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The availability and visibility of animals moderate the association between green space and recreational walking: Using street view data

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ABSTRACT

Introduction: Awareness is amounting that understanding the people-animal-environment relationships and further considering it in city design are important to make future cities and society more resilient and sustainable. The presence of green space stimulates recreational walking behaviour. Also, animals in urban outdoor spaces have a restorative effect. However, scant attention has been paid to whether and how green space and animals have a synergistic effect on recreational walking behaviour.

Method: Using survey data collected from 26 neighbourhoods in Guangzhou, China, this study is the first to explore the potential moderating effect of the availability and visibility of animals on the associations between green space and recreational walking behaviour using street view data and a machine learning approach. Multilevel linear and logistic regressions were used for the statistical analysis.

Results: Results showed that the quantity and quality of green space, and availability and visibility of animals were positively associated with recreational walking propensity and duration. Also, the availability and visibility of animals may strengthen the associations between green space and recreational walking behaviour.

Conclusions: Policymakers should consider animal-inclusive green space to maximize the beneficial effect of urban green space on recreational walking.

1. Introduction

Maintaining regular physical activity can benefit people's health by preventing diabetes, cardiovascular diseases, and mental disorders (Lee et al., 2012; Yang et al., 2024). Hence, physical inactivity is the fourth leading risk factor for global mortality, which

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leads to about 3.2 million deaths annually (World Health Organization, 2016). However, 28% of adults in the world were not physically active enough in 2016 (23% men and 32% women) (World Health Organization, 2016). In 2015, only 14.7% of Chinese adults aged 20–69 take regular physical activity (General Administration of Sport of China, 2015), and thus physical inactivity has become a serious public health issue in the Chinese context (Li et al., 2016). Walking can potentially increase overall physical activity levels, which may help people achieve the World Health Organization's recommended level of weekly physical activity (including walking and cycling) (World Health Organization, 2010). Hence, walking, either for transport or recreational purposes, is one of the most common types of physical activity, which not only has health benefits, but also comes along with environmental benefits (Cavill et al., 2008; Loo, 2021; Loo and Siiba, 2019; Yang et al., 2022). For example, recreational walking can save energy and reduce CO_2 emissions, since it does not involve any fossil energy consumption compared with common indoor physical activities (e.g., working out in a fitness club or using a treadmill) (Salvo et al., 2021). Therefore, encouraging more recreational walking is necessary for achieving various sustainable development goals (SDGs) proposed by the United Nations (Dai and Menhas, 2020).

Understanding the influence of different built environment factors on recreational walking behaviour is important to create walking-friendly and healthy cities (Bai et al., 2022; Jiang et al., 2022; Kerr et al., 2016; Koohsari et al., 2020; Lu et al., 2019; Neale et al., 2020, 2022; Pucher and Buehler, 2010; Wu et al., 2023). Urban green space, as an important element of green infrastructure, can influence people's recreational walking behaviour, since it can provide people with a safe, comfortable, and pleasant walking environment (Liu et al., 2023; Sun et al., 2022; Wang et al., 2022; L. Yang et al., 2021; Y. Yang et al., 2019; Yin et al., 2023). For example, trees can provide pedestrians with shade, which can make their walking experience more pleasant (Lu et al., 2018), while other vegetation can reduce mental stress and make the street an attractive place to walk and travel (He et al., 2021; Ki and Lee, 2021; D. Li et al., 2018; Zhu et al., 2020).

The presence of animals in green spaces may matter for recreational walking behaviour because they can improve people's sense of naturalness and biodiversity, which may increase the mental restorative effect, i.e., recovering from mental fatigue and strengthening attentional capabilities (Bijker and Sijtsma, 2017; Rasidi et al., 2012; Stigsdotter and Grahn, 2011). However, most evidence regarding the health benefits of animals in green space is still limited to mental health (Zhao and Gong, 2022). There is little evidence about the benefit of the presence of animals in green spaces on physical activity. For example, a scoping review suggested that the presence of dogs may encourage more physical activity for both dog owners and non-owners (Toohey and Rock, 2011). Dog owners need to engage in dog walking, which increases their level of physical activity (Toohey and Rock, 2011). Also, the presence of dogs may facilitate social interactions among dog owners and other residents and increase people's sense of safety in the open space, which encourages more physical activity for non-owners (Toohey and Rock, 2011). Furthermore, although Zhao and Gong (2022) found that green space with more urban animals (e.g., birds and dogs) is more attractive for residents than those with fewer, it is still unclear whether and how green space and animals in green space have a synergistic effect on recreational walking behaviour. Therefore, the central aim of the present study is to identify the moderating effect of the presence of animals on the associations between green space exposure and recreational walking behaviour. Our research questions (RQs) were as follows.

