Travel Behaviour and Society 27 (2022) 128–138

Contents lists available at ScienceDirect

Travel Behaviour and Society

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

Perceived accessibility: How access to dockless bike-sharing impacts activity participation

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ARTICLE INFO

Keywords:
Perceived accessibility
Dockless bike-sharing
Beijing
Cycling
Activity participation
Shared mobility

ABSTRACT

The emergence and popularity of dockless bike-sharing systems have attracted extensive attention due to the associated environmental and health benefits. However, little consideration has been given to the potential individual social implications of dockless bike-sharing. Our knowledge about whether dockless bike-sharing systems have the ability to facilitate individuals' engagement in daily activities is limited. The goal of this study is to gain more insight into how individuals' personal characteristics and neighborhood environment features influence perceived access to different types of activities by dockless bike-sharing. Using survey data collected from residents in Beijing, we employed four ordinary least squares (OLS) regressions to assess the effect of individual and spatial attributes on the role dockless bike-sharing plays in users' perceived accessibility to activities overall as well as to three different categories of activities—subsistence, maintenance and leisure. The results indicated that male users reported enjoying more benefits in accessing activities. Dockless bike-sharing users' perceived benefits in accessing activities largely relied on their social support from their family and friends and their attitudes towards environmental and health concerns of travel. Additionally, users who agreed that dockless bike-sharing has helped them access bus stops and metro stations perceived higher benefits of dockless bike-sharing on activity participation. Our analysis also highlighted that dockless bike-sharing users in Beijing benefited most in their commuting trips, and to a lesser degree, when attending maintenance and leisure activities. The percentage of cycling paths within the home neighborhood tended to be positively associated with individuals' perceived accessibility to subsistence activities.

1. Introduction

In many regions around the world, governments have been implementing policies to promote sustainable travel. Many initiatives have positively influenced the use of active transport and enabled new modes, such as shared dockless bicycles and other forms of micromobility, to become an increasingly common sight on city streets. As one of the pinnacles of micromobility, dockless bike-sharing systems provide flexible short-term access to public bicycles without the constraint of geographically fixed bike-sharing stations. These systems are often privately operated, rely on a Global Positioning System (GPS) located on the bicycles, and a mobile application for necessary functions of locating bicycles, unlocking bicycles, and processing cashless mobile payment. The large expansion and wide-scale adoption of dockless bike-sharing systems has increasingly made them an unneglectable part of transport systems in many regions worldwide (Zhang, 2018). The environmental and health benefits of dockless bike-sharing, including emission and congestion reductions, improved physical activity level, and connections to public transit, are becoming increasingly clear (e.g., Zhang & Mi, 2018; Zhao & Li, 2017). However, little consideration has been given to the potential individual social implications of dockless bike-sharing, such as the ability to facilitate individuals' engagement in daily activities.

Individuals engage in activities such as work, household chores, personal care, shopping and/or sports to meet their households' basic needs and preferences (Maat & Timmermans, 2009). A basic function of an urban mobility system is to facilitate individuals' (potential) activity participation. Dockless bike-sharing can be considered a new form of bicycling service that has potential advantages in terms of convenience for short distance trips, flexibility and efficiency for trip chaining, and low cost. Therefore, having access to dockless bike-sharing is likely to extend the activity space and range for users. Overall accessibility in a region or city may especially increase for carless and/or low-income individuals or households, whose access to this low-cost shared mode

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https://doi.org/10.1016/j.tbs.2022.01.002
Received 9 August 2020; Received in revised form 29 November 2021; Accepted 3 January 2022
Available online 13 January 2022

is likely to result in increases in their objective and perceived accessibility to (potential) activities (Chen et al., 2020a). An Individual's objective accessibility is place-based and usually refers to their accessibility to a number of predetermined destinations using available transport systems in the area. Perceived accessibility is person-based, capturing an individual's perception of the ease of accessing activities of choice (Lättman et al., 2018).

Common objective measures of accessibility are cumulative opportunity and gravity measures, which evaluate the aggregated levels of accessibility and lack the ability to differentiate between individuals within specific geographic boundaries (Ryan et al., 2016). Alternatively, when individuals' perceptions of accessibility are measured, they may or may not be aligned with a measurement of the actual opportunities available because individuals possess different knowledge and awareness levels of transport, destinations, activity options and opportunities (Geurs & van Wee, 2004; van Wee, 2016). Moreover, assessing perceived accessibility provides an opportunity to consider and account for individuals' preferences (Curl et al., 2015; Lättman et al., 2018), as the destinations where individuals need or want to travel may not be the nearest opportunities (supermarkets, jobs, parks, etc.) available. Therefore, it is also essential to assure that individuals' perceived accessibility, apart from objective accessibility, is and remains sufficient (Levinson & Krizek, 2005; Pyrialakou et al., 2016). However, in the transport field, much attention has been given to objective accessibility (Lättman et al., 2018). More emphasis should be placed on perceived accessibility, as it complements objective accessibility on different levels of planning and evaluation in transport practice by identifying individuals' perceived differences regarding their access to activities across time.

Users of dockless bike-sharing systems who have different personal characteristics and spatial contexts can be presumed to have different perceptions of how increased access to dockless bike-sharing assists their activity engagements. Dockless bike-sharing users' usage frequencies and trip purposes have been found to vary based on their sociodemographic characteristics (Du & Cheng, 2018), implying differences in perceived accessibility. Meanwhile, individuals' access to public transportation facilities or bicycle infrastructure, etc., can vary based on different neighborhood attributes (such as street connectivity and the public transport provision). Hence, having or increasing access to dockless bike-sharing means different things for people from distinct neighborhoods in terms of their daily mobility, and thus, differentially influences their activity participation. When taking individuals' attitudes into consideration, people with a pro-car attitude, for instance, may not use the transport infrastructure in the same way as those from the same neighborhood with pro-public transit attitudes. Such differences in the perspectives that people have regarding their available travel options can lead to differences in perceived accessibility.

The present study aims to provide insight into what kinds of users benefit most from dockless bike-sharing systems with regard to increases in perceived accessibility to daily life activities. Using a quantitative approach, we set out to explore the following two research questions:

- How do individuals' personal characteristics and the spatial attributes of neighborhoods influence the changes of dockless bike-sharing users' perceived access to activities?
- How do the impacts of dockless bike-sharing on perceived accessibility vary between activities of different daily life functions?

Research into the relationships between dockless bike-sharing and perceived accessibility to various activities can shed light on potential individual social implications of dockless bike-sharing and how access to dockless bike-sharing impacts people's activity participation.

