Travel Behaviour and Society 20 (2020) 104–113

Contents lists available at ScienceDirect

Travel Behaviour and Society

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

Urban greenery, active school transport, and body weight among Hong Kong children

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ARTICLE INFO

Keywords:
Urban greenery
Physical activity
Active transport
BMI
Childhood obesity
School environment

ABSTRACT

Children who are overweight or obese are at a higher risk of several diseases and are more likely to be overweight or obese in adulthood. Physical inactivity among children and adolescents is one of the major causes of the prevalence of overweight and obesity problems, and hence promoting physical activity, especially active school transport (AST), is a public health priority. Previous studies have provided evidence that urban greenery may promote physical activity and improve body weight outcomes among children. However, the relationships reported between these factors are inconsistent, partly due to the use of different measures of urban greenery. In the present study, we assessed different dimensions of urban greenery using three measures: number of parks; the Normalized Difference Vegetation Index (NDVI) based on satellite imagery; and street greenness based on Google Street View images. Multilevel regression analysis and structural equation modeling were conducted to investigate the complex relationships among urban greenery, AST, and body weight for 1,148 primary school students in Hong Kong. Overall, children attending schools with greener surrounding areas were more likely to engage in AST and had lower body mass index (BMI). In addition, AST partially mediated the impact of urban greenery on BMI. The findings demonstrate the importance of greenery around schools for children's body weight status. They also offer public health and planning guidance on how to address overweight and obesity problems among children.

1. Introduction

The prevalence of childhood overweight and obesity has increased over the last four decades, making this a worldwide public health problem (Hruby and Hu, 2015). Children with overweight and obesity problems are at a higher risk of developing many chronic health conditions and diseases that injure mental and physical health, including asthma, sleep disorder, bone and joint problems, type II diabetes, and heart disease (Kumar and Kelly, 2017; Ranjani et al., 2016). In the long term, a child who is overweight or obese is more likely to be obese as an adult, which is associated with a higher risk of developing heart disease, type II diabetes, metabolic syndrome, and many types of cancer as well (Arroyo-Johnson and Mincey, 2016; Phillips, 2017). In Hong Kong, the rate of overweight and obesity among primary school students increased from 16.1% in 1996 to 20.0% in 2014, making childhood overweight and obesity a serious public health concern (Wang et al., 2017; Wong et al., 2005).

Physical inactivity among children is one of the major causes of the prevalence of childhood overweight and obesity (Goran et al., 1999). The World Health Organization recommends that school-aged children engage in 60 min of moderately intense to vigorous physical activity a day. The results of experimental studies have indicated that modest amounts of physical activity can provide health benefits and that vigorous activities may provide even greater benefits (Janssen and LeBlanc, 2010). The recommended physical activity guidelines encourage various combinations of play, recreation, physical education activities, sport, and active transport. However, in Hong Kong, less than 50% of young people meet these guidelines (CUHK, 2018).

The transportation modes between home and school typically include passive modes, such as busing or riding in a private vehicle, and active modes, such as walking or cycling. Active school transport (AST) is a major source of children and adolescent's physical activity (Tudor-

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https://doi.org/10.1016/j.tbs.2020.03.001
Received 22 October 2019; Received in revised form 21 February 2020; Accepted 2 March 2020
Available online 12 March 2020

Locke et al., 2001). A review focused on the relationship between AST and physical activity and body weight has shown that children walking or cycling to school had higher level of overall physical activity compared with those who travel to school in passive modes (Faulkner et al., 2009). Empirical studies found the proportions of children meeting physical activity guidelines significantly differed by school transportation modes. Measured by accelerometers, active school commuters exhibited higher overall physical activity levels per hour (Cooper et al., 2003; Sirard et al., 2005), or more minutes of moderate-to-vigorous physical activity per day, than passive commuters (Alexander et al., 2005; Faulkner et al., 2009; Kek et al., 2019; Sirard et al., 2005). In Ireland, Cyprus and Canada, children who walked to school significantly exhibited higher step counts during the before school period, the after school period and the whole day compared to children who used motorized transportation mode (Elaine and Marie, 2011; Loucaides and Jago, 2008; Pabayo et al., 2012). Researchers also found evidence that primary school boys who walked or cycled to school were significantly more physically active than those traveling by car, while girls who walked but not cycled to school were significantly associated with higher daily physical activity levels (Cooper et al., 2005). AST is also well placed to address inequalities in physical activity participation in terms of age, gender, and socioeconomic status (Brainard et al., 2019; Mandic et al., 2015; Stark et al., 2018). Thus, AST has the potential to make a substantial contribution to children's daily overall physical activity (Pate et al., 2016). However, AST has declined dramatically in various contexts, including Australia, the United States, the United Kingdom, and Hong Kong. In the United States, nearly half (49%) of children aged 5 to 14 actively traveled to school in 1969 but in 2009, the rate had dropped to 13% (McDonald et al., 2011). In Hong Kong, the rate of AST also dropped from 40% to 29% over the last several decades (Census & Statistics Department of Hong Kong, 2016).

