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From oppressiveness to stress: A development of Stress Reduction Theory in the context of contemporary high-density city

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ABSTRACT

Due to intense urbanization in the last decade, high-density city has become a major type of human habitat globally. In those cities, oppressiveness has been recognized as a dominating environmental perception. Stress Reduction Theory is a leading theory that explains the relationship between environmental exposure and mental stress. However, the theory missed that perceived oppressiveness may substantially explain impacts of environmental exposure on mental stress in the context of high-density city. This study aimed to address that significant theoretical deficiency. A new pathways model was proposed to investigate whether and to what extent environmental exposure impacts mental stress through perceived oppressiveness.

To test this pathways model, we conducted an online photo-based experiment with Hong Kong city residents. Firstly, we used a grid method to randomly choose 90 street spots in the city area. We created one GIF image by integrating nine Google Street photos to cover the full 360° viewshed for each spot. The percentage of all streetscape elements for each GIF image was measured. Then, 1396 participants were randomly assigned to view three of 90 GIF images. After viewing each image, participants reported perceived oppressiveness, perceived environmental quality, and acute mental stress responses. Lastly, participants reported their socioeconomic, demographic, and other background information.

We identified three pathways linking streetscapes to mental stress response. After controlling for covariates, perceived oppressiveness was the major mediator to link streetscapes and mental stress, explaining 50.2% of relationship. Tree canopy and sky had the greatest association with lower level of stress through perceived oppressiveness, while vehicles and billboards had the greatest association with higher level of stress through perceived oppressiveness.

This new pathways model confirms the major role of perceived oppressiveness in interpreting the impact of urban streetscapes on mental stress in the high-density cities. The results suggest an update of Stress Reduction Theory is feasible and necessary.

1. Introduction

Mental stress is one of biggest global health challenges in modern societies (Ustun, 1999; White et al., 2021). The accumulation of acute mental stress leads to chronic mental stress, which further leads to depression, suicide, cardiovascular disease, stroke, type 2 diabetes, cancer, and other diseases (Cavanagh, Carson, Sharpe, & Lawrie, 2003; Liu et al., 2015; Wilson et al., 1995). Mental stress is not only influenced by social, economic, and demographic factors (Avison & Turner, 1988) but also by the physical environments people experience in their daily life (Hartig, Mitchell, de Vries, & Frumkin, 2014; Lee & Maheswaran, 2011).

In the field of environmental psychology, Stress Reduction Theory (SRT) is a leading theory to explain the relationship between environmental exposure and mental stress (Ulrich et al., 1991). In general, SRT states that exposure to natural settings reduce mental stress while artificial settings induce mental stress (Ulrich et al., 1991). Many empirical studies have been based on this binary theory, comparing the stress reduction effects of different types of natural and artificial (urban) environments (see Bratman et al., 2019; Yao, Zhang, & Gong, 2021, for

Abbreviations: SRT, Stress Reduction Theory; PO, Perceived oppressiveness; PEQ, Perceived environmental quality; GSV, Google Street View; HK, Hong Kong.

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reviews). However, these studies have paid much less attention to the underlying pathways by which environments influence mental stress, especially in the context of high-density cities. Consequently, SRT may insufficiently explain how high-density urban environments influence people's mental stress.

Due to intense urbanization in the last decade, high-density cities have become a major type of urban habitat globally. High-density cityscapes are perceived as more oppressive than low or moderate-density ones (Asgarzadeh et al., 2009, 2012; Gascon et al., 2015; Hartig et al., 2014). The term "perceived oppressiveness" in this study refers to people's feelings of psychological pressure when they are in high-density urban environments (Asgarzadeh et al., 2012; Chung, Chau, Masullo, & Pascale, 2019). High-density urban settings often feature high-rise building complexes, crowded streets (e.g. automobile and pedestrian traffic), and busy artificial features along the streets (e.g., road, façade, billboards). Previous studies hint that perceived oppressiveness may be a critical link between exposure to high-density urban environments and the prevalence of mental stress in urban dwellers, but few studies have proved this link.

2. Conceptual framework and hypotheses

2.1. Stress Reduction Theory

Stress Reduction Theory (SRT), proposed by Ulrich et al. (1991), argues that natural environments reduce mental stress while artificial environments induce mental stress. These mental stress responses result from millions of years of evolution in nature, leading to humans' innate preference for natural environments rather than artificial ones. In recent decades, SRT has been supported by numerous empirical studies (see Bratman et al., 2019 for a review). The beneficial effects of green landscapes, such as trees and shrubs, on mental stress reduction have been well documented (e.g. Gascon et al., 2015; Hartig et al., 2014; Jiang, Li, Larsen, & Sullivan, 2016; Kuo, 2015; Lee & Maheswaran, 2011; Roe et al., 2013; Thompson et al., 2012). Studies show that other natural landscapes, such as skyscapes and waterscapes, can also reduce mental stress and promote mental health (e.g., Gascon et al., 2015; Masoudinejad & Hartig, 2020; White et al., 2010). Studies have also shown how exposure to artificial settings or features, such as barren plazas, buildings, and cars, are associated with higher levels of mental stress (e.g., Bornioli, Parkhurst, & Morgan, 2018; Ghorbanzadeh, 2018; Lindal & Hartig, 2013).

The studies based on SRT often focus on a comparison between artificial and natural settings with various levels of greenness. The main argument is clear: A setting with a higher level of greenness or naturalness is more beneficial for mental stress reduction. However, these studies did not explore underlying pathways through which these settings impact mental stress. In addition, most of these studies have been conducted in western cities with low or moderate urban density. SRT is therefore limited in its ability to explain the underlying pathways by which high-density urban environments influence urban dwellers' mental stress.

2.2. Perceived oppressiveness: a major link between high-density urban streetscapes and mental stress?

Streetscapes are a dominant feature in high-density cities and a major cause of people's perceived oppressiveness (PO hereafter) (Asgarzadeh et al., 2009, 2012). Although several studies have examined the impact of streetscape elements on PO, to our knowledge they have not examined the potential connections between PO and mental stress. Studies have explored how characteristics of buildings, including width, height, angle, and configuration, can significantly impact PO (Asgarzadeh et al., 2012, 2014; Ohno, Tsujiuchi, & Inagami, 2003; Takei & Oohara, 1978; Zarghami, Karimimoshaver, Ghanbaran, & Saadativaghar, 2019). Moreover, distance from buildings to people inversely impacts PO (Chung et al., 2019; Hwang, Yoshizawa, Munakata, & HIRATE, 2007). Studies have also suggested that urban nature may decrease PO. For example, planting trees in front of high-rise buildings tends to attenuate the PO associated with artificial elements, especially buildings, by functioning as a visual buffer, partially screening the wall of buildings (Asgarzadeh et al., 2012, 2014; Zarghami et al., 2019).

Although there is a paucity of scientific evidence connecting PO with mental stress response, some circumstantial evidence hints at a strong causal connection. Asgarzadeh and colleges (2014; 2012) argued that PO essentially is a "negative psychological pressure." Two studies found that the more crowded a setting is, the weaker people's sense of self-control, which may cause mental stress (Cohen, 1980; Fleming, Baum, & Weiss, 1987). The other two studies found that PO can elicit a sense of annoyance and feelings of being unsafe, which may also cause mental stress (Chung et al., 2019; Stamps, 2005).

2.3. Perceived environmental quality: another potential link between urban streetscapes and mental stress?

Perceived environmental quality (PEQ hereafter) is people's evaluation of a physical environment, which is based on how people process environmental information (Leslie, Sugiyama, Ierodiaconou, & Kremer, 2010). Research suggests that PEQ is a critical predictor of mental stress response (Falfán, Muñoz-Robles, Bonilla-Moheno, & MacGregor-Fors, 2018; Wang, Feng, Pearce, Liu, & Dong, 2021; Wheeler et al., 2015). People were more stressed when they were in a place that had a lower PEQ (Kallio et al., 2020). Specific aspects of PEQ, including perceived quality of lighting, sound, air, and thermal comfort, were associated with mental stress (Thach et al., 2020). In addition, some studies reported circumstantial evidence that may connect PEQ with mental stress. For example, studies found PEQ is a key predictor of mental distress (Dunleavy et al., 2020) and mental restoration (Ríos-Rodríguez, Rosales, Lorenzo, Muinos, & Hernández, 2021). People reported a higher level of satisfaction with a place when the place had a higher PEQ (e.g., higher level of traffic safety, crime safety, and aesthetic value) (Lee et al., 2017).

Significant mediating effects of PEQ in some types of environmental exposure-mental response have been reported but none of these studies have specifically looked at the effect of PO on these relationships. For example, environmental features in a hospital room had a significant impact on patients' stress reduction, and that impact was partially mediated by PEQ (Andrade, Devlin, Pereira, & Lima, 2017). Certain aspects of PEQ, including perceived safety, accessibility to park, and building density, significantly mediated the relationship between neighborhood environment and satisfaction (Lee et al., 2017). In addition, PEQ mediated the relationship between exposure to residential greenspaces and young residents' mental health status (Dzhambov et al., 2018, 2021).

