



The role of perceived environment, neighbourhood characteristics, and attitudes in walking behaviour: evidence from a rapidly developing city in China

Eric T. H. Chan¹ · Tim Schwanen¹ · David Banister¹

Published online: 19 October 2019

© The Author(s) 2019

Abstract

The associations between objective and subjective dimensions of the built environment and walking behaviour have been examined extensively in existing studies. However, the interaction effects of those dimensions of the built environment on walking behaviour are understudied and may be more complex than hitherto suggested. Apart from the subjective dimensions of the built environment, walking attitudes also play a role in moderating these relationships. This paper investigates the independent and joint effects of objective neighbourhood characteristics, people's perceptions of the neighbourhood environment, and walking attitudes on the frequency of walking by using Shenzhen as a case study. Since those effects may vary across different kinds of walking trips, the analysis looks separately at three major types of walking at the neighbourhood level—walking for work/school, walking for leisure/recreation, and walking for household responsibilities. Logistic regression analyses confirm that the correlates of people's walking frequency vary considerably among different types of walking. Statistically significant interaction effects of objective neighbourhood characteristics and perceived environment are found. The results suggest that positive perceptions of the environment can compensate for the effect that low objective walkability of neighbourhoods has on people's walking frequency. When seeking to encouraging walking at the neighbourhood level, policymakers should not only concentrate on improving objective neighbourhood characteristics but also consider people's perception of the neighbourhood environment and their attitudes towards walking.

Keywords Walking behaviour · Built environment · Perceived environment · Attitudes · Shenzhen · China

✉ Eric T. H. Chan
eric-th.chan@ouce.ox.ac.uk

¹ Transport Studies Unit, School of Geography and the Environment, University of Oxford, South Parks Road, Oxford OX1 3QY, UK

Introduction

Physical inactivity is one of the major challenges to global public health (Sallis et al. 2016). Studies have shown that 18% of the population in developing countries are physically inactive (Dumith et al. 2011). For instance, the average level of physical activity for adults in China has dropped by nearly 50% from 1991 to 2011 (Zang and Ng 2016), and almost 80% of its adolescents were reported having inadequate exercise (Chen et al. 2014). In this context, walking has become a most sustainable form of physical activity in our daily lives, which enables people to interact with the environment in a more direct way due to its slow speed (Kamruzzaman et al. 2016; Larrañaga et al. 2016). Increasing evidence reveals that the improvements of the built environment can facilitate walking and other types of physical activity by providing more convenient transportation (Ball et al. 2001), accessible destinations (Owen et al. 2007), aesthetically pleasing features (Inoue et al. 2010), and well-maintained footpaths (McCormack et al. 2010), etc.

However, several recent studies have drawn attention to the divergent effects of objective and subjective dimensions of the built environment in explaining variations in walking behaviour (Hanibuchi et al. 2015; Koohsari et al. 2015). It has been suggested that both dimensions of the built environment should be included, as different associations have been found between the objective and subjective dimensions of the environmental features with walking behaviour (Ma et al. 2015; Orstad et al. 2017). Nonetheless, the relationships between those dimensions of the built environment and walking behaviour may be more complex than hitherto suggested. There may be interactions in how objective neighbourhood characteristics and neighbourhood perceptions affect walking behaviour. Such interaction effects need to be examined further in a structured manner.

Additionally, walking attitudes may moderate the environmental influences on physical activity (Yang and Diez-Roux 2017), although previous research has largely focused on measuring travel attitudes in general (Kitamura et al. 1997; Larrañaga et al. 2016). Recent studies suggest that compared to general attitudes, behaviour-specific attitudes have stronger correlations with the behaviour (Kroesen and Chorus 2018). How walking attitudes play a role in shaping the associations between the built environment and walking behaviour deserves further exploration (Ma and Cao 2017; Kamruzzaman et al. 2016). Hence, including behaviour-specific attitudes (walking attitudes in this study) may help to improve our understanding on the associations between the built environment and walking behaviour.

In this study, rather than portraying walking as a generic form of movement, we pay special attention to the purpose of and activities generated by the walking trips. The influence of the built environment on walking behaviour may vary for trips with different purposes, such as household responsibilities, work/study, and leisure. Thus, it is opportune to examine the influence of the built environment on different purposes of walking behaviour. Moreover, our current knowledge of the associations between the built environment and walking is mostly based on findings from developed cities in North America, (Western) Europe, Australia and New Zealand (Feng 2016). Case studies in rapidly developing countries, in particular China, are still limited to date. Metropolitan cities in China, such as Beijing, Shanghai, and Shenzhen, have highly mixed land uses, extremely high population densities and are less car-dependent compared to Western cities (Kenworthy and Hu 2002). In view of such differences in social, cultural, and economic contexts, it is urgently needed to investigate the associations between the

built environment and walking behaviour in the Chinese context. The results of such studies will inform urban planners and policymakers in designing more appropriate and contextualised strategies for intervention.

To fill these gaps, this paper examines the association between objective neighbourhood characteristics, perceptions of the neighbourhood environment, walking attitudes, and walking behaviour for three specific types of neighbourhood walking trips. We include both objective and subjective dimensions of the neighbourhood environment, and explore their interaction effects in order to understand the impacts of the built environment to walking behaviour more comprehensively. Using Shenzhen as a case study allows us to enrich the literature of walking by incorporating a non-western perspective. This paper is organised as follows. First, drawing insights from current literature, we discuss the links between the built environment, walking attitudes, and walking behaviour. We then present the methodology of this research, followed by discussions of the empirical results. Lastly, the conclusion summarises the major findings and provides directions for future studies.

Literature review

In this section, we discuss the connections between the built environment, walking attitudes, and walking with different purposes by reviewing the comparable and contradictory findings that derived from both the Western and Chinese contexts. We acknowledge that the experiences, practices, and theories generated from previous studies may not be transferable to other contexts, especially rapidly developing countries like China.

Understanding walking behaviour

Public health literature has provided important insights into the connections between environment and behaviour by exploring complex interactions between people's perceptions and cognitions, the social, cultural, and physical environment, and human behaviour (Sallis and Owen 2015; Millward et al. 2013). These studies usually categorise walking into two major types: walking for transportation and walking for leisure (Humpel et al. 2004; Turrell et al. 2013). For instance, they tended to classify all walking trips undertaken to reach a destination (e.g. walking to work and walking to shopping) as a generic type of "walking for transportation", regardless of the trip's nature, main purpose, and activities generated by that trip. Overlooking the activity and demand associated with a walking trip might be problematic, for most people may not make separate decisions regarding their walking trips, but schedule their activities and walking in a daily pattern. As such, most of their walking trips will be derived from the demand for participation in activities, as argued from the activity-based approach that travel is regarded as a derived demand (Reichman, 1976; Kwan 2000; Schwanen et al. 2008; Vilhelmsen 1999). Increasing number of studies start to distinguish different types of walking when examine the association between built environment and walking behaviour. For example, a recent study by Cho and Rodríguez (2015) found that the built environmental factors associated with walking for work and walking for shopping and/or eating were considerably different, although these two types were both regarded as walking for transportation.

Following the work of Reichman (1976) and many others (Lu and Pas 1999; Wang and Lin 2013), the present study distinguishes walking into three types associating with respective activities, namely walking for work/school, for leisure/recreation, and for household

responsibilities, based on traditionally classified daily activities such as work-related, leisure and obligatory activities. By doing so, we intend to explore further the influence of the built environment on different types of walking trips.

Environmental influence on walking behaviour

Numerous studies conducted in Western contexts have revealed that land use mix and proximity to destinations are positively related with frequency of walking (Krizek 2003; King et al. 2015) and that more pedestrian activities can be found in the neighbourhoods with more complete street networks (Moudon et al. 1997). Some Chinese studies have found different results. For example, a study conducted in Shanghai found that street connectivity was negatively associated with leisure time physical activity (Zhou et al. 2013). Similarly, based on a survey of 1070 residents in Shanghai and Hangzhou, Alfonzo et al. (2014) found that people who perceive their residential environment to be less convenient actually spent more time walking. This might be because people with few alternatives to reach their destinations (e.g. lower automobile access) would have to walk more for non-commuting purposes.

Safety has been considered as one of the common issues in walking in many Western cities (Foster et al. 2004). A recent review has demonstrated how concerns over safety are triggered by factors such as social incivilities, absence of people on street, and other undesirable environmental features (Brown et al. 2007). Speedy traffic and inadequate pedestrian crossing facilities are also found to be negatively associated with walking (Saelens et al. 2003). However, no conclusive findings have been found in Chinese cities to date. Some studies found that traffic safety was negatively associated with physical activity for adults in Shanghai (Zhou et al. 2013), while in other studies, no significant associations were found between traffic safety and leisure time physical activity (Su et al. 2014).