Children's levels of physical activity are highly volatile and may be influenced by a multitude of factors, including physiological, psychological, sociocultural, and environmental determinants (Almanza et al., 2012; Duncan et al., 2014; Goran et al., 1999; Lovasi et al., 2011). Their level of physical activity is associated with numerous built environment factors (Saelens et al., 2003), such as land use mix (Aytur et al., 2008; Frank et al., 2004; Saelens et al., 2003), urban density (Saelens et al., 2003; Schlossberg et al., 2006), and street connectivity (Larsen et al., 2009; Saelens et al., 2003). However, evidence for the built environment determinants of AST remains mixed. In a recent study conducted in New Zealand with 2,840 participants, AST was positively associated with intersection density (1 km buffer) and negatively related to dwelling density (1 km buffer) and distance to school (Ikeda et al., 2018). Distance between home and school is regarded as one of the most consistent correlates of AST, with long distance as one of the greatest barriers (Chica-Olmo et al., 2018; Mandic et al., 2017; Rothman et al., 2018). In the ultra-dense metropolis of Hong Kong, most districts are highly self-contained and children usually attend schools close to their housing estates, which may facilitate AST (Census & Statistics Department of Hong Kong, 2011).

Among the relevant built environment factors, the relationship between urban greenery and physical activity has received increasing research attention because rapid urbanization is reducing people's opportunities to contact with nature (Gubbels et al., 2016; Hunter et al., 2015; Lu, 2018a; Mårtensson et al., 2014). A study conducted in the United States found that children living in areas with more street trees were more physically active (Lovasi et al., 2011). In another study of 208 children, which used the normalized difference vegetation index (NDVI) as an objective measure of urban greenery from satellite imagery, researchers found that greenness exposure was positively associated with the odds of engaging in moderate to vigorous physical activity (Almanza et al., 2012). Another study demonstrated that children's green space exposure was positively linked to their physical activity (James et al., 2015). Specifically, researchers also found a significantly positive association between the likelihood of conducting AST and the presence of street trees and parks, good maintenance of green spaces, and absence of litter (Larsen et al., 2009; Van Kann et al., 2014).

Yet, findings regarding the association between urban greenery and body weight status for children are mixed. A systematic review focusing on urban greenness, physical activity, and body weight found fairly strong evidence of a positive association between greenness and physical activity and a less consistent negative association between greenness and body weight (James et al., 2015). One group of researchers found that greenness was significantly associated with a decreased risk of overweight among children in high-density areas, but not in low-density counterparts (Liu et al., 2007). Another study found that street tree density, but not park area, was associated with a lower obesity prevalence level among children (Lovasi et al., 2013). Some researchers have argued that these inconsistent results are due to the use of different measures of urban greenery (de Vries et al., 2013; Fan et al., 2011; Picavet et al., 2016). Recent studies have indicated that perceived greenness plays a more significant role than overall objectively measured greenness in daily physical activity and body weight status (Bai et al., 2013; de Jong et al., 2012; Hipp et al., 2016). To this end, in this study, we used three methods to measure urban greenery near children's home and school: the number of parks, the NDVI, and street greenness (extracted from Google Street View (GSV) images). The measure of eye-level street greenery can effectively capture residents' daily exposure to greenness and has been applied in recent public health studies (Lu, 2018b).

1.1. Conceptual model and hypotheses

To address this research gap, we constructed a conceptual framework for modeling the effects of urban greenery on body weight status (Fig. 1). As supported by strong evidence, the exposure to urban

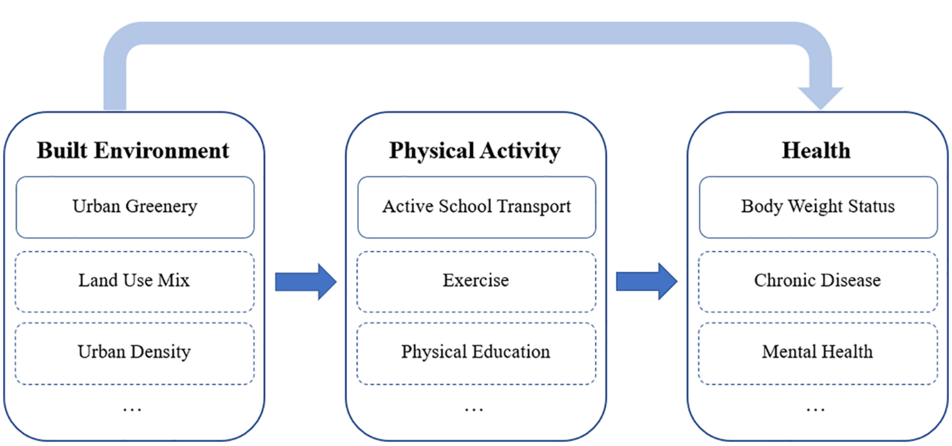

Fig. 1. The concept framework among built environment, physical activity and health. For example, urban greenery can affect body weight status via promoting physical activity, or other pathways, such as promoting social contacts and reducing air pollution and stress. Dark arrows represent the strong evidence of direct impact while the light arrow represents the weak evidence of potential direct and indirect impact.

