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Effects of new mobile bicycle-sharing programs on cycling: a retrospective study in Shanghai

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Abstract

Objectives To examine 1) the effect of new mobile bicycle-sharing programs on change in travel mode and 2) the correlates of change in travel mode.

Design A retrospective natural experimental study

Setting 12 neighborhoods in Shanghai.

Participants 1265 respondents were recruited for a retrospective study in May 2017.

Main outcome measures Prevalence of cycling. Determination of association between sociodemographic characteristics, social norms, and travel mode before and after the advent of the new mobile bicycle-sharing programs as well as perceived bikeability of the environment.

Results The proportion of participants cycling for transport increased from 33.3% prior to the launch of the bicycle-sharing programs to 48.3% one year after the launch (p<0.001). Among those reporting no cycling before the launch, participants aged 30 to 49 years (OR=2.28 (95% CI 1.30-4.00)) compared with those aged 50+) and participants who lived within the inner ring (OR=2.27 (95% CI 1.22-4.26) compared with those between the inner and middle ring) were more likely to adopt cycling for transport. Dedicated bicycle lanes (OR=1.37, 95% CI 1.12-1.68) and perceiving riding shared bicycles as fashionable (OR=1.46, 95% CI 1.21-1.76) were positively and access to a public transportation stop/station (OR=0.82, 95% CI 0.67-0.99) inversely correlated with adopting cycling for transport.

Conclusions Mobile bicycle-sharing may promote bicycle use in a metropolitan setting. Findings from this study also highlight the importance of built environments and cultural norms as moderators of the uptake of mobile bicycle-sharing.

Keywords: bicycle-sharing; cycling; travel mode; active travel; built environment; social norms

Introduction

Regular physical activity (PA) reduces the risk of major chronic diseases and premature mortality.[1] However, around the world large proportions of the population are not sufficiently active or completely inactive which has significant health and economic consequences.[2-5] Active transportation by cycling has the potential to contribute considerably to overall activity levels of adults and is associated with significant health benefits.[6-11] Moreover, greater use of bicycles for day-to-day travel provides wider benefits, including reductions in carbon emissions, air pollution, and traffic congestio.[10,12] In Chinese cities, cycling was once a conventional mode of travel for most people, to the point that the country was once referred to as the "Kingdom of Bicycles".[12] However, since the turn of the century, Chinese cities have become increasingly cycling-unfriendly due to increasing car ownership and car-oriented urban planning policies such as the conversion of non-motorized to motorized lanes and banning non-motorized vehicles from arterial roads in some cities.[13] With the economic development and booming car industry, between 2002 and 2010-2012, the proportion of people using motorized transport increased from 33.5% to 61.9%, while the proportion traveling by bicycle and walking decreased from 35.8% and 30.7% to 15.6% and 22.5%, respectively.[14]

As a strategy for promoting cycling and sustainable transportation overall, public bicycle-sharing programs (PBSP) have been introduced in many cities around the world to provide bicycles as a mode of transportation for relatively short trips and to bridge "the last mile" of public transport services.[15,16] These PBSPs usually have docking stations where users obtain and return the rental bikes.[17] Although some studies have shown that cycling has increased in some cities that are operating PBSPs, such as Washington DC, Dublin, Beijing and Hangzhou, China, there are still some common problems and challenges for conventional PBSPs, which may have limited their reach and usage at a population level, such as reliance on docking stations, inconvenience in payment and insufficient supply of shared bicycles.[15,18-20]

With the increasing popularity of smart phone payments, Global Positioning System (GPS) tracking and other technology, mobile bicycle-sharing provides opportunities for promoting active travel. Dock-less PBSPs utilize mobile-controlled wheel lock and GPS tracking, so that users can locate the nearest bicycle, unlock and lock the bicycle, and pay (usually, around 1RMB~0.15 USD per half hour) through a mobile app. Moreover, some of the shared bicycles (e.g., Mobike) have solid tires, which are durable and low-maintenance. Dock-less PBSPs are currently deployed in many cities in China such as Shanghai, Beijing, and Guangzhou.[21] As of May 2017, a total of 10 million mobile shared bicycles had been deployed in China, 1.5 million of which in Shanghai, which led the government to ban additional shared bicycles.[22,23] However, there has been limited evidence on the effectiveness of dock-less mobile bicycle-sharing systems in promoting travel mode change.[24] Further, the introduction of the bicycle-sharing scheme alone may not lead to population-level uptake, as individual behaviors may be influenced by various factors. In line with social-ecological models, previous research suggests that population-level cycling behavior is associated with a range of individual- and environmental-level characteristics, all of which have rarely been examined in evaluations of PBSPs.[25,26-28] An ecological framework can guide inquiry into a more comprehensive understanding of the factors that influence cycling behaviors in the context of PBSP.[25] Therefore, this study aims to 1) evaluate whether the introduction of mobile dock-less bicycle-sharing programs leads to more cycling, and 2) to examine correlates of initiation of cycling, including sociodemographic characteristics and perceived built and social environments.

MATERIALS AND METHODS

Patient and Public Involvement

Written informed consent statement forms about the development of the research question and outcome measures were obtained from participants. The right to withdraw, autonomy of responses and requirement of results were also explained. An intercept convenient sample survey of 12 community residents was conducted. This study received ethical approval from the ethics committee of School of Public Health of Fudan University, China (IRB00002408 & FWA0002399).

Design

A retrospective study was conducted in May 2017 where participants were asked to report travel modes after and retrospectively before the launch of city-wide mobile PBSPs.

Intervention

Mobile bicycle-sharing systems can be considered as a city-level intervention for travel mode. The system was officially launched in Shanghai in April 2016. By July 2017, there were more than 13 million registered users and more than 1 million mobile shared bicycles in Shanghai.[29] The development of mobile shared bicycles was so rapid in China that it limited the opportunities for prospective data collection or inclusion of a control city comparable to Shanghai, but without a bicycle-sharing system. Therefore, a retrospective study design was used.

