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The influence of urban roadside trees and their physical environment on stress relief measures: A field experiment in Shanghai

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ABSTRACT

In recent years, the worldwide accelerated rate of urbanization has highlighted the critical necessity of creating more green spaces for the leisure and recreation activities of urban residents. Nevertheless, the human psychological responses to urban roadside trees with different vegetation have not been fully explored. This study investigates the psychological states (mood, anxiety, restorative outcomes and subjective vitality) after short walks along different urban roads. Three-hundred and sixty-four participants visited four types of urban road: a road where buildings are concentrated was selected as a control road, and three roads surrounded by Sakura, London plane, and Metasequoia trees respectively. The Profile of Mood States, State-Trait Anxiety Inventory, Restorative Outcomes, and Subjective Vitality Scales were used to determine the participants' psychological responses. The physiologically equivalent temperature was utilized to assess the thermal comfort conditions of the selected roads. The results reveal that a short walk along urban roads surrounded by Metasequoia or Sakura or London plane trees respectively significantly reduced the negative psychological states of tension, fatigue, confusion, and anxiety compared to the control road. Additionally, the participants' restorative outcome and vitality were higher after walking along the Metasequoia and Sakura roads. Moreover, no significant differences in the psychological responses to the different roads were detected between male and female participants. Thermal adaptation and psychological parameters strongly affect human thermal comfort levels in outdoor spaces. Our results offer essential insights on the use of urban roadside trees as a resource for mitigating stress and promoting health in urban dwellers.

1. Introduction

The urban population of the world has significantly increased from 751 million in 1950 to 4.2 billion in 2018. Asia, despite its relatively lower level of urbanization, is home to 54% of the world's urban population, followed by Europe and Africa with 13% each. With this pace of population rise, by 2050, it is anticipated that China will have added 255 million urban inhabitants (United Nations, 2018). This rapid urbanization has caused various ecological and environmental problems and has also corrupted the quality of numerous environments worldwide (Zhao et al., 2006; Matteucci and Morello, 2009). In consequence, just as green spaces have constantly diminished over time, urban life has become extremely demanding often resulting in stress-related health issues (Sluiter et al., 2000). As urbanization is a growing public health concern worldwide, alleviating the negative impacts of modern city environments, maintaining good health, controlling stress issues, and preventing stress-related diseases is crucial to human success in urbanized societies. Studies over the past three decades have concentrated on providing scientific proof of the health advantages and restorative and relaxing impacts of forest and natural environments (Park et al., 2009; Takayama et al., 2014; James et al., 2016). Numerous studies from various parts of the world reported that contact with, or perception of, nature and plants seems to bring benefits to human wellbeing from various perspectives including reducing stress, depression and aiding recuperation from attentional fatigue (Kaplan, 1995; Beyer et al., 2014), increasing wellbeing and reducing anxiety (Chang and Chen, 2005; Elsadek et al., 2013a, b; Tsunetsugu et al., 2013; White et al., 2013; Reklaitiene et al., 2014; Hassan et al., 2018), improving emotional states (Shin et al., 2010; Elsadek and Fujii, 2014; Elsadek et al., 2017), enhancing human mood states, concentration and performance (Hartig et al., 2003), shortening rehabilitation after surgery (Chiesura, 2004) and in general strongly increasing happiness (MacKerron and Mourato, 2013). Besides, perception of gardens decreases the negative psychological states of tension, fatigue, confusion,

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and anxiety (Lee, 2017), as well as, possibly having considerable emotional, and healing values for humans (Elsadek et al., 2019). Moreover, studies have demonstrated that walking in forest environments diminishes blood pressure, skin conductivity, muscle tension, pulse rate, cortisol levels, sympathetic nerve activity and enhances parasympathetic activity (the components of heart rate variability) (Song et al., 2014; Takayama et al., 2014; Lee et al., 2014). Also, green spaces in residential areas improve perceived general health and longevity (Takano et al., 2002). Moreover, parks could serve as sites for physical activity, which is empirically associated with enhanced health, psychological wellbeing and reductions in many chronic diseases (Grahn and Stigsdotter, 2010; Ernstson, 2012). A park experience has been shown to reduce stress (Ulrich et al., 1991; Woo et al., 2009). Generally, the above-mentioned studies have shown the health benefits of green space and conducted measurements within a single space (forests or gardens or parks) and compared them with an urban space. In spite of the existing research base, still more evidence and systematic rigorous research is required into the effects of nature on psychological health. A recent study in the Netherlands has assessed both quantity and quality of streetscape greenery based on self-reported health and found that both were associated with improvements in perceived general health, mental health, and acute health complaints (de Vries et al., 2013). Relationships were generally stronger for quality than for quantity. However, little is known about the effect of urban roadside trees on human wellbeing, and most of the available studies have focused on the vehicle drivers' experience of the roadside, where it was reported that drivers judge forested urban highways to have higher visual quality and it was associated with driving-stress reduction compared to urban roads (Wolf, 2005; Mok et al., 2006; Wolf and Bratton, 2006). To the best of our knowledge, few investigations have endeavored to focus on the influence of the physical variables of urban roadside trees on urban dwellers' psychological responses. It is notable that trees are essential parts of a city's infrastructure and significantly affect the overall environmental conditions through the direct removal of air pollutants and alterations to local microclimates (Nowak et al., 2014). Also, they supply many ecosystem services that help in creating healthy living environments and in restoring degraded ecosystems. The cooling effect of trees on urban environments has been studied and its advantages recognized (Kong et al., 2014; Abreu-Harbich et al., 2015; Hsieh et al., 2016). The knowledge of the positive wellbeing effects of urban roadside trees should be better incorporated into land-use policy and planning with a specific goal to preserve green areas close to homes. Nevertheless, it has so far remained obscure whether different tree species with different vegetation can differentially influence the psychological states of urban dwellers. Given these gaps in knowledge, through the present study, we attempt to present scientific evidence of the health benefits that urban roadside trees bring to human wellbeing. Accordingly, the aims of this study are to (i) examine the psychological impacts of urban roadside trees and how individuals evaluate the physical effects of different urban roadside trees with different vegetation; (ii) determine the thermal conditions of the studied roads and link them with the human psychological responses. The specific research question for the present study is: Does short-term walking along roads surrounded by different trees with different vegetation reduce depression and anxiety, improve mood, and restore vitality among people with high levels of stress? It is our expectation that these results can be used to improve planning and to change the future urban plantation estate. The hypothesis in our study is that a short walk along an urban road surrounded by trees would positively influence human psychological outcomes. We expect that roads surrounded by different trees differ in terms of their restorative quality.

