Landscape and Urban Planning 191 (2019) 103435

Contents lists available at ScienceDirect

Landscape and Urban Planning

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

Research Paper

Using Google Street View to investigate the association between street greenery and physical activity

Yi Lu[a,b,*]

[a] Department of Architecture and Civil Engineering, City University of Hong Kong, Hong Kong Special Administrative Region
[b] City University of Hong Kong Shenzhen Research Institute, Shenzhen 518057, China

ARTICLE INFO

Keywords:
Street greenery
Urban greenspace
Google Street View (GSV)
Physical activity
Healthy city

ABSTRACT

Urban greenspaces have been demonstrated to have associations with physical activity and health. Yet empirical studies have almost exclusively focused on parks rather than street, although streets are among the most popular venues for physical activity and street greenery is an indispensable component of urban greenspaces. Even fewer greenspace-physical activity studies have objectively assessed eye-level street greenery. By using free Google Street View images, this study assessed both the quantity and quality of street greenery and associated them with the recreational physical activity occurring in green outdoor environments of 1390 participants in 24 housing estates in Hong Kong. After controlling for socio-demographic characteristics and other built environment factors, multilevel regression models revealed that the quality and quantity of street greenery were positively linked to recreational physical activity. Our finding is important for interpretations of the operational mechanisms between street greenery and health benefits because it demonstrates that physical activity is an intermediate health-related outcome. The findings also reveal the influences of eye-level street greenery on residents' physical activity levels and hence contribute to the development and implementation of healthy cities to stimulate physical activity.

1. Introduction

Urban greenspaces are increasingly recognized as playing a crucial role in residents' physical activity and health outcomes in neighborhood environments (Hartig, Mitchell, de Vries, & Frumkin, 2014; Lee & Maheswaran, 2011; Markevych et al., 2017). Urban greenspaces, such as tree-lined streets, parks, and natural areas, often serve as pleasant environments through/within which walking, jogging and cycling can take place, especially physical activity for health and recreational purposes (Li, Fisher, Brownson, & Bosworth, 2005; Saelens & Handy, 2008). Furthermore, physical activity that takes place in greenspaces may yield physiological and psychological health benefits above the benefits of physical activity in other environments (Lee et al., 2012; Sallis, Floyd, Rodríguez, & Saelens, 2012). Hence, residents are more likely to engage in more physical activity and be healthier in neighborhoods with more greenspaces (Hartig et al., 2014; Kaczynski & Henderson, 2007; Lachowycz & Jones, 2011).

1.1. Availability of greenspace and physical activity

Most greenspace-physical activity empirical studies have focused on parks and open greenspaces. After reviewing 50 studies addressing parks, Kaczynski and Henderson (2007) conclude that most studies revealed positive associations between the availability of parks in a neighborhood and physical activity (Coombes, Jones, & Hillsdon, 2010; Floyd, Spengler, Maddock, Gobster, & Suau, 2008; Giles-Corti et al., 2005; Kaczynski, Potwarka, Smale, & Havitz, 2009; Koohsari, Karakiewicz, & Kaczynski, 2013; Lu, Sarkar, Ye, & Xiao, 2017). For example, the total physical activity of adolescent girls was significantly associated with the number of parks within one mile of their residence (Cohen et al., 2006). The total walking time of old adults was positively related to the presence of parks and to the total area of greenspaces in the neighborhood (Li et al., 2005). Furthermore, people using parks were more likely to achieve the recommended levels of physical activity than those avoiding parks (Lee & Maheswaran, 2011).

Some studies, however, have reported a negative association (Duncan & Mummery, 2005) or no association (King et al., 2005) between the availability of parks and physical activity. The inconsistency may be explained by the fact that such studies associated the presence of greenspace with different domains of physical activity. Evidence suggests that different characteristics of the built environment may be associated with different domains of physical activity (Durand, Andalib,

* Address: Department of Architecture and Civil Engineering, City University of Hong Kong, Hong Kong Special Administrative Region.
E-mail address: yilu24@cityu.edu.hk.

https://doi.org/10.1016/j.landurbplan.2018.08.029
Received 11 July 2017; Received in revised form 11 July 2018; Accepted 5 August 2018
Available online 28 September 2018

Dunton, Wolch, & Pentz, 2011; Saelens & Handy, 2008). Aesthetic quality, including neighborhood greenness, is often associated with physical activity for recreational purposes rather than walking or cycling for transportation purposes (Saelens & Handy, 2008). Hence, greenspace is likely to affect participation in recreational green physical activity—that is, walking or cycling in green outdoor environments for recreational purposes (De Vries, van Dillen, Groenewegen, & Spreeuwenberg, 2013; Li et al., 2005; Saelens & Handy, 2008).