greenery can increase physical activity, and increased physical activity can achieve better body weight outcomes. However, few researchers have used a single comprehensive framework to explore the mediating effects of physical activity on the relationship between urban greenery and body weight among children. Although it is intuitive to develop urban greenery interventions to increase children's physical activity and hence improve their body weight outcomes, there is little rigorous scientific evidence to support such a policy. Based upon previous studies, we proposed that urban greenery may affect children's body weight outcomes via the mechanism of increasing physical activity (Mitchell, 2013; Richardson et al., 2013; Zhang et al., 2018).

In the present study, we used structural equation modeling (SEM) to examine the degree to which AST mediates the relationship between urban greenery and body weight outcomes. As a powerful method of examining the complex relationships among a set of variables, SEM has been widely used in the health literature (Mohamadian et al., 2011; Weden, Carpiano, & Robert, 2008; Zhang et al., 2018). It can be used to estimate abstract concepts (such as individual health outcomes) using measured variables, to examine the complex mediating relationships among variables, and to improve the accuracy and credibility of model results by considering the influence of measurement error. Using SEM, a recent study found that daily greenspace exposure directly influenced adults' health and indirectly affected health status through physical activity (Zhang et al., 2018), which may help researchers to understand the role of physical activity in mediating the relationship between urban greenery and health status among adults. Nevertheless, few studies have focused on the mediating mechanism of AST between urban greenery and the weight status among children.

Fig. 2 shows the potential relationships among urban greenery, AST, and body weight status. We hypothesized that urban greenery has a significant effect on body weight status; and that it promotes daily physical activity and thus indirectly improves body weight status. Our five specific hypotheses are listed in Table 1.

2. Method

2.1. Participants

We conducted a face-to-face survey in March 2018 with 1,148 Hong Kong primary school students, comprised of 559 girls and 589 boys from the fifth and sixth grades of 40 primary schools in Hong Kong, of which 11 were located in Kowloon, 13 in Hong Kong Island, and the other 16 in New Territories. The 40 primary schools were selected by stratified random sampling, aimed at selecting schools in neighborhoods with different socio-economic and built environment contexts. The list of participating schools is given in Appendix A.

Interviews were conducted by trained interviewers to collect data about participants' demographic information, household information, and active school transport record. Participants were asked about "how many days did you walk or bike to/from school during the last 7 days?" Hence, we identified participants who had done active school transport and those who had not done so. The participants and their parents were also required to provide a dwelling address, which was used to assess the built environment factors. Besides, participants were required to provide their body weight and height, which were then used to calculate body mass index (BMI), namely, the ratio between the weight in kilograms to the square of height in meters. BMI is a widely used screening tool for measuring overweight and obesity. Researchers have found that BMI is similar to other measurements in being highly related to disease risks for children and adolescents (Lawlor et al., 2010; Steinberger et al., 2005), and measuring height and weight is easier and less expensive than other methods of assessing weight status.

2.2. Urban greenery

In this study, urban greenery was measured using three objective methods: the number of parks, the NDVI, and street greenness. The number of parks was defined as the total number of parks within two buffer zones of a participant's dwelling and school address. The data on the urban parks were obtained from the Land Department of Hong Kong SAR. Two buffer zones commonly used in walking/cycling built environment studies were adopted in this study: 400 m and 800 m. Using multiple buffer zones can also mitigate the modifiable areal unit problem, which indicates that built environment–active travel associations are influenced by the scale of the aggregation unit (Houston, 2014; Wong, 2009).

The NDVI was used to assess the gross urban greenness of a whole area from a multispectral imagery dataset, based on the contrast between two bands: the chlorophyll pigment absorptions of plants in the red band (*Red*) and the high reflectivity in the near-infrared band (*NIR*). The NDVI equation is expressed as

$$NDVI = (NIR - Red) / (NIR + Red).$$

NDVI values range between −1.0 and 1.0, with higher values representing higher levels of vegetation. The average NDVI value within a buffer zone for a dwelling and school location was used to measure the overall urban greenness.

The street greenness extracted from GSV images was used to estimate the level of greenness perceived by students on streets. GSV-generating points were created along all streets at a spacing of 50 m. The coordinates of the GSV-generating points were input into a Python script, and four GSV images were downloaded for each point, with a 90° field of view and headings of north, east, south, and west.

