Landscape and Urban Planning 224 (2022) 104444

Contents lists available at ScienceDirect

Landscape and Urban Planning

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

# More visible greenspace, stronger heart? Evidence from ischaemic heart disease emergency department visits by middle-aged and older adults in Hubei, China

Yao Yao [a,1], Changwu Xu [b,c,d,1], Hanyu Yin [a], Ledi Shao [a], Ruoyu Wang [e,*]

[a] School of Geography and Information Engineering, China University of Geosciences, Wuhan 430074, PR China
[b] Department of Cardiology, Renmin Hospital of Wuhan University, Wuhan 430060, PR China
[c] Cardiovascular Research Institute, Wuhan University, Wuhan 430060, PR China
[d] Hubei Key Laboratory of Cardiology, Wuhan 430060, PR China
[e] UKCRC Centre of Excellence for Public Health/Centre for Public Health, Queen's University Belfast, Belfast, Northern Ireland, United Kingdom

## HIGHLIGHTS

- The association between visible greenspace and ischemic heart diseases (IHD) is still unclear.
- This study explores the association between residential street view greenspace (SVG) exposure and IHD emergency department visits for middle-aged and older adults.
- SVG-grass is negatively associated with IHD mortality and recovery time from IHD.
- No evidence can support SVG-tree is related to IHD.
- Male patients, older patients and patients living in low-income neighbourhood can benefits more from SVG exposure.

## ARTICLE INFO

*Keywords:*
Street view greenspace
Ischaemic heart diseases
Emergency department visits
Middle-aged and older adults
China

## ABSTRACT

Awareness is increasing that greenspace is beneficial for people's heart health. While a plethora of studies have focused on the relationship between neighbourhood greenspace and cardiovascular diseases in the general population, scant attention has been given to ischaemic heart disease (IHD) emergency department visits for middle-aged and older adults. This study aimed to systematically explore the association between residential street view greenspace (SVG) exposure and IHD emergency department visits for middle-aged and older adults in Chinese cities. The IHD mortality and recovery time of surviving patients were treated as dependent variables. We used street view data to assess residential SVG, and we also distinguished between trees (SVG-tree) and grasses (SVG-grass) when calculating SVG. The results showed that SVG-grass is negatively associated with IHD mortality and recovery time from IHD. However, there is no evidence that SVG-tree is related to IHD. Hence, the stratified analysis indicates that that the effect of SVG on IHD varies significantly by individual demographic and socioeconomic characteristics. Male patients, older patients and patients living in low-income neighbourhoods can benefit more from SVG exposure. Our findings suggest the necessity of providing sufficient residential visible vegetation, especially grassland, to promote heart health in Chinese urban settings.

## 1. Introduction

Cardiovascular diseases (CVDs) have become a serious global public health issue (Lozano, et al., 2012). Among all CVDs, ischaemic heart diseases (IHDs) are the leading cause of death globally (Roth, et al., 2017). In China, ischaemic heart disease was also the leading cause of CVD deaths in 2016 (Liu, et al., 2019). Most previous studies have focused on the effect of lifestyle-related behaviours such as drinking and

* Corresponding author at: UKCRC Centre of Excellence for Public Health/Centre for Public Health, Queen's University Belfast, Belfast, Northern Ireland, United Kingdom.
*E-mail addresses:* r.wang-54@sms.ed.ac.uk, r.wang@qub.ac.uk (R. Wang).
[1] These authors contributed equally to this work.

https://doi.org/10.1016/j.landurbplan.2022.104444
Received 19 November 2021; Received in revised form 15 April 2022; Accepted 16 April 2022

smoking on CVDs (Cosselman et al., 2015; Yang, et al., 2015). In recent years, other studies have shown that residential environments, such as greenspace exposure, also contribute to the risk of CVDs.

There are a number of mechanisms underlying the association between greenspace and CVDs (Nieuwenhuijsen, 2018). First, greenspace can mitigate environmental hazards such as air pollution (Aerts, et al., 2020), noise (Nieuwenhuijsen, 2018) and heat waves (Shen and Lung, 2016), which all have negative impacts on CVDs. For example, Aerts et al. (2020) found that air pollution mediates the association between forest cover and cardiovascular medication sales. Shen and Lung et al. (2016) pointed out that green structures reduce the mortality of cardiovascular diseases by mitigating the negative impact of high temperature. Second, restorative features of greenspace help people reduce stress, which is beneficial to CVDs (Nieuwenhuijsen, 2018). A recent study in Australia found that greenspace can improve sleep duration, which helps people restore energy (Astell-Burt and Feng, 2020a). Additionally, Grahn and Stigsdotter (2010) found that urban greenspace is an important restorative environment for stressed individuals.

Finally, greenspace can encourage more physical activity, which enhances physical functions and is beneficial to heart health (Jia, et al., 2018; Nieuwenhuijsen, 2018; Richardson et al., 2013; Sharifi et al., 2021; Wu & Kim, 2021; Xie et al., 2018; Yang et al., 2019). Richardson et al. (2013) found that physical activity partly explained greenspace-CVD associations in New Zealand. Jia et al. (2018) also found that physical exercise mediates the effects of greenspace on CVDs in China. Hence, greenspace strengthens social interaction and coherence, which can enhance people's health-related knowledge and reduce CVDs (Nieuwenhuijsen, 2018). Although the mediating effect of social cohesion has not yet been confirmed, greenspace-social cohesion (Jennings & Bamkole, 2019) and social cohesion-CVD associations (Robinette et al., 2018) have been verified.

Accumulated findings suggest that exposure to greenspace within people's residential neighbourhood is beneficial for heart health (Nieuwenhuijsen, 2018). A recent meta-analysis found that greenspace exposure is significantly related to a reduction in the risk of cardiovascular disease mortality (Gascon, et al., 2016). Various cross-sectional and longitudinal studies have confirmed that exposure to residential greenspace is associated with CVDs (Nieuwenhuijsen, 2018). In a cross-sectional study, Yeager et al. (2018) found that neighbourhood greenspace is associated with a lower risk of CVDs in the USA. Similar results were found in Israel (Yitshak-Sade et al., 2017), Australia (Pereira, et al., 2012), Canada (Chum and O'Campo, 2015) and China (Yang, et al., 2020). However, based on an ecological study design, Richardson et al. (2010) found no evidence that greenspace influenced CVDs in New Zealand.

For longitudinal studies, Seo et al. (2019) found that greater greenspace coverage is associated with a reduced risk of CVD in Korea. Astell-Burt and Feng (2020b) found that tree canopy is negatively associated with the odds of prevalent CVDs in Australia. Chen et al. (2020) observed that residential greenspace is related to CVD incidence, readmission, and mortality in Canada. A field experiment further investigated the health benefits of visiting green environments and found that they are beneficial for blood pressure, heart rate and heart rate variability (Lanki, et al., 2017).

However, most of the existing literature mainly focused on greenspace-chronic CVD associations for the general population, while scant attention has been given to CVD emergency department visits, especially for middle-aged and older adults. Middle-aged and older adults have a higher risk of CVD prevalence and mortality than young adults (Roth, et al., 2017), so further examination of greenspace-CVD emergency department visits, especially for middle-aged and older adults, has become an urgent issue.

The heterogeneous health benefits of greenspaces should also be noted. The 'equigenesis' theory indicates that disadvantaged groups can benefit more from greenspace exposure since they may not be able to afford good medical care, and green infrastructure is a kind of public facility that is free to access (Mitchell et al., 2015). For example, Mitchell and Popham (2008) found that the association between greenspace exposure and CVD mortality is stronger for income-deprived groups than for high-income groups. Additionally, gender differences is another aspect of the heterogeneous health benefits of greenspace. For instance, Richardson and Mitchell (2010) found that greenspace exposure is associated with lower CVD mortality for men, but such an association was not significant for women. However, few studies have focused on the heterogeneous health benefits of greenspace in developing countries, so such heterogeneity for greenspace-CVD associations remains unclear in developing countries.

