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Determinants of bicycling for transportation in disadvantaged neighbourhoods: Evidence from Xi'an, China

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ABSTRACT

Over the past decade, there has been a strongly increased interest in investigating bicycling behaviour. However, the vast majority of these studies have been limited to Western (North-American and European) contexts and draw evidence from the general population. Much less studies of bicycling behaviour have been carried out in East- Asian contexts and focus on lower social-economic population. Relying a survey data from Xi'an, China, this study investigates the personal, spatial, social and psychological factors associated with bicycling for transportation in disadvantaged neighbourhoods. In contrast to the results of many previous studies, this study finds that social norms have the greatest effect on bicycling behaviour, while attitudes toward bicycling do not affect bicycling. Among the neighbourhood environment characteristics, this study finds neighbourhood aesthetics, bicycle infrastructure, and access to subway stations are important factors in promoting utilitarian bicycling in disadvantaged neighbourhoods in China. Finally, an interesting finding of our study is that the spatial characteristics that improve attitudes toward bicycling (such as access to amenities and street connectivity) do not lead to more bicycling, due to their positive effect of walking. Overall, these findings offer important policy implications regarding designing effective interventions to promote bicycling in disadvantaged neighbourhoods and Chinese cities, and the special policy consideration of stimulating walking and bicycling jointly.

1. Introduction

Over the past decade, there has been a strongly increased interest in investigating bicycling behaviour, with the ultimate aim of developing policies that promote bicycling. The rationale for this objective is that bicycling has been associated in many studies with positive outcomes for physical health, reduced chance of overweight, mental health and well-being. Also, direct satisfaction with bicycling trips has consistently found to be higher than satisfaction with car or pubic transport trips. In addition, in contrast to car trips, bicycling trips do not contribute to local air pollution and noise, and greenhouse gas emissions that add to global climate change. Also, a modal shift from car to bicycle adds to mitigating congestion and lower demand for parking space in urban areas.

Logically, much effort has gone into investigating which factors potentially stimulate bicycling behaviour. These factors include personal characteristics as well as spatial characteristics (see Section 2 for an overview). In addition, the role of psychological

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constructs such as attitudes, social norms and perceived control for bicycling have been investigated, building on psychological theories such as the theory of Planned Behaviour. To date, however, limited research has examined the interactions between these factors and their interactive effects on bicycling. The spatial factors, for example, might influence bicycling behaviour through affecting travel preferences, social norms, and perceived control over the bicycling behaviour, based on the environmental determinism hypothesis (Ewing et al., 2016; Lin et al., 2017). The self-selection hypothesis, however, argues that the residential location choice is endogenous to travel preferences. In a recent review paper, Guan et al. (2020) have highlighted the bi-directional relationships among the built environment, travel attitudes, and travel behaviour. Although these studies suggests a complex relationship between the personal, spatial, psychological factors, and travel behaviour, little research has examined these hypotheses specially for bicycling behaviour. Improved understanding of these complex relationships could be important for understanding the mechanism of the critical factors determining bicycling behaviour and for identifying potential interventions to promote bicycling.

Further, the vast majority of these studies have been limited to Western (North-American and European) contexts. Much less studies of bicycling behaviour have been carried out in East- Asian contexts. It is unlikely that results found in Western contexts can be generalized to East-Asian/Chinese contexts, given the differences in terms of socio-economic, spatial and cultural context. For instance, the still lower level of economic development may lead to different attitudes toward car ownership and the status of bicycling. In addition, Chinese cities differ markedly from Western cities in terms of density, availability of bicycling infrastructure and the sheer size of cities.

A second limitation of the existing literature on bicycling behaviour is that most studies use samples randomly drawn from the general population, which, as a result of response bias, tend to overrepresent higher educated and higher income groups. As a result, limited knowledge has been accumulated about the factors influencing bicycling behaviour of lower socio-economic segments of the population, often living in more disadvantaged conditions, that may differ in terms of bicycling friendliness and social support for bicycling. Also, psychological constructs such as attitudes, social norms and behavioural control may be differently affected by the environment, and have a different impact on bicycling behaviour.

In the context of the above limitations, this paper aims to increase our insight into the factors influencing bicycle use in Chinese cities and among lower socio-economic classes, by analysing a unique data set, collected in four disadvantaged neighbourhoods in Xi'an. The paper investigates how spatial and personal characteristics influence the use of bicycle to travel to nearby locations, either directly, or via psychological constructs such as attitudes, social norms and perceived behavioural control, as suggested by the Theory of Planned Behaviour.

2. Literature review

In this review we focus on reviewing previous findings regarding the effects of personal and spatial factors on utilitarian bicycling behaviour (i.e. bicycling for transportation purposes) and psychological theories applied to bicycling decision making. We also compare results from different regions, including evidence from North America, Europe, and Asia.

2.1. Personal factors influencing bicycling

2.1.1. Evidence from North America

Overall, bicyclists in North America are more likely to be male, young- and middle- aged adults, and non-Hispanic whites (Pucher et al., 2011). Relying on the US National Household travel Survey (NHTS) in 2001 and 2009, Pucher et al. (2011) found that only around 33% and 24% of all bike trips in the US were made by women in 2001 and 2009 respectively. They also found that most of the growth in bicycling trips from 2001 to 2009 in the US was in the age group of 40–64. Further, their study revealed that bicycling in the US was dominated by non-Hispanic whites, who contributed to 83% and 77% of all bike trips in 2001 and 2009 respectively.

The stark gender gap in bicycling in North America has received much attention from scholars. Akar et al. (2013) examined the reasons of the gender gaps in bicycling, and they concluded that women's attitudes and perceptions in terms of safety and feasibility of alternative transportation modes were different from men, and they were more sensitive to the access to bicycle trails and paths. Further, women's household role is also often cited as a barrier for women to bicycle. Women in the US are more likely to trip chain and take children or older adults to destinations, and bicycle is often not feasible to complete these trips (Garrard et al., 2012).

There is no unidirectional association between level of education and income and utilitarian bicycling. For example, Nehme et al. (2016) showed that both those with below high school qualifications and those with a college degree and above were more likely to bicycle for transportation. Pucher et al. (2011) found that bicycling rates in the US varied little among different income groups, while the lowest quartile of income group had a slightly higher share of bicycle use in 2009.

2.1.2. Evidence from Europe

In contrast, bicyclists in European countries have a much lower level of gender and age differences, comprising a much diverse population in terms of gender, age, and income (Pucher and Buehler, 2008). Relying on national aggregate data from three European countries, including the Netherlands, Denmark and Germany, Pucher and Buehler (2008) found that women were as likely to bike as men, contributing to around 50% of all bike trips in these countries. They also found that bicycling rates remain high even among the elderly, and bicycling rates are similar across different income classes. Similar findings are also reported from studies conducted at the disaggregate levels. Two studies (Heinen et al., 2013; Oakil et al., 2016) that examined the individual's decision to bicycle to work in the Netherlands have found that most of socio-demographic variables, including gender, income, education etc., were not significantly associated with the odds of using bicycle for commuting. These findings confirm that there is not much variation in the level of bicycling among different socio-demographic groups in Europe.

2.1.3. *Evidence from Asia*

Very limited bicycling behaviour research has been conducted for Asian cities, and mixed results are reported. Overall, utilitarian bicyclists in developing Asian countries, such as China, Malaysia and India, tend to have lower levels of income. Bicycling often serves as a main transport mode in the absence of better alternatives, rather than as a personal choice for health or environmental concerns in these countries. For example, two studies (Yang and Zacharias, 2016; Zhao, 2014) have examined the factors associated with the odds of commuting by bicycle in Beijing, and they found that bicycling commuters tended to be older in age and lower in income. In South Asia, Yamamoto (2009) also found that lower income people were more likely to bicycle in Kuala Lumpur. A study of bicycling in the Bangalore found that people perceived the mode shifting from bicycles to motorised vehicles was "a sign of prosperity" (Verma et al., 2016). In developed Asian countries, such as Japan and South Korea, however, income becomes a less important factor that affects bicycling (Andrade and Kagaya, 2012; Sharma et al., 2019).

