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When healthy aging meets Vitamin G: Assessing the associations between green space and heart health in older adults using street view and electrocardiography

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HIGHLIGHTS

- Examined the association between community green space exposure and heart health for Chinese older adults.
- General heart heat was measured through electrocardiography.
- Street view trees (SVG-tree) and grass (SVG-grass) were used as the proxy for green space exposure.
- SVG-grass is negatively associated with older adults' odds of reporting electrocardiographic abnormalities.
- The effectt of SVG was more pronounced for males, older adults with lower income or educational attainment.

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Street view

ABSTRACT

Heart health is important for the quality of life, especially for older adults. Awareness is mounting that green space possibly matters for promoting heart health. While most studies mainly focused on the relationship between green space and cardiovascular diseases among older adults, scant attention has been paid to general heart heat measures through electrocardiography (ECG). This study aims to systematically assess the association between community green space exposure and heart health for Chinese older adults using street view and ECG. This observational, cross-sectional study was based on data from the 33 Chinese Community Health Study (33 CCHS). The heart health was measured by the presence of electrocardiographic abnormalities. We used street view data to calculate exposure to community street view green space (SVG) and further distinguished between street view trees (SVG-tree) and grass (SVG-grass). As a green space reference, we also incorporated the Normalized Difference Vegetation Index (NDVI). The results showed that SVG-grass was negatively associated with older adults' odds of reporting electrocardiographic abnormalities, but there is no evidence that SVG-tree or NDVI was related to that. Also, the stratified analyses indicated that the results vary across demographic and socioeconomic groups. Heart health for males and older adults with lower income or educational attainment were significantly associated with SVG exposure, while such findings were not found for their counterparts. Our findings suggest ECG and street view data are promising in understanding green space-heart health associations. Hence, it is

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essential to promote the provision and visibility of community green space especially for older adults in disadvantaged groups.

1. Introduction

Cardiovascular diseases (CVDs) including stroke, coronary heart disease (CHD), and heart failure have become the primary cause of death worldwide, with 18.6 million deaths in 2019 (Roth et al., 2020). In 2016, there were 290 million Chinese people affected by CVDs, making it the country with one of the highest prevalence of CVDs (Eisenberg, Vanderbom, & Vasudevan, 2017). CVDs are much more prevalent in older adults than in young adults due to the decline in physical function (Roth et al., 2020). In the last twenty years, the older population in China has rapidly increased, and it is currently still growing much faster than any other country (World Health Organization, 2015). In 2010, there were 177.6 million Chinese people above the age of 60 years, accounting for 13 % of the total population (The State Council of the People's Republic of China, 2017), and the number is projected to reach 402 million by 2040, accounting for 28 % of the total population (Luo et al., 2021; Wu & Dang, 2013). Therefore, greater attention should be paid to the heart health of older adults in China.

Existing evidence has suggested that more than 70 % of the global burden of CVDs is attributable to modifiable risk factors including both individual health-related behaviour and characteristics of the physical environment (Koohsari et al., 2020; Maher, Ford, & Unwin, 2012; Omura et al., 2020). Among the physical environment, green space (also known as 'Vitamin G') has attracted much attention as a public health resource to promote older people's health (Groenewegen et al., 2006). Hence, older adults are at higher risk of CVDs compared to younger adults (Roth et al., 2020), so it is important to pay more attention to the associations between green space and CVDs in older adults.

'Equigenesis' theory suggests that socioeconomically disadvantaged population groups may be more influenced by green infrastructures, which could mean that those less well-off gain more health benefits and thus socioeconomic disparities in health narrow (Huang et al., 2022; Wang, Feng, et al., 2022). Socioeconomically underprivileged groups usually have fewer health-related resources and are less able to afford medical services, so they may have to rely more on health-supportive public infrastructures such as green space (Mitchell, Richardson, Shortt, & Pearce, 2015; Pearce et al., 2015). Therefore, it is possible that green space might help with narrowing socioeconomic inequalities in health (Mitchell et al., 2015; Pearce, Mitchell, & Shortt, 2015). For example, Thiering et al. (2016) found that adolescents in greener communities have lower insulin resistance in Germany, and such association tends to be stronger in those with lower socioeconomic status. Yitshak-Sade et al. (2019) suggested that the beneficial effect of neighbourhood greenness on cardiovascular mortality is stronger in neighbourhoods of lower socioeconomic status in America. Lachowycz and Jones (2014) showed that green space access was associated with a reduction in mortality in England, but this relationship was only apparent in the most deprived areas. Grazuleviciene et al. (2020) found that people of lower socioeconomic status in areas with fewer green spaces had a higher risk of hypertension in Lithuania than people with more green space, but such a finding was not significant for people with higher socioeconomic status. However, most of the evidence is based on developed countries (e.g., Europe or North America), while less attention has been paid to developing countries (Rigolon, Browning, McAnirlin, & Yoon, 2021). Due to pronounced differences in social contexts and the environment, it is unclear whether the 'equigenesis' theory applies to developing countries including China (Liu, Ma, et al., 2022).