2. Materials and methods

2.1. Study sites

A field experiment was conducted in May 2018 when the trees were in full leaf with no flowers in Tongji University, Shanghai, the most populous city in China and the largest city proper in the entire world, home to approximately 25.58 million people. The criteria for selecting the roads to be studied in Tongji University were: 1- roads surrounded by common urban trees in Shanghai. 2- roads with different percentages of tree canopy cover. 3- roads that are relatively close to each other in order to minimize the participants' inconvenience. Based on a preliminary investigation of the roadside trees in Shanghai, three roads surrounded by three different tree species were chosen: (1) Sakura (*Prunus serrulata*), a species of cherry native to China, Japan and Korea which is used for its spring cherry blossom displays and festivals. Also, it is known to be the most popular ornamental tree in Asia and has been cultivated for more than 1000 years (Kuitert, 1999). (2) The London plane (*Plantanus hispanica*) which is widely grown for shade in city streets and gardens. This species is the most frequently planted, two out of three trees in Shanghai are London plane trees. It grows in most soils, and because it has shallow roots, it does not break up the roads. Its leafy canopy on top of crooked branches provides shade in hot summers. (3) *Metasequoia* (*Metasequoia glyptostroboides*), the growth of which has been quickly expanded worldwide, is therefore an obvious choice of urban foresters when developing afforestation plans in the new urban centers in subtropical areas such as Shanghai (Kim and Lee, 2016). The tree has the advantages of fast growth and a narrow crown (minimal effect on adjacent building). Particularly, *M. glyptostroboides* forests accounted for 5.7% of Shanghai's forest area (Zheng et al., 2018). The three roads were selected along with a road surrounded by buildings as a control road (Fig. 1). To estimate the influence of surrounding buildings and vegetation density on air circulation and outdoor thermal comfort, the sky view factor (SVF) can be used (He et al., 2014; Abreu-Harbich et al., 2015). The SVF was determined using a fish-eye lens (Sigma EX DC 4.5 mm) at a height of 1 m above the ground and HemiView software was used for analysis. The sky view factor was measured in the morning once during the measurement period at the same points as the microclimate measurements. The sky view factor was highest with low canopy cover, with mean values of 0.87 and 0.51 in the control and Sakura roads respectively. Meanwhile, London plane and Metasequoia roads with high canopy cover had lower SVFs of 0.11 and 0.06 respectively (Fig. 2). The weather on the days of the experiment was sunny to cloudy.

During the experiment, the sound level was measured on all experimental roads by using a smartphone with the sound level analyzer lite (SLA lite) application. According to Murphy and King (2016) and Bielinis et al. (2018), this application is an excellent application

Fig. 1. The experimental road trees. A: Control, B: Sakura, C: London plane and D: Metasequoia.

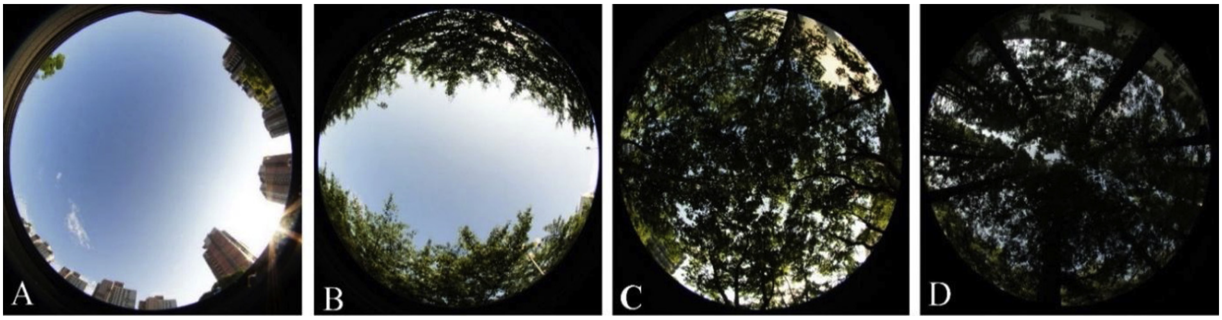

Fig. 2. Sky view factor for the four roads. A: control, B: Sakura, C: London plane and D: Metasequoia.

comparable with a professional laboratory sound analyzer. The sound level average (± SD) for the control road was 59.03 ± 2.60 dB, whereas the average sound level in the Sakura, London plane and Metasequoia roads were 56.40 ± 1.57, 55.60 ± 1.71 and 52.25 ± 0.64 dB respectively.

2.2. Participants

As mentioned, this study was conducted at Tongji University. Hence, the respondents for the study were students and visitors to the University. Three hundred and sixty-four Chinese subjects (200 males and 164 females, 23 ± 4.6 years) visited all four experimental roads. Two ways were used to recruit volunteers to the experiment: (1) advertisements describing the study details were sent to college students through WeChat groups (Chinese social media app). (2) the authors of the present study met individuals in person in each road and asked them to participate in the experiment. The participants were fully informed about the aim of the study, its procedures, how long the experiment would take, the types and purpose of the questionnaire, the benefits to society, especially for urban dwellers, and their ability to withdraw from the experiment at any time without consequences. Thus, participation was entirely voluntary. The participants were physically and mentally healthy adults. Smoking and Alcohol consumption were prohibited during the study period. This study was conducted in accordance with the ethics regulations of Tongji University.

2.3. Experimental design

The experiment was carried out during working days, to ensure that the participants were in need of restoration to potentiate restorative effects (Ojala et al., 2018). The time of the experiment was chosen by the participants so that the experimental days would fit their timetables, and they had all the rights to cancel and/or change the time to participate in the study. On the first road, the participants were given a full explanation of the experiment, and also signed written consent for their voluntary participation. They were divided into groups with a maximum of five participants. The group size was determined to avoid creating congestion on the experimental roads. At a waiting point for each road, the participants were asked to complete the four questionnaires first and then were guided by the experimenter on a speed-controlled slow walk for 15 min. After walking, the participants returned to the waiting area to complete the four questionnaires. Then, after they had rested for 5 min (Ochiai et al., 2015), each group was guided by the author to repeat the experiment along the other experimental roads (see the experimental design in Fig. 3). The length of the walk was the same for all 4 roads. All walking activities were performed during daytime (10:00 a.m. to 3:30p.m.). There were no significant differences in average walking speed on the four roads. The participants were guided to visit each study site once. The order of visiting the roads was randomized in order to eliminate the order effect.