In brief, previous studies have found that a better PEQ is tied to a lower level of mental stress. Further, PEQ has a mediating effect on the relationship between environmental exposure and some mental responses. However, few studies have investigated the mediating effect of PEQ on the environmental exposure-mental stress relationship. We do not know the extent to which this effect is through influencing PO.

2.4. Impacts of various urban streetscape elements on mental stress

Streetscapes are one of the most common public spaces in cities and have a significant impact on residents' mental health. In this study, we use streetscapes as representative of high-density city spaces. The significant impacts of streetscapes on mental stress and other mental responses have been well documented, but some gaps remain. Jiang et al. (2016) found that a higher level of eye-level tree canopy density led to a greater reduction of self-reported mental stress. Conversely, higher levels of eye-level artificial landscapes led to higher levels of self-reported mental stress. Another study found that quantity and quality of streetscape greenery were associated with mental stress (De Vries, Van Dillen, Groenewegen, & Spreeuwenberg, 2013). A brief visual exposure to street trees had a significant impact on mental stress recovery, with different types of street trees associated with different levels of mental stress recovery (Guo, Zhao, Ren, Niu, & Zhang, 2020). A casual walk along urban streets bordered by trees with high levels of shade has been found to be a therapeutic strategy to relieve mental stress for city residents (Elsadek, Liu, Lian, & Xie, 2019). Drivers encountering natural roadside views displayed reduced mental stress levels compared with those viewing built settings (Parsons, Tassinary, Ulrich, Hebl, & Grossman-Alexander, 1998). A green façade (with climbing plants) is associated with reduced mental stress levels, compared to a more traditional built wall (Elsadek, Liu, & Lian, 2019).

Other studies have examined the impact of streetscapes on other mental responses, which may imply an increase or decrease of mental stress. Higher levels of greenness and plant diversity, less non-motor vehicles, and clearer traffic signs have been found to be associated with a higher likelihood of mental restoration (Lindal & Hartig, 2015; Zhao, Wu, & Wang, 2020). The effect of historic elements on mental restoration likelihood was positive, whereas the effect of building height and traffic was negative (Lindal & Hartig, 2013). A higher density of street trees was significantly associated with reduced risk of depression, especially for individuals in at-risk groups (Marselle et al., 2020; Taylor, Wheeler, White, Economou, & Osborne, 2015). Billboards or advertising signs were found to cause distraction (Herrstedt, Greibe, & Andersson, 2013) and reduce ability to concentration (Nowghabi & Talebzadeh, 2019).

In sum, we know that natural streetscape features, especially trees, are beneficial for mental stress reduction. We also know that artificial streetscape features can aggravate negative mental responses, which suggests that artificial streetscapes may have a similar impact on mental stress. However, most of these studies were not conducted in high-density cities. A comprehensive study of all streetscape features of high-density city is still missing. More importantly, to our best knowledge, previous studies did not examine the extent to which streetscape features of high-density cities influence mental stress, with PO as a mediator for the relationship. This critical knowledge gap is worthy of investigation.

2.5. Four critical knowledge gaps

Four critical knowledge gaps justify this study. First, although SRT can explain the distinct effects between natural and artificial environments, it cannot fully interpret new and complex relationships between exposure to high-density urban environments and mental stress responses. The conventional methods of binary or categorical comparison may need to be updated. Second, high-density streetscapes tend to arouse PO, yet the role of PO remains unclear in the high-density streetscape-mental stress relationship. Including PO in the SRT may be a critical development. Third, the mediating effect of PEQ remains unknown in the high-density streetscape-mental stress response relationship. We do not know the extent to which that effect is relevant to PO. Fourth, we don't know whether and to what extent streetscape features of high-density cities influence mental stress by directly or indirectly influencing PO.

2.6. Proposing a new pathways model with four hypotheses

To address those four critical knowledge gaps, this study aimed to develop a new pathways model to describe the relationship between streetscapes and mental stress in the context of high-density cities (Fig. 1). In this model, we proposed PO and PEQ as mediators, forming four hypotheses with three pathways.

Hypothesis 1. Urban streetscape elements impact mental stress through PO as a mediator (Pathway 1).

Hypothesis 2. Urban streetscape elements impact mental stress through PEQ as a mediator (Pathway 2).

Hypothesis 3. Urban streetscape elements impact mental stress through PEO and then PO as mediators (Pathway 3).

Hypothesis 4. Various streetscape elements have different levels of impact on mental stress. Some impacts are significant and others nonsignificant.

3. Methods

To test the hypothesized pathways model, we recruited 2600 residents in Hong Kong (HK hereafter) to participate in an online photograph-based psychological experiment. 1396 participants (53.7% of all participants) successfully finished the task. Each participant was randomly assigned to view three of the 90 GIF images of high-density cities' streetscapes. Each GIF image contained diverse streetscape elements of varying densities. Then, participants reported PO, PEQ, and mental stress responses by answering Visual Analog Scale (VAS) questionnaires. Lastly, participants' socio-economic characteristics, demographic characteristics, chronic mental stress level, size of an electronic screen used for the experiment, and many other covariates were measured through a background questionnaire.

3.1. Site

HK is a high-density, modern, international city with around 7.4 million people living in a 1100 square kilometer territory (The World Bank, 2020). HK is often regarded as an appropriate representative of high-density cities across the world, such as New York, Los Angeles, Singapore, London, Shanghai, and Tokyo (Song, Huang, Kim, Wen, & Li, 2020; Xiang, Cai, Ren, & Ng, 2021).

To select street sites for our study, we employed the following steps: First, we downloaded a high-resolution Google Earth Professional map.

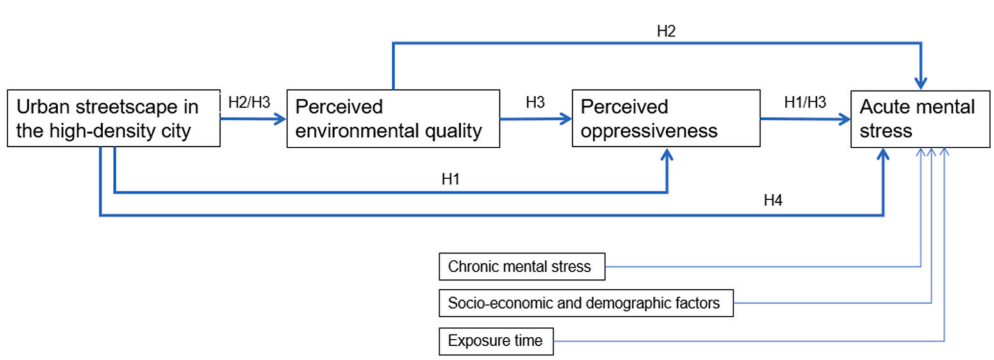

Fig. 1. The hypothesized pathways model.
Note: H1, H2, H3, & H4 refer to Hypothesis 1, Hypothesis 2, Hypothesis 3, & Hypothesis 4.

Then, we divided the HK map into grid cells, 100m * 100m, using ArcGIS. We chose this grid cell size because a high-density city block is around 100 m and this grid size has been used in many urban studies (Almeida et al., 2005; Ye et al., 2019). We randomly selected 100 cells within the developed areas of HK and chose a street spot along the central line that is nearest to the center of each cell in ArcGIS. The spot was used to collect Google Street images.

3.2. Creating streetscape stimulation materials

We exported the location file with coordinates into Google Earth Professional, and then Google Street View (GSV) images were collected (Wu et al., 2014). To simulate streetscape exposure and show more detailed information, we captured nine images for each spot, including four horizontal angle images, four 45 oblique angle images, and one vertical angle image (Fig. 2). Then, we created one GIF image for each spot looping the nine static images. The duration for each GIF was 18 s.

To mitigate cultural bias, we intentionally chose scenes that only contain modern architectural and landscape features. We narrowed the pool of GIF images down to 90 by applying the following criteria: 1) no conspicuous traditional ornamentations; 2) no buildings or landscapes with significant local historical and cultural characteristics; 3) no significant visual obstacles in front of lens; 4) no unique landmark buildings or landscape features; 5) no special objects, animals, or individuals, such as luxury cars, physically attractive people, and pets. All photos were shot in the daytime with sunny or slightly cloudy weather.

3.3. Participants

To certify the appropriate sample size for this study, we conducted a statistical power calculation using G*Power 3.1.9.4 (Faul, Erdfelder, Buchner, & Lang, 2009). Multiple regression analysis was the main method for data analysis. A sample size of 30 per group can produce a power value of 0.77 with the H1 ρ2 value at 0.35 and the alpha error probability value at 0.05. We recruited 2600 current residents of Hong Kong. Some participants quit before they finished the survey. We received 1396 valid responses. The average sample size per image was 46.53 (Min = 33, Max = 59, SD = 6.38), producing a power value of 0.95 with the H1 ρ2 value at 0.30. Each participant spent an average of 653.11 s (Min = 301, Max = 1590, SD = 239.93) participating in the survey. Participants' socioeconomic and demographic information is presented in Table 1.

3.4. Procedure

Data were collected in 2019 using an online photo-based experiment.