In terms of gender and education level, Yang and Zacharias (2016) found both were not associated with bicycle commuting in Beijing, while Zhao (2014) found males were more likely to bicycle for commuting. A study from Taipei (Liao et al., 2015) also found gender and education level were not correlated with bicycling for transportation. In contrast, based on the evidence from Seoul, South Korea, Sharma et al. (2019) found females were less likely to bicycle regularly. Regarding the effect of age, several studies (Liao et al., 2015; Yang and Zacharias, 2016; Zhao, 2014) found a positive association between age and bicycling, while one study (Sharma et al., 2019) found a negative relationship.

2.2. *Spatial factors influencing bicycling*

The role of the built environment in promoting bicycling has received increasing attention in both the transportation and public health disciplines over the last decade. The common spatial factors that have been used to predict bicycling behaviour include bicycling infrastructure, and the Ds variables, such as density, land use diversity, design (street connectivity), distance to CBD, distance to transit, etc., assessed using both subjective and objective measures.

2.2.1. *Evidence from North America*

Previous research on bicycling behaviour conducted in North America has focused on the effects of such bicycling infrastructure as on-road striped bike lanes and off-road paths on bicycling. Findings regarding the association between striped bicycle lanes and levels of bicycling are mixed. Aggregate studies (Dill and Carr, 2003; Nelson and Allen, 1997) often find a positive correlation, but individual-level studies sometimes do not (Dill and Voros, 2007; Vernez-Moudon et al., 2005). Comparing with the effects of bike lanes, some studies have found a stronger relationship between bicycling levels and off-street bike paths (Akar et al., 2013; Parkin et al., 2008). Further, some studies have suggested that bicyclists may prefer to use low-traffic or quiet streets. One GPS-revealed preference study confirmed that bicyclists went out of their way to use bicycle boulevards (Broach et al., 2012).

In terms of Ds variables, empirical studies conducted in North America have generated very mixed findings. There is little evidence to support the positive associations between levels of bicycling and density and land use mix, which are often found to be positively and significantly associated with walking. Actually, several studies have found employment/population density was negatively associated with levels of bicycling (Cervero and Duncan, 2003; Forsyth and Oakes, 2015). Comparing with density and diversity, there is a relatively consistent finding regarding the positive association between street connectivity and utilitarian bicycling (Yang et al., 2019). These findings highlight the differences in the built environment to support walking and bicycling behaviour.

2.2.2. *Evidence from Europe*

In general, empirical studies from Europe also support a positive association between the presence of bicycling infrastructure and levels of bicycling. Different from bicycling infrastructure in the US, cycle-tracks and coloured bike lanes are more common in European cities (Pucher et al., 2010). Several studies conducted in Denmark, the Netherlands, German, and Denmark have found that cycle-tracks and raised and coloured cycle lanes helped to increase the levels of bicycling (Garder et al., 1998; Jensen, 2008).

In terms of Ds variables, empirical studies from Europe also reported mixed results regarding the associations between bicycling and the Ds. Several studies concluded a highly walkable environment featured with high density, mixed land use and connected streets also promote bicycling behaviour (Owen et al., 2010; Van Dyck et al., 2010). However, Nielsen et al. (2013), based on the evidence from Denmark, found number of retail jobs and street connectivity within 500 m were both negatively associated with bicycling propensity, suggesting the competition between walking and bicycling within the walkable distance.

2.2.3. *Evidence from Asia*

The positive effects of bicycling infrastructure on levels of bicycling are also found in empirical studies focusing on Asian cities. For example, Zhao (2014) found the density of exclusive bicycle lanes was positively associated with the odds of commuting by bicycle in Beijing. Andrade and Kagaya (2012) found the presence of bicycle paths on the way to campus affected bicycle choice for commuting in Sapporo, Japan.

Regarding the effects of Ds variables on bicycling, previous research in Asian cities also reported mixed results. For example, Zhao (2014) found the population density did not affect the decision of using bicycle for commuting in Beijing. He explained that this was probably because the city had slight differences in population density across different zones. Yamamoto (2009), however, found a positive relationship between population density and bike ownership in Osaka, Japan, but a negative relationship in Kuala Lumpur, Malaysia. In terms of land use mix, Yamamoto (2009) found land use mix was positively associated with bike ownership in both Osaka and Kuala Lumpur, and Zhao (2014) found land use diversity was positively associated with odds of bicycle commuting in Beijing. Further, Zhao (2014) found objectively measured street connectivity was positively related to bicycling for commuting. Finally, it is interesting to note that several studies (Andrade and Kagaya, 2012; Yamamoto, 2009; Zhao, 2014) have reported a negative association between transit accessibility and bicycling, suggesting bicycling is competing rather than complementing with transit in these cities.

2.3. Psychological models applied to bicycling decision making

Early research linking the built environment and bicycling behaviour has recognised the limitation of applying the utility maximising theory in explaining the variation in levels of bicycling. Recent studies have made an effort to expand previous theoretical framework by applying psychological theories. Among these theories, the theory of planned behaviour (Ajzen, 1991) and the social ecological model (Sallis et al., 2002) are the widely-used psychological theories in bicycling research.

Ecological models assume that the behaviour is affected by multiple levels of factors that originate at the individual level and later expand outward to encompass the social and physical factors. Several recent studies on bicycling behaviour (Emond and Handy, 2012; Handy and Xing, 2011; Handy et al., 2010; Xing et al., 2010) applied the ecological models and incorporated such factors as attitudes, perceptions, physical and social environment into their statistical models. These studies found that individual, social environment, and physical environment factors all have significant effects on bicycling behaviour, but individual attitudes seem to have stronger effects on bicycling behaviour than the physical and social environment.

The theory of planned behaviour (TPB) (Ajzen, 1991) holds that behaviour is guided by (1) a person's attitude toward the behaviour, including the likely consequences of the behaviour; (2) subjective norms, including the expectations of others; and (3) the person's perceived control over the behaviour (PBC). Attitudes are people's favourable or unfavourable evaluative reactions to the behaviour of interest. Subjective norms concern the perception of whether important others think the person should or should not perform the behaviour of interest. Finally, perceived behavioural control is the extent to which people believe they have the skills and ability to enact the behaviour. These factors determine the person's intention to behave in a certain way which, in turn, influences actual behaviour, as long as the behaviour is under the person's control. The theory has been applied to a wide range of behaviours, including playing video games, voting, shoplifting, and gift giving. Gärling et al. (1998) described how the theory could be useful in travel-behaviour research, and there is a growing body of research linking TPB to travel-mode choice. However, much of the TPB travel-behaviour research has not included variables related to the built environment (Van Acker et al., 2010).

Using TPB theoretical model and a survey data from several cities in the Netherlands, Heinen et al. (2011) found commuters' attitudes toward bicycling, subjective norms, PBC, and habit all affected the decision to bicycle to work. They also found that the subjective norms only mattered for the bicycle mode choice for commuting trips with short distances, and this association was only marginally significant. Based on a survey data from Portland, Oregon, Dill et al. (2014) also applied the theory of planned behaviour in studying the utilitarian bicycling behaviour. They found that attitudes toward bicycling had the strongest effect on bicycling behaviour, and PBC also affected bicycling but to a lesser extent than attitudes. Social norms, however, was not found to affect bicycling behaviour in this study. Similar findings were also reported from a study conducted in Madrid, Spain that found only attitudes and PBC were significant in predicting odds of bicycle to work (Muñoz et al., 2013).