1.2. The quality of greenspace and physical activity

The quality of greenspace is also associated with physical activity. Physical characteristics such as the availability of sports grounds (Floyd et al., 2008), restrooms and changing rooms, wooded areas, and trails (Kaczynski & Henderson, 2008) and the presence of amenities (Giles-Corti et al., 2005; Kaczynski & Henderson, 2008) may stimulate participation in physical activity within parks. The conditions of a park also affect its appeal and use. People tend to avoid parks in poor condition because of safety concerns (Bedimo-Rung, Mowen, & Cohen, 2005). The attractiveness of parks is positively related to walking behavior within them (Pikora, Giles-Corti, Bull, Jamrozik, & Donovan, 2003), especially to walking for recreational purposes (Ball, Bauman, Leslie, & Owen, 2001; Cerin, Sit, Barnett, Cheung, & Chan, 2013). Other aspects of quality, such as high-quality pathways, a lack of litter, and clean restrooms are also related to increased walking (Sugiyama, Francis, Middleton, Owen, & Giles-Corti, 2010). Finally, several studies focus on the availability and quality of greenspaces. One study reported that the attractiveness and size of greenspaces were related to more walking even after controlling for distance to those greenspaces (Giles-Corti et al., 2005). Another study reported that the size of parks, presence of walking/cycling routes, and pleasant views were correlated with physical activity in nearby parks (Schipperijn, Bentsen, Troelsen, Toftager, & Stigsdotter, 2013).

1.3. Physical activity and street greenery

According to several national surveys, streets are the most popular setting for walking, cycling, and other recreational physical activity, followed by homes and then parks (Bauman, 1997; Rosenberg et al., 2010). Yet evidence on the relationship between street greenery and physical activity is scarce, although associations have been demonstrated between street greenery and various health outcomes. The quantity of street trees, for instance, is linked to decreased prevalence of obesity (Lovasi et al., 2013) and asthma for children (Lovasi, Quinn, Neckerman, Perzanowski, & Rundle, 2008), and the presence of walkable green streets is related to longer life spans for older adults (Takano, Nakamura, & Watanabe, 2002). Both the amount and the quality of street greenery, as evaluated by field audit, are significantly related to self-reported physical and psychological wellbeing (van Dillen, de Vries, Groenewegen, & Spreeuwenberg, 2012). Street greenery provides various health benefits to urban residents, yet establishing a causal relationship remains difficult (Lee & Maheswaran, 2011). It is often hypothesized that physical activity is one of the mediators of the relationship between street greenery and health outcomes. Understanding how street greenery influences physical activity may shed light on the hypothesized causal mechanism.

1.4. The gap

As shown in several reviews, street greenery has received less research attention than parks (Kaczynski & Henderson, 2007; Lachowycz & Jones, 2011). This may be partially attributed to methodological limits. Street greenery includes a variety of vegetation, such as trees, shrubs, lawn, green walls, or front gardens next to streets. Nearly all current studies used one of three methods to assess street greenery in health studies: questionnaires (Takano et al., 2002), field audits (De Vries et al., 2013; van Dillen et al., 2012), and obtaining data (Lovasi et al., 2011, 2008, 2013; Sarkar et al., 2015). All three methods have their strengths and limitations. Questionnaires may be subject to people's bias and involve the burden of enlisting participants. Field audits are more objective, yet time-consuming and inefficient because raters need to physically visit all of the sites (Brownson, Hoehner, Day, Forsyth, & Sallis, 2009). While obtaining data, such as tree count or Normalized Difference Vegetation Index (NDVI), is objective and time-efficient, such data often do not include detailed information about street vegetation, especially smaller elements such as shrubs or lawns. Assessments of overhead-view street greenery often differ from perceptions of eye-level street greenery (Jiang et al., 2017; Li et al., 2015; Yang, Zhao, McBride, & Gong, 2009). NDVI, for instance, may fail to detect lawns or shrubs under a tree canopy, green walls, or vegetation covered by a bridge (Li et al., 2015).

To address these methodological limits, this study uses Google Street View (GSV) images to assess eye-level street imagery. GSV is a free image service that provides panoramic views along streets in many cities worldwide. The GSV images were captured by cars, trikes, and pedestrians moving along streets; by retrieving GSV images with GSV API, panoramic streetscape images of various locations can be recreated (Google Inc., 2016). These panoramic images closely resemble what a pedestrian sees. The quality and quantity of street greenery can be assessed with these images. GSV has already been demonstrated to be an effective and free data source for various built environment assessments, such as overall neighborhood environment conditions (Charreire et al., 2014; Rundle, Bader, Richards, Neckerman, & Teitler, 2011), urban open space (Edwards et al., 2013), and sky view factors (Li, Ratti, & Seiferling, 2017; Liang et al., 2017), and street greenery (Li et al., 2017, 2015; Long & Liu, 2017; Lu, Sarkar, & Xiao, 2018).

Furthermore, apart from the abovementioned methodological gap, this study focuses on a densely populated Asian city, Hong Kong, China. Most empirical studies have been conducted in North America or Europe, which differ from Chinese cities in their urban and social environments. For example, Hong Kong has much higher residential density and lower car ownership than many cities in western countries. Although China is the most populous nation, it has received little attention in greenspace-physical activity studies (Day, 2016). Thus, it is important to extend our knowledge of greenspace-physical activity associations to China to inform planning policy and urban design to support increased physical activity for local governments. Findings from multiple countries can also improve the generalization of the relationship between physical activity and greenspaces.