Study areas and recruitment of participants

To explore the correlates of travel mode, a two-stage sampling method was employed. First, based on the Shanghai Transportation Map, the city was divided into four areas: within the inner ring, between the inner and middle rings, between the middle and outer rings, and beyond the outer ring. Then, three neighborhoods were selected in each of the four areas of Shanghai by purposive sampling. The selection criteria for neighborhoods were determined as follows: (1) within 1-2 km distance from the nearest subway station; (2) the number of residents within the neighborhood was more than 1,000. Within each selected neighborhood, trained interviewers conducted at least 100 self-administered intercept surveys in May 2017. The inclusion criteria for participants were (1) being 18-70 years old; (2) having lived in the selected neighborhood for more than 3 months; and (3) being physically capable of riding a bicycle. Altogether, 1265 respondents were sampled from 12 neighborhoods. After excluding 100 respondents with more than 20% missing data, 1165 respondents (92.1%) remained in the analysis.

Measurements

Travel mode

Travel mode before and after the advent of the mobile PBSPs was assessed by asking respondents two questions: (1) How did you travel most of the time before the advent of mobile PBSPs? (2) How have you been travelling most of the time after the advent of mobile PBSPs? Respondents selected one of the following options, including walking, cycling, by car, public transport (subway, bus, ferry, and shuttle bus), motorcycles/electric motorcycles, combined public transport with walking (>500m), combined public transport with cycling, do not travel (staying at home), and other. According to respondents' travel mode before and after the advent of mobile PBSPs, they were classified into cyclists and non-cyclists at both time points. Cyclists were defined as participants who traveled by bicycle or those who combined cycling and public transport most of the time.

Perceived bikeability

To date, only few instruments have been developed to measure perceived bicycle-friendliness of neighborhood environments and most of these were developed for the physical environments of Western countries.[30] A new scale for measuring Chinese neighborhood bikeability was developed based on existing instruments, literature reviews, field visits, and expert consultation. Specifically, we adopted five questions (i.e., distance to a public transportation stop/station, access to destinations, physical condition of bicycle lanes, maintenance of lanes, and vegetation/shades along the bicycle lanes) from the Chinese Walkable Environment Scale (CWES) for urban community residents.[31] Based on consultation with several Chinese local physical activity experts to discuss potential correlates and determinants of cycling, we added four questions to the survey, including the presence of dedicated bicycle lanes, and the degree to which traffic violations, traffic volume, and motorbikes/electric scooters impede cycling. Finally, this instrument was pilot-tested and adjusted prior to the survey. All bikeability variables were on a 5-point scale and the composite score was analyzed as a continuous variable. More details about the questions are provided in Appendix 1.

Social norms

Two survey items assessed social norms by the statements “Riding mobile shared bicycles is fashionable” and “Riding mobile shared bicycles represents low socioeconomic status”. Each item was rated on a 5-point scale, from 1 (strongly disagree) to 5 (strongly agree).

Demographic variables and other covariates

Self-reported sociodemographic variables included gender, age, education, personal monthly income, and marital status. Age was categorized as <30, 30-49, and ≥50 years. Educational attainment was categorized as ≤ junior high school, high school/technical secondary school, junior college, and university and higher. Monthly income was categorized as <¥2000, ¥2000-4999, ¥5000-9999, and ≧¥10000 (1 CNY=0.15 USD in May 2017). In addition, questions about motor vehicle and bicycle ownership and characteristics of the commute were asked, including the following: (1) what is the distance between your home and work/college/university, and (2) how long does it take you to go to work/college/university every day, both of which were converted to categorical variables.

Statistical analysis

McNemar’s test was used to examine the change in travel mode after the introduction of the mobile PBSPs. To explore the potential correlates of change in travel mode, we focused on the participants who did not cycle before the bicycle-sharing became available and classified them as those who (1) changed from not cycling to cycling, and (2) remained not cycling as their travel mode. More details can be found in the consort flow diagram (Figure 1). Because the data were hierarchical in nature (individuals clustered within neighborhoods), we explored multi-level modeling.

However, upon examination of the outcome variable, we decided against multi-level modeling because the intraclass correlation coefficient was merely 0.0645 and we only found a significant random effect in one out of 12 neighborhoods. Therefore, logistic regression was conducted to examine the association of socio-demographic variables, perceived bikeability, and social norms with change in cycling behavior. Sequential modeling was used with Model 1 including only sociodemographic variables, Model 2 including sociodemographic and bikeability variables, and Model 3 additionally including social norms. Statistical analysis was performed using Statistical Package for Social Sciences 20.0 (Chicago, SPSS, Inc.) and the significance level was set at 0.05.

RESULTS

The demographic characteristics of the study sample are reported in Table 1. The final sample consisted of 1,165 participants from 12 neighborhoods. Nearly 40% of the participants were 30 to 49 years old, and over 75% were married. More than 40% reported an income level between 2000 and 4999 RMB/month. Over 75% of the participants owned bicycles, while nearly half of the participants had motor vehicles. The average distance from work/college/university was 5.6 km, while the average commuting time was 26.6 minutes.