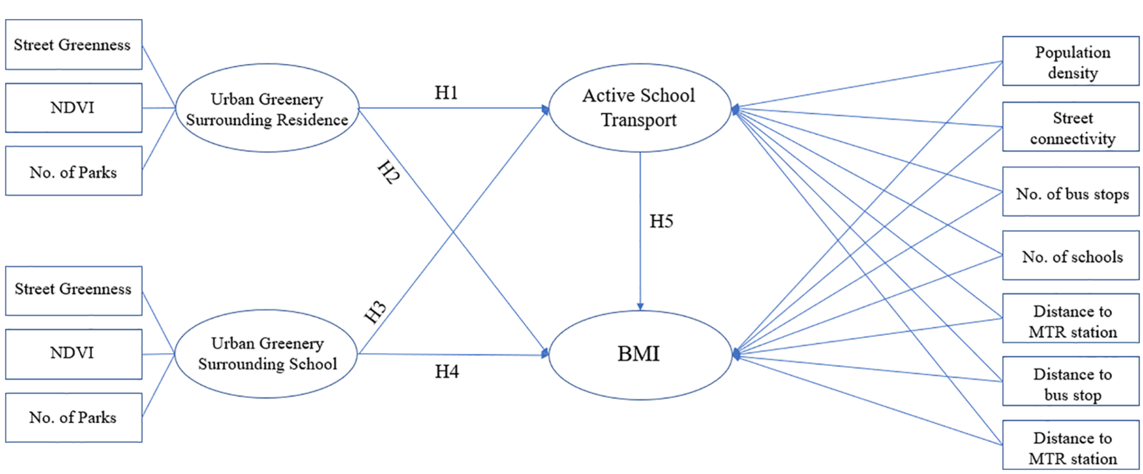

Fig. 2. Conceptual model and the interaction among urban greenery, physical activity, and weight status.

Table 1
The five hypotheses.

Hypotheses	
H1	Urban greenery surrounding residence has a significant positive effect on AST
H2	Urban greenery surrounding residence has a significant positive effect on body weight status
H3	Urban greenery surrounding school has a significant positive effect on AST
H4	Urban greenery surrounding school has a significant positive effect on body weight status
H5	AST has a significant positive effect on body weight status

A separate script was developed to determine the level of greenness in each GSV image using an automated machine-learning vegetation extraction method (Houston, 2014). The ratio of greenery pixels to total pixels in four images from a GSV-generating point was used to assess the level of street greenness for the point, as shown in the following equation:

$$Street\ greenness = \frac{\sum_{i=1}^{4} Greenerypixels_i}{\sum_{i=1}^{4} Totalpixels_i}.$$

Street greenness values range between 0.0 and 1.0, with higher values representing higher levels of street greenness. The average value for all GSV-generating points within the buffer zone of a dwelling or school location was used to assess the level of street greenness. The automated vegetation extraction was validated using manual extraction. In our pilot study, 30 GSV images were randomly selected, and their vegetation was manually extracted by a researcher using Adobe Photoshop. The values of the GSV greenness extraction were highly correlated with those of the manual extraction ($r = 0.91$; $p < 0.01$).

2.3. Other built environment variables

We also calculated other built environment variables within the two buffer zones and adjusted the analysis models to incorporate them. These variables were as follows: distance between school and dwelling location, population density, street intersection density, number of shops, number of bus stops, number of schools, distance between dwelling location and bus stops, and distance between dwelling location and Mass Transit Railway (MTR) stations. Population density was calculated by the residential population per unit of land area in a pupil's residential neighborhood. Street intersection density was measured by the number of street intersections involving three or more ways per unit of land area. The age and gender of the participants were also included in the analysis as potential confounding variables.

3. Data analysis

3.1. Multilevel modeling

A two-step analysis strategy was implemented corresponding to the data we collected from participants: 1) logistic regression to examine the association between urban greenness and the odds of engaging in AST; 2) linear regression to examine the association between urban greenness and BMI. Multilevel modeling was used for the analysis after controlling for other built environment and individual confounding variables. Individual participants were clustered within street blocks, which are census defined and aggregated in Hong Kong as urban planning units. Models 1 and 2 were used for the 400-m and 800-m buffers, respectively. All of the analyses were performed using the statistical software STATA 13.0 (StataCorp LLC).

3.2. Structural equation modeling

Before conducting the SEM, the reliability and validity of the variables were verified using Cronbach's alpha and factor analysis. Cronbach's alpha is a measure of internal consistency. It is considered to be a measure of scale reliability (Bland and Altman, 1997; Raykov, 1997). The fit index CMIN/DF is the minimum discrepancy divided by its degrees of freedom, and the ratio should be close to 1 for correct models. The goodness of fit index (GFI) was devised by (Joreskog and Sorbom, 1984) for maximum likelihood and unweighted least squares) estimation. The adjusted GFI (AGFI) takes into account the degrees of freedom available for testing the model. The population root mean square error of approximation (RMSEA) was also calculated (Joreskog and Sorbom, 1984).

