the landscape lane is 10 m. For both *tree-regular* and *tree-random* conditions, the trees were placed in a single central line, with a

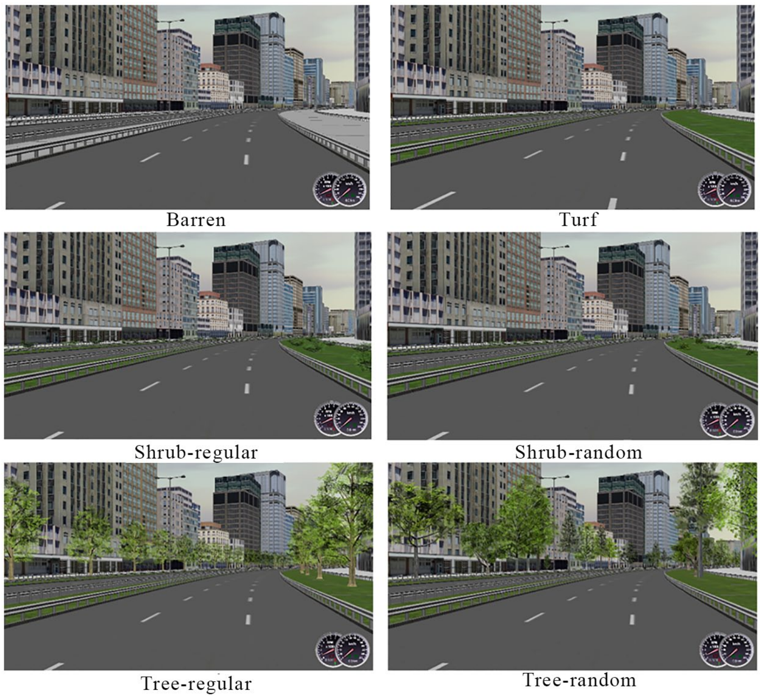

Figure 1. Six types of freeway landscape conditions.

distance of 5 m between each tree trunk and the edge of the roadway. For both *shrub-regular* and *shrub-random* conditions, the shrubs were centered on evenly spaced double lines, with a distance of 3.3 m between the center of each shrub and the edge of the roadway (Figure 2). For the *tree-regular* condition, we placed trees evenly 20 m apart, while for the *shrub-regular* condition, we placed the shrubs 10 m apart. The distance between tree trunks or shrubs was established based on a review of standards in major US cities (Gilman, 2015; Macdonald et al., 2006). For the *tree-random* and *shrub-random* conditions, we used Grasshopper® plugins (0.9.0076) to develop randomly configured intervals for trees and shrubs alongside the road, respectively. The sum dimension and number of shrubs and trees for both regular and random layouts were set in Esri CityEngine® (2015) to make sure the total green volume for both conditions is identical. We selected Aesculus hippocastanum for *tree-regular* and Boxwood hybrids for the *shrub-regular*

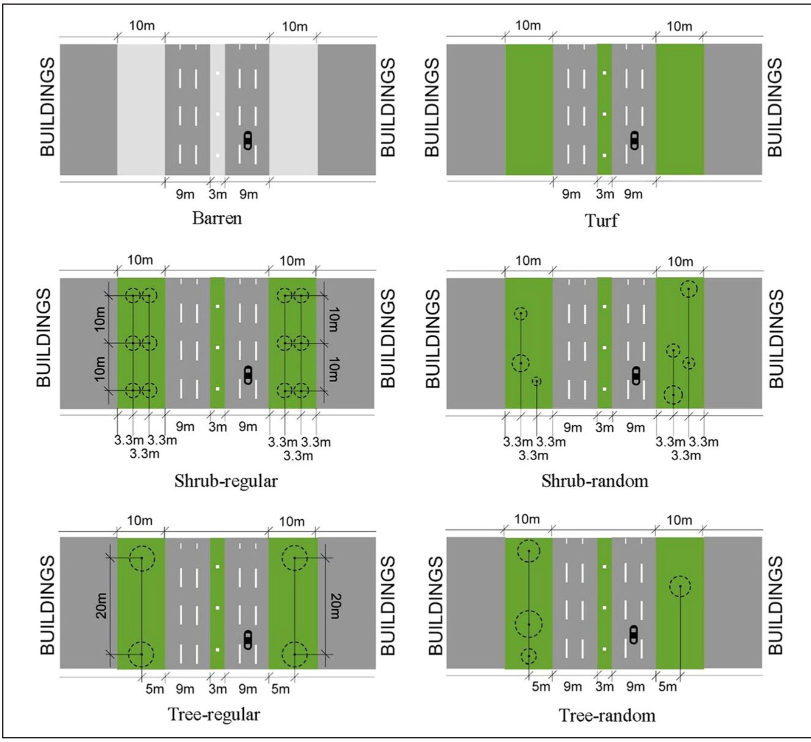

Figure 2. Typical layouts and sections of a freeway for six landscape conditions.

because they are widely used street plants for major cities throughout both sub-tropical and temperate zones (e.g., New York, Chicago, London, Hong Kong, etc.) (Erzurumlu & Tekinalp, 2018; Harris County Extension Horticulturists [HCEH], 2009; Petrova et al., 2014; Thomas et al., 2019; Weerakkody et al., 2017). We selected ten common shrubs and ten common tree species from street vegetation lists of those cities for *shrub-random* and *tree-random* accordingly (Supplemental Tables A and B) (Biodiversity Information System for Europe [BISE], n.d.; Global Biodiversity Information Facility [GBIF], n.d.; The Morton Arboretum [TMA], n.d.; United States Department of Agriculture [USDA], n.d.).

Participants

To determine the number of participants, we conducted a statistical power calculation with the assistance of G*Power 3.1.9.2 (Buchner et al., 2014;

Faul et al., 2007, 2009). Because of the nature of the experimental setting, we implemented the calculation with an ANOVA test (repeated measures, within-between interaction) with the alpha error probability value set at 0.05. Results indicated that a sample size of 30 could produce a power value of 0.98 with the effect size at 0.5. We obtained valid data sets from 33 participants in our study, which ultimately produced a power value of 0.99.

To select participants, we used a convenience sampling method (Etikan et al., 2016). We recruited people ages 18 to 60 from an international university campus in Hong Kong. We recruited participants by placing flyers in multiple locations both on and off of the university campus and through social media platforms. Participants needed to have a valid driver license to participate. Participants were excluded if they had been diagnosed with any sort of mental or physical illness or if they had had any sort of vehicle accident trauma. Individuals were also not allowed to participate in the study if their visual acuity (after vision correction) was less than 20/20. We asked participants to refrain from consuming alcoholic or caffeinated drinks 6 hours before the experiment. We also asked participants to receive ample sleep the night before the experiment.

We recruited 40 healthy individuals and collected complete data sets from 33 individuals (21 males, 12 females, see Table 1 for demographic information). Each participant visited the lab six times to experience all six of the different driving condition simulations. We used Latin Square to achieve a randomized order for the simulations to largely mitigate practice and order effects (Cochran & Cox, 1950; Jacobson & Matthews, 1996). The participants were randomly assigned to as many possible orders as the Latin Square requires, and each participant viewed the simulations in one of the possible orders. Participants completed a background questionnaire consisting of questions about their age, gender, education, economic status, marital status, and self-reported driving performance history.

Experimental Equipment

We set up the driving operation software environment using Lenovo ThinkStation P910, and rendered the simulation in OpenDS®. We configured the driving hardware environment by using Logitech G29 driving set and included a steering wheel, pedals (clutch, brake, accelerator) (Eudave & Valencia, 2017), and play-seat. We used 79" LG SUPER UHD TV 79UF9500 for simulation display, and a Sony SS-WSB128 speaker system to simulate the car engine sound. The lab space for the experiment was surrounded by black canvas to eliminate interference from other light sources.

Table 1. Descriptive Statistics of Socio-demographic Characteristics and Driving Record.

Measures	*N*	%
Social-demographic		
Age		
18–25	15	45.5
26–30	12	36.4
31–40	2	6.1
41–50	3	9.1
51–60	1	3.0
Gender		
Male	21	63.6
Female	12	36.4
Education		
Elementary school	0	0
High school	1	3.0
Bachelor	19	57.6
Master	10	30.3
Doctorate	3	9.1
Monthly income (HKD)		
≤5,000	4	12.1
5,001–10,000	4	12.1
10,001–20,000	15	45.5
20,001–30,000	5	15.2
30,001–50,000	3	9.1
≥50001	2	6.1
Marital status		
Never married	28	84.8
Married/Living with a partner	4	12.1
Widowed/Divorce/Separated	1	3.0
Year (s) holding a driver license (driving experience)		
≤1	5	15.2
2–5	14	42.4
6–10	8	24.2
11–20	4	12.1
21–30	2	6.1
Over 2,000 **miles driving experience during last 3 years**		
Yes	14	42.4
No	19	57.6

(continued)

Table 1. (continued)

Measures	N	%
Convicted of any driving violation(s) during last 3 years		
Yes	5	15.2
No	28	84.8
Any accident(s) involving traffic violation convictions		
Yes	0	0
No	33	100.0
Involvement in any vehicle accident while driving during last 3 years		
Yes	1	3.0
No	32	97.0
Self-reported historical driving performance		
Very bad skill = 0; Moderate = 5; Very good skill = 10	*M*	*SD*
	6.69	1.30

Mental Status Measures

We measured participants' self-reported mental status using a Visual Analog Scale (VAS) questionnaire, consisting of 10-cm horizontal lines ranging from "not at all" on one side to "extremely" on the other (Jiang et al., 2014). Participants placed an X anywhere along the lines to indicate their mental status related to seven mental aspects: boredom, anger, frustration, tension, anxiety, avoidance, and fatigue. We chose these mental aspects because a) studies have shown that they significantly impact drivers' mental status (Frumkin et al., 2004); and b) they have been frequently examined in empirical studies exploring the impacts of urban environments on city dwellers' mental status (e.g., Antonson et al., 2009; Gastaldi et al., 2014; Jiang et al., 2014). After the simulation task, participants were asked to describe their mental status while driving by typing on a computer keyboard.