Most studies on green space-heart health associations only focused on the diagnosis of CVDs, while only a few assessed the general health status of the heart which may be more important for prevention (Qin, Zhou, Sun, Leng, & Lian, 2013; Van den Berg et al., 2015). Electrocardiography (ECG) is an accurate and efficient technique to assess the heart's health status. It is widely used for early diagnosis of heart abnormalities (Lih et al., 2020) and facilitates early CVD interventions and prevention (Lih et al., 2020). However, few observational studies have adopted such a technique, and the omission is largely due to methodological limitations (Qin et al., 2013; Van den Berg et al., 2015). The ECG equipment is quite expensive and setting up the ECG procedure is complex and labour-intensive requiring the involvement of professional medical workers. Therefore, only a handful of experimental studies have applied it, and face several limitations including small samples ($n < 50$), narrow research area (i.e., assessment of only one community), and the recruitment of only younger adults due to the complexity of the operation of ECG. Also, awareness is amounting that street-level vegetation is important for the prevention of chronic diseases (Wang, Feng, et al., 2022; Wang et al., 2021; Wang et al., 2020). This is because street-level vegetation is likely more accessible and visible and people spend more time on the street (Wang, Feng, et al., 2022; Wang et al., 2021; Wang et al., 2020). However, previous studies have mainly focused on how green space exposure is related to heart health based on remote sensing imagery or land use data. As we are aware, only two studies assessed the effect of street-level vegetation on heart health (CVDs) (Wang, Dong, et al., 2022; Yao, Xu, Yin, Shao, & Wang, 2022), while no studies have ever linked street-level vegetation to heart health collecting from ECG.

The current study aims to fill the knowledge gaps discussed above. The central aim of the present study is to assess the associations between street-level green space and heart health in older adults using street view and electrocardiography. Our research questions (RQ) were as follows:

- (RQ1) Whether street-level green space exposures at people's places of residence are associated with heart health in older adults?
- (RQ2) Whether the street-level green space - heart health associations vary across socioeconomic groups?

Our hypotheses were as follows:

- (H1) Street-level green spaces are positively associated with heart health, and
- (H2) Street-level green space - heart health associations are more pronounced in socioeconomically disadvantaged population groups.

This study extends the existing literature on the association between green space exposure and heart health in older adults for several aspects. First, while most studies deal with North American or the European context, we systematically explore the effect of community green space and heart health for older patients in China, which provides important policy implications for healthy ageing. Second, we make a methodological contribution to the study of green space-heart health by using street view and electrocardiography (ECG). Third, we also stratified analysis to understand how green space - heart health varies across demographic and socioeconomic population groups, which enhances our knowledge of environmental justice and 'equigenesis' theory (Mitchell et al., 2015; Pearce et al., 2015).

2. Data and methods

2.1. Survey data

This observational, cross-sectional study is based on data from the 33 Chinese Community Health Study (33 CCHS) (XXX, 2019 masked for blind review; XXX, 2019 masked for blind review). The participants were recruited from three cities in northern China including Shenyang, Anshan, and Jinzhou (average population = 4.96 million). Probability-proportional-to-size sampling was used to select participants. First, the three cities (i.e., Shenyang, Anshan, and Jinzhou) were chosen from fourteen major cities in northern China. Second, 33 communities (*shequ*) were randomly selected from eleven districts in the three sampled cities. Third, 700–1,000 households from each community were then randomly recruited from these 33 communities. Last, an adult respondent (aged over 18) was randomly chosen from each household.

2.2. Survey data

In total, 24,845 participants completed the questionnaire out of 28,830 invited persons (response rate 86.2 %). The electrocardiography test mainly targeted at older population and after excluding respondents with missing information, 3,942 valid older adults (>60 years) were included in the final analysis. The study was conducted with the principles stipulated by the Declaration of Helsinki. Written informed consent was obtained from each participant. All procedures were approved by the ethics review committee of XXX University (Identification code: XXX masked for blind review).

2.3. Heart health

The heart health data was collected along with the 33 CCHS survey data. It was measured based on the 12-lead electrocardiography (ECG) (Goldberger, Goldberger, & Shvilkin, 2017). It has ten electrodes, which were placed on the participants' limbs and chest. The overall magnitude of the heart's electrical potential was measured from twelve different angles. Finally, the overall magnitude and direction of the heart's electrical depolarization were recorded at each moment throughout the cardiac cycle. Following existing studies (Cassidy, Petty, Laxer, & Lindsley, 2010), electrocardiographic abnormalities include first-degree heart block, right and left bundle branch block, premature atrial and ventricular contractions, nonspecific T-wave changes, and evidence of ventricular hypertrophy. Although the above abnormalities were associated with different etiological characteristics (Cassidy et al., 2010), we mainly focused on the general abnormalities. Therefore, heart health was treated as a binary variable ('1' = electrocardiographic abnormalities, which means the respondent has at least one of the above symptoms; '0' = electrocardiographic normality, which means the respondent does not have any of the above symptoms).

2.4. Green space exposure

Tencent Maps is a comprehensive mapping platform in China, where we collected street-view images (2011 and 2012) to assess exposure to street-view green space (SVG). OpenStreetMap (OSM), an open geographic and mapping database (https://www.openstreetmap.org), was used to construct the sampling points (with 100-m intervals) for collecting SV images. Following existing studies (Wang, Feng, et al., 2022; Wang et al., 2021; Wang et al., 2020), we collected four images (i.e., at 0, 90, 180, and 270 degrees) for each sampling point. In total, we obtained 666,758 street-view images.

