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Research paper

Where do networks really work? The effects of the Shenzhen greenway network on supporting physical activities

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HIGHLIGHTS

- Shenzhen greenways in well-developed areas were more popular.
- Greenway network could not attract physical activities in less-developed areas.
- Greenway network encouraged activity diversity in green and well-developed areas.
- Greenway network planning should match the urban development, green and daily life.

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ABSTRACT

In recent decades, greenways have been the focus of an international movement to improve urban environment quality. In metropolitan areas, more greenways are interconnected, forming a greenway network (GN). A GN is considered to encourage physical activities, but verifying this statement is difficult, as traditional social survey methods do not obtain fine-grain activity geographic data on a large scale. In view of this shortcoming, the volunteered geographic information and the geographic information system techniques were used to describe the distribution of physical activities in a GN, to explore the effects of greenway network features on supporting activities. The 1640-km-long Shenzhen GN was selected as a representative case, and walking, jogging and cycling were chosen as typical activities. The results showed that only a quarter of greenways were with activities. Greenways with dense residences, mixed land-use, advanced street network and large parks yielded positive effects on supporting physical activities, and advanced public transportation further improved activity diversity. Due to the spatial mismatch between the GN distribution and well-developed areas, the GN density showed negative effects on the presence of physical activities; within the greenways in use, the GN density significantly improved activity diversity, indicating the positive effect of network feature on supporting activities. Compared with neighbourhood greenways, city and regional greenways supported more physical activities due to richer natural resources. The findings reveal that GN in green and welldeveloped areas supports physical activities better. Location, green quality and network form are necessary for greenways and should be integrated into GN planning.

1. Introduction

A greenway is a "linear open space established either along a natural corridor, such as a riverfront, stream valley, or ridgeline, or overland along a railroad right-of-way that has been converted to recreational use, a canal, a scenic road, or other route" (Little, 1990). In the 1980s, greenway planning projects boomed in the United States as multi-benefit planning practices for ecology, economy, society and cultural preservation, and similar projects have since spread to Canada, north-western European countries, Australia, New Zealand, South Africa, Singapore and China, etc., as a part of the International Greenway Movement (Fábos & Ryan, 2006). In the early stages, greenways were developed as individual linear spaces, while in recent years planners have proposed the concept of

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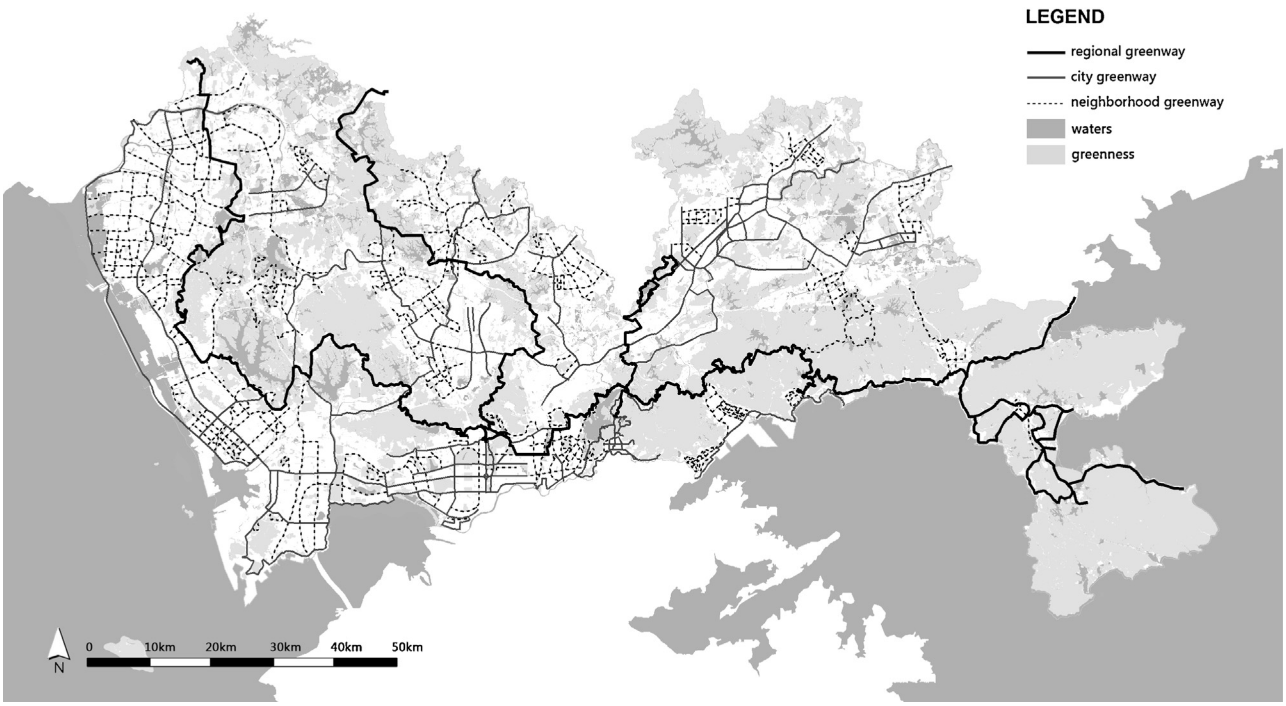