Procedure

The experiments took place between July 2017 and November 2017 at a university campus in Hong Kong. All experiments were conducted in the same laboratory room, and the lab environment was arranged in the same configuration and set to a consistent temperature and lighting condition (Figure 3). Three investigators administered the experiment for the participants, and each was trained to follow an identical procedure (Figure 4). Investigators were evenly assigned to administer the procedure for the six different landscape conditions.

Figure 3. A laboratory environment for the experiment (left: experimental space; right: backstage space).

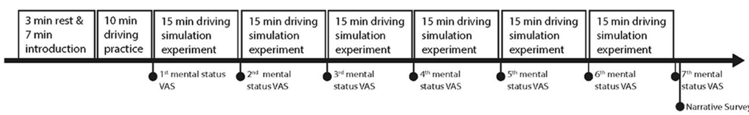

Figure 4. Experiment procedure.

When a participant entered the laboratory, an investigator introduced the experimental procedure, gave the participant a consent form to sign, and reviewed inclusion criteria. Then the participant practiced driving for 10 minutes in a plain freeway loop without environmental features to let them get familiar with the operation of the driving simulation equipment. The purpose of the practice drive was to reduce the impact of the learning effect on participants' driving performance during the later experiment and also create a baseline mental status for participants. Next, the participant completed a baseline VAS questionnaire and then began the 90-minute driving simulation with one of six types of curbside landscape. The participant was asked to keep a legal driving speed, which is regulated by the local freeway code in Hong Kong (70–120 km/hour). The 90-minute procedure was divided into six 15-minute segments, and the VAS questionnaire was administered after each segment, during a one-minute break.

Following the driving simulation, the participant was asked to answer a short background questionnaire, followed by an open-ended question: "Please take around 10 minutes to describe your feelings during the driving experiment." The participant then typed narratives on a computer keyboard. The whole experiment took around 110 minutes to complete.

Results

We present results in three parts: First, we present descriptive statistics of the primary measures and their correlations. Second, we present results of one-way ANOVA with repeated measures to reveal the impact of all six landscape conditions on the seven mental status measures and on a summary mental status measure. Third, we present results of two-way ANOVA with repeated measures to reveal the impact of greenness and complexity of landscapes on mental status. Last, we present the results of the textual analysis from participants' narratives.

Descriptive Statistics, Correlation, and Reliability

The descriptive statistics are presented in Table 2. The results of Cronbach's Alpha analysis demonstrate high reliability among the seven mental status measures for composing a summarized mental status measure. *Cronbach's Alpha if Item Deleted* values are 0.916 (boredom), 0.904 (anger), 0.889 (frustration), 0.893 (avoidance), 0.894 (anxiety), 0.894 (tension), 0.895 (mental fatigue). The general Cronbach's Alpha value is .911. Results of the Pearson correlation analysis suggest the seven measures are mostly correlated with each other at moderate levels (0.40–0.70). All seven measures have a strong correlation with the summarized measure (0.79–0.88), and all correlations are significant, $p < .001$ (Table 3).

One-way ANOVA with Repeated Measures

Using one-way repeated measures ANOVA analysis, we examined the impacts of the six landscape conditions on drivers' mental status immediately before the driving experiment (*baseline*), and during the 90-minute driving experiment (*experiment*). ANOVA analysis was conducted with a Greenhouse-Geisser correction. We analyzed the seven different mental status measures (boredom, anger, frustration, tension, anxiety, avoidance, and mental fatigue), and also created a *summarized mental status* measure that combined all of the measures. At the *baseline*, there were no significant differences among the six landscape conditions for all seven mental status measures and the summarized mental status measures. During the experiment, there were significant differences among the six conditions, which we present below.

Boredom was significantly different among the six conditions, F (3.72, 732.96) = 14.15, p = .000. The *tree-regular* evoked significantly lower boredom scores than all other conditions, while the *barren* condition was associated with significantly higher levels of boredom than all other conditions

Table 2. Descriptive Statistics of Measures of Mental Status.

		Boredom		Anger		Frustration		Avoidance		Anxiety		Tension		Mental fatigue		Summarized mental status	
		Baseline	Experiment	Baseline	Experiment	Baseline	Experiment	Baseline	Experiment	Baseline	Experiment	Baseline	Experiment	Baseline	Experiment	Baseline	Experiment
Barren	Mean	1.82	4.50	0.52	1.20	0.61	1.72	0.90	2.57	0.82	1.77	1.09	1.71	1.23	3.73	1.00	2.46
	SD	1.97	2.90	0.80	1.76	0.83	2.18	1.52	2.81	1.05	2.03	1.65	2.09	1.22	2.29	1.40	2.58
	95%CI	1.15, 2.50	4.10, 4.91	0.25, 0.79	0.95, 1.44	0.33, 0.89	1.42, 2.03	0.38, 1.42	2.18, 2.97	0.46, 1.17	1.49, 2.05	0.53, 1.66	1.42, 2.00	0.81, 1.64	3.41, 4.05	0.82, 1.18	2.32, 2.59
	N	33	198	33	198	33	198	33	198	33	198	33	198	33	198	231	1,386
Turf	Mean	1.94	3.95	0.43	1.04	0.73	1.61	0.86	2.32	0.66	1.54	0.75	1.53	1.12	3.22	0.93	2.18
	SD	2.36	2.95	0.63	1.29	1.30	1.83	1.71	2.48	0.97	1.71	1.05	1.67	1.31	2.22	1.48	2.30
	95%CI	1.14, 2.75	3.54, 4.37	0.21, 0.64	0.86, 1.22	0.28, 1.17	1.36, 1.87	0.27, 1.44	1.98, 2.67	0.33, 0.99	1.30, 1.78	0.40, 1.11	1.30, 1.77	0.68, 1.57	2.91, 3.53	0.74, 1.12	2.05, 2.30
	N	33	198	33	198	33	198	33	198	33	198	33	198	33	198	231	1,386
Shrub regular	Mean	1.68	3.61	0.45	1.02	0.64	1.67	0.85	2.39	0.67	1.64	0.73	1.60	1.23	3.33	0.89	2.18
	SD	1.98	2.77	0.88	1.42	1.22	2.17	1.63	2.52	1.00	1.89	1.01	1.83	1.60	2.41	1.42	2.36
	95%CI	1.00, 2.35	3.23, 4.00	0.15, 0.75	0.82, 1.22	0.22, 1.06	1.37, 1.97	0.29, 1.41	2.04, 2.74	0.33, 1.01	1.37, 1.90	0.39, 1.08	1.35, 1.86	0.68, 1.77	2.99, 3.66	0.71, 1.08	2.05, 2.30
	N	33	198	33	198	33	198	33	198	33	198	33	198	33	198	231	1,386
Shrub random	Mean	1.59	4.16	0.59	1.25	0.63	1.74	0.86	2.81	0.70	1.81	0.75	1.62	0.93	3.28	0.87	2.38
	SD	2.09	3.18	0.98	1.70	1.06	2.12	1.78	3.00	1.09	2.04	1.11	1.85	1.28	2.39	1.42	2.57
	95%CI	0.88, 2.31	3.71, 4.60	0.26, 0.93	1.01, 1.49	0.27, 0.99	1.45, 2.04	0.26, 1.47	2.39, 3.23	0.33, 1.07	1.53, 2.10	0.37, 1.13	1.36, 1.88	0.49, 1.37	2.95, 3.61	0.68, 1.05	2.25, 2.52
	N	33	198	33	198	33	198	33	198	33	198	33	198	33	198	231	1,386
Tree regular	Mean	1.20	3.22	0.44	0.93	0.45	1.12	0.84	2.09	0.67	1.26	0.81	1.15	1.15	2.91	0.79	1.81
	SD	1.74	2.74	0.97	1.41	0.70	1.36	1.33	2.35	1.01	1.62	1.19	1.36	1.37	2.25	1.24	2.12
	95%CI	0.61, 1.79	2.84, 3.60	0.11, 0.77	0.73, 1.12	0.21, 0.69	0.93, 1.31	0.39, 1.29	1.76, 2.42	0.33, 1.01	1.03, 1.48	0.41, 1.22	0.96, 1.34	0.68, 1.62	2.59, 3.22	0.63, 0.95	1.70, 1.92
	N	33	198	33	198	33	198	33	198	33	198	33	198	33	198	231	1,386
Tree random	Mean	1.87	4.04	0.40	0.98	0.52	1.52	0.92	2.30	0.64	1.45	0.62	1.38	1.40	3.20	0.91	2.12
	SD	2.25	3.05	0.65	1.35	0.94	1.88	1.56	2.39	0.99	1.68	0.95	1.61	1.66	2.30	1.46	2.34
	95%CI	1.10, 2.63	3.61, 4.46	0.18, 0.62	0.80, 1.17	0.20, 0.84	1.26, 1.78	0.39, 1.45	1.97, 2.63	0.30, 0.97	1.22, 1.68	0.29, 0.94	1.15, 1.60	0.83, 1.96	2.88, 3.52	0.72, 1.10	2.00, 2.25
	N	33	198	33	198	33	198	33	198	33	198	33	198	33	198	231	1,386

Table 3. Correlation Matrix Among Measures of Mental Status.