The quality of the pedestrian environment was found to be another influential factor for walking in both Western and Chinese studies. For example, Michael et al. (2006) found that well-maintained streets (without litter and graffiti) increased older people's inclination to walk. Likewise, the aesthetic qualities of the built environment, such as presence of attractive buildings and green spaces, have been found to be positively associated with walking (Moudon et al. 2007). Similarly, positive associations between aesthetic qualities and leisure time walking have been found in a Chinese study, but no associations with walking for transportation have been reported (Su et al. 2014).

Regarding the relationships between objective, perceived built environment and walking behaviour, two types of relationships have been proposed in previous studies—through mediation or moderation effects. The former hypothesised that the objective built environment influenced walking through perceived environment (Ma and Cao 2017; Orstad et al. 2017); while the latter proposed that the relationships between objective environment and walking depends on the perceived environment. For instance, some recent studies have explored various moderation effects between neighbourhood environment and physical activity through psychosocial factors (Serrano et al. 2018; Perez et al. 2016), and walking attitudes (Yang and Diez-Roux 2017). However, the effects of perceived environment in moderating the relationships between objective neighbourhood characteristics and three types of walking frequency are understudied and deserve more structured examination.

Attitudes and walking behaviour

Travel attitudes are usually measured by using factor analysis or carefully validated psychometric scales to capture meaningful constructs from numerous statements to reveal travelers' preferences, fondness and perceptions towards different transport modes, as well as intention to travel. Travel attitudes have been found to have significant effects on travel behaviour (Kitamura et al. 1997; Kamruzzaman et al. 2016; Vale and Pereira 2016). For example, Cao et al. (2006) identified four types of travel attitudes: pro-bike/walk, travel minimising, safety of cars, and car dependent during their investigation of relationships between built environment and travel behaviour. Likewise, Larrañaga et al. (2016) identified three types of travel attitudes: pro-walking, pro-car, and safety-neighbourhood by studying environmental influence and travel attitudes on walking in Porto Alegre, Brazil. Nonetheless, most of these studies devoted to capturing travel attitudes in general rather than attitudes associated with specific travel behaviour (Kroesen and Chorus 2018).

Recently, some studies started to examine the role of walking attitudes in understanding walking behaviour. Such behaviour-specific attitudes towards walking activity, like enjoyment, importance, and positive experience in the past were considered to have close relationships with people's walking behaviour. For instance, through examining the interaction effects of walking attitudes and neighbourhood environments on walking, Yang and Diez-Roux (2017) found that positive walking attitudes were associated with walking for transportation and leisure regardless of the environmental characteristics. However, some of these studies used a single item to measure attitudes, which might increase the sensitivity to measurement error. In light of the above considerations, the present study draws insights from previous studies on travel and walking attitudes (Joh et al. 2012; Handy et al. 2005) and develops a 7-item scale that specifically measures people's walking attitudes to explore the relationships between the built environment and walking behaviour.

Summary

The literature review pinpoints a number of gaps in the current walking and travel behaviour literature. First, it is noted that most of the current studies tended to treat walking as generic form of travel without fully considering its associations with people's demand, activities and purposes, which may have oversimplified the relationships between the built environment and walking. Second, existing studies have revealed both similar and contrasting findings between cities in the Chinese and Western context. More research is called for, focusing on non-Western context and providing useful insights on appropriate policy recommendations. Finally, recent studies have suggested to measure behaviour-specific attitudes and examine its associations with specific travel behaviour, as behaviour-specific attitudes may capture unique variabilities compared to general travel attitudes.

The present study aims to investigate the associations between objective neighbourhood characteristics, perceived neighbourhood environment, walking attitudes, and frequency of three types of walking. In addition, possible interaction effects between objective neighbourhood characteristics and perceived built environment and walking attitudes on walking frequency are explored. First, we expect positive associations for favourable perceived environmental factors and walking attitudes on walking frequency. Next, given that few studies have explored the interactions effects between objective neighbourhood characteristics and perceptions of the neighbourhood environment in relation to frequency of three

types of walking, the study will be exploratory in nature. This study can contribute to the literature in understanding the possible moderation effects of objective and perceived built environment on walking frequency.

Methodology

Study design and neighbourhood selection

Shenzhen is located in the southern region of Guangdong Province in China. By the end of 2015, it had a population of 11.38 million on its 1992 km² land area (Shenzhen Statistical Bureau 2016). Established as one of the special economic zones in 1980, Shenzhen has witnessed rapid economic growth and urban development since then, making it one of the major metropolitan cities alongside Beijing, Shanghai and Guangzhou. In 2012, the Ministry of Housing and Urban–Rural Development and National Development published a national-level policy document guiding the improvements of walking and cycling infrastructures in cities. Following this national guideline, Shenzhen was one of the earliest cities in China to develop its city level planning guidelines on encouraging walking and cycling.

We adopted a neighbourhood-based study design to limit the focus to the selected neighbourhoods. Unlike other transport modes that are usually performed at regional or city scale (traveling across different locations within the city), home-based walking trips are usually performed within people's own residential neighbourhoods. As such, neighbourhood-based design allows the researchers to have a more in-depth understanding of the associations between neighbourhood built environment and walking behaviour. A multi-stage sampling method was applied in selecting neighbourhoods for analysis. In the first stage, two sub-districts with contrasting regional accessibility were chosen, one in the inner urban area of the city (Shatou), and another in the outer urban area (Longchen). Most of the early development in Shenzhen was concentrated in the inner urban areas, and it was only in the past decade that the development gradually spread towards the outer urban areas. According to the 2010 census, 64% of the residential units in Shatou were built in 1980–1999, compared to only 38% in Longchen during the same period (Shenzhen Government 2011). Differences in land use patterns, street networks, and urban design can be observed in these areas. In view of such differences, it is necessary to select neighbourhoods in both areas to capture such variations (Su et al. 2017). In the next stage, within each sub-district, two neighbourhoods with the highest and lowest local accessibility were selected for further study. Local accessibility was measured by a composite index measuring the distance to nearest Shenzhen metro station, distance to the nearest park/plaza, and the number of restaurants within the neighbourhood boundary, using data from Baidu Map. For Shatou sub-district, Xinzhou (high local accessibility) and Xinsha (low local accessibility) were selected. For Longchen sub-district, Shangjing (high local accessibility) and Huilongpu (low local accessibility) were selected.

Survey

The data were obtained by means of a questionnaire survey conducted in the four selected neighbourhoods in Shenzhen from December 2016 to March 2017. The sampling design combined convenience sampling (all adults available in the park or open space) and random

probability sampling (surveyors were instructed to approach the next adult they encounter as a potential respondents). To minimise potential selection bias, we have conducted the surveys in multiple locations, both on weekdays and weekends, and during different time periods. Respondents were asked if they were living in this neighbourhood, with the assistance of a map showing the neighbourhood boundaries. A small gift (such as key chains, bookmarks, ball pens) was provided as an incentive for participation (about USD\$1). The number of respondents totaled 890. Although detailed records on the number of people who refused to participate were not gathered, the response rate was estimated to be about 50% based on the feedback from surveyors. The survey was divided into four parts, containing questions relating to well-being, walking behaviour, environmental perceptions and attitudes, and socio-demographic characteristics.

Variables

The variables used in this study consist of five categories: walking behaviour, perceptions of the neighbourhood environment, objective neighbourhood characteristics, walking attitudes and socio-demographics. Walking behaviour was measured by asking respondents to recall their most recent walking trips that they have performed for the three specific purposes of walking respectively in the past week within their neighbourhoods. They were then asked, “How often do you usually perform this trip?”. Five options ranging from “less than once a week” to “more than 7 times a week” were provided.

Perceptions of the neighbourhood environment were measured using selected items from the abbreviated version of the Neighbourhood Environment Walkability Scale (NEWS-A) (Cerin et al. 2009). Selected items were modified to make them more applicable to the context of the city of Shenzhen. Two sub-scores measuring residential density and land use diversity were excluded from this study to reduce the questionnaire length and hence respondent burden. Other modifications include eliminating items that were unsuitable for the case of Shenzhen. For example, one item asks participants whether “Walkers and bikers on the streets in my neighbourhood can be easily seen by people in their homes”. In Shenzhen, as in other high-density cities, multi-storied residential buildings are common and it is nearly impossible to observe pedestrians from these high-rise buildings. A number of statements derived from the findings of an exploratory qualitative study conducted preceding the present study were added to capture some other aspects of the built environment, including “poor footpath condition” and “maintenance and upkeep”. All neighbourhood perception items were measured using five-point Likert scales, ranging from 1 (strongly disagree) to 5 (strongly agree). Eight neighbourhood perception subscores were computed. Five of them were positive, including access to destinations, street network, physical infrastructure, aesthetics and maintenance and upkeep. Three of them were negative, including traffic safety, personal safety, and poor footpath condition. The statements used to measure neighbourhood perception are presented in “[Appendix](#)”.