Fig. 1. The Shenzhen City Management Bureau, 2013,Shenzhen GN Map (2013). Original. Source: Shenzhen Greenways Map (The Shenzhen City Management Bureau, 2013).

a greenway network (GN) that links different greenways to provide a green matrix for better connections between cities and nature and a counterbalance to the built environment (Kullmann, 2013). Based on this idea, more greenways have been developed to link together on different scales to form local and regional networks. In China, greenways were introduced initially as a type of spatial network (Liu & Yu, 2001), and the concept of the GN was broadly used in the Chinese greenway planning research. As a result, Chinese greenways have been developed with a more systematic, large-scale, and network-oriented view (Fang, Zhu, Yuan, Qiu, & Peng, 2011; Teng, Wu, Zhou, Lord, & Zheng, 2011), which have become representative of GNs all over the world.

In general, greenways are regarded as having multiple functions, such as ecologically significant corridors (Ergen, 2013; Linehan, Gross, & Finn, 1995; Miller, Collins, Steiner, & Cook, 1998), recreational places (Tzolova, 1995; Vasconcelos & Pritchard, 2007), and paths with historical or cultural significance (Fábos, 1995; Pena, Abreu, Teles, & Espirito-Santo, 2010). The concept of GN is similar with green infrastructure, since they are both network-oriented green space. But unlike green infrastructure, which is an interconnected network of green space to conserve natural ecosystem values (Benedict & McMahon, 2006), the core purpose of GN is to provide a continuous and networked recreational public space close to nature. Studies have shown that the majority of people use greenways for health, fitness, and leisure, and the primary activities are walking, jogging, and cycling (Lindsey, 1999; Siu, 2007a). Many studies have discovered the relationship between greenways and physical activities, and have determined that greenway location, shape, pavement, services provided, accessibility and surrounding features, such as residential density and land-use mixture, likely influence greenway use (Gobster, 1995; Price, Reed, & Muthukrishnan, 2012). These studies emphasized the key role of understanding greenway use for greenway planning, examined the relationships between people and the greenways, and proposed strategies to improve the greenway functions for users. Currently, these studies have focused primarily on specific segments of the greenways using research tools, such as observation, social survey, and portable global positioning system devices.

GNs are believed to be more accessible to the public (Tan, 2006) and therefore could support more physical activities, but this has yet to be proven in a formal study. The scarcity of research can be explained in part by the complexity of urban systems (Lindsey, Wilson, Yang, & Alexa, 2008) and a lack of fine-grain physical activity data at the city or regional scale (Hirsch et al., 2014). However, geographic information system (GIS) and its spatial analysis function can process and calculate a large amount of data on built environments. Based on the ideas of *citizens as sensors* (Goodchild, 2007), the recent innovation and popularization of self-tracking applications, which record and collect users' routes and workouts, could provide rich volunteered geographic information (VGI) regarding users' physical activities at a large scale. With these techniques and records, describing the distribution of physical activities in GNs and discovering the relationships between them becomes easier. Using these new methods, Hirsch et al. (2014) performed a pilot study to test the feasibility of this VGI collection method from a self-tracking application named MapMyFitness. They concluded that this method effectively provided massive and extensive geographic scale information on physical activity with a low participant burden and could be a feasible new method to conduct large-scale environment behaviour research. Through the use of physical activity VGI, studying the relationship between GNs and physical activities has become possible on a citywide scale.

In this respect, this study used the Shenzhen GN which is totally 1640 km in length as a research site and fully utilized the physical activity VGI and GIS techniques to describe the presence and the diversity of physical activities in greenways, and to discover and explain where and how the GN supports or discourages physical activities. The goal of the study was to explore the effect of network-oriented greenways on physical activity distribution and to propose GN planning suggestions for physical activity promotion.

Table 1
Description of the physical activity VGI in January, April and July 2014.

