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Research Paper

How greenway exposure reduces body weight: A natural experiment in China

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HIGHLIGHTS

- Among the first natural experiment studies to assess the causal influence of greenspace on people's BMI.
- Both men and women in the treatment group experienced a minor BMI reduction after intervention.
- Mediation pathways between the greenspace intervention and BMI change were gender specific.

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ABSTRACT

Access to public greenspaces is assumed to influence peoples' body weight. However, causal evidence on this topic is limited, especially in developing countries. Using natural experiment approach, this study assessed 1) to what extent peoples' body mass index (BMI) changed following a greenway intervention, and 2) potential gender disparities in both direct effects and underlying mediating pathways linking greenway exposure and BMI changes. Baseline and follow-up survey data on 1,020 adults were collected before and after the completion of East Lake greenway in Wuhan, China. Participants were split into treatment and control groups based on a 2 km threshold distance from housing estates to the greenway. Difference-in-difference (DID) estimations and structural equation models were used to assess the effects and pathways between the greenway intervention and BMI changes. The results showed that treatment group experienced a minor BMI reduction, while the BMI increased in the control group. DID models indicated that the effects of the greenway intervention on BMI changes are significant for both men and women. We also found distinct mediating mechanisms across gender. Changes in moderate to vigorous physical activity (MVPA) mediated the association between the greenway intervention and a reduction in BMI among men, while mental health changes mediated the association for women. Our findings provided compelling evidence that exposure to greenway prevents body weight increase and strengthened the rationale for green infrastructure investments to enhance public health in high-density cities.

1. Introduction

The prevalence of overweight and obesity has gradually evolved into a global epidemic and threatened public health (Swinburn et al., 2019). Excess body fat impairs health and causes various types of chronic diseases, especially cardiovascular diseases (Egede & Zheng, 2002). Due to the rapid urbanization and transformation of lifestyles in China, the percentage of overweight adults (i.e., adults with a body mass index (BMI) of $\geq$ 24) increased from 22.8% in 2002 to 30.1% in 2012 (National Health Commission of China, 2015). To curb this trend, more health-supportive urban infrastructure interventions, such as attractive and accessible greenspace, have been advocated (Bennett et al., 2018).

A growing body of cross-sectional evidence, suggests that proximity to greenspaces is associated with a lower probability of being

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overweight or obese (Nieuwenhuijsen, Khreis, Triguero-Mas, Gascon, & Dadvand, 2017). Apart from the direct association (Jiang, Wang, Ren, Yang, & Lu, 2022; Yang, He, Lu, Ren, & Huang, 2021), several underlying pathways linking urban greenspaces and body weight have been proposed (Twohig-Bennett & Jones, 2018). First, greenspace use promotes physical activity by providing pleasant venues and facilities, and increased energy expenditure could prevent the accumulation of excessive body fat (Coombes, Jones, & Hillsdon, 2010; Lu, 2019; Yang, Ao, Ke, Lu, & Liang, 2021). Second, greenspace exposure relieves psychological stress and mental fatigue (He et al., 2022), and further induces the intake of unhealthy 'comfort' food, which is rich in sugar and fats (Harding et al., 2014). Consequently, greenspace exposure may reduce the intake of high-calory food by improving mental health (Feng & Astell-Burt, 2019).

However, several research gaps prevent us from fully realizing and utilizing the effects of urban greenspaces in maintaining healthy body weight. First, although most studies found an inverse greenspace proximity–body weight association (Michael, Nagel, Gold, & Hillier, 2014; Wolch et al., 2011), a recent systematic review stressed that 81% of the studies were based on cross-sectional data (Luo et al., 2020). Since some residents select residential environment based on their living preference, these reported associations were prone to a residential self-selection bias and the studies failed to identify causal relationships (Michael et al., 2014; Zick et al., 2013). For example, residents with a positive attitude toward healthy lifestyles may choose to live in neighborhoods with more accessible greenspace to exercise more (Sarkar, 2017). Thus, the observed associations between greenspace and body weight may be explained by personal factors rather than by the actual effect of greenspace (Luo et al., 2020).

Second, despite making an important step toward a causal understanding of how greenspace affects body weight, the evidence derived from experimental studies may also be influenced by unobserved confounders, especially those affect treatment groups and control groups differently (Keall et al., 2015). For example, the creation of a large-scale park may be accompanied by the improvement in public transit and street connectivity around the park. Observed change in body weight outcomes for the treatment group may be due to unmeasured environmental changes. To rule out this possibility, investigating the pathways through which an intervention shapes outcomes could strengthen causal attribution (Panter & Ogilvie, 2015; Prins, Panter, Heinen, Griffin, & Ogilvie, 2016).