Neighbourhood characteristics were measured by two dummy variables capturing the objective characteristics of the selected neighbourhoods. The first variable denotes whether the neighbourhood was an outer urban neighbourhood, the other variable distinguishes whether the neighbourhood was a low local accessibility neighbourhood.

There is currently no consensus on standardised measures on travel attitudes, let alone more specific walking attitudes. Drawing insights from previous literature (Handy et al. 2005; Joh et al. 2012), seven statements were used to measure walking attitudes. Respondents were asked whether they agree or disagree with the statements in “[Appendix](#)” using

Table 1 Descriptive statistics of socio-demographic variables

Variables	Categories	Sample	Population (%)
Age	18–30	182 (24.9%)	36.90
	31–40	191 (26.2%)	24.20
	41–50	120 (16.4%)	14.20
	51–60	133 (18.2%)	4.50
	Over 60	104 (14.2%)	2.90
Gender	Male	316 (43.3%)	54.80
	Female	414 (56.7%)	45.90
Employment	Full-time	303 (41.5%)	81.50
	Not full-time	427 (58.5%)	18.50
Education level	Primary or lower	42 (5.8%)	5.30
	Secondary	305 (42.0%)	75.80
	Tech. institute/junior college	183 (25.2%)	10.30
	University and above	196 (27.0%)	8.60
Household income, Chinese Yuan (CNY)	Less than 100,000	251 (40.3%)	N/A
	100,000 to 300,000	305 (49.0%)	
	More than 300,000	67 (10.8%)	
Driver's license	Yes	405 (56.0%)	N/A
	No	318 (44.0%)	
Length of residency	Less than 2 years	107 (14.7%)	N/A
	2–5 years	337 (46.4%)	
	6–10 years	205 (28.2%)	
	More than 10 years	78 (10.7%)	
Body Mass Index (BMI)	Less than 18.5	54 (7.5%)	N/A
	18.5–24.9	499 (69.4%)	
	25.0–29.9	148 (20.6%)	
	30.0 or above	18 (2.5%)	

Shenzhen population data was obtained from 2010 Shenzhen Population Census

seven-point Likert scales ranging from 1 (strongly disagree) to 7 (strongly agree). A walking attitudes sub-score was constructed based on the mean score of the seven statements.

The socio-demographic variables used in this study include age, gender, employment status, educational level, household income, having a driver's license. Length of residency in the present neighbourhood and body mass index (BMI) are also included, as length of residency might affect the decision of a person to walk for various purposes and BMI can control for body type. Self-reported height and weight were collected, the weight in kilograms was divided by the height in meters squared (kg/m^2) to obtain the BMI. The socio-demographic variables are shown in Table 1, and compared with the 2010 Shenzhen Population Census. Within the sample there is an over-representation of older people, women and people without full-time employment and with a higher education level.

Limitations of this study

There are several limitations in this study. First, this study is cross-sectional, so it is impossible to evaluate whether the established correlations reflect causality. Future studies can

benefit from the use of longitudinal data or experimental design. Second, walking behaviour, attitudes, and perceived environmental features are all based on self-reporting, and there may be discrepancies between individuals' perception and a more general inter-subjective consensus view. Although the basic socio-demographic variables have been controlled for in all of the regression models, it is possible that some other unobserved (or unmeasured) variables might also play a role in mitigating the relationships between the built environment and walking behaviour, thus affecting the results of the analyses. Besides, objective built environment was only measured with neighbourhood characteristics in two dimensions (inner or outer urban neighbourhoods and high or low local accessibility), which might not truly capture the micro environmental features that the respondents encounter during their daily walking. The recruitment of local residents in public spaces using intercept survey might have resulted in selection bias. It might be expected that people who are healthier or more willing to walk and use the public areas are overrepresented, whilst other people who might have mobility limitations could be underrepresented. Although the surveys were conducted both on weekdays and weekends at various times of the day and multiple locations to minimise the impact of this problem, such bias might still be possible. Future studies with less selection bias can enhance rigor in this field of research. Moreover, this study focused on one city—Shenzhen, and within a number of selected neighbourhoods only, which might limit the application of the results to other cities.

Data analysis

Since the dependent variables are categorical data, logistic regression analyses were used to examine the relationships between neighbourhood characteristics, perceived environment and walking attitudes in affecting the frequency for three types of walking (Hosmer et al. 2013). Given that the focus of this paper was to explore the environmental influences on different types of walking, rather than people's mode choice decision, so separate logistic regression models were constructed for each type of walking. Binary logistic regression was used for work/school related walking frequency model to distinguish between those who walk for work/school at least half of trips per week¹ (medium and high frequency) and those who only walk occasionally (low frequency). Multinomial logistic regression was used for walking for leisure/recreation and household responsibilities related activities (low vs medium vs high frequency). In addition, we examined the possible interaction effects between the objective neighbourhood characteristics and perceived environment and walking attitudes. For each interaction, the product term was added separately and *p* value of the interaction term was used to evaluate the statistical significance. Interaction terms that were significant at the .05 level were entered into the model. After that, insignificant variables were removed stepwise to maintain the parsimony of the final models, except for the basic socio-demographic variables, including age, gender, employment, and income, which were included in all regression models as control. The inclusion of interaction variables into logistic regression models might lead to multicollinearity problems because the interaction terms are correlated with the main effects terms used to calculate

¹ As most of the employees and students need to go to work or school for only 5 days per week, separating walking frequency into low (less than 3 times) and medium–high (3 times or more) allow us to indicate whether walking is the common choice for their daily travel (3 out of 5 times per week).

Table 2 Descriptive statistics of frequency for three types of walking

Walking frequency	All respondents (%)	Inner urban neighbourhood (%)	High accessibility neighbourhood (%)
<i>Work/school related walking</i>			
Low (less than 3 times/week)	78 (15)	37 (15.4)	37 (15.1)
Medium–high (3 times and more/week)	442 (85)	204 (84.6)	208 (84.9)
<i>Leisure/recreation related walking</i>			
Low (less than 3 times/week)	347 (43.1)	176 (43.7)	144 (34.8)
Medium (3–6 times/week)	221 (27.4)	103 (25.6)	108 (26.1)
High (7 times or more/week)	238 (29.5)	124 (30.8)	162 (39.1)
<i>Household responsibility related walking</i>			
Low (less than 3 times/week)	315 (42.06)	164 (43.2)	135 (34.7)
Medium (3–6 times/week)	235 (31.37)	121 (31.8)	112 (28.8)
High (7 times or more/week)	199 (26.57)	95 (25)	142 (36.5)

them. Following Kreft and Leeuw (1998), the method of centering was adopted in this study to reduce multicollinearity between the main and interaction effects. The perceived environment variables and walking attitudes were mean-centered by subtracting the mean from each variable's observed value. To account for the clustered nature of data, all of the regression models were adjusted to ensure the standard errors are not underestimated. Statistical analysis was conducted using STATA 14.0.

Results

Descriptive statistics

Table 2 shows the responses for walking frequency, and three major points are worth discussing. First, there are more respondents who walk 7 or more times per week (29.5%) for leisure/recreation walking, compared to walking for household responsibilities (26.6%). Second, walking 7 or more times per week occurs more often in neighbourhoods with higher local accessibility, especially for leisure/recreation (39.1 vs 29.5%) and for household responsibilities (36.5 vs 26.6%), but not much difference can be found for work/school walking. The above observations suggest that respondents' walking frequency for the three types of walking varies considerably. These results reinforce the need to consider the purpose of walking trips in understanding people's walking behaviour.