In the present study, we mainly focused on the direct impact of urban greenery on individual BMI and the indirect impact of urban greenery on individual BMI via AST. Personal characteristics and other built environment variables were treated as confounders in the models.

4. Results

4.1. Results of Multilevel regression model

Table 2 and 3 shows the characteristics of the participants and built environment respectively. Of the total 1,148 primary school students from the fifth and sixth grades, 813 provided an accurate household address. There were slightly more sixth graders than fifth graders (53.4% vs. 46.6%). In terms of AST, 37.11% of the students walked or rode a bicycle to school four or five days a week (426 of 1148), while 31.7% of the participants never walked or rode a bicycle to school. Boys slightly outnumbered girls, but girls were more likely to walk or ride a bicycle to schools than boys (51.3% vs. 48.7%).

The results of the regression model analysis for predicting the odds of engaging AST are shown in Table 4. Street greenness and the number of parks surrounding school were both positively associated with the odds of engaging in AST with the 400 m buffer (OR [95% CI]: 1.32 [1.18, 1.51] and 1.21 [1.13, 1.32] respectively). The overall greenness surrounding school was also positively associated with the odds of

Table 2
Demographics and AST characteristics of the sample ($n = 1148$).

Individual characteristics	Number of participants	Percentage (%)	Engaged in active school transport (%)
Grade (y)			
5 (11–12 years old)	535	46.6	62.6
6 (12–13 years old)	613	53.4	66.2
Gender			
Male	589	51.3	62.1
Female	559	48.7	67.0
Height (cm)			
< 120	6	0.5	33.3
120–140	275	24.0	50.2
140–160	773	67.3	67.9
> 160	94	8.2	80.9
Weight (kg)			
< 30	64	5.6	62.5
30–40	463	40.3	57.4
40–50	485	42.2	66.4
50–60	124	10.8	84.7
> 60	12	1.0	66.7

Table 3
Descriptive statistics of urban greenness and built environment factors.

Variable	400 m buffer		800 m buffer	
	Mean	SD	Mean	SD
Urban Greenness				
H-Street greenness (GSV)	0.137	0.0417	0.1375	0.0344
H-Overall greenness (NDVI)	0.1686	0.1256	0.1798	0.1297
H-Number of parks	5.3247	3.709	16.22	9.0326
S-Street greenness (GSV)	0.1495	0.047	0.1459	0.0452
S-Overall greenness (NDVI)	0.2024	0.1405	0.2139	0.1505
S-Number of parks	4.4	3.7608	13.625	9.4345
Built environment				
H-Population density	43,720	21,783	38,529	16,449
H-Street intersection density	78.659	39.455	63.588	29.079
H-Number of bus stops	20.31734	10.60963	60.967	30.76
H-Number of schools	11.049	5.4603	31.82	13.969
H-Distance to MTR station	660.2021	787.2687	660.2021	787.2687
H-Distance to bus stop	82.27403	49.81983	82.27403	49.81983
S-Street intersection density	72.837	38.914	59.046	30.959
S-Number of bus stops	17.4	11.247	53.4	31.596
S-Distance to MTR station	920.45	1155.8	920.45	1155.8
S-Distance to bus stop	105.91	76.091	105.91	76.091
HK-Distance	1783	4030.6	1783	4030.6

Note: "H-" stands for home-based measures; "S-" stands for school-based measures.

engaging in AST with the 800 m buffer (OR [95% CI]: 1.09 [1.02, 1.17]).

Among other built environment factors, the street connectivity of the school, which was defined as the density of street intersections within the school's surrounding area, was positively associated with the odds of engaging in AST with both buffers (OR [95% CI]: 1.08 [1.01, 1.15] with the 400 m buffer and 1.03 [0.97, 1.12] with the 800 m buffer). The number of bus stops in the neighborhood was negatively associated with the odds of engaging in AST with the 400 m buffer. Other built environment factors were not significantly associated with engagement in AST.

The results of linear regression models for predicting BMI and built environment factors are shown in Table 5. Street greenness and the number of parks surrounding schools were significantly positively associated with BMI with the 400 m buffer (β [95% CI]: 0.132 [0.019, 0.257] for street greenness and 0.118 [0.006, 0.204] for number of parks). Other built environment factors were not significantly associated with BMI.

4.2. Results of structural equation modeling

The results of the fitting test suggest that the SEM established in the present study (presented in Fig. 2) was an ideal research model, with high agreement and stability through the matching degree analysis.

The model was constructed and analyzed using the statistical software package AMOS 21.0 (IBM, USA). It had a high degree of model fitness, as indicated in Table 6 and Fig. 3.