		Num.	Distance (km)				Duration (min)				Speed (km/h)			
			Mean	Max	Min	SD	Mean	Max	Min	SD	Mean	Max	Min	SD
Type of physical activity	Cycling	51	14.26	48.10	2.86	11.13	73.29	304	16	61.49	13.24	45.10	3.61	5.95
	Jogging	679	7.54	42.82	0.69	4.34	52.62	440	9	33.00	8.79	23.00	1.93	2.13
	Walking	211	5.79	20.90	0.68	3.21	65.73	297	8	42.35	5.66	17.14	1.41	1.93

2. Methods

2.1. Study area

Shenzhen, a major financial centre in southern China, is located in the Pearl River Delta, which is one of the most important metropolitan areas in the country. In 2010, China began to develop the Pearl River Delta GN according to a typical top-down process in which six regional greenways were designed as the framework of the GN to connect regional country parks, nature preserves, historical heritage sites, and cities (Department of Housing and Urban-rural Development of Guang Dong Province, 2010). Guided by regional GN planning, each city planned and developed a city-scale GN as a sub-system of the Pearl River Delta GN.

The Shenzhen GN, a part of the Pearl River Delta GN, was planned in 2010 and gradually completed between 2011 and 2013. The Shenzhen GN is made up of three greenway hierarchies: regional greenways that are at least 100 m wide to link Shenzhen to other cities with a regional ecological function; city greenways approximately 20 m wide to connect different clusters in each city for a city-scale ecological system; and neighbourhood greenways to reach community parks and street-corner green areas primarily for daily recreation (Shan, Zhou, & Shao, 2013). The planning of the Shenzhen GN regarded the regional greenways as a framework and followed the planning principle of 5 min to the neighbourhood greenways, 15 min to the city greenways, and 30–45 min to the regional greenways. The GN also connected existing parks, greenbelts, waterfronts, and historical heritage sites and shaped an evenly distributed network around the city. By the end of 2013, the total length of the Shenzhen GN had reached approximately 1640 km, including 312 km of regional greenways, 539 km of city greenways, and 789 km of neighbourhood greenways (Figs. 1 and 2).

Considering that physical activities are influenced by greenways and the surrounding built environment (Brownson, Hoehner, Day, Firsyth, & Sallis, 2009), a 500-m buffer zone along the greenways were designated as the study area. The scale of the buffer was based on the distance that can be walked in 5 min (Mitra & Buliung, 2012) to greenways.

2.2. Data resources

2.2.1. Physical activity VGI

VGI is a kind of crowdsourcing geographic information, which is provided by the mass on a certain open data platform. In this study, the VGI was collected from Codoon, one of the most popular self-tracking applications in China. With Codoon, people can track workout routes and record the activity date, type (classified as walking, jogging and cycling), distance, speed, and duration. In addition, the social function of Codoon guides users to upload, share, and compare their workouts on social networks such as Sina Weibo (one of the largest Chinese social networks). By the end of 2013, Codoon had more than 20 million registered users, and the released records from Sina Weibo reached 1.4 million, which together formed a rich VGI database. To cover the physical activities in the different seasons, the VGI from January, April and July 2014 located in Shenzhen was selected for this study. These workout routes were geocoded into ArcGIS 10 with attributes, including the Web name, gender, activity date, time, type, distance, speed, duration, point of origin, and destination. The records without routes and for activities shorter than 5 min were excluded, which left 941 unique cases (Table 1).

2.2.2. Shenzhen GN data

The Shenzhen City Management Bureau (2013) published an official Shenzhen GN map that mapped the greenway hierarchy and routes. This map was geocoded into the GIS platform, with attributes that included the hierarchy and length, as the Shenzhen GN dataset.

2.2.3. Built environment data

In consideration of the impact of the built environment on physical activity (Cervero & Kockelman, 1997; Ewing & Cervero, 2010; Giles-Corti et al., 2013; Siu, 2007a; Troped, Wilson, Matthews, Cromley, & Melly, 2010), built environmental data were introduced for this study and comprised two parts: 1) land use data from the Shenzhen Land Use Survey (2009), in which land was classified as one of nine types (residential land, commercial land, government and institutional land, industrial land, warehouse land, street land, infrastructure land, parklands and other lands); and 2) traffic data in Shenzhen from OpenStreetMap, including five types (motorway, primary, secondary, branch, and others).

2.3. Measures

2.3.1. Dependent variables: physical activity distributions within greenways

2.3.1.1. The presence of physical activities. A dummy variable was generated to indicate the presence or absence of physical activities in greenways. In ArcGIS 10, the physical activity VGI was overlaid on the GN data to obtain a new dataset of partial GNs with physical activities by means of an intersect tool, and the remaining sections of the GNs were considered to be out of use. By this method, the Shenzhen GN was divided into 636 segments, of which 278 were with physical activities.