	Boredom	Anger	Frustration	Avoidance	Anxiety	Tension	Mental_fatigue	Summarized_mental_status
Boredom		0.41	0.57	0.65	0.48	0.50	0.69	0.79
Anger	0.41		0.73	0.54	0.77	0.74	0.55	0.77
Frustration	0.57	0.73		0.75	0.75	0.80	0.61	0.88
Avoidance	0.65	0.54	0.75		0.64	0.63	0.65	0.86
Anxiety	0.48	0.77	0.75	0.64		0.83	0.63	0.84
Tension	0.50	0.74	0.80	0.63	0.83		0.62	0.85
Mental_fatigue	0.69	0.55	0.61	0.65	0.63	0.62		0.83
Summarized_mental_status	0.79	0.77	0.88	0.86	0.84	0.85	0.83	

r value: 0.0, 0.2, 0.4, 0.6, 0.8, 1.0

Note. All correlations are significant, $p < .001$.

Table 4. Post hoc (LSD) of Condition Factor with Boredom Evaluated by VAS Among the Six Conditions (Six Measures After Each Driving Section Combined).

	Barren	Turf	Shrub-regular	Shrub-random	Tree-regular	Tree-random
Barren	-					
Turf	>***	-				
Shrub-regular	>***	>**	-			
Shrub-random	>*	ns	<***	-		
Tree-regular	>***	>***	>*	>***	-	
Tree-random	>*	ns	<*	ns	<***	-

Note. $^{*}p < .05$. $^{**}p < .01$. $^{***}p < .001$. ^{ns}p = non-significant. "$>$" suggests the value of the column is greater than the value of the row.

(Table 4 and Figure 5). The *shrub-random*, *tree-random*, *turf*, and *shrub-regular* conditions ranked 2nd to 5th for boredom.

Anger was significantly different among the six conditions, F (2.54, 500.02) = 32.90, p = .000. Specifically, the *tree-regular* evoked significantly lower

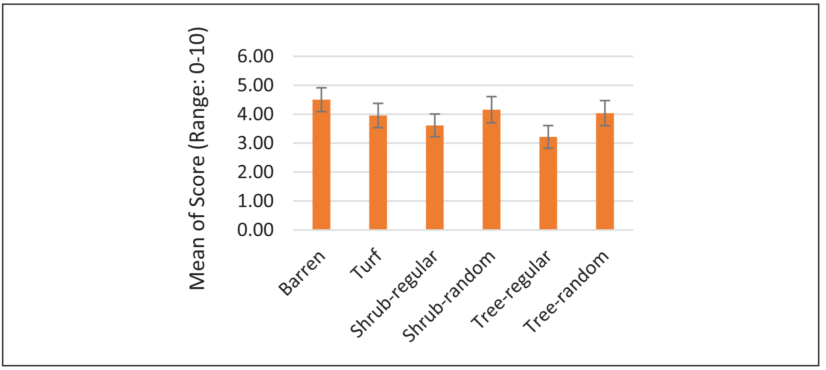

Figure 5. Boredom (M ± 2SE).

Table 5. Post hoc (LSD) of Condition Factor with Anger Evaluated by VAS Among the Six Conditions (Six Measures After Each Driving Section Combined).

	Barren	Turf	Shrub-regular	Shrub-random	Tree-regular	Tree-random
Barren	-					
Turf	>***	-				
Shrub-regular	>***	ns	-			
Shrub-random	ns	<***	<***	-		
Tree-regular	>***	>***	>***	>***	-	
Tree-random	>***	>**	>**	>***	<**	-

Note. $^{**}p < .01$. $^{***}p < .001$. ^{ns}p = non-significant.

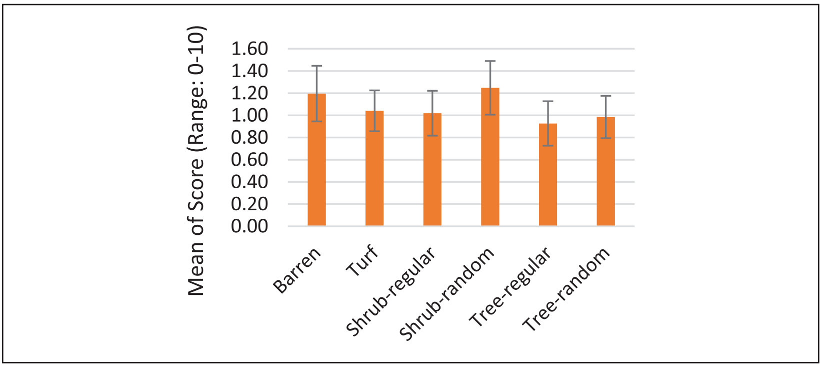

Figure 6. Anger (M ± 2SE).

Table 6. Post hoc (LSD) of Condition Factor with Frustration Evaluated by VAS Among the Six Conditions (Six Measures After Each Driving Section Combined).

	Barren	Turf	Shrub-regular	Shrub-random	Tree-regular	Tree-random
Barren	-					
Turf	>***	-				
Shrub-regular	>*	ns	-			
Shrub-random	ns	<***	<**	-		
Tree-regular	>***	>***	>***	>***	-	
Tree-random	>***	>***	>***	>***	<***	-

Note. *$p < .05$. **$p < .01$. ***$p < .001$. ns$p$ = non-significant.

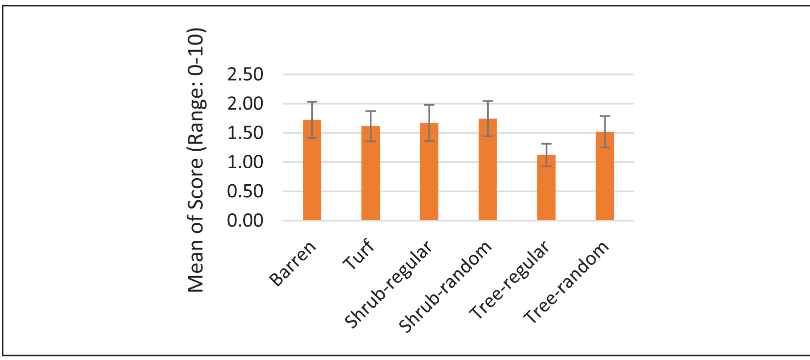

Figure 7. Frustration (M ± 2SE).

anger levels than all other conditions, while the *barren and shrub random* evoked significantly higher levels of anger than the four other conditions. There was no statistical difference between *barren* and *shrub-random*. *Turf*, *shrub-regular*, and *tree-random* ranked from 3nd to 5th (Table 5 and Figure 6).

Frustration was significantly different for the six conditions, F (1.81, 355.88) = 76.56, p = .000. The *tree-regular* condition evoked significantly lower frustration than all other conditions, while the *barren* and *shrub random* conditions evoked significantly higher frustration than the other four conditions. There was no statistical difference between *barren* and *shrub random*. *Shrub-regular*, *turf*, and *tree-random* ranked from 3nd to 5th on the evoked level of frustration (Table 6 and Figure 7).

Avoidance was significantly different among the six conditions, F (1.69, 331.97) = 115.49, p = .000. The *tree-regular* condition evoked

Table 7. Post hoc (LSD) of Condition Factor with Avoidance Evaluated by VAS Among the Six Conditions (Six Measures After Each Driving Section Combined).

	Barren	Turf	Shrub-regular	Shrub-random	Tree-regular	Tree-random
Barren	-					
Turf	>***	-				
Shrub-regular	>***	<***	-			
Shrub-random	<***	<***	<***	-		
Tree-regular	>***	>***	>***	>***	-	
Tree-random	>***	ns	>***	>***	<***	-

Note. $^{***}p < .001$. ^{ns}p = non-significant.

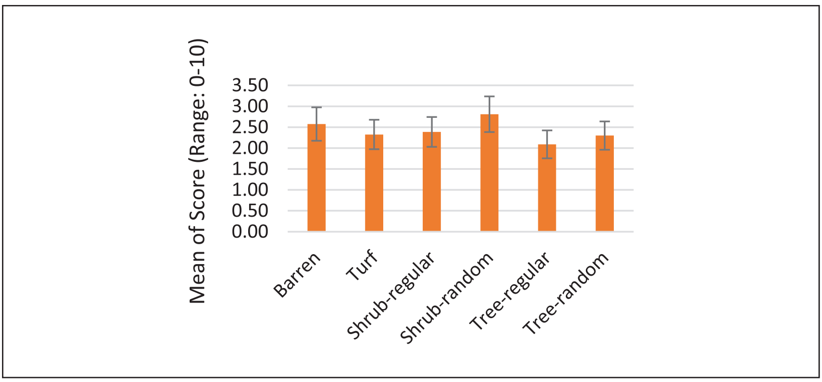

Figure 8. Avoidance (M ± 2SE).

significantly lower avoidance levels than all other conditions. In comparison, the *shrub random* condition evoked significantly higher levels of avoidance than all other conditions, and the *barren* condition was significantly worse than all the other conditions except for *shrub-random*. The *shrub-regular*, *turf*, and *tree-random* conditions ranked from 3nd to 5th on avoidance level (Table 7 and Figure 8).

Anxiety among the six conditions was significantly different, F (2.51, 494.71) = 110.22, p = .000. The *tree-regular* condition evoked significantly lower anxiety than all other conditions, while the *barren* and *shrub random* conditions evoked significantly higher levels of anxiety than the other four conditions, with no significant difference between *barren* and *shrub-random*.

Table 8. Post hoc (LSD) of Condition Factor with Anxiety Evaluated by VAS Among the Six Conditions (Six Measures After Each Driving Section Combined).

	Barren	Turf	Shrub-regular	Shrub-random	Tree-regular	Tree-random
Barren	-					
Turf	>***	-				
Shrub-regular	>***	<***	-			
Shrub-random	ns	<***	<***	-		
Tree-regular	>***	>***	>***	>***	-	
Tree-random	>***	>***	>***	>***	<***	-

Note. ***$p < .001$. ^{ns}p = non-significant.