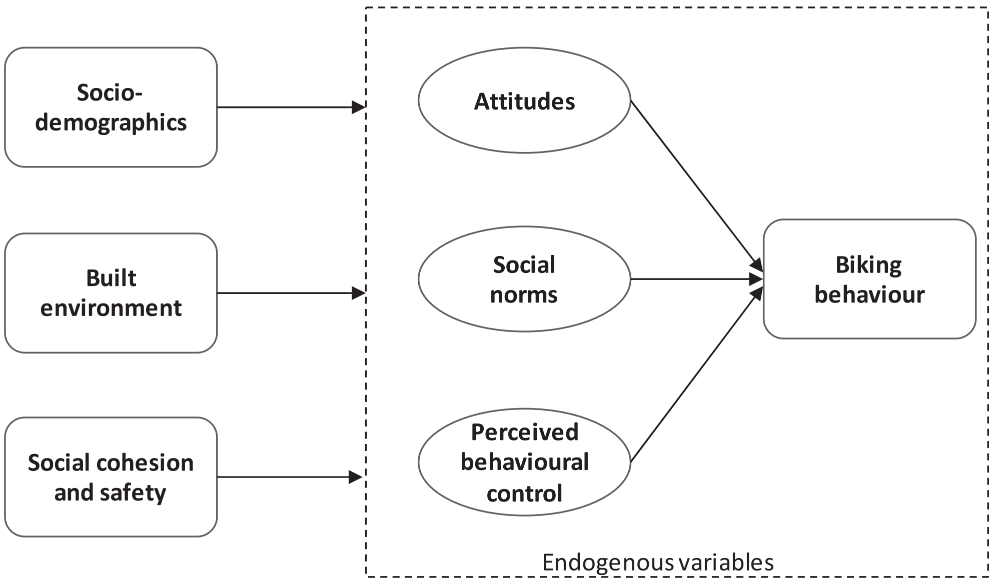

Fig. 1. Conceptual model.

In summary, factors associated with bicycling behaviour show significant variation across regions and countries. This suggests that bicycling policies derived from evidence from one region or country cannot be directly applied to another region or country. Second, very few studies have specially focused on bicycling behaviour in Asian cities, which have quite different physical and social environment from the Western cities. Previous theories on individual travel (bicycling) behaviour are primarily based on the evidence from the US and Europe. The applicability of these theories in Asian cities are not well known. Third, existing bicycling behaviour research in Asian cities has primarily focused on the role of the built environment. However, numerous studies have highlighted the psychological factors, such as attitudes, social norms, and PBC, are more important factors in affecting bicycling. This suggests that a comprehensive examination of the multi-dimensional factors associated with bicycling behaviour is necessary to design effective policy for promoting or reviving bicycling in Asian cities. This study aims to fill out this research gap by investigating how personal, spatial, social and psychological factors either directly or interactively influence the use of bicycle for transportation based on the evidence from Xi'an, China.

2.4. Conceptual framework

This study employs the theory of planned behaviour (TPB) as the basic theoretical framework, but expanded it by including socio-demographics, built environment, and neighbourhood social environment (as measured by social cohesion and neighbourhood safety). This framework is illustrated in Fig. 1. In this framework, the three psychological factors, including attitudes, social norms, and PBC, are latent and endogenous variables, and hypothesized to affect bicycling behaviour directly. Respondents' socio-demographic characteristics, the built environment, and social environment characteristics of their home neighbourhood are exogenous variables and hypothesized to influence bicycling behaviour both directly and indirectly through the path of the three psychological factors. We have to acknowledge that the relationships between these variables is much more complex than our hypothesized uni-directional relationships as shown in this framework. Regarding the relationship between travel attitude and travel behaviour, for example, Kroesen et al. (2017) found that travel attitude and travel behaviour mutually influence each other over time, and travel behaviour had a greater effect on travel attitude than vice versa. In a review, Guan et al. (2020) further highlighted the complex relationships and summarized the possible roles of travel attitudes in the relationship between the built environment and travel behaviour, including as confounders, moderators, and mediators. They also concluded that bi-directional relationships among the built environment, travel attitudes, and travel behaviour were both theoretically reasonable and being confirmed by a growing number of empirical studies. Further, while the self-selection hypothesis argues that the travel attitudes affect the built environment, Ettema and

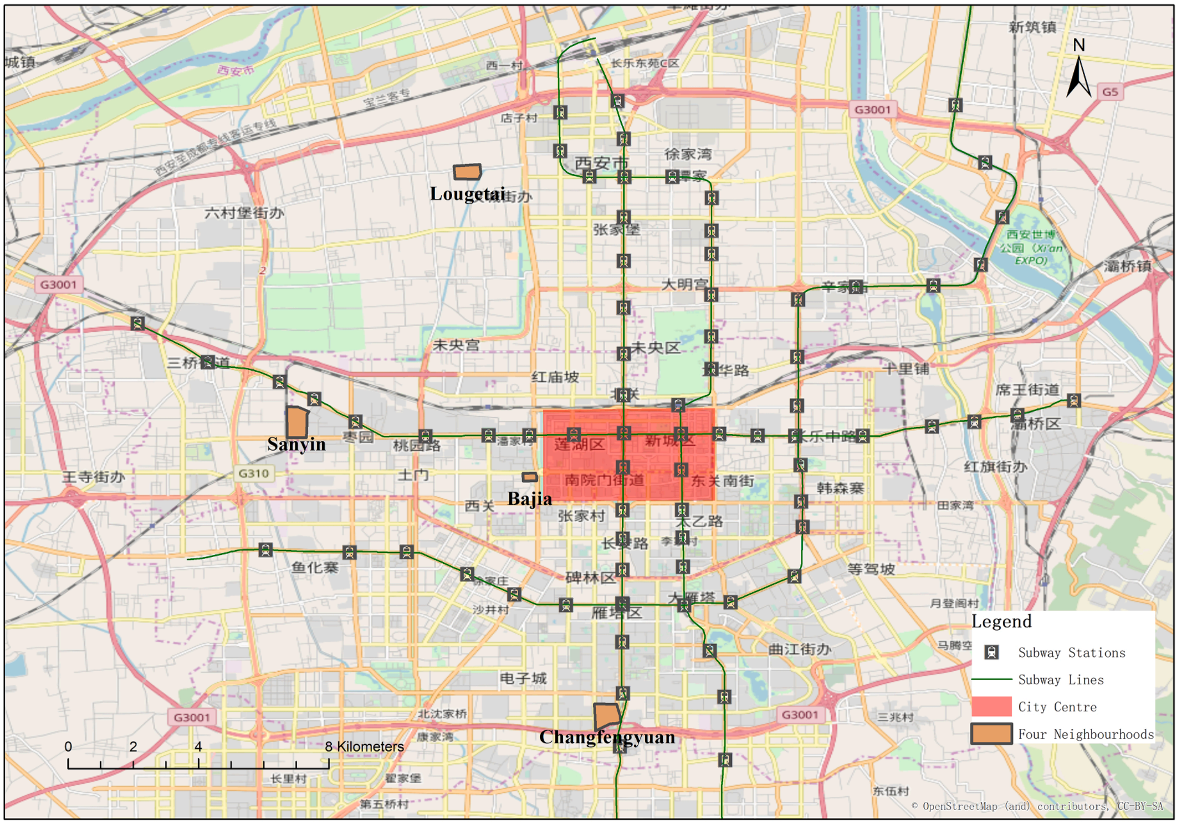

Fig. 2. Location of the four selected neighbourhoods.

Nieuwenhuis (2017) challenged the common way of controlling self-selection issue using travel attitudes, and found the association between the built environment and travel attitudes was rather weak.

Given the cross-sectional design of our research, we hypothesized a more reasonable causal link, from the built environment to travel attitudes, as suggested by Ewing et al. (2016) and Guan et al. (2020), as the built environment was measured before the travel attitudes. Also, as our respondents were from four disadvantaged neighbourhoods, they were less likely to have much freedom to self-select into the neighbourhoods based on their travel preferences, and therefore the causal mechanism from the built environment to travel attitudes is a more appropriate hypothesis than self-selection, based on the conclusion of Lin et al. (2017).