2.3.1.2. Physical activity diversity. This variable measured the number of different physical activities in each greenway segment in use and the degree to which they were represented. An entropy index was used in this study, which varied between 0 and 1 (0 for maximum specialization, 1 for maximum diversification).

$$PA\_DIVERSITY = \{-\sum_{k}[(p_i)(1\mathrm{n}p_i)]\}/(\mathrm{ln}k)$$

where

k = Number of physical activity types (k = 3, including walking, jogging and cycling)

p_i = Distance proportion of each of the three physical activity types

2.3.2. Independent variables: network characteristics of the greenways

Network and hierarchy are two key characteristics of the Shenzhen GN. Referring to network indicators (Hou et al., 2010), and

Fig. 2. The three hierarchies of the Shenzhen GN.

Fig. 3. The presence of physical activities in the Shenzhen GN.

given the greenway hierarchy in the Shenzhen GN map, we selected three variables to measure GN characteristics.

2.3.2.1. GN density. This variable was measured as the total greenway length per unit area of the 500-m-buffer zone along each greenway segment, to indicate the density of the GN around each segment.

2.3.2.2. Link-node ratio of GN. This variable is an index of greenway network connectivity, which equals the number of links divided by the number of nodes in the 500-m-buffer zone along each greenway segment, where links were greenway segments and nodes were greenway intersections and cul-de-sacs. A high ratio value indicates better connectivity.

2.3.2.3. Greenway hierarchy. A categorical variable was generated to represent the hierarchy of each greenway segment, including regional greenways, city greenways and neighbourhood greenways.

In addition, many studies have mentioned that physical activities are partly influenced by some detailed characteristics of greenways, such as pavement and service facilities (Lindsey, 1999; Mundet & Coenders, 2010). Considering that the Shenzhen GN was developed with overall planning and unified design standards,

Table 2
Control variables to indicate the surrounding built environment features.

5Ds	Factor	Measure
Density	Residential density	Percentage of the total parcel area for residential uses within the 500-m-buffer zone
Diversity	Land-use mixture	Entropy index of land uses within the 500-m-buffer zone (Song & Rodriguez, 2004)
Design	Intersection density	Number of four-way intersections per unit area within the 500-m-buffer zone (Forsth, Hearst, Oakes, & Schmitz, 2008)
Destination accessibility	Proportion of parklands	Percentage of total parcel area for parks within the 500-m-buffer zone
Distance to transit	Bus stops density	Number of bus stops per unit area within the 500-m-buffer zone (Ewing & Cervero, 2010)

Table 3
Predictive regression models and the hypothesized effect.

		Model 1		Model 2	
Dependent variable		The presence of physical activities (in use = 1, out of use = 0)		physical activity diversity	
Regression model		Binary logistic regression		Linear regression	
Number of cases		636 (all the greenways)		278 (greenways in use)	
Hypothesized effect		Step 1	Step 2	Step 1	Step 2
Control variables	Residential density	Positive	Positive	Positive	Positive
	Land-use mixture	Positive	Positive	Positive	Positive
	Intersection density	Positive	Positive	Positive	Positive
	Proportion of parklands	Positive	Positive	Positive	Positive
	Bus stop density	Positive	Positive	Positive	Positive
Independent variables	GN density	–	Positive	–	Positive
	Link-node ratio of GN	–	Positive	–	Positive
	Greenway hierarchy 1- RG[a]	–	Negative	–	Negative
	Greenway hierarchy 2- CG[b]	–	Negative	–	Negative

[a] RG: Regional Greenway.
[b] CG: City Greenway.

those detailed characteristics of greenways were ignored in this research.

2.3.3. Control variables: built environment characteristics

Following the 5Ds model to explain the effects of the built environment on transport-related physical activities (Ewing & Cervero, 2010), five factors were selected to represent the surrounding characteristics as control variables including density, diversity, design, destination accessibility and distance to transit. Table 2 shows the measure of the five factors, in which, considering that enjoying the green environment is the primary purpose of people to utilize greenways, the proportion of parklands within the 500-m-buffer zone was selected to indicate destination accessibility.

Because the physical activity VGI could not provide the precise sociodemographic data of users for this study, demographic variables were not considered as control variables.

2.4. Data merging and processing

The geocoded physical activity data, the Shenzhen GN data, and built environment data were overlaid in ArcGIS 10 with the Shenzhen local coordinate system to form the database for this study. To reduce the error in the process of route drawing, we created 25-m-buffer polygons around the physical activity routes to intersect the Shenzhen GN trails. The variables were measured with Arc toolbox and guided by NEAT-GIS Protocols (D'sousa, Forsyth, & Koepp, 2012).