2.4. Psychological assessments

To estimate the participants' psychological responses, four types of psychological questionnaire were administered to the participants before and after completing their walks to measure their mood, anxiety, restorative outcomes, and vitality. The English version of each questionnaire was translated into the Chinese language by an expert team. The first questionnaire is the Profile of Mood States (POMS), which is designed to evaluate short-term mood changes and to assess people within six different mood domains: tension-anxiety, depression, anger-hostility, fatigue, confusion, and vigor (Park et al., 2009, 2010; Shahid et al., 2011; Tsunetsugu et al., 2013). The Total Mood Disturbance (TMD) score was also calculated from the POMS data. This scale has been previously used to estimate the impact of forest environments on mood states (Bielinis et al., 2018). To reduce the load on the participants, the version of POMS used in the present study consists of 24 items. To compare the changes in the level of anxiety for each road, the State-Trait Anxiety Inventory (STAI) asks how the participant feels "right now," using 20 questions that measure the participant's feelings of tension, nervousness, worry, and activation/arousal of the autonomic nervous system (Hidano et al., 2000). Low scores imply a slight form of anxiety whereas median scores imply a moderate form of anxiety and high scores indicate a severe form of anxiety (Julian, 2011). The third questionnaire is the Restorative Outcome Scale (ROS), which is a reliable and valid scale (Korpela et al., 2010). It was used to evaluate humans' psychological responses to nature and green spaces (Takayama et al., 2014; Bielinis et al., 2018). The ROS scale consists of six items; each one was evaluated by the participants using a seven-point Likert scale (from 1 - "not at all" to 7 - "completely"). Three items reflecting a feeling of relaxation "I feel myself calmer after being here", "After visiting this place I always feel restored and relaxed", "I get new enthusiasm and briskness to my everyday routines from here", (one item reflecting attention restoration "my concentration and alertness increase here clearly". Two items reflecting clearing one's thoughts "I can forget everyday worries here", "visiting here is a way of clearing and clarifying my thoughts". The last questionnaire is the Subjective Vitality Scale (SVS), which reflects feelings of energy, vitality and wellbeing (Ryan and Frederick, 1997). Four items were used (e.g. "I feel alive and vital" or "I look forward to each new day") (Takayama et al., 2014). The four items were assessed by participants using the same seven-point Likert scale, but with one negative item being inversely scored. For all psychological data, the mean sum scores were calculated, considering some reverse items of the scales. Utilizing different types of the questionnaire which are convenient for the participants, inexpensive, and quick to appraise to evaluate participants' psychological and restorative responses might be an important way to help urban planners and landscape designers to create new styles of green space which are appropriate for urban dwellers.

2.5. Assessment of roads physical variables (microclimate)

The road microclimates were measured using a portable weather

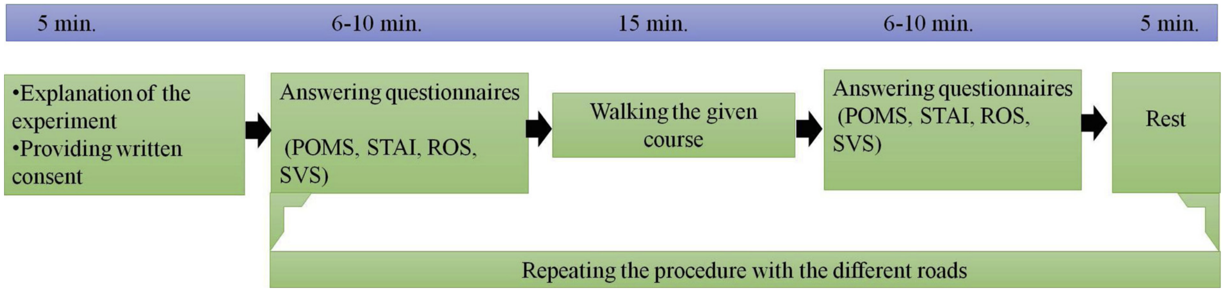

Fig. 3. Experimental Design.

station meter (WatchDog weather station, Spectrum 2900 ET, Technologies, Inc., USA) recording the values of air temperature, relative humidity, wind speed, and ground temperature for each road. Microclimatic measurements were taken at the center of the road at three points, giving a total of three measurement points for each street. The measurements were made at 1 m above ground level. The data loggers were set to acquire data at 5-min. intervals automatically.

2.6. Physiological equivalent temperature index for human thermal comfort

The thermal index used to estimate human thermal comfort in the present study was the physiologically equivalent temperature (PET), which is the most appropriate choice to assess thermal comfort conditions of outdoor environments (Hoppe, 1999; Spagnolo and Dear, 2003; Lin et al., 2010). The microclimatic parameters of air temperature, relative humidity, wind speed, solar radiation, and the Mean Radiant Temperature (MRT) were used as an input for PET estimation. RayMan software was used in this study to estimate PET (Matzarakis et al., 2007). Physiologically equivalent temperature gives a value in ˚C, which is easy for professionals, such as urban planners, to use and relate to (Deb and Ramachandraiah, 2010).

2.7. Statistical analysis

We conducted repeated-measures analyses of variance (ANOVA) to calculate the effects of intervention in the four different roads. In the analysis we used four 'within-subjects' factors in the urban (control), Sakura, London plane, and Metasequoia roads and two testing time-points of intervention (before walking (BW), and after walking (AW) for the POMS, STAI, ROS and SVS as well as the participants' gender (male or female). Statistical analysis was conducted using SPSS 24.0 (IBM Corporation, Armonk, NY, USA). All data were presented as mean ± standard error (SE) and the statistical differences were considered to be significant at $p < 0.05$.

3. Results

3.1. Validity and reliability of the questionnaire scales

As presented in Table 1, Cronbach's α is used for measuring the internal consistency across all experiments. POMS and SVS had good internal consistency, whereas, STAI and ROS had high internal consistency.

Table 1
Verification of the internal consistency.