Further, the neighbourhood built environment and social environment could influence the social norms because the neighbourhood's physical and social environment could influence the attitudes of others, including one's family members and close friends, towards different travel modes. The feedback effect, however, is also possible as the social expectations on one's travel behaviour might influence her or his residential location choice. Finally, neighbourhood built environment and social environment could influence perceived behaviour control as the neighbourhood environment could facilitate or hinder one's performance of the travel behaviour.

3. Methodology

3.1. Data

The data for this study were mainly collected through a self-administered survey conducted between August 20 and November 4, 2018 in Xi'an, China. The survey data collection was focused on four selected neighbourhoods in Xi'an with relatively lower levels of socio-economic status and diverse built environment characteristics. These four neighbourhoods cover typical types of disadvantaged communities in Chinese cities, including a (1) economically depressed community near the inner city (*Bajia*), (2) an urban village in the city fringe (*Lougetai*), (3) a work-unit yard in the inner suburb (*Sanyin*), and (4) a redeveloped urban village (*Changfengyuan*) in the inner suburb. The locations of the four neighbourhoods are presented in Fig. 2.

Bajia (called *BJ* for simplicity) is a redeveloped shanty town near the city centre, and the main buildings within the neighbourhood are six-storey apartments. Its residents include both the previous local low-income residents and many urban migrant workers. As it is close to the city centre, *BJ* has a high level of accessibility to variety of amenities, including shops, restaurants, banks, parks, etc. *Lougetai* (called *LGT* for simplicity) is a typical urban village in Xi'an with many rural–urban migrants rented in this neighbourhood. Most of the buildings in this neighbourhood are 2–3 stories with poor quality. The urban village is a unique urban form in Chinese cities driven by fast urbanization. It is usually surrounded by newly-developed high-rise buildings, and associated with low-quality housing conditions and deteriorating public services and facilities. Despite the poor image perceived by the government authorities, the urban village is important in providing affordable housing to rural migrants and disadvantaged local residents (Song et al., 2008).

Sanyin (called *SY* for simplicity) is a typical 'work unit' neighbourhood. The work unit is another unique type of urban form in Chinese cities, and it is a legacy of planned economy system before the 1980s. The main feature of the work unit is its multifunctional form in land use that includes residence, employment, education and commerce. Most of the daily activities can be completed within the work unit compound by walking and bicycling. The work units were traditionally owned and operated by government agencies, public institutions, or state-owned factories. Following the market economy starting from the 1980s, however, many state-owned factories bankrupted and residents living in those work units were unemployed. The work unit we included in this study was a factory bankrupted about 10 years ago, but the original spatial pattern is preserved, and many workers still live there. Most of the residential buildings are 6-storey apartments built around 1970s. *Changfengyuan* (called *CFY* for simplicity) used to be an urban village, but has been redeveloped about ten years ago. The neighbourhood now primarily consists of high-rise buildings, with both previous villagers and rural-urban migrants lived there. This neighbourhood also has good accessibility to public transport and amenities such as shops, restaurants, parks etc.

Fig. 3 and Table 1 illustrates and summarises the built environment characteristics (objectively measured) of the four neighbourhoods.

The survey was conducted through face-to-face interviews with residents by the authors and trained graduate students. Before formally distributing the survey, a pilot survey was conducted with volunteer local residents with a mix of gender, income level, education level, and age, aiming to test the validity of the survey questions. The formal survey was conducted in four neighbourhoods one by one, and each took about two weeks to complete. With the help of local neighbourhood committee, we first chose a fixed site within each neighbourhood to conduct the survey, usually it was the community centre or public plaza within the neighbourhood that attracts most local residents. In each site, we provided a long table and several chairs for respondents to complete the survey on site, and a big banner advertising our study. The survey was conducted from 9am until 9 pm in each day of the two weeks, including weekends, except rainy days, aiming to recruitment as many participants as possible.

As many participants in these neighbourhoods are older adults with relatively low levels of education, it was difficult for them to complete the surveys themselves. The face-to-face interviews have proven to be an appropriate method in this project, as many respondents asked for clarifications or explanations for some of the survey questions during the data collection process. A small thank you gift (i.e., a vacuum cup, a plastic basin or an umbrella) was offered to each participant as an incentive. To ensure each

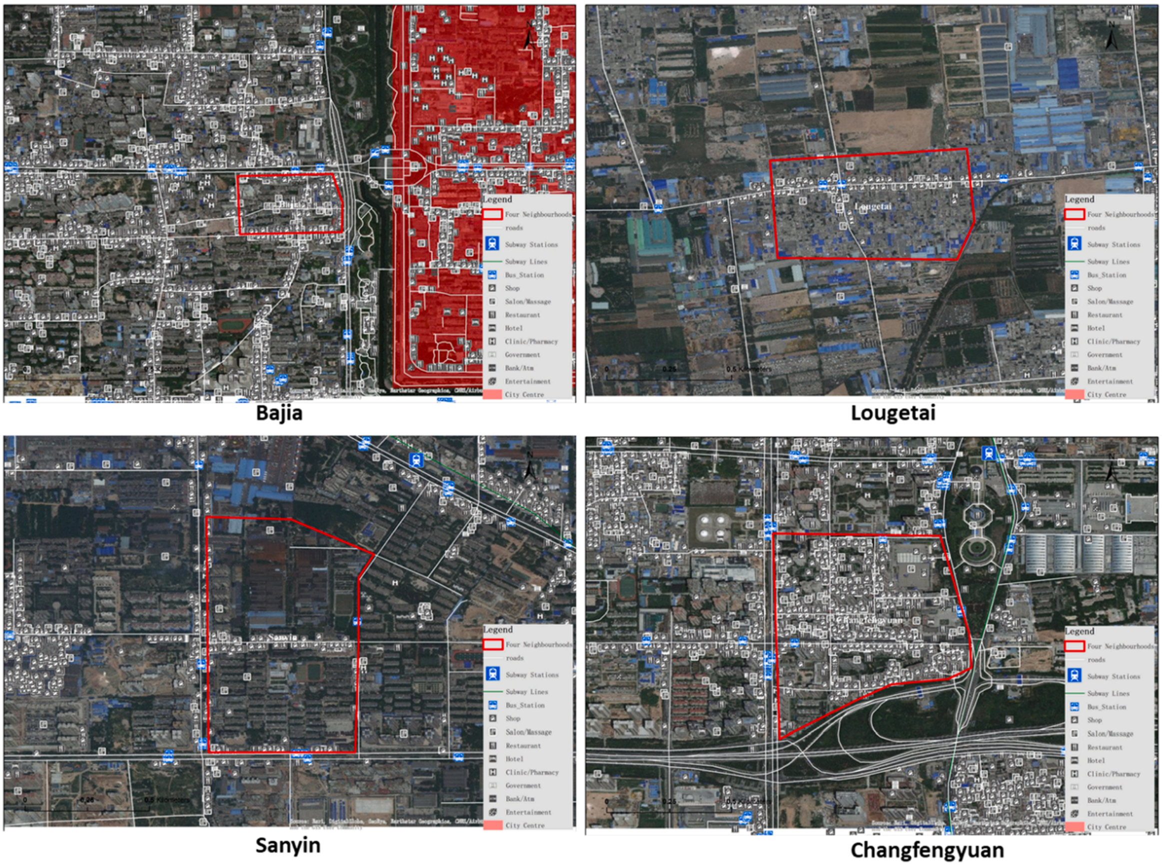

Fig. 3. Built environment of the four selected neighbourhoods.

Table 1
Built environment characteristics of the four neighbourhoods.