In summary, this study examines the associations of recreational green physical activity and the quality and quantity of street greenery, which are assessed with GSV images, in 24 neighborhoods of Hong Kong. We hypothesize that there are positive relationships based on the findings of previous studies.

2. Methods

2.1. Study areas

Hong Kong is located on the southeast coast of China, with a land area of 1104 km^2 (Fig. 1). Its sub-tropical climate is mild, and most street greenery is evergreen or semi-evergreen. In 2015, the population was 7.29 million, with a gross population density of 6603 people per km^2 (Census & Statistics Department of Hong Kong, 2016). This population density is much higher than that of western cities in which greenspace-physical activity studies have been conducted.

Hong Kong has 487 major housing estates (Census & Statistics Department of Hong Kong, 2016). A major housing estate is a group of residential buildings developed by the same developer in a neighborhood and with at least 1000 residential units. Housing estates are the smallest census unit in Hong Kong.

We selected 24 housing estates according to the quantity of street

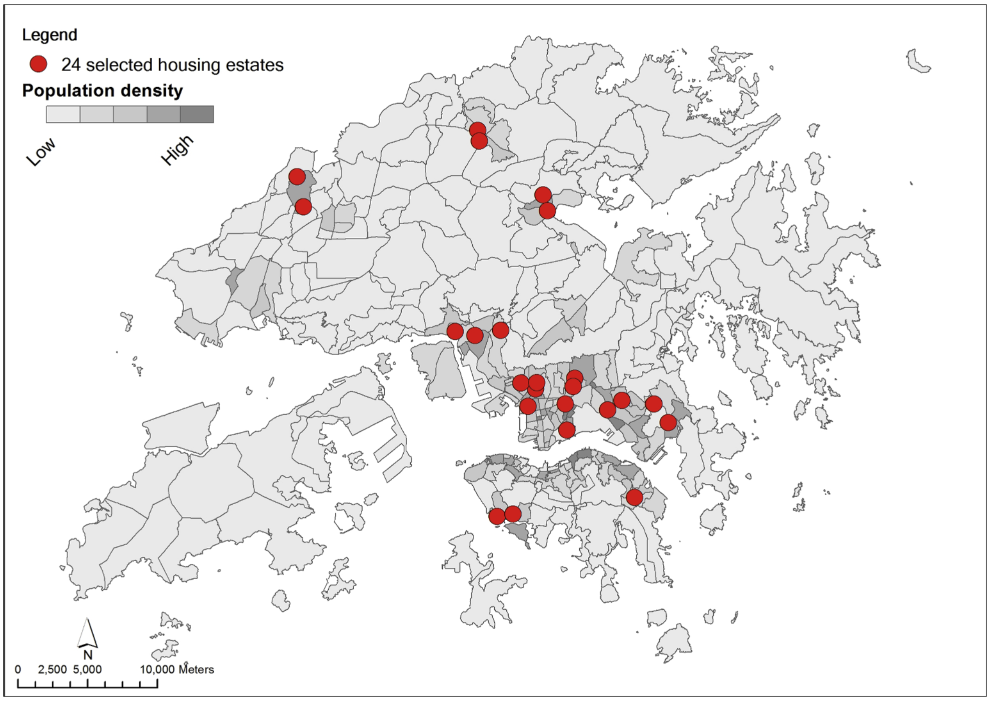

Fig. 1. The location of 24 selected housing estates in Hong Kong. The selection was based on the quantity of street greenery in the 1000 m street network buffer around a housing estate.

greenery in the 1000 m street network buffer around a housing estate (Fig. 1). The selection of a 1000 m radius was based on average walking distance and suggestions by previous studies (Cervero, Sarmiento, Jacoby, Gomez, & Neiman, 2009; Frank et al., 2006; Millward, Spinney, & Scott, 2013). We purposely selected our study areas to maximize the variation in the quantity of street greenery. The quantity of street greenery of each housing estate was divided into deciles. The housing estates within the second and third deciles were considered low street greenery estates, those within the fifth and sixth deciles were considered medium street greenery estates, and those within the eighth and ninth deciles were considered high street greenery estates. During the selection, we also sought to select housing estates with similar homogeneous socioeconomic (SES) profiles; thus, we selected housing estates with similar median household incomes. Based on those criteria, eight house estates were randomly selected in each of three groups (low/medium/high street greenery); a total of 24 housing estates were selected.

2.2. Quantity of street greenery

The quantity of street greenery was measured using Google Street View (GSV) images in conjunction with ArcGIS software (ESRI, US). First, all street segments within the 1000 m street network buffer around a housing estate were selected (Fig. 2a). Then, GSV-generating points were created along the selected streets with a uniform distance of 20 m. The average number of points around a housing estate was 435 (SD = 207).

The coordinates of the GSV-generating points were input into a Python script. With the script, four GSV images were downloaded for each point: north, east, south, and west headings, each with a 90-degree field of view. The four images can be seamlessly stitched together to create a panoramic view (Fig. 2b).

The quantity of greenery for each image was calculated as a green view index using an automated greenery extraction method (Li et al., 2015). This method identifies green pixels in an image based on the color differences along the green, red, and blue color band (Fig. 3).