Awareness is increasing that streets have become an important context for greenspace exposure, since people spend a large amount of time in such a context (Chaix, et al., 2013; Jiang et al., 2020; Lachowycz et al., 2012; Li et al., 2018; Mennis et al., 2018). For example, Zhang et al. (2020) used wearable cameras to measure people's dynamic greenspace exposure and found that the proportion of dynamic exposure (which happens on the street) is much greater than that of static exposure. Nieuwenhuijsen (2018) also highlighted that street greenspace is important for CVDs since it is an essential context for walking, cycling and other physical activities. Previous investigations have mainly focused on the impact of greenspace exposure on health based on remote sensing and land use data, with less evidence derived from street-level visible greenspace (Helbich et al., 2021; Markevych, et al., 2017). No studies have examined the effect of street-level visible greenspace on CVDs, so it is unclear whether street-level visible greenspace contributes to CVDs. Hence, Astell-Burt and Feng (2020b) found that the tree canopy is associated with CVDs, while total green space is not, so identifying whether different types of street vegetation influence CVDs differently is also necessary.

This study aimed to explore the association between residential street view greenspace (SVG) exposure and IHD for middle-aged and older adults in Hubei, China, using hospital emergency department visits and Tencent street view data. It particularly focuses on the effects of both street-level visible trees and grasses. Additionally, the heterogeneous effects of demographic and socioeconomic status (SES) factors are included. This study extends previous research in several respects. First, it enhances our knowledge of the beneficial effect of residential greenspace exposure on IHD by focusing on middle-aged and older patients in China. Second, it makes a methodological contribution to the study of the cardiovascular benefits of residential greenspace exposure by using street view greenspace as a surrogate for visible greenspace exposure. Last, this study further contributes to the 'equigenesis' theory by examining the greenspace-IHD association.

## 2. Data and methods

### 2.1. Health outcomes

IHD emergency department visits for 2016–2019 were obtained from Hubei Provincial People's Hospital. IHD identification was based on the primary discharge diagnosis code of each patient. The following outcomes [International Classification of Diseases, Tenth Revision (ICD-10 codes)] were included: acute myocardial infarction [I21], subsequent ST elevation (STEMI) and non-ST elevation (NSTEMI) myocardial infarction [I22], certain current complications following ST elevation (STEMI) and non-ST elevation (NSTEMI) myocardial infarction (within the 28-day period) [I23], other acute ischaemic heart diseases [I24] and heart failure [I50]. The residential locations of the targeted participants are shown in Fig. S1. We calculated the global Moran's I (Moran, 1950) for the spatial autocorrelation of IHD, and the result (Moran's index $= -0.000$; p value $= 0.579$) indicates that no evidence can support that there is a spatial cluster for participants with IHD.

This hospital emergency department visit data provided information regarding whether patients survive or die of IHD, so we treated IHD mortality as a binary variable ('0'= survive, '1' = die of IHD). Hence, for surviving patients, recovery time was also recorded, and we treated it as a continuous variable (days). Data also included the sex, age and housing address of each study participant. Since we mainly focused on middle-aged and older adults (Gordon-Salant et al., 2010), we excluded respondents below 40 years old (146 respondents were excluded). In total, 4224 respondents were included in the final data. This study obtained appropriate Institutional Review Board approval from the People's Hospital of Wuhan University (WDRY2021-K054).

### 2.2. Street view greenspace

We collected Tencent street view images (https://map.qq.com/jiejing) from 2017 to 2019 to assess neighbourhood street view greenspace (SVG) exposure. Sampling points based on the road network from OSM (open street map) (https://www.openstreetmap.org) were 100 m apart. Following the methods used in previous studies (Wang et al., 2020), we collected four street view images (0, 90, 180 and 270) for each sampling point. In sum, we collected 666,758 street view images. Previous studies indicated that trees and grasses have different influences on residents' health (Wang et al., 2019), so we calculated both SVG exposure based on trees (SVG-tree) and grasses (SVG-grass) using street view images and machine learning approaches. Following the approach proposed by Wang et al. (2019), we used a fully convolutional neural network (FCN-8s) (Kang and Wang, 2014) and an annotated image dataset called ADE20K (Zhou, et al., 2016) for the machine learning training process. The accuracy of this approach was more than 0.85 in identifying trees and grasses in our data. Finally, we calculated the SVG-tree and SVG-grass for respondents by averaging the SVG-tree and SVG-grass scores for all sampling points within 600-metre circular buffers of each respondents' housing address. Normally, 800 m is used to measure the 10-minute walking distance for a healthy adult (Merriam et al., 2017), but we reduced the size (600 m) of the buffer due to the physical conditions of our participants.

### 2.3. Covariates

First, the existing literature pointed out that there are age and gender differences in CVDs (Anderson et al., 1991), so we adjusted for these two individual confounding covariates. Additionally, neighbourhood built environments are important for CVD prevention (Koohsari et al., 2020), so we included a series of neighbourhood confounding covariates to reflect the density, design and diversity of the built environments. First, following Frank et al. (2006), we chose three land use-related variables, including population density (persons/km$^2$), street intersection density (intersections/km$^2$) and land use mix (0–1). Population density was calculated based on the Tencent location data (https://heat.qq.com/) following Yao et al. (2018). Street intersection density was extracted from the OSM dataset. Hence, the entropy score based on Gaode POI (points of interest) data (https://www.amap.com/) was treated as the proxy for land use mix. Since previous studies indicated that greenspace accessibility is associated with CVDs (Koohsari et al., 2020), we also included the distance to the nearest park (meters) based on Gaode POIs. Last, since there are neighbourhood socioeconomic disparities in cardiovascular health (Koohsari et al., 2021), we controlled for neighbourhood SES (socioeconomic status) (10,000 Chinese yuan/km$^2$), which also reflects the neighbourhood social environment. It was provided by the Resource and Environment Science and Data Centre (https://www.resdc.cn/DOI/doi.aspx?DOIid=33). The summary statistics for all variables are shown in Table 1.

### 2.4. Methods

To assess the linkage between neighbourhood SVG and IHD, we fitted both logistic regressions (for IHD mortality, which is a binary variable) and linear regressions (for the recovery time of surviving patients, which is a continuous variable). Variance inflation factors (VIF < 3) suggested no severe multicollinearity among the independent variables. The Akaike information criterion (AIC) (Sakamoto et al., 1986) was used for model assessment (Table S1). The existing literature has pointed out that the smaller the AIC is, the better the model is (Sakamoto et al., 1986). Additionally, if the difference in AIC between the two models is above 3, then they are significantly different (Sakamoto et al., 1986). The results (Table S1) indicated that the fully adjusted models were better than the crude models.