	BJ	LGT	SY	CFY
Types	Replacement housing	Urban village	Traditional work unit	Redeveloped urban village
Relative building density	6-storey	3-storey	6-storey	20-storey
Amenity accessibility (# amenities/km^2)	High (1123)	Low (97)	Medium (241)	High (730)
Street connectivity (# 3/4-way intersections/km^2)	24	1	5	8
Bus stop density (#stops/ km^2)	34	2	9	42
Having subway stations within 400 m of the neighbourhood	No	No	Yes	Yes
Having parks within 400 m of the neighbourhood	Yes	No	No	Yes
Distance from the centroid of neighbourhood to the city centre (metre)	245	8,973	7,248	7,619

neighbourhood has a large enough sample size for the following statistical analysis, a goal of 300 responses in each neighbourhood were set before the survey recruitment. In total, 1263 survey responses were collected from the four neighbourhoods. The initial survey responses were then screened for validity by two methods. Firstly, the time taken for completing the survey must be longer than 18 min.[1] Before survey data collection, several tests were conducted by 20 volunteers including both students and employees and the minimum time taken for completing a survey was around 18 min. Secondly, a “trap” question[2] was included in the survey to identify the inattentive respondents. By applying these two conditions, 921 valid survey responses were finally used for the following analysis.

Table 2 provides the sample characteristics. In general, the survey captures a variety of population in these disadvantaged

[1] On average, it took the respondents around 33 min to complete the survey, and those who failed to meet this criterion only spent an average of 4 min on completing the survey, leaving many missing values in their responses.

[2] The trap question is: “This question is for quality assurances purposes for our survey. Please select ‘Strongly agree’ from following answers”. Respondents who did not choose ‘Strongly agree’ were removed from the sample as they clearly were not focussed on the survey questions.

Table 2
Sample characteristics.

	Number	Percent
Age groups		
below 25	48	5.2
25–35	175	19.0
35–45	107	11.6
45–55	153	16.6
55–65	235	25.5
65 and over	202	22.0
Gender		
Female	643	69.8
Male	278	30.2
Education		
Did not go to school	16	1.7
Finished primary school	64	7.0
Completed secondary school qualification	520	56.5
Completed technical school	75	8.1
Completed Junior college	128	13.9
Completed bachelor degree qualification	104	11.3
Completed post-graduate qualification	14	4.5
Household Income		
¥1-¥19,999 per year (¥1-¥1,666 per month)	96	15.5
¥20,000 -¥39,999 (¥1,667 -¥3,333)	154	24.8
¥40,000 -¥59,999 (¥3,334 -¥5,000)	110	17.7
¥60,000 -¥79,999 (¥5,001 - ¥6,666)	84	13.5
¥80,000 -¥99,999 (¥6,667 - ¥8,333)	62	10.0
¥100,000 -¥149,999 (¥8,334 - ¥12,499)	72	11.6
¥150,000 -¥199,999 (¥12,500 - ¥16,666)	21	3.4
¥200,000 and over (¥16,667 and above)	22	3.5
#cars in household		
0	320	34.7
1	470	51.0
2	95	10.3
>2	36	3.9
BMI (calculated based on self-reported weight and height)		
below 18.5	47	5.2
18.5–24.9	533	59.0
25–29.9	207	22.9
30 and up	117	12.9
Self-reported health		
Excellent	157	17.1
Very good	255	27.7
Good	192	20.9
Fair	279	30.3
Poor	38	4.1
Having driving license		
Yes	238	25.8
No	683	74.2
Home Ownership		
Rent	210	22.8
Own	627	68.1
Parent's home	68	7.4
Employment Status		
Full-time	316	34.3
Part-time	52	5.7
Unemployed	190	20.6
Retired	363	39.4

neighbourhoods in Xi'an. However, due to lack of official statistical data at this level, we don't know the extent our sample is representative to the population of the four neighbourhoods. The sample is composed of more female than male respondents (69.8% vs. 30.2%) and is relatively older (47.5% over 55 years old). Most respondents in this sample did not receive a higher education (73.7% without a college or above degree), and had a household income below the average level of Xi'an (81.5% below ¥100,000). Only around one third of the respondents were working full time, most were unemployed or retired (60.0%). While most respondents reported not holding a driver license (74.2%), many households owned at least one car (64.2%). Finally, most respondents reported a good health condition (59.0% BMI: 18.5–24.9; 65.6% rated good–excellent for health condition), and owned their home property (68.1%).

3.2. Variables

This study focuses on identifying the key factors that matter for bicycling use in the disadvantaged neighbourhoods. We applied an extended theory of planned behaviour (TPB) to examine this research question. The three core elements of TPB, including attitudes, social norms, and perceived behaviour control (PBC), were measured using the survey questions adapted from Dill et al. (2014). The bicycling behaviour was measured by asking the respondents to report how often they ride a bike from their home to the following six types of places including civic buildings, service providers, shops, restaurants or cafés, places for entertainment/recreation, and places to exercise in a typical month with good weather. Each question was coded using a 6-point scale from 1 (never) to 6 (two or more times per week). The sum of these scores from the six questions was then used as the measure of utilitarian bicycling behaviour. This measure, therefore, only reflects the frequency of bicycling for daily errands.

Following the conceptual framework (Fig. 1), exogenous variables include perceived built environment, neighbourhood aesthetics, traffic hazards, crime, neighbourhood trust/cohesion, and social demographics. Survey questions adapted from the Neighbourhood Environment Walkability Scale (NEWS), which has been validated in several studies with different contexts (Saelens et al., 2003), were used to measure the neighbourhood environment attributes. NEWS scale measure the participants' evaluation of various dimensions of the built environment, including residential density (e.g. predominance of single-family, townhouse, apartment), accessibility (walking time to shop, supermarket, post office, school, fast food, restaurant, bank), street connectivity, infrastructure and safety for walking (sidewalks, grass/dirt strips, lights, crossings and signals), neighbourhood surroundings/aesthetics (presence of street trees and views, and evaluation of the attractiveness of buildings), traffic hazards, and crime. Each item was coded using a 4-point scale from strongly disagree to strongly agree. The final score on each dimension of the neighbourhood environment was calculated, based on the scoring method provided by Saelens et al. (2003), except the measure of accessibility.

Table 3
Model variables.

Variable	Description	Code or Unit
Behaviour		
Bicycling	In the past month how often have the respondent ridden a bicycle from home to the destinations nearby: civic buildings, service providers, shops, restaurants or cafés, places for entertainment/recreation, and places to exercise.	Sum
Neighbourhood Environment		
Density	How would you describe the type of housing unit where you currently live?	Weighted sum
Accessibility to amenities	Walking time to shop, supermarket, restaurant, etc.	Factor score
Accessibility to schools	Walking time to primary/middle school	Factor score
Accessibility to subway	Walking time to subway station	1 = Strongly disagree; 2 = Somewhat Disagree; 3 = Somewhat agree; 4 = Strongly agree
Accessibility to park	Walking time to park/open space	1 = Strongly disagree; 2 = Somewhat Disagree; 3 = Somewhat agree; 4 = Strongly agree
Street connectivity	(1) The distance between intersections…is usually short; (2) There are many alternative routes…; (3) The streets…do not have many cul-de-sacs.	Mean
Aesthetics	(1) There are trees along the streets…; (2) …interesting things…; (3) …attractive natural sights…; (4) …attractive buildings…; (5) …greenery…	Mean
Traffic hazards	(1) …so much traffic along…; (2) …so much traffic nearby…; (3) The speed of traffic…is slow; (4) Most drivers exceed…(5) …a lot of exhaust fumes.	Mean
Crime rate	(1) …high crime rate…; (2) …unsafe to walk during the day; (3) …unsafe ty walk at night; (4) …safe enough…let a 10-year-old boy walk…	Mean
Social trust/ cohesion	Five statements adapted from Sampson et al. (1997).	Mean
Bike infrastructure	(1) There are off-street bike trails…(2) There are bike lanes…(3) there are quiet streets…	Mean
Attitude		
ATT1	I like riding a bike	1 = Strongly disagree; 2 = Somewhat Disagree; 3 = Neither Agree nor Disagree; 4 = Somewhat agree; 5 = Strongly agree
ATT2	I prefer to bike rather than drive whenever possible	
ATT3	Bicycling can sometimes be easier for me than driving.	
Social Norms		
SN1	Most people who are important to me, for example my family and friends, think I should bike more	1 = Strongly disagree; 2 = Somewhat Disagree; 3 = Neither Agree nor Disagree; 4 = Somewhat agree; 5 = Strongly agree
SN2	Most people who are important to me, for example my family and friends, would support me to bike more	
SN3	Many of my family, friends, and co-workers ride a bike to get to places, such as errands, shopping, and work	
Perceived Behaviour Control		
PBC1	For me to ride a bicycle for daily travel from home would be easy	1 = Strongly disagree; 2 = Somewhat Disagree; 3 = Neither Agree nor Disagree; 4 = Somewhat agree; 5 = Strongly agree
PBC2	I know where safe bike routes are in my neighbourhood	
PBC3	Many of the places I need to get to regularly are within bicycling distance of my home.	