We used ADE20K data, a free and pre-labelled database for training algorithms in image segmentation (Zhou et al., 2019), to train a fully convolutional neural network (FCN-8 s) (Long, Shelhamer, & Darrell, 2015) for image segmentation (Wang, Feng, et al., 2022; Wang et al., 2021; Wang et al., 2020). During the training process, the labelled information in ADE20K data acted as the outcomes, and FCN-8 s were trained on them. FCN-8 s identified ground objects from images out of the ADE20K data after the training process. Overall, the trained model has high accuracy and identifies >85 % of vegetation. Since existing evidence showed that trees and grasses have different health effects (Wang et al., 2020; Yao et al., 2022), we not only calculated SVG exposure but also distinguished between trees (SVG-tree) and grass (SVG-grass). ADE20K data has provided us with many labelled images, which can be used for training the FCN-8s. There are 150 semantic categories in ADE20K data (e.g., trees, grasses, pavements, and cars). Therefore, after the training process, the FCN-8s can be used to identify objects from our street view images (Fig. S1 shows the detailed workflow for image segmentation). SVG exposure per image refers to the proportion of vegetation pixels for each image, while SVG-tree/SVG-grass per image is the proportion of tree/grass pixels for each image, so SVG-tree/SVG-grass can be used as the proxy for measuring the visibility and presence of street-level trees/grasses. It should be noted that there are different plants species within the grass family, so SVG-grass should reflect the presence of grasses and other low growing vegetation. The SVG exposure for each respondent is the mean value of all images within the 1,000-metre circular buffer of the residential neighbourhood address (based on the survey data). We used the 1,000-metre buffers because it typically equals a 10 to 15-minute walking distance capturing most of people's daily activities in the residential area (Merriam, Bality, Stein, & Boehmer, 2017).

We also included the Normalized Difference Vegetation Index (NDVI) (Tucker, 1979) to measure the presence of general green space. This index can reflect the greenness of specific areas and has been widely in epidemiology studies (Markevych et al., 2017). We obtained two cloud-free Landsat 5 Thematic Mapper satellite images during August 2010 (i.e., the greenest month in Northeastern China). The NDVI was calculated as follows: (NIR-VIS)/(NIR + VIS), where NIR is the reflectance in the near-infrared band and VIS is the reflectance in the visible range. We removed pixels with negative values following existing studies (Markevych et al., 2017). We averaged the NDVI values of all 30 m pixels within the 1,000-metre circular buffer of the residential neighbourhood address as SVG. NDVI usually varies between −1 and 1. Higher values refer to more green space exposure. However, since negative pixels are usually water bodies which are out of our scope, we removed pixels with negative values when calculating the neighbourhood-level NDVI following existing literature (Markevych et al., 2017).

2.5. Covariates

As suggested elsewhere (Shrier & Platt, 2008), a directed acyclic graph (DAG) can help researchers visualize and conceptualize the causal effects between the exposure and outcomes especially when there are multiple covariates confounding the associations. Then, following the literature (Wang, Dong, et al., 2022; Yang et al., 2019), we constructed a DAG for the associations among green space, the covariates, and electrocardiographic abnormalities (Fig S5). Guided by the DAG, the following covariates were retained in our statistical models: sex (males, females), ethnicity (Han, minorities), educational attainment (primary school or below, high school, college or above), age (in years), annual household income (<30,000 Yuan, ≥30,000 Yuan; the interval is based on census), smoking behaviour (non-smoker, smoker), physical exercise behaviour (active, inactive), low calories and low-fat diet (yes, no), intake of sugared beverages (yes, no), and body mass index (BMI, kg/m^2).

We also included annual average levels of particulate matter (PM) with an aerodynamic particle diameter ≤ 2.5 μm ($PM_{2.5}$, $\mu g/m^3$). $PM_{2.5}$ concentrations were calculated using a land use regression model based on ground-monitored data, aerosol optical depth data from Moderate Resolution Imaging Spectroradiometers, vegetation data, land use information, meteorological data, and other spatial predictors. The fitted model was then used to predict gridded $PM_{2.5}$ concentration at unobserved locations on a grid of 1000-metre. The cross-validated R^2 was 75 %. We averaged the $PM_{2.5}$ values of the pixels within the 1,000-metre circular buffer of the residential neighbourhood address. An in-depth description can be found in Yang et al. (2018).

2.6. Statistical analysis

To assess the associations between community green space exposure and heart health in older adults, we fitted several multilevel logistic regression models (Guo & Zhao, 2000). Variance inflation factors (VIF < 3) indicated no severe multicollinearity among the covariates. The intra-class correlation coefficient (ICC) for the null model was 0.07 which means that living within the same community accounted for 7 % of total variation in respondents' odds of electrocardiographic abnormalities. This confirmed the necessity of multilevel models.