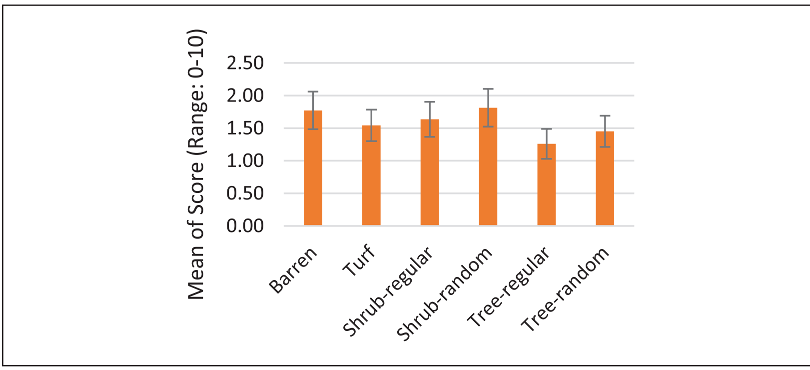

Figure 9. Anxiety (M $\pm$ 2SE).

The *shrub-regular*, *turf*, and *tree-random* conditions ranked from 3nd to 5th on the evoked level of anxiety, and comparisons among them are all significant (Table 8 and Figure 9).

Tension among the six conditions was significantly different, F (1.75, 345.59) = 87.45, p = .000. The *tree-regular* condition evoked significantly lower tension levels than all other conditions, while the *barren* condition evoked significantly higher levels of tension than all other conditions. The *shrub-random, shrub-regular, turf*, and *tree-random* conditions ranked from 2nd to 5th on tension, and all comparisons yielded significant results except the comparison between *shrub-random* and *shrub-regular* (Table 9 and Figure 10).

Table 9. Post hoc (LSD) of Condition Factor with Tension evaluated by VAS among the Six Conditions (Six Measures After Each Driving Section Combined).

	Barren	Turf	Shrub-regular	Shrub-random	Tree-regular	Tree-random
Barren	-					
Turf	>***	-				
Shrub-regular	>***	<**	-			
Shrub-random	>**	<***	ns	-		
Tree-regular	>***	>***	>***	>***	-	
Tree-random	>***	>***	>***	>***	<***	-

Note. ** $p < .01$. *** $p < .001$. ns p = non-significant.

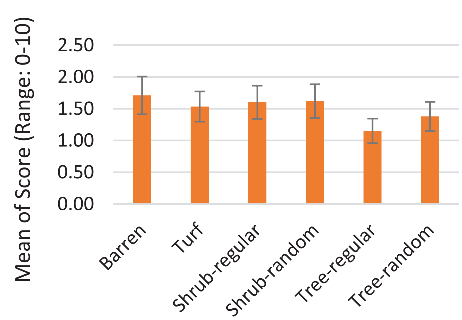

Figure 10. Tension (M ± 2SE).

Mental fatigue. Mental fatigue among the six conditions was significantly different, F (3.41, 671.94) = 3.69, $p < .01$. The ANOVA analysis was conducted with a Greenhouse-Geisser correction. The *tree-regular* condition evoked the lowest level of fatigue but was only statistically lower than *barren* ($p < .01$) and *shrub-regular* ($p < .05$). *Barren* and *shrub regular* evoked significantly higher levels of fatigue than the other four conditions, and there was no significant difference between *barren* and *shrub-regular.* The *shrub-random, turf, and tree-random* ranked from 3nd to 5th on fatigue, but none of the comparisons among them are significant (Table 10 and Figure 11).

Summarized mental status. The summarized mental status measure is the average value of the seven measures of negative mental status (boredom,

Table 10. Post hoc (LSD) of Condition Factor with Mental Fatigue Evaluated by VAS Among the six Conditions (Six Measures After Each Driving Section Combined).

	Barren	Turf	Shrub-regular	Shrub-random	Tree-regular	Tree-random
Barren	-					
Turf	>*	-				
Shrub-regular	ns	ns	-			
Shrub-random	>**	ns	ns	-		
Tree-regular	>***	ns	>*	ns	-	
Tree-random	>***	ns	ns	ns	ns	-

Note. *$p < .05$. **$p < .01$. ***$p < .001$. ns$p$ = non-significant.

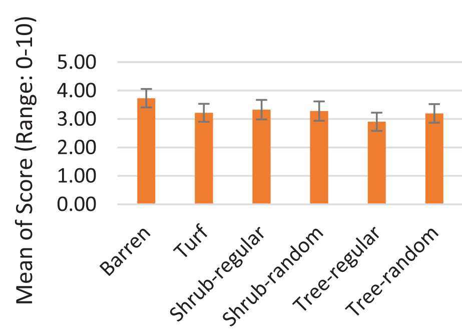

Figure 11. Mental fatigue (M ± 2SE).

anger, frustration, tension, anxiety, avoidance, mental fatigue). The summarized mental status measure among the six conditions was significantly different, F (4.39, 886.22) =14.01, $p = .000$. Explicitly, the *tree-regular* condition evoked significantly lower levels of negative mental status than all other conditions ($p < .001$). The *barren* and *shrub random* conditions evoked significantly higher levels of negative mental status than the other four conditions, and there is no significant difference between *barren* and *shrub-random*. The *turf, shrub regular, and tree-random* conditions ranked from 3nd to 5th on evoked level of negative mental status, but none of the comparisons between them are significant (Table 11 and Figure 12).

Table 11. Post hoc (LSD) of Condition Factor with Summarized Mental Status Evaluated by VAS Among the Six Conditions (Six Measures After Each Driving Section Combined).

	Barren	Turf	Shrub-regular	Shrub-random	Tree-regular	Tree-random
Barren	-					
Turf	>***	-				
Shrub-regular	>**	ns	-			
Shrub-random	ns	<*	<*	-		
Tree-regular	>***	>***	>***	>***	-	
Tree-random	>***	ns	ns	>*	<***	-

Note. $^{*}p < .05$. $^{**}p < .01$. $^{***}p < .001$. ^{ns}p = non-significant.

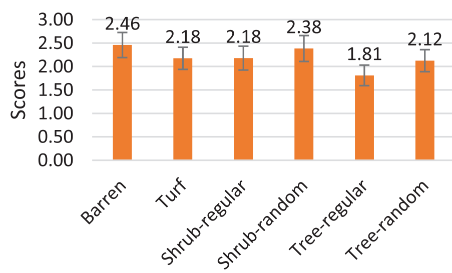

Figure 12. Summarized mental status (M ± 2SE).

Two-way Repeated Measures ANOVA Analysis: Greenness versus Complexity

It is worth noting that *shrub-random* and *tree-random* conditions yielded significantly higher levels of negative mental status than their corresponding *shrub-regular* and *tree-regular* pairs in many measures of mental status. To examine the impact of landscapes' greenness and complexity on drivers' mental status, we conducted a two (greenness) × two (complexity) ANOVA with repeated measures for the *summarized mental status* among the four landscape conditions: *shrub regular*, *shrub random*, *tree regular*, and *tree random* (Tables 12 and 13).

At the *baseline*, the within-subjects effect of greenness (F [1, 32] = 0.08, p = .78), complexity (F [1, 32] = 0.33, p = .57), and their interaction effect

Table 12. Descriptive Statistics of 2 (Greenness) × 2 (Complexity) Repeated Measures ANOVA for the Experiment.

Greenness	Complexity	Mean	SD	*n*
Low (1)	Low (1)	2.18	1.79	198
	High (2)	2.38	1.94	198
	Total	2.28	1.87	396
High (2)	Low (1)	1.81	1.54	198
	High (2)	2.12	1.66	198
	Total	1.97	1.61	396
Total	Low (1)	1.99	1.68	396
	Low (2)	2.25	1.81	396
	Total	2.12	1.75	792

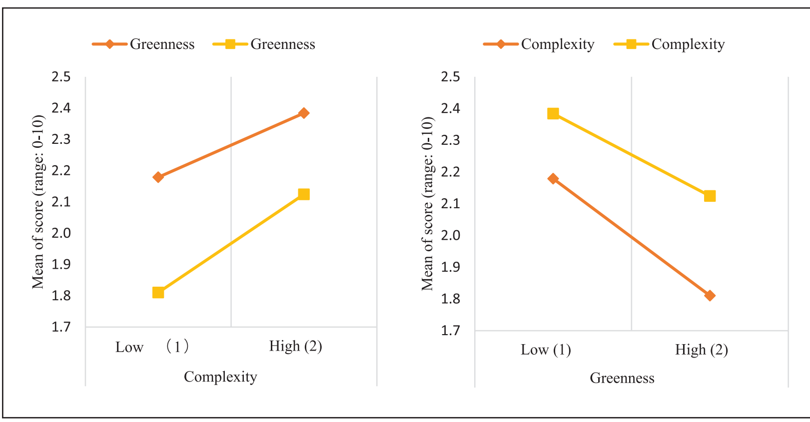

Figure 13. Two (greenness) × Two (complexity) ANOVA analysis for the *summarized mental status*.

(F [1, 32] = 0.37, p = .55) is not statistically significant, indicating no pronounced discrepancy between different greenness and complexity levels at the baseline.

For the *experiment*, the within-subjects effect of greenness (F [1, 197] = 11.10, p = .001) and complexity (F [1, 197] = 7.53, p = .007) are both statistically significant. The interaction effect between greenness and complexity is not statistically significant (F [1, 197] = 0.27, p = .603) (Table 13 and Figure 13). These findings suggest conditions with greater greenness and lower complexity are more beneficial for drivers' mental status.

Table 13. Test of Within-subject Effects.