Table 1. Participant characteristics

Variable		n (%)
Gender	Male	587 (50.5)
	Female	575 (49.5)
Age, years	18-29	297 (25.5)
	30-49	460 (39.5)
	≥5035091	408 (35.0)
Education	Junior high school	289 (25.2)
	High school/technical secondary school	339 (29.5)
	Junior college	210 (18.3)
	University and above	310 (27.0)
Personal monthly income (RMB)	<2000	203 (17.5)
	2000-4999	504 (43.4)
	5000-9999	329 (28.3)
	>10000	125 (10.8)
Marital status	Married	891 (76.5)
	Unmarried/Divorced/Widowed	274 (23.5)
Area of residence	Within the inner ring	284 (24.4)
	Between the inner and middle rings	265 (22.7)
	Between the middle and outer rings	316 (27.1)
	Beyond the outer ring	300 (25.8)
Ownership of bicycle	Yes	879 (75.5)
	No	286 (24.5)
Ownership of motor vehicle	Yes	550 (47.2)
	No	615 (52.8)
Distance from work / college / university	<1.5km	282 (25.0)
	1.5-5km	432 (38.2)
	>5km	319 (28.2)
	Staying at home/ Not working	97 (8.6)
Commuting time (one way)	<15min	359 (31.8)
	15-30min	416 (36.8)
	>30min	257 (22.8)
	Staying at home / Not working	97 (8.6)

Change in travel mode

Before the launch of the mobile PBSPs, 33.3% of the participants cycled for transport which increased significantly to 48.3% after the launch (p<0.001). Among the participants who usually travelled by car/motorcycles/electric motorcycles, walking/walking combined with public transport, and public transport before the launch of the mobile PBSPs, there were 115 (28.4%), 50 (28.2%), and 28 (29.2%) participants who adopted cycling after the launch, respectively.

Correlates of initiating commuting cycling

As shown in Table 2, in Model 1, participants who were <30 and 30-49 years old had more than twice the odds of adopting commuting cycling than participants who were 50 and older. Participants who lived within the inner ring had more than twice the odds to adopt cycling compared with those who lived in the area between the inner and middle rings. Participants living more than 5km from work/college/university had more than twice the odds of initiating cycling compared with those living within 1.5km from work/college/university. In Model 2, presence of dedicated bicycle lanes was positively associated with adopting cycling. Model 3 showed that participants who owned motor vehicles were more likely to adopt cycling than those without motor vehicles. In Model 3, access to a public transportation stop/station was inversely associated with adopting cycling, and perceiving riding mobile shared bicycles as fashionable was positively correlated with adopting cycling. Meanwhile, the perception that riding mobile shared bicycles represents low socio-economic status was inversely correlated with adopting cycling.

Table 2. Predictors of adopting cycling

Demographic characteristics	Model 1 (n=645) OR (95% CI)	Model 2 (n=641) OR (95% CI)	Model 3 (n=641) OR (95% CI)
Gender			
Female (ref)	1.00	1.00	1.00
Male	0.81 (0.56-1.16)	0.73 (0.50-1.06)	0.75 (0.51-1.11)
Age (years)			
≥50 (ref)	1.00	1.00	1.00
30-49	2.26 (1.32-3.87)**	2.31(1.33-4.00)**	2.28(1.30-4.00)**
<30	2.23 (1.18-4.21)*	2.11 (1.10-4.07)*	1.92 (0.99-3.74)
Education			
University and above (ref)	1.00	1.00	1.00
Junior college	0.95 (0.57-1.59)	0.91 (0.53-1.54)	0.86 (0.50-1.48)
High school/ Technical secondary school	1.31 (0.79-2.17)	1.30 (0.77-2.18)	1.26 (0.74-2.13)
Junior high school	0.88 (0.45-1.72)	0.83 (0.42-1.66)	0.75 (0.38-1.52)
Marital status			
Unmarried/Divorced/ Widowed (ref)	1.00	1.00	1.00
Married	0.85 (0.53-1.37)	0.85 (0.52-1.39)	0.83 (0.50-1.37)
Personal monthly income (RMB)			
≧10000 (ref)	1.00	1.00	1.00
5000-9999	1.26(0.70-2.27)	1.25 (0.68-2.30)	1.29 (0.70-2.41)
2000-4999	1.45 (0.78-2.69)	1.39 (0.74-2.64)	1.43 (0.75-2.74)
<2000	0.94 (0.41-2.15)	0.86 (0.37-2.02)	1.01 (0.42-2.41)
Area			
Within the inner ring (ref)	1.00	1.00	1.00
Between the inner and middle ring	0.52 (0.29-0.93)*	0.45 (0.25-0.84)*	0.44 (0.24-0.82)**
Between the middle and outer ring	0.92 (0.56-1.51)	0.78 (0.46-1.31)	0.72 (0.43-1.23)
Beyond the outer ring	0.69 (0.42-1.15)	0.59 (0.33-1.05)	0.56 (0.31-1.01)
Ownership of motor vehicle			
No (ref)	1.00	1.00	1.00
Yes	1.37 (0.95-1.98)	1.45 (0.99-2.12)	1.53 (1.04-2.25)*
Ownership of bicycle			
No (ref)	1.00	1.00	1.00
Yes	0.85 (0.54-1.33)	0.84 (0.53-1.35)	0.92 (0.57-1.48)
Distance from work/college/university			
≤1.5km (ref)	1.00	1.00	1.00
1.5-5km	1.28 (0.73-2.24)	1.27 (0.71-2.27)	1.33 (0.73-2.39)