2.5. Statistical analysis

The quantitative data were outputted into Excel 2010 and SPSS 19 for statistical analysis. The collinearity diagnostics among the independent and control variables were done before modelling, and the result showed there was no highly correlation among the variables (VIF < 10). Two regression models were used to explain the presence of physical activities and physical activity diversity in the GN ($p \le 0.05$). Each model performed two steps: (1) control variables were imported to establish the relationship between the control variables and the dependent variables, and (2) independent variables were added to the previous regression model to determine the contribution on the dependent variables. The hypotheses of the models were based on current studies (Table 3), in which the density, diversity, design, destination accessibility and distance to transit of the surrounding built environment, GN density and link-node ratio were assigned positive effects. Among three greenway hierarchies, we assumed neighbourhood greenways might support activities better than regional and city greenways, as neighbourhood greenways were more accessible.

3. Results

3.1. Descriptive characteristics

3.1.1. The presence of physical activities in the GN

Approximately 387 km of the greenways were used, accounting for 24% of the total length. The majority of physical activities were through or close to city parks, green corridors, waterfronts and continuous streets. The physical activities in the GN were not evenly distributed among the different administrative divisions (Fig. 3). The highest proportion of greenway length in use was in Futian District (64%) and the lowest was in Longgang District (less than 8%). Greenways in the well-developed areas were relatively better utilized than those in the underdeveloped areas (Fig. 4).

3.1.2. Physical activity diversity in the GN

The mean value for physical activity diversity was 0.27 (SD, 0.31), which signified that the diversity of physical activities in greenways was quite low. Fig. 5 shows the distribution of physical activity diversity in the greenways. The most diverse physical activities were distributed along continuous green corridors, such as Shennan Avenue, Shenzhen Bay waterfront, Dasha riverside and Futian riverside. More than 50 km of greenways in use were supporting only one type of physical activity.

Fig. 4. The proportion of greenway length in use by the administrative division.

Fig. 5. Physical activity diversity in the Shenzhen GN.

3.1.3. Network characteristics of the shenzhen greenways

The average GN density was approximately 0.5 km per square kilometre, and the link-node ratio is approximately 1.96, which indicates a high connectivity of the network. The GN density around the greenways in use was lower than those out of use, while the link-node ratio of the part in use was higher (Table 4).

Within the three hierarchies of the GN, the percentage of the city greenways in use was higher than the regional and neighbourhood greenways. An odds ratio analysis indicated that the city greenways were relatively better used than other types (Table 5).

3.1.4. Surrounding built environment characteristics

On average, within the 500-m-buffer zone, the proportion of residential land was 21% and land-use mixture was approximately 0.62, which indicated the high land-use diversity. Approximately 24 intersections and 54 bus stops were present per square kilometre, and the proportion of parklands was 30%. The five variables of the built environment along the greenways in use were all higher than the ones out of use (Table 6).

3.2. Statistical modelling results

A binary logistic regression was performed to explain the presence of physical activities. In the first step, the surrounding built environment features were imported, and the results showed that residential density, land-use mixture, intersection density and the proportion of parklands were all positively related with the presence of physical activities. Afterward, the network features were

Table 4
Description of the network characteristics of the Shenzhen greenways.

	Greenways in use				Greenways out of use				Total
	Mean	Standard Deviation	Maximum	Minimum	Mean	Standard Deviation	Maximum	Minimum	Mean
GN density (km/km^2)	0.33	0.27	1.04	0.01	0.63	0.26	1.36	0.01	0.50
Link-node ratio of GN	2.04	0.75	6.00	0.00	1.89	0.48	5.00	0.00	1.96

Table 5
Description of the GN hierarchy.

		Greenways in use		Greenways out of use			
		Length (km)	% (in type)	Length (km)	% (in type)	Total length (km)	Odd ratio
GN hierarchy	Regional greenways	59.6	19	252.3	81	311.9	0.96
	City greenways	169.6	32	369.4	68	539.0	1.44
	Neighbourhood greenways	157.4	20	630.4	80	787.8	0.76
	Total	386.6	24	1252.1	76	1638.7	–

Table 6
Description of the surrounding built environment characteristics.