(RQ1) Whether green space exposure and availability of animals may be associated with recreational walking behaviour?
(RQ2) Whether the availability of animals may moderate the associations between green space exposure and recreational walking behaviour?

To answer these questions, we measured both green space quantity and quality within people's neighbourhoods. Also, we assessed the availability of all animals and birds using field audits, street view data, and a machine learning approach. The conceptual framework is shown in Fig. 1. We also proposed the following three hypotheses.

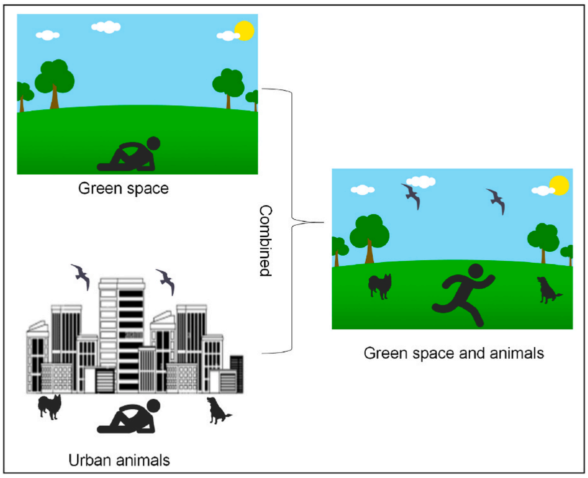

Fig. 1. The conceptual framework in this study.

(H1). Green space quantity and quality are positively associated with recreational walking.

(H2). Availability of animals is positively associated with recreational walking.

(H3). Availability of animals may moderate (strengthen) the associations between green space exposure and recreational walking.

The remainder of this paper is organized as follows. The ensuing section reviews the literature on the associations between the availability and visibility of animals, green space and recreational walking. Section 3 introduces the data and method of regression models and moderation analysis procedure. Section 4 presents the results of the association between green space and recreational walking. Also, the moderating role of availability and visibility of animals for the green space - recreational walking association is further explored. Section 5 discusses major findings, practical implications, and research limitations.

2. Literature review

Research has demonstrated that urban green space is associated with recreational walking (Astell-Burt et al., 2014; Chen et al., 2022; McEvoy et al., 2022; Sugiyama et al., 2013; Toftager et al., 2011; Zhang et al., 2020). Overall, living in greener areas was associated with higher recreational walking propensity (L. Yang et al., 2021) and longer recreational walking duration (Lu, 2019; Y. Yang et al., 2019). There are several explanations for such associations. First, green spaces such as trees can provide pedestrians with shade, which may improve their walking experience (X. Li et al., 2018). This can make pedestrians more comfortable by mitigating direct sunlight exposure and offering them a cool and refreshing environment, especially in summer (Lu, 2018; Lu et al., 2018; Xu et al., 2021). Second, existing evidence has suggested that green space has a restorative effect by helping people restore their emotional and functional resources and capabilities (Kaplan, 1995). Attention restoration theory indicates that green space has four types of restorative features (being away, extension, compatibility, and fascination), which relieve people's stress and reduce attention fatigue (Kaplan, 1995). For example, several experiments have confirmed that being exposed to green space can help participants recover from a stressful experience and promote their attentional functioning (Jiang et al., 2016). Third, green space was found to be able to prevent the negative impact of environmental hazards such as noise (Jang et al., 2015) and improve air quality (Pugh et al., 2012), which both can improve the quality of the walking environment. Green space can purify air pollutants such as fine particulate matter and improve air quality (Pugh et al., 2012). As for noise, green space can mitigate the detrimental effect of noise by blocking and weakening the sound waves of noise, which can be explained by the diffraction, destruction, and absorption characteristics of sound waves (Jang et al., 2015). In addition, existing evidence has documented that both green space quantity and quality may influence recreational walking behaviour, so it is important to examine the effect of both (Sugiyama et al., 2013). For example, Lu (2019) found that the quality and quantity of street greenery were positively associated with recreational physical activity including walking in Hong Kong. Sugiyama et al. (2013) also suggested that both green space quality and quantity were positively related to maintaining recreational walking behaviour in Adelaide, Australia. Hillsdon et al. (2006) pointed out that higher quality of urban green space was associated with increased levels of recreational physical activity in Norwich, UK.