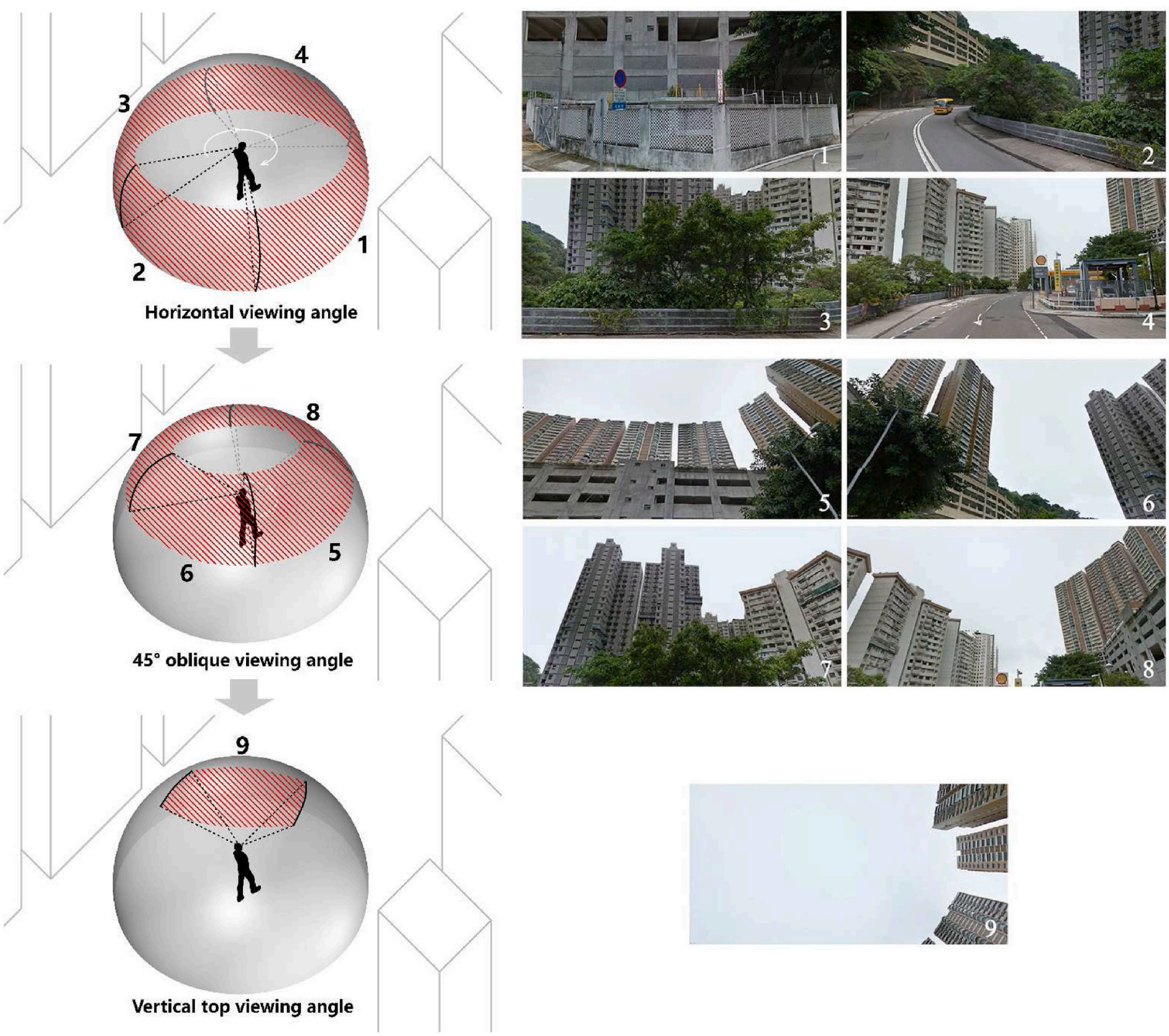

Fig. 2. The GIF image consisted of nine view angles of one street spot. The viewshed delivered by the GIF image covers the full 360° viewshed for each sampled spot (Photo source: Google Street).

Table 1
Socioe-conomic and demographic information of participants (%).

Measures	%	Measures	%
District		Household income per capita (HK$ per month)	
Hong Kong Island	25.4	≤ 1999	4.2
Kowloon	30.7	2000–3999	8.3
New Territories	43.9	4000–5999	17.7
		6000–7999	8.5
Gender		8000–9999	11.0
Male	35.8	10,000–14,999	15.1
Female	64.2	15,000–19,999	7.7
		20,000–24,999	5.8
Age		25,000–29,999	2.9
15–19	8.7	30,000–39,999	10.0
20–24	36.0	40,000–59,999	5.5
25–29	22.5	≥ 60,000	3.3
30–34	13.3		
35–39	7.0	**Screen size of the electronic device used for this survey**	
40–44	4.1	<7"	71.9
45–49	3.3	7″- 13"	5.4
50–54	2.1	13″–21"	12.9
55–59	1.9	21″–27”	8.2
≥ 60	0.6	>27”	1.7
Marriage status		**Landscape/Architecture/ Urban Planning related work**	
Single (never married/ Separated/Divorced/ Widowed)	75.5	Yes	21.3
Married/domestic partnership	24.5	No	78.7
Education level		**Type of city where I lived in before 15 years old**	
Primary or below	0.4	Rural area	4.6
Secondary	4.9	Suburban area	4.2
Undergraduate	49.9	Low dense city	11.9
Graduate	33.6	Medium dense city	24.1
Doctorate	11.3	Highly dense city	55.2
Average working hours (per week)		**Type of city where I lived in the past three years**	
<18	24.1	Rural area	0.6
18–29	12.0	Suburban area	2.4
30–39	11.2	Low dense city	2.3
40–49	27.9	Medium dense city	16.8
50–59	13.6	Highly dense city	77.9
≥ 60	11.2		

The experiment was designed and conducted via Qualtrics (https://www.qualtrics.com). We recruited participants through email, posters on and off campus, and through social media, including Facebook, WhatsApp, and WeChat. Participants clicked the link to access the survey and started after they e-signed the informed consent form. After reading a short set of instructions, participants viewed one of 90 GIF images for at least one loop. After viewing the image, they immediately reported their mental stress, PO, and PEQ. Then, participants rested for 15 s and repeated these steps for two additional GIF images. The three GIF images for each participant were randomly selected from the 90 GIF images by the Qualtrics and were presented in a random sequence. Lastly, each participant was asked to report chronic mental stress state, socio-economic and demographic background, and screen size of the electronic device. To enhance generalizability, this study offered the questionnaire in three languages to meet the needs of diverse participants. The English questionnaire was translated into Simplified and Traditional Chinese by three experts in the field of environmental psychology and landscape architecture. These experts use English, Traditional Chinese (Cantonese), and Simplified Chinese (Mandarin) for written and oral communication on a daily basis. The three versions of the questionnaire were then reviewed and finalized by two leading investigators of this study. We received valid responses from 1396 participants: 1182 (84.6%) in traditional Chinese, 141 (10.1%) in simplified Chinese, and 73 (5.2%) in English. The ratio of languages largely matches the ratio of HK residents who use different languages as their native language. Among all HK residents, native speakers of Cantonese, Mandarin, and English are around 88.8%, 3.9%, and 1.4% respectively (Census and Statistics Department, 2019).

3.5. Measures

3.5.1. Independent variables: streetscape elements

We measured the density of streetscape elements at eye level to represent the objective streetscape (Jiang, Chang, & Sullivan, 2014). To calculate the percentage of streetscape elements, we applied a widely recognized calculation method for each collected GSV image using Photoshop (Jiang, Deal, et al., 2017). First, five investigators viewed 810 images from 90 sites. They confirmed the streetscape elements to include: *Tree Canopy*, *Shrub, Lawn*, *Green Hill & Slope*, *Sky*, *Other Natural Elements*, *Glass Façade*, *Other Artificial Façade*, *Concrete Containing Wall*, *Road Surface*, *Billboard*, *Vehicle*, *People*, *Fence*, *and Other Artificial Elements*. Then, the investigators selected areas of each element in a GSV image and identified the number of pixels contained in each element's area, as well as the overall number of pixels in the image. Then, the investigators divided the number of pixels associated with each element by the total number of pixels to represent the percentage of streetscape elements in each image. Three major investigators checked and confirmed the results. Finally, the average value of the nine images of each site was used as the value of one environmental treatment (GIF image). Although this method is time-consuming, it is more accurate than a deep-learning algorithm, which may miss micro-scale elements that potentially impact mental stress significantly (Jiang, Deal, et al., 2017). The percentage of all streetscape elements is shown below (Table 2). Most elements have a wide span, suggesting the selected GIF images are representative streetscapes with differing levels of urban density.

3.5.2. Dependent variable: mental stress

We adopted the VAS to measure participants' self-reported mental stress levels. Due to its high level of sensitivity and freedom, this method has been commonly used in clinical research to measure environmental perceptions and self-reported mental status (Childs, Vicini, & De Wit, 2006; Kirschbaum, Pirke, & Hellhammer, 1993). The modified VAS mental stress version comprises three 10-cm horizontal lines for three items: anxiety, tension, and avoidance (Jiang et al., 2016). Immediately after viewing a GIF image, participants placed a marker on each line to indicate their acute mental stress response to the photographed scene.