	Greenways in use				Greenways out of use				Total
	Mean	Standard Deviation	Maximum	Minimum	Mean	Standard Deviation	Maximum	Minimum	Mean
Residential density (%)	23	14	68	0	20	13	57	0	21
Land-use mixture	0.64	0.13	0.86	0.03	0.61	0.14	0.83	0.04	0.62
Intersection density (/km^2)	27.60	22.93	114.03	0.00	20.52	21.53	117.71	0.00	23.62
Proportion of parklands (%)	31	22	99	0	29	23	99	0	30
Bus stop density (/km^2)	59.73	38.08	193.20	0.00	49.14	37.43	192.37	0.00	53.77

added to the model, and the result showed that city greenways were more likely to support physical activities, while GN density discouraged physical activities. In addition, regional greenways have a slight positive effect on the presence of physical activities, while the link-node ratio of the GN had no clear relationship. Compared with the first step, the introduction of the network feature variables caused the intersection density to lose significance, and Cox and Snell R Square increased from 0.101 to 0.317, to indicate the latter model fit the data better (Table 7).

The greenways in use (n = 278) were selected to further explore the relationships between the physical activity diversity and the GN with surrounding features using a multiple linear regression. In the first step, the result showed that the land-use mixture and the bus stop density both increased physical activity diversity. In the second step, the GN density, regional greenways and city greenways were all positively related with the diversity, and the bus stop density remained at the same contribution, while the land-use mixture lost significance. The link-node ratio of the GN still had no clear effect. Compared with the first step, Cox and Snell R Square also increased to indicate an improvement of the model (Table 8).

4. Discussion

4.1. The positive effects of well-developed surrounding built environments

The above analysis proved the positive effects of greenways: along these areas, residential density, land-use diversity, intersection density and accessibility to parks all were significantly positively correlated with the presence of physical activities. This result is consistent with current built environment studies related to greenway use (Gobster, 1995; Price, Reed, & Muthukrishnan, 2012) and physical activity behaviour (Hou et al., 2010; Troped, Wilson, Matthews, Cromley, & Melly, 2010). The study further determined that a higher bus stop density improved physical activity diversity, to indicate that a public accessible built environment could support more kinds of activities. In Shenzhen, Futian and Nanshan Districts are both high-density areas with diverse and advanced urban development, which is the primary reason that the greenways within these regions are more popular.

4.2. The contrary contributions of GN density in different models

As shown in the statistical analyses above, the GN density negatively influenced the presence of physical activities in Model 1, while positively relating with the physical activity diversity in Model 2. The Shenzhen GN planning believes that the network could increase the possibility of people using them, but the models revealed the confusing results. To explain these results, bivariate correlation analyses were conducted to examine the relations between the GN density and surrounding variables (Table 9).

In the cases where all of the greenways were considered, the correlation analysis showed that the places with a high GN density primarily contained a high proportion of parklands, combined with low residential density, intersection density and bus stop density, which suggested that the distribution of greenways was denser in natural environments and sparser in well-developed areas. Current studies have revealed the key role of greenways' locations on supporting physical activities (Coutts, 2009). Without dense residential areas and convenient traffic facilities surrounding the greenways, accessing greenways is difficult, even with a complete network form and a rich natural environment. Consequently, the overall mismatch between the Shenzhen GN and the well-developed built environment likely causes negative effects of the GN density on the presence of physical activities.

In the cases of greenways in use, no clear relationship existed between the GN density and the surrounding features, which excluded the influence of the surrounding environment on the GN density. To a certain extent, the positive effects of GN density on physical activity diversity proved that the network features could promote physical activities. This result is consistent with the definition of an effective network, by which users and their needs are matched, thereby attracting more users to strengthen the network function (Shapiro & Varian, 2013). A network-oriented greenway

Table 7
Binary logistic regression model of the presence of physical activities.

Model 1 (Binary logistic regression)		Step 1 (surrounding features)		Step 2 (surrounding & network features)	
		B	Sig.	B	Sig.
Control variables	Residential density	3.426	**0.000**	2.647	**0.011**
	Land-use mixture	5.139	**0.000**	7.513	**0.000**
	Intersection density	0.013	**0.003**	0.002	0.707
	Proportion of parklands	5.192	**0.000**	5.840	**0.000**
	Bus stop density	0.006	0.062	0.006	0.075
Independent variables	GN density	–	–	−4.569	**0.000**
	Link-node ratio of GN	–	–	0.208	0.227
	Greenway hierarchy 1- RG[a]	–	–	0.842	0.052
	Greenway hierarchy 2- CG[b]	–	–	0.641	**0.010**
(Constant)		−6.414	0.002	−6.121	0.002
N		636			
Cox and Snell R Square		**0.101**		**0.317**	

Dependent variable: The presence of physical activities (in use = 1, out of use = 0).
[a] RG: Regional Greenway.
[b] CG: City Greenway.

Table 8
Linear regression model of the physical activity diversity.