2. Literature review

2.1. Perceived accessibility

In transport research, accessibility is an important concept used to measure access to potential activities using transport systems (Curtis & Scheurer, 2016; Geurs & Ritsema van Eck, 2001; Hansen, 1959; Lucas et al., 2015; Neutens et al., 2011; Schwanen & Kwan, 2008). The contemporary empirical knowledge regarding accessibility focuses on place-based objective measures (Lättman et al., 2018), which are often limited by assuming a consistent accessibility level for all individuals within a certain area and ignoring individual variances (Curl et al., 2015; Thériault & Des Rosiers, 2004). Perceived accessibility is a complementary subjective approach to accessibility based on individuals' knowledge or awareness of potential access possibilities, as well as individuals' own preferences and abilities. It captures but is not restricted to an individual's (or groups of individuals') perceptions of the level of ease to access and use transport systems, to reach preferred goods or services, or to access activities of choice (Lättman et al., 2016). Scott et al. (2007) indicated that perceptions of accessibility to recreational facilities are more useful than objective accessibility measures in predicting the actual use of the facilities. In addition, Scheepers et al. (2016)'s study in the Netherlands argued that it is a preferable option to concentrate on perceived accessibility rather than objective accessibility to encourage the adoption of active travel modes among individuals. In this study, we evaluate perceived accessibility among dockless bike-sharing users.

The usage patterns of dockless bike-sharing systems differ according to the activities in which individuals engage. For example, in their case study of Beijing, China, Chen et al. (2020b) reported that the use frequency of dockless bike-sharing for work or education commuting is four times that of attending sports, recreational and grocery activities. Accordingly, we can assume that users' perceived accessibility to activities provided by dockless bike-sharing are also diverse and based on activities of different needs for daily living. The transport literature commonly presents a three-way subdivision of activities: subsistence, maintenance and leisure activities (e.g., Golob, 2000; Wang & Cao, 2017). Subsistence activities usually refer to work or work-related activities. Maintenance activities are those obligated or compulsory activities that fulfill physiological needs, such as home chores and grocery shopping. Leisure activities are easily understood as leisure and social pursuits (Lane & Lindquist, 1988; Reichman, 1977). Considering this, we compare the discrepancy between different categories of activities in perceived accessibility outcomes.

2.2. Individual and spatial determinants of perceived accessibility

Urban transport research has contributed to suggesting that accessibility to activities can be related to spatial characteristics, as activities of different functions tend to take place in different locations, and individuals can adopt different modes of transport to access these activities. In light of this, research has been employing the usage of space for daily travel and activities, that is, the activity space, to delineate the corresponding geographical mobility patterns for accessing daily activities (e.g., Li & Tong, 2016; Yuan & Raubal, 2016). Activity space represents the geographical area where individuals travel to access and undertake activities such as working, sporting, grocery shopping, etc.; additionally, it has also been suggested that activity spaces include knowledge of the geographical area and the opportunities that an individual possesses (Li & Tong, 2016; Schönfelder & Axhausen, 2003). Tana et al. (2016) performed a comparative study of individual activity spaces in inner suburbs in Beijing and Chicago. This study found that as access to public transit increased, so did individuals' overall activity space in both cities. Based on the results of a longitudinal analysis of the change in people's activity space in Hong Kong from 2002 to 2011, Tao et al. (2020) found that all income groups in the new towns (newly developed towns since the 1970s in new territories in the suburban region) had larger average activity space than those in the urban areas (Hong Kong Island and Kowloon). These differences were found to be due to the distinct spatial and economic features, as the new towns had lower levels of employment opportunities and less heterogeneous populations, while urban areas are characterized by denser mixed land use and economic centers.

Individuals surrounded by similar neighborhood environments may behave differently in their mobility behavior and activity participation; this might be due to the diversity of individuals' attitudes and social environment (e.g., subjective social norms and behavioral control) towards transport systems (Mokhtarian & Cao, 2008; Van Acker et al., 2010). The transport domain has extensively employed the theory of planned behavior (Ajzen, 1991) to explain the influence of individuals' attitudes and subjective social environment on the execution of travel and activity behavior. Individuals' attitudes towards cars, public transit, and other different transport modes, as well as their perceptions of the expectations from their family, friends or colleagues to perform certain mobility or activity behavior, have the potential to affect people's cognition of and preference among available transport options (de Bruijn et al., 2005; Heinen et al., 2011; Willis et al., 2014). In addition, perceived accessibility to activities is not only subject to people's awareness or knowledge of activity opportunities but is also related to their perception and preference of daily mobility options to accomplish these activities (Lättman et al., 2020; Scheepers et al., 2016). In this regard, individuals' attitudes and social environment can thus be hypothesized to also indirectly play a role in perceived accessibility to activities by affecting people's daily travel.

Apart from individual discrepancies, disparities in people's objective and perceived accessibility to activities may also occur across different sociodemographic population segments. Paez et al. (2009) argued that elderly, lower income, and disabled individuals in Toronto and Montreal traveled less and consequently had less access to key services than the average population in both study cities. Compared to people in higher income groups, people in lower income groups rely more on public transport due to less access to cars, which limits their participation in activities. Hine and Mitchell (2003) found in their Scottish study that residents without a car tended to engage in fewer shopping trips and visited friends and family less often, while evidence from the USA suggested that low-income households without cars also tended to endure lower levels of accessibility to public transport and therefore experienced large difficulties in accessing work (Cervero, 2004). However, these empirical studies mainly focused on the objective measurements of accessibility to activities. Whether the individuals' sociodemographic characteristics can also potentially exert an influence on perceived accessibility requires further investigation.

2.3. Dockless bike-sharing and perceived accessibility

A previous study by Chen et al. (2020a) presented a concise discussion, suggesting that dockless bike-sharing systems could provide an additional widely available travel option for people with fewer opportunities to participate in social activities due to fewer mobility options or temporal constraints. In addition, dockless bike-sharing is widely used as a "first/last-mile" trip option for accessing public transit and extends the transfer radius of public transit (Ai et al., 2018; Mobike Global et al., 2017). However, some individuals' travel needs for daily activity participation might not align with the features of dockless bike-sharing that are most advantaged for short distance trips (Mobike Global et al., 2017). The private, for-profit nature of dockless bike-sharing also means that operators tend to concentrate the placement of dockless shared bikes in wealthier, denser or popular areas to maximize usage and thereby revenue (Shi et al., 2018; Spinney & Lin, 2018). Therefore, residents living in suburbs or peripheral areas of a monocentric city, for example, might not travel with dockless shared bikes or might travel less frequently to access certain activities, as these neighborhoods may be marginalized from sufficient provision of dockless shared bikes, or they may instead choose motorized modes to accomplish the relatively longer journey to downtown areas for activity participation.