Third, several studies showed that greenspace use as well as how greenspace is valued and perceived, differ across socio-demographic groups (Sang et al., 2020). Gender may modify the relationship among greenspace, daily behaviors, and health outcomes (Lachowycz & Jones, 2011; Richardson & Mitchell, 2010; Sander, Ghosh, & Hodson, 2017). The following explanations have been put forward: Women were more sensitive to external restrictions (e.g., safety concerns and tolerance to destination proximity), and distinct motivations and opportunities to use greenspace may occur (Lachowycz & Jones, 2013). In addition, gender-specific perceptions and behavioral patterns in greenspace use were observed (Sang et al., 2020), which may modify the effectiveness of greenspace exposure (Richardson & Mitchell, 2010; Sang, Knez, Gunnarsson, & Hedblom, 2016). Consequently, uneven health outcomes may occur with unidentical greenway exposure in the long run (Persson et al., 2018). Several studies indicated stronger association between greenspace and better body weight among women was observed than men (Astell-Burt, Feng, & Kolt, 2014; O'Callaghan-Gordo et al., 2020; Persson et al., 2018). However, these studies usually explored gender disparities in greenspace–body weight associations by selecting heterogeneous neighborhoods with distinctive greenspaces features (e.g., scale and quality).

Longitudinal evidence on whether gender disparities exist between a single urban greenspace intervention and changes in body weight outcomes remains scarce. Natural experimental approach has been proposed to infer the causal relationship between interventions and health outcomes (He, Lu, Xie, & Helbich, 2021; Sun, Du, Ni, Zhao, & Webster, 2021). A natural experiment occurs when a particular external intervention is conducted, but its implementation is not controlled by the researchers (Sun, Zhao, Webster, & Lin, 2020; Xie, Lu, Wu, & An, 2021). By collecting data on the outcome both before and after an intervention (Craig, Katikireddi, Leyland, & Popham, 2017), longitudinal data allows observation of the effects of an intervention across a treatment and a control group. Such a setting rules out the possibility that the changes in outcomes are caused by temporal attributes (Craig et al., 2012).

The aim of the present study was to identify BMI changes following a large-scale greenway intervention in Wuhan, China. To the best of our knowledge, it was among the first to investigate the long-term benefits of greenspace on body weight by means of a natural experiment approach. Our research questions (Q1-3) were the following:

1) What is the effect of the greenway intervention on BMI change?
2) Does gender modify the significance and strength of the effect of the greenway intervention on BMI change?
3) Does the influence of two potential mediating pathways, namely changes in moderate to vigorous physical activity (MVPA) and mental health, differ between men and women?

To comprehend the mechanisms, we proposed the conceptual framework (shown in Fig. 1) and two hypotheses. First, we hypothesized that green space intervention significantly decreases the BMI level for treatment groups. Second, we assumed that distinctive treatment effects or mediating mechanisms may occur between men and women.

2. Material and method

2.1. Research design

2.1.1. Study site and greenway intervention

Wuhan is the largest city in central China, with a population of over 11.2 million by the end of 2019 (Li et al., 2022). Due to its subtropical climate and unique topography (e.g., low terrain), there are numerous rivers and lakes across the metropolitan area (Lyu & Zhang, 2019).

The second largest inner-city lake in China, the East Lake, is within the highly built-up area (Fig. 2). To facilitate public health and improve ecosystem services, the local government converted a motorized vehicle road around the lake into a traffic-free greenway, to create a public space and connect nearby scenic spots (Xie et al., 2021). This project spanned 102 km and was constructed in two phases and operated in December 2017. The East Lake greenway has become very popular among the public; for example, it attracted over 23 million visitors in 2019. In summary, the large-scale project provided a unique opportunity to examine health benefits for nearby residents.

2.1.2. Data collection

A baseline survey was carried out in April 2016 and a follow-up survey in April 2019. The three-year interval ensured that there was sufficient time for the treatment group to accumulate health benefits delivered by the greenway. April was selected due to suitable apparent temperature and pleasant weather conditions in spring, which were essential for respondents' daily behaviors and instantaneous emotions. Meteorological data confirmed comparable conditions across the two waves (Xie et al., 2021).

At baseline, multistage stratified sampling was used to ensure the representativeness of the respondents. First, the data collection sites were selected. There are five entrances to the East Lake greenway and three of them mainly serve local residents. Street-network buffers with a 5 km radius were superimposed onto the three entrances. The rationale for this distance threshold was that city-level greenways in China are expected to have catchment areas of 5 km (Liu, Siu, Gong, Gao, & Lu, 2016) and the threshold had been used in previous infrastructure-related intervention studies (Panter & Ogilvie, 2015). Second, 52