3.5.3. Potential mediators

(1) Perceived oppressiveness

Table 2
Statistical information of objectively measured streetscape elements percentages for all GIF images.

Elements	N	Min (%)	Max (%)	M (%)	SD (%)
Tree Canopy	90	0.0	60.8	14.1	15.5
Shrub	90	0.0	9.4	0.7	1.6
Lawn	90	0.0	2.5	0.1	0.3
Green Hill & Slope	90	0.0	16.6	1.5	3.5
Sky	90	2.0	60.9	19.6	10.4
Other Natural Elements	90	0.0	3.8	0.2	0.5
Glass Façade	90	0.0	45.7	4.9	10.0
Other Artificial Façade	90	2.8	89.9	46.0	20.2
Concrete Containing Wall	90	0.0	16.6	1.5	3.5
Road Surface	90	1.0	13.7	5.8	2.6
Billboard	90	0.0	9.1	1.0	1.2
Vehicle	90	0.0	9.9	2.0	2.2
People	90	0.0	2.5	0.3	0.5
Fence	90	0.0	12.0	2.2	2.6
Other Artificial Elements	90	0.0	10.6	1.1	1.9

VAS was also used for self-reported PO. VAS is ideal for measuring PO, a psychological response that is aroused quickly, due to its high sensitivity and simplicity (Childs et al., 2006; Kirschbaum et al., 1993). Participants placed a marker on the 10-cm line to indicate their degree of PO immediately after viewing the GIF image (Asgarzadeh et al., 2014). A score of 0 indicated a feeling of no oppressiveness at all, and 10 indicated a feeling of extreme oppressiveness.

(2) Perceived environmental quality

Five aspects of Perceived environmental quality (PEQ) were selected by three experts in the field of environmental psychology and landscape architecture. The selection was based on a review of literature and experts' research experience of high-density city environments. 1) Perceived visual quality is associated with apparent characteristics of environments, such as aesthetics, elements, structure, and configuration, which is an essential aspect of environmental quality assessments, significantly influencing human's mental states (Ak, 2013; Bonaiuto, Fornara, & Bonnes, 2003; Moran et al., 2017). 2) Perceived acoustic quality: The acoustic environment of high-density cities has a significant impact on human perception and resulting psychological states (Jiang et al., 2021). Researchers have found visual perception of environments can be transferred to acoustic perception through 'visually-evoked auditory responses'. The transfer normally is more convenient if the visual perception is more similar to what participants encounter in everyday life (Fassnidge & Freeman, 2018; Raij et al., 2010). 3) Perceived greenness. Environments with a higher density of greenness are significantly associated with having higher level of environmental quality and many mental states (Jiang et al., 2016; van den Bogerd et al., 2020; White & Gatersleben, 2011). 4) Perceived safety. Feeling safe from crime and from traffic when walking on the sidewalk or crossing the street can influence how people perceive the environmental quality and their psychological states (Jiang, Mak, Zhong, & Webster, 2018; Parra et al., 2010). 5) Perceived economic quality is often determined by the material quality and daily maintenance of streetscapes, which is a critical component of environmental quality and has significant impacts on people's behavioral and mental states (Jiang et al., 2018; Moran et al., 2017; Wood et al., 2018; Zhang & Dong, 2018). We measured these aspects by asking: What do you think of the visual quality/acoustic quality/greenness/safety level/economic level of the environment here based on your experience? A five-point Likert scale (from 1 very low to 5 very high) was used.

3.5.4. Potential covariates

(1) Chronic mental stress state

Chronic mental stress has a high correlation with acute mental stress (Hammen, Kim, Eberhart, & Brennan, 2009; McGonagle & Kessler, 1990; Rohleder, 2019; Turner & Turner, 2005), so we controlled for it as a covariate. Chronic mental stress state was measured using a 7-item stress scale from the Depression, Anxiety, and Stress Scale (DASS-21). DASS-21 is a 21-item self-report questionnaire designed to measure depression, anxiety, and stress over the previous week; seven of the items apply to mental stress (Henry & Crawford, 2005; Osman et al., 2012).

(2) Exposure duration

Exposure duration to the natural environment is associated with many affective states (Ojala, Korpela, Tyrväinen, Tiittanen, & Lanki, 2019; Ulrich et al., 1991). In this study, we do not require people to view each image for a set amount of time. Participants can view each image according to their situation to report their feelings after viewing the environment clearly. Thus, we considered the duration of the experiment (duration exposure) as one covariate.

(3) Socio-economic and demographic information and other factors

We controlled for the following covariates: age, gender, marriage status, education level, occupational relevance, household income per person, work hours per week (Kabisch, 2019), the city type lived in as a child (under 15 years old), the city type lived in the past three years (Ojala et al., 2019), and the screen size of electronic device used for this survey (de Kort, Meijnders, Sponselee, & IJsselsteijn, 2006). All descriptive statistics of these factors are shown in Table 1.

3.6. Data analysis

To test the proposed model and hypotheses, Structural Equation Modeling (SEM) was performed using the IBM SPSS Amos 26.0 software. SEM tests the hypothesized model through a single analysis (instead of through a series of regression analyses), which can provide a high statistical power and reduce the likelihood of type 1 error. We tested the hypothesized model following the standard steps described below (Anderson & Gerbing, 1988).

First, we verified the measurement model before verifying the structural model (Thompson, 2004). The proposed model involved four latent variables (not observed variables); we performed Confirmatory Factor Analysis (CFA) to check the validity of the measurement model. For the convergent validity, the values of standard factor loading (SFL$>$ 0.50), composite reliability (CR $>$ 0.60), and average of variance extracted (AVE$>$ 0.50) are acceptable (Fornell & Larcker, 1981). The discriminant validity is ideal if the square root of AVE is higher than the Pearson correlation of constructs.

In the second step, we tested the hypothesized model with the path analysis. For the proposed multi-mediator model, we used 10000 bootstrap sampling (Hayes, 2009; MacKinnon, 2012) rather than a traditional mediator variable approach based on ordinary regression analyses, i.e., the Baron and Kenny's Approach and Sobel Test. Bootstrap sampling provides more statistical rigor and maintains an accurate type 1 error rate because the sampling distribution of indirect effects is always not standard normal (MacKinnon, 2012). Point estimates and the percentile 99% confidence intervals and the bias-corrected percentile 99% confidence intervals of the unstandardized regression coefficients were derived.

We improved the model fit step-by-step according to the statistic indicator (modification indices). To assess the model fit, we relied on the Goodness of Fit (GFI$>$0.90) and the Adjusted Goodness of Fit (AGFI$>$ 0.90), the Non-Normed Fit Index (NNFI$>$ 0.90), the Comparative Fit Index (CFI$>$ 0.90), the Root Mean Square Error of Approximation (RMSEA$<$ 0.08) and the Standardized Root Mean Square Residual (SRMR$<$ 0.08), following the suggestion of Hu and Bentler (1999).

4. Results

4.1. Measurement model

The CFA was performed on the four constructs to verify the measurement model. The reliability and validity of the measurement model were all supported. The results showed that the SFL of all individual items ranged from 0.577 to 0.955 ($>$0.50) and were statistically significant. The CR of each construct ranged from 0.845 to 0.945 ($>$0.60), giving preliminary support for internal consistency reliability (see Table A in Appendix). The AVE for the four measurement models ranged from 0.529 to 0.852 ($>$0.50). Moreover, the estimated intercorrelations among all measurement models were less than the square root of the AVE in each model (see Table B in Appendix).

4.2. Structural equation model

4.2.1. Is the proposed pathways model reasonable?

The initial model could not produce an output since the iteration was over 49 and minimization was unsuccessful. This indicates that the multicollinearity of this model is very high. We tested correlating our independent and confounding variables with the Pearson correlation coefficient (see Table C in Appendix). To reduce the multicollinearity of this model, we deleted the "Other Artificial Façade" element since it is highly correlated with many other variables, especially *Tree Canopy* ($r = -0.699$, $p < 0.001$) and *Sky* ($r =$ - 0.466, $p < 0.001$). Then, we conducted the structural modeling analysis. The results showed satisfactory fit indices for the final hypothesized model from the data: GFI = 0.941, AGFI = 0.917, CFI = 0.926, RMSEA = 0.042, verifying our pathways model.

4.2.2. Do specific streetscape elements impact mental stress?

We analyzed the standardized total effects of all elements on mental stress. The results show that the density of *Tree Canopy* ($\beta = -0.224$, SE = 0.017, $p < 0.001$), *Green Hill & Slope* ($\beta = -0.056$, SE = 0.016, $p =$ 0.001), and *Sky* ($\beta = -0.181$, SE = 0.018, $p < 0.001$) were significantly and negatively associated with participants' lower mental stress level after controlling for all covariates (Table 3). The density of *Road Surface* ($\beta = 0.063$, SE = 0.016, $p < 0.001$), *Billboard* ($\beta = 0.070$, SE = 0.018, $p < 0.001$), and *Vehicle* ($\beta = 0.102$, SE = 0.016, $p < 0.001$) were significantly and positively associated with higher mental stress levels after controlling for all covariates. Hypotheses 4 was thus verified.