First, considering the possible non-linear associations between green space and health, and the non-normal distribution of SVG, we reclassified SVG into quartiles as done elswhere (Helbich et al., 2019). We regressed electrocardiographic abnormalities on SVG, SVG-tree, SVG-grass, and NDVI respectively (Models 1). We present the results of adjusted models. Second, we conducted several sensitivity analyses. Since older adults aged >80 may have a different perception of natural elements, we excluded them and re-ran the adjusted model (Model 2a). Also, we used robust standard errors and re-ran the adjusted model (Model 2b) to test whether our results may be affected by different optimization techniques. We treated SVG measures as continuous variables as references for SVG - heart health associations (Model 2c). Then, we fitted Generalized Additive Mixed Models (GAMMs) (Pedersen et al., 2019) with thin plate regression splines to explore possible non-linear associations between green space and electrocardiographic abnormalities (Model 3). Following Wood (2017), we also applied GAMMs using knot-based penalized cubic regression splines and P-splines. Since all three splines give similar effective degrees of freedom (EDF) and thin plate regression splines result in the best mean squared error (MSE) performance, we only present the result of the default setting of splines. Finally, we conducted three stratified analyses to explore the heterogeneous effects across sex (Models 3: males vs. females), income (Models 4: <30,000 Yuan vs. ≥30,000 Yuan), and educational attainment (Models 5: high school or below vs. college or above). We estimated the relative excessive risk due to interaction (RERI) (a 95 % CI of RERI that does not include 0 indicates a significant interaction) to test whether the difference between groups is significant. Last, previous studies suggested that physical activity, BMI and $PM_{2.5}$ may mediate the association between green space and heart health (Bloemsma et al., 2019; Markevych et al., 2017; Liu, Ma, et al., 2022), so we conducted the stepwise mediation analysis for physical activity, BMI, and $PM_{2.5}$ (MacKinnon et al., 2007). We defined statistical significance as $p < 0.05$. Results are presented as odds ratios (OR) with 95 % CIs. Analyses were conducted using Stata version 15.1 (StataCorp LP, College Station, TX) and R version 3.6.3.

3. Results

Table 1 summarizes the basic characteristics of the sample. Participants were on average 66.26 years and 43.40 % were females. Nearly 96.98 % of the participants were of Han nationality and 89.80 % had a high school or lower education. About 17.86 % of the participants had an annual household income of ≥30,000 Yuan. Also, 29.43 % of the participants were smokers, 49.75 % were physically inactive, 34.37 % had low calories and low-fat diets, and 2.94 % had an intake of sugared beverages. The mean BMI level was 24.64 kg/m^2, and the average level of $PM_{2.5}$ was 82.66 μg/m^3.

Fig. 1 shows the results of the associations between green space exposures and heart health. Model 1 indicated that respondents living in communities in the highest SVG-grass quartile (Q4) (OR = 0.825, 95 % CI: 0.683–0.998) were less likely to report electrocardiographic abnormalities. However, there is no evidence that SVG, SVG-tree, or NDVI was associated with electrocardiographic abnormalities. In addition, we reran models using 300-metre, 500-metre, and 800-metre buffers (Figs. S2, S3 and S4). Despite some differences in magnitude, the results remained the same. We used the 1,000-metre buffers in our main analysis since this threshold corresponds closely to the '15-minute city' planning concept for older adults (i.e., 4.26 km/h for elderly in dry conditions and 3.5 km/h for elderly in winter) (Willberg et al., 2023).

Table 1
Summary statistics of the sample.

Variables	Mean (SD)/Numbers (%)
Sex	
Male	2,231(56.60)
Female	1,711(43.40)
Ethnicity	
Han	3,823(96.98)
Minorities	119(3.02)
Age (years)	66.26(4.06)
Educational attainment	
Primary school or below	1,774(45.00)
High school	1,766(44.80)
College or above	402(10.20)
Annual household income	
<30,000 Yuan	3,238(82.14)
≥30,000 Yuan	704(17.86)
Smoking behaviour	
Smoker	1,160(29.43)
Non-smoker	2,782(70.57)
Low calories and low-fat diet	
Yes	1,355(34.37)
No	2,587(65.63)
Intake of sugared beverages	
Yes	116(2.94)
No	3,826(97.06)
Physical activity behavior	
Active	1,981(50.25)
Inactive	1,961(49.75)
BMI (kg/m^2)	24.64(3.50)
$PM_{2.5}$ (μg/m^3)	82.66(15.84)
Electrocardiographic abnormalities	
Yes	1,717(43.56)
No	2,225(56.44)
SVG (0–1) Median (Q1 - Q3)	0.106(0.086–0.122)
NDVI (0–1) Median (Q1 - Q3)	0.299(0.249–0.383)
SVG-tree (0–1) Median (Q1 - Q3)	0.102(0.086–0.120)
SVG-grass (0–1) Median (Q1 - Q3)	0.003(0.001–0.004)

Note: The number and proportion of participants were reported for electrocardiographic abnormalities, sex, ethnicity, educational attainment, age, annual household income, smoking behaviour, physical exercise behaviour, low calories and low-fat diet, and intake of sugared beverages. The mean value and standard deviation were reported for BMI and $PM_{2.5}$. The median value, quartile 1 (Q1) and quartile 3 (Q3) values were reported for SVG and NDVI.

Based on previous studies (Bloemsma et al., 2019; Markevych et al., 2017; Liu, Ma, et al., 2022), physical activity, BMI and $PM_{2.5}$ may mediate the association between green space and heart health, so we excluded them and reran the model. The results (Fig. S6) showed that despite some differences in magnitude, the results remained similar to the fully adjusted model. We then conducted the stepwise mediation analysis for physical activity, BMI, and $PM_{2.5}$ (MacKinnon et al., 2007). We found no evidence that physical activity, BMI, or $PM_{2.5}$ mediates the associations.