We found that the internal consistency of the 14 questions on accessibility was quite low, and therefore principal component analysis (PCA) was applied to reduce the dimensions. Among the 14 measures on accessibility, walking time to subway and park were treated as two independent variables, and not included in the PCA analysis, as we want to examine their unique impacts on bicycling behaviour. PCA analysis was then applied on the rest 12 items of accessibility measures, and two factors were extracted, representing two different types of accessibility: (1) accessibility to amenities (e.g., shops, supermarket, restaurants, market, bank), and (2) accessibility to schools (including primary and middle schools). Factor scores were then used to measure these two accessibility variables. Survey questions on bicycle infrastructure are adapted from Ma and Dill (2015). We asked the respondents to rate using a 4-point Likert scale on the following three statements including “There are off-street bike trails or paved paths in or near my neighbourhood that are easy to get to”; (2) “There are bike lanes that are easy to get to” (3) “There are quiet streets, without bike lanes, that are easy to get to on a bike”.

In addition to the NEWS, neighbourhood cohesion was measured using a scale adapted from Sampson et al. (1997). This scale includes responses to statements such as “People around my neighbourhood are willing to help their neighbours”; “This is a close-knit neighbourhood”; “People in this neighbourhood can be trusted”; “People in this neighbourhood generally don’t get along (reverse scored)”; and “People in this neighbourhood do not share the same values (reverse scored)”. Each item was coded using a 4-point Likert scale from strongly disagree to strongly agree. The measure of the social cohesion was calculated as the mean of the scores on these five items.

A detailed description of the variables appears in Table 3 and descriptive statistics comparing the four neighbourhoods are in Table 4.

3.3. Analysis methods

We first analysed the effects of the built environment and the three TPB variables on bicycling behaviour at the neighbourhood level. Structural Equation Modelling (SEM) was then used to examine the structural relationships between the variables as proposed in

Table 4
Descriptive statistics for the four neighbourhoods.

	BJ n = 200	LGT n = 221	SY n = 289	CFY n = 211	Total n = 921
Socio-demographics					
Age	53.8	46.8	60.6	42.7	51.7
% female	72%	71%	75%	61%	70%
Education (1–8)	4.6	3.4	4.1	5.2	4.3
HH income (1–13)	6.4	4.9	7.1	8.0	6.7
# cars	0.7	0.8	0.9	0.9	0.9
# bikes	0.5	1.0	0.6	0.3	0.6
# e-bikes	0.5	1.2	0.4	0.4	0.6
% holding driver’s license	22%	23%	18%	44%	26%
% rental	20%	43%	10%	22%	23%
Years living in the neighbourhood	16.9	23.6	24.9	6.7	18.7
% full-time employees	31%	37%	20%	55%	34%
Neighbourhood environment					
Building density	3.2	1.8	3.2	4.4	3.2
Accessibility to amenities	0.4	−0.3	−0.4	0.5	0.0
Accessibility to schools	0.2	0.0	0.7	−1.0	0.0
Accessibility to subways	2.3	1.5	2.5	3.4	2.4
Accessibility to parks	3.9	2.1	1.5	3.0	2.5
Street connectivity	3.1	2.8	2.8	2.9	2.9
Aesthetics	2.5	2.1	2.1	2.4	2.3
Traffic volume	2.5	2.7	2.6	2.7	2.6
Crime rate	2.3	2.2	2.4	2.2	2.3
Bicycle infrastructure	2.5	2.1	2.3	2.5	2.3
Social cohesion	2.7	3.0	3.0	2.7	2.9
Attitude					
I like riding a bike	3.2	3.2	3.0	3.1	3.1
I prefer to bike…	3.3	3.2	2.7	3.2	3.1
Bicycling can sometimes be easier…	3.5	3.3	3.0	3.2	3.2
Social Norms					
Most people…think I should bike more	2.0	2.1	1.6	2.1	1.9
Most people…would support me to bike more	2.1	2.3	1.6	2.3	2.1
Many of my family, friends… ride a bike to get to places…	2.3	2.6	2.1	2.4	2.3
Perceived Behaviour Control (PBC)					
For me to ride a bicycle… would be easy	2.7	2.7	2.3	2.7	2.5
I know where safe bike routes are in my neighbourhood	2.7	2.7	2.2	2.6	2.5
…places I need to get to regularly are within bicycling distance…	2.8	2.9	2.3	2.7	2.7
Bicycling behaviour					
# bike frequency for daily errands	9.2	12.6	9.8	10.4	10.5

the conceptual model (Fig. 1) at the individual level. Different from multivariate regressions, SEM enables simultaneous equations to reveal the relationships among exogenous and endogenous variables. In this model, the three constructs of TPB, including attitudes, social norms and perceived behavioural control, were specified as latent variables. Each of these latent variables were measured by three observed indicators as detailed in Table 4. All other variables were directly observed. Amos 24.0 was used to estimate the SEM models.

The SEM models were developed using maximum likelihood estimation, which assumes that observed variables follow a multivariate normal distribution. Violating this assumption can lead to underestimation of standard errors, even though it may not affect parameter estimates (Kline, 2005). We therefore estimated the models using a bootstrapping approach, which is a process of drawing repeated sample from the data with replacement (Hayes, 2009). In this study, we used Monte Carlo (or bootstrapped parameter estimates) bootstrapping set to generate 5000 samples. Bias-corrected bootstrap confidence intervals were used to detect significant effects.

4. Results and discussion

Tables 1 and 4 provide a comparison between the four neighbourhoods in terms of respondents' socio-demographic characteristics, the objectively measured built environment, the subjectively measured built environment, attitudes toward bicycling, social norms, perceived behaviour control, and bicycling behaviour. In terms of the built environment, comparing with *LGT* and *SY*, *BJ* and *CFY* were the two neighbourhoods with relatively higher density, better amenity accessibility and street connectivity, however, residents in these two neighbourhoods, on average, reported a lower level of bicycling frequency for daily errands. This suggests that a highly walkable neighbourhood might not necessarily support utilitarian bicycling behaviour. With regards to the three psychological variables, on average, residents in *BJ* reported the most positive attitudes towards bicycling, but they had the lowest level of bicycling frequency, indicating a mismatch between the travel attitudes and bicycling behaviour. Further, residents in *LGT* reported the highest levels of social norms and PBC, as well as the highest level of bicycling frequency, highlighting the important roles of these two psychological factors in determining the bicycling behaviour for transportation purposes. It is also worth noting that respondents from *SY* reported the least favourable attitudes, social norms and PBC, though *SY* had relatively higher density and better transit accessibility than *LGT*, suggesting the built environment that supports bicycling might not necessarily lead to positive attitudes, social norms, and PBC towards bicycling. All these findings again highlight the complex relationships between the built environment, subjective attitudes, and travel behaviour as mentioned in conceptual framework. This aggregate level analysis only provides a simple association between the built environment, the three TPB variables and bicycling behaviour, without accounting for socio-demographics, other covariates, and interactions between variables. The individual level analysis was then followed using SEM model.