Currently, the perceived accessibility effects of dockless bike-sharing are a relatively unexplored area of research. Previous studies on the influence of general cycling and new bicycle infrastructure on access to services, goods or activities are able to provide theoretical support. Pritchard et al. (2019) examined the potential impacts of the bicycle as a connection for public transit trips on the accessibility to jobs in São Paulo, Brazil. Their results showed that bike-and-ride integration had the ability to substantially increase the accessibility to jobs in different areas if investments in the quality and safety of cycling and transit networks were made. In addition, Panter et al. (2016) suggested that the provision of new sustainable transport infrastructure could effectively increase active commuting but did not show benefits in recreational activities. However, these studies tended to suggest a positive impact on objective accessibility, and to the best of the authors' knowledge, there are limited studies that evaluated the perceived accessibility impacts of new bicycle infrastructure. Although there exist gaps between objectively measured accessibility to activities and how the opportunities and abilities to travel and access activities are perceived by individuals (Scheepers et al., 2016), perceived accessibility also relies on attributes similar to objective accessibility, such as the availability and the features of specific destinations, activity spots or transport infrastructures (Lättman et al., 2018). A dockless bike-sharing system can be considered a newly developed bicycle service that provides residents with feasibly accessible shared bikes. Therefore, we can also speculate that the widespread usage of this system has the potential to pose a positive effect on users' perceived accessibility to activities, and this effect may vary based on activities of different natures.

Fig. 1 summarizes the reviewed literature and illustrates the theoretical framework for the present study. This paper examined the influence of individual attributes and spatial attributes of the neighborhoods that the individuals live in on the role dockless bike-sharing systems play in users' perceived accessibility to activities. Individual attributes that have been accounted for include individuals' sociodemographic characteristics, social environment, and travel attitudes. Neighborhood-related attributes take both objective and subjective measures into consideration. The perceived accessibility impacts of dockless bike-sharing were compared between three categories of activities: subsistence, maintenance and leisure activities.

3. Study context and data

The data used in this study were obtained from a comprehensive online survey collected from August 7th to November 31st, 2018, among residents of Beijing, China. Beijing is a megacity with a population of 21.5 million (as of the end of 2018). The urban transport of Beijing is based on the six concentric ring roads that start from the Forbidden City as the geographical center and extend outwards. Public transport (including metros and buses) is the dominant travel mode of Beijing, accounting for 46% of all trips in 2018 (Beijing Transport Research Center, 2019).

The first dockless bike-sharing system was introduced in June 2015 on the Peking University campus for students' convenience but expanded to other areas of Beijing soon afterwards and subsequently to other major cities in China. In 2017, the number of registered users in Beijing was close to 11 million, accounting for nearly half of the city's population (Beijing Municipal Commission of Transport, 2018). As the oversupply and the deregulated nature of dockless shared bikes resulted in negative impacts such as violating pedestrian rights and blocking cycle paths (Chang et al., 2018; Shi et al., 2018), the volume of operating shared bikes was restricted by the city government at a total of 1.91 million bicycles from nine operators in August 2018. Nevertheless, the average number of trips per day reached 1.42 million in Beijing in 2018 (Beijing Municipal Commission of Transport, 2018).

We hired a recruitment company (www.wjx.cn) to administer the distribution of our questionnaire. Randomly selected Beijing residents

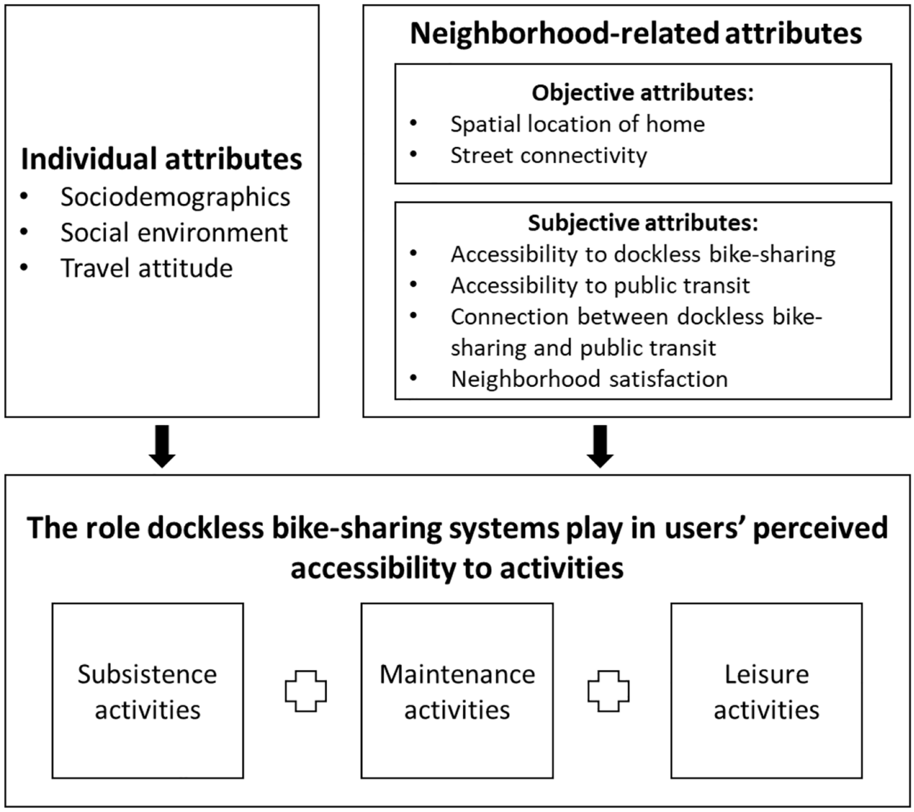

Fig. 1. Theoretical framework.