Previous studies pointed out that outdoor animals may have a positive influence on outdoor physical activities such as recreational walking (Apfelbeck et al., 2020; Methorst et al., 2021). There are two major reasons to support such a claim. First, animals, especially birds, in green spaces can provide people with a pleasant and attractive soundscape, which may relieve individuals' mental fatigue and stress (Jessica Claris Fisher et al., 2021). Furthermore, animal sounds can buffer negative emotions arising from noise (Jo and Jeon, 2020; Maculewicz et al., 2016). For example, a study in Paris, France suggested that natural sound from animals is important for visitors' outdoor activities in urban parks (Jo and Jeon, 2020). Second, animals in green spaces also improve the sense of biodiversity and naturalness of the overall environment (Humpel et al., 2004; Owen et al., 2004; Suminski et al., 2005). Animal-assisted therapy theory indicates that animals (e.g., birds and squirrels) in urban green spaces can attract pedestrians' attention, which helps them reduce stress (Apfelbeck et al., 2020; Weisser and Hauck, 2017; Zhao and Gong, 2022). For example, Methorst et al. (2021) found that biodiversity is important for mental health. Also, animals prefer to live in a more natural environment, so more animals in green spaces usually indicate a higher level of naturalness in green spaces (Zhao and Gong, 2022). The Biophilia hypothesis indicates that people have a predisposition to respond positively to natural elements including wild animals (Jiang et al., 2016). Therefore, viewing animals in green spaces can evoke positive emotions and encourage outdoor activities (Ulrich, 1983). In summary, much literature pinpoints the positive effects of animals in green space on mental health (Apfelbeck et al., 2020; Jessica C. Fisher et al., 2021; Jessica Claris Fisher et al., 2021; Methorst et al., 2021; Sandifer et al., 2015; Sang et al., 2016; Wood et al., 2018). Such evidence implies that animals in urban green spaces may also encourage more creational walking, although direct evidence is missing.

The lack of empirical evidence on the effect of animals in green spaces on recreational walking may be due to methodological limitations (Zhao and Gong, 2022). As mentioned above, the premise of being affected by animals in green space is first to be able to see animals (Zhao and Gong, 2022). However, since animals are usually small and dispersed in urban green spaces, visual exposure to animals is hard to measure (Zhao and Gong, 2022). The traditional methods for assessing the availability of animals are usually based on a field audit approach, which is time-consuming and may not be able to reflect people's visual exposure to animals (Zhao and Gong, 2022). Recently, due to the progress in computer vision techniques and online mapping services, empirical studies have explored the possibility of estimating visible exposure to different ground objects, including both green space and animals, using street view images (R. Wang et al., 2021; R. Wang et al., 2020; R. Wang et al., 2019). Therefore, combining street view images and a machine learning approach can help us better understand the health benefits of animals in green spaces.

3. Methodology

3.1. Data collection

This study is based on survey data (supplement file) collected in urban neighbourhoods in Guangzhou between March and August in 2017. The survey questionnaire contains information regarding participants' socioeconomic status, walking behaviour, and neighbourhood location. The participants were selected using a multi-stage stratified PPS (probability proportionate to population size) sampling technique. In the first stage, residential neighbourhoods were selected randomly from seven urban districts. Second, households from each targeted neighbourhood were randomly selected. Last, one adult member from each household was chosen using the Kish Grid method (Binson and Catania, 2000) to participate in the survey. The survey yielded a total of 1003 valid respondents. The survey was approved by Sun Yat-sen University, and all participants agreed to give informed consent.

3.2. Dependent variable: walking behaviours

We used two measures of recreational walking behaviour in this study: the propensity (binary variable) and duration of recreational walking (continuous variable). Respondents were asked: "How many days have you walked for recreation in the past week?" and "On average, how many minutes have you spent on daily recreational walking in the past week?" We categorized the participants into two groups: people who had done some recreational walking for one day (recreational walking propensity = 1) and those who had not done so (recreational walking propensity = 0). The duration of recreational walking is the total amount of recreational walking time in the past week (daily duration × days).

3.3. Independent variable

3.3.1. Green space quantity

The Normalized Difference Vegetation Index (NDVI) (Tucker, 1979) was used to measure green space quantity. It was calculated using satellite images from Landsat 8 OLI (Operational Land Imager) and TIRS (Thermal Infrared Sensor) at 30 m × 30 m spatial resolution in Guangzhou. The images were obtained for the year 2017 from the USGS EarthExplorer (https://earthexplorer.usgs.gov/). Based on existing literature (Tucker, 1979), the NDVI was calculated using the following formula: (NIR − Red)/(NIR + Red), where NIR is the reflectance in the near-infrared band and Red is the spectral reflectance measurements acquired in the red. The NDVI for each sampled neighbourhood was calculated using all pixels within the 1000-m circular buffers of each neighbourhood.