>5km	2.04 (1.07-3.90)*	2.22 (1.13-4.33)*	2.58 (1.30-5.12)**
Commuting time (one way)			
≤15min (ref)	1.00	1.00	1.00
15-30min	0.96 (0.57-1.61)	0.97 (0.57-1.65)	0.93 (0.54-1.60)
>30min	0.84 (0.45-1.58)	0.91 (0.48-1.73)	0.83 (0.43-1.62)
Perceived bikeability			
Presence of dedicated bicycle lane		1.38 (1.12-1.68)**	1.37 (1.12-1.68)**
Access to a public transportation stop/station		0.83 (0.68-1.01)	0.82 (0.67-0.99)*
Access to destinations		0.85 (0.66-1.10)	0.81 (0.63-1.06)
Physical condition of bicycle lanes		1.19 (0.89-1.59)	1.15 (0.85-1.54)
Maintenance of lanes		0.81 (0.60-1.08)	0.82 (0.61-1.11)
Vegetation/shades along the bicycle lanes		1.29 (0.97-1.71)	1.23 (0.91,1.65)
Traffic violation as a barrier		1.01 (0.79-1.29)	1.01 (0.79-1.29)
Traffic volume as a barrier		1.14 (0.87-1.49)	1.18 (0.90-1.56)
Motor bikes/electronic scooters as barriers		0.99 (0.76-1.29)	0.96 (0.74-1.26)
Social norms			
Riding mobile shared bicycles perceived as fashionable			1.46 (1.21-1.76)**
Riding mobile shared bicycles represents low socioeconomic status			0.91 (0.76-1.08)

Model 1 included only demographic variables. Model 2 included perceived environmental and demographic variables. Model 3 included all variables. *p<0.05, **p<0.01

DISCUSSION

Over the last 30 years, China has witnessed rapid economic development and a booming car industry and consequentially, a dramatic decrease in cycling.[12-14] This is the first community-based study to evaluate the effect of new dock-less mobile PBSPs on cycling for transport. We found that the proportion of participants that cycled for transport increased significantly from 33.3% to 48.3% after the advent of mobile PBSPs.

Nearly 30% of the participants who usually travelled by car/motorcycles/electric motorcycles adopted cycling after the launch. In comparison, a study that evaluated conventional PBSPs with docking stations showed that in Beijing, Shanghai and Hangzhou, 5.2%, 0.46% and 4% of car trips were replaced by bicycle.[32] Studies about PBSPs with docking stations in Barcelona, London, Montreal and Washington, DC have all reported low transfer rates from car journeys to shared bicycles.[18,33] It appears that dock-less mobile PBSPs might have the potential to be more effective and to have a wider reach in promoting cycling than conventional PBSPs.[20,34] However, it is important to take into account that the effect sizes are not comparable because our study used individual-level data and previous evaluations used trip-level data. We offer several potential explanations for the potentially more effective dock-less mobile PBSPs as follows. Firstly, the large number of bicycles in circulation and the GPS positioning function allow for better access to bicycles. Secondly, conventional PBSPs in China require local "HuKou" (a permanent residency system unique to China) and are therefore not available to visitors and temporary residents. Instead, mobile PBSPs are available to all who have registered an account online. Thirdly, a fully dockless system makes it convenient for users to pick up and drop off bicycles. Lastly, mobile payment is instantaneous and convenient. However, it is important to note that a prerequisite for successful mobile PBSPs is the ubiquity of mobile payment, as is the case in China.[35]

Based on our preliminary evidence, one may conclude that mobile PBSPs have great potential for cycling promotion in China. Perhaps a key ingredient for the success of mobile PBSPs in Shanghai is China's history of cycling as a social norm.[36] Another reason for the success of mobile PBSPs is that they have been created and promoted by the private sector which has vested interest in the wide adoption of shared bicycles.

Business competition stimulates continuous development and improvement of bicycle-sharing technology and promoting of cycling at the population level.[37]

We further explored the correlates of adopting commuting cycling in the context of the new mobile PBSPs. We found that younger participants were more likely to adopt cycling, which is consistent with previous studies.[38-40] We found that gender and education were not related to adopting cycling, which was consistent with a study conducted in Beijing, but different to results from other studies from the United States, Spain, and UK which found that males and those with higher education were more likely to cycle.[27,39-41] Previous evidence on the associations between income and cycling was mixed, and our findings suggested that there was no association between income and change in travel mode.[26,27,39,42] It is noteworthy that we found positive associations of commuting distance and car ownership with adopting cycling, which is counter-intuitive and different from previous findings.[39-41,43] A potential explanation is that those who lived within walking distance (<1.5 km) to work/college/university may not own a car or consider cycling, so bicycle-sharing was most likely to affect those who lived relatively far away from work/college/university and previously traveled by car because they could not easily access public transportation stops/stations without shared bicycles.

Among the perceived bikeability of the environment, presence of dedicated bicycle lanes were positively associated with change in travel mode which is in line with several other studies, including some from Beijing.[26,39,43-47] Among them, a study in India suggested that dedicated bicycle lanes were the most important attribute of bicycle infrastructure.[45] A study from Beijing found that the perception that bicycle lanes have gradually been taken over by motorized vehicles is a key deterrent for people to switch to cycling.[39] On the other hand, consistent with other studies, we found an inverse association between access to a public transportation stop/station and adopting cycling.[28,40,47] Unlike some previous studies, we did not find an association between other aspects of the bikeability of the environment, such as traffic safety and aesthetics, with adopting cycling.[26,38,41,43,44]

Another finding from our study is that about social norms. Although previous studies have found effects of attitudes towards cycling and other modes of transportation on mode choice, our study examined effects of both positive and negative attitudes toward cycling.[48-51] Our data showed that the perception that riding mobile shared bicycles is fashionable was positively correlated with adopting cycling while considering riding mobile shared bicycles representing low income was inversely correlated with switching to cycling. This finding highlights that promoting positive social norms may be critical to increasing cycling at the population level.

Limitations

There are some limitations to this study. First, all measures were based on self-reports, however, the measures have been validated [31]. Second, this study applied a retrospective design, due to practical reasons outlined earlier. This limits causal inference from the current study. Third, because we did not collect total physical activity levels at two time points, we could not determine whether those who have adopted cycling have become more physically active overall. Therefore, our study could not verify whether the significant change from inactive transport modes to cycling has increased physical activity at the population level.