4.2.3. Do PO and PEQ mediate the effects of streetscape elements on mental stress?

We analyzed the standardized direct and indirect effects of six significant predicting elements on mental stress. The indirect effects of the density of *Tree Canopy* ($\beta = -0.238$, SE = 0.014, $p < 0.001$), *Green Hill & Slope* ($\beta = -0.067$, SE = 0.011, $p < 0.001$), *Sky* ($\beta = -0.216$, SE = 0.013, $p < 0.001$), *Road Surface* ($\beta = 0.033$, SE = 0.012, $p = 0.004$), *Billboard* ($\beta = 0.077$, SE = 0.013, $p < 0.001$), and *Vehicle* ($\beta = 0.074$, SE = 0.011, $p < 0.001$) on mental stress through PO and PEQ were all significant (Table 4). The direct effect of density of *Sky* ($\beta = 0.035$, SE = 0.013, $p <$ 0.01) on mental stress through mediators was significant, while the direct effects of the other five elements on mental stress were insignificant. Thus, PO and PEQ together completely mediate the effects of *Tree Canopy*, *Green Hill & Slope*, *Road Surface*, *Billboard*, and *Vehicle* on mental stress, and partially mediate the effect of *Sky* on mental stress.

4.2.4. What are the specific mediatory pathways linking streetscape elements to mental stress?

Given that all significant effects of streetscape elements on mental stress were mediated by the two mediators, what are the specific mediatory pathways for the two mediators? First, the specific indirect effects of *Green Hill & Slope* ($\beta =$ -0.024, SE = 0.006, $p < 0.001$), *Sky* ($\beta =$ -0.067, SE = 0.008, $p < 0.001$) on mental stress through PO were significant (Table 5 & Fig. 3). Hypothesis 1 (pathway 1) was supported.

Second, the specific indirect effects of *Tree Canopy* ($\beta = -0.114$, SE = 0.010, $p < 0.001$), *Green Hill & Slope* ($\beta = -0.021$, SE = 0.005, $p < 0.001$), *Sky* ($\beta = -0.072$, SE = 0.008, $p < 0.001$), *Road Surface* ($\beta =$ 0.017, SE = 0.005, $p = 0.001$), *Billboard* ($\beta = 0.042$, SE = 0.006, $p < 0.001$), *Vehicle* ($\beta = 0.039$, SE = 0.006, $p < 0.001$) on mental stress through PEQ were significant (Table 5 & Fig. 3). Thus, Hypothesis 2 (pathway 2) was supported.

Third, the specific indirect effects of *Tree Canopy* ($\beta = -0.122$, SE = 0.008, $p < 0.001$), *Green Hill & Slope* ($\beta = -0.022$, SE = 0.005, $p < 0.001$), *Sky* ($\beta = -0.077$, SE = 0.007, $p < 0.001$), *Road Surface* ($\beta =$ 0.018, SE = 0.005, $p = 0.001$), *Billboard* ($\beta = 0.045$, SE = 0.007, $p < 0.001$), and *Vehicle* ($\beta = 0.042$, SE = 0.006, $p < 0.001$) on mental stress through PEQ and then through PO were significant (Table 5 & Fig. 3). Thus, Hypothesis 3 (pathway 3) was supported.

4.2.5. Summary of results

The complex model is summarized in Fig. 4 where the three hypothesized pathways are verified, and they collectively explain a

Table 3
Standardized total effects of specific streetscape elements, confounding variables, and mediators on mental stress.

	Point estimate	Product of coefficients		Bootstrapping				
				Percentile 95% CI		Bias-corrected percentile 95% CI		Tow tailed significance
		SE	z	Lower	Upper	Lower	Upper	
Total effects (TF)								
Tree Canopy	−0.224	0.017	−13.176	−0.269	−0.179	−0.270	−0.179	0.000**
Shrub	−0.042	0.016	−2.625	−0.085	0.002	−0.085	0.002	0.014
Lawn	0.035	0.017	2.059	−0.009	0.077	−0.010	0.077	0.040
Green Hill & Slope	−0.056	0.016	−3.500	−0.096	−0.015	−0.096	−0.015	0.001*
Sky	−0.181	0.018	−10.056	−0.226	−0.136	−0.226	−0.137	0.000**
Other Natural Elements	−0.028	0.015	−1.867	−0.066	0.010	−0.066	0.010	0.051
Glass Façade	0.011	0.018	0.611	−0.035	0.056	−0.034	0.056	0.532
Road Surface	0.063	0.016	3.938	0.020	0.105	0.020	0.105	0.000**
Concrete Containing Wall	−0.029	0.018	−1.611	−0.074	0.017	−0.074	0.017	0.098
Billboard	0.070	0.018	3.889	0.024	0.116	0.026	0.117	0.000**
Vehicle	0.102	0.016	6.375	0.062	0.144	0.061	0.144	0.000**
People	−0.012	0.019	−0.632	−0.060	0.037	−0.062	0.035	0.501
Fence	−0.009	0.016	−0.563	−0.050	0.034	−0.050	0.034	0.602
Other Artificial Elements	0.037	0.015	2.467	0.000	0.076	0.000	0.076	0.010
Chronic Mental Stress	0.160	0.012	13.333	0.128	0.191	0.129	0.191	0.000**
CT15Y	−0.027	0.013	−2.077	−0.059	0.007	−0.058	0.007	0.043
CT3Y	−0.001	0.011	−0.091	−0.030	0.030	−0.030	0.030	0.969
Screen Size	−0.007	0.011	−0.636	−0.034	0.020	−0.034	0.020	0.517
Working Hours	−0.026	0.012	−2.167	−0.057	0.003	−0.058	0.003	0.022
Income	−0.029	0.011	−2.636	−0.059	0.000	−0.059	0.000	0.009*
Occupational Relevance	−0.018	0.011	−1.636	−0.047	0.010	−0.047	0.011	0.103
Education Level	−0.004	0.012	−0.333	−0.036	0.028	−0.036	0.028	0.754
Gender (M = 1, F = 2)	0.033	0.011	3.000	0.004	0.061	0.003	0.060	0.005*
Age	−0.044	0.015	−2.933	−0.083	−0.002	−0.083	−0.002	0.007*
Marriage Status	0.031	0.015	2.067	−0.008	0.069	−0.009	0.069	0.041
Experiment Time	−0.060	0.012	−5.000	−0.092	−0.031	−0.092	−0.030	0.000**
Perceived Environmental Quality	−0.658	0.016	−41.125	−0.698	−0.617	−0.698	−0.616	0.000**
Perceived Oppressiveness	0.502	0.020	25.100	0.450	0.551	0.450	0.551	0.000**

Note: Standardized estimating of 10000 bootstrap sample, $^{*}p < 0.01$, $^{**}p < 0.001$. CT15Y = city type lived in under 15 years old; CT3Y = city type lived in the past three years.

Table 4
Standardized direct effects and indirect effects of specific streetscape elements and mediators on mental stress.

	Point estimate	Product of coefficients		Bootstrapping				
				Percentile 95% CI		Bias-corrected percentile 95% CI		Tow tailed significance
		SE	z	Lower	Upper	Lower	Upper	
Direct effects (DF)								
Tree Canopy	0.014	0.013	1.077	−0.021	0.047	−0.021	0.047	0.322
Green Hill & Slope	0.011	0.012	0.917	−0.020	0.041	−0.022	0.040	0.386
Sky	0.035	0.013	2.692	0.000	0.069	0.001	0.069	0.009*
Road Surface	0.030	0.012	2.500	0.000	0.061	0.000	0.061	0.010
Billboard	−0.007	0.013	−0.538	−0.039	0.027	−0.039	0.027	0.596
Vehicle	0.029	0.012	2.417	−0.002	0.059	−0.002	0.059	0.019
Perceived Environmental Quality	−0.317	0.022	−14.409	−0.376	−0.261	−0.376	−0.261	0.000**
Perceived Oppressiveness	0.502	0.020	25.100	0.450	0.551	0.450	0.551	0.000**
Indirect effects (IF)								
Tree Canopy	−0.238	0.014	−17.000	−0.272	−0.203	−0.272	−0.203	0.000**
Green Hill & Slope	−0.067	0.011	−6.091	−0.095	−0.038	−0.095	−0.038	0.000**
Sky	−0.216	0.013	−16.615	−0.251	−0.182	−0.252	−0.182	0.000**
Road Surface	0.033	0.012	2.750	0.003	0.063	0.003	0.064	0.004*
Billboard	0.077	0.013	5.923	0.044	0.110	0.044	0.110	0.000**
Vehicle	0.074	0.011	6.727	0.044	0.103	0.044	0.103	0.000**
Perceived Environmental Quality	−0.341	0.016	−21.313	−0.382	−0.300	−0.382	−0.300	0.000**

Table 5
Standardized specific indirect effects of specific streetscape elements on mental stress.