Source	Type III sum of squares	df	Mean square	F	Sig.	Partial eta squared
Greenness	19.56	1	19.56	11.10	0.001	.053
Error	347.08	197	1.76			
Complexity	13.33	1	13.33	7.53	0.007	.037
Error	348.84	197	1.77			
Greenness × Complexity	0.59	1	.59	0.27	0.603	.001
Error	428.98	197	2.18			

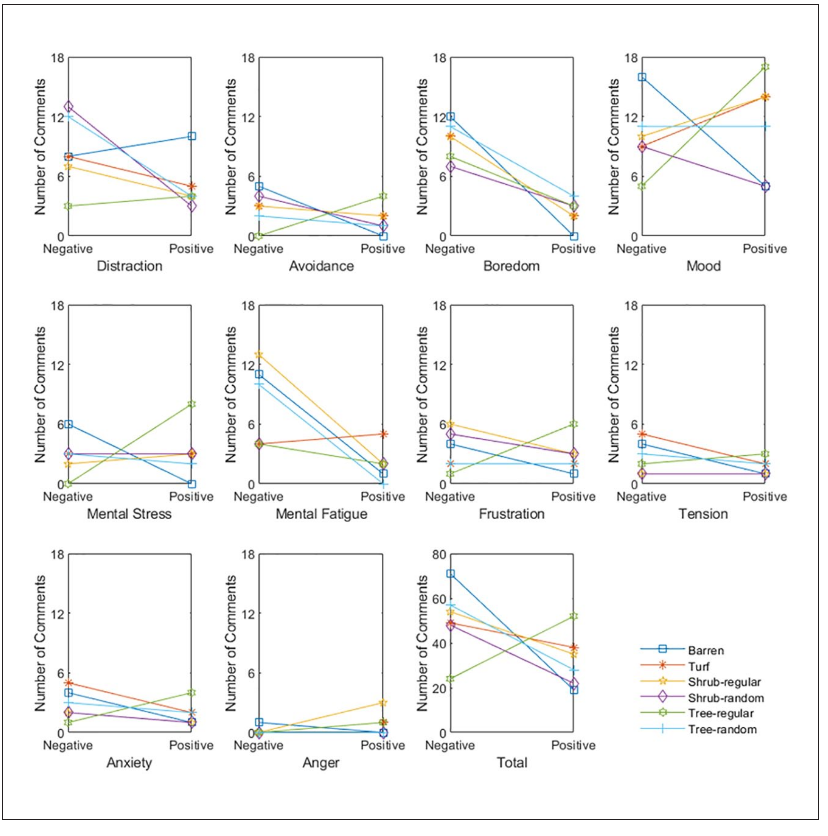

Figure 14. Positive and negative comments for each type of mental status and a summarized (total) mental status.

Analysis of Drivers' Narratives

To further explore the different impacts of the six landscape conditions on drivers' mental status, we conducted a textual analysis of participants' narratives. In the narratives, participants answered a single open-ended question in which they described their feelings during each driving task. Three investigators categorized participants' words into ten themes: 1. Distraction; 2. Avoidance; 3. Boredom; 4. Mood; 5. Mental stress; 6. Mental fatigue; 7. Frustration; 8. Tension; 9. Anxiety; 10. Anger. Each word was coded as a negative or a positive comment, and the total amount of negative and positive comments were calculated (Table 14).

Chi-square tests of Independence were used to measure the level of effects. Participants' comments differed significantly for measures, including 4. Mood ($\chi^2_{(5)}$ =14.95, $p < .01$); 5. Mental stress ($\chi^2_{(5)} = 14.33$, $p < .01$); 6. Mental fatigue ($\chi^2_{(5)} = 12.06$, $p < .03$); and total ratings ($\chi^2_{(5)} = 43.55$, $p < .01$). Participants' positive versus negative comments did not generate significant differences among the six types of greenness for 1. Distraction ($\chi^2_{(5)} = 7.16$, $p = .21$); 2. Avoidance ($\chi^2_{(5)} = 2.70$, $p = .75$); 3. Boredom ($\chi^2_{(5)} = 4.66$, $p = .46$); 7. Frustration ($\chi^2_{(5)} = 6.67$, $p = .25$); 8. Tension ($\chi^2_{(5)} = 2.22$, $p = .82$); 9. Anxiety ($\chi^2_{(5)} = 4.68$, $p = .46$); and 10. Anger (There was not enough samples for analysis).

The main patterns found in the narrative data are similar to the findings from the VAS data (Figures 14 and 15). The *tree-regular* condition yielded the most positive feedback measured by the number of positive comments minus the number of negative comments (52–24 = 28). In contrast, *barren* yielded the most negative feedback (19–71 = −52). The *tree random* (−29), *shrub random* (−26), *shrub regular* (−19), *and turf* (−11) conditions ranked from 2nd to 5th on the level of negative feedback (Figure 15). It is important to note that *tree regular* was the only condition that yielded more positive comments than negative comments.

Discussion

Summary of Findings

There are two main findings in this within-subject experimental study. First, the greenness of landscape settings does impact drivers' mental status. In general, as the greenness of the roadside environment increases (from *barren* to *turf* to *shrub* to *tree*), drivers reported lower levels of negative mental status. The *tree-regular* condition elicited the greatest mitigation of negative mental status, while the *barren* condition yielded the

Table 14. Participants' Comments on the General Effect of Greenness on Mental Status.

		Barren	Turf	Shrub-regular	Shrub-random	Tree-regular	Tree-random
Distraction	Negative	8	8	7	13	3	12
	Positive	10	5	4	3	4	4
Avoidance	Negative	5	3	3	4	0	2
	Positive	0	2	2	1	4	1
Boredom	Negative	12	10	10	7	8	11
	Positive	0	2	2	3	3	4
Mood	Negative	16	9	10	9	5	11
	Positive	5	14	14	5	17	11
Mental stress	Negative	6	3	2	3	0	3
	Positive	0	3	3	3	8	2
Mental fatigue	Negative	11	4	13	4	4	10
	Positive	1	5	2	2	2	0
Frustration	Negative	4	2	6	5	1	2
	Positive	1	2	3	3	6	2
Tension	Negative	4	5	1	1	2	3
	Positive	1	2	1	1	3	2
Anxiety	Negative	4	5	2	2	1	3
	Positive	1	2	1	1	4	2
Anger	Negative	1	0	0	0	0	0
	Positive	0	1	3	0	1	0
Total	Negative	71	49	54	48	24	57
	Positive	19	38	35	22	52	28
	Diff.	−52	−11	−19	−26	+28	−29

smallest mitigation effect. Second, the visual complexity of the landscape does impact the drivers' mental status. We found that when greenness levels are similar, a landscape setting with more visual complexity elicited higher levels of negative mental status (*tree-random* vs. *tree-regular*; *shrub-random* vs. *shrub-regular*).

Interpretation of Findings

Questions for attention restoration theory and stress reduction theory. This study provides new evidence to support Attention Restoration Theory (ART) and Stress Reduction Theory (SRT) in that greener landscapes were associated with more positive mental responses than barren ones or ones

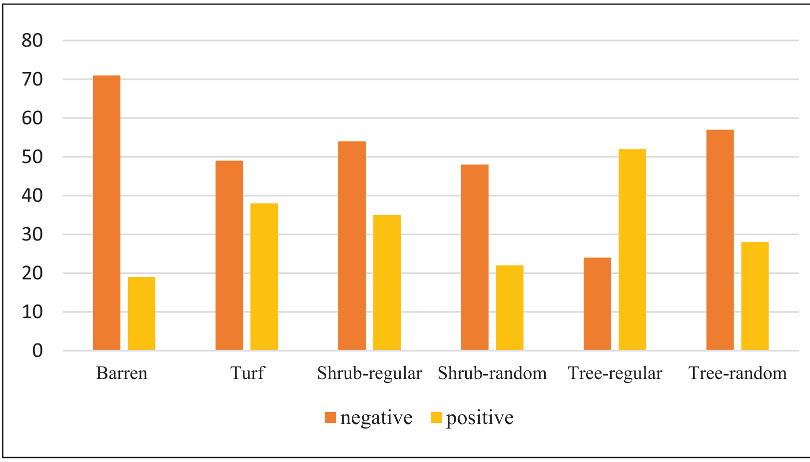

Figure 15. Combined positive and negative narratives for each type of landscape condition.

with less greenery. This study also raises new questions for ART and SRT. To our best knowledge, both ART and SRT do not consider speed of active movement as a component of the theoretical models (Kaplan, 1995; Ulrich et al., 1991). Empirical studies have not examined the validity of these theories when participants are actively moving at high speeds. Instead, studies have examined participants' mental responses to green landscapes when participants are actively moving at slow speeds (walking, jogging, or cycling) or even static (e.g., Berman et al., 2008; Roe & Aspinall, 2011; Travis et al., 1996).

Driving at moderate or high speeds is the primary mode of active movement in the modern world. Driving may share the same landscapes as other types of active movement (walking, jogging, or cycling) because all these types of movement demand that humans directly or indirectly control their body to move through a space or set of spaces safely. All these forms of movement require humans to make an immediate and accurate analysis of environmental information and then make correct decisions regarding their movement. Still, driving, especially at high speeds, demands accurate and fast information processing, which makes the experience of driving at speed more stressful and tiring than slower forms of movement (Frumkin, 2002). While a few studies have examined the impact of green landscapes on people driving on urban roads at moderate speeds, they have not explored the impacts of speed on mental restoration in different landscape settings (Parsons et al., 1998; Wang et al., 2016). The study presented here enriches our understanding of attention restoration and stress recovery because, to the best of our knowledge, it is the first to demonstrate that humans' mental responses to landscape settings vary when they are actively moving at high speeds, such as driving on the freeway.