3.3.2. Green space quality

Existing literature pointed out that residents' sense of comfort in green space can reflect their subjective perception of general green space quality (Brindley et al., 2019; Gidlow et al., 2012). Following previous studies (Feng and Astell-Burt, 2017; R. Wang et al., 2021), we used a self-reported question to evaluate neighbourhood green space quality. Participants were asked: "Do you agree that you feel comfortable in the open space such as green space, park, and square in this neighbourhood?" Their answers range from "1 = strongly disagree" to "5 = strongly agree". We regarded "1 = strongly disagree", "2 = disagree", and "3 = neither agree nor disagree" as low green space quality, while "4 = agree" and "5 = strongly agree" were regarded as high green space quality.

3.3.3. Street view visibility of animals

We used street-view images to assess street street-view visibility of animals. We collected street view images from the Tecent Map in 26 neighbourhoods based on the sampling points constructed on OpenStreetMap (Haklay and Weber, 2008). To reflect people's visibility of the street environment from different angles, we collected four images from four different angles (0°, 90°, 180°, and 270°) for each sampling point within the neighbourhood (Luo et al., 2023). In total, 223,234 street-view images were collected for the whole research area.

Street view visibility of animals was extracted from the street view images using a fully convolutional neural network (FCN-8s) (Long et al., 2015). First, the FCN-8s were trained by feeding the ADE20K dataset, which is a widely used labelled image collection (Zhou et al., 2019). After the training process, the accuracy of our model achieved 85%. Since the training images in the ADE20K dataset include more than 150 different objects (e.g., animals), our trained FCN-8s were able to identify animals from each image we collected. Second, we further used it for image segmentation, and the proportion of animals was calculated for each street view image. Finally, the street view visibility of animals in each sampling point was calculated as the mean proportion of the animals in four images. The street view visibility of animals for each neighbourhood is the average street view visibility of animals of each sampling in circular buffers of 1000 m around each neighbourhood centroid. The workflow for calculating the street view visibility of animals is shown in Fig. S1. In the 20,210 training images of the ADE20K dataset, most of the urban animals (both wild and domestic animals) such as dogs, cats, birds and squirrels were labelled, so they should be identifiable from the street view images. However, all animals were classified as one category in the ADE20K dataset, so we are not able to distinguish among different species of animals in the street view images. The example showing an animal detected after the image segmentation process of street view data was presented in Fig. S2.

3.3.4. Availability of birds

Existing studies indicated that birds can provide residents with a natural and better soundscape and thus encourage more outdoor activities (Apfelbeck et al., 2020; Jessica C. Fisher et al., 2021; Jessica Claris Fisher et al., 2021). Also, birds are more visible and populated in urban environments than other wild animals (Apfelbeck et al., 2020; Jessica C. Fisher et al., 2021; Jessica Claris Fisher et al., 2021). Therefore, we used the eBird Observation Dataset (EOD) provided by the Global Biodiversity Information Facility (Auer et al., 2020) to measure the presence of birds in our research area. The EOD was created through a citizen science approach, which means it was collected by experts in a wide range of fields using the field audit approach (Sullivan et al., 2014). It contains information regarding the counts of all birds observed during a single field audit visit and the location and time for the visit (Sullivan et al., 2014). The field audit presence of birds for each sampled neighbourhood was calculated using the total number of birds that were observed within the 1000-m circular buffers of each neighbourhood. Since street view visibility of animals and availability of birds were of skewed distribution and we want to focus on the heterogeneous effect of the relative difference of them, were split both of them into four quartile range rather than treating them as continuous variables.

3.4. Covariates

We adjusted for a series of confounding covariates, including sex, age (years), education attainment, marital status, hukou status, presence of chronic disease, and household income (Chinese Yuan). The neighbourhood deprivation index was created using the following neighbourhood-level variables: homeownership rates, unemployment rates, low levels of education, and low-status occupation. Following previous studies (R. Wang et al., 2022), we used a principal component analysis to calculate the neighbourhood deprivation index using the above four variables. The descriptive statistics for all variables are shown in Table 1.

3.5. Statistical analysis

To identify the linkage between neighbourhood greenspace, animals, and walking behaviour, we used multilevel linear and logistic regressions (Tom et al., 1999), since participants in this study were clustered in neighbourhoods. Variance inflation factors (VIF < 3) suggested no severity of multicollinearity among all independent variables. The intra-class correlation coefficient (ICC) for the null model predicting the recreational walking duration and propensity is 0.084 (linear regression model) and 0.068 (logistic regression model), respectively. This means that neighbourhood-level variations accounted for 8% and 7% of the total variation in participants' recreational walking duration and propensity, respectively.

First, we estimated the association between green space, the availability of animals, and recreational walking behaviour (Models 1 and 2). Second, we estimated the moderating effect of the presence of all animals and birds for green space exposure - recreational

Table 1
Descriptive statistics.