The results of sensitivity analysis on the correlation between SVG and green and heart health are also summarized (Figs. S7-S9). In Figs. S7 and S8, despite some differences in magnitude, the significance of the SVG-grass - electrocardiographic abnormalities associations remained constant. In Fig. S9, the result indicated that SVG-grass was negatively associated with the odds of reporting electrocardiographic abnormalities (OR = 0.876, 95 % CI: 0.816–0.940). Also, the GAMM results (Fig. S10) indicated that the EDFs of NDVI and SVG-tree are 1, which means that their relationships with electrocardiographic abnormalities are linear. Also, the EDF of SVG-grass is between 1 and 2, indicating weak non-linear associations with electrocardiographic. The EDF of SVG is above 2, which means its relationship with electrocardiographic abnormalities is highly non-linear. Therefore, SVG and SVG-grass have nonlinear associations with electrocardiographic abnormalities. For

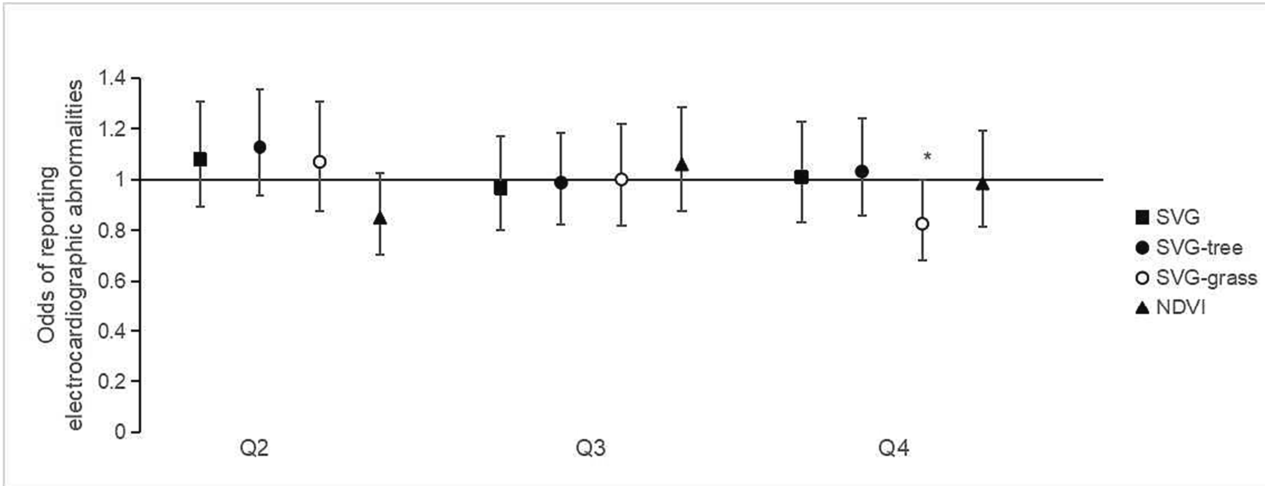


Fig. 1. Analyses of change in odds of reporting electrocardiographic abnormalities (with 95 % CIs) associated with different quartiles of green space metrics (referenced group = Q1). The models were fully adjusted. *p < 0.05.

example, SVG-grass was negatively associated with electrocardiographic abnormalities and such association got stronger with the increase of SVG-grass. However, there is no evidence that SVG-tree or NDVI had non-linear associations with electrocardiographic abnormalities. Since the MSEs of GAMMs are larger than multilevel logistic regression models, our main analyses were still based on multilevel logistic regression models.

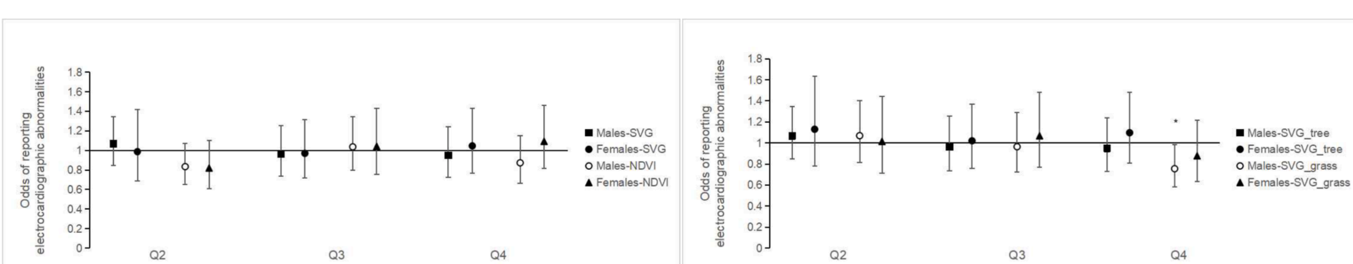
Figs. 2 to 4 show the heterogeneous effects of sex, income, and educational attainment. Fig. 2 displays the effect of green space on electrocardiographic abnormalities for males and females. Fig. 2b indicated that men living in communities with Q4 SVG-grass (OR = 0.755, 95 % CI: 0.581–0.982) were less likely to report electrocardiographic abnormalities. However, null associations were found for SVG. Fig. 3 displays the effect of SVG on the odds of reporting electrocardiographic abnormalities for respondents with household income <30,000 Yuan and ≥30,000 Yuan. The results (Fig. 3b) indicated that low incomers (<30,000 Yuan), living in communities with high levels of SVG-grass (Q4) (OR = 0.795, 95 % CI: 0.648–0.977) were less likely to report electrocardiographic abnormalities. However, SVG was unrelated to electrocardiographic abnormalities for those with a household income ≥30,000 Yuan. Fig. 4 displays the green space associations stratified by educational attainment. Fig. 4b indicates that respondents with high school or below educational attainment, living in communities with Q4 SVG-grass (OR = 0.846, 95 % CI: 0.693–0.931) were less likely to report electrocardiographic abnormalities. Null associations were observed for respondents with college or above educational attainment. Hence, Fig. 4a indicates that respondents with college or above educational attainment, living in communities with Q2 NDVI (OR = 0.254, 95 % CI: 0.079–0.817) were less likely to report electrocardiographic abnormalities. The relative excessive risk due to interaction (RERI) provides statistical evidence regarding the difference between different stratified groups, and the results again support the above findings (Table S1).