In this study, we found that *regular* landscapes elicited lower levels of drivers' negative mental responses than their *random* pairs, which poses a challenge to these theories. We argue that green landscapes may not be fully restorative for people who are actively moving, such as driving, at high speeds. Green landscapes are indeed more restorative than barren ones, but if the green landscapes contain too much diversity in size, form, texture, and spatial characteristics, this diversity might consume drivers' directed attention, arouse drivers' stress, and evoked other negative mental states. Thus, there might be a trade-off effect between greenness and complexity at high speeds: A landscape with high greenness may be mentally restorative, but the effect might be weakened if it has high visual complexity. This finding is distinct from the findings of previous studies that measured participants' mental responses to landscapes while participants were static or moving slowly through a landscape. In these studies, both greenness and complexity of natural landscapes positively impact mental restoration (e.g., Fuller et al., 2007; McAllister et al., 2017).

The findings here add a new dimension to ART and SRT by pointing out that the impacts of landscape greenness and complexity on humans' mental status may interact with the speed of human movement. We propose that at a static or slow moving speed, both greenness and complexity positively impact restoration, which is consistent with the ideas of ART and SRT. However, there may be a trade-off between greenery and complexity when people are actively moving at high speed, which is a ripe area for future research.

Why Might a Higher Level of Greenness Mitigate Drivers' Negative Mental Responses?

This finding is consistent with previous theories and empirical evidence. Attention Restoration Theory (Kaplan, 1995) suggests that barren environments consume more of our directed attention than green ones, making us more mentally fatigued, a finding that is supported by a great deal of empirical research (Jiang et al., 2018b; Kuo & Sullivan, 2001; Parsons et al., 1998; Sullivan & Lovell, 2006). Stress reduction theory (Ulrich, 1981, 1984) suggests that artificial environments can arouse psycho-physiological stress while green environments can reduce stress, a finding that is also supported by many empirical studies (Hunter et al., 2019; Jiang et al., 2014, 2016, 2019).

Higher levels of greenness are also associated with other aspects of mental status, such as lower levels of depression (Min et al., 2017; Sarkar et al., 2018), lower levels of anger (Kuo & Sullivan, 2001; Kweon et al., 2008), higher levels of cognitive functioning (Chen et al., 2016; Jiang et al., 2018b; Tang et al., 2017), a greater sense of safety (Jiang et al., 2017, 2018a), and a more positive mood (Bratman et al., 2015; Sarkar et al., 2018).

Besides the direct restorative effect, green roadside landscapes also provide a visual buffer between the freeway and artificial streetscapes, which may also lead to more positive mental responses. From *barren* to *turf* to *shrub* to *tree*, the buffer effect becomes more potent as greenness, especially the greenness at the eye-level, increases (Jiang et al., 2017; Lu, 2018). The tree canopy in the two *Tree* conditions blocks a good deal of the artificial streetscapes so that the complex artificial environment does not consume drivers' directed attention (hard pavement, building façades, billboards). Meanwhile, less visual contact with the artificial environment leads to a lower level of stress and other negative moods.

Why Might a Condition with Greater Complexity Evoke a Higher Level of Negative Mental Responses?

Compared to the *regular* conditions, the *random* conditions had similar amounts of trees or shrubs (greenness), but greater species diversity and spatial variation of plants (complexity). Drivers responded more positively to the two *regular* landscape conditions than their *random* pairs, and the difference was consistent across all mental status measures.

At first glance, this finding is surprising because some studies have reported that biodiversity of vegetation and naturalistic landscapes are associated with more positive mental responses while controlling for greenness (Dallimer et al., 2012; Fuller et al., 2007). Also, a study reported that less monotonous landscapes could elicit lower levels of boredom and more positive mental status (Thiffault & Bergeron, 2003).

However, these findings have not been validated in high-speed driving environments. When people are sitting, walking, or even biking, they may perceive green landscapes that are diverse and complex as soft, restorative, and fascinating. People may not have the same reaction when driving at high speeds, where safety is more of a concern. Green landscapes may remain restorative to some extent, but if they are too complex or diverse, they will require drivers to exert more mental effort to perceive them, process them, and make decisions about them (Kaplan et al., 1989; Plass & Kalyuga, 2019). In other words, for freeway drivers, the random and diverse green landscapes might be riskier than formal and simple landscapes because the former ones have a higher level of cognitive load (Sweller, 1988). When tree characteristics (size, form, texture, and distance to the curb) keep changing along the freeway, drivers must pay more attention to stay safe (Antonson et al., 2014; Fitzpatrick et al., 2014). Our results suggest that visual complexity in freeway landscapes may be negatively associated with drivers' mental status.

Applications of Findings for Policy-making and Design Practice

There are three critical potential applications. Most importantly, policy-makers and design practitioners in the field of transportation need to know that roadside landscapes significantly impact drivers' mental status. In the past, they have mainly focused on designing artificial infrastructure, such as the road layout, width, radius, and pavement. We should regard green roadside landscapes as an essential part of transportation infrastructure, not an insignificant decoration.

Second, we should avoid barren landscapes in a freeway environment. Green landscapes, especially tree landscapes, provide a buffer to the artificial built environment and evoke significantly lower levels of many negative mental responses, such as boredom, anger, and frustration. Mitigating negative mental responses may help promote drivers' health and safety, as negative mental responses are associated with mental and physical illness, as well as a higher risk of accidents and fatalities (Cohen et al., 2001; Dimsdale, 2008; Frumkin, 2002; Staufenbiel et al., 2013). We found that landscapes with turf or shrubs only elicit slightly lower levels of negative mental responses than barren landscapes, suggesting that low-level vegetation is not enough for drivers at high speeds. Landscapes with greater levels of greenness, such as those with a vertical outline of trees, are far more restorative.

Third, it is crucial to keep the content of green landscapes simple to maximize their positive impact on drivers' mental status. Too much visual complexity (in terms of tree species variety, spacing, and size) might counteract the benefits of greenness for people driving vehicles at high speeds. However, this does not necessarily mean landscapes should be monotonous and formal, as roadside landscapes that are too monotonous have been found to lead to boredom and fatigue (Thiffault & Bergeron, 2003). More research needs to be done to find the optimal levels of complexity and greenness for freeway landscapes.

Directions for Future Research

In this study, we measured the impact of six of the most representative freeway landscapes on drivers' mental status during a 90-minute simulated driving test. We did not examine other types of landscapes, such as combinations of shrubs and trees, flowers, landscapes with diverse colors, and landscapes during different seasons. More research is needed to examine these different landscape characteristics. In addition, the duration of the drive might also impact mental status, which needs to be examined further.

Our experiment consisted of a 90-minute driving simulation along an urban freeway loop, but our simulation did not include complex traffic situations that often occur in actual freeway environments, such as tailgating, aggressive drivers, construction zones, and complicated lane changes (He et al., 2014, 2015). We also did not consider other types of freeway layouts. Future research should create more realistic driving conditions with higher complexity and different freeway layouts to increase the validity and generalizability of the findings (Farahmand & Boroujerdian, 2018; Oron-Gilad & Ronen, 2007). Future research could also find ways to measure drivers' mental status in real driving conditions. In order to further strengthen the applicability of the findings, future studies should investigate the similarities and differences between driving in simulated and real urban freeways. Nevertheless, many studies have reported that simulated urban environments are often reliable surrogates for real ones (Browning et al., 2020).

This study used common landscape species and settings from the major cities in the north temperate zone. It might be inappropriate to directly apply these findings to major cities in other climate zones, rural areas, or low-density urban areas with different appearance and configuration of green landscapes and artificial environments. This study should be duplicated for other types of physical environments to enhance its generalizability. In addition, this study only tested landscapes with green and full foliage; future research should examine the same issue with consideration for seasonal differences of natural landscapes (Brooks et al., 2017).

Finally, researchers should explore other ways of experiencing high-speed environments. Many people experience roadside landscapes as passengers in other people's cars, taxis, buses, or trains and do not experience the cognitively demanding task of driving. These "passive" passengers' experience the landscape differently than "active" drivers who must process information and make rapid decisions. Moreover, automated driving technologies might free people's attention from driving tasks, which will likely change how people respond to roadside landscapes (Farahmand & Boroujerdian, 2018). Future researchers should explore these passive ways of experiencing high-speed environments and examine the interactive impacts of speed and landscape on humans' mental status.

Conclusion

This study is an initial effort to understand the impacts of freeway landscapes on drivers' mental status. Through an experiment examining people's self-reported mental responses to six common freeway landscapes during a prolonged driving simulation, we provide strong evidence that landscapes along freeways significantly impact drivers' mental status. The within-subjects design gives more statistical power to the findings than many previous between-subjects studies or correlation studies.

Our results show that freeway landscapes are an essential part of freeway infrastructure with measurable mental restoration benefits. Designers should note the trade-off effect of greenness and complexity. They can maximize landscapes' mental health benefits by making them have more greeness and less complexity. Creating restorative freeway landscapes can promote health and safety for hundreds of millions of freeway drivers and passengers worldwide. Finally, the most significant contribution of this study might be it extends Attention Restoration Theory and Stress Reduction Theory to landscapes that are experienced while driving at high speeds, suggesting the speed of human's active movement should be considered as an essential factor in these two theories.

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Supplemental Material

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References

Antonson, H., Ahlström, C., Mårdh, S., Blomqvist, G., & Wiklund, M. (2014). Landscape heritage objects' effect on driving: A combined driving simulator and questionnaire study. *Accident Analysis & Prevention*, *62*, 168–177. https://doi.org/10.1016/j.aap.2013.09.021

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

Ayres, P., & Paas, F. (2012). Cognitive load theory: New directions and challenges. *Applied Cognitive Psychology*, *26*(6), 827–832. https://doi.org/10.1002/acp.2882

Beck, K. H., Daughters, S. B., & Ali, B. (2013). Hurried driving: Relationship to distress tolerance, driver anger, aggressive and risky driving in college students. *Accident Analysis & Prevention*, *51*, 51–55.