**Table 1**
Summary statistics for all variables.

| Variables | Proportion/Mean (SD) |
|---|---|
| Dependent variables | |
| IHD mortality (%) | |
| Recovery | 93.706 |
| Dead | 6.294 |
| Recovery time of surviving patients (days) | 10.499(6.940) |
| Independent variables | |
| SVG-tree (0–1) | 0.132(0.076) |
| SVG-grass (0–1) | 0.017(0.029) |
| Controlled variables | |
| Gender (%) | |
| Male | 73.923 |
| Female | 26.077 |
| Age (years) | 65.099(11.703) |
| Neighbourhood population density (persons/km$^2$) | 3925.951(4542.046) |
| Neighbourhood land use mix (0–1) | 0.653(0.214) |
| Density of interactions (numbers/km$^2$) | 26.326(33.769) |
| Distance to the nearest park (m) | 4974.897(23947.247) |
| Neighbourhood GDP (10000 Chinese Yuan/km$^2$) | 26552.975(40650.473) |

First, we regressed IHD mortality on SVG and covariates (Model 1a). Second, we regressed the recovery time of the surviving patients on SVG and covariates (Models 1b). Third, for sensitivity analysis of the relationships between neighbourhood SVG and IHD, the following additional sensitivity tests were performed. We excluded respondents over 85 years old since their restricted functional ability may influence the SVG-IHD association (Model 2). We changed the buffer size to 800 m and reran the fully adjusted model (Model 3). Since respondents having IHD emergency department visits on the same day may be influenced by the same unobserved factors, we reran the fully adjusted model and used the cluster confidence interval and standard error based on the date of IHD emergency department visits (Model 4). Finally, we conducted three stratified analyses to explore the heterogeneous effects of demographics and SES, including gender (Models 5 and 6), age (Models 7 and 8) and neighbourhood SES (Models 9, 10 and 11). A test for interaction terms was incorporated into the regression models to further validate the findings from the stratified analysis (Table S2). We defined statistical significance as $p < 0.05$ for main effects and interactions.

## 3. Results

Tables 2 and 3 show the results of Model 1. Model 1a indicated that respondents living in neighbourhoods with Q4 SVG grass (OR = 0.701, 95% CI: 0.472–0.942) were less likely to die of IHD. However, there is no evidence that that SVG-tree is associated with IHD mortality. Model 1b indicated that respondents living in neighbourhoods with Q4 SVG grass (Coef. = −0.639, SE = 0.319) had a shorter recovery time from IHD. However, no evidence supports that SVG-tree is associated with the recovery time of IHD. The above results indicated that SVG-grass is negatively associated with IHD mortality and recovery time from IHD.

Tables 4 and 5 display the results of the sensitivity tests on the correlation between the neighbourhood street view greenspace and IHD. Despite some differences in magnitude, the SVG-grass-IHD associations remained significant across all models. However, the association between SVG-tree and the two IHD metrics is insignificant, which indicates there is no evidence that SVG-tree is related to IHD.

Table 6 shows the heterogeneous effects of gender, age and neighbourhood SES. Models 5 and 6 displayed the effect of SVG on males' and

**Table 2**
The association between SVG and IHD mortality.

| | Model 1a (DV: IHD mortality) |
|---|---|
| | OR. (95% CI) |
| Independent variables | |
| SVG-tree (ref: Q1) | |
| Q2 | 1.328(0.902–1.955) |
| Q3 | 1.146(0.758–1.732) |
| Q4 | 1.057(0.702–1.593) |
| SVG-grass (ref: Q1) | |
| Q2 | 0.734(0.500–1.076) |
| Q3 | 0.703*(0.477–1.035) |
| Q4 | 0.701**(0.472–0.942) |
| Covariates | |
| Male (ref: female) | 0.986(0.742–1.310) |
| Age | 1.060***(1.047–1.072) |
| Neighbourhood land use mix | 2.202(0.742–6.533) |
| Density of interactions | 1.001(0.997–1.005) |
| Distance to the nearest park | 1.001(0.999–1.001) |
| Neighbourhood population density | 1.042(0.658–1.651) |
| Neighbourhood GDP | 1.332(0.899–1.973) |
| Constant | 0.001***(0.000–0.001) |
| AIC | 1780.384 |

DV = dependent variable; OR = odds ratio; CI = confidence interval; AIC = Akaike information criterion. *p < 0.10, **p < 0.05, ***p < 0.01.

**Table 3**
The association between SVG and IHD recovery time.

| | Model 1b (DV: Recovery time of surviving patients) |
|---|---|
| | Coef. (SE) |
| Independent variables | |
| SVG-tree (ref: Q1) | |
| Q2 | 0.161(0.338) |
| Q3 | 0.376(0.352) |
| Q4 | −0.022(0.331) |
| SVG-grass (ref: Q1) | |
| Q2 | −0.230(0.348) |
| Q3 | −0.088(0.339) |
| Q4 | −0.639**(0.319) |
| Covariates | |
| Male (ref: female) | −0.498(0.263) |
| Age | 0.015(0.010) |
| Neighbourhood land use mix | −0.181(0.608) |
| Density of interactions | −0.002(0.004) |
| Distance to the nearest park | 0.001(0.000) |
| Neighbourhood population density | 0.312(0.347) |
| Neighbourhood GDP | −0.008(0.287) |
| Constant | 7.902***(0.959) |
| AIC | 25984.43 |

DV = dependent variable; Coeff. = coefficient; SE = standard error; AIC = Akaike information criterion. *p < 0.10, **p < 0.05, ***p < 0.01.

**Table 4**
Sensitivity analysis (IHD mortality).

| | Model 2a (DV: IHD mortality) | Model 3a (DV: IHD mortality) | Model 4a (DV: IHD mortality) |
|---|---|---|---|
| | OR. (95% CI) | OR. (95% CI) | OR. (95% CI) |
| Independent variables | | | |
| SVG-tree (ref: Q1) | | | |
| Q2 | 1.521 (0.910–2.291) | 1.295 (0.876–1.914) | 1.328 (0.851–1.532) |
| Q3 | 1.232 (0.799–1.900) | 1.148 (0.758–1.739) | 1.146 (0.899–1.461) |
| Q4 | 1.066 (0.692–1.642) | 1.069 (0.708–1.614) | 1.057 (0.955–1.170) |
| SVG-grass (ref: Q1) | | | |
| Q2 | 0.782 (0.524–1.167) | 0.758 (0.515–1.115) | 0.734 (0.686–1.185) |
| Q3 | 0.725 (0.481–1.093) | 0.733 (0.496–1.082) | 0.701* (0.487–1.010) |
| Q4 | 0.627** (0.414–0.949) | 0.709** (0.475–0.957) | 0.703*** (0.602–0.821) |
| AIC | 1643.005 | 1750.257 | 1758.384 |

Models were fully adjusted. DV = dependent variable; OR = odds ratio; CI = confidence interval; Coeff. = coefficient; SE = standard error; AIC = Akaike information criterion. *p < 0.10, **p < 0.05, ***p < 0.01.

**Table 5**
Sensitivity analysis (IHD recovery time).

| | Model 2b (DV: Recovery time of surviving patients) | Model 3b (DV: Recovery time of surviving patients) | Model 4b (DV: Recovery time of surviving patients) |
|---|---|---|---|
| | Coef. (SE) | Coef. (SE) | Coef. (SE) |
| Independent variables | | | |
| SVG-tree (ref: Q1) | | | |
| Q2 | 0.224(0.317) | 0.079(0.326) | 0.224(0.252) |
| Q3 | 0.345(0.324) | 0.246(0.337) | 0.345(0.197) |
| Q4 | −0.158(0.305) | −0.104(0.318) | −0.158(0.370) |
| SVG-grass (ref: Q1) | | | |
| Q2 | −0.341(0.324) | −0.270(0.333) | −0.341(0.260) |
| Q3 | −0.213(0.315) | −0.136(0.326) | −0.213(0.263) |
| Q4 | −0.761**(0.305) | −0.625**(0.318) | −0.761**(0.289) |
| AIC | 25206.9 | 26951.07 | 25184.9 |