aged 16 or older from the recruitment company's large online survey panel with 2.6 million members in China were emailed questionnaires to gather information about individuals' sociodemographic characteristics, social environment, travel attitudes, travel behavior, and dockless bike-sharing system usage. System users were asked to provide their views and opinions about dockless bike-sharing, including the extent to which they used dockless bike-sharing to travel to different activities as well as questions about their perceived accessibility. Individuals who are under age 16 are not allowed to register to use the dockless bike-sharing systems, and thus, they were not included in the study. A total of 606 valid questionnaires were received from the respondents; 489 questionnaires were from dockless bike-sharing users. Our study did not look at comparing the equity of perceived accessibility between users and nonusers. Rather, we were more interested in the changing perceived accessibility levels between users who have access to dockless bike-sharing by definition, exploring to what extent people benefit from dockless bike-sharing if they have chosen to use it. Therefore, the current study only included the 489 questionnaires from dockless bike-sharing users in the analysis. The survey respondents were not representative of the Beijing population. However, the overrepresentation of dockless bike-sharing users was an attempt to ensure adequate coverage of users likely to experience various physical and social environments, consistent with the main focus of this research. A summary of the sample used in this analysis is presented in Table 2

4. Methodology

This paper used a series of ordinary least squares (OLS) regressions to examine the association between individual- and neighborhood-related attributes and users' perceived accessibility that dockless bike-sharing provides to activities and how the role dockless bike-sharing plays on users' perceived accessibility varies between three different categories of activities—subsistence, maintenance and leisure activities. The individual attributes and neighborhood-related attributes, as demonstrated in the theoretical framework, were explored as explanatory variables (see Table 2).

The dependent variables used in the OLS regressions were from a subjective, self-reported evaluation, completed by users, on the impacts of dockless bike-sharing in assisting accessibility to different activities. Fifteen types of activities, including work, study, visiting restaurants, leisure or sports, shopping, and other activities that people take to be necessary for their regular daily lives, were identified from the Poverty and Social Exclusion United Kingdom 2012 living standards questionnaire and attitudes to necessities and services questionnaire (PSE UK, 2012). Survey participants were asked to rate to what extent they agree that dockless bike-sharing systems have made accessing these fifteen activities easier, using a seven-point scale from "strongly disagree" to "strongly agree". Therefore, all responses recorded were the participants' perceptions of their own situations. The scores for these fifteen activities were summed and then averaged to derive a total score. In addition, we differentiated the average score for accessing subsistence, maintenance, and leisure activities to facilitate a comparative analysis between perceived accessibility benefits of dockless bike-sharing among different categories of activity participation. The fifteen activities were aggregated into the following categories based on their functions and according to Wang and Cao (2017):

- Subsistence activities: work or study
- Maintenance activities: visiting the doctor, post office, pharmacy, bank, corner shop, supermarket, restaurant, snack bar (Cronbach's $\alpha = 0.881$)
- Leisure activities: visiting friends and relatives, public sport facility, library, museum, pub, shopping mall (Cronbach's $\alpha = 0.810$)

Therefore, four models were developed using the same sample: one for perceived accessibility to all activities and the other three for subsistence, maintenance, and leisure activities individually.

Table 1
Derived factor groups—types of travel attitude.

Factor groups	Indicators	Loadings
Pro-car	• *I like driving*	*0.715*
	• *Without a car, I cannot handle my daily life*	*0.678*
	• *Owning a car allows me to do more*	*0.812*
	• *Owning a car gives me freedom*	*0.821*
	• *I do not have any alternative for car use*	*0.732*
	• *A car gives me prestige and status*	*0.618*
Pro-e-bikes or e-scooters	• *I like riding e-bikes*	*0.891*
	• *If possible, I would rather use e-bikes than take public transport*	*0.911*
	• *Riding e-bikes can sometimes be easier for me than other modes*	*0.906*
	• *I think that traveling by e-bike is safer than all other modes*	*0.805*
Pro-public transport	• *I like to use public transport*	*0.807*
	• *If possible, I would rather use public transport than driving*	*0.731*
	• *Public trans port can sometimes be easier for me than other modes*	*0.784*
	• *Public transport is unreliable*	*− 0.532*
	• *Traveling by public trans port is safer than other modes*	*0.456*
Pro-bicycles	• *I like cycling*	*0.834*
	• *If possible, I would rather cycle than take public transport*	*0.839*
	• *Cycling can sometimes be easier for me than other modes*	*0.843*
	• *I think that traveling by bicycle is safer than all other modes*	*0.726*
Pro-walking	• *I like walking*	*0.782*
	• *If possible, I would rather walk than take public transport*	*0.791*
	• *Walking can sometimes be easier for me than other modes*	*0.788*
	• *I think that traveling by foot is safer than all other modes*	*0.661*
Pro-environment or health	• *I am concerned about the environmental impacts of my daily travel*	*0.770*
	• *I am willing to change travel mode if it is good for the environment*	*0.795*
	• *I am concerned about the health impacts of my daily travel*	*0.691*
	• *The trip to/from work is a useful transition between home and work*	*0.537*
Anti-public transport	• *Transferring to other buses or metros is annoying*	*0.664*
	• *It bothers me that public transport is too crowded*	*0.846*
Anti-traveling	• *Travel time is generally wasted time*	*0.761*
	• *I prefer to organize my errands so that I make as few trips as possible*	*0.712*

Note. Adapted from "Exploring Dockless Bikeshare Usage: A Case Study of Beijing, China" by Z. Chen, D. van Lierop, and D. Ettema, D, 2020, *Sustainability, 12*, p. 1238.

4.1. Measurements

To investigate disparities between individuals in perceived accessibility that dockless bike-sharing provides to activities, we analyzed a set of individual attributes comprising individuals' sociodemographic characteristics, social environment, and travel attitude. Individuals' self-reported health came from a question where respondents were asked to rate their health on a five-point scale from "poor" to "excellent". The responses were then merged into three new categories — "poor and fair", "good", and "very good and excellent".

The social environment variable refers to the social norms and behavioral control that individuals experience regarding dockless bike-sharing usage. Five questions based on Ma and Dill (2015) asked participants to rank the following statements on a five-point scale from "strongly disagree" to "strongly agree": (1) Most people who are important to me, for example, my family and friends, think that I should use dockless shared bikes more; (2) Most people who are important to

Table 2
Variables in the regression models (N = 489).