Variables	Proportion/Mean (Standard Deviation)
Outcome	
Duration of weekly walking for recreation (min)	71.251 (80.641)
Recreational walking propensity (%)	
Walking for recreation at least once a week	63.410
Do not have any recreational walking	36.590
Predictors	
Greenspace quantity (NDVI)	0.103 (0.027)
Greenspace quality (%)	
High	34.197
Low	65.803
Field audit presence of birds (times)	3.726 (3.211)
Street view visibility of animals	0.003 (0.006)
Covariates	
Sex (%)	
Male	49.951
Female	50.049
Age (in years)	38.359 (63.310)
Marital status (%)	
Single, divorced, or widowed	19.941
Married	80.059
Hukou status (%)	
Local hukou	80.957
Non-local hukou	19.043
Education (%)	
Junior high school or below	6.381
Senior high school	27.517
College or above	66.102
Presence of chronic disease (%)	
Yes	12.861
No	87.139
Gross monthly household income (Chinese Yuan)	15637.187 (8488.459)
Neighbourhood deprivation index	0.207 (0.169)

walking propensity association (Models 3 and 4). Third, we estimated the moderating effect of the presence and viewing of animals for green space exposure - duration of weekly walking for recreation association (Models 5 and 6). Multilevel logistic regressions were used for the outcome of recreational walking propensity (binary variable), and odds ratios and 95% confidence interval were reported. Also, multilevel linear regressions were used for the outcome of the duration of weekly walking for recreation (continuous variable), and coefficients and 95% confidence interval were reported. As for the moderation analysis, we focused on the interaction terms between green space and the availability/visibility of animals. If the interaction terms are significant and in the same direction as green space metrics, then it means the availability/visibility of animals may strengthen the effect of green space on walking. STATA (v.15.1) was used for the statistical analysis (STATA, Inc. College Station, TX USA).

4. Results

Model 1 in Table 2 shows the baseline model for associations between greenspace, availability of animals, and recreational walking propensity. The results indicate that NDVI was positively associated with the odds of having recreational walking (OR = 2.216, 95% CI = 1.598–3.073). Respondents living in a neighbourhood with high greenspace quality were more likely to have recreational walking (OR = 1.421, 95% CI = 1.046–1.931). Also, respondents living in a neighbourhood with Q4 availability of all animals (OR = 1.390, 95% CI = 1.216–1.706) were more likely to have recreational walking than those in the Q1 group. Respondents living in a neighbourhood with Q3 availability of birds (OR = 1.643, 95% CI = 1.015–2.661) were more likely to have recreational walking than those in the Q1 group.

Model 2 in Table 2 shows the baseline model for associations between greenspace, availability of animals, and duration of weekly recreational walking. The results indicate that NDVI was positively associated with the duration of weekly recreational walking (Coef = 0.844, 95% CI = 0.558–1.130). Respondents living in a neighbourhood with high greenspace quality had a higher duration of weekly walking for recreation (Coef = 0.434, 95% CI = 0.128–0.740). Also, respondents living in a neighbourhood with Q4 availability of all animals (Coef = 0.978, 95% CI = 0.415–1.541) had a higher duration of weekly walking for recreation than those in the Q1 group. Respondents living in a neighbourhood with Q2 (Coef = 0.541, 95% CI = 0.065–1.017) and Q3 (Coef = 0.583, 95% CI = 0.101–1.065) availability of birds had a higher duration of weekly recreational walking than those in the Q1 group.

Model 3 in Table 3 shows the moderating effect of the availability of all animals and birds on the association between greenspace indicators (NDVI and quality) and recreational walking probability. The results indicate that the availability of all animals positively moderates the association between NDVI and the odds of having recreational walking, which indicates that the availability of all animals strengthens the positive effect of NDVI on recreational walking probability. Also, the availability of all animals positively moderates the association between greenspace quality and the odds of having recreational walking, which indicates that the

Table 2
The baseline models.