The results of the SEM path analysis suggest that three hypotheses (H3, H4, and H5) were verified (C.R. > 1.96, $p < 0.05$). Urban greenery surrounding school had a significant effect on both AST and BMI, confirming H3 and H4. AST also had a significant effect on body weight, confirming H5. However, urban greenery surrounding residence has no significant effect on AST or body weight ($p > 0.05$), refuting H1 and H2. The direct effect of urban greenery surrounding school on body weight was 0.43, while the indirect effect with the mediation of AST was 0.08 (Fig. 4 and Table 7). The total effect of urban greenery surrounding school on body weight (direct effect + indirect effect) was 0.51.

5. Discussion

In this study, we examined the associations between urban built environment factors, AST, and body weight for 1,148 primary school students in Hong Kong. As suggested in the literature, uncertainty about the effects of urban greenery on physical activity and health stems partially from the use of different measures of urban greenery. Hence, we assessed different dimensions of urban greenery using three measures: the number of parks, the NDVI (by satellite imagery), and street greenness (by GSV images). Street greenness represents the eye-level greenness perceived by school commuters on streets and therefore can objectively estimate the daily greenery exposure of urban residents. We further applied SEM to examine the mediation effects of AST between urban greenery and weight status.

5.1. Major findings

We found significant associations between street greenness in the

Table 4
Logistic regression models for predicting the odds of engaging in active transport to school.

Model predictor	Model 1 (buffer = 400 m)		Model 2 (buffer = 800 m)	
	OR (95% CI)	*p*-value	OR (95% CI)	*p*-value
Urban greenness				
H-Street greenness (GSV)	1.10 (0.99, 1.24)	0.102	1.08 (1.01, 1.16)	0.450
H-Overall greenness (NDVI)	1.13 (1.04, 1.25)	0.913	1.19 (1.09, 1.30)	0.125
H-Number of parks	1.04 (0.98, 1.12)	0.281	1.03 (0.97, 1.11)	0.159
S-Street greenness (GSV)	1.32 (1.18, 1.51)	< 0.001***	1.42 (1.23, 1.59)	0.844
S-Overall greenness (NDVI)	0.96 (0.90, 1.02)	0.979	1.09 (1.02, 1.17)	< 0.001***
S-Number of parks	1.21 (1.13, 1.32)	< 0.001***	0.97 (0.90, 1.07)	0.129
Built environment				
H-Population density	0.99 (0.91, 1.10)	0.201	0.99 (0.91, 1.10)	0.303
H-Street intersection density	0.97 (0.90, 1.06)	0.430	0.98 (0.91, 1.09)	0.108
H-Number of bus stops	0.96 (0.89, 1.06)	0.002**	1.00 (0.93, 1.11)	0.580
H-Number of schools	1.12 (1.04, 1.23)	0.060	1.01 (0.94, 1.13)	0.342
H-Distance to MTR station	1.00 (0.91, 1.09)	0.401	1.00 (0.91, 1.09)	0.087
H-Distance to bus stop	1.003 (0.92, 1.10)	0.111	1.003 (0.92, 1.10)	0.469
S-Street intersection density	1.08 (1.01, 1.15)	< 0.001***	1.03 (0.97, 1.12)	< 0.001***
S-Number of bus stops	1.01 (0.94, 1.13)	0.495	1.01 (0.94, 1.13)	0.465
S-Distance to MTR station	0.91 (0.85, 0.96)	0.667	1.004 (0.92, 1.10)	0.102
S-Distance to bus stop	1.005 (0.92, 1.11)	0.197	1.006 (0.92, 1.11)	0.196
HS-Distance	1.001 (0.91, 1.09)	0.172	1.00 (0.91, 1.08)	0.098

Note: "H" stands for home-based measures; "S" stands for school-based measures.

Table 5
Multilevel linear regression models for predicting BMI.