Models were fully adjusted. DV = dependent variable; OR = odds ratio; CI = confidence interval; Coeff. = coefficient; SE = standard error; AIC = Akaike information criterion. *p < 0.10, **p < 0.05, ***p < 0.01.

females' IHD, respectively. The results indicated that men living in neighbourhoods with Q3 SVG-grass (OR = 0.624, 95% CI: 0.390–0.998) and Q4 SVG-grass (OR = 0.580, 95% CI: 0.356–0.946) were less likely to die of IHD. Additionally, men living in neighbourhoods with Q4 SVG grass (Coef. = −0.599, SE = 0.269) had a shorter recovery time from IHD. However, there is no evidence that SVG was associated with females' IHD. Models 7 and 8 displayed the effect of SVG on middle-aged adults' and older adults' IHD, respectively. The results indicated that older adults living in neighbourhoods with Q4 SVG-grass (OR = 0.664, 95% CI: 0.430–0.926) were less likely to die of IHD. Additionally, older adults living in neighbourhoods with Q4 SVG grass (Coef. = −0.876, SE = 0.425) had a shorter recovery time from IHD. However, there is also no evidence that SVG is associated with middle-aged adults' IHD. Models 9, 10 and 11 display the effect of SVG on IHD of respondents living in low-income, middle-income and high-income neighbourhoods, respectively. Model 9 shows the results for respondents living in a low-income neighbourhood. Respondents living in neighbourhoods with Q4 SVG grass (OR = 0.864, 95% CI: 0.305–0.946) were less likely to die of IHD. Additionally, respondents living in neighbourhoods with Q4 SVG-grass (Coef. = −1.128, SE = 0.495) had a shorter recovery time from IHD. However, there is no evidence that SVG is associated with the IHD of respondents who live in middle-income and high-income neighbourhoods. The test for interaction terms (Table S2) indicates that the above interactions were statistically significant only for IHD mortality.

## 4. Discussion

This study extends previous studies on the association between greenspace exposure and IHD in several respects. First, the present study is the first to systematically explore the effect of residential greenspace and IHD for middle-aged and older patients in the Chinese context. Second, it makes a novel methodological contribution to the study of the cardiovascular benefits of residential greenspace exposure in China by

**Table 6**
The heterogeneous effects of SVG.

| | Model 5a (DV: IHD mortality) Males OR. (95% CI) | Model 5b (DV: Recovery time of surviving patients) Males Coef. (SE) | Model 6a (DV: IHD mortality) Females OR. (95% CI) | Model 6b (DV: Recovery time of surviving patients) Females Coef. (SE) |
|---|---|---|---|---|
| Independent variables | | | | |
| SVG-tree (ref: Q1) | | | | |
| Q2 | 1.352(0.838–2.181) | 0.316(0.381) | 1.271(0.659–2.453) | −0.255(0.725) |
| Q3 | 1.119(0.675–1.855) | 0.606(0.390) | 1.140(0.558–2.331) | −0.247(0.782) |
| Q4 | 1.135(0.690–1.869) | 0.103(0.374) | 0.861(0.415–1.786) | −0.465(0.708) |
| SVG-grass (ref: Q1) | | | | |
| Q2 | 0.736(0.466–1.164) | −0.435(0.392) | 0.751(0.371–1.523) | 0.262(0.751) |
| Q3 | 0.624** (0.390–0.998) | −0.055(0.374) | 0.989(0.495–1.975) | −0.190(0.765) |
| Q4 | 0.580** (0.356–0.946) | −0.599**(0.269) | 1.078(0.539–2.157) | −0.654*(0.429) |
| AIC | 1198.225 | 18994.23 | 589.737 | 6979.269 |

| | Model 7a (DV: IHD mortality) Middle-aged adults OR. (95% CI) | Model 7b (DV: Recovery time of surviving patients) Middle-aged adults Coef. (SE) | Model 8a (DV: IHD mortality) Older adults OR. (95% CI) | Model 8b (DV: Recovery time of surviving patients) Older adults Coef. (SE) |
|---|---|---|---|---|
| Independent variables | | | | |
| SVG-tree (ref: Q1) | | | | |
| Q2 | 0.853(0.344–2.116) | 0.793(0.537) | 1.476(0.967–2.255) | −0.164(0.431) |
| Q3 | 0.480(0.163–1.414) | 1.033(0.553) | 1.323(0.843–2.078) | 0.065(0.450) |
| Q4 | 0.571(0.221–1.476) | 0.196(0.532) | 1.195(0.763–1.872) | −0.161(0.420) |
| SVG-grass (ref: Q1) | | | | |
| Q2 | 0.574(0.197–1.677) | −0.811(0.570) | 0.726(0.481–1.094) | −0.015(0.438) |
| Q3 | 0.452(0.160–1.279) | 0.126(0.528) | 0.732(0.483–1.111) | −0.207(0.437) |
| Q4 | 1.014(0.436–2.355) | −0.139*(0.087) | 0.664** (0.430–0.926) | −0.876**(0.425) |
| AIC | 356.749 | 8494.531 | 1479.564 | 17470.07 |

| | Model 9a (DV: IHD mortality) Low-income neighbourhood OR. (95% CI) | Model 9b (DV: Recovery time of surviving patients) Low-income neighbourhood Coef. (SE) | Model 10a (DV: IHD mortality) Middle-income neighbourhood OR. (95% CI) | Model 10b (DV: Recovery time of surviving patients) Middle-income neighbourhood Coef. (SE) | Model 11a (DV: IHD mortality) High-income neighbourhood OR. (95% CI) | Model 11b (DV: Recovery time of surviving patients) High-income neighbourhood Coef. (SE) |
|---|---|---|---|---|---|---|
| Independent variables | | | | | | |
| SVG-tree (ref: Q1) | | | | | | |
| Q2 | 1.401(0.485–4.045) | 0.248(0.565) | 1.084(0.544–2.161) | 0.731(0.546) | 1.488(0.867–2.552) | 0.029(0.660) |
| Q3 | 0.495(0.114–2.152) | 0.261(0.600) | 1.151(0.564–2.348) | 0.404(0.564) | 1.263(0.716–2.228) | 0.768(0.675) |
| Q4 | 0.606(0.207–1.777) | −0.377(0.492) | 0.927(0.450–1.906) | 0.129(0.561) | 1.271(0.713–2.264) | 0.511(0.693) |
| SVG-grass (ref: Q1) | | | | | | |
| Q2 | 0.806(0.248–2.618) | 0.167(0.577) | 0.587(0.282–1.222) | −0.972(0.586) | 0.813(0.493–1.340) | 0.205(0.646) |
| Q3 | 0.702(0.204–2.406) | −1.016*(0.566) | 0.559(0.277–1.129) | 0.047(0.543) | 0.790(0.473–1.320) | 0.679(0.657) |
| Q4 | 0.864** (0.305–0.946) | −1.128**(0.495) | 0.816(0.415–1.606) | −0.093(0.568) | 0.640* (0.467–1.005) | −1.042*(0.665) |
| AIC | 275.883 | 8474.986 | 579.859 | 8568.417 | 944.309 | 8905.559 |

Models were fully adjusted. DV = dependent variable; OR = odds ratio; CI = confidence interval; Coeff. = coefficient; SE = standard error; AIC = Akaike information criterion. *$p < 0.10$, **$p < 0.05$, ***$p < 0.01$.

focusing on street view greenspace. Third, it further investigates the heterogeneous effects of demographic and SES factors and thus contributes to the 'equigenesis' theory, which points out that local greenspace may be more beneficial for people in socioeconomically disadvantaged circumstances (Mitchell et al., 2015).