Berman, M. G., Jonides, J., & Kaplan, S. (2008). The cognitive benefits of interacting with nature. *Psychological Science*, *19*(12), 1207–1212. https://doi.org/10.1111/j.1467-9280.2008.02225.x

Biodiversity Information System for Europe. (n.d.). *Biodiversity Information System for Europe*. https://biodiversity.europa.eu/

Bratman, G. N., Daily, G. C., Levy, B. J., & Gross, J. J. (2015). The benefits of nature experience: Improved affect and cognition. *Landscape and Urban Planning*, *138*(0), 41–50. http://dx.doi.org/10.1016/j.landurbplan.2015.02.005

Brooks, A. M., Ottley, K. M., Arbuthnott, K. D., & Sevigny, P. (2017). Nature-related mood effects: Season and type of nature contact. *Journal of Environmental Psychology*, *54*, 91–102. https://doi.org/10.1016/j.jenvp.2017.10.004

Browning, M. H. E. M., Saeidi-Rizi, F., McAnirlin, O., Yoon, H., & Pei, Y. (2020). The role of methodological choices in the effects of experimental exposure to simulated natural landscapes on human health and cognitive performance: A systematic review. *Environment and Behavior*. Advance online publication. https://doi.org/10.1177/0013916520906481

Buchner, A., Erdfelder, E., Faul, F., & Lang, A.-G. (2014). Universität Düsseldorf: G*Power. http://www.gpower.hhu.de/

Buckley, B., Nugent, N., Sledjeski, E., Raimonde, A. J., Spoonster, E., Bogart, L. M., & Delahanty, D. L. (2004). Evaluation of initial posttrauma cardiovascular levels in association with acute PTSD symptoms following a serious motor vehicle accident. *Journal of Traumatic Stress*, *17*(4), 317–324.

Chen, Z., He, Y., & Yu, Y. (2016). Enhanced functional connectivity properties of human brains during in-situ nature experience. *PeerJ*, *4*, e2210.

Cochran, W. G., & Cox, G. M. (1950). *Experimental design*. John Wiley & Sons.

Cohen, S., Miller, G. E., & Rabin, B. S. (2001). Psychological stress and antibody response to immunization: A critical review of the human literature. *Psychosomatic Medicine*, *63*(1), 7–18.

Cunningham, M., & Regan, M. (2016). The impact of emotion, life stress and mental health issues on driving performance and safety. *Road and Transport Research*, *25*, 40–50.

Dallimer, M., Irvine, K. N., Skinner, A. M. J., Davies, Z. G., Rouquette, J. R., Maltby, L. L., Warren, P. H., Armsworth, P. R., & Gaston, K. J. (2012). Biodiversity and the feel-good factor: Understanding associations between self-reported human well-being and species richness. *Bioscience*, *62*(1), 47–55.

Day, A. J., Brasher, K., & Bridger, R. S. (2012). Accident proneness revisited: The role of psychological stress and cognitive failure. *Accident Analysis & Prevention*, *49*, 532–535.

de Kort, Y. A. W., Meijnders, A. L., Sponselee, A. A. G., & Ijsselsteijn, W. A. (2006). What's wrong with virtual trees? Restoring from stress in a mediated environment. *Journal of Environmental Psychology*, *26*(4), 309–320. https://doi.org/10.1016/j.jenvp.2006.09.001

Dimsdale, J. E. (2008). Psychological stress and cardiovascular disease. *Journal of the American College of Cardiology*, *51*(13), 1237–1246. https://doi.org/10.1016/j.jacc.2007.12.024

Dula, C. S., Adams, C. L., Miesner, M. T., & Leonard, R. L. (2010). Examining relationships between anxiety and dangerous driving. *Accident Analysis & Prevention*, *42*(6), 2050–2056.

Dula, C. S., & Ballard, M. E. (2003). Development and evaluation of a measure of dangerous, aggressive, negative emotional, and risky driving. *Journal of Applied Social Psychology*, *33*(2), 263–282.

Erzurumlu, G. S., & Tekinalp, M. F. (2018). Aesthetic and functional evaluation of urban road planting: Nigde city case. *Science, Ecology and Engineering Research in the Globalizing World*, 430–441.

Etikan, I., Musa, S. A., & Alkassim, R. S. (2016). Comparison of convenience sampling and purposive sampling. *American Journal of Theoretical and Applied Statistics*, *5*(1), 1–4.

Eudave, L., & Valencia, M. (2017, May). Physiological response while driving in an immersive virtual environment. In *2017 IEEE 14th International Conference on Wearable and Implantable Body Sensor Networks (BSN)* (pp. 145–148). IEEE.

Farahmand, B., & Boroujerdian, A. M. (2018). Effect of road geometry on driver fatigue in monotonous environments: A simulator study. *Transportation Research Part F: Traffic Psychology and Behaviour*, *58*, 640–651. https://doi.org/10.1016/j.trf.2018.06.021

Faul, F., Erdfelder, E., Buchner, A., & Lang, A.-G. (2009). Statistical power analyses using G* Power 3.1: Tests for correlation and regression analyses. *Behavior Research Methods*, *41*(4), 1149-1160.

Faul, F., Erdfelder, E., Lang, A.-G., & Buchner, A. (2007). G* Power 3: A flexible statistical power analysis program for the social, behavioral, and biomedical sciences. *Behavior Research Methods*, *39*(2), 175–191.

Fitzpatrick, C. D., Harrington, C. P., Knodler, M. A., & Romoser, M. R. E. (2014). The influence of clear zone size and roadside vegetation on driver behavior. *Journal of Safety Research*, *49*, 97.e91-104. https://doi.org/10.1016/j.jsr.2014.03.006

Frumkin, H. (2002). Urban sprawl and public health. *Public Health Reports*, *117*(3), 201–217.

Frumkin, H., Frank, L., & Jackson, R. (2004). *Urban Sprawl and Public Health*. Island Press.

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

Gastaldi, M., Rossi, R., & Gecchele, G. (2014). Effects of driver task-related fatigue on driving performance. *Procedia-Social and Behavioral Sciences*, *111*, 955–964.

Gilman, E. F. (2015, February 27). Spacing between trees. *Landscape Plants*. http://hort.ifas.ufl.edu/woody/spacing.shtml

Global Biodiversity Information Facility. (n.d.). *Global Biodiversity Information Facility*. https://www.gbif.org/

Grahn, P., & Stigsdotter, U. A. (2003). Landscape planning and stress. *Urban Forestry & Urban Greening*, *2*(1), 1–18.

Green, P. A., Jeong, H., & Kang, T.-P. (2014). *Using an OpenDS driving simulator for car following: A first attempt*. Paper presented at the Adjunct Proceedings of the 6th International Conference on Automotive User Interfaces and Interactive Vehicular Applications, Seattle, WA.

Harris County Extension Horticulturists. (2009). *Native & Adapted Plants for Houston*. http://counties.agrilife.org/harris/files/2011/05/houstonplants.pdf

He, J., Choi, W., McCarley, J. S., Chaparro, B. S., & Wang, C. (2015). Texting while driving using Google Glass™: Promising but not distraction-free. *Accident Analysis & Prevention*, *81*, 218-229.

He, J., Chaparro, A., Nguyen, B., Burge, R. J., Crandall, J., Chaparro, B., Ni, R., & Cao, S. (2014). Texting while driving: Is speech-based text entry less risky than handheld text entry?. *Accident Analysis & Prevention*, *72*, 287–295.

Hennessy, D. A., & Wiesenthal, D. L. (1997). The relationship between traffic congestion, driver stress and direct versus indirect coping behaviours. *Ergonomics*, *40*(3), 348–361.

Hunter, M. R., Gillespie, B. W., & Chen, S. Y.-P. (2019). Urban nature experiences reduce stress in the context of daily life based on salivary biomarkers. *Frontiers in Psychology*, *10*(722). https://doi.org/10.3389/fpsyg.2019.00722

Jacobson, M. T., & Matthews, P. (1996). Generating uniformly distributed random Latin squares. *Journal of Combinatorial Designs*, *4*(6), 405–437.

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*(0), 26–36. http://dx.doi.org/10.1016/j.landurbplan.2014.08.005

Jiang, B., Deal, B., Pan, H., Larsen, L., Hsieh, C.-H., Chang, C.-Y., & Sullivan, W. C. (2017). Remotely-sensed imagery vs. eye-level photography: Evaluating associations among measurements of tree cover density. *Landscape and Urban Planning*, *157*, 270–281. http://dx.doi.org/10.1016/j.landurbplan.2016.07.010

Jiang, B., Li, D., Larsen, L., & Sullivan, W. C. (2016). A dose-response curve describing the relationship between urban tree cover density and self-reported stress recovery. *Environment and Behavior*, *48*(4), 607–629. https://doi.org/10.1177/0013916514552321

Jiang, B., Mak, C. N. S., Larsen, L., & Zhong, H. (2017). Minimizing the gender difference in perceived safety: Comparing the effects of urban back alley interventions. *Journal of Environmental Psychology*, *51*, 117–131. https://doi.org/10.1016/j.jenvp.2017.03.012

Jiang, B., Mak, C. N. S., Zhong, H., Larsen, L., & Webster, C. J. (2018a). From broken windows to perceived routine activities: Examining impacts of environmental interventions on perceived safety of urban alleys. *Frontiers in Psychology*, *9*(2450). https://doi.org/10.3389/fpsyg.2018.02450

Jiang, B., Schmillen, R., & Sullivan, W. C. (2018b). How to waste a break: Using portable electronic devices substantially counteracts attention enhancement effects of green spaces. *Environment and Behavior*, 0013916518788603. https://doi.org/10.1177/0013916518788603

Jiang, B., Wang, H. Q., Larsen, L., Bao, F. Y., Li, Z. G., & Pryor, M. (2019). Examining relationships between features of outdoor environments of the "sweatshop" factory and workers' mental stress and anxiety status: A participatory smartphone-photograph survey. *Journal of Environmental Psychology*, 101336. https://doi.org/10.1016/j.jenvp.2019.101336

Kaplan, R., & Basu, A. (Eds.) (2015). *Fostering reasonableness: Supportive environments for bringing out our best*. Michigan Publishing.