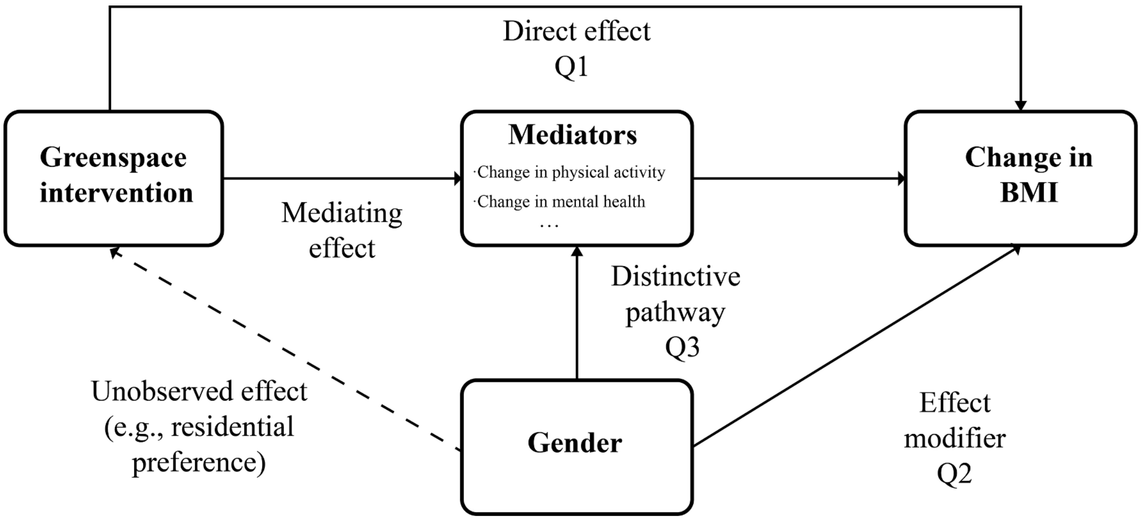

Fig 1. Conceptual framework of this study (we examined the mechanisms indicated with solid lines).

housing estates (*xiao qu*) were sampled, with equal numbers of high- and low-socioeconomic status (SES) estates (based on average housing price) in different segments of the buffers (i.e., 0–1 km, >1–2 km, >2–3 km, >3–4 km, and > 4–5 km). Third, Research team approached the sampled households randomly in each estate, and the number of participants was proportional to the total population of each estate. Participants living within 2 km of the greenway were oversampled.

Trained interviewers conducted face-to-face interviews with sampled respondents (aged > 18 years) based on pre-set questionnaires. Of the 4,634 respondents approached in the first wave, 2,331 completed all questionnaire items. The latter's mobile phone numbers were noted so that they could be contacted to participate in the follow-up. After excluding those who declined to participate in the follow-up wave or had relocated by then, our valid sample included a total of 1,020 respondents (retention rate of 43.8%).

To ensure the representativeness of our sample, typical individual characteristics (e.g., age, gender composition, and household annual income) were cross-compared with those of the overall population in the urban center of Wuhan. Descriptive statistics revealed no significant differences between the two groups (Xie et al., 2021). Notably, the research protocol was approved by the ethical committee of the City University of Hong Kong (No. H000691).

2.1.3. *Treatment and control groups assignment*

Previous studies have employed various distance thresholds to define whether participants were exposed to an intervention (Craig et al., 2017), and such threshold distances ranged from 500 m to several km (Frank, Hong, & Ngo, 2019; West & Shores, 2011). The use of inconsistent distance thresholds stemmed from the varying types and scales of interventions, as well as study contexts. For instance, due to lower urban density, the scale of intervention in Western settings tended to be limited, which resulted in the use of smaller distance thresholds to assign treatment–control groups.

We initially calculated the walking distance from each housing estate to the nearest greenway entrance along the street network to represent residential proximity to the greenway. The participants were then divided into treatment and control groups. The former included the respondents living in a housing estate within 2 km to a greenway entrance, while the latter included those living between 2 and 5 km to an entrance. We chose this distance threshold for two reasons: 1) prior natural experiment studies adopted a similar distance threshold to identify the physical activity or health effects of greenway intervention (Merom, Bauman, Vita, & Close, 2003), and 2) previous studies of the East Lake Greenway project confirmed that its catchment area was about 2 km, and such threshold showed good validity in evaluating different health outcomes of this greenway (He et al., 2021; Xie et al., 2021).

2.2. *Data*

2.2.1. *Outcome*

BMI is the most commonly used indicator to represent overweight and obesity outcomes (Romero-Corral et al., 2008; Yin, Yao, & Sun, 2022). In both waves of survey, respondents were requested to report height and weight information (preferring that from a recent medical examination) to calculate the BMI values (i.e., weight [in kg] / height [in m]). Thereafter, we determined the BMI changes before and after the greenway intervention, as done elsewhere (Hobbs, Griffiths, Green, Christensen, & McKenna, 2019).

2.2.2. *Mediators*

Based on the two-wave survey data, changes in MVPA and mental health were considered as potential mediators. First, MVPA was assessed with the following items from the International Physical Activity Questionnaire (IPAQ): "How many days did you engage in moderate/vigorous physical activities for at least 10 min during the prior seven days?", and "How much time in total did you usually spend on moderate/vigorous physical activities each day?" Based on the total time spent on MVPA per week, and the official IPAQ scoring protocol (https://www.ipaq.ki.se), we represented the overall MVPA energy expenditure as the metabolic equivalents (METs) per week (Ekelund et al., 2006). Second, the participants completed the 36-item Short-Form Health Survey (SF-36) (Lam, Eileen, Gandek, & Fong, 2005). SF-36 provides eight-scale health profiles of which two components represent physical and mental health. The calculation of the mental health component summary score (MCS) was based on Varimax-rotated factor analysis as recommended (Jenkinson, 1999), which had the merits of comparability and simplicity.