Compared with previous studies (Gascon, et al., 2016; Nieuwenhuijsen, 2018; Yeager et al., 2018), we focused on IHD department visits for middle-aged and older adults. Our results showed that SVG-grass is negatively associated with IHD mortality and recovery time from IHD for middle-aged and older adults. This further suggests that street vegetation is not only protective for the general population but also beneficial for patients with IHD.

There are several potential explanations for such an association. First, street vegetation has been proven to be able to encourage physical activity and facilitate social cohesion (de Vries et al., 2013; Wang et al., 2019). Street vegetation encourages people to engage in outdoor physical activity, such as walking and cycling, since it provides residents with a pleasant setting (Wang, et al., 2020). The existing literature also suggests that greenspace exposure can strengthen the beneficial effect of physical activity on heart health indicators (i.e., heart rate and blood pressure), since people find it more enjoyable to engage in physical activity in such an environment and are more likely to keep exercising at a later date (Thompson Coon, et al., 2011). Middle-aged and older adults with IHD are more likely to survive and recover quicker from IHD emergency department visits if they live in neighbourhoods with more street vegetation, since they can also benefit from light physical activity, such as walking on the street.

Street vegetation also facilitates social cohesion by providing residents with a public space to gather together (de Vries, et al., 2013). A plethora of studies have documented the role of social cohesion in influencing CVDs (Robinette, et al., 2018). Robinette et al. (2018) indicated that neighbourhood social cohesion is associated with various CVD biomarkers, such as cholesterol, C-reactive protein, haemoglobin A1c, high-density lipoprotein cholesterol and glycosylated haemoglobin, since people living in neighbourhoods with higher social cohesion tend to have less physiological wear and tear, which is beneficial for heart health. Greener streets can also provide an enjoyable setting for middle-aged and older adults with IHD to socialize within their neighbourhood, so they may be less stressed and can acquire more CVD-related knowledge from neighbours.

Many studies have confirmed that street vegetation can help people restore their energy (Dzhambov, et al., 2019; Yu et al., 2020), which is also related to heart health. Some studies have pointed out that greenspaces, especially street greenspaces, are an important restorative environment for urban dwellers (Jiang et al., 2014). Street vegetation can stimulate positive emotions and make people feel relaxed, which is beneficial for various biomarkers, such as the heart rate, blood pressure, level of the sympathetic nervous system and parasympathetic nervous system (Yu, et al., 2020). och Dag et al. (2020) pointed out that stressful and negative emotions are relevant to CVDs because they may lead to autonomic dysregulation, inflammatory responses, endothelial dysfunction and serotonergic dysregulation. Middle-aged and older adults with IHD can view street greenspace from their home or during outdoor activities, so living in neighbourhoods with more street vegetation can help them enjoy the restorative effects of virtual natural settings, which is beneficial for recovering from IHD.

Finally, the mitigation effect of street vegetation on air pollution and other environmental hazards has been verified by the existing literature (Nieuwenhuijsen, 2018). Street vegetation can reduce the effect of noise by directly absorbing sound waves (Van Renterghem and Botteldooren, 2016). Hence, street vegetation also absorbs pollutants such as fine particulate matter and solid particles from the air (Jeanjean et al., 2016). Noise has a negative influence on heart rate and blood pressure (Khosravipour and Khanlari, 2020), while air pollution is associated with inflammation, oxidative stress, autonomic nervous system imbalance, inflammation, and epigenetic changes (Yang, et al., 2019), so both noise and air pollution are environmental hazards for CVDs. Middle-aged and older adults with IHD are especially sensitive to environmental hazards, so living in neighbourhoods with more street vegetation may reduce these hazards and benefit their heart health.

Furthermore, we found that the effect of SVG-grass on IHD was dose-responsive. We only observe a significant association between SVG-grass and IHD when SVG-grass was at Q4. One possible explanation is that the amount of street grass is too small to provide residents with enough open public space. Previous studies have indicated that the size of the greenspace can influence people's use of it, since people are less likely to visit or use it (i.e., engage in physical activity) when it becomes crowded (Azad et al., 2018; Ekkel and de Vries, 2017). Additionally, the size and density of street greenspaces can influence people's perception and restorative experience on the street (Jiang, et al., 2014; Jiang et al., 2015; Jiang et al., 2016; Suppakittpaisarn et al., 2019). Jiang et al. (2014) found a dose–response effect between street vegetation density and people's self-reported stress recovery experience, while Suppakittpaisarn et al. (2019) suggested that such a dose–response effect is also valid for street vegetation density-landscape preference associations. Hence, the mitigation effect of greenspace is also influenced by its quantity, since each single plant has a limited ability to block sound waves or air pollutants (Dzhambov et al., 2017).

This finding highlights the importance of going beyond the question of whether more street greenspace is beneficial for heart health. More attention should be given to the threshold at which street greenspace begins to produce significant effects on CVDs (Shanahan et al., 2015). Based on land use data, (Feng and Astell-Burt, 2017) found that the association between land-use greenspace and general health becomes significant when the quantity of greenspace is over 0.215. Additionally, Jiang et al. (2014) pointed out that the dose–response curve for the urban tree-stress association is an inverted-U shape. Our finding implies that the association between street greenspace and CVDs is nonlinear, and the threshold needs to be further investigated since it may help policy-makers adjust urban planning regulations.

However, there is no evidence that SVG-tree is associated with IHD. It is important to note that this finding is not conclusive evidence that street trees do not have an effect on IHD. There are some potential reasons why the protective effects of street trees were not found in this research. First, we measured street greenspace from a horizontal perspective, so it cannot reflect some important features of street trees, such as tree canopies. Tree canopy has been proven to be related to shade provision (Li et al., 2018) and air purification (Vailshery et al., 2013), so a recent study found that it is related to people's CVDs in Australia (Astell-Burt and Feng, 2020b). Additionally, a recent study showed that street view images cannot reflect the presence of backyard trees since their view may be blocked by buildings (Labib et al., 2020). Second, the measures of IHD are also not without limitation. We only focused on ischaemic heart disease emergency department visits for middle-aged and older adults. However, the health benefit of SVG-tree may not manifest in IHD in middle-aged and older adults but perhaps in other dimensions of CVDs, such as prevalent CVD incidence (Astell-Burt and Feng, 2020b). Third, we do not know people's actual use of street greenspace, so only measuring SVG-tree within residential neighbourhoods may cause bias. For example, Arnberger and Eder (2011) found that people from different age groups have various preferences on the recreational use of urban greenspace. Therefore, SVG-tree in residential neighbourhoods may not capture middle-aged and older adults' actual exposure to street trees. Fourth, there may also be a dose–response effect between SVG-tree and IHD, so SVG-tree may not achieve the threshold for achieving health benefits. In sum, this study should be viewed as a call for attention to incorporate assessments of different types of street vegetation and CVD-related health outcomes.

Our stratified analysis suggests that the association between SVG-grass and IHD tends to vary across sociodemographic factors. First, we found that SVG-grass is only associated with males' IHD. Although based on an ecological study design, Richardson and Mitchell (2010) also found that urban greenspace availability is negatively associated with CVD mortality, such associations are not found for women. This difference may be because middle-aged and older men tend to spend more time engaging in outdoor physical activity than women (Hallal, et al., 2012), so they are more likely to benefit from street greenspace exposure. Women also spend more time on housework than men (Altintas and Sullivan, 2016), so they may be less likely to be influenced by street greenspace exposure. Hence, the existing literature indicates that the restorative effect of street greenspace is stronger for men than women (Jiang, et al., 2014), which may also explain our finding of gender differences.