Kaplan, R., & Kaplan, S. (1989). *The experience of nature: A psychological perspective*. Cambridge University Press.

Kaplan, R., Kaplan, S., & Brown, T. (1989). Environmental preference: A comparison of four domains of predictors. *Environment and Behavior*, *21*(5), 509–530. https://doi.org/10.1177/0013916589215001

Kaplan, S. (1995). The restorative benefits of nature - toward an integrative framework. *Journal of Environmental Psychology*, *15*(3), 169–182.

Kaplan, S., & Berman, M. G. (2010). Directed attention as a common resource for executive functioning and self-regulation. *Perspectives on Psychological Science*, *5*(1), 43–57. https://doi.org/10.1177/1745691609356784

Knight, L., & Riggs, W. (2010). Nourishing urbanism: A case for a new urban paradigm. *International Journal of Agricultural Sustainability*, *8*(1–2), 116–126. https://doi.org/10.3763/ijas.2009.0478

Kuo, F. E., & Sullivan, W. C. (2001). Aggression and violence in the inner city - Effects of environment via mental fatigue. *Environment and Behavior*, *33*(4), 543–571.

Kweon, B. S., Ulrich, R. S., Walker, V. D., & Tassinary, L. G. (2008). Anger and stress - The role of landscape posters in an office setting. *Environment and Behavior*, *40*(3), 355–381. https://doi.org/10.1177/0013916506298797

Lal, S. K. L., & 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

Lu, Y. (2018). Using Google Street View to investigate the association between street greenery and physical activity. *Landscape and Urban Planning*, *191*, 103435. https://doi.org/10.1016/j.landurbplan.2018.08.029

Macdonald, E., Harper, A., Williams, J., & Hayter, J. A. (2006). *Street trees and intersection safety*. https://escholarship.org/uc/item/9t6465vq

Math, R., Mahr, A., Moniri, M. M., & Müller, C. (2012, October). OpenDS: A new open-source driving simulator for research. In *Proceedings of the International Conference on Automotive User Interfaces and Interactive Vehicular Applications, Adjunct Proceedings* (pp. 7–8).

McAllister, E., Bhullar, N., & Schutte, N. S. (2017). Into the woods or a stroll in the park: How virtual contact with nature impacts positive and negative affect. *International Journal of Environmental Research and Public Health*, *14*(7), 786.

Min, K.-B., Kim, H.-J., Kim, H.-J., & Min, J.-Y. (2017). Parks and green areas and the risk for depression and suicidal indicators. *International Journal of Public Health*, *62*(6), 647–656. https://doi.org/10.1007/s00038-017-0958-5

Nesbit, S. M., Conger, J. C., & Conger, A. J. (2007). A quantitative review of the relationship between anger and aggressive driving. *Aggression and Violent Behavior*, *12*(2), 156–176.

Oron-Gilad, T., & Ronen, A. (2007). Road characteristics and driver fatigue: A simulator study. *Traffic Injury Prevention*, *8*(3), 281–289. https://doi.org/10.1080/15389580701354318

Owen, N., King, H., & Lamb, M. (2015). Literature review of race driver fatigue measurement in endurance motorsport. *Procedia Engineering*, *112*, 344–348.

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.

Peters, A., von Klot, S., Heier, M., Trentinaglia, I., Hörmann, A., Wichmann, H. E., & Löwel, H. (2004). Exposure to traffic and the onset of myocardial infarction. *New England Journal of Medicine*, *351*(17), 1721–1730. https://doi.org/10.1056/NEJMoa040203

Petrova, S., Yurukova, L., & Velcheva, I. (2014). Possibilities of using deciduous tree species in trace element biomonitoring in an urban area (Plovdiv, Bulgaria). *Atmospheric Pollution Research*, *5*(2), 196–202.

Plass, J. L., & Kalyuga, S. (2019). Four ways of considering emotion in cognitive load theory. *Educational Psychology Review*. https://doi.org/10.1007/s10648-019-09473-5

Roe, J., & Aspinall, P. (2011). The restorative benefits of walking in urban and rural settings in adults with good and poor mental health. *Health & Place*, *17*(1), 103–113. doi:10.1016/j.healthplace.2010.09.003

Sarkar, C., Webster, C., & Gallacher, J. (2018). Residential greenness and prevalence of major depressive disorders: A cross-sectional, observational, associational study of 94 879 adult UK Biobank participants. *The Lancet Planetary Health*, *2*(4), e162–e173.

Seen, K. S., Tamrin, S. B. M., & Meng, G. Y. (2010). Driving fatigue and performance among occupational drivers in simulated prolonged driving. *Global Journal of Health Science*, *2*(1), 167–177.

Steptoe, A., Cropley, M., Griffith, J., & Kirschbaum, C. (2000). Job strain and anger expression predict early morning elevations in salivary cortisol. *Psychosomatic Medicine*, *62*(2), 286–292.

Staufenbiel, S. M., Penninx, B. W. J. H., Spijker, A. T., Elzinga, B. M., & van Rossum, E. F. C. (2013). Hair cortisol, stress exposure, and mental health in humans: A systematic review. *Psychoneuroendocrinology*, *38*(8), 1220–1235. https://doi.org/10.1016/j.psyneuen.2012.11.015

Sullivan, W. (2015). In search of a clear head. In R. Kaplan & A. Basu (Ed.), *Fostering Reasonableness: Supportive Environments for Bringing Out Our Best* (pp. 54–69). Michigan Publishing. http://dx.doi.org/10.3998/maize.13545970.0001.001

Sullivan, W. C., & Lovell, S. T. (2006). Improving the visual quality of commercial development at the rural–urban fringe. *Landscape and Urban Planning*, *77*(1–2), 152–166. http://dx.doi.org/10.1016/j.landurbplan.2005.01.008

Sung, E.-J., Min, B.-C., Kim, S.-C., & Kim, C.-J. (2005). Effects of oxygen concentrations on driver fatigue during simulated driving. *Applied ergonomics*, *36*(1), 25–31.

Suppakittpaisarn, P., Jiang, B., Slavenas, M., & Sullivan, W. C. (2018). Does density of green infrastructure predict preference? *Urban Forestry & Urban Greening*, *40*, 236–244. https://doi.org/10.1016/j.ufug.2018.02.007

Sweller, J. (1988). Cognitive load during problem solving: Effects on learning. *Cognitive Science*, *12*(2), 257–285.

Tang, I. C., Tsai, Y.-P., Lin, Y.-J., Chen, J.-H., Hsieh, C.-H., Hung, S.-H., Sullivan, W.C., Tang, H. -F., & Chang, C.-Y. (2017). Using functional Magnetic Resonance Imaging (fMRI) to analyze brain region activity when viewing landscapes. *Landscape and Urban Planning*, *162*, 137–144. https://doi.org/10.1016/j.landurbplan.2017.02.007

The Morton Arboretum. (n.d.). *The Morton Arboretum*. https://www.mortonarb.org/

Thiffault, P., & Bergeron, J. (2003). Monotony of road environment and driver fatigue: A simulator study. *Accident Analysis & Prevention*, *35*(3), 381–391. http://dx.doi.org/10.1016/S0001-4575(02)00014-3

Thomas, P. A., Alhamd, O., Iszkuło, G., Dering, M., & Mukassabi, T. A. (2019). Biological lora of the British Isles: Aesculus hippocastanum. *Journal of Ecology*, *107*(2), 992–1030.

Travis, S. S., Duncan, H. H. P. R. N., & McAuley, W. J. (1996). Mall walking: An effective mental health intervention for older adults. *Journal of Psychosocial Nursing & Mental Health Services*, *34*(8), 36–38.

Ulrich, R. S. (1984). View through a window may influence recovery from surgery. *Science*, *224*. https://doi.org/10.1126/science.6143402

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.

United States Department of Agriculture. (n.d.). *United States Department of Agriculture*. https://plants.sc.egov.usda.gov/

von Klot, S., Heier, S., Trentinaglia, M., Hormann, I., Wichmann, H. E., Lowel, H., & Peters, A. (2005). The role of duration in the association of exposure to traffic with the onset of myocardial infarction. *Epidemiology*, *16*(5), S127–S127. https://doi.org/10.1097/00001648-200509000-00320

Walker, E. L. (1980). *Psychological complexity and preference: A hedgehog theory of behavior*. Brooks/Cole Publishing Company.

Wang, L., Bie, Y., & Li, S. (2016). The impact of roadside landscape colors on driver's mean heart rate considering driving time. *Transportation Research Part F: Traffic Psychology and Behaviour*, *42*, 151–161. https://doi.org/10.1016/j.trf.2016.07.009

Weerakkody, U., Dover, J. W., Mitchell, P., & Reiling, K. (2017). Particulate matter pollution capture by leaves of seventeen living wall species with special reference to rail-traffic at a metropolitan station. *Urban Forestry & Urban Greening*, *27*, 173–186.

Williamson, A. M., Feyer, A.-M., & Friswell, R. (1996). The impact of work practices on fatigue in long distance truck drivers. *Accident Analysis & Prevention*, *28*(6), 709–719.

Yang, B., Li, S., Elder, B. R., & Wang, Z. (2013). Community-planning approaches and residents' perceived safety: A landscape analysis of park design in the Woodlands, Texas. *Journal of Architectural and Planning Research*, *30*(4), 311–327.

Zhang, T., & Chan, A. H. S. (2016). The association between driving anger and driving outcomes: A meta-analysis of evidence from the past twenty years. *Accident Analysis and Prevention*, *90*, 50–62. https://doi.org/10.1016/j.aap.2016.02.009

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