	Model 1	Model 2
	OR (95% CI)	Coef. (95% CI)
Fixed part		
Predictors		
Greenspace quantity (NDVI)	2.216***(1.598–3.073)	0.844***(0.558–1.130)
High greenspace quality (ref: low greenspace quality)	1.421**(1.046–1.931)	0.434***(0.128–0.740)
Street view visibility of animals (ref: Q1)		
Q2	0.906(0.527–1.556)	−0.102(-0.635–0.431)
Q3	1.187(0.396–1.595)	0.421(-0.122–0.964)
Q4	1.390***(1.216–1.706)	0.978***(0.415–1.541)
Field audit presence of birds (ref: Q1)		
Q2	1.388(0.865–2.228)	0.541**(0.065–1.017)
Q3	1.643**(1.015–2.661)	0.583**(0.101–1.065)
Q4	0.843(0.480–1.481)	0.100(-0.455–0.655)
Covariates		
Male (ref: female)	1.042(0.795–1.366)	0.030(-0.240–0.300)
Age	1.000(0.998–1.002)	0.001(-0.001–0.003)
Married (ref: single, divorced, or widowed)	1.500**(1.068–2.108)	0.454**(0.105–0.803)
Local hukou (ref: non-local hukou)	1.039(0.729–1.482)	0.055(-0.302–0.412)
Senior high school (ref: junior high school or below)	0.997(0.513–1.939)	−0.019(-0.629–0.591)
College or above (ref: junior high school or below)	0.648(0.342–1.229)	−0.391(-0.977–0.195)
Gross monthly household income	0.879(0.618–1.250)	0.082(-0.269–0.433)
With chronic disease (ref: without chronic disease)	1.246(0.802–1.936)	0.199((-0.222–0.620)
Neighbourhood deprivation index	0.655(0.222–1.929)	−0.357(-1.455–0.741)
Constant	0.863(0.027–7.794)	1.396(-2.005–4.797)
Random part		
Var (Neighbourhoods)	0.027***	0.039***
Var (Individuals)		4.609***
Log-likelihood	−623.573	−2190.817
AIC	1285.147	4421.634

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

Table 3
Associations between greenspace and recreational walking probability and testing of a potential moderating effect of presence and viewing of wild animals.

	Model 3	Model 4
	OR (95% CI)	OR (95% CI)
Predictors		
Greenspace quantity (NDVI)	1.774**(1.562–5.604)	2.202***(1.457–3.328)
High greenspace quality (ref: low greenspace quality)	1.753**(1.719–4.278)	1.472**(1.166–2.828)
Street view visibility of animals (ref: Q1)		
Q2	0.723(0.333–1.570)	0.913(0.502–1.661)
Q3	1.509(0.235–2.103)	1.617(0.286–2.329)
Q4	1.250***(1.136–1.461)	1.375***(1.184–1.764)
Field audit presence of birds (ref: Q1)		
Q2	1.998**(1.030–3.874)	1.207(0.688–2.118)
Q3	2.638***(1.416–4.917)	1.791**(1.296–3.223)
Q4	1.979(0.793–4.941)	1.074(0.523–2.205)
Interaction term		
Greenspace quantity (NDVI) × Street view visibility of animals (ref: Q1)		
Greenspace quantity (NDVI) × Q2	0.479(0.167–1.372)	
Greenspace quantity (NDVI) × Q3	0.804(0.283–2.287)	
Greenspace quantity (NDVI) × Q4	1.217**(1.011–3.601)	
High greenspace quality (ref: low greenspace quality) × Street view visibility of animals (ref: Q1)		
High greenspace quality × Q2	1.226**(1.057–1.896)	
High greenspace quality × Q3	1.075(0.226–5.123)	
High greenspace quality × Q4	1.726**(1.446–6.687)	
Greenspace quantity (NDVI) × Field audit presence of birds (ref: Q1)		
Greenspace quantity (NDVI) × Q2		1.576(0.635–3.909)
Greenspace quantity (NDVI) × Q3		0.918(0.364–2.312)
Greenspace quantity (NDVI) × Q4		0.666(0.281–1.575)
High greenspace quality (ref: low greenspace quality) × Field audit presence of birds (ref: Q1)		
High greenspace quality × Q2		1.013(0.336–3.056)
High greenspace quality × Q3		1.278(0.485–3.370)
High greenspace quality × Q4		0.762(0.206–2.811)
Log-likelihood	−615.154	−621.367
AIC	1278.309	1292.734

Models adjusted for covariates. OR = odds ratio; CI = confidence interval; AIC = Akaike information criterion. *p < 0.10, **p < 0.05, ***p < 0.01.

availability of all animals strengthens the positive effect of greenspace quality on recreational walking probability. Model 4 in Table 3 shows the moderating effect of the availability of birds on the association between greenspace indicators (NDVI and quality) and recreational walking probability. Neither moderating effect is significant.

Model 5 in Table 4 shows the moderating effect of the availability of all animals and birds on the association between greenspace indicators (NDVI and quality) and duration of recreational walking. The results indicate that the availability of all animals positively moderates the association between NDVI and the duration of recreational walking, which indicates that street view visibility of animals strengthens the positive effect of NDVI on the duration of recreational walking. Also, the availability of all animals positively moderates the association between greenspace quality and duration of recreational walking, which indicates that street view visibility of animals strengthens the positive effect of greenspace quality on the duration of recreational walking. Model 6 in Table 4 shows the moderating effect of the availability of birds on the association between greenspace indicators and the duration of recreational walking. Neither moderating effect is significant.