Scales	Cronbach's α
POMS	0.82
STAI	0.92
ROS	0.90
SVS	0.83

3.2. Psychological assessments

3.2.1. Psychological evaluation measured by POMS

The Bonferroni test was used to compare the differences between the POMS subscale results obtained from the participants who walked along the different roads. A significant main effect of the road as well as time on the ratings of the POMS outcomes was observed. Fig. 4 shows the average values of POMS subscale scores reported by 364 subjects before and after walking along the four roads. No significant differences were reported by the participants before walking along the four roads. As shown in Fig. 4, significant differences were found in the T-A, A–H, F, C, V and TMD subscales of POMS. Regarding the tension and anxiety (T-A) subscale, significant differences were found in the reported scores between after walking along the control road and the three other roads (Sakura, London plane and Metasequoia roads). The results suggest that short-term walking along roads without trees leads to increased feelings of tension and anxiety (3.14 ± 0.14). On the other hand, Fig. 4 shows that the participants reported less tension and anxiety for the Metasequoia (0.47 ± 0.10) road followed by the Sakura road (0.50 ± 0.10) and the London plane road (0.67 ± 0.10). Regarding the depression (D) subscale, significant differences were observed between the results reported after walking along the control (2.99 ± 0.10), Metasequoia (0.26 ± 0.19), Sakura (0.27 ± 0.15) and London plane (0.336 ± 0.11) roads respectively. A similar attitude was observed in the other POMS subscales: anger-hostility, fatigue and confusion. All these three subscales that are related to negative emotions were observed to decrease after walking along the roads surrounded by Metasequoia or Sakura or London plane and to increase after a short walk along the control road. In contrast to the above, an opposite tendency was observed in the case of the vigor (F) subscale, the participants reported that they felt more vigorous after a short walk along the urban road surrounded by the Metasequoia (4.30 ± 0.16), Sakura (4.25 ± 0.10) and London plane (3.92 ± 0.20) respectively compared to the control road (1.38 ± 0.20).

As shown in Fig. 4, the scores for the total mood disturbance (TMD) subscale were calculated as follows:

$$TMD = (T\text{-}A + D + A\text{–}H + F + C) - V$$

After the participants had walked along the roads surrounded by Metasequoia (-2.00 ± 1.07), Sakura (-1.86 ± 1.2) and London plane (-0.85 ± 0.95) respectively, their TMD scores were significantly lower compared to the control road (14.93 ± 0.50). Also, significant differences between the "before walking" and "after walking" scores were observed. Therefore, performing a short-term walking activity along roads surrounded by Metasequoia, Sakura and London plane respectively has a positive impact and can decrease the total mood disturbance (TMD) compared with the road without trees.

3.2.2. Psychological evaluation measured by STAI

The participants' STAI scores showed significant differences in their psychological responses after a short walk along the four roads. However, no significant differences were observed between these roads

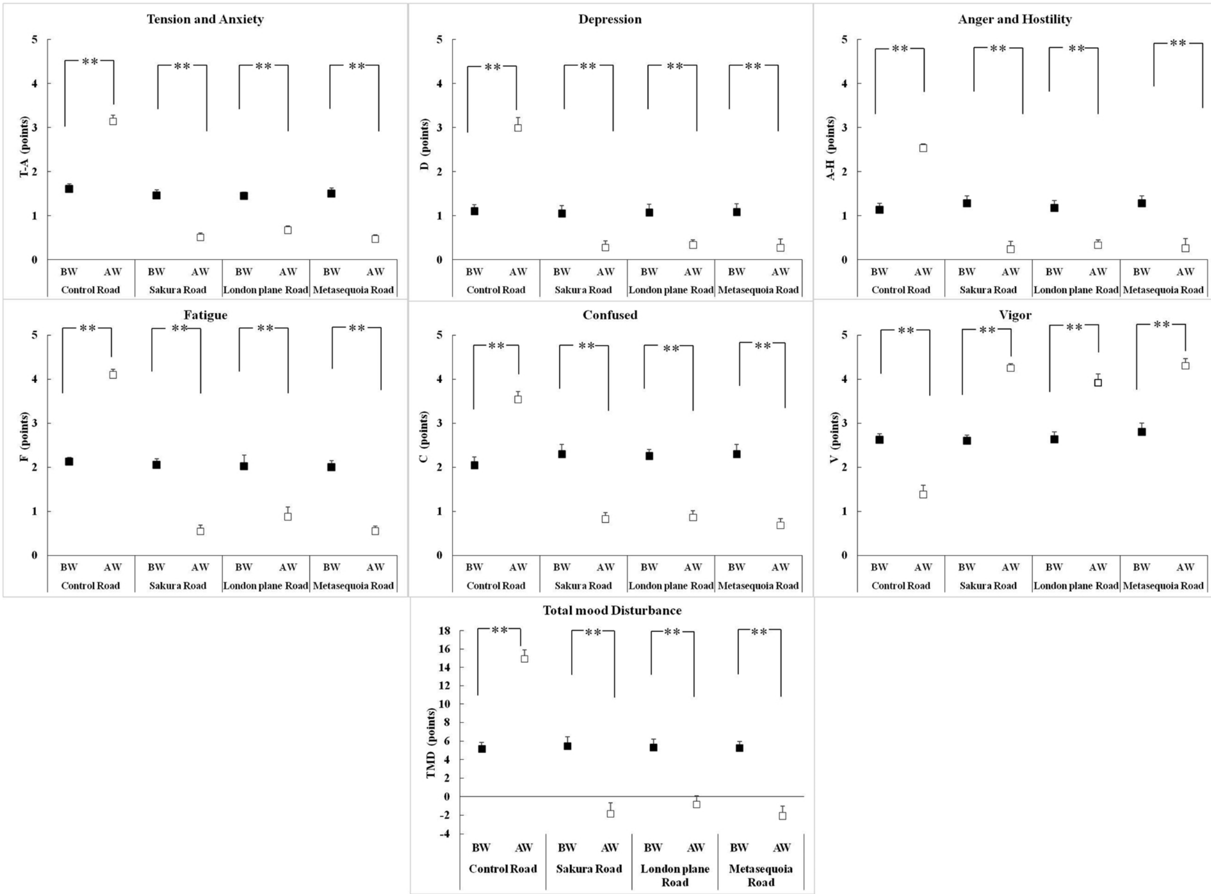

Fig. 4. Comparison of POMS subscale results showing the observed differences among the four roads, before walking “BW” and after walking “AW”. Average ± SE. ** $p < 0.05$ as determined by the Bonferroni test.