4. Discussion

Our analysis showed that SVG-grass was negatively associated with older adults' odds of reporting electrocardiographic abnormalities, but there is no evidence that SVG-tree or NDVI was related to that. Also, the stratified analyses indicated that the results vary across demographic and socioeconomic groups. Heart health for males and older adults with lower income or educational attainment were significantly associated with SVG exposure, while such findings were not found for their counterparts.

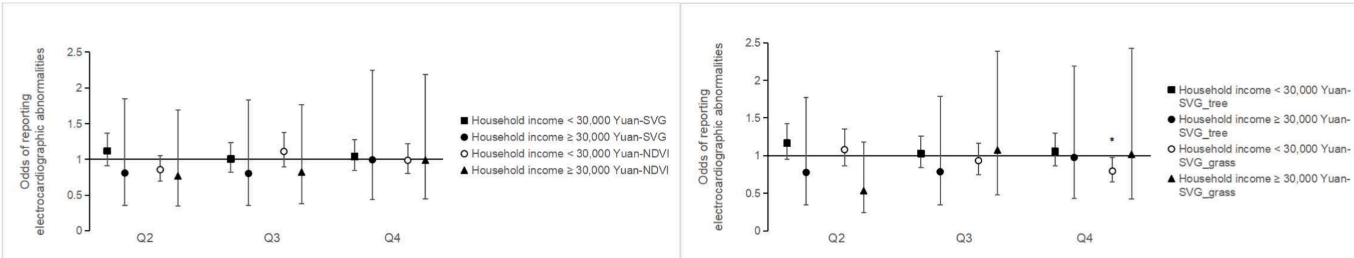
4.1. *The association between SVG and heart health in older adults based on electrocardiography*

Compared with previous studies (Liu, Ma, et al., 2022), we focused on the association between visible green space and heart health for older adults using street view and ECG. Our results showed that SVG-grass is negatively associated with the odds of electrocardiographic abnormalities for older adults. First, compared with trees, grasses usually cover larger areas in an urban context which may act as a large open space for more users (Wang et al., 2020). A plethora of studies have reported the role of physical activity such as walking and cycling in explaining the association between exposure to green space and heart health (Liu, Ma, et al., 2022; Richardson, Pearce, Mitchell, & Kingham, 2013; Seo, Choi,



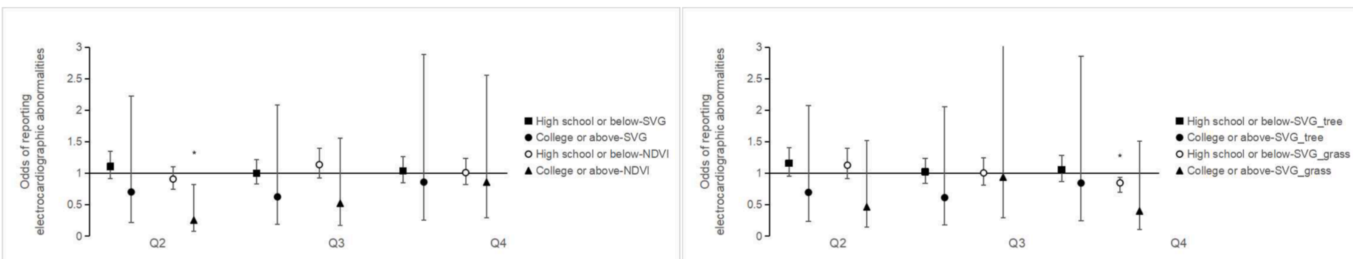
(a) (b)

Fig. 2. Subgroup analyses of change in odds of reporting electrocardiographic abnormalities (with 95 % CIs) associated with different quartiles of green space metrics (referenced group = Q1) (Model 4: sex difference). The models were fully adjusted. *p < 0.05. (a) SVG and NDVI; (b) SVG-tree and SVG-grass.



(a) (b)

Fig. 3. Subgroup analyses of change in odds of reporting electrocardiographic abnormalities (with 95 % CIs) associated with different quartiles of green space metrics (referenced group = Q1) (Model 5: income difference). The models were fully adjusted. *p < 0.05. (a) SVG and NDVI; (b) SVG-tree and SVG-grass.



(a) (b)

Fig. 4. Subgroup analyses of change in odds of reporting electrocardiographic abnormalities (with 95 % CIs) associated with different quartiles of green space metrics (referenced group = Q1) (Model 6: education difference). The models were fully adjusted. *p < 0.05. (a) SVG and NDVI; (b) SVG-tree and SVG-grass.