Regression analysis

Tables 3, 4 and 5 below show the logistic regression results, illustrating the influence of socio-demographics, walking attitudes, perceived environment and neighbourhood characteristics on walking frequency for the three types of walking trips. Table 3 is a binary logistic model for work/school related walking; Tables 4 and 5 are multinomial logistic models for leisure/recreation walking and household responsibilities related walking respectively. The reference category is walking for low frequency (less than 3 times/week) for all three

Table 3 Binary logistic model for work/school related walking frequency

Variables	B	P value	Odds ratio
Constant	.410	.427	
<i>Socio-demographics</i>			
Length of residency (ref \geq 10 years)			
Less than 2 years	.162	.781	1.177
2 to 5 years	.669	.046*	1.953
6 to 10 years	.753	.099	2.125
BMI (ref \geq 30.0)			
Less than 18.5	1.708	.002**	5.523
18.5–24.9	1.308	.002**	3.702
25.0–29.9	1.325	.095	3.761
<i>Neighbourhood characteristics and environmental perceptions</i>			
Outer urban neighbourhood (ref = inner urban)	.380	.000*	1.462
Low accessibility neighbourhood (ref: high)	−.155	.613	.985
Poor footpath condition	−1.046	.000**	.351
<i>Significant interaction effects</i>			
Low accessibility \times poor footpath condition	1.569	.000**	4.802
Log-likelihood (final model)	−134.849		
Log-likelihood (constants only model)	−152.277		
Log-likelihood (equally-likely model)	−266.169		
Pseudo r^2 (equally-likely base)	.493		
Pseudo r^2 (constants only base)	.114		
Sample size	384		

Reference category: low frequency (less than 3 times/week)

Other socio-demographic variables were controlled for in this model

* $p < .05$; ** $p < .01$

models. In order to obtain parsimonious models, all of the independent variables and interaction terms that were insignificant at the .05 level were removed from the final models.²

Walking to work/school

For work/school related walking (Table 3), only one perceived environment variable—“poor footpath condition”—was significant at the .05 level. The interaction effect of this variable and accessibility level of neighbourhood was also significant, so the interpretation will combine the main and interaction effects. The interaction effects are shown in Fig. 1 below.

Figure 1 shows the interaction effect of poor footpath condition and the objective level of neighbourhood accessibility. After converting the findings to predicted probabilities, we found that when the perception of poor footpath condition increased, the probability to walk for work/school less than 3 times per week was 11 times higher for people who live

² Except for the main effects of the significant interaction terms.

Table 4 Multinomial logistic model for leisure/recreation walking frequency

Variables	Medium frequency			High frequency		
	B	P value	Odds ratio	B	P value	Odds ratio
Constant	−1.05	.002**		−.025	.973	
<i>Socio-demographics</i>						
Age (ref = 18–30)						
31–60	.212	.364	1.236	.107	.702	1.129
Over 60	1.060	.000**	2.886	.731	.035*	2.078
Length of residency (ref = less than 2 years)						
2 to 5 years	.814	.000**	2.258	−.442	.384	.643
6 to 10 years	.621	.000**	1.861	.011	.983	1.011
More than 10 years	.772	.061	2.163	.160	.722	1.173
<i>Walking attitudes</i>						
Walking attitudes	.006	.945	1.006	.405	.000**	1.499
<i>Neighbourhood characteristics and environmental perceptions</i>						
Low accessibility neighbourhood (ref = high)	−.403	.163	.668	−1.025	.000**	.359
Poor footpath condition	−.287	.040*	.751	−.289	.101	.749
Access to destinations	−1.020	.016*	.361	−.359	.223	.698
Aesthetics	.603	.002**	1.827	.076	.477	1.079
Personal safety	−.034	.711	.967	.185	.048*	1.203
<i>Significant interaction effects</i>						
Low accessibility × poor footpath condition	.677	.012*	1.969	−.027	.876	.974
Low accessibility × access to destinations	.998	.047*	2.712	.393	.297	1.481
Log-likelihood (final model)	−643.063					
Log-likelihood (constants only model)	−703.917					
Log-likelihood (equally-likely model)	−718.492					
Pseudo r ² (equally-likely base)	.105					
Pseudo r ² (constants only base)	.086					
Sample size	654					

Reference category: low frequency

Other socio-demographic variables were controlled for in this model

* $p < .05$; ** $p < .01$

in a high-accessibility neighbourhood. But the same increase in poor footpath condition decreased the probability to walk for work/school less than 3 times per week, for people living in low-accessibility neighbourhoods. This might seem counterintuitive in the first instance, but it might reflect that the limited transport options available (e.g. bus stops and other public transportation) in low-accessibility neighbourhoods force people to walk more despite their perceptions. This finding is in line with a recent study conducted in China showing that respondents who perceived their neighbourhood to be less convenient for walking actually spent more time walking compared to other respondents (Alfonzo et al. 2014).

Table 5 Multinomial logistic model for household responsibilities related walking frequency

Variables	Medium frequency			High frequency		
	B	p value	Odds ratio	B	p value	Odds ratio
Constant	−1.44	.000**		−.124	.627	
<i>Socio-demographics</i>						
Age (ref ≥ 18–30)						
31–60	.568	.000**	1.764	.175	.298	1.191
Over 60	.636	.140	1.888	.608	.011*	1.837
Length of residency (ref = less than 2 years)						
2 to 5 years	1.256	.000**	3.512	−.243	.241	.784
6 to 10 years	1.275	.000**	3.579	.178	.516	1.195
More than 10 years	.752	.128	2.122	−.721	.119	.486
Employment (ref = not full time)						
Full-time employed	−.579	.062	.560	−.482	.000**	.617
<i>Neighbourhood characteristics and environmental perceptions</i>						
Outer urban neighbourhood (ref = inner urban)	.030	.843	1.031	.072	.000**	1.074
Low accessibility neighbourhood (ref = high)	−.052	.743	.949	−1.037	.000**	.354
Physical infrastructure	.348	.038*	1.416	.274	.075	1.315
Maintenance and upkeep	−.278	.000**	.757	.269	.237	1.310
<i>Significant interaction effects</i>						
Low accessibility × physical infrastructure	−.833	.000**	.435	−.287	.186	.750
Low accessibility × maintenance and upkeep	.636	.000**	1.889	−.120	.633	.887
Log-likelihood (final model)	−647.233					
Log-likelihood (constants only model)	−703.554					
Log-likelihood (equally-likely model)	−798.691					
Pseudo r ² (equally-likely base)	.190					
Pseudo r ² (constants only base)	.080					
Sample size	727					

Reference category: low frequency

Other socio-demographic variables were controlled for in this model

* $p < .05$; ** $p < .01$

Among the socio-demographic variables, BMI was found to be associated with walking to work/school. People with lower BMI (less than 25) were more likely to walk to work/school 3 or more times per week. Length of residency was also found to be significant, people living in the neighbourhood for 2–5 years were more likely to walk to work/school 3 or more times per week.

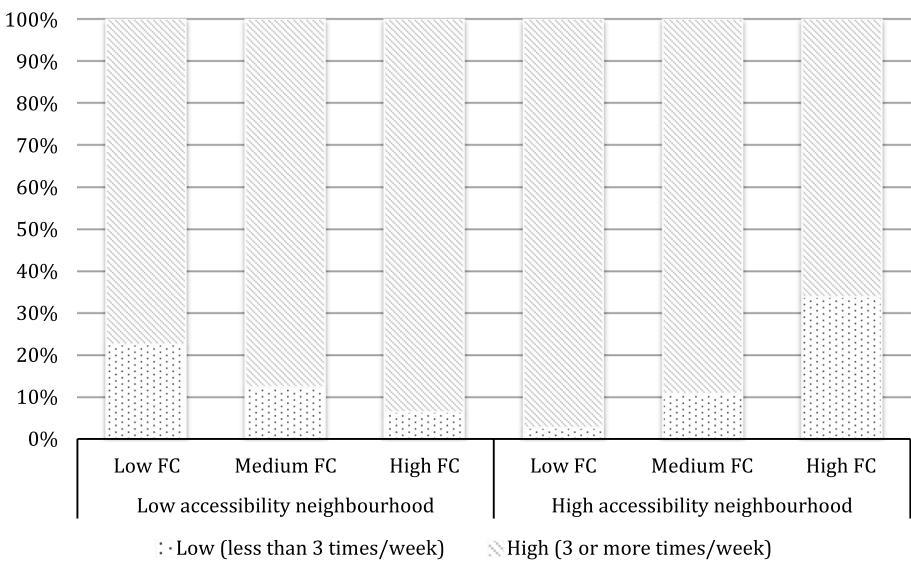


Fig. 1 Predicted probabilities of work/school walking frequency for low- and high-accessibility neighbourhoods with changes in poor footpath condition (FC)