2.2.3. *Covariates*

Several covariates were included due to possible confounding effect. Respondents reported information regarding demographics, socioeconomic status (SES), and lifestyles at baseline. Specifically, age in years was included, and gender was grouped into female vs. male. Marital status was divided into married vs. others, and employment status was grouped into employed vs. others. Educational attainment contained college or above vs. others, and annual household income was incorporated as a continuous variable (in 1,000 CNY). Self-reported intakes of vegetables & fruit and high-calorie food were incorporated separately

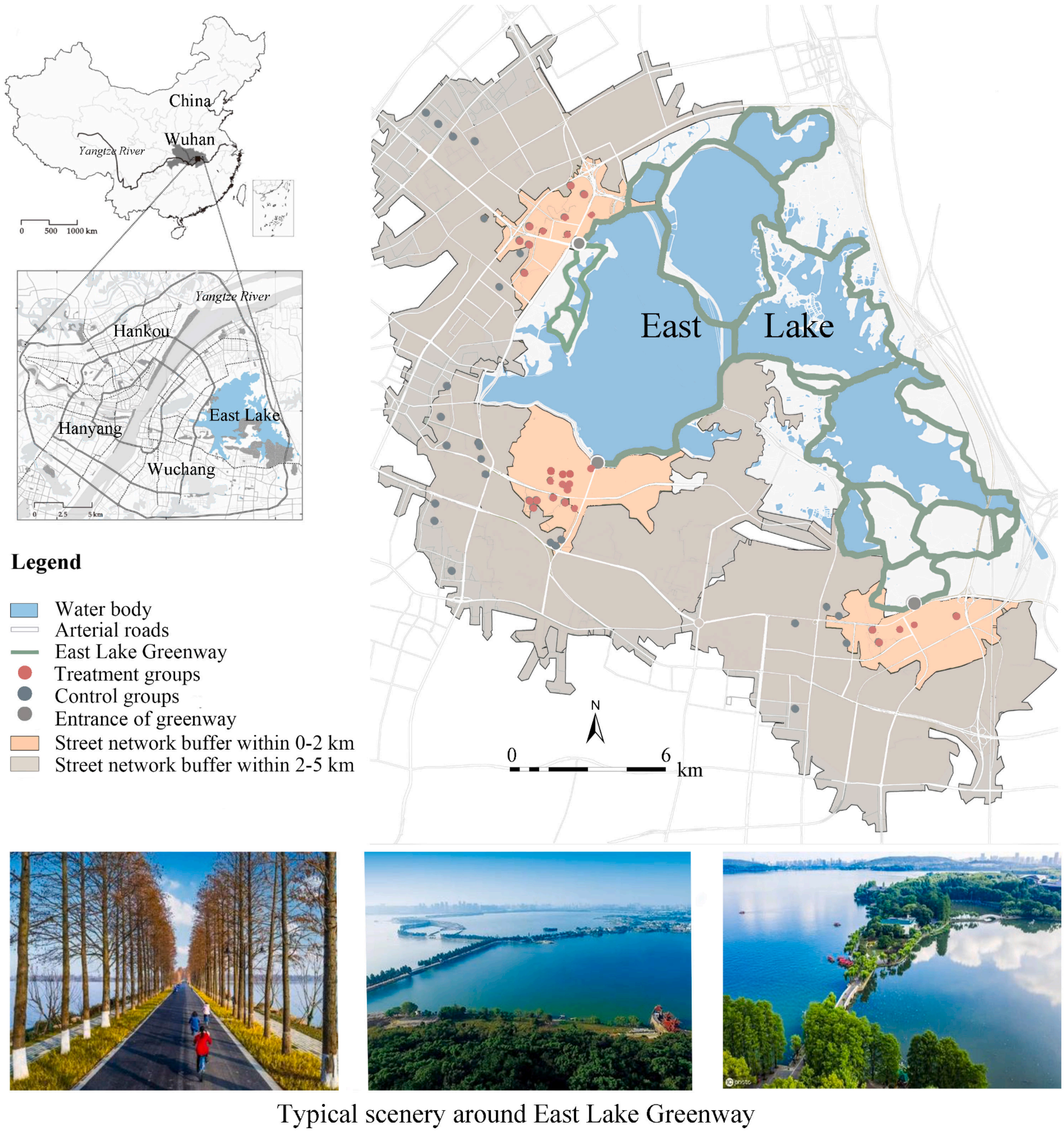

Fig 2. Study site and the distribution of selected housing estates.

based on 5-point Likert scale (1 = never, 5 = almost every day).

Neighborhood environmental attributes were collected based on 500 m street-network buffers centered on each housing estate (Xie et al., 2021). We included the number of road intersections, building coverage ratio, land-use mix, number of parks, and number of bus stops(Li, Li, Jia, Zhou, & Hijazi, 2022). Information on these characteristics was collected at baseline from the local planning bureau. Land-use mix was measured by the Shannon diversity index using seven land-use types (e. g., commercial land, residential land). Building coverage ratio was measured as the proportion of the area of land occupied by buildings and the total land area of a neighborhood. Neighborhood-level SES was represented through the average estate-level housing price in 2016 (Moudon, Cook, Ulmer, Hurvitz, & Drewnowski, 2011), dichotomized into above (high SES) or below the average price of 20,000 CNY/m^2 (low SES) (Xie et al., 2021).