Model predictor	Model 1 (buffer = 400 m)		Model 2 (buffer = 800 m)	
	β (95% CI)	*p*-value	β (95% CI)	*p*-value
Urban greenness				
H-Street greenness (GSV)	0.097, (−0.022, 0.189)	0.238	0.089 (−0.037, 0.173)	0.928
H-Overall greenness (NDVI)	0.122, (0.027, 0.213)	0.493	0.126 (0.032, 0.236)	0.527
H-Number of parks	0.043, (−0.031, 0.128)	0.167	0.033 (−0.028, 0.109)	0.629
S-Street greenness (GSV)	−0.132, (0.019, 0.257)	< 0.001***	0.142 (0.023, 0.274)	0.481
S-Overall greenness (NDVI)	−0.041, (−0.126, 0.039)	0.197	0.109 (−0.004, 0.198)	0.167
S-Number of parks	−0.118, (0.006, 0.204)	< 0.001***	0.107 (0.002, 0.187)	0.290
Built environment				
H-Population density	−0.001 (−0.067, 0.042)	0.720	0.009 (−0.076, 0.100)	0.092
H-Street intersection density	0.007 (−0.082, 0.089)	0.098	0.008 (−0.081, 0.099)	0.681
H-Number of bus stops	0.006 (−0.083, 0.098)	0.349	0.001 (−0.095, 0.087)	0.012
H-Number of schools	0.114 (0.020, 0.217)	0.682	0.102 (0.019, 0.202)	0.375
H-Distance to MTR station	0.001 (−0.093, 0.090)	0.574	0.001 (−0.093, 0.091)	0.762
H-Distance to bus stop	0.003 (−0.087, 0.094)	0.132	0.003 (−0.089, 0.094)	0.849
S-Street intersection density	0.074 (−0.016, 0.178)	0.806	0.077 (−0.014, 0.178)	0.447
S-Number of bus stops	0.011 (−0.072, 0.101)	0.975	0.012 (−0.072, 0.103)	0.542
S-Distance to MTR station	0.005 (−0.062, 0.078)	0.728	0.004 (−0.057, 0.081)	0.103
S-Distance to bus stop	−0.001 (−0.074, 0.066)	0.110	0.006 (−0.049, 0.112)	0.124
HS-Distance	0.002 (−0.113, 0.135)	0.437	0.001 (−0.087, 0.095)	0.098

Note: "H-" stands for home-based measures; "S-" stands for school-based measures.

Table 6
Analysis of the structural equation model's fitting test.

Measure	Result	Suggested value
Cronbach's Alpha (Bland & Altman, 1997)	0.718	≥0.70
KMO (Dziuban and Shirkey, 1974)	0.784	≥0.70
Sig	0.000	< 0.05
CMIN/DF (Hirotsu, 1986)	1.352	≤5
GFI (Cheung & Rensvold, 2002)	0.972	> 0.90
RMSEA (Steiger, 1998)	0.055	< 0.08
AGFI (Cheung & Rensvold, 2002)	0.916	> 0.90
NFI (Hu and Bentler, 1999)	0.947	≥0.95
CFI (Hu and Bentler, 1999)	0.969	≥0.95

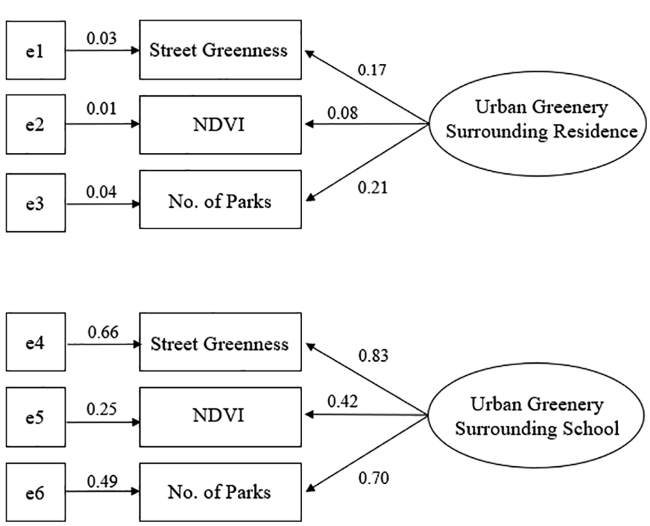

Fig. 3. Confirmatory Factor Analysis for latent variable of urban greenery surrounding residence and school.

school buffer area and both the pupils' odds of engaging in AST and their body weight status. The findings of our study concur with previous findings regarding the relationship between urban greenery and children's engagement in physical activity (Almanza et al., 2012; Bell et al., 2008). Children attending a school with a greener surrounding environment are more likely to commute to school on foot or by bicycle

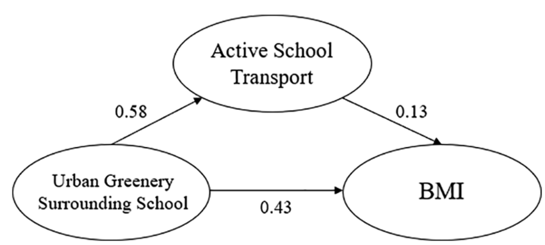

Fig. 4. Effects of urban greenery surrounding school on weight status.

and have a lower BMI. Furthermore, we supplement previous studies by providing strong and positive evidence of the association of urban greenery and the BMI of children (Lovasi et al., 2013). Our results emphasize the role of urban greenery surrounding a school on AST and BMI, whereas other studies have typically emphasized the role of urban greenery near residential neighborhoods. This difference may stem from our sampling methods and research design. We carefully selected participants from primary schools with different built environment characteristics, while other studies have selected participants based on their dwelling locations. Hence, we observed greater variation in urban greenery surrounding a school than in other studies.