5. Discussion

This study extends previous research in three aspects. First, this is among the first studies to systematically explore the potential moderation effects of the availability of animals on the association between greenspace and recreational walking in a densely populated Chinese context. Second, it makes a novel methodological contribution to the measurement of the availability of animals in the urban context by using street view data and a machine-learning approach. Third, this study also focuses on the effect of both green space quantity and quality, which enhances our understanding of the health benefits of green space exposure.

Our results suggest that green space quantity was positively associated with both the odds and duration of recreational walking. These results are consistent with previous studies originating from both developed countries (Astell-Burt et al., 2014; Sugiyama et al., 2013; Zhang et al., 2020) and developing countries (Asri et al., 2022; Benjamin-Neelon et al., 2019; Shen et al., 2021; H. Wang et al., 2019; Wendel et al., 2012). For example, a higher level of green space quantity was associated with more recreational walking trips in a representative sample of the general population in London, UK (Zhang et al., 2020). A systematic review suggested that green space quantity indicators such as availability and accessibility were positively related to the odds of conducting recreational walking in China (Shen et al., 2021). This association might be explained in part by the beneficial effect of green space on reducing environmental hazards and improving environmental quality (Shen et al., 2021). For instance, street vegetation especially dense trees not only provides shade to pedestrians (X. X. Li et al., 2018) but also blocks traffic noise (Jang et al., 2015) and improves air quality (Pugh et al.,

Table 4
Associations between greenspace and duration of recreational walking and testing of a potential moderating effect of presence and viewing of wild animals.

	Model 5	Model 6
	Coef. (95% CI)	Coef. (95% CI)
Predictors		
Greenspace quantity (NDVI)	0.992**(0.041–1.943)	0.818***(0.467–1.169)
High greenspace quality (ref: low greenspace quality)	0.525**(0.035–1.015)	0.528**(0.062–0.994)
Street view visibility of animals (ref: Q1)		
Q2	0.593(-0.154–1.340)	0.395(-0.271–1.061)
Q3	1.453***(0.873–2.033)	1.093***(0.468–1.718)
Q4	0.992**(0.041–1.943)	0.818***(0.467–1.169)
Field audit presence of birds (ref: Q1)		
Q2	0.895***(0.231–1.559)	0.318(-0.225–0.861)
Q3	0.980***(0.374–1.586)	0.654**(0.099–1.209)
Q4	0.584(-0.323–1.491)	0.151(-0.555–0.857)
Interaction term		
Greenspace quantity (NDVI) × Street view visibility of animals (ref: Q1)		
Greenspace quantity (NDVI) × Q2	1.359*(-0.005–2.723)	
Greenspace quantity (NDVI) × Q3	0.221(-1.327–1.769)	
Greenspace quantity (NDVI) × Q4	1.408**(0.099–2.717)	
High greenspace quality (ref: low greenspace quality) × Street view visibility of animals (ref: Q1)		
High greenspace quality × Q2	−0.679(-1.714–0.356)	
High greenspace quality × Q3	−0.175(-1.212–0.862)	
High greenspace quality × Q4	0.396**(0.110–0.682)	
Greenspace quantity (NDVI) × Field audit presence of birds (ref: Q1)		
Greenspace quantity (NDVI) × Q2		0.697(-0.209–1.603)
Greenspace quantity (NDVI) × Q3		0.039(-0.865–0.943)
Greenspace quantity (NDVI) × Q4		0.451(-0.411–1.313)
High greenspace quality (ref: low greenspace quality) × Field audit presence of birds (ref: Q1)		
High greenspace quality × Q2		0.377(-0.564–1.318)
High greenspace quality × Q3		0.300(-0.627–1.227)
High greenspace quality × Q4		−0.201(-1.459–1.057)
Log-likelihood	−2182.394	−2187.04
AIC	4416.789	4426.08

Models adjusted for covariates. OR = odds ratio; CI = confidence interval; AIC = Akaike information criterion. *$p < 0.10$, **$p < 0.05$, ***$p < 0.01$.

2012). Hence, green space can facilitate more outdoor activities, including recreational walking (Y. Jiang et al., 2021).

We also found a positive association between green space quality and recreational walking. Prior evidence suggested positive associations between green space quality and a higher likelihood of walking maintenance in Adelaide, Australia (Sugiyama et al., 2013). Similar findings were also confirmed for recreational walking propensity in Hong Kong (Lu et al., 2018). Unlike green space quantity, green space quality may influence recreational walking through the restorative effect of nature (Sugiyama et al., 2013). Existing studies pointed out that the quality of green space is directly linked to an attractive environment, which can help people reduce stress and improve mental health (Deng et al., 2020).