Results of SEM model are presented in Table 5. The model fit indices, CFI (0.979) and RMSEA (0.035), indicate a good fit, based on Hu and Bentler (1999), who suggest a cutoff value close to 0.95 for CFI and a cut-off value close to 0.06 for RMSEA are needed to conclude there is a relatively good fit between the hypothesized model and the observed data. Further, the standardized loadings of the nine observed indicators assessing the three constructs of TPB are of sufficient magnitude, ranging from 0.647 to 0.809 for attitudes, from 0.429 to 0.920 for social norms, and from 0.849 to 0.932 for PBC, respectively. All the coefficients reported in Table 5 are the standardised coefficients.

First, of the three constructs of TPB, only social norms and PBC were significantly associated with bicycling, however, attitudes were not ($p = 0.124$). This result is surprising, as attitudes are often found to be the most important predictor of bicycling behaviour in

Table 5
Model results ($n = 866$).

	Attitudes $R^2 = 0.095$		Social Norms $R^2 = 0.226$		PBC $R^2 = 0.107$		Bike behaviour $R^2 = 0.265$			
	Direct effects		Direct effects		Direct effects		Direct effects		Total Effects	
Attitudes							0.065		0.065	
Social Norms							0.167	***	0.167	***
PBC							0.084	**	0.084	**
Access Amenity	0.115	***	−0.035		0.079	**	−0.148	***	−0.140	***
Access School	−0.013		−0.051		−0.036		0.071	**	0.059	*
Subway	−0.031		−0.013		−0.015		0.076	**	0.071	**
Street connectivity	−0.008		−0.025		0.084	**	−0.072	**	−0.069	**
Aesthetics	0.039		0.055		0.000		0.099	***	0.110	***
Traffic hazards	0.079	*	0.017		0.007		0.037		0.046	
Crime rate	−0.077	*	−0.007		−0.016		0.039		0.032	
Social cohesion	0.005		0.013		0.054		−0.017		−0.010	
Bike infrastructure	0.115	***	0.098	***	0.100	**	0.049		0.081	**
Age	−0.114	**	−0.418	***	−0.229	***	−0.248	***	−0.344	***
Female	−0.076	**	−0.128	***	−0.099	***	−0.082	**	−0.116	***
Education	−0.026		−0.045		−0.038		−0.015		−0.027	
#cars	−0.075	*	0.043		0.033		0.035		0.040	
#bikes	0.181	***	0.114	***	0.154	***	0.114	***	0.157	***
#e-bikes	−0.039		−0.002		−0.006		0.060	*	0.056	

Note: $*p < .1$; $**p < .05$; $***p < .01$.

previous studies (Handy and Xing, 2011; Heinen et al., 2011; Ma and Dill, 2015; Xing et al., 2010). To some extent, we think this is probably because of a mismatch between the attitudes and bicycling behaviour. On the one hand, some residents in these disadvantaged neighbourhoods may bicycle just because of their socio-economic constraints rather than they like to bike. If bicycling is a constrained choice rather than a free choice from alternatives, then attitudes towards bicycling might not play a role in bicycling behaviour. A previous study (Ye and Titheridge, 2019) that compared the commute satisfaction between the lower income and higher income respondents echoes our finding. It found that the bicycle commuters in the lower income groups rated their commute satisfaction significantly lower than bicycle commuters with a higher income, and a mismatch between the attitudes and bicycling behaviour in the lower income contributed to this difference. On the other hand, our data indicates that some of the respondents who relied on bicycling for daily errands also used other alternative modes, such as bus and walking, for transportation purposes, suggesting that bicycle was not a fully constrained choice. Another possible reason leading to the mismatch is that the presence of a rather similar alternative such as walking may prevent attitudes from translating into cycling behaviour.

The results are also interesting in terms of the relative size of the coefficients of the TPB variables. We found that social norms were the most important factor that affects bicycling, followed by PBC and attitudes. This is somewhat in contrast to previous studies that have shown that social norms either had no significant effect or had a smaller effect on bicycling than attitudes and PBC. These differences might be partially attributed to the cultural differences between China and the Western world. Traditional Chinese culture emphasizes collectivism, whereas individualism is more typical for Western countries. Individual behaviour may therefore be more strongly influenced by one's family and society in China. The social influence, therefore, could have a greater impact on travel behaviour in China than it would have in the Western world. A previous study (Pavlou and Chai, 2002) that compared e-commerce behaviour between China and the U.S. confirmed a similar hypothesis, and it found that social norms had a greater impact on the intention of using e-commerce in China than in the U.S. This collectivist culture may also contribute to the dissonance between attitudes and behaviour as mentioned above. For example, it is possible that some people who like to bike may abandon bicycling just because bicycling, as a travel mode, is perceived as a symbol of lower level of social economic status in China.

In terms of the built environmental characteristics, accessibility to amenities (e.g., shops, restaurants, markets, banks, etc.) were positively associated with bicycling attitudes and PBC, but negatively associated with bicycling behaviour. This is an unexpected result. One possible explanation is that walking could be a competing mode with bicycling in places with high level of accessibility. Similar findings were also reported in previous studies (Ma and Dill, 2015). A simple bivariate correlation analysis shows that amenity accessibility was positively associated with walking frequency for daily errands ($r = 0.109$, $p < 0.01$). Hence, high walking accessibility may be a factor preventing positive attitudes toward bicycling and high perceived behavioural control from being translated into bicycling behaviour. Accessibility to school was not significantly associated with the three TPB variables, but directly and positively associated with bicycling behaviour. Similarly, living close to a subway station was associated with more bicycle use for daily errands. This suggests that many local residents bicycled to subway stations. Street connectivity was positively correlated with PBC, however, it was negatively associated with bicycling behaviour. Again, this is possibly because walking is a more attractive mode than bicycle in the locations with good street connectivity. While exploring this relationship at the aggregate neighbourhood level, we found that *BaJia* (near city centre) had the highest level of street connectivity (Table 4), however, the respondents from this neighbourhood reported the lowest level of bicycle use. In contrast, the average reported frequency of walking to destinations in *Bajia* was the highest among the four neighbourhoods. This provides more evidence regarding the competing relationship between walking and bicycling in neighbourhoods with high accessibility and street connectivity. In addition to accessibility and street connectivity, neighbourhood aesthetics (e.g., presence of trees, greenery, interesting things, landscape, historical building, etc.) had a direct and positive effect on bicycling behaviour. This finding is consistent with some of the previous studies (Lee and Moudon, 2008; Wendel-Vos et al., 2004), but not all (Van Holle et al., 2012).

In terms of traffic safety, traffic hazards only had a weak (positive) association with bike attitudes, and it was not significantly associated with most of the endogenous variables. The link between traffic and bicycling is inclusive in previous studies. Although one study (Parkin et al., 2008) found a positive association between traffic volume and bicycle commuting, a review (Van Holle et al., 2012) based on 19 previous studies found that traffic hazards/safety was not associated with bicycling for transportation purposes. The positive relationship found in this study needs further investigation in this context. Perceived crime rate within the neighbourhood was only negatively associated (marginally significant) with bike attitudes, and it was not significantly associated with social norms, PBC and bicycling behaviour. Apparently, higher crime rates make bicycling less appealing, but do not withhold people from bicycling. Only a few studies have examined the relationship between crime rate and bicycling for transportation, and their results are inconsistent. For example, this study (Van Dyck et al., 2011) found a positive correlation between safety from crime and bicycling for transportation, while this study (De Geus et al., 2007) did not find a significant association. Different from our hypothesis, neighbourhood social cohesion was not associated with any of the TPB variables, nor with bicycling frequency. Previous studies have also reported the insignificant association between social cohesion and bicycling (Forsyth and Oakes, 2015) and walking behaviour (Mendes de Leon et al., 2009). In terms of bicycling infrastructure, it was significantly and positively associated with bike attitudes, social norms and PBC. Although the direct effect was not significant, the total effects of bicycling infrastructure on bicycling behaviour was statistically significant. These findings highlight the importance of bicycling infrastructure in promoting bicycling behaviour in these disadvantaged neighbourhoods.