Second, SVG-grass is associated with older adults' IHD, but such an association is not significant for middle-aged adults. One possible explanation is that residential neighbourhoods are a more important greenspace exposure context for older adults than middle-aged adults, since middle-aged adults may still have to work and spend less time within their neighbourhoods, which reduces their visits and use of neighbourhood greenspaces (Arnberger and Eder, 2011; Shan, 2020). Another explanation is that older adults attach more importance to neighbourhood greenspace than middle-aged adults (Jim and Shan, 2013; Lo and Jim, 2010), which strengthens its effect. For example, Jim and Shan (2013) found that older adults think urban greenspace is more important in daily life than other age groups. Additionally, from a life-course perspective, greenspace exposure may have different influences on health during different stages of life (Pearce et al., 2016). Therefore, our findings suggest that greenspace exposure may be more crucial to CVDs in old age than in middle age. Hence, the existing literature highlights that the effect of greenspace exposure may be cumulative (Ekkel and de Vries, 2017) and that the total cumulative effect of green space exposure is higher for older adults than for middle-aged adults since they live longer in their neighbourhood. Therefore, the total cumulative effect of greenbelt exposure in middle-aged adults may not achieve the threshold to achieve a significant effect.

Last, a significant association between SVG-grass and IHD is only observed for people living in low-income neighbourhoods. 'Equigenesis' theory suggests that disadvantaged groups can benefit more from access to public facilities such as greenspace, since they have fewer other health-related resources (Mitchell, et al., 2015). Additionally, people with lower socioeconomic status have more time constraints and cannot afford long-distance travel (Begley, et al., 2011), so they may spend more time within the residential neighbourhood and be more exposed to neighbourhood greenspace.

The following limitations of this study should be noted. First, this study is based on an analysis of repeated cross-sectional data, so it is difficult to infer causation between SVG and IHD. Second, the data we used were from a single hospital. Although Hubei Provincial People's Hospital is one of the largest hospitals in Hubei, it cannot provide data on all IHD emergency department visits in Hubei. Third, SVG has some potential limitations. For example, the street view images are collected in a certain period, so they cannot reflect seasonal changes in vegetation. Fourth, we did not have detailed information about the respondents' socioeconomic and biomarker information, such as occupation, disease history and metabolic indices, which are all related to IHD. Fifth, we were not able to address selection bias despite the inclusion of three sensitivity tests. Sixth, due to participants' daily mobility, they may not stay within the neighbourhood and could experience greenspace exposure elsewhere. However, we do not have GPS data to reflect the participants' actual daily activities and duration of greenspace exposure, which may lead to underestimation of their daily greenspace exposure (Li, Deal, Zhou, Slavenas, & Sullivan, 2018; Mennis, Mason, & Ambrus, 2018; Wang, Feng, Pearce, Zhou, et al., 2021; Wang, Feng, Pearce, Liu, & Dong, 2021). Last, there is a scale effect for the association between urban green spaces and health (Zhang and Tan, 2019), so our calculation of the buffer size may lead to a miscalculation of green space exposure.

## 5. Conclusion

This study is the first to systematically explore the association between SVG exposure and IHD emergency department visits for middle-aged and older adults in Chinese cities. The results of the statistical analyses show that SVG-grass is negatively associated with IHD mortality and recovery time from IHD. However, there is no evidence that SVG-tree is related to IHD. Our results pass a series of robustness checks. Hence, the stratified analysis indicates that the effect of SVG on IHD varies significantly by individual demographic and socioeconomic characteristics, including gender, age and neighbourhood SES. To achieve the goal of supporting heart health through urban planning in China, more attention should be given to residential visible vegetation, especially grassland.

## Funding

This work was supported by the National Natural Science Foundation of China (41801306) and the "CUG Scholar" Scientific Research Funds at China University of Geosciences (Wuhan) (Project No. 2022034).

## Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

## Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.landurbplan.2022.104444.

## References

Aerts, R., Nemery, B., Bauwelinck, M., Trabelsi, S., Deboosere, P., Van Nieuwenhuyse, A., Nawrot, T. S., & Casas, L. (2020). Residential green space, air pollution, socioeconomic deprivation and cardiovascular medication sales in Belgium: A nationwide ecological study. *Science of the Total Environment, 712*, Article 136426.

Altintas, E., & Sullivan, O. (2016). Fifty years of change updated: Cross-national gender convergence in housework. *Demographic Research, 35*, 455–470.

Anderson, K. M., Odell, P. M., Wilson, P. W., & Kannel, W. B. (1991). Cardiovascular disease risk profiles. *American Heart Journal, 121*(1), 293–298.

Arnberger, A., & Eder, R. (2011). The influence of age on recreational trail preferences of urban green-space visitors: A discrete choice experiment with digitally calibrated images. *Journal of Environmental Planning and Management, 54*, 891–908.

Astell-Burt, T., & Feng, X. (2020a). Does sleep grow on trees? A longitudinal study to investigate potential prevention of insufficient sleep with different types of urban green space. *SSM-Population Health, 10*, Article 100497.

Astell-Burt, T., & Feng, X. (2020b). Urban green space, tree canopy and prevention of cardiometabolic diseases: A multilevel longitudinal study of 46 786 Australians. *International Journal of Epidemiology, 49*, 926–933.

Azad, S. P., Morinaga, R., & Kobayashi, H. (2018). Effect of housing layout and open space morphology on residential environments-applying new density indices for evaluation of residential areas case study: Tehran, Iran. *Journal of Asian Architecture and Building Engineering, 17*, 79–86.

Begley, C., Basu, R., Lairson, D., Reynolds, T., Dubinsky, S., Newmark, M., Barnwell, F., Hauser, A., & Hesdorffer, D. (2011). Socioeconomic status, health care use, and outcomes: Persistence of disparities over time. *Epilepsia, 52*, 957–964.

Chaix, B., Meline, J., Duncan, S., Merrien, C., Karusisi, N., Perchoux, C., Lewin, A., Labadi, K., & Kestens, Y. (2013). GPS tracking in neighborhood and health studies: A step forward for environmental exposure assessment, a step backward for causal inference? *Health & Place, 21*, 46–51.

Chum, A., & O'Campo, P. (2015). Cross-sectional associations between residential environmental exposures and cardiovascular diseases. *BMC Public Health, 15*, 438.

Cosselman, K. E., Navas-Acien, A., & Kaufman, J. D. (2015). Environmental factors in cardiovascular disease. *Nature Reviews Cardiology, 12*, 627.

de Vries, S., Van Dillen, S. M., Groenewegen, P. P., & Spreeuwenberg, P. (2013). Streetscape greenery and health: Stress, social cohesion and physical activity as mediators. *Social Science & Medicine, 94*, 26–33.

Dzhambov, A., Dimitrova, D., Markevych, I., & Tilov, B. (2017, June). Association between different indices of greenspace "exposure" and noise annoyance in youth. In Proceedings of the 12th ICBEN Congress on Noise as a Public Health Problem, Zurich, Switzerland (pp. 18–22).

Dzhambov, A. M., Hartig, T., Tilov, B., Atanasova, V., Makakova, D. R., & Dimitrova, D. D. (2019). Residential greenspace is associated with mental health via intertwined capacity-building and capacity-restoring pathways. *Environmental Research, 178*, Article 108708.

Ekkel, E. D., & de Vries, S. (2017). Nearby green space and human health: Evaluating accessibility metrics. *Landscape And Urban Planning, 157*, 214–220.

Feng, X., & Astell-Burt, T. (2017). Do greener areas promote more equitable child health? *Health & Place, 46*, 267–273.