2.3. Statistical analyses

We used a two-step analysis to examine the direct effects between the greenway intervention and BMI as well as the mediating pathways separately. First, mixed-effect difference-in-difference (DID) regression models were employed to assess the effects of the greenway intervention on changes in BMI. Three models were for all participants (Model 1), men (Model 2), and women (Model 3) respectively. Relevant methods have been extensively used in natural experimental studies (Alemi, Rodier, & Drake, 2018; Delaruelle, van de Werfhorst, & Bracke, 2019). The merits of such models include the ability to account for both unobserved and observed variation in the fixed characteristics of groups, thus making them less prone to confounding bias (Craig et al., 2017). The information from the follow-up survey (t_2) was matched with the baseline survey (t_1) using a unique identifier. The detailed information of DID models is as follows:

$$BMI_{ijt} = \beta_1 Proximity_{ij} + \beta_2 Time_{it} + \beta_3 Proximity_{ij}{*}Time_{it} + \beta_4 Covariates_{ij} + u_{ij}$$

BMI_{ijt} is the BMI of participant i in estate j in time t. $Proximity_{ij}$ is a binary variable of greenway exposure (exposed vs. unexposed), and β_1 represents the net difference between the participants exposed/unexposed to the greenway. $Time_{it}$ is binary variable of data collection period (baseline vs. follow-up), and β_2 captures the net difference in BMI between the baseline and follow-up. $Proximity_{ij}{*}Time_{it}$ is an interaction term representing the difference-in differences effects of being exposed to greenway intervention. Hence, if β_3 is significant, we can infer the greenway intervention can reduce the body weight of the participants in treatment group. In addition, β_4 shows the effects of different covariates, and u_{ij} is the error term. Notably, all the continuous variables were standardized to make sure all variables contribute evenly to a scale.

Second, we used structural equation modeling (SEM) to investigate the mediating pathways between the greenway intervention and the change in BMI for men (Model 4) and for women (Model 5). SEM is a confirmatory and flexible approach that depicts the unidirectional effects of different mediators, which is desirable for longitudinal analyses (Pek & Hoyle, 2016). We modeled different potential mediators (i.e., changes in MVPA and mental health) simultaneously in our SEM and examined the pathways between the greenway intervention (treatment vs. control) and changes in BMI as outlined in Fig. 1.

Since participants' BMI across the waves may be influenced by unobserved environmental and lifestyles changes, a sensitivity test was conducted. We fitted another DID model to examine the association between weekly exposure time in the greenway and BMI (Model 6). Furthermore, due to the inconsistent distance thresholds when assigning treatment–control group (Hunter et al., 2015), we used an alternative distance threshold of 1 km (Model 7). All statistical analyses were conducted in STATA 15.0.

3. Results

3.1. Descriptive statistics

Table 1 presents the summary statistics of the sample. Paired t-tests were used to compare the changes in BMI of treatment and control groups across both waves. The BMI of the treatment group showed a slight decline at follow-up ($p < 0.01$), whereas the BMI of the control group increased ($p < 0.01$). Meanwhile, there were no significant differences in BMI change between men and women. The treatment group showed an inverse trend in the changes in the two mediators compared with the control group. Between baseline and follow-up, the participants in the treatment group experienced increased MVPA and improved mental health, while those in the control group experienced increased MVPA and worsened mental health. Women experienced a more pronounced MVPA and mental health improvement than men. Men showed higher education attainment and were fully employed. The intervention and control groups were similar concerning the covariates, and there were no significant differences except for employment status and park accessibility.

3.2. Difference-in-difference analysis

Table 2 presents the results of the DID models for all samples and stratified by gender. Model 1 shows a negative effect of greenway intervention on BMI for all samples after adjusting covariates. In addition, age is positively associated with BMI, and respondents who are married and intake more high-calorie food have higher BMI.

For gender stratified models, Model 2 illustrates a negative effect of greenway intervention on BMI for men. Some covariates are positively associated with BMI for men, including age, intake of high-calorie food, and land-use mix.

Model 3 also shows a negative effect of greenway intervention on

Table 1
Descriptive characteristics of the sample in this study.