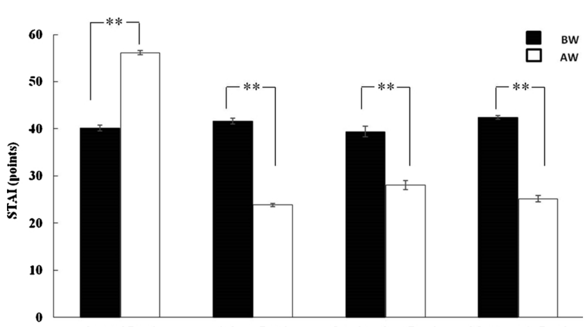

Fig. 5. Comparison of the state of Anxiety obtained before walking (BW) and after walking (AW) in the four roads: control, Sakura, London plane and Metasequoia. Average ± SE. ** $p < 0.05$ as determined by the Bonferroni test.

before walking. There was a significant main effect of road on ratings of the state of anxiety, F = 51.29, $p < .0001$. Also, there was a significant main effect of time on the state of anxiety F = 54.11, $p < 0.0001$. As shown in Fig. 5, the total STAI were significantly reduced after the participants had walked along the road surrounded by Sakura (23.87 ± 0.41), Metasequoia (25.16 ± 0.68) and London plane (28.09 ± 0.35) respectively compared to the control road (56.13 ± 0.65).

3.2.3. Psychological evaluation measured by ROS and SVS

For the ROS, there was a significant main effect of the road on ratings of the restorative outcome, F = 13.52, $p < 0.0001$. Contrasts revealed that the urban roads surrounded by trees were differently restorative and had significantly more positive effect on the perceived restoration than the control road. Also, there was a significant main effect of time on the restorative outcome F = 42.82, $p < 0.0001$. Contrasts revealed that there was a significant difference between BW and AW, indicating that the feelings of restoration change after walking along the roads surrounded by trees. The significant interaction between the road and time effects of the measures during the experiment, F = 14.21, $p < 0.0001$, indicated that the participants felt restoration in different ways depending on the road and time. Fig. 6 shows that the ROS score was higher after the participants had walked along the road surrounded by the Metasequoia (27.27 ± 0.54) and then the roads surrounded by Sakura (24.56 ± 0.59) and London plane (24.24 ± 0.40) respectively, compared to the control road (9.91 ± 0.80). This means that the participants perceived significantly higher levels of restoration after 15 min of walking along roads surrounded by the studied trees compared to the control road.

Regarding SVS, there was a significant main effect of the road on ratings of subjective vitality, F = 37.88, $p < .0001$. Contrasts revealed that ratings of roads surrounded by trees were significantly higher compared to the control. There was also a significant main effect of time on the subjective vitality measure before and after the experiment, F =60.11, $p < .0001$. As shown in Fig. 6, the participants perceived significantly higher vitality after walking along the roads surrounded by Metasequoia (20.28 ± 0.23), Sakura (20.13 ± 0.21) and London plane (19.47 ± 0.20) respectively compared to the control road (10.70 ± 0.14). The results show that the subjective vitality scores increase after walking along the roads surrounded by trees compared to the control road where the vitality scores decrease (see interaction in Fig. 6).

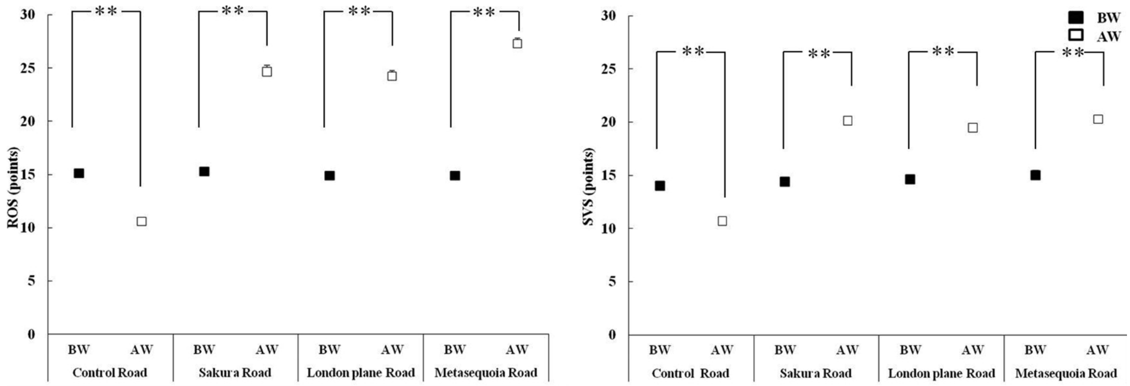

Fig. 6. Comparison of participants' restorative outcome scale (ROS) and the subjective vitality scale (SVS) before (BW) and after (AW) walking in the four roads. Average ± SE. ** $p < 0.05$ as determined by the Bonferroni test.

Table 2
Interaction terms between two-way ANOVA with repeated measures (Road x Time).

Scales	Subscales	F-test	*p*-value	Significance Road x Time
POMS	T-A	106.95	.000	***
	D	499.22	.000	***
	A-H	50.86	.000	***
	F	115.52	.000	***
	C	54.72	.003	***
	V	35.69	.000	***
	TMD	237.00	.000	***
STAI		57.09	.010	***
ROS		14.21	.000	***
SVS		28.12	.000	***

$^{***}p <$ .000, n = 364.

3.2.4. Interaction terms

The 'place x time' interaction terms were significant ($p < .001$) regarding the POMS, STAI, ROS, SVS questionnaires, as shown in Table 2. The significant interaction effect between the road and the time of the measures during the experiment showed that the participants felt positive and negative moods - anxiety, restoration and vitality in different ways depending on the road and time. This means that the participants felt higher levels of positive mood, and experienced more vitality and restoration after a short walk of 15 min. along the roads surrounded by Metasequoia, Sakura and London plane respectively, compared to the control road.

On the other hand, as presented in the Table 3, the 'road x gender x time' interaction is not significant. There were no significant differences between the two genders' responses, males did not achieve higher or lower values in the questionnaires compared to females. But there is a main effect of gender for the C and TMD subscales of POMS as well as for the STAI and SVS scales (Data not presented).

Table 3
Interaction terms between two-way ANOVA with repeated measures (Road x Time x Gender).

Scales	Subscales	F-test	*p*-value	Significance Road x Gender x Time
POMS	T-A	0.19	0.90	ns
	D	0.10	0.95	ns
	A-H	0.09	0.96	ns
	F	0.23	0.88	ns
	C	0.26	0.85	ns
	V	0.37	0.77	ns
	TMD	0.37	0.77	ns
STAI		0.12	0.94	ns
ROS		0.04	0.99	ns
SVS		0.24	0.87	ns

n.s, not significant. $p <$ .05, n = 364.