CONCLUSION

We found that mobile bicycle-sharing can be effective in increasing bicycle use and might have the potential to be scaled up internationally. To maximize the impact of mobile PBSPs at the population level, improvement to attributes of the built environments, such as dedicated bicycle lanes, and promoting positive social norms about cycling should be considered.

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Contributors

YJ and HF conceived the idea, analyzed the data and drafted the paper. DD, KG, LC, SZ, and ZM contributed to the writing and assisted with the analysis and interpretation. YJ, LC, SZ, and ZM contributed to collect data. All authors have read and approved the final manuscript.

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Competing interests

The authors declare that they have no competing interests.

Abbreviations

PA: Physical activity; PBSP: Public bicycle-sharing program; GPS: Global Positioning System; CWES: Chinese Walkable Environment Scale; SPSS: Statistical Package for Social Sciences.

Availability of data and material

Please contact authors for data requests.

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Figure 1. Consort flow diagram for analysis

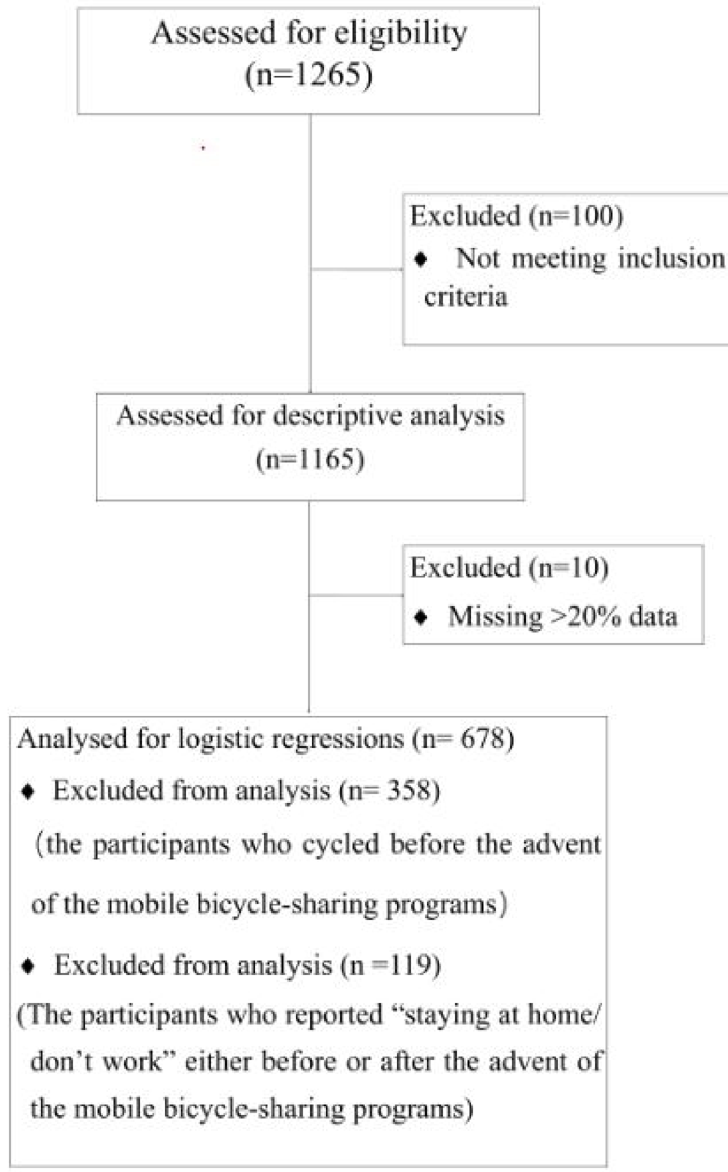

Figure 1. Consort flow diagram for analysis

133x179mm (96 x 96 DPI)

Appendix 1

Table 1. The questions measuring bikeable neighborhood environment.

Questions	Rating				
	1	2	3	4	5
1. Among the surrounding roads, how many dedicated bicycle lanes are set up?	none	a few	half	most	all
2. Distance from neighborhood to a public transportation stop/station (subway station/bus station)	>2km	1-2km	0.5- <1km	0.2 km - <0.5km	<0.2km
3. Access to destinations such as supermarkets, pharmacy, and small market	poor	a little poor	moderate	good	perfect
4. Physical condition of bicycle lanes	poor	a little poor	moderate	good	perfect
5. Maintenance of lanes	poor	a little poor	moderate	good	perfect
6. Vegetation/shade along bicycle lanes	poor	a little poor	moderate	good	perfect
7. Obstruction through traffic violation	serious	some	moderate	a little	little
8. Obstruction through motor vehicles	serious	some	moderate	a little	little
9. Obstruction through motorbikes / electric motorcycles	serious	some	moderate	a little	little

CONSORT 2010 checklist of information to include when reporting a randomised trial*

Section/Topic	Item No	Checklist item	Reported on page No
Title and abstract			
	1a	Identification as a randomised trial in the title	1
	1b	Structured summary of trial design, methods, results, and conclusions (for specific guidance see CONSORT for abstracts)	3
Introduction			
Background and objectives	2a	Scientific background and explanation of rationale	4,5
	2b	Specific objectives or hypotheses	5,6
Methods			
Trial design	3a	Description of trial design (such as parallel, factorial) including allocation ratio	6
	3b	Important changes to methods after trial commencement (such as eligibility criteria), with reasons	No
Participants	4a	Eligibility criteria for participants	7
	4b	Settings and locations where the data were collected	7
Interventions	5	The interventions for each group with sufficient details to allow replication, including how and when they were actually administered	6
Outcomes	6a	Completely defined pre-specified primary and secondary outcome measures, including how and when they were assessed	7-9
	6b	Any changes to trial outcomes after the trial commenced, with reasons	No
Sample size	7a	How sample size was determined	No
	7b	When applicable, explanation of any interim analyses and stopping guidelines	9,10
Randomisation:			
Sequence generation	8a	Method used to generate the random allocation sequence	No
	8b	Type of randomisation; details of any restriction (such as blocking and block size)	No
Allocation concealment mechanism	9	Mechanism used to implement the random allocation sequence (such as sequentially numbered containers), describing any steps taken to conceal the sequence until interventions were assigned	No
Implementation	10	Who generated the random allocation sequence, who enrolled participants, and who assigned participants to interventions	No
Blinding	11a	If done, who was blinded after assignment to interventions (for example, participants, care providers, those	No