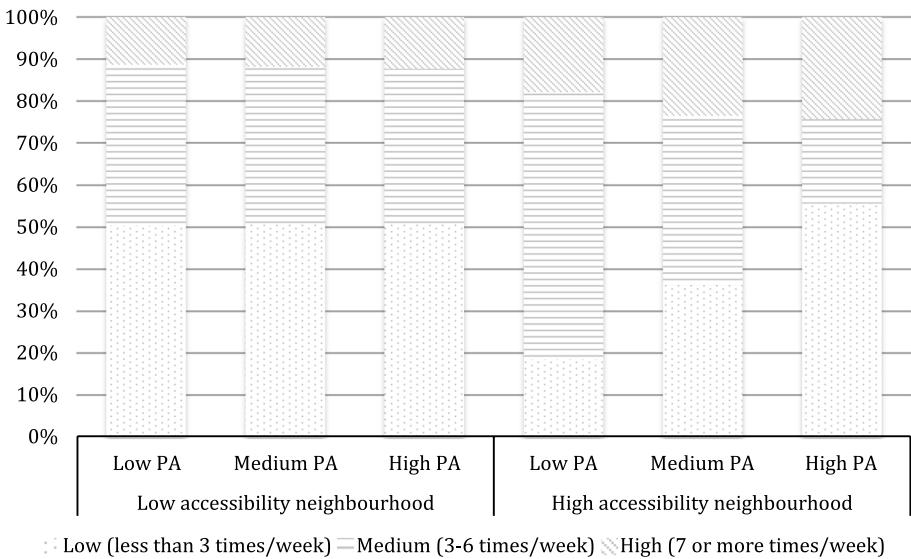


Fig. 2 Predicted probabilities of leisure/recreation walking frequency for low- and high-accessibility neighbourhoods with changes in perceived access to destinations (PA)

Walking for leisure/recreation

For leisure/recreation related walking (Table 4), four perceived environment variables—"access to destinations", "poor footpath condition", "aesthetics" and "personal safety"—were significant in the model. Significant interaction effects were found for the

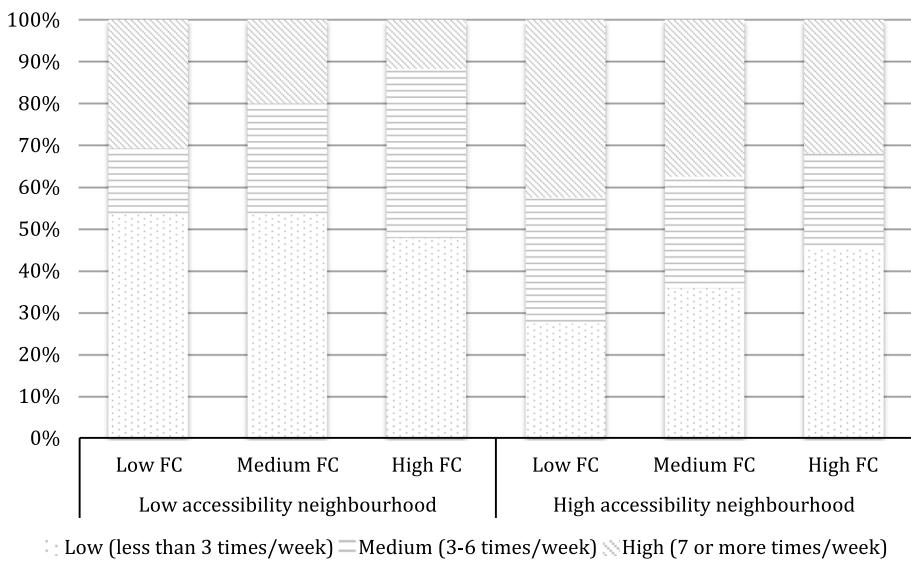


Fig. 3 Predicted probabilities of leisure/recreation walking frequency for low- and high-accessibility neighbourhoods with changes in poor footpath condition (FC)

first two perceived environment variables and accessibility level of the neighbourhood (Figs. 2, 3).

Figure 2 shows the interaction effect between perceived access to destinations and low accessibility neighbourhood for medium frequency (3–6 times/week) compared to low frequency (less than 3 times/week) of leisure/recreation walking. After converting the findings to predicted probabilities for interpretation, we see that perceived access to destinations played a limited role in low-accessibility neighbourhoods. When the value of perceived access to destinations was low, the probabilities to walk for leisure/recreation more than 3 times per week was higher in high-accessibility neighbourhoods. In addition, perceived access to destinations changed the distribution of frequency of walking in the high-accessibility neighbourhoods. When perceived access to destinations increased, people were more likely to walk either very frequently or very little.

Figure 3 shows the interaction effect between local accessibility and the perceived poor footpath condition. When we convert the findings to predicted probabilities, we observe that, in high-accessibility neighbourhoods, poor perceived footpath conditions were associated with less frequent walking. But in low-accessibility neighbourhoods, perceived poor footpath conditions had no influence on low frequency walking, but more negative perceptions were correlated with a shift away from high to medium frequency of walking.

In terms of perceived environment variables, “aesthetics” was associated with walking for leisure/recreation for medium frequency compared to low frequency, but no significant association was found for high frequency walking. The positive coefficient of “aesthetics” indicated that a one-unit increase in perceived aesthetic value increased the odds of walking 3–6 times per week for leisure/recreation by 82.7%. This finding is in line with previous studies which suggest that an interesting and attractive neighbourhood environment is associated with higher frequencies of leisure walking (Ball et al. 2001; Saelens et al. 2012). “Personal safety” was also found to be associated with walking for leisure/recreation in high frequency compared to low frequency only. The positive coefficient indicated respondents

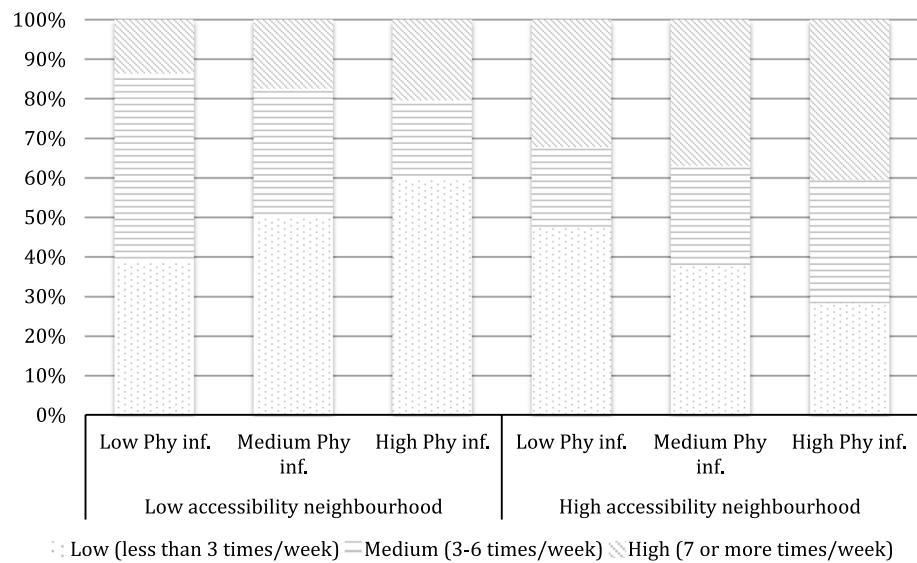


Fig. 4 Predicted probabilities of household responsibilities walking frequency for low- and high-accessibility neighbourhoods with changes in physical infrastructure (Phy inf.)

were more likely to walk for 7 or more times per week for leisure/recreation when they perceive the built environment to be safe. This finding coincides with previous studies showing that people tends to walk more when they feel safe in their neighbourhoods (Mason et al. 2013).

The effect of walking attitudes was positive in the model for leisure/recreation, showing that respondents with more positive walking attitudes were more likely to walk 7 or more times per week. It is found that a one-unit increase in walking attitudes increased the odds of walking for high frequency for leisure/recreation by 50%, but a similar effect was not found for medium frequency (3–6 times per week). In addition, age and length of residency were also significant in the model. Older adults (over 60 years old) were more likely to walk for medium (3–6 times per week) and high frequency (7 or more times per week) for leisure/recreation. For length of residency, respondents who lived in the neighbourhood for 2 to 10 years were more likely to walk 3–6 times per week for leisure/recreation.

Walking for household responsibilities

For walking related to household responsibilities (Table 5), significant interaction effects were found for “physical infrastructure” (Fig. 4) and “maintenance and upkeep” (Fig. 5) with accessibility level of the neighbourhood.

Figure 4 shows the interaction effects between local accessibility and perceived physical infrastructure. When we convert the findings to predicted probabilities, we observe that, those who lived in the low-accessibility neighbourhoods and had positive perceptions on physical infrastructure were less likely to walk 3–6 times per week for household responsibilities. But for respondents who lived in the high-accessibility neighbourhoods, the increase was occurring in the high frequency category only at the expense of the low frequency, suggesting that people were more likely to walk when perceived physical infrastructure was high.