Finally, most of the socio-demographic variables had expected associations with the three TPB variables and bicycling behaviour. Older adults and female are less likely to hold positive bike attitudes, receive support for bicycling from family and friends, and perceive high level of behaviour control, and therefore, were less likely to bicycle for transportation. Education level was not associated with any of the endogenous variables. This is in contrast with some of previous studies from the US (Dill et al., 2014) that found a positive association between level of education and bicycling behaviour. Bike ownership, as expected, was significantly associated with bike attitudes, social norms, PBC, and bicycling behaviour. It should be noted though, that the causality is not necessarily straightforward. While bike ownership clearly facilitates bicycle use, its relationship with attitudes, social norm and perceived behaviour control is ambiguous. It is possible (as expressed in the model) that bike ownership influences attitudes, social norms and PBC, as a process of cognitive dissonance, implying that, for instance, not being able to drive a car and owning a bike, leads to adjustment of attitudes, norms and PBC. It is, however, also possible that positive attitudes and norms lead to a decision to buy and use a bicycle. The effects of car ownership and e-bike ownership were weak in terms of influencing the three psychological factors and bicycling behaviour.

5. Conclusions and policy implications

This study examines the multi-dimensional factors associated with bicycling for transportation in disadvantaged neighbourhoods in a Chinese city using an extended Theory of Planned Behaviour (TPB) framework. Through collecting a unique survey data from four contrasting neighbourhoods in Xi'an and SEM modelling analysis, this study makes a unique contribution to the bicycling behaviour literature by focusing on disadvantaged populations and Chinese context. Bicycling is a low-cost and healthy travel mode, and could play an important role in fulfilling the daily travel needs of residents in Chinese disadvantaged neighbourhoods. This study offers insights on the policies on promoting bicycling as a travel mode in the low-income neighbourhoods and Chinese cities.

Our analyses reveal that after accounting for the socio-demographic variables, social norms have the greatest effect on bicycling behaviour. As discussed above, this is a quite different finding from previous studies that are based on the evidence from the Western countries. This implies that different approaches and intervention programs are needed in promoting bicycling behaviour in Chinese cities. In China, more collectivist culture, promoting bicycling should put more emphasis on changing the social norms toward bicycling. Although bicycling used to be the dominant travel mode before 1990 s when China was under planned economy, share of bicycling as a travel mode had a dramatic decrease in the last 30 years in large Chinese cities. The fast urban expansion and spatial segregation of homes and jobs are the main drivers of travel mode changes (Pan et al., 2009). However, the overall negative attitudes toward bicycling is also a critical factor leading to the dumping of bicycling when other motorised travel modes become available and affordable. In general, social marketing programs that emphasize the health and environmental benefits of bicycling and promote bicycling as a trendy rather than just a low-cost travel mode should be designed and integrated into Chinese city planning. The programs may include distributing broachers and posters containing information regarding the benefits of bicycling to the local neighbourhoods. They could also be in the electronic format delivered through social media. Annual public events that inviting mayors or celebrities to bike may have demonstrating effects on changing public attitudes toward bicycling. While the greater role of social norms in China in general suggests the application of social marketing campaigns as described above, it should be kept in mind that our study focused on lower socio-economic groups in disadvantaged neighbourhoods, who more often than usual, are captive bicycle users, explaining why bicycling attitude does not significantly influence bicycling behaviour. This raises issues with respect to objectives of bicycling policies and the measures to be taken for this group. From a public health point of view, it would be advisable to stimulate physical activity via bicycling. However, the fact that relatively many bicycle out of necessity implies that they are more likely to drop out if better options come along. One objective of policies could therefore to increase bicycling attitudes, which, to our results could be achieved by improving bicycling infrastructure and improving access to amenities. On the other hand, if people bicycle out of necessity, optimizing accessibility will be an important policy objective. This requires careful planning of a variety of amenities and facilities particularly in disadvantaged neighbourhoods, keeping in mind acceptable bicycling distances.

Further, this study finds older adults and female are less likely to be encouraged and supported by their families and friends for bicycling. This highlights the needs of tailored interventions for these population groups. For example, social marketing programs should have specific information regarding the bicycling benefits to these population groups. Further, improving traffic safety and quality of bicycling infrastructure are also important to meet the needs of female and older adults to bike.

Comparing with social norms, PBC has a smaller but significant effect on bicycling frequency. The social market programs and the public bicycling events as mentioned above will also help to improve the level of PBC. Such programs and events will help the local residents to better know the location of safe bicycle routes, bicycle safety facts and tips, and locations of bicycle-accessible businesses and destinations and familiarize the local residents with the bicycle-friendly designs in their neighbourhoods (Ma et al., 2014). Further, wayfinding signage that includes bicycling distances and travel times to key destinations may also change perceptions. This study also finds that improving accessibility to amenities, street connectivity, and bicycling infrastructure helps to boost the level of PBC.

Among the neighbourhood environment characteristics, this study finds neighbourhood aesthetics is an important factor in promoting bicycling in disadvantaged neighbourhoods. The suggests that improving urban design and quality of neighbourhood environment should be considered as a planning strategy to encourage bicycling. These improvements should focus on increasing greenery and open spaces, such as trees, parks, plazas, landmarks, etc., within and around the neighborhoods. A better designed neighborhood environment will improve the experience of active travel, leading to the increase of attractiveness of using bicycling or walking as travel modes. Further, bicycle infrastructure also plays an important role in improving bicycling for transportation. Although most of Chinese cities used to have comprehensive and dedicated bicycle infrastructure network, the fast motorization in the last 20 years has leaded to the previous dedicated bicycle lanes giving way to express motorways and the new development areas even did not incorporate bicycle infrastructure into its transportation network (Yang et al., 2015). Further, the significant association between access to subway and bicycling frequency suggests that integration of bicycles and rail transit should be considered as a strategy to improve bicycling. The integration may include providing bike parking equipment at transit stations, constructing easy access infrastructure, and installing bike racks on carriages.

Finally, an interesting finding of our study is that spatial characteristics that improve attitudes toward bicycling (such as access to amenities and street connectivity) do not lead to more bicycling, due to their positive effect of walking. This does however not imply that increasing access to amenities and increasing street connectivity are no useful measures to take. The fact that they stimulate walking actually provides benefits both from a public health and accessibility point of view. In addition, walkability has been found to be associated with increased social interaction as an added benefit. Hence, walking and bicycling outcomes of policies need to be taken into account jointly, when thinking about policies to stimulate active travel.

This study has several limitations. Although we applied the standard and validated questionnaire to collect data, answering some of our questions requires high cognitive demand, posing challenges to some of our respondents. This might bring some measurement errors. Further, all of the neighbourhood environment variables at individual level are self-reported. While there is a high consistency between the self-reported measures (Table 4) and objective measures (Table 1) at the neighbourhood level, previous studies have found a mismatch between the types of measures at the individual level and they may have independent effects on bicycling behaviour (Ma and Dill, 2015, 2016; Van Acker et al., 2013). Regarding the accessibility measure, we focused on the destinations nearby only, but destinations in the middle range of travel distance (1–5 miles) are within the reasonable bike distance. Finally, longitudinal research would make the causal inferences among the built environment, psychological variables, and bicycling behaviour more robust.

CRediT authorship contribution statement

Liang Ma: Conceptualization, Investigation, Methodology. **Dick Ettema:** Conceptualization, Investigation, Methodology. **Runing Ye:** Conceptualization, Funding acquisition, Investigation, Methodology.

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