The ratio of green pixels to the total pixels from the four images of a GSV-generating point was used to assess the green view index for that point, as shown in this equation:

$$\text{Green view index} = \frac{\sum_{i=1}^{4} \text{Green pixels}_i}{\sum_{i=1}^{4} \text{Total pixels}_i} \quad (1)$$

The average value for all GSV-generating points of a housing estate was used to assess the quantity of street greenery of a housing estate.

2.3. Quality of street greenery

The quality of street greenery was assessed by GSV images and validated by field observation. For each housing estate, the 10 longest streets in the 1000 m buffer were identified in GIS. A trained researcher then explored and audited those streets with GSV in Google Maps. A 4-item audit tool was adapted from field audit tools (Pikora et al., 2002; van Dillen et al., 2012). These items are variation of greenery, absence of litter, maintenance, and general condition. A researcher assessed those items with 5-point scales. In total, 240 streets were audited. Two inter-rater reliability tests were conducted on different dates. In each test, a subset of 30 streets was physically visited by a second observer and audited with the same audit tool. The results of both tests showed reasonable inter-rater reliability (Pearson correlation $r = 0.85$; percentage agreement > 80%). The average score of the four items was used to assess the quality of street greenery. The average quality score of all 10 streets was reported as the overall quality of the street greenery of a housing estate.

2.4. Participants and recreational green physical activity

The study enlisted 55–60 adults from each housing estate using convenience sampling, with a total of 1390 participants during Oct-Nov 2016. The participants were Chinese adults aged 18+ who could perform physical activity independently and had lived in the estates for more than one year.

A modified short-form International Physical Activity Questionnaire (IPAQ) was adopted to assess physical activity. IPAQ is a standard

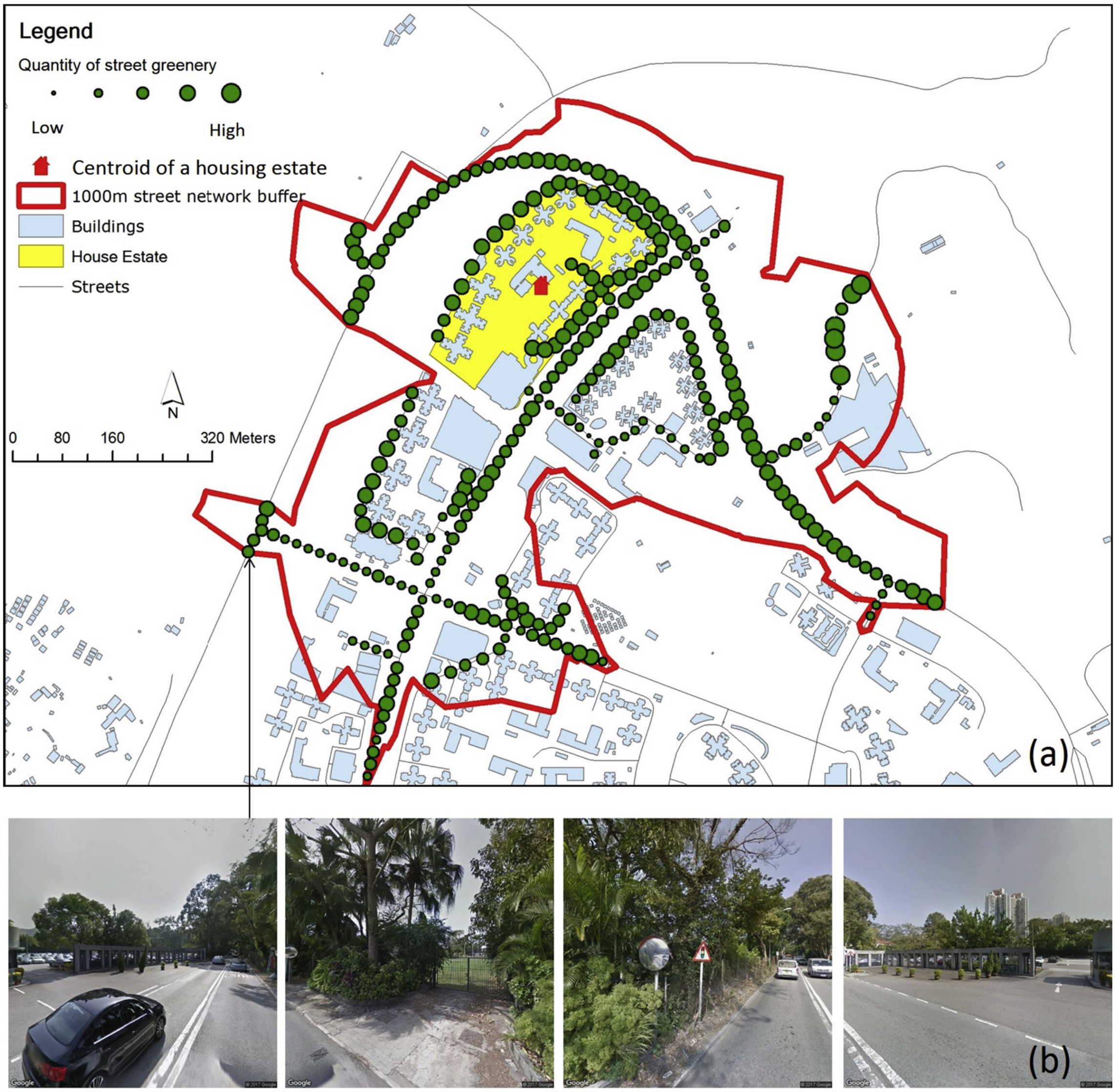

Fig. 2. (a) Examples of the GSV-generating points of a housing estate. All of the streets in the 1000 m network buffer were selected (blue lines). The points were created along the selected streets with a spacing of 20 m. (b) For each point, four GSV images constituting a panoramic view were obtained with a Python script working with GSV API. Those images were used to measure both the quality and quantity of street greenery. (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article.)