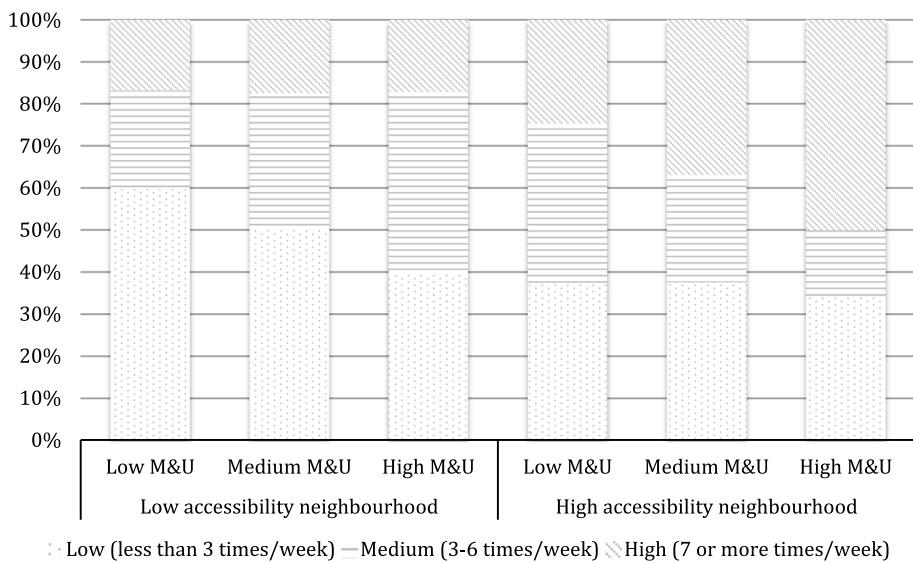


Fig. 5 Predicted probabilities of household responsibilities walking frequency for low- and high-accessibility neighbourhoods with changes in maintenance and upkeep (M&U)

As shown in Fig. 5, when the value of “perceived maintenance and upkeep” increased, people were more likely to walk for household responsibilities for 3–6 times per week in the expense of reduction in low frequency walking in low-accessibility neighbourhoods. But in high-accessibility neighbourhoods, the probabilities to walk for household responsibilities for 7 or more times per week increased at the expense of reduction in medium frequency walking.

In addition, respondents who live in outer urban neighbourhoods were more likely to walk very often (7 or more times per week) for household responsibilities. Among the socio-demographic variables, respondents in full-time employment were less likely to walk frequently to carry out household related activities. Respondents who had lived in the neighbourhood for more than 2 years (2–5 years or 6–10 years) were more likely to walk at least 3 times per week for household related activities. Age was also significant in the model; middle-aged (31 to 60 years old) respondents were more likely to walk for 3–6 times per week for household responsibilities, and older (over 60) respondents were more likely to walk for 7 or more times per week.

Discussion and conclusion

This study examines the associations between the objective neighbourhood characteristics, perceptions of the built environment, walking attitudes and walking frequency for three different activities—work/school, leisure/recreation and household responsibilities—in Shenzhen. The regression analyses demonstrate that the variables associated with walking frequency vary markedly among different types of walking, which is in line with previous studies (Saelens and Handy 2008; Vale and Pereira 2016). More perceived environment variables are found to be associated with walking for leisure/recreation than for household responsibilities and work/school. Such differences can be explained by Vilhelmsen’s

(1999) work on time use and mobility. Trips for leisure/recreation—and associated activities—are more flexible in time and space; their location and timing can be altered more easily than is the case with, say, commuting to work/school. The flexibility of these walking trips allows pedestrians to interact with the environment more actively (Edensor 2000). Built environment features may thus have a stronger influence on the trips associated with more flexible activities compared to those with more fixed activities (Cho and Rodríguez 2015).

Another innovative aspect of this study is that we further explored the associations by examining the interaction effects between objective neighbourhood characteristics, perceived environment and walking attitudes. Significant interaction effects were found in all three types of walking. The identified interaction effects demonstrate how the objective and subjective dimensions of the built environment influence people's walking behaviour in complex and interconnected ways. For walking for leisure/recreation, a significant interaction effect between low-accessibility neighbourhood and "access to destinations" was found. This suggests that the perceived access to destinations has a stronger facilitating effect on walking frequency among those who live in neighbourhoods with lower local accessibility. People may have a positive perception, despite a less walkable built environment, and this may result in a positive influence on their walking behaviour, suggesting that positive perceptions of the environment can, in some circumstances, compensate for the effects of living in less walkable neighbourhoods on people's walking frequency in a manner that is different from what is observed in more walkable environments. This implies that policies aimed at promoting physical activity could include other measures such as place-making activities (Friedmann 2010) and educational campaigns for perceptual and behavioural change (Spears et al. 2013), instead of only focusing on improving physical infrastructure. These "soft" measures would also be helpful for shaping people's perceptions and/or attitudes towards the environment and subsequently encouraging walking.

The significance of perceived environment variables was also revealed in different types of walking. However, there were some contradictions showing between our findings and previous research. For instance, different from results from Hong Kong (Cerin et al. 2013) and Shanghai (Zhou et al. 2013) which demonstrated neighbourhood aesthetics were not associated with walking for transport or leisure, we found that perception of aesthetics was associated with leisure/recreation walking. Local residents in Shenzhen were more likely to walk more frequently for leisure or recreation if they considered the environment to be more attractive. This is in line with several studies conducted in Western countries (Ball et al. 2001; Inoue et al. 2010). Possible explanations may be that we examined walking frequency instead of walking time, and used different measurement items to represent the aesthetic qualities of the neighbourhood environment.

The newly developed variables—"maintenance and upkeep" and "poor footpath condition"—were used to measure the perceived upkeep of the pedestrian environment, as well as the temporary barriers on footpaths, such as the presence of commercial activities, crowdedness and parked cars and bicycles on the footpath, which are particularly common in rapidly developing cities in China. Our findings showed that there were significant associations between these two variables and the three types of walking, suggesting that instead of only examining static physical infrastructure, the dynamics and the changing conditions of the walking environment are worth considering in a more rigorous manner in future studies.

This study also highlights the significant associations of walking attitudes and walking for leisure/recreation, which is in line with the wider literature on travel behaviour and attitudes (Kamruzzaman et al. 2016; Vale and Pereira 2016). However, no significant associations were found between walking attitudes and walking for work/school and household responsibilities, and this warrants attention. Unlike walking for leisure/recreation, most people who walk for work/school conduct walking as part of their trips, and their trips would involve other transport modes. The decision to choose a particular combination of transport modes to work/school may depend more on other factors, such as the quality of public transport services and the availability of other transport modes. Similarly, for household-related walking, it is also possible that pedestrians already established a daily routine in terms of when and where to fulfil their household responsibilities. Thus, in this case, other possible factors, such as preferences and habit, may have stronger influences on these two types of walking.

Several directions for future research are recommended here to advance the present discussions. First, existing studies have put much emphasis on the effects of the built environment on walking behaviour. However, more recent studies start to highlight the importance of other psychosocial factors (e.g. habit, intentions, and preferences) in moderating or mediating such relationships (Kamruzzaman et al. 2016; Ma and Cao 2017). Future studies could further explore these potentially important factors by developing more advanced strategies for measurement and examining their effects in more detail. Second, future studies can include other difficult-to-measure, yet potentially important variables, such as social status because these variables may help to prevent unobserved variable biases and provide further explanations to some of the unusual results from the analyses. Additionally, given that pedestrians' walking behaviour is embedded within a wider socio-cultural context (Fitt 2017), more qualitative studies in the future can extend the current discussions by further exploring the ways in which pedestrians perceive their walking environment in different social and cultural contexts. Future studies could also rethink how the built environment can be conceptualised by moving beyond the static measures of the 3Ds (density, diversity and design) (Cervero and Kockelman 1997), and considering how people actually perceive the built environment, as well as the influence of dynamics in the walking environment on people's walking behaviour.

Acknowledgements The authors wish to express their gratitude to the editor and three anonymous reviews for their constructive comments that helped to improve the quality of this paper.

Funding Funding was provided by the Royal Geographical Society [Grant No. Hong Kong Research Grant (HK03/15)].

Compliance with ethical standards

Conflict of interest The authors declare that they have no conflict of interest.

Open Access This article is distributed under the terms of the Creative Commons Attribution 4.0 International License (<http://creativecommons.org/licenses/by/4.0/>), which permits unrestricted use, distribution, and reproduction in any medium, provided you give appropriate credit to the original author(s) and the source, provide a link to the Creative Commons license, and indicate if changes were made.