		assessing outcomes) and how	
	11b	If relevant, description of the similarity of interventions	No
Statistical methods	12a	Statistical methods used to compare groups for primary and secondary outcomes	9,10
	12b	Methods for additional analyses, such as subgroup analyses and adjusted analyses	9,10
Results			
Participant flow (a diagram is strongly recommended)	13a	For each group, the numbers of participants who were randomly assigned, received intended treatment, and were analysed for the primary outcome	26
	13b	For each group, losses and exclusions after randomisation, together with reasons	26
Recruitment	14a	Dates defining the periods of recruitment and follow-up	7
	14b	Why the trial ended or was stopped	No
Baseline data	15	A table showing baseline demographic and clinical characteristics for each group	11
Numbers analysed	16	For each group, number of participants (denominator) included in each analysis and whether the analysis was by original assigned groups	26
Outcomes and estimation	17a	For each primary and secondary outcome, results for each group, and the estimated effect size and its precision (such as 95% confidence interval)	13,14
	17b	For binary outcomes, presentation of both absolute and relative effect sizes is recommended	13,14
Ancillary analyses	18	Results of any other analyses performed, including subgroup analyses and adjusted analyses, distinguishing pre-specified from exploratory	13,14
Harms	19	All important harms or unintended effects in each group (for specific guidance see CONSORT for harms)	No
Discussion			
Limitations	20	Trial limitations, addressing sources of potential bias, imprecision, and, if relevant, multiplicity of analyses	17
Generalisability	21	Generalisability (external validity, applicability) of the trial findings	17
Interpretation	22	Interpretation consistent with results, balancing benefits and harms, and considering other relevant evidence	14-17
Other information			
Registration	23	Registration number and name of trial registry	No
Protocol	24	Where the full trial protocol can be accessed, if available	No
Funding	25	Sources of funding and other support (such as supply of drugs), role of funders	18

*We strongly recommend reading this statement in conjunction with the CONSORT 2010 Explanation and Elaboration for important clarifications on all the items. If relevant, we also recommend reading CONSORT extensions for cluster randomised trials, non-inferiority and equivalence trials, non-pharmacological treatments, herbal interventions, and pragmatic trials. Additional extensions are forthcoming: for those and for up to date references relevant to this checklist, see www.consort-statement.org.

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Effects of new dock-less bicycle-sharing programs on cycling: a retrospective study in Shanghai

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Title: Effects of new dock-less bicycle-sharing programs on cycling: a retrospective study in Shanghai

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Abstract

Objectives To examine 1) the effect of new dock-less bicycle-sharing programs on change in travel mode and 2) the correlates of change in travel mode.

Design A retrospective natural experimental study

Setting 12 neighborhoods in Shanghai.

Participants 1265 respondents were recruited for a retrospective study in May 2017.

Main outcome measures Prevalence of cycling before and after launch of dockless bicycle sharing program.

Results The proportion of participants cycling for transport increased from 33.3% prior to the launch of the bicycle-sharing programs to 48.3% one year after the launch (p<0.001). Being in the age group of 30-49 years (OR=2.28; 95%CI: 1.30-4.00), living within the inner ring of the city (OR=2.27; 95%CI: 1.22-4.26), having dedicated bicycle lanes (OR=1.37, 95% CI 1.12-1.68) and perceiving riding shared bicycles as fashionable (OR=1.46, 95% CI 1.21-1.76) were positively associated with adopting cycling for transport. Access to a public transportation stop/station (OR=0.82, 95% CI 0.67-0.99) was inversely correlated with adopting cycling for transport.

Conclusions Dock-less bicycle-sharing may promote bicycle use in a metropolitan setting. Findings from this study also highlight the importance of cycling-friendly built environments and cultural norms as facilitators of adopting cycling.

Keywords: bicycle-sharing; cycling; travel mode; active travel; built environment; social norms

Strengths and limitations of this study

- An ecological framework can guide inquiry into a more comprehensive understanding of the factors that influence cycling behaviors.
- This study is the first to quantitatively evaluate whether the introduction of dock-less bicycle-sharing programs leads to more cycling.
- All measures were based on self-reports.
- This study applied a retrospective design, due to practical reasons outlined earlier. This limits causal inference from the current study.
- It could not verify whether the significant change from inactive transport modes to cycling has increased physical activity at the population level.

Introduction

Regular physical activity (PA) reduces the risk of major chronic diseases and premature mortality.[1] However, around the world large proportions of the population are not sufficiently active or completely inactive which has significant health and economic consequences.[2-5] Active transportation by cycling has the potential to contribute considerably to overall activity levels of adults and is associated with significant health benefits.[6-11] Moreover, greater use of bicycles for day-to-day travel provides wider benefits, including reductions in carbon emissions, air pollution, and traffic congestion.[10,12] In Chinese cities, cycling used to be a conventional mode of travel for most people, to the point that the country was once referred to as the “Kingdom of Bicycles”.[12] However, since the turn of the century, Chinese cities have become increasingly cycling-unfriendly due to increasing car ownership and car-oriented urban planning policies such as the conversion of non-motorized to motorized lanes and banning non-motorized vehicles from arterial roads in some cities.[13] With the economic development and booming car industry, between 2002 and 2010-2012, the proportion of people using motorized transport as the main mode of transportation increased from 33.5% to 61.9%, while the proportion traveling by bicycle and walking decreased from 35.8% and 30.7% to 15.6% and 22.5%, respectively.[14]