Model 2 (Linear regression)		Step 1 (surrounding features)		Step 2 (surrounding & network features)	
		B	Sig.	B	Sig.
Control variables	Residential density	−0.199	0.303	−0.010	0.995
	Land-use mixture	0.462	**0.029**	0.116	0.548
	Intersection density	0.000	0.862	0.000	0.664
	Proportion of parklands	0.276	0.084	−0.058	0.694
	Bus stop density	0.002	**0.008**	0.001	**0.013**
Independent variables	GN density	–	–	0.481	**0.000**
	Link-node ratio of GN	–	–	0.036	0.104
	Greenway hierarchy 1- RG[a]	–	–	0.157	**0.026**
	Greenway hierarchy 2- CG[b]	–	–	0.099	**0.014**
(Constant)		−0.199	0.303	−0.128	0.447
N		278			
Adjusted R Square		**0.035**		**0.244**	

Dependent variable: physical activity diversity.
[a] RG: Regional Greenway.
[b] CG: City Greenway.

planning is confirmed to have the potential to support more physical activities.

In addition, there's no clear relationship between link-node ratio of GN and physical activities, it is probably because the Shenzhen GN is evenly distributed with a high average connectivity.

4.3. The roles of greenway hierarchy to support physical activities

Based on the Shenzhen GN planning principle of 5 min to the neighbourhood greenways, 15 min to the city greenways, and 30–45 min to the regional greenways, the neighbourhood greenways were believed to be more accessible and had more potential to support physical activities. However, in the analysis results, the regional greenways and city greenways were positively related with the presence of physical activities and their diversity. The result seems to contradict the principle and current studies on greenway accessibility (Mundet & Coenders, 2010). In the Shenzhen GN, the regional greenways and city greenways are primarily wider and are continuous with, cross over or are close to large parks and waterfront, while neighbourhood greenways are narrower and close to residences without rich green surroundings (Fig. 6). Gobster & Westphal (2004) have emphasized the importance of green resources for recreational needs, and thus the lack of green features likely reduces the attraction of neighbourhood greenways to physical activities, despite being more accessible. Regional greenways and city greenways, particularly city greenways, could provide sufficient green public space within the well-developed built environment, and therefore performed better on supporting physical activities.

4.4. The keys of GN to support physical activities

A greenway is intended to provide continuous recreational public space close to nature, and the goal of a GN is to make more greenways and recreational places available to the public. Therefore, connecting users and green recreational places is the primary function of a GN. In Shenzhen, greenways are network-oriented in undeveloped areas and sparse within high-density urban areas. The mismatched distribution of the network cannot connect green places to the public well and were negatively related with current physical activities as a consequence. Despite this, the study still proved the positive effect of network feature on physical activities, as the GN density improved the diversity of physical activities within the greenways in use. To support physical activities, greenways should be networked in those areas with a high residential density, mixed land-use and intersection density, and proximity to large parks, instead of green infrastructure to serve the ecosystem.

In addition, the balance between nature and the built environment is important for greenways (Siu, 2001, 2007a). In Shenzhen, with the similar surrounding features, neighbourhood greenways had negative effects on supporting physical activities, which is likely due to the lack of sufficient green environments, despite

Table 9
Bivariate correlation between the GN density and surrounding variables.

			Residential density	Land-use mixture	Intersection density	Proportion of parklands	Bus stop density
All of the greenways (n = 636)	GN density	Pearson Correlation	−0.230*	−0.064	−0.275*	0.138*	−0.131*
		Sig. (2-tailed)	0.000	0.108	0.000	0.000	0.001
Greenways in use (n = 278)	GN density	Pearson Correlation	−0.100	0.117	−0.012	0.097	−0.030
		Sig. (2-tailed)	0.095	0.052	0.838	0.105	0.624

* Correlation is significant at the 0.01 level (2-tailed).

theoretically being the most accessible greenways. However, in comparison, regional greenways and city greenways were effectively supporting physical activities, as they were wider and had a richer natural environment. Green is the most attractive feature of greenways for the public, and therefore a GN should provide an accessible network with a high-qualified green surrounding composed of rivers, waterfront, hillside, large parks, lakes and other linear open spaces with green potential, such as railways and continuous streets, instead of non-mobilized systems to reach every residence.

The findings reveal that GN in well-developed areas with high-qualified green environment could support physical activities better.