Understanding how AST mediates the effect of urban greenery on health is of paramount importance to develop effective interventions to improve children's body weight outcomes. Previous studies have provided strong evidence of the direct effect of urban greenery on body weight and BMI (Bell et al., 2008; Duncan et al., 2014). However, the indirect effect of urban greenery on body weight and BMI via AST has not been explored. We conducted SEM to understand the complex relationships among urban greenery, AST, and BMI. Our findings suggest that urban greenery directly affects body weight and also indirectly affects body weight via AST. The findings of this study echo others (Almanza et al., 2012; Bell et al., 2008) in stressing the importance of urban greenness for promoting AST and preventing childhood overweight and obesity. Our findings are analogous to those of a previous study among adults, which reported that urban greenery directly influences physical health and also indirectly affects it through physical activity (Zhang et al., 2018). Hence, the direct effect of urban greenery on health and its indirect effect via physical activity can be regarded as reasonably robust and may be applicable across age groups.

From a methodological perspective, street greenness measured by

Table 7
Effect relationship between urban greenery surrounding school, AST and BMI in SEM.

Total effect	Direct effect	Indirect effect
Urban greenery surrounding school → BMI 0.51	Urban greenery surrounding school → BMI 0.43	Urban greenery surrounding school → AST → BMI 0.08 (=0.58 × 0.13)

GSV images, but not by the NDVI, was found to have a positive effect on AST and BMI. As we mentioned in Section 1, inconsistent results of studies on the association between urban greenness and body weight status may be due to the different measures of urban greenery, and the results of our study also support this argument. It is plausible that street greenness and the NDVI capture different dimensions of urban greenery, given that the former focuses on eye-level greenness and the latter focuses on the overall greenery in an area. Street greenness may better estimate daily greenery exposure because it better represents what a resident perceives and streets are used more than other areas (Lu, 2018b). The superior performance of street greenness over the NDVI is also consistent with the previous finding that perceived greenness has a stronger impact on people's health and physical activity than overall greenness, as measured by the NDVI (Leslie et al., 2010; Sugiyama et al., 2008).

Previous studies have reported correlations between AST and body weight and other built environment factors, such as urban density, street connectivity, and distance between school and residence (Duncan et al., 2014; Faulkner et al., 2009; Mitchell, 2013). In contrast, we found only one such association (between AST and body weight and street connectivity). This difference may be accounted for by differences in urban contexts (Lu et al., 2019). For example, Hong Kong has a much higher urban density than the Western cities in which most previous studies were conducted. Understanding the different contexts of the social and built environments could aid in developing localized public health and planning policy for children.

5.2. Policy implications

The findings of our study demonstrate the importance of urban greenery, especially around schools, in promoting children's AST behavior and improving their body weight status. These findings have important implications for policymakers, health promoters, and urban planners and designers. Government agencies should consider establishing targeted policy plans to promote children's health by creating new greenspaces or improving existing greenspaces around schools. More specifically, future planning and design of urban greenspaces should shift from an exclusive focus on the size or the number of greenspaces to the practice considering the accessibility and visibility of those greenspaces, so they can be easily perceived by children in their daily lives. This is particularly critical for high-density cities, such as Hong Kong, where land supply is limited and greenspaces in built-up areas are scarce.

5.3. Strengths and limitations

One strength of this study is that we assessed urban greenery using three methods. The simultaneous use of three urban greenery methods may help us to distinguish which aspects of urban greenery are of particular importance for children's AST behaviors and body weight status. The other strength is the use of SEM to explore the direct effect of urban greenery on body weight status and the indirect effect via AST. This advanced statistical technique helped us to understand the relationships between urban greenery, AST, and body weight. However, we could not infer any causal relationships because of the cross-sectional research design. Future studies could use natural experiments to deliver more robust scientific evidence. We also used questionnaires to assess AST, which may be subject to recall bias or social desirability bias. In future studies, school travel behaviors could be collected by portable GPS and/or accelerometer equipment for more objective measures (Li et al., 2019).

6. Conclusion

Using three urban greenery measures (number of parks, NDVI, and street greenery with GSV images), we found that street greenery in the area surrounding a school was significantly associated with children's AST behaviors and body weight status. AST was also found to play a mediating role in the relationship between urban greenery and the body weight status of children. The findings of this study join others in highlighting the importance of greenery exposure around schools in promoting AST and improving body weight status among children. Future planning and design practice should consider the visibility of greenspaces as well as more traditional planning parameters such as the size or number of greenspaces.

7. Ethics approval and consent to participate

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.

Funding

The work described in this paper was fully supported by grants from the National Natural Science Foundation of China (Project No.51778552) and the Research Grants Council of the Hong Kong Special Administrative Region, China (Project No. CityU11666716).

CRediT authorship contribution statement

Yiyang Yang: Conceptualization, Methodology, Formal analysis, Investigation, Writing - original draft. **Yi Lu:** Conceptualization, Methodology, Supervision, Writing - review & editing. **Linchuan Yang:** Writing - review & editing. **Zhonghua Gou:** Writing - review & editing. **Xiaoling Zhang:** 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.