As a strategy for promoting cycling and sustainable transportation overall, public bicycle-sharing programs (PBSP) have been introduced in many cities around the world to provide bicycles as a mode of transportation for relatively short trips and to bridge "the last mile" of public transport services.[15,16] These PBSPs usually have docking stations where users obtain and return the rental bicycles.[17] Although some studies have shown that cycling has increased in some cities since the introduction of PBSPs, such as Washington DC, Dublin, Beijing and Hangzhou, China, there are still some common problems and challenges for conventional PBSPs, which may have limited their reach and usage at a population level, such as reliance on docking stations, inconvenience in payment and insufficient supply of shared bicycles.[15,18-20]

With the increasing popularity of smart phone payments, Global Positioning System (GPS) tracking and other technology, dock-less bicycle-sharing provides new opportunities for promoting active travel and physical activity.[21] Dock-less PBSPs utilize mobile-controlled wheel lock and GPS tracking, so that users can locate the nearest bicycle, unlock and lock the bicycle, and pay (usually, around 1RMB~0.15 USD per half hour) through a mobile app. Moreover, some of the shared bicycles (e.g., Mobike) have solid tires, which are durable and low-maintenance. Dock-less PBSPs are currently deployed in many cities in China such as Shanghai, Beijing, and Guangzhou.[22] As of May 2017, a total of 10 million dock-less shared bicycles had been deployed in China, 1.5 million of which in Shanghai, which even led the government to ban additional shared bicycles.[23,24] Despite the rapid growth in dock-less PBSPs, there is very limited evidence on whether dock-less PBSPs can change travel modes at the population level.[25] Furthermore, the introduction of bicycle-sharing schemes alone may not lead to population-level uptake, as various other factors may need to be present to facilitate population level cycling. In line with social-ecological models, previous research suggests that population-level cycling behavior is associated with a range of individual- and environmental-level characteristics. [26-29] However, these socio-ecological correlates have rarely been examined in evaluations of PBSPs and remain important research gaps. Therefore, this study aims to 1) evaluate whether the introduction of dock-less PBSPs leads to more cycling, and 2) to examine correlates of initiation of cycling, including sociodemographic characteristics and aspects of the built and social environment.

MATERIALS AND METHODS

Patient and Public Involvement

A retrospective study was conducted in May 2017. An intercept convenience sample survey was conducted among residents from 12 neighborhoods. Upon approaching potential participants, information about the study was provided and written informed consent was obtained before participating in the study. This study received approval from the ethics committee of the School of Public Health of Fudan University, China

(IRB00002408 & FWA0002399). Participants have the right to find out the results of the study by contacting the member of the project.

Intervention

Dock-less bicycle-sharing systems can be considered as a city-level intervention for travel mode. The system was officially launched in Shanghai in April 2016. By July 2017, there were more than 13 million registered users and more than 1 million dock-less shared bicycles in Shanghai.[30] The development of dock-less shared bicycles was so rapid in China that it limited opportunities for prospective data collection or inclusion of a control city that is comparable to Shanghai, but without a bicycle-sharing system. Therefore, a retrospective study design was used.

Study areas and recruitment of participants

To explore the correlates of travel mode, a two-stage sampling method was employed. First, based on the Shanghai Transportation Map, the city was divided into four areas: within the inner ring, between the inner and middle rings, between the middle and outer rings, and beyond the outer ring. Then, three neighborhoods were selected in each of the four areas of Shanghai by purposive sampling. The selection criteria for neighborhoods were as follows: (1) within 1-2 km distance from the nearest subway station; (2) the number of residents within the neighborhood was more than 1,000. Within each selected neighborhood, trained interviewers conducted at least 100 self-administered intercept surveys in May 2017. The inclusion criteria for participants were (1) being 18-70 years old; (2) having lived in the selected neighborhood for more than 3 months; and (3) being physically capable of riding a bicycle. Altogether, 1265 respondents were sampled from 12 neighborhoods. After excluding 100 respondents with more than 20% missing data, 1165 respondents (92.1%) remained in the analysis.

Measurements

Travel mode

Travel mode before and after the advent of the dock-less PBSPs was assessed by asking respondents two questions: (1) How did you travel most of the time before the advent of dock-less PBSPs? (2) How have you been travelling most of the time after the advent of dock-less PBSPs? Respondents selected one of the following options, including walking, cycling, by car, public transport (subway, bus, ferry, and shuttle bus), motorcycles/electric motorcycles, combined public transport with walking (>500m), combined public transport with cycling, do not travel (staying at home), and other. According to respondents' travel mode before and after the advent of dock-less PBSPs, they were classified into cyclists and non-cyclists at both time points. Cyclists were defined as participants who traveled by bicycle or those who combined cycling and public transport most of the time.

Perceived bikeability

To date, only few instruments have been developed to measure perceived bicycle-friendliness of neighborhood environments and most of these were developed for the physical environments of Western countries.[31] A new scale for measuring Chinese neighborhood bikeability was developed based on existing instruments, literature reviews, field visits, and expert consultation. Specifically, we adopted five questions (i.e., distance to a public transportation stop/station, access to destinations, physical condition of bicycle lanes, maintenance of lanes, and vegetation/shade along the bicycle lanes) from the Chinese Walkable Environment Scale (CWES) for urban community residents.[32] Based on consultation with several Chinese local physical activity experts to discuss potential correlates and determinants of cycling, we added four questions to the survey, including the presence of dedicated bicycle lanes, and the degree to which traffic violations, traffic volume, and motorbikes/electric scooters impede cycling. Finally, this instrument was pilot-tested and adjusted prior to the survey. All bikeability variables were on a 5-point scale and the composite score was analyzed as a continuous variable. More details about the questions are provided in Appendix 1.