Appendix: Statements used to measure environmental perceptions and walking attitude

Variables (Cronbach's alpha)	Statements
<i>Environmental perceptions</i>	
Access to destinations (.692)	<p>Stores are within easy walking distance of my home</p> <p>There are many places to go within easy walking distance of my home</p> <p>It is easy to walk to a transit stop (bus, train, MTR) from my home</p> <p>Streets in my neighbourhood are hilly, making my neighbourhood difficult to walk in^a</p> <p>There are major barriers to walking in my local area that make it hard to get from place to place (for example, freeways, railway lines, rivers)^a</p> <p>Parks and plazas are within walking distance</p>
Street network (.680)	<p>The streets in my neighbourhood do not have many cul-de-sacs (dead-end streets)</p> <p>The distance between intersections in my neighbourhood is usually short</p> <p>There are many alternative routes for getting from place to place in my neighbourhood</p>
Physical Infrastructure (.693)	<p>Footpaths are separated from the road/traffic in my neighbourhood by railings/bollards</p> <p>My neighbourhood streets are well lit at night</p> <p>There are crosswalks and pedestrian signals to help walkers cross busy streets in my neighbourhood</p>
Aesthetics (.718)	<p>There are trees along the streets in my neighbourhood</p> <p>There are many interesting things to look at while walking in my neighbourhood</p> <p>There are many attractive natural sights in my neighbourhood (e.g. landscaping, views)</p> <p>There are attractive buildings in my neighbourhood</p>
Traffic safety (.667)	<p>There is so much traffic along nearby streets that it makes it difficult or unpleasant to walk in my neighbourhood</p> <p>Most drivers exceed the posted speed limits while driving in my neighbourhood^a</p> <p>There are many cyclists riding on footpaths, which makes it unpleasant to walk in my neighbourhood^a</p>
Personal safety (.752)	<p>There is a high crime rate in my neighbourhood^a</p> <p>The crime rate in my neighbourhood makes it unsafe to go on walks during the day^a</p> <p>The crime rate in my neighbourhood makes it unsafe to go on walks at night^a</p>
Poor footpath condition (.707)	<p>There are many commercial activities (e.g. hawkers, outdoor catering area) on the street that makes it unpleasant to walk in this neighbourhood^a</p> <p>There are many construction works taking place that creates obstructions to my walking^a</p> <p>I usually feel quite crowded when I walk in this neighbourhood^a</p> <p>Cars and bicycles are frequently parked on footpaths that obstruct my walking^a</p>

Variables (Cronbach's alpha)	Statements
Maintenance and upkeep (.799)	Most of the footpaths in this neighbourhood are wide enough The surface of footpaths in this neighbourhood is well maintained in general The footpaths are quite clean Pedestrians signage is well-kept in this neighbourhood
<i>Walking attitudes</i>	
Walking attitudes (.767)	I enjoy walking in the neighbourhood where I live Walking is not important for me at all ^a In general, my walking experience in the neighbourhood where I live is positive I walk because it is good to my health I walk because it is good to the environment I walk because it involves no monetary costs Walking in the neighbourhood where I live is a habit

^aNegatively scored items

References

- Alfonzo, M., Guo, Z., Lin, L., Day, K.: Walking, obesity and urban design in Chinese neighborhoods. *Prev. Med.* **69**, S79–S85 (2014)
- Ball, K., Bauman, A., Leslie, E., Owen, N.: Perceived environmental aesthetics and convenience and company are associated with walking for exercise among Australian adults. *Prev. Med.* **33**(5), 434–440 (2001)
- Brown, B.B., Werner, C.M., Amburgey, J.W., Szalay, C.: Walkable route perceptions and physical features: converging evidence for en route walking experiences. *Environment and behavior* **39**(1), 34–61 (2007)
- Cao, X., Handy, S.L., Mokhtarian, P.L.: The influences of the built environment and residential self-selection on pedestrian behavior: evidence from Austin, TX. *Transportation* **33**(1), 1–20 (2006)
- Cerin, E., Conway, T.L., Saelens, B.E., Frank, L.D., Sallis, J.F.: Cross-validation of the factorial structure of the Neighborhood Environment Walkability Scale (NEWS) and its abbreviated form (NEWS-A). *International Journal of Behavioral Nutrition and Physical Activity* **6**(1), 32 (2009)
- Cerin, E., Lee, K., Barnett, A., Sit, C.H.P., Cheung, M., Chan, W.: Objectively-measured neighborhood environments and leisure-time physical activity in Chinese urban elders. *Prev. Med.* **56**(1), 86–89 (2013)
- Cervero, R., Kockelman, K.: Travel demand and the 3Ds: density, diversity, and design. *Transportation Research Part D: Transport and Environment* **2**, 199–219 (1997)
- Chen, Y., Zheng, Z., Yi, J., Yao, S.: Associations between physical inactivity and sedentary behaviors among adolescents in 10 cities in China. *BMC public health* **14**(1), 744 (2014)
- Cho, G.-H., Rodríguez, D.A.: Neighborhood design, neighborhood location, and three types of walking: results from the Washington DC area. *Environ. Plan. A* **42**(3), 526–540 (2015)
- Dumith, S.C., Hallal, P.C., Reis, R.S., Kohl, H.W.: Worldwide prevalence of physical inactivity and its association with human development index in 76 countries. *Prev. Med.* **53**(1), 24–28 (2011)
- Edensor, T.: Walking in the British countryside: reflexivity, embodied practices and ways to escape. *Body & Society* **6**(3–4), 81–106 (2000)
- Feng, J.: The built environment and active travel: evidence from Nanjing, China. *International journal of environmental research and public health* **13**(3), 301 (2016)
- Fitt, H.: Do social meanings matter? How and how much social meanings influence everyday transport practices? *NZ Geogr.* **73**(3), 181–191 (2017)
- Friedmann, J.: Place and place-making in cities: a global perspective. *Planning Theory & Practice* **11**(2), 149–165 (2010)
- Foster, C., Hillsdon, M., Thorogood, M.: Environmental perceptions and walking in English adults. *J. Epidemiol. Community Health* **58**(11), 924–928 (2004)

- Handy, S., Cao, X., Mokhtarian, P.: Correlation or causality between the built environment and travel behavior? Evidence from Northern California. *Transportation Research Part D: Transport and Environment* **10**(6), 427–444 (2005)
- Hanibuchi, T., Nakaya, T., Yonejima, M., Honjo, K.: Perceived and objective measures of neighborhood walkability and physical activity among adults in Japan: a multilevel analysis of a nationally representative sample. *International journal of environmental research and public health* **12**(10), 13350–13364 (2015)
- Hosmer Jr., D.W., Lemeshow, S., Sturdivant, R.X.: Applied logistic regression, vol. 398. Wiley, Hoboken (2013)
- Humpel, N., Owen, N., Iverson, D., Leslie, E., Bauman, A.: Perceived environment attributes, residential location, and walking for particular purposes. *Am. J. Prev. Med.* **26**(2), 119–125 (2004)
- Inoue, S., Ohya, Y., Odagiri, Y., Takamiya, T., Ishii, K., Kitabayashi, M., Suijo, K., Sallis, J.F., Shimomitsu, T.: Association between perceived neighborhood environment and walking among adults in 4 cities in Japan. *Journal of epidemiology* **20**(4), 277–286 (2010)
- Joh, K., Nguyen, M.T., Boarnet, M.G.: Can built and social environmental factors encourage walking among individuals with negative walking attitudes? *Journal of Planning Education and Research* **32**(2), 219–236 (2012)
- Kamruzzaman, M., Washington, S., Baker, D., Brown, W., Giles-Corti, B., Turrell, G.: Built environment impacts on walking for transport in Brisbane, Australia. *Transportation* **43**(1), 53–77 (2016)
- Kenworthy, J., Hu, G.: Transport and urban form in Chinese cities: an international comparative and policy perspective with implications for sustainable urban transport in China. *DISP-The Planning Review* **38**(151), 4–14 (2002)
- King, T.L., Bentley, R.J., Thorntun, L.E., Kavanagh, A.M.: Does the presence and mix of destinations influence walking and physical activity? *International journal of behavioral nutrition and physical activity* **12**(1), 115 (2015)
- Kitamura, R., Mokhtarian, P.L., Laidet, L.: A micro-analysis of land use and travel in five neighborhoods in the San Francisco Bay Area. *Transportation* **24**(2), 125–158 (1997)
- Koohsari, M.J., Badland, H., Sugiyama, T., Mavoa, S., Christian, H., Giles-Corti, B.: Mismatch between perceived and objectively measured land use mix and street connectivity: associations with neighborhood walking. *Journal of Urban Health* **92**(2), 242–252 (2015)
- Kreft, I., Leeuw, J.D.: Introducing Multilevel Modeling. Sage Publications Ltd., London (1998)
- Krizek, K.J.: Operationalizing neighborhood accessibility for land use-travel behavior research and regional modeling. *Journal of Planning Education and Research* **22**(3), 270–287 (2003)
- Kroesen, M., Chorus, C.: The role of general and specific attitudes in predicting travel behavior—a fatal dilemma? *Travel behaviour and society* **10**, 33–41 (2018)
- Kwan, M.P.: Gender differences in space-time constraints. *Area* **32**(2), 145–156 (2000)
- Larrañaga, A.M., Rizzi, L.I., Arellana, J., Strambi, O., Cybis, H.B.B.: The Influence of built environment and travel attitudes on walking: a case study of Porto Alegre, Brazil. *International journal of sustainable transportation* **10**(4), 332–342 (2016)
- Lu X, Pas EI (1998) Socio-demographics, activity participation and travel behavior. *Transp Res Part A Policy Pract* **33**(1), 1–18
- Ma, L., Cao, J.: How perceptions mediate the effects of the built environment on travel behavior? *Transportation* **46**, 1–23 (2017)
- Ma, L., Dill, J., Mohr, C.: The objective versus the perceived environment: what matters for bicycling? *Transportation* **41**(6), 1135–1152 (2015)
- Mason, P., Kearns, A., Livingston, M.: “Safe Going”: the influence of crime rates and perceived crime and safety on walking in deprived neighbourhoods. *Soc. Sci. Med.* **91**, 15–24 (2013)
- McCormack, G.R., Rock, M., Toohey, A.M., Hignell, D.: Characteristics of urban parks associated with park use and physical activity: a review of qualitative research. *Health & place* **16**(4), 712–726 (2010)
- Michael, Y.L., Green, M.K., Farquhar, S.A.: Neighborhood design and active aging. *Health & place* **12**(4), 734–740 (2006)
- Millward, H., Spinney, J., Scott, D.: Active-transport walking behavior: destinations, durations, distances. *J. Transp. Geogr.* **28**, 101–110 (2013)
- Moudon, A., Hess, P., Snyder, M., Stanilov, K.: Effects of site design on pedestrian travel in mixed-use, medium-density environments. *Transportation Research Record: Journal of the Transportation Research Board* **1578**, 48–55 (1997)
- Moudon, A.V., Lee, C., Cheadle, A.D., Garvin, C., Johnson, D.B., Schmid, T.L., Weathers, R.D.: Attributes of environments supporting walking. *American Journal of Health Promotion* **21**(5), 448–459 (2007)