Variables	Definitions	Mean (Std. Dev.)	No.	Pct.
Individual attributes				
Age (years)	17–30			61.10%
	31–45			33.60%
	46–61			5.30%
Gender	Female		249	50.90%
	Male		240	49.10%
Education	High school/Secondary technical school and below		18	3.70%
	University/College Bachelors' degree		355	72.60%
	Master's degree and above		116	23.70%
Household income	Low income (less than 12,000 yuan)		144	29.40%
	Median income (12000–20000 yuan)		187	38.20%
	High income (more than 20,000 yuan)		158	32.30%
Employment	Full-time employment		364	74.40%
	Part-time employment, students, etc.		125	25.60%
Living situation	Private purchase/Self-built		238	48.70%
	Employer-provided/ Student dormitory		97	19.80%
	Others		154	31.50%
Self-reported health	Poor and fair		172	35.20%
	Good		173	35.40%
	Very good and excellent		144	29.40%
Car ownership	No		130	26.60%
	Yes		359	73.40%
Social environment		3.83 (0.63)		
Travel attitude	Pro-car	0.00 (0.96)		
	Pro-e-bikes or e-scooters	0.02 (0.99)		
	Pro-public transport	0.07 (0.98)		
	Pro-bicycles	0.20 (0.87)		
	Pro-walking	−0.02 (0.99)		
	Pro-environment or health	0.02 (0.99)		
	Anti-public transport	0.03 (0.95)		
	Anti-traveling	−0.02 (0.98)		
Neighborhood-related attributes				
Spatial location of home address	Outside the 4th ring road		266	54.40%
	Within the 4th ring road		223	45.60%
Cycle paths ratio		0.24 (0.17)		
Easy access to dockless bike-sharing systems	Not at all true		24	4.90%
	Somewhat true		94	19.20%
	Mostly true		182	37.20%
	Entirely true		189	38.70%
Easy access to bus stops and metro stations	Not at all true		9	1.80%
	Somewhat true		59	12.10%
	Mostly true		223	45.60%
	Entirely true		198	40.50%
Neighborhood satisfaction	Very unsatisfied		3	0.60%
	Unsatisfied		30	6.10%
	Neutral		206	42.10%
	Satisfied		223	45.60%
	Very satisfied		27	5.50%
	Strongly disagree		16	3.30%
	Disagree		17	3.50%

(*continued on next page*)

Table 2 (*continued*)

Variables	Definitions	Mean (Std. Dev.)	No.	Pct.
Dockless bikeshare helps easily access metro or bus	A bit disagree		9	1.80%
	Neutral		57	11.70%
	A bit agree		74	15.10%
	Agree		150	30.70%
	Strongly agree		166	33.90%

me would support me in using dockless shared bikes more; (3) The people who I live with ride dockless shared bikes to get to places, such as errands, shopping and work/school; (4) Many of my friends ride dockless shared bikes to get to places, such as errands, shopping and work/school; and (5) Many of my coworkers/classmates ride dockless shared bikes to get to work/school. Social environment was measured as the average score for the above questions.

Individuals' travel attitudes were obtained through survey responses to a series of statements related to attitudes towards various travel modes. The respondents indicated their extent of agreement with these statements using a five-point scale from "strongly disagree" to "strongly agree". We used a previously established factor analysis that we derived from the same dataset (for details see: Chen et al. (2020b)). A principal component analysis with varimax rotation determined that these responses could be expressed by eight significant latent factors extracted from the 31 observed variables (see Table 1). We considered factor loadings greater than $\pm$ 0.40 to be more important and acceptable in our analysis (Peterson, 2000). The derived eight factors explained 64.8% of the total variance of the responses, and Cronbach's α (α > 0.7) for each factor indicated an internal consistency among the indicators. The eight subscales of individuals' travel attitudes were then used in further OLS regression modeling.

Two distinct components of neighborhood-related attributes were explored. First, the objectively captured attributes, spatial location of home and street connectivity, were derived using the Geographic Information System (GIS) based on respondents' self-reported home location. The spatial location of home was classified into two categories: respondents' home location within and outside the fourth ring road. The measured indicator for street connectivity was the cycle paths ratio: the percentage of the total length of bicycle paths to the total length of all roads within the neighborhood. Considering the criteria that require an average distance of 500–600 m between bus stops in Beijing (Beijing Municipal Administration of Quality and Technology Supervision, 2018), we chose the area within a 600-m radius of the respondents' reported home location as the living neighborhood.

The second component consisted of subjective attributes that are related to individuals' perceptions of having access to dockless bike-sharing, having access to bus stops or metro stations, neighborhood satisfaction and the potential integration between dockless bike-sharing and public transit. The accessibility to dockless bike-sharing as well as to bus stops or metro stations were measured by asking the respondents to what extent they consider "having easy access to dockless bike-sharing systems" and "having easy access to bus stops or metro stations", respectively, to be applicable to their living neighborhoods; responses were indicated on a four-point scale from "not at all true" to "entirely true". The variable neighborhood satisfaction was drawn from the following question: "How satisfied are you with the neighborhood you live in?", which was answered on a five-point scale from "very unsatisfied" to "very satisfied". The variable connection between dockless bike-sharing and public transit was assessed by the respondents' extent of agreement with the statement that dockless bike-sharing systems have made it easier to access the metros and buses; responses were indicated on a seven-point scale from "strongly disagree" to "strongly agree".

5. Results

The analysis of these four OLS regressions provides information from two perspectives. First, the results indicated which individual or neighborhood attributes were significantly associated with the perceived accessibility benefits of dockless bike-sharing. Second, they compared the perceived accessibility impacts of dockless bike-sharing, as well as the relevant influential factors, between three categories of activities.

5.1. Descriptive results

The means, standard deviations and group sizes for the explanatory variables used in the modeling are presented in Table 2. The entire sample comprised 489 dockless bike-sharing users aged 17 to 61 years with a balanced gender distribution. Individuals aged between 17 and 30 were the main contributors to the research sample. This sample included a wide variety of full-time employees, part-time employees, students, retirees, and homemakers. However, the majority of the respondents were full-time employees and owned at least one car in their household. This study oversampled people with at least a Bachelors' degree, which can be in part explained by a higher engagement of higher educated individuals in adopting dockless bike-sharing systems (Du & Cheng, 2018). This was not a disadvantaged sample, as it includes both income-advantaged and disadvantaged participants, and individuals with low, median, and high household incomes were captured in relatively equal proportions.

Regarding the neighborhood context, the research sample involved individuals living both in central areas and areas outside the fourth ring road. One-third of the respondents indicated that dockless bike-sharing systems were easily available in their neighborhoods. Generally, respondents displayed a neutral or positive attitude towards their neighborhoods, and most users agreed that dockless bike-sharing systems have helped them access metros and buses.