Kim, Kim, & Park, 2019). SVG-grass can reflect the presence of street-level natural environments, which can encourage residents living nearby to engage in outdoor physical activity (e.g., walking) (Lu et al., 2018). Also, there is scientific evidence that conducting physical activity such as walking in street-level green spaces can generate more health benefits than other environments (R. Mitchell, 2013; Thompson Coon et al., 2011). Second, facilitating social contacts also lies in the pathway linking green space to heart health (Dalton & Jones, 2020; Jimenez et al., 2020). SVG-grass can also reflect the presence of street-level open spaces, which may provide a publicly available space for residents to socialize with each other (Liu et al., 2020). Many studies have found protective effects of community social cohesion on heart health because people living in a cohesive community may benefit more from collective efficacy and are more subject to the regulation of unhealthy behaviours (Choi et al., 2014; F. Hu et al., 2014; Riumallo-Herl, Kawachi, & Avendano, 2014). Third, some scholars argued that visual green space exposure plays a central role in reducing psychological stress which may also explain its influence on heart health (Massa, Pabayo, Lebrão, & Chiavegatto Filho, 2016; Roe et al., 2013). SVG-grass can reflect the visibility of street-level green space, which can distract people from daily psychological stressors and may be beneficial for heart health (Yao et al., 2022). Hence, grasses may cover larger areas in an urban context than trees (Wang et al., 2020), so the restorative effect of SVG-grass could also be stronger than other measures.

However, we found no evidence that SVG-tree is also associated with the odds of electrocardiographic abnormalities for older adults, which is inconsistent with previous studies from Australia, which indicate that tree canopy was associated with CVDs (Astell-Burt & Feng, 2020; Astell-Burt et al., 2021). One possible explanation is that our study area is in northern China, where trees are not evergreen, so their health benefits may weaken during the winter. For example, the mitigation effect of street trees on air pollution and noise is influenced by the density of its leaves (Nowak, Crane, & Stevens, 2006; Pathak, Tripathi, & Mishra, 2011), and unlike in Australian cities, the tree leaves are quite sparse in northern China during the winter (Liang, Shao, & He, 2005), thus may not exert beneficial effects on heart health through the mitigation pathway. Also, the restorative effect of green space is positively associated with its greenness (Jiang, Chang, & Sullivan, 2014), while there is not much visible greenness on street trees during the winter, which again weakens its health benefits. Another possible explanation is that some tree species are beneficial for health, while others may even cause allergies (Aerts et al., 2021; Cariñanos & Casares-Porcel, 2011; Stas et al., 2021). Therefore, it is possible that street tree species in our study areas may not be significantly beneficial for heart health, which can partly explain the insignificant associations. Also, there is no evidence that NDVI is associated with electrocardiographic abnormalities among older adults. This may be because the NDVI is better at measuring the presence or greenness of large green spaces such as parks and forests, but worse at measuring small street-level vegetation (Sun & Lu, 2022; Wang, Dong, et al., 2022; Yao et al., 2022). In our study area, however, large green infrastructures could play a minor role in the health effects, since they may not be as visible as street-level vegetation for older adults' daily lives (Helbich et al., 2019).

4.2. 'Equigenesis' in the association between SVG and heart health in older adults

We found that the effect of SVG-grass on the odds of electrocardiographic abnormalities for older adults varies across demographic and socioeconomic groups. Specifically, the stratified analysis indicated that males, those with lower educational attainment or lower income are more influenced by SVG-grass. First, evidence from previous studies in developed countries found that males are usually more physically active and may have more chances and longer duration of outdoor green space exposure, while females may spend more time at home and be more occupied by housework (Richardson & Mitchell, 2010; Sillman, Rigolon, Browning, & McAnirlin, 2022). his is similar to the Chinese context that older males in China spend a large amount of time doing activities outdoors after retirement (Y. Guo, Shi, Yu, & Qiu, 2016), while older females usually spend more time caring for grandchildren at home

(Chen & Liu, 2012). Second, older adults with lower educational attainment can benefit more from SVG-grass, which may be explained by their lack of health-related knowledge and weak social networks (Mitchell et al., 2015; Pearce et al., 2015). Older adults with higher educational attainment usually have more health-related knowledge which can help them better devote themselves to a healthier lifestyle (e.g., doing more physical activity and eating healthier), while older adults with lower educational attainment do not have such knowledge and are more likely to be unaware of the importance of prevention in chronic diseases (Walsemann, Gee, & Ro, 2013). Under such circumstances, green space exposure even unconsciously is crucial for older adults with lower educational attainment, since it may encourage their health promotion behaviour such as physical activity. Also, highly educated older adults usually have stronger and high-quality social networks, which is beneficial for their health, because not only can they get more health-related information through the networks, but also the network can act as a norm to supervise them to have healthier lifestyle (Latkin & Knowlton, 2015). However, since green space can function as an open space for socializing, it may be more important for older adults with lower educational attainment to build up their social networks and collect health-related information (Thompson, Roe, & Aspinall, 2013). Third, older adults with lower income also benefit more from SVG-grass for their heart health. Older adults with higher incomes can afford more medical resources such as routine physical exams and supplements (e.g., vitamins) (Dubay & Lebrun, 2012). Also, wealthier older adults may rely less on green space around the community, since they can enjoy better green space far away from the residential area (e.g., private golf club) (Wenjie, Chen, & Ye, 2020). However, older adults with lower income may have to rely more on nearby green spaces to promote their heart health as neither are they able to afford to visit private green spaces nor do they have sufficient funds for regular physical exams for the heart.