Frank, L. D., Sallis, J. F., Conway, T. L., Chapman, J. E., Saelens, B. E., & Bachman, W. (2006). Many pathways from land use to health: Associations between neighborhood walkability and active transportation, body mass index, and air quality. *Journal Of the American Planning Association, 72*, 75–87.

Gascon, M., Triguero-Mas, M., Martínez, D., Dadvand, P., Rojas-Rueda, D., Plasència, A., & Nieuwenhuijsen, M. J. (2016). Residential green spaces and mortality: A systematic review. *Environment International, 86*, 60–67.

Gordon-Salant, S., Frisina, R. D., Fay, R. R., & Popper, A. (Eds.). (2010). The aging auditory system (Vol. 34). Springer Science & Business Media.

Grahn, P., & Stigsdotter, U. K. (2010). The relation between perceived sensory dimensions of urban green space and stress restoration. *Landscape And Urban Planning, 94*, 264–275.

Hallal, P. C., Andersen, L. B., Bull, F. C., Guthold, R., Haskell, W., & Ekelund, U. (2012). Global physical activity levels: Surveillance progress, pitfalls, and prospects. *The Lancet, 380*, 247–257.

Helbich, M., Poppe, R., Oberski, D., van Emmichoven, M. Z., & Schram, R. (2021). Can't see the wood for the trees? An assessment of street view-and satellite-derived greenness measures in relation to mental health. *Landscape and Urban Planning, 214*, Article 104181.

Jeanjean, A. P., Monks, P. S., & Leigh, R. J. (2016). Modelling the effectiveness of urban trees and grass on PM2. 5 reduction via dispersion and deposition at a city scale. *Atmospheric Environment, 147*, 1–10.