Furthermore, a descriptive analysis was conducted on four dependent variables, dockless bike-sharing users' perceived accessibility that dockless bike-sharing provides to activities overall as well as to activities in three different categories—subsistence, maintenance, and leisure activities (see Table 3). It seems that in general, users tended to show a positive attitude and agree (Mean = 4.91 > midpoint = 4) that dockless bike-sharing has somewhat played a role in helping them access activities. Among the three categories of activities, subsistence activities scored highest, which suggested that from the dockless bike-sharing users' perspectives, they were likely to benefit most from using dockless bike-sharing systems for their commuting trips. The availability of dockless bike-sharing systems provides individuals with increased flexibility to choose an accessible and even a preferable travel mode to complete trips for subsistence activities. However, as maintenance or leisure activities often follow a more flexible time and route pattern, individuals often have more choices to engage in these trips. Therefore, the availability of dockless bike-sharing might not contribute as much to the improvement of perceived accessibility to maintenance or leisure activities compared to subsistence activities. Table 4 displays the correlation between dependent variables regarding the three categories of activities. In comparison to subsistence activities, the perceived accessibility impacts of dockless bike-sharing to maintenance and leisure

Table 3
The improvement in perceived accessibility to activities that dockless bike-sharing provides (N = 489).

Dependent variables	Mean	Median	Std. Dev.	Min	Max
All activities	4.91	5.00	1.04	1	7
Subsistence activities	5.21	6.00	1.70	1	7
Maintenance activities	5.00	5.12	1.14	1	7
Leisure activities	4.74	4.83	1.09	1	7

Table 4
Correlations of the perceived accessibility impacts of dockless bike-sharing between different categories of activities.

		Subsistence activities	Maintenance activities	Leisure activities
Subsistence activities	Pearson Correlation	1		
	Sig. (2-tailed)			
Maintenance activities	Pearson Correlation	**0.487**	1	
	Sig. (2-tailed)	0.000		
Leisure activities	Pearson Correlation	**0.507**	**0.723**	1
	Sig. (2-tailed)	0.000	0.000	

activities had a significantly higher correlation (Pearson correlation = 0.723), which may be explained by the similar requirement for more flexible travel patterns for these activities compared to commuting.

5.2. OLS regression results

Table 5 illustrates the results of the four regression models assessing the role dockless bike-sharing plays in users' perceived accessibility to activities. All four models were statistically significant. The individual attributes and neighborhood-related attributes overall accounted for 47% of the variance in the positive impact that dockless bike-sharing had on perceived accessibility to all activities, suggesting a good fit for the data. For models of the perceived accessibility to subsistence, maintenance, and leisure activities, these explanatory variables helped explain 21.2%, 44.2% and 34.7% of the variance, respectively.

5.2.1. Individual and neighborhood factors associated with perceived accessibility to all activities

Generally, individuals' sociodemographic characteristics were not significantly associated with their perceived accessibility to different activities provided by dockless bike-sharing. An exception was for gender; males tended to score higher on the perceptions that dockless bike-sharing positively impacts their accessibility to all activities compared to females. This could be related to safety concerns, as female cyclists tend to be more risk averse than male cyclists (Emond et al., 2009). In addition, females tended to be burdened to allocate time

Table 5
Regression analysis of impacts of dockless bike-sharing on perceived accessibility.

	All activities		Subsistence activities		Maintenance activities		Leisure activities	
	Coef.	Std. Error	Coef.	Std. Error	Coef.	Std. Error	Coef.	Std. Error
Intercept	0.589	0.437	−0.213	0.874	0.477	0.493	**0.872 .**	**0.511**
Individual attributes								
Age	0.005	0.005	0.004	0.010	0.008	0.006	0.001	0.006
Male (Ref. = female)	**0.223****	**0.071**	0.197	0.141	**0.210****	**0.080**	**0.245****	**0.083**
Education (Ref. = high school equivalent and below)								
University/college Bachelors' degree	0.066	0.190	−0.005	0.380	0.027	0.215	0.131	0.222
Masters' degree and above	0.008	0.202	−0.147	0.404	−0.049	0.228	0.111	0.236
Household income (Ref. = low income)								
Median income	−0.033	0.091	0.078	0.182	−0.037	0.103	−0.046	0.107
High income	−0.138	0.099	0.015	0.197	−0.157	0.111	−0.138	0.115
Employment (Ref. = part-time employment, students, etc.)								
Full-time employment	0.013	0.111	0.091	0.222	0.026	0.125	−0.019	0.130
Living situation (Ref. = private purchase/self-built)								
Employer provided/student dormitory	−0.053	0.131	0.325	0.262	−0.162	0.148	0.031	0.153
Other	0.027	0.086	0.175	0.171	0.001	0.097	0.037	0.100
Self-reported health (Ref. = poor and fair)								
Good	−0.023	0.085	−0.017	0.171	−0.015	0.096	−0.035	0.100
Very good and exellent	0.073	0.092	0.232	0.183	0.099	0.104	0.011	0.107
Car ownership (Yes)	0.126	0.087	0.180	0.174	0.159	0.098	0.073	0.102
Social environment	**0.492****	**0.068**	**0.721****	**0.137**	**0.495****	**0.077**	**0.451****	**0.080**
Pro-car attitude	0.021	0.039	−0.110	0.079	0.042	0.044	0.016	0.046
Pro-e-bike/e-scooter attitude	**0.109****	**0.036**	**0.118 .**	**0.071**	**0.098***	**0.040**	**0.121****	**0.042**
Pro-public transport attitude	0.018	0.038	−0.048	0.077	0.008	0.043	0.042	0.045
Pro-bicycle attitude	**0.102***	**0.046**	0.108	0.092	0.073	0.052	**0.141****	**0.054**
Pro-walking attitude	−0.038	0.036	−0.102	0.071	**−0.072 .**	**0.040**	0.018	0.042
Pro-environment/health attitude	**0.074***	**0.037**	0.089	0.074	0.046	0.042	**0.108***	**0.044**
Anti-public transport attitude	−0.044	0.037	−0.021	0.074	−0.019	0.042	**−0.081 .**	**0.043**
Anti-traveling attitude	**−0.065 .**	**0.037**	−0.055	0.073	−0.055	0.041	**−0.080 .**	**0.043**
Neighborhood-related attributes								
Spatial location of home (Within the 4th ring road)	0.063	0.073	−0.001	0.146	0.073	0.082	0.060	0.085
Cycle path ratio	−0.069	0.210	**0.906***	**0.420**	−0.168	0.237	−0.099	0.246
Easy access to dockless bike-sharing systems	**0.077 .**	**0.046**	0.027	0.093	**0.119***	**0.052**	0.030	0.054
Easy access to bus stops and metro stations	**−0.129***	**0.055**	−0.085	0.111	**−0.145***	**0.063**	**−0.115 .**	**0.065**
Neighborhood satisfaction	**0.162****	**0.051**	0.079	0.102	**0.117***	**0.058**	**0.237****	**0.060**
Dockless bike-sharing helps easily access metro or bus	**0.295****	**0.024**	**0.310****	**0.047**	**0.339****	**0.027**	**0.234****	**0.028**
Model estimation								
Observations	489		489		489		489	
R^2	0.499		0.255		0.473		0.383	
Adjusted R^2	0.470		0.212		0.442		0.347	
Residual Std. Error (df = 461)	0.755		1.508		0.851		0.882	
F Statistic (df = 27; 461)	**17.006****		**5.849****		**15.305****		**10.619****	