Variables	Treatment group	Control group	Men	Women	Overall
	Mean (SD)/%	Mean (SD)/%	Mean (SD)/%	Mean (SD)/%	Mean (SD)/%
BMI-related variables					
BMI at baseline	22.57 (3.03)	22.73 (2.96)	22.60 (2.93)	22.61 (3.07)	22.61 (3.01)
BMI at follow-up	22.55 (3.00)	22.94 (2.98)	22.67 (2.97)	22.64 (3.03)	22.65 (3.00)
Changes in BMI	−0.02 (0.91) ***	0.21 (0.71) ***	0.07 (0.86)	0.02 (0.89)	0.04 (0.87)
Mediator-related variables					
MVPA at baseline (METs/week)	657.17 (676.76)	668.53 (596.90)	652.13 (654.43)	666.04 (660.38)	660.00 (657.51)
MVPA at follow-up (METs/week)	719.88 (705.96) ***	675.02 (604.26) ***	687.87 (660.33)	724.70 (698.41)	708.71 (682.05)
Changes in MVPA (METs/week)	448.93 (1732.43)	−20.27 (903.69)	251.52 (1384.72)	393.94 (1713.65)	332.08 (1580.44)
Mental health at baseline	52.01 (7.40)	53.67 (7.57)	52.52 (7.66)	52.35 (7.34)	52.43 (7.47)
Mental health at follow-up	52.49 (7.27) ***	53.46 (8.03) ***	52.69 (7.81)	52.76 (7.22)	52.74 (7.48)
Changes in mental health	0.48 (3.32)	−0.21 (3.03)	0.17 (3.40)	0.41 (3.15)	0.31 (3.26)
Covariates					
Age (in years)	50.12 (16.33)	52.77 (15.40)	51.01 (16.28)	50.61 (16.05)	50.79 (16.14)
Gender (% women)	59.44	55.61	N.A.	N.A.	56.57
Education (% with college or above)	49.48	52.76	57.79	44.54	50.29
Employed (% employed)	58.61	47.64	65.23	48.70	55.88
Marital status (% married)	84.07	81.89	81.26	85.27	83.53
Household income (in 1,000 CNY)	203.78 (202.88)	197.78 (392.22)	197.62 (216.98)	205.87 (293.51)	202.29 (263.00)
Intake of vegetables and fruit	4.82 (0.57)	4.70 (0.75)	4.80 (0.61)	4.78 (0.63)	4.79 (0.63)
Intake of high-calorie food	2.31 (1.20)	2.06 (1.17)	2.17 (1.25)	2.09 (1.13)	2.12 (1.19)
Building coverage ratio	0.18 (0.05)	0.22 (0.09)	0.20 (0.06)	0.19 (0.06)	0.19 (0.06)
Land-use mix	1.69 (0.45)	1.61 (0.37)	1.69 (0.42)	1.65 (0.44)	1.67 (0.43)
Number of road intersections	48.57 (39.61)	44.89 (51.60)	49.08 (44.42)	46.56 (41.73)	47.65 (42.93)
Number of parks	0.46 (0.83)	0.03 (0.26)	0.38 (0.79)	0.34 (0.73)	0.36 (0.76)
Number of bus stops	2.98 (2.33)	1.69 (1.24)	2.53 (2.03)	2.75 (2.29)	1.34 (1.26)
Neighborhood SES (% with high SES)	48.42	62.53	55.98	61.35	59.49
N (respondents)	766	254	443	577	1020

Note: (1) Paired t-tests were used to compare the participants' changes in BMI from baseline to follow-up.
(2) Changes in the variables = mean value at t_2 – mean value at t_1.
(3) $^{*}p < 0.1$, $^{**}p < 0.05$, $^{***}p < 0.01$.
(4) N.A. = not applicable.

Table 2
Results of the mixed-effect DID regression models.

	BMI		
	Model 1 (all samples)	Model 2 (men)	Model 3 (women)
	Standardized beta (SE)	Standardized beta (SE)	Standardized beta (SE)
Explanatory variables			
Time (follow-up vs. baseline)	0.070 *** (0.018)	0.084 *** (0.028)	0.061 *** (0.024)
Greenway proximity (treatment vs. control group)	0.036 (0.089)	0.051 (0.123)	−0.011 (0.122)
Time × greenway proximity	−0.072 *** (0.021)	−0.077 ** (0.032)	−0.070 ** (0.028)
Covariates			
Age	0.216 *** (0.033)	0.233 *** (0.049)	0.220 *** (0.044)
Education (ref. = high school or lower)	0.016 (0.066)	0.066 (0.096)	−0.025 (0.090)
Employed (ref. = not employed)	0.048 (0.067)	0.113 (0.099)	0.017 (0.091)
Marital status (ref. = not married)	0.209 ** (0.082)	0.086 (0.117)	0.339 *** (0.117)
Household income	−0.039 (0.032)	−0.002 (0.058)	−0.063 * (0.038)
MVPA	−0.015 (0.018)	−0.061 (0.029)	0.009 (0.022)
Mental health	−0.024 (0.018)	0.004 (0.025)	−0.036 (0.025)
Intake of vegetables and fruit	0.014 (0.049)	0.010 (0.073)	0.015 (0.065)
Intake of high-calorie food	0.092 *** (0.028)	0.119 *** (0.039)	0.068 * (0.038)
Building coverage ratio	0.011 (0.041)	0.035 (0.057)	−0.027 (0.055)
Land-use mix	0.043 (0.044)	0.104 * (0.057)	−0.002 (0.061)
Number of road intersections	−0.008 (0.040)	−0.055 (0.052)	0.046 (0.057)
Number of parks	−0.075 * (0.044)	−0.084 (0.051)	−0.078 (0.063)
Number of bus stops	0.007 (0.043)	−0.073 (0.060)	0.054 (0.057)
Neighborhood SES (ref. = low)	−0.034 (0.075)	−0.002 (0.101)	−0.079 (0.105)
Constant	−0.498 (0.271)	−0.559 (0.393)	−0.449 (0.357)
AIC	3211.31	1367.23	1859.60
N	1020	443	577

Note: SE = standard error, AIC = Akaike information criterion, **p* < 0.1, ***p* < 0.05, ****p* < 0.01.