Jennings, V., & Bamkole, O. (2019). The relationship between social cohesion and urban green space: An avenue for health promotion. *International Journal of Environmental Research and Public Health, 16*, 452.
Jia, X., Yu, Y., Xia, W., Masri, S., Sami, M., Hu, Z., Yu, Z., & Wu, J. (2018). Cardiovascular diseases in middle aged and older adults in China: The joint effects and mediation of different types of physical exercise and neighborhood greenness and walkability. *Environmental Research, 167*, 175–183.
Jiang, B., Chang, C.-Y., & Sullivan, W. C. (2014). A dose of nature: Tree cover, stress reduction, and gender differences. *Landscape and Urban Planning, 132*, 26–36.
Jiang, B., Larsen, L., Deal, B., & Sullivan, W. C. (2015). A dose–response curve describing the relationship between tree cover density and landscape preference. *Landscape and Urban Planning, 139*, 16–25.
Jiang, B., Li, D., Larsen, L., & Sullivan, W. C. (2016). A dose-response curve describing the relationship between urban tree cover density and self-reported stress recovery. *Environment and Behavior, 48*, 607–629.
Jiang, X., Larsen, L., & Sullivan, W. (2020). Connections–between daily greenness exposure and health outcomes. *International Journal of Environmental Research and Public Health, 17*, 3965.
Jim, C., & Shan, X. (2013). Socioeconomic effect on perception of urban green spaces in Guangzhou, China. *Cities, 31*, 123–131.
Kang, K., & Wang, X. (2014). Fully convolutional neural networks for crowd segmentation. *Computer Science, 49*, 25–30.
Khosravipour, M., & Khanlari, P. (2020). The association between road traffic noise and myocardial infarction: A systematic review and meta-analysis. *Science Of the Total Environment*, Article 139226.
Koohsari, M. J., McCormack, G. R., Nakaya, T., & Oka, K. (2020). Neighbourhood built environment and cardiovascular disease: Knowledge and future directions. *Nature Reviews Cardiology, 17*(5), 261–263.
Koohsari, M. J., Nakaya, T., McCormack, G. R., & Oka, K. (2021). Socioeconomic disparity in cardiovascular health: The role of where we live. *Environmental Research Letters, 16*(4), Article 041001.
Labib, S. M., Huck, J. J., & Lindley, S. (2020). Modelling and mapping eye-level greenness visibility exposure using multi-source data at high spatial resolutions. *Science Of the Total Environment*, 143050.
Lachowycz, K., Jones, A. P., Page, A. S., Wheeler, B. W., & Cooper, A. R. (2012). What can global positioning systems tell us about the contribution of different types of urban greenspace to children's physical activity? *Health & Place, 18*, 586–594.
Lanki, T., Siponen, T., Ojala, A., Korpela, K., Pennanen, A., Tiittanen, P., Tsunetsugu, Y., Kagawa, T., & Tyrväinen, L. (2017). Acute effects of visits to urban green environments on cardiovascular physiology in women: A field experiment. *Environmental Research, 159*, 176–185.
Li, D., Deal, B., Zhou, X., Slavenas, M., & Sullivan, W. C. (2018). Moving beyond the neighborhood: Daily exposure to nature and adolescents' mood. *Landscape & Urban Planning, 173*, 33–43.
Liu, S., Li, Y., Zeng, X., Wang, H., Yin, P., Wang, L., Liu, Y., Liu, J., Qi, J., & Ran, S. (2019). Burden of cardiovascular diseases in China, 1990–2016: Findings from the 2016 global burden of disease study. *JAMA Cardiology, 4*, 342–352.
Lo, A. Y. H., & Jim, C. Y. (2010). Differential community effects on perception and use of urban greenspaces. *Cities, 27*, 430–442.
Lozano, R., Naghavi, M., Foreman, K., Lim, S., Shibuya, K., Aboyans, V., Abraham, J., Adair, T., Aggarwal, R., & Ahn, S. Y. (2012). Global and regional mortality from 235 causes of death for 20 age groups in 1990 and 2010: A systematic analysis for the Global Burden of Disease Study 2010. *The Lancet, 380*, 2095–2128.
Markevych, I., Schoierer, J., Hartig, T., Chudnovsky, A., Hystad, P., Dzhambov, A. M., De Vries, S., Triguero-Mas, M., Brauer, M., & Nieuwenhuijsen, M. J. (2017). Exploring pathways linking greenspace to health: Theoretical and methodological guidance. *Environmental Research, 158*, 301–317.
Mennis, J., Mason, M., & Ambrus, A. (2018). Urban greenspace is associated with reduced psychological stress among adolescents: A Geographic Ecological Momentary Assessment (GEMA) analysis of activity space. *Landscape and Urban Planning, 174*, 1–9.
Merriam, D., Bality, A., Stein, J., & Boehmer, T. (2017). Improving public health through public parks and trails: Eight common measures. Summary report. Washington, DC, USA: US Department of Health and Human Services, Centers for Disease Control and Prevention and US Department of the Interior, National Park Service.
Mitchell, R., & Popham, F. (2008). Effect of exposure to natural environment on health inequalities: An observational population study. *The Lancet, 372*, 1655–1660.
Mitchell, R. J., Richardson, E. A., Shortt, N. K., & Pearce, J. R. (2015). Neighborhood environments and socioeconomic inequalities in mental well-being. *American Journal of Preventive Medicine, 49*, 80–84.
Moran, P. A. (1950). Notes on continuous stochastic phenomena. *Biometrika, 37*(1/2), 17–23.
Nieuwenhuijsen, M. J. (2018). Influence of urban and transport planning and the city environment on cardiovascular disease. *Nature Reviews Cardiology, 15*, 432–438.
och Dag, Y. N., Mehlig, K., Rosengren, A., Lissner, L., & Rosvall, M. (2020). Negative emotional states and negative life events: Consequences for cardiovascular health in a general population. *Journal of Psychosomatic Research, 129*, 109888.
Pearce, J., Shortt, N., Rind, E., & Mitchell, R. (2016). Life course, green space and health: Incorporating place into life course epidemiology. *International Journal of Environmental Research & Public Health, 13*, 331.
Pereira, G., Foster, S., Martin, K., Christian, H., Boruff, B. J., Knuiman, M., & Giles-Corti, B. (2012). The association between neighborhood greenness and cardiovascular disease: An observational study. *BMC Public Health, 12*, 466.
Richardson, E., Pearce, J., Mitchell, R., Day, P., & Kingham, S. (2010). The association between green space and cause-specific mortality in urban New Zealand: An ecological analysis of green space utility. *BMC Public Health, 10*, 240.
Richardson, E. A., & Mitchell, R. (2010). Gender differences in relationships between urban green space and health in the United Kingdom. *Social Science & Medicine, 71*, 568–575.
Richardson, E. A., Pearce, J., Mitchell, R., & Kingham, S. (2013). Role of physical activity in the relationship between urban green space and health. *Public Health, 127*, 318–324.
Robinette, J. W., Charles, S. T., & Gruenewald, T. L. (2018). Neighborhood cohesion, neighborhood disorder, and cardiometabolic risk. *Social Science & Medicine, 198*, 70–76.
Roth, G. A., Johnson, C., Abajobir, A., Abd-Allah, F., Abera, S. F., Abyu, G., Ahmed, M., Aksut, B., Alam, T., & Alam, K. (2017). Global, regional, and national burden of cardiovascular diseases for 10 causes, 1990 to 2015. *Journal of the American College of Cardiology, 70*, 1–25.
Sakamoto, Y., Ishiguro, M., & Kitagawa, G. (1986). Akaike information criterion statistics. *Dordrecht, The Netherlands: D. Reidel*, 81(10.5555), 26853.
Seo, S., Choi, S., Kim, K., Kim, S. M., & Park, S. M. (2019). Association between urban green space and the risk of cardiovascular disease: A longitudinal study in seven Korean metropolitan areas. *Environment International, 125*, 51–57.
Shan, X.-Z. (2020). Association between the time patterns of urban green space visitations and visitor characteristics in a high-density, subtropical city. *Cities, 97*, Article 102562.
Shanahan, D. F., Fuller, R. A., Bush, R., Lin, B. B., & Gaston, K. J. (2015). The health benefits of urban nature: How much do we need? *BioScience, 65*, 476–485.
Sharifi, F., Nygaard, A., & Stone, W. M. (2021). Heterogeneity in the subjective well-being impact of access to urban green space. *Sustainable Cities and Society*, 103244.
Shen, Y.-S., & Lung, S.-C.-C. (2016). Can green structure reduce the mortality of cardiovascular diseases? *Science Of the Total Environment, 566*, 1159–1167.
Suppakittpaisarn, P., Jiang, B., Slavenas, M., & Sullivan, W. C. (2019). Does density of green infrastructure predict preference? *Urban Forestry & Urban Greening, 40*, 236–244.
Thompson Coon, J., Boddy, K., Stein, K., Whear, R., Barton, J., & Depledge, M. H. (2011). Does participating in physical activity in outdoor natural environments have a greater effect on physical and mental wellbeing than physical activity indoors? A systematic review. *Environmental Science & Technology, 45*, 1761–1772.
Vailshery, L. S., Jaganmohan, M., & Nagendra, H. (2013). Effect of street trees on microclimate and air pollution in a tropical city. *Urban Forestry & Urban Greening, 12*, 408–415.
Van Renterghem, T., & Botteldooren, D. (2016). View on outdoor vegetation reduces noise annoyance for dwellers near busy roads. *Landscape And Urban Planning, 148*, 203–215.
Wang, R., Feng, Z., Pearce, J., Zhou, S., Zhang, L., & Liu, Y. (2021). Dynamic greenspace exposure and residents' mental health in Guangzhou, China: From over-head to eye-level perspective, from quantity to quality. *Landscape and Urban Planning, 215*, Article 104230.
Wang, R., Feng, Z., Pearce, J., Liu, Y., & Dong, G. (2021). Are greenspace quantity and quality associated with mental health through different mechanisms in Guangzhou, China: A comparison study using street view data. *Environmental Pollution, 290*, Article 117976.
Wang, R., Lu, Y., Wu, X., Liu, Y., & Yao, Y. (2020). Relationship between eye-level greenness and cycling frequency around metro stations in Shenzhen, China: A big data approach. *Sustainable Cities and Society, 59*, Article 102201.
Wang, R., Yang, B., Yao, Y., Bloom, M. S., Feng, Z., Yuan, Y., Zhang, J., Liu, P., Wu, W., Lu, Y., Baranyi, G., Wu, R., Liu, Y., & Dong, G. (2019). Residential greenness, air pollution and psychological well-being among urban residents in Guangzhou, China. *Science of the Total Environment*, 134843.
Wu, L., & Kim, S. K. (2021). Health outcomes of urban green space in China: Evidence from Beijing. *Sustainable Cities and Society, 65*, Article 102604.
Xie, B., An, Z., Zheng, Y., & Li, Z. (2018). Healthy aging with parks: Association between park accessibility and the health status of older adults in urban China. *Sustainable Cities and Society, 43*, 476–486.
Yang, B.-Y., Guo, Y., Morawska, L., Bloom, M. S., Markevych, I., Heinrich, J., Dharmage, S. C., Knibbs, L. D., Lin, S., & Yim, S.-H.-L. (2019). Ambient PM1 air pollution and cardiovascular disease prevalence: Insights from the 33 Communities Chinese Health Study. *Environment International, 123*, 310–317.
Yang, B.-Y., Hu, L.-W., Jalaludin, B., Knibbs, L. D., Markevych, I., Heinrich, J., Bloom, M. S., Morawska, L., Lin, S., & Jalava, P. (2020). Association between residential greenness, cardiometabolic disorders, and cardiovascular disease among adults in China. *JAMA Network Open, 3*, e2017507–e2017507.
Yang, L., Li, L., Lewington, S., Guo, Y., Sherliker, P., Bian, Z., Collins, R., Peto, R., Liu, Y., & Yang, R. (2015). Outdoor temperature, blood pressure, and cardiovascular disease mortality among 23 000 individuals with diagnosed cardiovascular diseases from China. *European Heart Journal, 36*, 1178–1185.
Yeager, R., Riggs, D. W., DeJarnett, N., Tollerud, D. J., Wilson, J., Conklin, D. J., O'Toole, T. E., McCracken, J., Lorkiewicz, P., & Xie, Z. (2018). Association between residential greenness and cardiovascular disease risk. *Journal of the American Heart Association, 7*, Article e009117.
Yitshak-Sade, M., Kloog, I., & Novack, V. (2017). Do air pollution and neighborhood greenness exposures improve the predicted cardiovascular risk? *Environment International, 107*, 147–153.
Yu, C.-P., Lee, H.-Y., Lu, W.-H., Huang, Y.-C., & Browning, M. H. (2020). Restorative effects of virtual natural settings on middle-aged and elderly adults. *Urban Forestry & Urban Greening, 56*, Article 126863.

Zhang, Z., Long, Y., Chen, L., & Chen, C. (2020). Assessing personal exposure to urban greenery using wearable cameras and machine learning. *Cities*, 103006.

Zhang, L., & Tan, P. Y. (2019). Associations between urban green spaces and health are dependent on the analytical scale and how urban green spaces are measured. *International Journal of Environmental Research and Public Health, 16*(4), 578.

Zhou, B., Zhao, H., Puig, X., Fidler, S., Barriuso, A., & Torralba, A. (2016). Semantic understanding of scenes through the ADE20K dataset. *arXiv preprint arXiv: 1608.05442*.