" **.** " Significant at 0.1; "*" Significant at 0.05; "**" Significant at 0.01.

between working, household chores, and childcare, which can be difficult to accomplish with dockless bike-sharing use. Our study found no significant influence of education level or employment. This may be due to a self-selection effect that dockless bike-sharing users are more likely to consist of full-time employees and higher educated individuals (Du & Cheng, 2018; Fishman et al., 2014). Nonetheless, while our study included users with various ranges of household income, no significant income disparity was found in users' perceptions that dockless bike-sharing positively impacts their accessibility to all activities.

Alternatively, the users' social environments were strongly significant and positively related to the benefits that dockless bike-sharing exerts on their perceived accessibility to activities. An increase of one unit in the score that the users rate their social environment was associated with an increase of 0.492 (scores ranging from 1 to 7) in their score for the perceived accessibility to activities that dockless bike-sharing provides. Having a more positive attitude towards e-bikes/e-scooters or bicycles was associated with higher perceived accessibility to all activities that was provided by dockless bike-sharing. Consistent with environmentally sustainable and active travel promotion initiatives, users who were more aware of the environmental and health benefits of travel tended to have a higher perception of the benefits that dockless bike-sharing provides in accessing all activities.

Two types of neighborhood-related attributes were explored. Neither of the objective attributes—home address located within or outside the 4th ring and the cycle path ratio in the home neighborhood—were found to have a significant association with the perceived accessibility that dockless bike-sharing provides to all activities. On the other hand, the subjective attributes tended to play a part. People's perception of their neighborhoods as easily accessible to dockless bike-sharing or not was slightly significant ($P < 0.10$) and positively correlated with the perceived accessibility to all activities. This weak significant association could be due to the nuance among the three different categories of activities, as the attribute "easy access to dockless bike-sharing systems" showed a significantly positive association only with the perceived benefits on accessing maintenance activities. In contrast, a significant and negative association between the extent to which people think they can easily assess metro stations or bus stops and the positive impact that dockless bike-sharing provides on perceived accessibility to all activities was revealed. One hypothesized explanation is that when dockless bike-sharing users perceive their neighborhood to have easily accessible bus stops or metro stations, they may rely less on dockless bike-sharing systems and more often walk to get to the bus stops or metro stations. Additionally, individuals residing in neighborhoods with high quality and frequent transit service within walking distance to their home locations likely consider themselves to have more alternatives to dockless shared bikes to complete the whole journey when accessing different activities.

Another subjective attribute that displayed a strongly significant and positive relationship with the impacts of dockless bike-sharing on users' perceived accessibility to all activities is the overall satisfaction of the users with their neighborhood. Since this analysis was cross-sectional, it is difficult to know the actual direction of the association – whether the neighborhood itself is satisfying enough so that people enjoy higher perceived accessibility benefits from dockless bike-sharing, or whether the users are satisfied with the neighborhood because dockless bike-sharing has helped them participate in activities that would otherwise not be easily accessible.

The connection between dockless bike-sharing and public transit variable was strongly significant in all four models. Table 5 shows that the positive correlation coefficients for the impacts of dockless bike-sharing on perceived accessibility to subsistence, maintenance and leisure activities were relatively consistent. In other words, users who tended to agree that dockless bike-sharing systems help them access bus stops and metro stations perceived a higher benefit of dockless bike-sharing to access various types of activities. This finding suggests that the existence of multimodal travel behavior involving dockless bike-sharing and public transit in trips can facilitate dockless bike-sharing users in accessing subsistence, maintenance, and leisure activities.

5.2.2. Disparity in perceived accessibility across subsistence, maintenance, and leisure activities

Since there were similarities to the results presented in the model for all activities, the presentation of the results for models on subsistence, maintenance and leisure activities will focus on the differences. The modeling results for subsistence activities differed considerably from the results for maintenance and leisure activities. Compared with maintenance and leisure activities, travel for subsistence activities tends to be more time-pressed and have a routine pattern. Among individual attributes, only the social environment showed a strong positive correlation with the impacts of dockless bike-sharing in improving perceived accessibility to subsistence activities. The cycle path ratio appeared to display a significantly positive correlation. High cycle path ratios indicate a domination of bicycle roads and a low percentage of motorways in the neighborhoods. This means that a higher total length of bicycle roads in the users' living neighborhood itself is not necessarily associated with higher perceived benefits of dockless bike-sharing on accessing subsistence activities. Only users living in a neighborhood dominated by bicycle roads perceived higher benefits of dockless bike-sharing on subsistence activities than those living in a neighborhood dominated by motorways. A possible explanation could be that travel for subsistence activities tends to concentrate in the morning or evening peaks where the crowding of all transport modes and travelers occurs. Therefore, neighborhoods with relatively more bicycle paths may be more pleasant and safer for cyclists during peak hours.

The results of the models for maintenance and leisure activities tended to have more similarities, partly due to a higher correlation on the benefits of dockless bike-sharing on perceived accessibility to maintenance and leisure activities, as presented in Table 4. However, important differences also exist. Placing a high value on the environment/health benefit of travel was associated with higher benefits of dockless bike-sharing on perceived accessibility to leisure activities but not perceived accessibility to maintenance activities. This could be because the leisure activities consist of more sport- or lifestyle-related activities. In addition, as mentioned above, the extent to which people believe they can easily access dockless bike-sharing showed a significantly positive association only with perceived accessibility to maintenance activities.

6. Conclusion and discussion

Using survey data collected among residents in Beijing, this study assessed the role dockless bike-sharing plays in users' perceived accessibility. The results of our study showed that users generally agreed that dockless bike-sharing systems have played a positive role in assisting them to access activities, as evidence suggested that the availability of a new transport mode increases individuals' access to essential daily activities (e.g., Crane et al., 2017; Panter et al., 2016). By segmenting the individuals' activity participation into three categories: subsistence, maintenance, and leisure activities, our research demonstrated that dockless bike-sharing users benefited most in their commuting trips and to a lesser degree in attending maintenance and leisure activities such as going to supermarkets, visiting friends and relatives, and visiting public sport facilities. This finding echoes what Panter et al. (2016) suggested: the provision of new sustainable transport infrastructure effectively increases active commuting while showing no benefits in recreational activities.