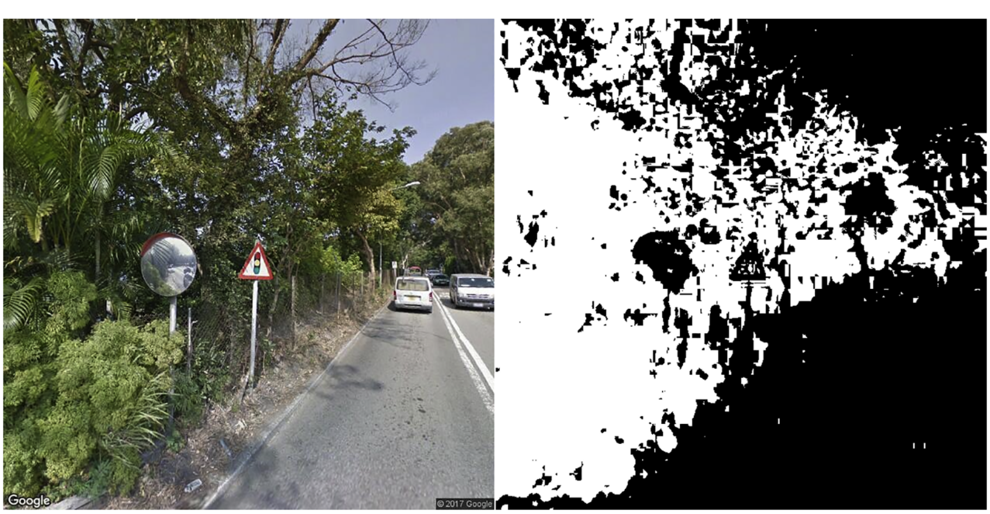

Fig. 3. Example of greenery extraction from a GSV image based on color differences along the green, red, and blue color bands. The quantity of greenery was assessed as the proportion of green pixels to the total pixels in an image. (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article.)

Table 1
Descriptive information for recreational green physical activity, socio-demographic characteristics, housing estate-level street greenery, and other built environment factors in Hong Kong, sampled in 2016.

Variables	Mean (sd)/%
Outcome (N = 1390)	
Recreational green physical activity, % ≥150 min	37%
Socio-demographic variables (N = 1390)	
Age	53 (20)
Gender, % male	49%
Household income	
Low, % ≤12000 HKD	42%
Medium, % 12000–15000 HKD	32%
High, % ≥15000 HKD	25%
Street greenery (N = 24)	
quantity of greenery, green view index (0–1, higher means more)	0.16 (0.05)
quality of greenery (1–5, higher means better)	3.21 (0.86)
Other built environment factors (N = 24)	
Population density (person/km2)	74,911 (18874)
Street intersection density (number of intersections/km2)	103 (34)
Land use mix	0.51 (0.31)
Total park area (m^2)	72,839 (73076)

physical activity questionnaire, and its validity and reliability have been proven in several countries (Craig et al., 2003). The questionnaire was administered via face-to-face interviews to ensure no missing information. The information gathered concerned recreational green physical activity, that is, recreational physical activity occurring in the green outdoor environment, which included walking, jogging, or cycling for recreational purposes. Recreational green physical activity was assessed with the following questions: 1) "During the last 7 days, on how many days did you walk or jog in the outdoor environment for at least 10 min at a time during your leisure time?"; 2) "How much time did you usually spend on one of those days walking or jogging in the outdoor environment during your leisure time?"; 3) "During the last 7 days, on how many days did you cycle in the outdoor environment for at least 10 min at a time during your leisure time?"; 4) "How much time did you usually spend on one of those days cycling in the outdoor environment during your leisure time?"; 5) "Not counting walking, jogging, or cycling that you have already mentioned, during the last 7 days, on how many days did you exercise (e.g. dancing or Tai Chi) in the outdoor environment for at least 10 min at a time during your leisure time?"; and 6) "How much time did you usually spend on one of those days exercising in the outdoor environment during your leisure time?" The average activity duration (in minutes) per day and number of active days in a week were multiplied to obtain the total duration (in minutes) for recreational walking/jogging, cycling, and other exercise. The durations of recreational walking/jogging, cycling, and other exercise were summed up to obtain total duration (in minutes) for recreational green physical activity in a week.

2.5. Covariates

For the 24 selected housing estates, other built environment features in the 1000 m street network buffer were measured: population density, street intersection density, land use mix, and total park area. Individual-level covariates included household income, gender, and age; they were also collected through interviews.