Table 3
Results of the SEM stratified by gender.

	Indirect effect for men (Model 4)		Direct effect
Mediator	Change in MVPA Standardized beta (SE)	Change in mental health Standardized beta (SE)	Standardized beta (SE)
Greenway proximity (treatment vs. control group)	−0.472 * (0.048)	−0.010 (0.011)	−0.278** (0.125)
	Indirect effect for women (Model 5)		Direct effect
Mediator	Change in MVPA Standardized beta (SE)	Change in mental health Standardized beta (SE)	Standardized beta (SE)
Greenway proximity (treatment vs. control group)	−0.160 (0.011)	−0.245* (0.033)	−0.179*** (0.109)

Note: 1) **p* < 0.1, ***p* < 0.05, ****p* < 0.01.
(2) Fitting test of the model: RMSEA ≤ 0.08; CFI ≥ 0.90.
(3) The covariates were controlled in the models.

Table 4
Sensitivity tests: regression estimates of the greenway exposure time and distance threshold on BMI.

	Model 6	Model 7
	Standardized beta (SE)	Standardized beta (SE)
Time (follow-up vs. baseline)	0.103 *** (0.022)	0.032 *** (0.012)
Greenway proximity (treatment vs. control group)	0.014 (0.092)	−0.022 (0.073)
Time × greenway proximity	−0.078 *** (0.022)	−0.036 ** (0.018)
Weekly exposure time to the greenway	−0.038 * (0.196)	
AIC	3034.50	3220.53

Note: SE = standard error, AIC = Akaike information criterion, **p* < 0.1, ***p* < 0.05, ****p* < 0.01.

BMI for women. In terms of the covariates, age, being married, and intake of high-calorie food are positively associated with BMI for women. These results verify that the East Lake Greenway intervention is effective in reducing higher body weight for both men and women.

3.3. Mediating analysis

Results of the mediating analysis are presented in Table 3. Model 3 shows that the BMI effect of the greenway is partly mediated by change in MVPA (-0.472, $p < 0.1$) among men, after controlling for covariates. The effect of changes in MVPA accounts for 15.5% of the overall effect of the greenway on the changes in BMI. In contrast, changes in mental health do not exert significant mediating effects among men.

Model 4 indicates that the BMI effect of the greenway is mediated by mental health changes (-0.245, $p < 0.1$) among women. The effect of changes in mental health accounts for 8.2% of the overall effect. No significant mediating effects are observed for changes in MVPA among women.

3.4. Sensitivity tests

Results of the sensitivity tests are presented in Table 4. Model 6 shows that a person's weekly greenway exposure time is negatively associated with BMI. By using a 1 km distance threshold in Model 7 (rather than 2 km as used in Models 1–3), we find that the treatment effects of greenway intervention remain significant. Overall, our additional tests confirm the robustness of the primary DID analyses.

4. Discussion

4.1. Main findings

This study used a natural experiment approach to investigate how a large-scale greenway intervention in Wuhan, China, affected individuals' body weight maintenance. Our results showed that the greenway intervention was effective in maintaining BMI for the treatment group, and no significant gender inequalities in body weight benefits were observed. However, we found distinct mediating mechanisms for men and women: A change in MVPA partly mediated 15.5% of the total effect of greenway intervention on body weight changes for men, while a change in mental health mediated 8.2% of the total effect for women.

4.2. Greenway intervention on BMI changes

Although increasing cities in China have recently created numerous public greenspaces (e.g., parks, greenways, and wetlands) or improved existing ones, their population-level health benefits remain unclear (Lu, Zhao, Wu, & Lo, 2021). Because the creation or modification of greenspaces requires massive investments and long-term planning, causal evidence is needed to support further intervention projects.

The results showed that the treatment group experienced significant BMI changes relative to the control group over a three-year period. Although the average BMI reduction in the treatment group (i.e., those living within 2 km of greenway entrances) was marginal with a 0.02 kg/m^2 decrease in BMI, the body weight benefits of the greenway intervention were salient considering that the BMI increased by, on average, 0.21 kg/m^2 in the control group. This decrease in BMI among the treatment group could be explained by the fact that they were more likely to visit the greenway to stimulate energy expenditure and maintain mental health (He et al., 2021). Constrained by the greater residential distance from the intervention, the participants in the control group tended to be unaffected by greenway and experienced BMI increase. Two reasons could strengthen this argument. First, prior studies indicated that BMI may accompany the increase in age among adults (He et al., 2017). Second, the prevalence of being overweight or obese in China may suggest that the population-level body weight increased during the observation period.

The observed association between green space and BMI are in line with those from cross-sectional studies (Huang et al., 2020a; Sarkar, 2017), while we further assessed the treatment effects of greenway intervention on BMI change with rigorous research design. These findings also strengthen the rationale of green infrastructure investment in maintaining public health in high-density cities. Urban dwellers living in densified environments tend to have limited access to greenspaces. The construction of a greenway greatly improved residents' health behaviors and mental health, which alleviated the trend of increasing BMI. Considering that the population density exceeds 30,000 persons per km^2 in the urban center of Wuhan and the large catchment area of this greenway, the long-term health benefits (three years in our study) are prominent.