	Point estimate	Product of coefficients		Bootstrapping				
				Percentile 95% CI		Bias-corrected percentile 95% CI		Tow tailed significance
		SE	z	Lower	Upper	Lower	Upper	
Specific indirect effects (SIE)								
Tree Canopy→PO→MS	−0.002	0.008	−0.250	−0.021	0.018	−0.022	0.018	0.784
Green Hill & Slope→PO→MS	−0.024	0.006	−4.000	−0.041	−0.009	−0.041	−0.009	0.000**
Sky→PO→MS	−0.067	0.008	−8.375	−0.086	−0.047	−0.086	−0.047	0.000**
Road Surface→PO→MS	−0.003	0.006	−0.500	−0.019	0.013	−0.019	0.013	0.634
Billboard→PO→MS	−0.010	0.007	−1.429	−0.028	0.009	−0.028	0.009	0.180
Vehicle→PO→MS	−0.007	0.007	−1.000	−0.025	0.010	−0.025	0.010	0.294
Tree Canopy→PEQ→MS	−0.114	0.010	−11.400	−0.140	−0.089	−0.140	−0.089	0.000**
Green Hill & Slope→PEQ→MS	−0.021	0.005	−4.200	−0.034	−0.008	−0.034	−0.008	0.000**
Sky→PEQ→MS	−0.072	0.008	−9.000	−0.092	−0.053	−0.093	−0.053	0.000**
Road Surface→PEQ→MS	0.017	0.005	3.400	0.005	0.032	0.005	0.032	0.001*
Billboard→PEQ→MS	0.042	0.006	7.000	0.026	0.059	0.027	0.060	0.000**
Vehicle→PEQ→MS	0.039	0.006	6.500	0.025	0.055	0.025	0.055	0.000**
Tree Canopy→PEQ→PO→MS	−0.122	0.008	−15.250	−0.144	−0.102	−0.145	−0.102	0.000**
Green Hill & Slope→PEQ→PO→MS	−0.022	0.005	−4.400	−0.036	−0.008	−0.036	−0.008	0.000**
Sky→PEQ→PO→MS	−0.077	0.007	−11.000	−0.096	−0.060	−0.097	−0.060	0.000**
Road Surface→PEQ→PO→MS	0.018	0.005	3.600	0.005	0.034	0.005	0.034	0.001*
Billboard→PEQ→PO→MS	0.045	0.007	6.429	0.029	0.062	0.029	0.063	0.000**
Vehicle→PEQ→PO→MS	0.042	0.006	7.000	0.027	0.057	0.027	0.057	0.000**

majority of the relationship between exposure to urban streetscape in high-density city and acute mental stress. Among these findings, the most critical finding is that PO explained 50.2% of acute mental stress ($\beta = -0.502$). The effect of PO can further be explained by indirect impact (through PEO, $\beta = -0.680$) and direct impact ($\beta = 0.033$) of urban streetscapes. Taken together, PO is a major factor in explaining the impacts of exposure to urban streetscapes in a high-density city on participants' acute mental stress. Moreover, PEO is major support for PO's mediating effect ($\beta = -0.680$).

5. Discussion

This experimental study investigated whether and to what extent urban streetscapes in the high-density city influenced urban dwellers' acute mental stress through PO. A valid pathways model was verified. In this section, we first interpret the main findings and then present the study's theoretical and practical contributions. Lastly, we present the study's limitations which could lead to opportunities for future research.

5.1. *Interpretation of key findings*

5.1.1. *A new pathways model: including PO in Stress Reduction Theory*

Stress Reduction Theory (SRT) argues that human perception of and response to physical environments is shaped by humans' long evolutionary history in nature (Ulrich et al., 1991). In 1983, Ulrich presented his 'psycho-evolutionary' framework, arguing that place preference is influenced by key environmental characteristics including complexity, focality, ground surface texture, depth, and mystery (Ulrich, 1983). These factors influence perception and comprehension of surroundings which are critical for human survival and prosperity. Ulrich (1991, p. 206) further pointed out that "preference is considered to be an important effect but is constructed only as one of a broad range of emotions (e.g., fear, interest, anger, sadness) that are central to the psychological component of stress and restoration." Interestingly, Ulrich did not further establish the causal link between multiple environmental characteristics and mental stress response in the SRT model. Instead, SRT mainly focuses on a binary comparison between the impacts of natural (green) and built (barren) environments on mental stress. Thus, it is not surprising that

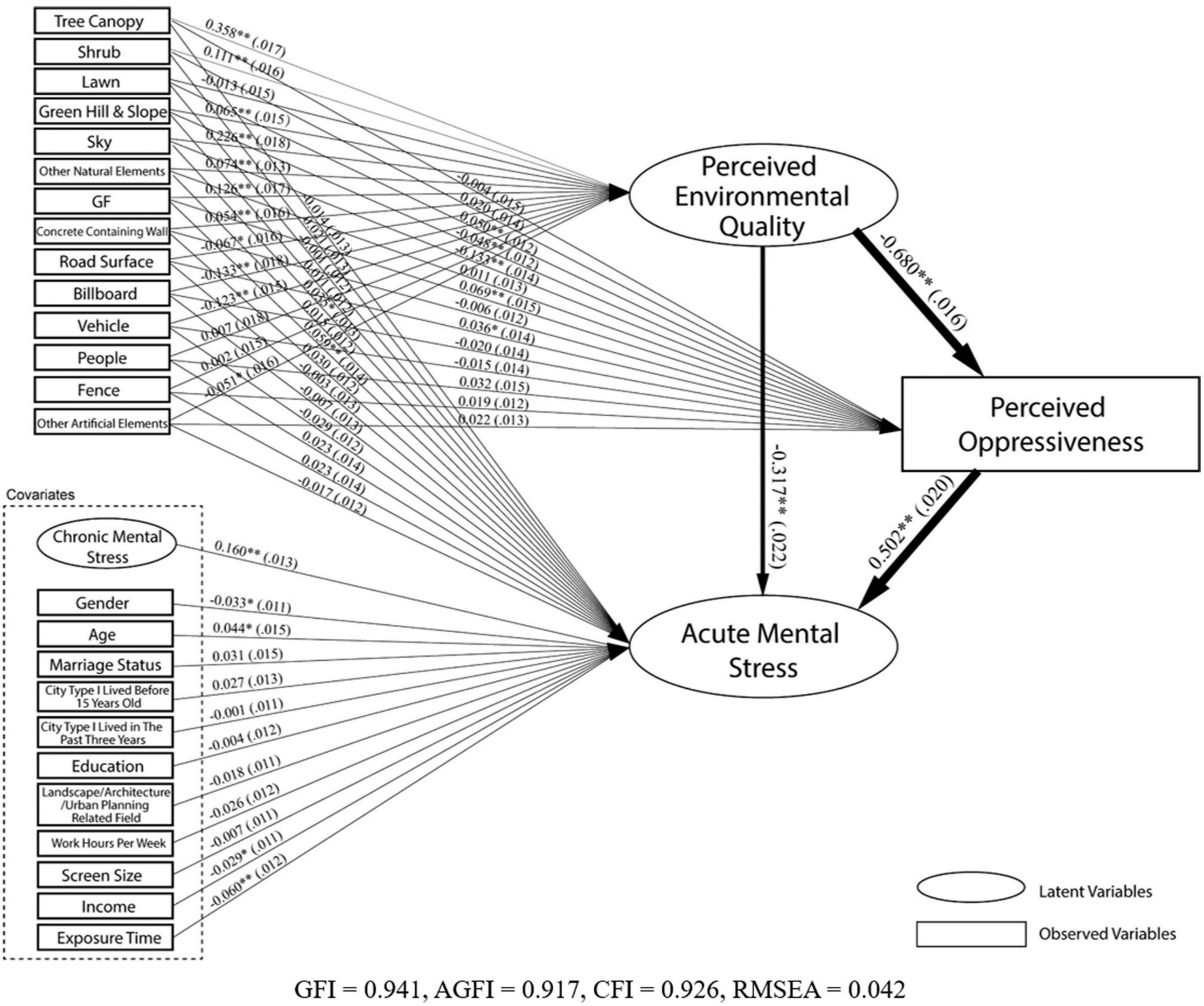

Fig. 3. Standardized coefficients (with cluster standard errors) of the Structural Equation Modeling of the pathways model. Note: $*p < 0.01$, $**p < 0.001$.

oppressiveness was not included in the SRT at this early stage. To our best knowledge, most of Ulrich's studies were not conducted in the context of high-density cities; the western cities where Ulrich conducted his major studies were generally not high density cities.

We argue that SRT needs to be updated to account for constantly evolving urban environments. Our more comprehensive pathways model links urban streetscapes and mental stress and acknowledges the significant impact of PO on mental stress in the context of high-density cities, enriching the content and structure of SRT. Further, our model is more comprehensive and detailed than past binary or categorical comparisons presented by most previous SRT-based studies. Although numerous past studies have investigated the relationship between streetscapes and mental stress, this is an initial effort to investigate the underlying pathways of various streetscape elements on residents' mental stress in a high-density context.