We further found that NDVI was negatively associated with the odds of electrocardiographic abnormalities for older adults with high educational attainment. It could be that the large green infrastructures near well-educated older adults may be better maintained and have higher quality due to higher affordability for such groups (Wang, Dong, et al., 2022; Yao et al., 2022). Existing evidence has suggested that the quality of the natural environment has a significant effect on health promotion (Kattel et al., 2021; Putra et al., 2021a; Putra et al., 2021b; Sun, Lu & Jin, 2023; Wang, Feng, et al., 2022; Wang et al., 2021; Zhang, Tan & Richards, 2021), so large green infrastructures near older adults with low educational attainment may not be in good quality to exert such health benefits. Another possible explanation is that well-educated older adults are more likely to be able to afford to visit (larger) none publicly available green spaces (e.g., commercial parks or sports fields) which are more accurately captured by the NDVI metric. Also, NDVI can capture the presence of private green infrastructures, which might be more accessible to socioeconomically advantaged groups.

4.3. Policy implications

Our findings have some implications for promoting healthy communities by improving the provision of urban green spaces. First, the results showed that SVG-grass is negatively associated with older adults' odds of reporting electrocardiographic abnormalities, but there is no evidence that SVG-tree or NDVI is related to that. NDVI is better at capturing the presence of large green amenities, while SVG is better at capturing the presence of street-level vegetation (Helbich et al., 2019), it may be more efficient and useful to promote the provision of street-level vegetation in areas with a larger burden of CVDs than building up large green amenities (e.g., parks). Second, heart health for males and older adults with lower income or educational attainment was significantly associated with SVG exposure, while such findings were not found for their counterparts. It may be critical to prioritise the intervention of green spaces for socioeconomically disadvantaged groups and more green spaces should be planned in deprived communities.

4.4. Strengths and limitations

This study's data sources presented both strengths and limitations. The ECG can provide more accurate information than self-reported measures regarding the general heart health in older adults. Compared with diagnosed measures of CVD, ECG can provide more information on heart function (Goldberger, Goldberger, & Shvilkin, 2017). Also, street view data can reflect visual exposure to green space in the urban context, which is important for older adults' daily lives. Furthermore, our analysis is based on relatively representative data from China, which ensures that our findings can be largely generalized to the Chinese population. However, there are still some limitations to be noted. First, we were not able to specify different abnormalities, which prevents us from further understanding how SVG may be associated with different etiological characteristics. ECG does not provide precise information on a specific CVD symptom, so we can only infer the general health status of the heart. Future studies should consider separating each symptom using the ECG data and examine whether the green space - heart health association may be different across symptoms. Hence, although ECG was operated by professional medical workers, some measurement bias due to the participants' specific physical conditions may still occur. Second, street view data were taken over a short period, so we were unable to capture seasonal differences in greenness. Also, although street view images are collected along the street, they can still capture some inaccessible sites. For example, some street streets may be behind the fence or in someone's private yard, so they are visible but may not be accessible to pedestrians. Despite the application of street view data, we were unable to understand the pure effect for the visibility of street-level green space, since SVG can still reflect the presence of general open green space to a certain degree. Therefore, our interpretation of the results of SVG may not be accurate as some are more related to the presence of general open green space rather than the visibility of street-level green space. Hence, image segmentation may not distinguish grass from low shrubs, ground cover or any such combination, so we could not understand the pure effect of grasses. Third, although older adults have less daily mobility, other exposures outside the residential community may still matter. Fourth, we did not have access to the older adults' biomarkers, so we were unable to disentangle the effect of personal biological differences. Also, we did not control for all covariates related to exposure to SVG (e.g., mode of communication), and this may lead to bias regarding the association between SVG and electrocardiographic abnormalities. Since grasses are known to be a significant factor in causing allergies, our findings regarding the association between SVG and ECG may still be biased. Fifth, the utilized data were cross-sectional, which prevents us from inferring causalities. Also, some of our arguments for observed differences in SVG-tree, SVG-grass and NDVI may be specific to the Chinese context and may not be valid in other countries (e.g., European or American contexts). Last, the difference in the sample size among different stratified groups may be an issue and could lead to an inaccurate effect estimation.

5. Conclusions

This study is the first to explore the association between community green space exposure and heart health for older adults using street view and electrocardiography. Our results show that SVG-grass, but not SVG-tree or NDVI is negatively associated with older adults' odds of reporting electrocardiographic abnormalities. Hence, socioeconomically disadvantaged groups are more influenced by SVG. To achieve the goal of healthy ageing and promoting heart health through urban planning, it is essential to promote the provision and visibility of community green space especially for older adults in disadvantaged groups.

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CRediT authorship contribution statement

Ruoyu Wang: Writing – review & editing, Writing – original draft, Methodology, Formal analysis, Conceptualization. **Guoping Dong:** Methodology. **Yang Zhou:** Methodology. **Tongyun Du:** Methodology. **Guang-Hui Dong:** Writing – review & editing, Supervision, Resources, Project administration, Funding acquisition. **Marco Helbich:** Writing – review & editing.

Data availability

The authors do not have permission to share data.

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Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.landurbplan.2024.105025.

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