Regarding the second hypothesis, the results support that the availability of all animals and birds was positively associated with recreational walking. Although previous studies pointed out that the presence and viewing of animals in green spaces may encourage outdoor activities (Methorst et al., 2021), there is still a lack of direct empirical evidence. The availability of animals in the urban context may encourage more recreation through several mechanisms. One possible explanation is that viewing different animals in the urban context can increase the sense of biodiversity and naturalness of the environment, which may finally increase the restorative effect of the environment (Liu et al., 2022). Another possible explanation is that interacting with or watching animals in a walking environment (both domestic and wild animals) may bring more fun to people (Garrido-Cumbrera et al., 2020). Also, the health benefits of animals, especially birds, can be explained by their contribution to a better soundscape for the walking environment (Jessica Claris Fisher et al., 2021). For instance, the sounds from birds and squirrels in green spaces can offer people a natural soundscape, which can reduce traffic noise and help walkers feel less stressed (Jessica Claris Fisher et al., 2021).

Regarding the last hypothesis, the results (interactive terms) only support that the availability of all animals moderates the association between green space and recreational walking behaviour. However, the availability of birds has no such moderating effect. The moderation effect of viewing animals can be explained by the three related mechanisms. First, the biophilia hypothesis indicates that both vegetation and wild animals play an important role in people's daily lives during the evolution process (Ulrich et al., 1991). Also, wild animals and vegetation usually coexist in ancient times, so the con-existence of both green space and animals may have a synergistic effect on the restorative effect by evoking strong feelings of naturalness (Egner et al., 2020; Menzel and Reese, 2022). Second, attention restoration theory indicates that natural elements have different types of restorative features (i.e., being away, extension, compatibility, and fascination) (Kaplan, 1995). Therefore, animals and green space may provide different restorative features, so viewing them simultaneously can complement their restorative feature and make the environment more attractive. Last, the presence of both green space and animals indicates a more diverse natural scene, which is also important for the restorative effect of the natural environment (Stoltz and Grahn, 2021). Existing studies found that the diversity of natural elements is positively associated with the aesthetic of the natural environment (Stoltz and Grahn, 2021). Hence, exposure to both green space and animals increases the attractiveness of the walking experience in such an environment (Veitch et al., 2017).

However, the availability of birds does not moderate the associations between green space exposure and recreational walking behaviour. There are two potential explanations. First, the restorative effect of animals may vary across different species (Zhao and Gong, 2022). Birds may not be the most important animal species in green space to affect people's recreational walking behaviour. Second, the availability of birds may not precisely measure the natural soundscape in our research area. The issue is exacerbated because the number of birds is quite low in a highly urbanized area (Reis et al., 2012).

Based on the above findings, we have also noted some policy implications. First, since the availability and visibility of animals were positively related to recreational walking, policymakers should try to make the city more animal-inclusive. For example, more birdhouses could be provided to attract more birds. Second, both green space quantity and quality were related to recreational walking, so the provision of green space should be increased. For instance, more trees and grasses could be planted in large open spaces. Third, we also found that the availability and visibility of animals may strengthen the beneficial effect of green space, so it is suggested that when implementing interventions in green space, its effects on animals within the green space should also be considered.

Our study has several limitations due to data constraints. First, our cross-sectional data makes it difficult to infer causation between green space, availability of animals, and recreational walking. Future studies are advised to use longitudinal data to deal with such issues. Second, participants' walking behaviour is self-reported, which is prone to recall bias. Future studies should apply portable accelerometers along with a geographical positioning system (GPS) tracker to objectively measure walking behaviour. Third, the green space quality is also self-reported, which is prone to recall bias. Future research should consider more objective measures such as using a field audit approach to assess the green space quality. Fourth, the field audit and street view data also have some limitations. For example, both field audit and street view data are collected in a certain period, so they may not be able to reflect the number of animals encountered by our participants due to the high mobility of animals. Fifth, our findings may not be completely valid in the post-pandemic period, since people's perception of animals, green space and travel preferences have already changed (Buehler and Pucher, 2023). Therefore, recent evidence should be examined to identify whether our findings is applicable in the post-pandemic period. Last, we were unable to identify different types or species, so some unattractive animals (e.g., rats) may be included and lead to bias on our estimation.

6. Conclusions

This study shows that both the quantity and quality of green space are positively associated with recreational walking. Also, the availability of all animals may moderate such associations. To maximize the health benefits of urban green infrastructure through urban planning and design, it is advised to pay more attention to the synergistic effect of green space and animals on walking. Urban planners and park managers may consider 'animal-inclusive landscape design' in future interventions.

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Author statement

All persons who meet authorship criteria are listed as authors. All authors certify that they have participated in the components of the work including participation in the concept, design, analysis, writing, or revision of the manuscript.

Authors statement

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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.

Data availability

The authors do not have permission to share data.

Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.jth.2023.101744.

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