2.6. Data analysis

The descriptive statistics for the sample characteristics are reported for all participants and all housing estates. The percentages are reported for the categorical variables. The mean and standard deviation (SD) values for the quantitative variables are also reported.

As the distribution of the total duration of green physical activity was highly skewed, with many participants reporting no or little activity, it was transformed into a binary variable (≥150 min/week vs < 150 min/week). The cutoff point of 150 min per week was based on the World Health Organization's recommendation (World Health Organization, 2010).

Multilevel logistic regression models were conducted to investigate the relationship between street greenery and recreational green physical activity. The house estates were assigned a random effect that accounts for the clustering in the physical activity of participants in the house estates. For ease of interpretation of the results, the quantity and quality of street greenery and other built environment variables were transformed into three-level tertiles with the lowest level serving as the reference category. The participants' ages were transformed into a categorical variable with three levels (18–39 years (reference category), 40–64 years, and ≥65 years). The household income (in HKD/month) was also transformed into a categorical variable with three levels (< 12 k (reference category), 12–15 k, > 15 k). The analysis used two multilevel logistic models:

$$ln\left(\frac{p_{ij}}{1-p_{ij}}\right) = \beta_0 + \beta_1 x_{ij} + u_j$$

where p_{ij} is the probability that resident i in housing estate j engages in regular recreational physical activity. β_0 is the common intercept. x_{ij} is a set of explanatory variables. β_1 is the regression coefficients for variables x_{ij}, and $\exp(\beta_1)$ is the odds ratios of variables x_{ij}. u_j is the random effect specific to housing estate *j*.

Model 1 included the quantity and quality of street greenery and other built environment variables: total park area, population density, street intersection density, and land use mix. Model 2 further controlled for individual covariates: gender, age, and household income. Odds ratios (ORs), their 95% confidence intervals, and *p* values are reported for all models. All analyses were conducted with R and a multilevel package *lme4* (R Core Team, 2014).

3. Results

The descriptive data are shown in Table 1. Approximately 36% of participants engaged in ≥150 min of recreational green physical activity in a week. Our participants were relatively older and poorer compared with the total Hong Kong population due to the convenience sampling method (Census & Statistics Department of Hong Kong, 2016).

The automated greenery extraction was validated with manual extraction. Thirty GSV images were randomly selected, and their street greenery was manually extracted by an expert using Adobe Photoshop software. The values of the GSV greenery extraction were highly correlated with those from the manual extraction, $r(28) = 0.91, p < 0.01$.

The average green view index across all study housing estates was 0.16, indicating that 16% of the pixels of GSV images were identified as greenery. The value also indicates that greenery constitutes 16% of the eye-level street view of a pedestrian. The average quality of street greenery was 3.21, indicating that street greenery in Hong Kong was relatively high quality.

The quantity of street greenery and total park area were not significantly correlated for the study housing estates, $r(22) = -0.17$, $p = 0.43$. The non-significant correlations indicate that the quantity of eye-level street greenery significantly differs from the availability of parks from a top-down viewpoint in our selected sites. A neighborhood with a larger total park area does not necessarily have a larger amount of street greenery, and vice versa.

The results of the multilevel logistic regression models associating engagement in ≥150 min of recreational green physical activity a week and street greenery were presented in Table 2. Model 1 includes the quantity and quality of street greenery, population density, street

Table 2
Multilevel logistic regression of street greenery and achieving ≥ 150 min of recreational green physical activity a week.

Model predictors	Model 1		Model 2	
	OR (95% CI)	p-value	OR (95% CI)	p-value
Street greenery				
Quantity of street greenery				
Low (reference)				
Medium	1.02 (0.91–1.22)	0.45	1.03 (0.89, 1.15)	0.42
High	1.22 (1.09–1.35)	< 0.01**	1.20 (1.08–1.33)	0.02**
quality of street greenery				
Low (reference)				
Medium	1.02 (0.71–1.21)	0.58	0.98 (0.69–1.16)	0.66
High	1.13 (1.08–1.29)	< 0.01**	1.10 (1.05–1.25)	< 0.01**
Built environment				
Total park area				
Low (reference)				
Medium	1.04 (0.94–1.15)	0.47	1.08 (0.98–1.19)	0.14
High	1.21 (1.09–1.35)	< 0.01**	1.22 (1.10–1.36)	< 0.01**
Population Density				
Low (reference)				
Medium	1.04 (0.95–1.16)	0.57	1.05 (0.97, 1.19)	0.53
High	1.09 (0.98–1.21)	0.11	1.04 (0.93–1.15)	0.51
Intersection Density				
Low (reference)				
Medium	1.17 (1.06–1.30)	< 0.01**	1.17 (1.05–1.29)	< 0.01**
High	1.21 (1.07–1.38)	< 0.01**	1.20 (1.06–1.37)	0.01*
Land use mix				
Low (reference)				
Medium	1.03 (0.93–1.13)	0.58	1.06 (0.96–1.17)	0.23
High	1.05 (0.94–1.17)	0.41	1.09 (0.98–1.22)	0.12
Individual factors				
Age				
18–39 (reference)				
40–64			0.98 (0.85–1.10)	0.37
65+			1.29 (1.24–1.35)	< 0.01**
Gender				
Male (reference)				
Female			1.32 (1.28–1.37)	< 0.01**
Household income				
Low (< 12 k) (reference)				
Medium (12–15 k)			0.66 (0.64–0.69)	< 0.01**
High (> 15 k)			0.54 (0.52–0.56)	< 0.01**

Note: * < 0.05; ** < 0.01. Model 1 includes the quantity and quality of street greenery, population density, street intersection density, land use mix, and total park area. Model 2 additionally includes individual variables—age, gender, and household income.

intersection density, land use mix, and total park area. Individual-level socio-demographic variables—age, gender, and household income—were further added to Model 2.