Our research contributes to the relatively small number of empirical studies on perceived accessibility evaluations. Instead of evaluating accessibility as a binary indicator, we rated participants' perceptions of the ease of reaching a list of different activities; therefore, for each activity, every individual had a corresponding perceived accessibility level. In addition, previous studies investigating accessibility to activities generally treated various activities as a homogenous group (e.g., Currie and Delbosc, 2010; Delbosc and Currie, 2011; Stanley et al., 2011). Our findings on different interventions and the variance in perceived benefits from dockless bike-sharing across activity categories suggested that it is important to at least separate subsistence activities from other utility-oriented or leisure activities in accessibility research. In the case of dockless bike-sharing, the availability and usage of dockless shared bikes for work or education activities often only meant that an individual has access to an additional modal option. Compared to utility-oriented or leisure activities, individuals tend to be more committed to engaging in subsistence activities. This is because, even when dockless bike-sharing systems are unavailable, these subsistence activities are completed with the help of other transport modes. Nonetheless, for utility-oriented or leisure activities, the benefits of a new transport service are not only associated with an additional modal choice but also produce new activity opportunities for social interactions.

The analysis of dockless bike-sharing users in Beijing confirmed the existence of a gender disparity, such that male users reported enjoying more benefits in accessing activities. However, the results suggested no significant association with other sociodemographic characteristics, including education level, household income, employment status and car ownership. These results differ from some studies in the American context, which suggested that socially advantaged groups (such as those with higher income or with a car) tend to enjoy more accessibility-related benefits from having access to transport systems (Cervero, 2004; Paez et al., 2009). In addition, our research found that the social support that users received from their families and friends to use dockless bike-sharing systems had a strong significant impact on promoting dockless bike-sharing users' perceived accessibility benefits. We conducted four additional regression analyses that excluded attitudinal variables from the independent variables to better understand the importance of dockless bike-sharing users' sociodemographic characteristics and travel attitudes in the contribution of perceived accessibility benefits from dockless bike-sharing systems. The results related to the impacts of individuals' sociodemographics and neighborhood-related attributes on perceived accessibility did not change much from the original models. It likely suggests that dockless bike-sharing systems can equally benefit individuals of different education levels, household incomes, employment statuses and car ownership, with regard to their perceived accessibility to different types of activities. We also confirmed that individuals' positive attitude towards e-bikes/scooters and bicycles and positive attitude towards environmental and health impacts of travel played an encouraging role in the perceived accessibility impacts of dockless bike-sharing. This paper adds to the empirical support for the important role individuals' attitudes towards transport systems and social environments play in individuals' perceived accessibility (Lättman et al., 2018; Van Acker et al., 2010).

Compared to individuals' sociodemographic characteristics, neighborhood-related attributes were of higher importance in dockless bike-sharing users' perceived accessibility. However, neighborhood-related attributes intervened in users' benefits from dockless bike-sharing in their perceived accessibility to activities in different ways. Accessing subsistence activities was more influenced by cycling infrastructure. However, for access to maintenance and leisure activities, the individuals' satisfaction with their living neighborhood and the perceived ease of gaining access to dockless bike-sharing systems, buses, and metros in their neighborhoods were of higher importance than cycling paths. The difference in the ways that neighborhood-related attributes influence people's perceived benefits of dockless bike-sharing on accessibility between subsistence activities and maintenance and leisure activities again suggests the necessity to separate the discussion of subsistence activities. The positive association between the perceived easy access to dockless bike-sharing and the benefits of dockless bike-sharing in users' perceived accessibility to some vital activities confirmed that it is of social significance to consider individuals' access to dockless bike-sharing when assessing transport equity (Spinney & Lin, 2018).

With regard to the limitations of this study, we were restricted by the data available; for example, other objective spatial attributes, such as population density, land-use mix, and neighborhood greenery, were not examined. Future studies could test whether these spatial variables provide additional explanations. Another limitation is that our sample was not representative of disadvantaged groups; it was skewed toward higher educated people, likely due to the self-selection effect. Future studies could consider better engaging users with lower levels of formal education. Third, in our study, we treated the bus and metro modes homogenously as public transit when investigating the role of having access to public transit and the integration of dockless bike-sharing and public transit. Future studies could test bus and metro modes separately, as their interaction with dockless bike-sharing may be different. Fourth, given the data available, we had limited information about trip details, such as the travel distance and other connecting modes, and whether the trip involved multiple modes. More detailed trip information could be collected in future surveys to help explain the heterogeneity of the associations between activity groups.

In addition to the environmental and health benefits, our study revealed the benefits of dockless bike-sharing on improving individuals' perceived accessibility. The improved perceived accessibility can be beneficial for residents, as the perceived ease of accessing activities may stimulate more activity participation, creating opportunities for social interaction, thus having the potential to improve the quality of life (Parkhurst & Meek, 2014). Policy makers could account for the perceived accessibility benefits in determining the trade-off of promoting or restricting the adoption of dockless bike-sharing systems due to their regulation difficulties. Our paper highlighted that dockless bike-sharing users' perceived benefits in accessing activities largely rely on their social support and attitudes. Local authorities could initiate public awareness programs to educate individuals about the importance of positive social support and to promote positive attitudes towards active travel from the perspectives of health and environmental benefits. In addition, policies should consider promoting the integration between dockless bike-sharing and public transit and providing adequate cycling paths in residential neighborhoods to increase dockless bike-sharing cyclists' comfort and safety.

CRediT authorship contribution statement

Zheyan Chen: Conceptualization, Data curation, Formal analysis, Funding acquisition, Investigation, Methodology, Software, Visualization, Writing – original draft, Writing – review & editing. **Dea van Lierop:** Conceptualization, Methodology, Supervision, Writing – review & editing. **Dick Ettema:** Conceptualization, Methodology, Supervision, Writing – review & editing, Project administration.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Acknowledgements

We would like to thank the China Scholarship Council for providing the scholarship. The authors greatly acknowledge the anonymous reviewers for their valuable comments on earlier drafts of this paper. Thanks also to the respondents for their time to fill in the survey.

Funding

This work was supported in part by grants from the China Scholarship Council grant numbers 201707720038

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