3.3. Measurements of physical variables (microclimate)

There were significant microclimate benefits in high-percentage canopy cover roads as compared with the low percentage canopy cover roads. As shown in Table 4 and Fig. 7, the average air temperatures in the control, Sakura, London plane and Metasequoia roads were 31.79, 31.18, 29.04 and 28.09 °C respectively. The highest air temperature was recorded for the control road, 33.65 °C while the lowest temperature was recorded for the Metasequoia road, 26.46 °C.

The relative humidity averages in the control, Sakura, London plane and Metasequoia roads were 42.82%, 47.01%, 50.89% and 52.85% respectively. The highest relative humidity was recorded for the Metasequoia road, 63.86%, while the lowest relative humidity was recorded on the control road, 34.28%.

For the wind speed average, the averages were 2.39, 0.84, 0.54 and 0.40 km/h in the control, Sakura, London plane and Metasequoia roads respectively. The highest wind speed was 3.18 km/h on the control road, while the lowest wind speed was 0.18 km/h on the Metasequoia road. Finally, regarding the ground temperature, it was observed that the highest ground temperature was recorded for the control road, 48.13 °C, and the lowest for the Metasequoia road, 27.82 °C.

3.4. Thermal comfort analysis based on the calculated PET

The thermal comfort classification (Lin and Matzarakis, 2008) has been utilized as a reference to assess outdoor thermal comfort. Accordingly, the thermal comfort range would correspond to PET values between 26 °C and 30 °C (neutral perception) while a relatively wider "acceptable range" for slightly cool, neutral, and slightly warm was defined for 22–34 °C PET.

As illustrated in Fig. 8, during the daytime, PET values for the control road were generally above the upper hot range limit of 34 °C. During the period between 10am and 4 pm, the respective PET values by far exceeded this limit and thermal comfort was noticeably very poor. The control road, which was surrounded by buildings, had basically the lowest level of comfort for most of the time. It can be observed that during this time, the buildings were unable to protect the area from solar radiation. On the other hand, the road surrounded by Sakura trees notably provided better thermal conditions from 10am to 12 pm compared to the control road. Also, it can be observed that around noon time 12 pm-3pm, the Sakura trees were unable to protect the area from high levels of solar radiation. On the other hand, for the Metasequoia and London plane roads, from 10am to 7 pm, the PET values were within the neutral thermal comfort range (PET < 30 °C). The fact that these trees provide an appropriate shaded area and, due to the shading

Table 4
Air temperature, relative humidity, wind speed and ground temperature differences comparing among the studied roads low canopy cover to high canopy cover.

Variables	Control	Sakura	London plane	Metasequoia
Temperature (°C)				
Average	31.79 ± 0.51	31.18 ± 0.50	29.04 ± 0.29	28.09 ± 0.30
Maximum	33.65 ± 0.44	33.54 ± 0.33	30.32 ± 0.12	29.37 ± 0.21
Minimum	29.16 ± 0.33	28.93 ± 0.23	27.40 ± 0.32	26.46 ± 0.32
Relative humidity (%)				
Average	42.82 ± 2.63	47.01 ± 2.48	50.89 ± 2.23	52.85 ± 2.27
Maximum	55.47 ± 1.10	58.85 ± 1.11	61.71 ± 1.11	63.86 ± 0.10
Minimum	34.28 ± 1.09	38.16 ± 1.07	42.37 ± 0.90	44.26 ± 1.06
Wind speed (Km/h)				
Average	2.39 ± 0.16	0.84 ± 0.13	0.54 ± 0.06	0.40 ± 0.05
Maximum	3.18 ± 0.35	1.40 ± 0.24	0.87 ± 0.27	0.58 ± 0.12
Minimum	1.78 ± 0.21	0.30 ± 0.09	0.30 ± 0.08	0.18 ± 0.07
Ground temperature (°C)				
Average	42.27 ± 1.71	35.44 ± 1.15	31.14 ± 0.47	29.32 ± 0.32
Maximum	48.13 ± 0.85	40.97 ± 1.08	33.27 ± 0.85	30.58 ± 0.52
Minimum	33.58 ± 1.00	31.37 ± 0.57	28.89 ± 0.73	27.82 ± 0.82

effects of the surrounding trees with less SVF, can block the low solar elevation before noon time. Hence, the results highlight significant differences between the PET values for the respective roads during the daytime.

3.5. Relationship between the physical variables that characterize the studied roads and the psychological evaluations

Pearson's correlation test was used to analyze the correlation between each of PET, SVF, TMD, STAI, ROS, and SVS as sources for the psychological responses. As presented in Table 5, strong relationships were observed between PET and "TMD" (r = 0.85), "STAI" (r = 0.79) "restorative" (r= –0.88), and "vitality" (r= –0.84). Moreover, strong correlations were also found between SVF and TMD (r = 0.87), STAI (r = 0.84), "restorative" (r= –0.92) and "vitality" (r= –0.87).

Over half of the world's population lives in urban areas, and this proportion is expected to increase. Although numerous studies have been conducted to focus on the link between nature and human health, few have focused on the impacts of urban roadside trees on human psychology. The roadside landscape may have a proportionally greater impact on urban dwellers due to the limited availability of green spaces in cities. The purpose of the current study was to investigate the human psychological responses after a short 15-min. walk along different urban roads. In addition, we attempted to identify the physical variables of these roads that were responsible for the observed improvements in psychological wellbeing. A built-up road was compared with