4.5. Advice on GN planning

In the United States and many other countries, a greater number of greenways connect cities and states, as people believe that an overall connection on a large scale could achieve great benefits for human beings and the entire ecological system. Accordingly, GN planning is generally a top-down system, which starts from the regional scale to build a large-scale network that serves the regional ecology. However, these connections overstep the scope of human daily life (Siu, 2007a, 2007b), and an artificial construction in the wild might not contribute positively to nature. Gobster (1995) suggested that local, rather than regional greenways should form the framework of a metropolitan system. This study also has determined that greenways far away from well-developed areas experienced a low rate of use, despite being well networked. Therefore, the scale of a GN should follow the scope of the physical activities in daily life, rather than unlimited expansion, and the construction of a GN should mainly concentrate on those developed and developing areas with potential dense populations.

In the Shenzhen GN, three quarters of greenways could not support physical activities well and caused a significant waste of the public resources. Green resources in Shenzhen are quite rich, not only in undeveloped areas but also within well-developed areas, which benefits from the clustered spatial structure (Zacharias & Tang, 2010). To improve the efficiency of the Shenzhen GN on supporting physical activities, planners should concentrate on developed and developing areas with dense residence, discovering and fully utilizing potential green resources, planning and building a greater number of network-oriented greenways, improving the surrounding land-use diversity, street network and public transportation, and extending the GN following the process of urban development. With regard to the less frequented greenway sections, the serious evaluation should be done to recognize the potential of greenways and the surrounding environment on attracting people. For those greenways in potential developing areas, planners should improve the green level and accessibility of the greenways, and make full use of the externality as the key driving force for local development, to promote the liveability, walkability, density and attraction of surrounding areas. And for those GN in natural reserves far away from the city, the density should be reduced by ecological restoration, left some main greenways with high-qualified landscape for tourism.

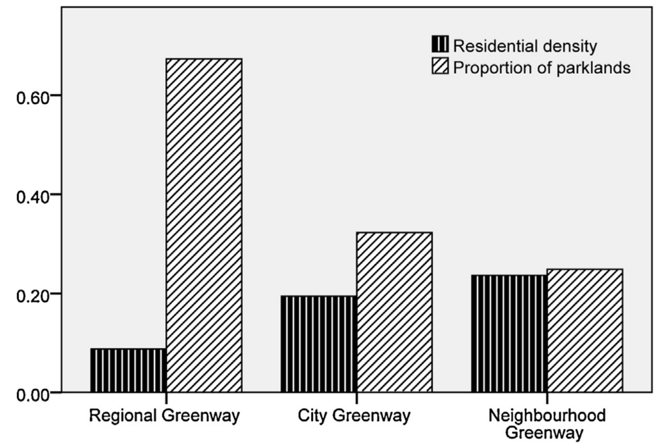

Fig. 6. Surrounding comparison among different greenway hierarchies.

4.6. Limitations

As mentioned by Hirsch et al. (2014), users of self-tracking applications may not be representative of the general population, as smartphone users may be younger, more modern, or have greater financial resources. Therefore, the patterns and preferences of their physical activities may not be generalized, and the greenway use analysis based on the VGI data might not report precisely the overall use of the GN. The reliability of the research results and the degree of representativeness requires further study. Moreover, physical activity VGI does not contain the users' socioeconomic information, and the results could not explain fully the relationship between the GN and users. Further studies can focus on collecting more demographic variables by means of a questionnaire using the Weibo platform to improve the accuracy of the models.

5. Conclusions

This study fully utilizes VGI and GIS techniques to describe and analyse greenway use to determine the effects of GNs on supporting physical activities. This approach could collect reliable mass physical activities within certain areas from the open VGI data pool, objectively determine greenway use on a large scale, process a large amount of built environment data with ease, and consequently demonstrate a strong potential for spatial behaviour research.

As the study has shown, in Shenzhen, physical activities were not distributed evenly and were conducted in well-developed areas. Based on the results and discussion presented above, we conclude that (1) to attract physical activities, greenways should be located within the areas with a dense residence, mixed land-use, complete street network and rich natural environment, and advanced public transportation could further improve the physical activity diversity; (2) based on the premise of the above location, network-oriented greenways could support more types of physical activities, otherwise the mismatch between well-developed areas and network distribution might reduce greenway use; and (3) the high grade greenways, such as regional greenways and city greenways, are more attractive, as they connect better qualified natural environments and have more recreational places. To improve the service for physical activities, well-developed areas, green quality and network form are significant for GN planning.

Although greenways are believed to have multiple benefits for ecology, economy, society, and cultural preservation, the fundamental goal is to provide places for citizens to enjoy nature. Therefore, greenways are different from either green infrastructures or non-motorized systems, as they provide a balance between nature and daily life. Consequently, top-down eco-oriented GN planning and large-scale projects should be reassessed, and greater attention to preferences among physical activities could inform greenway planning to make a greater contribution to public health and to protect more nature in virtue of citizen movements.

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