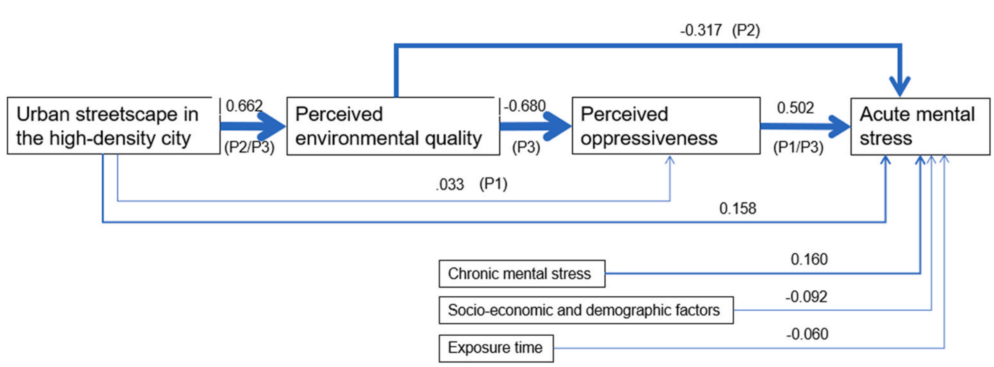

Fig. 4. Summary of Structural Equation Modeling of the pathways model.
Note: P1, P2, & P3 refer to pathway 1, pathway 2, & pathway 3.

5.1.2. Perceived oppressiveness (PO): a major mediator linking exposure to streetscapes in high-density cities and mental stress

We found that PO is a major mediator linking urban streetscapes and mental stress. The link between streetscape and PO is supported by literature discussed in the section 2.2. To our best knowledge, few studies have examined the effects of PO on mental stress. We offer three possible explanations for the significant link between PO and mental stress: First, according to the 'psycho-evolutionary' framework (Ulrich et al., 1991), a sense of oppressiveness is mainly caused by visual contact with artificial objects or spaces, such as high-rise buildings, artificial façades, hard surface roads, cars, and billboards, which are innately unfavorable and uncomfortable for humans. Second, streetscapes in high-density cities are commonly characterized as dense, complex, and chaotic, which may cause PO. This oppressiveness is associated with invasion of limited personal space and a sense of losing control, which may cause psychological stress (Chung et al., 2019; Cohen, 1980; Fleming et al., 1987). Third, oppressiveness perceived from streetscapes in high-density cities can occur when settings have a low level of visual permeability. Visual obstacles limit people's comprehension of surrounding environments, resulting in safety concerns and then mental stress (Jiang, Deal, et al., 2017; Kaplan & Kaplan, 2003).

5.1.3. Perceived environmental quality (PEO): a supportive mediator linking exposure to streetscapes in high-density cities to PO and to mental stress

We found that the impacts of streetscapes were mainly through PEO to PO and then to mental stress, which reveals that PEO plays a strong supporting role in PO's mediating effect. The strong supportive role of PEO may be explained as follows: First, streetscapes with more greenness are often more preferred (Jiang, Larsen, Deal, & Sullivan, 2015), which may imply better quality. Green landscapes are "softly fascinating" and serve as a buffer, reducing people's visual contact with artificial features, thus making streetscapes feel less oppressive and stressful (Jiang, He, Chen, Larsen, & Wang, 2020; Ulrich, 1984). Second, the visual presence of dense moving vehicles and pedestrians in a street scene implies a worse acoustic quality. The traffic and anthropologic noise increase people's psychological pressure, leading them to feel that the streetscape is oppressive and stressful (Alvarsson, Wiens, & Nilsson, 2010, Mar; Jiang et al., 2021). Third, urban streetscapes in wealthier areas tend to have a better supply and maintenance of landscapes, facilities, and destinations, which is an important aspect of environmental quality. People feel the streetscape is more comfortable, compatible, clean, and vital, which may contribute to a lower sense of oppressiveness and mental stress (Dunleavy et al., 2020; Gobster, 2001). Lastly, streetscapes with a greater sense of safety often make people feel a higher level of freedom and relaxation, which may reduce the sense of oppressiveness and mental stress (Jiang, Deal, et al., 2017).

5.1.4. Major streetscape elements impact mental stress through reduce or arouse PO

This study found that *Tree Canopy* and *Sky* were the top two mental stress relief elements through reducing PO. On the other hand, *Vehicles* and *Billboards* were the top two mental stress arousal elements through increasing PO.

Tree canopy is perceived as having high environmental quality due to people's innate preference for natural environments (Ulrich et al., 1991). Higher environmental quality leads to lower PO, resulting in mental stress reduction (Dunleavy et al., 2020). Also, tree canopy can function as a visual buffer to shield concrete walls and decrease the perceived strength and danger of buildings, resulting in lower PO and reduced mental stress (Andrade, Lima, Fornara, & Bonaiuto, 2012; Asgarzadeh et al., 2014; Hipp, Gulwadi, Alves, & Sequeira, 2016; Jiang et al., 2014).

People may perceive a space as having a higher environmental quality when more spacious views of sky are available. In high-density cities where developers construct high-rise buildings to maximize profit, expansive sky views are a rare luxury (Wang, Goggins, Zhang, Ren, & Lau, 2020). More expansive sky views as a mentally restorative resource (Masoudinejad & Hartig, 2020), mitigating PO and resulting in lower mental stress. Further, sky is a rich space. Through watching sky, people see many other natural elements, such as birds, sun, clouds, moon, and stars. The skyscape is dynamic, rich, and fascinating. All these contribute to an enhanced environmental quality, less PO, and then less mental stress. A greater amount of sky in people's field of vision also offers greater and deeper visual extent, leading to lower PO and mental stress (Asgarzadeh et al., 2012; Hwang et al., 2007). Lastly, a higher ratio of sky in the streetscape is negatively associated with building height and width (Asgarzadeh et al., 2012; Zarghami et al., 2019) and positively associated with space between buildings (Chung et al., 2019), giving people a greater sense of spaciousness, light, privacy, and freedom, which may also lower PO and then mental stress.

A greater presence of vehicles often relates to a higher density of artificial elements, creating unfavorable environments, triggering high PO and then high mental stress. Traffic jams create visual and noise pollution, leading people to perceive the environment as chaotic and out of control, further leading to high PO and then high mental stress (Fleming et al., 1987; Schmidt & Keating, 1979). In addition, speedy movement of vehicles increases the perception of invasion of personal space and risk of traffic accident, which may elicit a greater sense of oppressiveness and higher mental stress (Bornioli et al., 2018).

Billboards commonly use exaggerated colors, forms, and figures to grab people's attention (Herrstedt et al., 2013; Nowghabi & Talebzadeh, 2019). Streetscapes with dense billboards deliver complex, chaotic, and overloaded information to people. The delivery is often aggressive, repressive, and unpleasant (Ghorbanzadeh, 2018; Kaplan, 1987), increasing people's sense of oppressiveness and then mental stress. Moreover, many billboards block the sky overhead or the space inside the street, thus leading to a poor visual extent which can increase the sense of oppressiveness and then mental stress (Portella, 2016; Stamps, 2005). In addition, as a powerful mass media in the era of consumerism, advertisements on billboards encourage people to over-consume, creating excessive psychological pressure and status anxiety (Bauman, 2013; Gabriel & Lang, 2015; Zhang, 2021). The pressure can further cause a sense of oppressiveness and mental stress.

5.2. Theoretical and practical contributions

This study advances our understanding of the underlying pathways whereby urban streetscapes impact mental stress and the extent to which streetscape elements impact citizens' mental stress. This study further develops Ulrich's Stress Reduction Theory to interpret the streetscape-stress relationship in the context of high-density cities by providing a new pathways model. PO is a major mediator linking exposure to high-density urban environments to increase of mental stress. This study delivers a new message to government and society that PO plays a critical role in explaining residents' mental stress. To promote urban dwellers' mental health, reducing oppressiveness of streetscapes is a critical environmental intervention. We suggest planners and researchers consider the following potential solutions to promote mental health:

First, adding greenery to streetscapes is critical to mitigate PO and then mental stress. Adding umbrella-like tree canopy along streets may be more feasible since trees only occupy a small portion of ground area but provide a lot of greenness at the eye level. In addition, transforming barren vertical surfaces, such as concrete retaining walls and artificial façades, to green walls with vertical plants would also be an efficient intervention to reduce PO.

Second, sky view in urban streets is essential to relieve PO and then mental stress. Admittedly, providing more sky views by reducing an urban area's average Floor Area Ratio (FAR) may be financially naive. However, some open sky views can be added if we plan buildings with a greater variety of heights but keep the average FAR largely unchanged.

Third, controlling presence of vehicles is critical to reducing PO and then mental stress. An effective intervention may be to reroute vehicles through external or underground roads, leaving more spaces for pedestrians. In addition, green landscapes can be used to provide physical separation and a soft visual buffer between vehicle lanes and pedestrian paths.

Fourth, presence of billboards should be controlled to reduce PO and then mental stress. Side billboards should be reduced or be replaced by front billboards to mitigate their negative impact on visual extent. Further, we suggest that billboards that advertise luxurious products, tobacco, alcohol, violence, or eroticism should be reduced or restricted to designated areas.