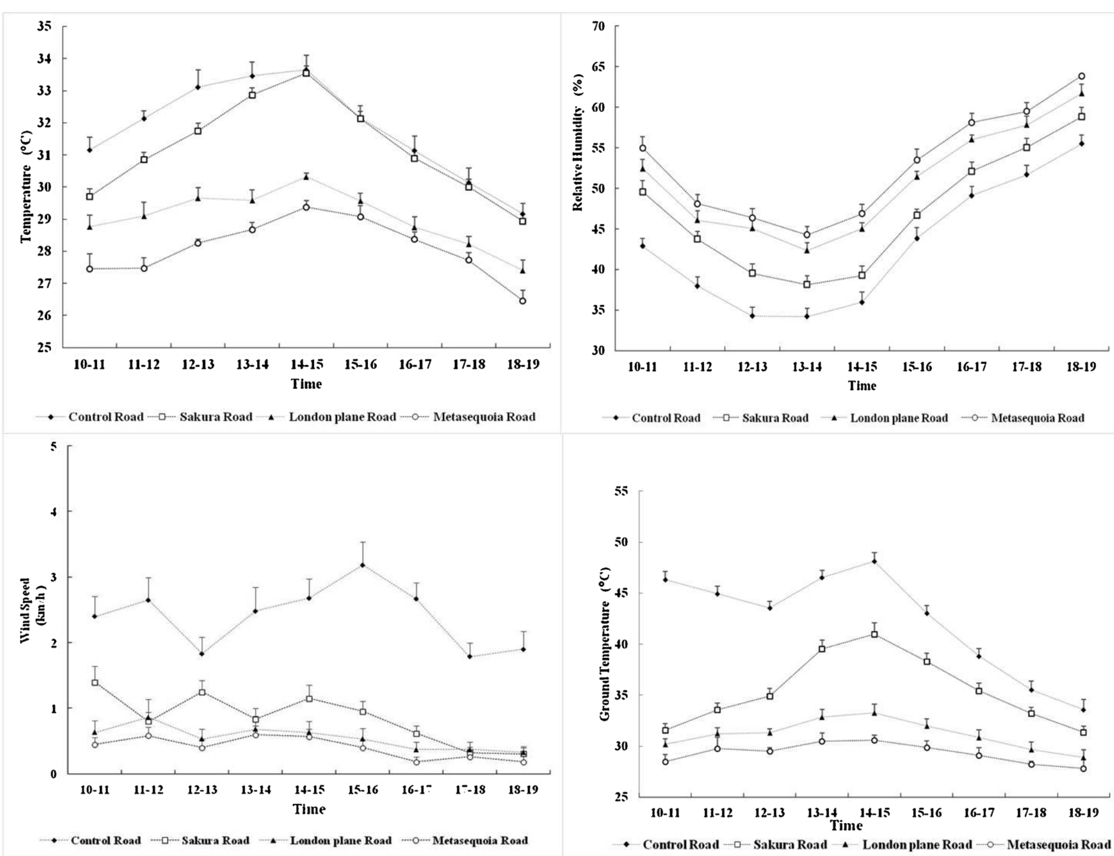

Fig. 7. Physical variables measured in the control, Sakura, London plane and Metasequoia roads.

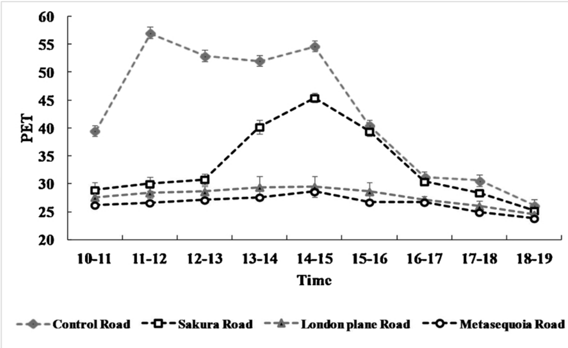

Fig. 8. Variation of calculated physiological equivalent temperature (PET) in the studied roads.

Table 5
Pearson's correlation coefficient between the psychological evaluation and the physical variables that characterize the studied roads.

	TMD		STAI		ROS		SVS	
	r	*p*-value	r	*p*-value	r	*p*-value	R	*p*-value
PET	0.85	.000	0.79	.000	−0.88	.000	−0.84	.000
SVF	0.87	.000	0.84	.000	−0.92	.000	−0.87	.000

three different roads surrounded by different trees, as opposed to most previous studies that compare a built-up environment to a natural environment. In our study, we used psychological responses (mood, anxiety, restoration outcomes and vitality) of a large sample of adult male and female students and post-graduates. Previous studies have had smaller sample sizes of workers (mainly female) (Tyrväinen et al., 2014) or students (mainly males) (Park et al., 2008). This study allows us to look at the impacts of walking along urban roads similar to their real-life situations, giving them the opportunity to relieve their stress. The findings confirmed a connection between the presence of trees with different vegetation and the positive psychological benefits for humans. The results from the POMS questionnaire showed that walking along the roads surrounded by Metasequoia, Sakura and London plane respectively decreased the negative moods of "depression-dejection", "tension-anxiety", "anger-hostility", "fatigue", and "confusion" and improved the participants' positive mood of "vigor" compared with walking along the control road. This suggests that urban roadside trees are able to enhance the positive mood states and reduce the negative mood states. The mean scores of POMS subscales (except the vigor subscale) in the control road were higher than before the experiment and after walking among the roadside trees. The mean score of the vigor subscale decreased, which suggests that the road with no trees had a debilitating effect. This finding broadly supports the results from other studies and confirms the hypothesis that the feelings of a positive mood would be increased in green environments and *vice-versa* in an urban area (Park et al., 2010; Ochiai et al., 2015). The results of the POMS questionnaire are well in line with those of previous studies documenting people's emotional responses after walking in a forest environment or viewing forest scenery (Park et al., 2011; Tsunetsugu et al., 2013; Song et al., 2014; Hassan et al., 2018).

Moreover, the results of the STAI questionnaire also show that higher negative emotions such as feeling uncomfortable, nervous, and upset were experienced along the control road with no trees, providing further evidence of the beneficial effects of trees for human wellbeing. These results correspond with the findings of other studies where urban areas induced negative emotions (Park et al., 2011; Hassan et al., 2018). Furthermore, these results corroborate the findings of Song et al. (2015) which clarified that lower levels of negative emotions and anxiety were expressed by the participants when they walked in an urban park. Additionally, the highest values of the ROS and SVS scales for the urban roads surrounded by trees confirmed these results. The outcomes of the current study also confirmed that experiential restoration can take place after a short walk along the roads surrounded by the trees. Additionally, increases in restorative outcomes and vitality for the urban roads surrounded by trees are shown by the interaction between 'road' and 'time' when compared to the control road. Thus, it seems that even short walks along urban roads surrounded by trees can bring numerous positive psychological benefits to the participants' mood and affect their vitality compared to a walk along the control road. Our main results support the earlier results of Ohtsuka et al. (1998); Park et al. (2010); Tsunetsugu et al. (2013) and Van den Berg et al. (2014).

Regarding the gender difference, ANOVA analysis showed that there were overall effects of gender on the confusion (C) and total mood disturbance (TMD) subscales of POMS as well as the STAI and SVS scales. Contrary to expectations, this study did not find a significant difference between the genders. A similar lack of clarity has also been reported by Bielinis et al. (2018). Further research should be undertaken to investigate the response of different genders to urban roadside trees.