4.3. Gender disparities

With respect to the overall gender-specific influence of the greenway on the change in BMI, we did not observe significant differences between men and women. This contrasted with other studies that found stronger effects of greenspace on women's body weight (O'Callaghan-Gordo et al., 2020; Persson et al., 2018). We found that men's and women's greenway usage were similar (on average, 100 min/week), which may explain the even greenway benefits. By contrast, previous studies mainly surveyed geographically heterogeneous neighborhoods (Huang et al., 2020a; Persson et al., 2018), whereas the scale and quality of greenspace, as well as the cultural context, varied greatly (Knobel et al., 2021; Nieuwenhuijsen et al., 2017). These studies were likely susceptible to unmeasured attributes (e.g., safety and attractiveness) of different greenspaces, which may unconsciously influence the greenspace use and further lead to gender disparity in body weight outcomes. Notably, we did observe some gender disparities in the association between a few built environment effects (e.g., land-use mix and number of parks) and BMI.

We also examined whether gender disparities exist in terms of pathways between the greenway intervention and BMI changes. The observed improvements in mental health mediated the relationship between the greenway intervention and BMI changes among women, while the promotion of MVPA was statistically significant for men. Several studies have also reported distinct greenspace use patterns across gender (Palliwoda, Kowarik, & von der Lippe, 2017; Richardson & Mitchell, 2010). Women tended to have diverse leisure activities than men in greenspaces (Sang et al., 2020). In doing so, interacting more with nature may promote stress recovery and further influence BMI change. In contrast, men tended to be more physically active in greenspaces (Casper, Harrolle, & Kelley, 2013). In our case, the East Lake greenway has many lakes, woodlands, and scenic spots, which provide venues and facilities for diverse greenspace use. As different gender groups could engage in their preferred activities, distinct drivers and behavior patterns could then unconsciously influence the efficiency of different mediating pathways. However, the exact reasons for the gender difference warrant further investigations (O'Callaghan-Gordo et al., 2020).

4.4. Strengths and limitations

Our research had multiple strengths. First, the present study was one of the first natural experiments to investigate the effects of a greenspace on changes in body weight outcomes. Greenways in prior studies were typically small (e.g., a few kilometers in length), and cumulative long-term benefits (e.g., body weight or chronic disease outcomes) were elusive. Because a large-scale greenway attracted residents living further away and increased greenway using time and frequency, its cumulative health effects, as demonstrated in this study, may be promising (Xie et al., 2021). Furthermore, we explored mediating mechanisms via which the greenway intervention affects body weight for both men and women. Such results improved our understanding of the causal relationship between intervention and health outcomes (Lachowycz and Jones, 2013).

Several limitations should be acknowledged. The major limitation was that we used self-reported data to measure body weight. Since individuals tend to underreport their body weight (Rothman, 2008), future studies are advised to use better adiposity outcomes (e.g., objectively measured weight, height, and waist circumstance). Moreover, some participants' BMI change was due to an increase in height. However, given that there were only 9 respondents younger than 22 years, the BMI change influenced by ontogenesis is negligible. Second, the participants provided physical activity information based on IPAQ items. Objective physical activity data collected by accelerometers and global positioning systems are recommended. Third, we cannot exclude the changes in individual-level attributes (i.e., health and major life events) between baseline and follow-up. Future longitudinal research should account for the occurrence of life events on the changes in participants' body weight. Fourth, we did not have access to high-resolution time series of air pollutant data. Air pollution has been hypothesized to promote metabolic dysfunction (Huang et al., 2020b), the reported protective greenspace effects may be partly explained through the filtering of health-threatening air pollutants by foliage (Huang et al., 2020a). In addition, it should be noted that our findings were based on samples with relatively high SES and ages, more evidence from different tiers of cities in China are warranted to get generalizable results.

5. Conclusion

This study assessed the extent to which a large-scale greenway intervention influenced peoples' body weight in Wuhan, China. The treatment group experienced a modest BMI reduction, while the control group experienced a relatively large BMI increase. The mixed-effect DID regression models robustly indicated that the effects of the greenway intervention on BMI changes were significant. The mediation analysis showed gender-specific pathways between the greenway intervention and changes in BMI. Specifically, improved mental health mediated the effect of greenway exposure on BMI for women, while increased MVPA mediated that effect for men. Our findings not only provided compelling evidence that a greenway intervention leads to body weight reduction, but also illustrated causal attribution of treatment effect for both men and women.

Ethics approval

Ethical approval for the study was obtained prior to this study from the Research Committee of City University of Hong Kong (No. H000691). All participants provided written informed consent.

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CRediT authorship contribution statement

Dongsheng He: Formal analysis, Methodology, Visualization, Writing – original draft. **Yi Lu:** Conceptualization, Supervision, Writing – review & editing. **Bo Xie:** Conceptualization, Data curation, Supervision, Writing – review & editing. **Marco Helbich:** Writing – review & editing.

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.

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