- Orstad, S.L., McDonough, M.H., Stapleton, S., Altincekic, C., Troped, P.J.: A systematic review of agreement between perceived and objective neighborhood environment measures and associations with physical activity outcomes. *Environment and Behavior* **49**(8), 904–932 (2017)
- Owen, N., Cerin, E., Leslie, E., Coffee, N., Frank, L.D., Bauman, A.E., Hugo, G., Saelens, B.E., Sallis, J.F.: Neighborhood walkability and the walking behavior of Australian adults. *Am. J. Prev. Med.* **33**(5), 387–395 (2007)
- Perez, L.G., Carlson, J., Slymen, D.J., Patrick, K., Kerr, J., Godbole, S., Elder, J.P., Ayala, G.X., Arredondo, E.M.: Does the social environment moderate associations of the built environment with Latinas' objectively-measured neighborhood outdoor physical activity? *Preventive medicine reports* **4**, 551–557 (2016)
- Reichman, S.: Travel adjustments and life styles: a behavioral approach. In: Stropher, P., Meyburg, A. (eds.) *Behavioral Travel Demand Models*, pp. 143–152. Lexington Books, Lexington, MA (1976)
- Saelens, B.E., Handy, S.L.: Built environment correlates of walking: a review. *Med. Sci. Sports Exerc.* **40**(7 Suppl), S550 (2008)
- Saelens, B.E., Sallis, J.F., Black, J.B., Chen, D.: Neighborhood-based differences in physical activity: an environment scale evaluation. *Am. J. Public Health* **93**(9), 1552–1558 (2003)
- Saelens, B.E., Sallis, J.F., Frank, L.D., Cain, K.L., Conway, T.L., Chapman, J.E., Slymen, D.J., Kerr, J.: Neighborhood environment and psychosocial correlates of adults' physical activity. *Med. Sci. Sports Exerc.* **44**(4), 637–646 (2012)
- Sallis, J.F., Cerin, E., Conway, T.L., Adams, M.A., Frank, L.D., Pratt, M., Salvo, D., Schipperijn, J., Smith, G., Cain, K.L.: Physical activity in relation to urban environments in 14 cities worldwide: a cross-sectional study. *The Lancet* **387**(10034), 2207–2217 (2016)
- Sallis, J.F., Owen, N.: Ecological models of health behavior. In: Glanz, K., Rimer, B.K., Viswanath, K. (eds.) *Health Behavior: Theory, Research, and Practice*, pp. 43–64. Jossey-Bass, San Francisco, CA (2015)
- Schwanen, T., Kwan, M.-P., Ren, F.: How fixed is fixed? Gendered rigidity of space–time constraints and geographies of everyday activities. *Geoforum* **39**(6), 2109–2121 (2008)
- Serrano, N., Perez, L.G., Carlson, J., Patrick, K., Kerr, J., Holub, C., Arredondo, E.M.: Sub-population differences in the relationship between the neighborhood environment and Latinas' daily walking and vehicle time. *Journal of transport & health* **8**, 210–219 (2018)
- Shenzhen Government: 深圳市2010年第六次全国人口普查主要数据公报 [Data bulletin of the sixth national census of Shenzhen 2010]. http://www.sztj.gov.cn/xgk/tjsj/pcgb/201105/t20110512_2061597.htm (2011). Accessed 21 Oct 2017
- Shenzhen Statistical Bureau: Shenzhen Statistical Yearbook 2016. China Statistics Press, Beijing (2016)
- Spears, S., Houston, D., Boarnet, M.G.: Illuminating the unseen in transit use: a framework for examining the effect of attitudes and perceptions on travel behavior. *Transportation Research Part A: Policy and Practice* **58**, 40–53 (2013)
- Su, M., Tan, Y.-Y., Liu, Q.-M., Ren, Y.-J., Kawachi, I., Li, L.-M., Lv, J.: Association between perceived urban built environment attributes and leisure-time physical activity among adults in Hangzhou, China. *Prev. Med.* **66**, 60–64 (2014)
- Su, S., Pi, J., Xie, H., Cai, Z., Weng, M.: Community deprivation, walkability, and public health: highlighting the social inequalities in land use planning for health promotion. *Land Use Policy* **67**, 315–326 (2017)
- Turrell, G., Haynes, M., Wilson, L.-A., Giles-Corti, B.: Can the built environment reduce health inequalities? A study of neighbourhood socioeconomic disadvantage and walking for transport. *Health & place* **19**, 89–98 (2013)
- Vale, D.S., Pereira, M.: Influence on pedestrian commuting behavior of the built environment surrounding destinations: a structural equations modeling approach. *International journal of sustainable transportation* **10**(8), 730–741 (2016)
- Vilhelmsen, B.: Daily mobility and the use of time for different activities. The case of Sweden. *GeoJournal* **48**(3), 177–185 (1999)
- Wang D, Lin T (2013) Built environments, social environments, and activity-travel behavior: a case study of Hong Kong. *J Trans Geograph* **31**, 286–295
- Yang, Y., Diez-Roux, A.V.: Adults' daily walking for travel and leisure: interaction between attitude toward walking and the neighborhood environment. *American Journal of Health Promotion* **31**(5), 435–443 (2017)
- Zang, J., Ng, S.W.: Age, period and cohort effects on adult physical activity levels from 1991 to 2011 in China. *International Journal of Behavioral Nutrition and Physical Activity* **13**(1), 40 (2016)

Zhou, R., Li, Y., Umezaki, M., Ding, Y., Jiang, H., Comber, A., Fu, H.: Association between physical activity and neighborhood environment among middle-aged adults in Shanghai. *Journal of environmental and public health* **2013**, 26 (2013)

Publisher's Note Springer Nature remains neutral with regard to jurisdictional claims in published maps and institutional affiliations.

Eric T. H. Chan is a DPhil candidate in the Transport Studies Unit (TSU), School of Geography and the Environment at University of Oxford. His research interests include sustainable transport, the built environment and travel behaviour with primary focus on the connections between various forms of mobilities and people's health and well-being.

Tim Schwanen is Professor of Transport Studies and Geography and Director of the Transport Studies Unit at the School of Geography and the Environment in the University of Oxford. He is a geographer interested in the transformations in the mobilities of people, goods and information that occur in conjunction with technological, environmental, cultural and other changes. He has previously held various researcher and lecturer positions at the University of Oxford and at Utrecht University, the Netherlands and was Visiting Professor in Geography at the University of Gothenburg, Sweden in 2016–2019.

David Banister is Emeritus Professor of Transport Studies at the School of Geography and the Environment and Transport Studies Unit, University of Oxford. He has published 25 books and over 200 academic papers on transport scenario building, sustainable cities, energy and environmental modelling, transport investment and economic development.