5.3. Limitations and directions for future research

There are many opportunities for future research. First, we used a set of 2D photographs to measure environmental features. Future research should use 3D videos or photographs which can provide participants a more immersive experience and allow investigators to measure the 3D spatial configuration and context. Second, this study could be replicated as an onsite experimental study. A real environment would give findings a greater level of validity, although controlling for environmental confounders will be a challenge. Lastly, this study was conducted in Hong Kong, a high-density, modern, and international city. To ensure a satisfactory level of generalizability, we selected sites and streetscapes with no significant local or Asian cultural or historic features. Nevertheless, we encourage researchers to replicate this study in many other high-density cities across the world to increase the study's generalizability.

6. Conclusion

This study identified a novel pathways model to describe the streetscapes-oppressiveness-stress relationship in the context of high-density cities. Our findings suggest a promising update of Stress Reduction Theory by adding perceived oppressiveness to the theoretical framework. Our findings serve as new scientific evidence to encourage city administrators, urban planners, and landscape architects to create less oppressive and stressful streetscapes in high-density cities to benefit hundreds of millions of people living in "concrete jungles."

Credit author statement

Lan Luo: Methodology – development of statistical model, Data curation, Formal analysis, Visualization, Writing – majority of original draft, Writing – review & editing. Bin Jiang: Conceptualization, Methodology – research design, Data curation, Writing – part of original draft, Writing – review & editing, Funding acquisition, Project administration, Resources, Supervision.

Ethics statement

The research was approved by the Human Research Ethics Committee (HREC) at The University of Hong Kong on February 28, 2019, before the commencement of data collection. The HREC's reference number is EA1901013. Participants were notified their rights by giving an e-signed informed consent.

Declaration of interest statement

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper. The manuscript is approved by all authors for publication. The work described is original research and it has not been published or under consideration for publication elsewhere.

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Appendix

Table A
Convergent validity of measurement models.

Construction measurement	Unstd.FL	S.E.	t	P	Std.FL	SMC	CR	AVE
Mental stress (score 0-100)								
MS1. Would you feel anxious if you were living or working at this place?	–				0.955	0.912	0.945	0.852
MS2. Would you feel tense if you were living or working at this place?	1.001	0.008	122.561	***	0.948	0.899		
MS3. Would you feel avoidant if you were living/working at this place?	0.977	0.011	92.584	***	0.863	0.745		
Chronic stress (score 1-5)								
CS1. I found it hard to wind down	–				0.753	0.567	0.890	0.536
CS2. I tended to over-react to situations	0.995	0.020	48.786	***	0.758	0.575		
CS3. I felt that I was using a lot of nervous energy	0.960	0.021	45.925	***	0.717	0.514		
CS4. I found myself getting agitated	1.050	0.021	50.303	***	0.780	0.608		
CS5. I found it difficult to relax	1.121	0.022	51.234	***	0.794	0.630		
CS6. I was intolerant of anything that kept me from getting on with what I was doing	0.786	0.020	38.360	***	0.606	0.367		
CS7. I felt that I was rather touchy	0.942	0.021	44.916	***	0.703	0.494		
Perceived environmental quality (score 1-5)								
PPQ1. How do you feel about the visual quality here?	–				0.891	0.794	0.845	0.529
PPQ2. How do you feel about the acoustic quality here?	1.027	.018	58.582	***	0.794	0.630		
PPQ3. How do you feel about the greenness level here?	1.053	.020	51.757	***	0.721	0.520		
PPQ4. How do you feel about the security level here?	.630	.015	41.349	***	0.605	0.366		
PPQ5. How do you feel about the economy level here?	.663	.017	38.937	***	0.577	0.333		

Note: Unstd.FL is unstandard factor loading; Std.FL is standard factor loading; SMC is square of multivariate correlation; CR is composite reliability; AVE is average of variance extracted.

Table B
Discriminant validity of measurement models.

	AVE	Mental Stress	Chronic Stress	Perceived Environmental Quality
Mental Stress	0.852	**0.923**		
Chronic Stress	0.536	0.208	**0.732**	
Perceived Environmental Quality	0.529	−0.641	−0.006	**0.727**

Note: Square root of AVE in bold on diagonals; off diagonals are Pearson correlation of constructs.

Table C
Correlations (Pearson's correlation coefficient) between the independent variables and confounding variables in the proposed pathways model.

Variables	Tree	Shrub	Lawn	GHS	Sky	ONE	GF	OAF	CCW	Road	Billboard	Vehicle	People
Tree Canopy	–												
Shrub	0.000	–											
Lawn	0.020	0.089**	–										
Green Hill & Slope	0.276**	0.027	0.001	–									
Sky	0.042*	0.228**	0.308**	−0.011	–								
Other Natural Elements	−0.106**	−0.060**	0.051*	0.001	−0.054*	–							
Glass Façade	−0.200**	0.240**	−0.070**	−0.116**	−0.230**	0.146**	–						
Other Artificial Façade	**−0.694****	−0.317**	−0.120**	−0.258**	**−0.467****	0.038	−0.239**	–					
Concrete Containing Wall	0.358**	−0.108**	−0.048*	0.238**	0.122**	−0.115**	−0.147**	−0.385**	–				
Road Surface	−0.098**	0.211**	0.008	0.213**	0.116**	−0.074**	−0.006	−0.097**	0.046*	–			
Billboard	−0.350**	−0.171**	−0.070**	−0.142**	−0.274**	−0.055**	0.125**	0.319**	−0.153**	−0.238**	–		
Vehicle	−0.125**	−0.151**	−0.053**	−0.212**	−0.124**	0.007	0.185**	0.052*	−0.275**	−0.212**	0.152**	–	
People	−0.361**	−0.170**	−0.072**	−0.172**	−0.360**	−0.035	0.295**	0.318**	−0.229**	0.036	0.512**	0.120**	–
Fence	0.156**	0.065**	−0.115**	−0.037	0.148**	0.026	−0.222**	−0.184**	0.018	−0.122**	−0.099**	−0.122**	−0.188**
Other Artificial Elements	−0.069**	0.202**	−0.043*	−0.002	0.168**	0.050*	0.043*	−0.176**	−0.085**	0.067**	−0.117**	0.028	−0.123**
Gender	−0.001	0.003	−0.007	−0.003	−0.024	0.016	0.003	0.009	0.000	0.004	0.010	0.000	0.015
Age	0.010	0.006	−0.001	0.015	−0.010	−0.016	0.008	−0.005	−0.005	−0.007	0.004	−0.007	−0.012
Marriage status	−0.004	0.000	−0.013	0.029	−0.019	0.005	0.020	0.001	−0.007	0.001	−0.007	0.002	−0.007
CT15Y	0.007	−0.001	0.019	0.002	0.040	0.016	−0.020	−0.014	−0.004	0.004	0.008	0.018	−0.022
CT3Y	−0.002	−0.004	0.019	0.014	0.010	0.008	0.004	0.003	−0.038	−0.015	−0.009	0.025	−0.016
Education	0.009	0.034	0.004	0.026	0.002	0.003	0.011	−0.019	−0.001	0.003	−0.011	0.016	0.002
Occupational relevance	−0.008	0.007	0.010	−0.013	0.008	0.015	−0.031	0.011	0.008	−0.006	0.010	0.000	−0.006
Work hours per week	0.001	0.019	0.029	−0.013	−0.011	−0.009	0.032	−0.005	−0.005	−0.011	0.002	−0.003	0.019
Screen size	0.011	0.014	0.046*	−0.018	0.009	−0.007	−0.013	−0.004	−0.007	0.000	−0.007	0.002	−0.004
Income	−0.009	0.022	0.000	−0.018	0.018	−0.006	−0.020	0.008	−0.007	−0.003	0.004	−0.020	−0.013
Exposure time	0.024	0.005	−0.010	0.019	0.003	−0.002	−0.010	−0.010	−0.001	0.005	−0.025	−0.019	−0.021
Chronic stress	0.024	0.017	−0.004	0.004	−0.013	0.002	0.029	−0.029	0.021	−0.013	0.020	−0.006	−0.026

Fence	OAE	Gender	Age	Marriage status	CT15Y	CT3Y	Education	LA/Archi/UP	WH	SS	Income	Exposure time	CS
–													
0.190**	–												
−0.006	0.011	–											
−0.020	0.023	−0.062**	–										
−0.011	0.020	−0.063**	0.621**	–									
−0.031	−0.013	0.049*	−0.036	−0.086**	–								
−0.012	−0.017	−0.072**	0.028	0.037	0.385**	–							
0.007	−0.012	−0.046*	−0.064**	0.067**	−0.178**	0.061**	–						
0.034	0.010	0.028	−0.009	−0.075**	0.160*sss*	0.000	−0.176**	–					
−0.019	−0.022	−0.112**	0.193**	0.169**	−0.072**	0.059**	0.239**	−0.076**	–				
−0.016	0.009	−0.028	0.054**	−0.029	0.175**	0.039	−0.061**	0.093**	0.006	–			
0.026	0.002	−0.045*	0.212**	0.225**	0.134**	0.064**	0.084**	0.044*	0.089**	0.125**	–		
−0.017	0.011	0.066**	0.285**	0.220**	−0.078**	−0.009	0.026	−0.116**	0.042*	0.043*	0.053*	–	
−0.025	0.017	−0.046*	−0.063**	−0.071**	0.103**	0.098**	−0.040*	0.018	0.056**	0.067**	−0.071**	−0.044*	

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