Both the quantity and quality of street greenery were positively associated with the likelihood of engaging in at least 150 min of recreational green physical activity in Models 1 & 2. Participants exposed to a high quantity of street greenery were significantly more likely to engage in regular recreational green physical activity than those exposed to low quantities of street greenery (OR 1.22, CI 1.09–1.35 in Model 1; 1.20, 1.08–1.33 in Model 2). Similarly, residents exposed to high quality street greenery also had a greater likelihood of achieving regular recreational green physical activity than those exposed to low quality street greenery (1.13, 1.08–1.29 in Model 1; 1.10, 1.05–1.25 in Model 2). However, participants exposed to a medium quantity of street greenery had no significantly greater likelihood than those exposed to a low quantity of street greenery, and participants exposed to a medium quality of street greenery had no significantly greater likelihood than those exposed to a low quality of street greenery. The insignificant association may be explained by the small variation between medium and low levels of quantity and quality of street greenery.

Among the built environment variables that may affect physical activity, total park area and street intersection density were positively associated with the likelihood of achieving at least 150 min of recreational green physical activity. Participants exposed to a high level of total park area had a greater likelihood than those exposed to a low level of total park area in the buffer (1.21, 1.09–1.35 in Model 1; 1.22, 1.10–1.36 in Model 2). Participants exposed to a high level of intersection density also had a greater likelihood than those exposed to a low level of intersection density (1.21, 1.07–1.38 in Model 1; 1.20, 1.06–1.37 in Model 2). Land use mix and population density, however, were not significantly associated with the likelihood of achieving at least 150 min of recreational green physical activity.

Among the individual covariates, age, gender, and household income were all significantly associated with the likelihood of achieving at least 150 min of recreational green physical activity. The age group of ≥65 years was more likely than the age group of 18–39 years (OR 1.29, 1.24–1.35). Females were more likely than males (1.32, 1.28–1.37). Participants with high or medium household income were significantly less likely than those with low household income (0.66, 0.64–0.69; 0.54, 0.52–0.56 for medium and high levels, respectively).

4. Discussion

This is one of the first studies to use Google Street View to investigate the street greenery-physical activity association for a relatively large sample size after adjusting for other covariates. As hypothesized, this study finds that the quality and quantity of street greenery were associated with a greater propensity for recreational green physical activity, which is physical activity taking place in an outdoor environment for health and recreational purposes.

Studies have established that the presence of street greenery, often assessed by street tree count or questionnaires, is related to various health outcomes: greater senior residents' longevity (Takano et al., 2002), decreased prevalence of obesity and asthma among children (Lovasi et al., 2008, 2013), and better mental and physical health (van Dillen et al., 2012). However, few studies have investigated the operational mechanisms by which street greenery might affect health. Four underlying operational mechanisms have been proposed: physical activity, social cohesion, air quality, and stress reduction (Hartig et al., 2014). We have found street greenery to be significantly related to recreational physical activity after adjusting for other factors that may influence physical activity. Our finding is important in interpreting the operational mechanisms between street greenery and health benefits because it demonstrates that physical activity is an intermediate health-related outcome in the hypothesized causal pathway.

Our finding also suggests that both street greenery and urban parks, as assessed by total park area, are independently and positively associated with recreational green physical activity. The result supplements existing evidence of urban park-physical activity associations (Coombes et al., 2010; Floyd et al., 2008; Giles-Corti et al., 2005; Kaczynski et al., 2009; Koohsari et al., 2013). Similar to parks, streets with adequate and well-maintained greenery offer pleasant and comfortable urban environments for walking, jogging, and other types of physical activity (Li et al., 2005; Saelens & Handy, 2008). Street greenery constitutes one of the most influential components of urban greenspaces because streets are popular settings for physical activity (Bauman, 1997; Rosenberg et al., 2010). People are more exposed to more street greenery in daily life than to parks, which are only visited for specific times and specific purposes. Hence, research into the greenspace-physical activity association should move away from its near-exclusive focus on parks to also consider street greenery in urban environments.