With regard to the physical variables that characterize the studied roads, such as air temperature, relative humidity, wind speed, ground temperature, and PET, the results reveal that all the studied physical parameters are significantly lower for the urban roads surrounded by trees compared to the control road. Additionally, a high-percentage of tree canopy cover would be able to improve human thermal comfort by reducing thermal stress. It is observed that the acceptable range of PET (less than 34 °C) existed during the late afternoon (4–7 pm) along the control road while the duration of acceptable thermal conditions extended from 10am to 1 pm for the Sakura road. However, the duration of acceptable thermal conditions, extended from 10am to 7 pm for the Metasequoia and London plane roads respectively. The results also indicate that the time period of 10am to 4 pm for the control road is considered as having the highest level of PET in line with the highest solar radiation levels. It is also shown that tree canopies with low SVF, Metasequoia and London plane respectively lead to greater reductions in PET values (Pearson Correlation, 0.919) by increasing the reflection and absorption of solar radiation, thus allowing only a small amount to penetrate the canopy (Sanusi et al., 2015). Correspondingly, shading is the noticeable characteristic of trees that provide a reduction in air temperature (Mayer et al., 2008; Lin et al., 2010; Liu et al., 2016; Wei and Liu, 2018). Consequently, the temperatures for roads surrounded by trees with high shade (Metasequoia and London plane respectively) were lower than the control and Sakura roads due to their lower exposure to direct solar radiation. On the other hand, the microclimatic benefits of trees are also provided through transpiration with significantly higher relative humidity being found in roads with low SVF, suggesting that the water vapor released to the atmosphere from transpiration increases the humidity of the air in that road canyon. As such, it is also assumed that the reduction in air temperature under a high-percentage of tree canopy cover in the present study was partly due to transpiration by those trees (Shashua-Bar and Hoffman, 2000). Zupancic et al. (2015) have demonstrated that urban roadside trees are particularly vital for reducing heat stress and alleviating the urban heat island phenomenon. Also, the wind speed was greater in roads with no trees compared to roads surrounded by trees because trees are able to change the wind movement within a road canyon by preventing the wind from moving into the road (Sanusi et al., 2015). Heisler (1990) measured the wind speed in a residential area and found that areas with trees reduced the wind speed to 70% in summer. Significant correlations were found between the participants' psychological responses and the physical variables that characterize the studied roads. It is worth noting that trees with low SVF are desirable in outdoor environments to increase thermal comfort and extend the continuity of the acceptable thermal conditions during the day (Makaremi et al., 2011). Therefore, roads with low SVF are more comfortable for people in terms of thermal conditions than the roads with high SVF. Our study findings revealed that thermal comfort is significantly correlated with positive emotional reports (Park et al., 2011), which suggests that tree-shading and thermal environments are important reasons for reporting more positive feelings in Metasequoia, Sakura, and London plane roads than in the control road. Together, these correlations suggest that tree shading is the main cause of reduced levels of discomfort in the studied roads; hence, planting trees with high canopy cover is strategically very important because PET can be significantly reduced (Emmanuel et al., 2007), thus improving urban dwellers' thermal comfort.

What is surprising is that the Sakura road, which has an average SVF of 0.51, provided equally strong restorative experiences as roads with higher shading levels. This finding was unexpected and suggests that the participants clearly overestimated the positive psychological influence of the Sakura trees because Sakura is a famous ancient tree in China and Japan, and its flowers are considered to be symbolic of spring, a time of renewal, and the fleeting nature of life. However, trees with no flowers can still stir positive memories for the participants. Every spring, people visit Japan from all over the world for special Sakura blossom viewings, known as *hanamif*, since Sakura is considered to be a symbol of "the cycle of life, death and rebirth" for many people (Emiko, 2010). Additionally, an abnormally profound experience often has an enduring effect on psychological perception. Similar findings that more distinctive wind situations become engrained in people's memory, resulting in unexpectedly low correlations between measurement data and perceptual schemata have been discovered (Lenzholzer, 2010). Additionally, the positive impact of trees might depend on the previous experiences about a particular environment (Faehnle et al., 2014).

According to these results, we can infer that a short walk along an urban road surrounded by trees is a simple, attainable, and effective method of improving the quality of life and wellbeing for urban dwellers. These results are partly consistent with previous findings related to forest therapy (Lee et al., 2011; Song et al., 2013). A possible explanation for the results might be the presence of trees with different levels of shade which alter the thermal environment, such as air temperature, humidity and wind speed. Overall, the reality is that urbanization and green space reduction put urban dwellers under stress thereby impairing the quality of city life (McKenzie et al., 2013). The urban roadside trees are able to improve urban dwellers' feelings and make the city cooler, which would be an insurance policy for the future. Thus, urban planners and landscape scientists should attempt to maintain green areas and pay more attention to the urban roadside trees to improve the quality of life for urban dwellers.

Our study, however, faces some limitations which should be considered in future research. First, in order to recruit more volunteers for reliable and valid results with greater precision, our volunteers had to make four successive measurements in one day. In the future, special efforts should be made by asking the participants to visit roads on separate days. Second, the surface of road D was different from the other roads. It is difficult to know how this affects the results of the experiment. Third, the higher level of noise was connected with the control road and might have an impact on the participants' psychological responses; although available evidence suggests that the roadside vegetative barriers are able to reduce the noise level, which translates into health benefits that might extend to improved wellbeing (Frumkin et al., 2017; Silva et al., 2018). It would be important to study further and to elaborate more upon the effects of the exposure to environmental noise in the restoration of urban roads. It is hypothesized that the psychological changes associated with visits to some natural environments may partly be due to reduced exposure to noise (Ojala et al., 2018). Fourth, although this study revealed important hints regarding human psychological benefits and their relationship with urban roadside trees, it is important to inquire further into the possible physiological evidence for these positive impacts by, for example, measuring brain activity, heart rate variability, and autonomic nerve activity.

4. Conclusion

This paper highlights the importance of urban roadside trees for public health. The study reveals that there are significant differences between the studied roads in how efficiently they can reduce stress and anxiety and increase restoration and vitality. The participants identified roadsides having increasing amounts of vegetation as having greater positive impacts. Greater cooling of the road microclimate occurs in roads with a low SVF than for roads with a high SVF. Our study provides an evidence base for urban planners and landscape designers as to the magnitude of the microclimatic and psychological benefits they can gain from increasing tree canopy cover in urban residential roads. Additionally, it provides evidence that brief walks along urban roads bordered by trees with high levels of shade can be viewed as a therapeutic strategy and as a useful tool in helping relieve stress levels and bring about multiple positive health impacts for city dwellers. Overall, the findings have important applications and should be incorporated as a guideline for urban green space managers to provide cities with the appropriate tree species where people can relax by walking along urban roads.

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Conflict of interest

The authors declare no conflict of interest.

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