The quality of street greenery is also associated with increased green physical activity, which is a relatively new finding. Previous studies indicate that the quality and features of parks, such as the presence of sports fields or running trails, maintenance, and safety affect park use and physical activity. This study complements their findings by showing that the quality of street greenery, assessed by the variation in greenery, maintenance, absence of litter, and general impression, also affects participation in recreational green physical activity. The quality of street greenery may be more consequential because it affects the perceived aesthetics or overall quality of the neighborhood's built environment (Agyemang et al., 2007; Buhyoff, Gauthier, & Wellman, 1984; Camacho-Cervantes, Schondube, Castillo, & MacGregor-Fors, 2014; Thayer & Atwood, 1978). For example, residents tend to increase their preference rating for urban scenes with more and higher quality greenery (Buhyoff et al., 1984; Camacho-Cervantes et al., 2014). It is possible the street greenery has both direct and indirect impacts on physical activity through the perceived aesthetics of the neighborhood. Additional studies are warranted to examine the complicated relationships among physical activity, street greenery, and the aesthetics of the neighborhood, the last of which has long been identified as a key factor affecting physical activity (Saelens & Handy, 2008; Sallis et al., 2012).

This study has focused on Hong Kong, a high-density metropolis in China, a previously understudied location. Local urban and cultural contexts may moderate built environment-physical activity associations. Urban density, assessed by residential units or population, for instance, may promote physical activity in low-density Western cities (Saelens & Handy, 2008), while it is insignificantly or negatively associated with physical activity in high-density Chinese cities (Lu, Xiao, & Ye, 2017; Xu et al., 2010). Yet this study's finding that the quantity and quality of street greenery influence the individual's decision on recreational green physical activity largely agrees with other studies conducted in low-density Western cities. The consistent findings from diverse cultures and locations demonstrate the robust relationship between greenspace and physical activity. Many cities in China have undergone unprecedented rapid growth, in addition to a rapid decline in residents' physical activity (Ng, Howard, Wang, Su, & Zhang, 2014; Ng, Norton, & Popkin, 2009). From 1991 to 2006, urban residents' physical activity level decreased by 32% (Ng et al., 2009). From the Chinese government's perspective, striving for activity-friendly urban design is an important strategy to reverse the decline. Design decisions to create new or improve existing urban greenspace remain a significant challenge. This study emphasizes the importance of eye-level street greenery on residents' physical activity in a high-density urban context.

The research further contributes to the methodological development of health studies. Most urban greenspace-physical activity studies have overlooked street greenery because the data are often expensive and scarce to obtain. The free, publicly available, eye-level GSV images are close to what a pedestrian perceives (Jiang et al., 2017; Li et al., 2015; Yang et al., 2009). Hence, the GSV method can accurately estimate residents' daily exposure of street greenery in neighborhoods and hence captures an important physical activity-influencing factor.

Furthermore, the quantity of GSV street greenery can be objectively extracted with computer scripts, and the quality of these images can be audited online. The accuracy of greenery extraction and quality audit have been verified in this and other studies (Li et al., 2015). Compared with questionnaires and field audits, both of which involve difficulty in recruiting participants or transporting raters to sites, GSV image assessment is more time- and cost-effective. The objective assessment of street greenery also eliminates the response bias of participants and hence may be more reliable and increase research repeatability. We believe that overall, GSV-based assessment is an efficient and accurate method that may benefit further studies of street greenery-physical activity/ health associations.

This study also has some limitations. 1) This study's cross-sectional nature leads to no inferences regarding the causality of street greenery on observed differences in physical activity. 2) Physical activity was self-reported in this study and thus subject to recall bias. Studies that objectively assess physical activity, for example via accelerometers and/or portable global positioning systems (GPS), are needed. 3) This study is also prone to the Modifiable Areal Unit Problem (MAUP) because all of the built environment variables were collected with one buffer size. The observed association may differ across buffer sizes. 4) Some limitations stem from the GSV images. GSV service only covers a limited number of cities and, potentially, limited areas in those cities. It may be unavailable in some places, although Google is actively expanding GSV coverage around the world (). 5) Currently, GSV images are taken and updated periodically; hence, it is possible to download images taken in different seasons. The street vegetation and the extracted quantity of street greenery may differ in winter compared with other seasons. Yet this may not be an issue in Hong Kong, as most of its vegetation is evergreen or semi-evergreen. In locations with higher latitude, the GSV images should be filtered with a specific date range to ensure seasonal consistency among all images. 6) Greenery extraction based on the color band may falsely identify man-made green objects, such as trucks, walls, or windows, as greenery; moveable objects, such as large buses, may also block the view of street greenery. Further studies may implement a machine learning approach to achieve better accuracy in greenery extraction by considering the shape and distributions of the green pixels in an image (Badrinarayanan et al., 2015).

5. Conclusion

This study highlights the associations of quality and quantity of street greenery with the increased propensity for recreational green physical activity for Hong Kong residents. Our finding is important for interpreting the operational mechanisms between street greenery and health benefits because it demonstrates that physical activity is an intermediate health-related outcome. From a methodological perspective, as demonstrated in this study, using Google Street View may benefit further health and physical activity studies. Furthermore, this study's findings help us recognize the impacts of environmental factors on residents' physical activity and hence contribute to targeted intervention strategies for creating activity-friendly urban design.

Acknowledgements

The work described in this paper was fully supported by the grants from the Research Grants Council of the Hong Kong SAR, China (Project No. CityU11666716) and National Natural Science Foundation of China (Project No.51578474 & 51778552).

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