Social norms

Two survey items assessed social norms:"Riding dock-less shared bicycles is fashionable" and "Riding dock-less shared bicycles represents low socioeconomic status". Each item was rated on a 5-point scale, from 1 (strongly disagree) to 5 (strongly agree).

Demographic variables and other covariates

Self-reported sociodemographic variables included gender, age, education, personal monthly income, and marital status. Age was categorized as <30, 30-49, and ≥50 years. Educational attainment was categorized as ≤ junior high school, high school/technical secondary school, junior college, and university and higher. Monthly income was categorized as <¥2000, ¥2000-4999, ¥5000-9999, and ≧¥10000 (1 CNY=0.15 USD in May 2017). In addition, questions about motor vehicle and bicycle ownership and characteristics of the commute were asked, including the following: (1) what is the distance between your home and work/college/university, and (2) how long does it take you to go to work/college/university every day, both of which were converted to categorical variables.

Statistical analysis

McNemar's test was used to examine the change in travel mode after the introduction of the dock-less PBSPs. To explore the potential correlates of change in travel mode, we focused on the participants who did not cycle before the bicycle-sharing became available and classified them as those who (1) changed from not cycling to cycling, and (2) remained not cycling as their travel mode. More details can be found in Figure 1. Because the data were hierarchical in nature (individuals clustered within neighborhoods), we explored multi-level modeling. However, upon examination of the outcome variable, we decided against multi-level modeling because the intraclass correlation coefficient was 0.0645 and we only found a significant random effect in one out of 12 neighborhoods. Therefore, logistic regression was conducted to examine the association of socio-demographic variables, perceived bikeability, and social norms with change in cycling behavior. Sequential modeling was used with Model 1 including only sociodemographic variables, Model 2 including sociodemographic and bikeability variables, and Model 3 additionally including social norms. Statistical analysis was performed using the Statistical Package for the Social Sciences 20.0 (Chicago, SPSS, Inc.) and the significance level was set at 0.05.

RESULTS

The demographic characteristics of the study sample are reported in Table 1. The final sample consisted of 1,165 participants from 12 neighborhoods. Nearly 40% of the participants were 30 to 49 years old, and over 75% were married. More than 40% reported an income level between 2000 and 4999 RMB/month. Over 75% of the participants owned bicycles, while nearly half of the participants had motor vehicles. The average distance from work/college/university was 5.6 km, while the average commuting time was 26.6 minutes.

Table 1. Participant characteristics

Variable	n (%)

Gender	Male	587 (50.5)
	Female	575 (49.5)
Age, years	18-29	297 (25.5)
	30-49	460 (39.5)
	≥50	408 (35.0)
Education	Junior high school	289 (25.2)
	High school/technical secondary school	339 (29.5)
	Junior college	210 (18.3)
	University and above	310 (27.0)
Personal monthly income (RMB)	<2000	203 (17.5)
	2000-4999	504 (43.4)
	5000-9999	329 (28.3)
	>10000	125 (10.8)
Marital status	Married	891 (76.5)
	Unmarried/Divorced/Widowed	274 (23.5)
Area of residence	Within the inner ring	284 (24.4)
	Between the inner and middle rings	265 (22.7)
	Between the middle and outer rings	316 (27.1)
	Beyond the outer ring	300 (25.8)
Ownership of bicycle	Yes	879 (75.5)
	No	286 (24.5)
Ownership of motor vehicle	Yes	550 (47.2)
	No	615 (52.8)
Distance from work / college / university	<1.5km	282 (25.0)
	1.5-5km	432 (38.2)
	>5km	319 (28.2)
	Staying at home/ Not working	97 (8.6)
Commuting time (one way)	<15min	359 (31.8)
	15-30min	416 (36.8)
	>30min	257 (22.8)
	Staying at home / Not working	97 (8.6)

Change in travel mode

Before the launch of the dock-less PBSPs, 33.3% of the participants cycled for transport which increased significantly to 48.3% after the launch (p<0.001). Among the participants who usually travelled by car/motorcycles/electric motorcycles, walking/walking combined with public transport, and public transport before the launch of the dock-less PBSPs, there were 115 (28.4%), 50 (28.2%), and 28 (29.2%) participants who adopted cycling as their primary travel mode after the launch, respectively.

Correlates of initiating commuting cycling

As shown in Table 2, in Model 1, among 645 participants who did not report cycling commuting cycling at baseline, those who were <30 and 30-49 years old had more than twice the odds of adopting commuting cycling than participants who were 50 and older. Participants who lived within the inner ring had more than twice the odds to adopt cycling compared with those who lived in the area between the inner and middle rings. Participants living > 5km from work/college/university had more than twice the odds of initiating cycling compared with those living within 1.5km from work/college/university. In Model 2, presence of dedicated bicycle lanes was positively associated with adopting cycling. Model 3 showed that participants who owned motor vehicles were more likely to adopt cycling than those without motor vehicles. In Model 3, access to a public transportation stop/station was inversely associated with adopting cycling, and perceiving riding dock-less shared bicycles as fashionable was positively correlated with adopting cycling. The perception that riding dock-less shared bicycles represents low socio-economic status was inversely correlated with adopting cycling.

Table 2. Predictors of adopting cycling

Demographic characteristics	Model 1 (n=645)[a] OR (95% CI)	Model 2 (n=641)[b] OR (95% CI)	Model 3 (n=641)[c] OR (95% CI)
Gender			
Female (ref)	1.00	1.00	1.00
Male	0.81 (0.56-1.16)	0.73 (0.50-1.06)	0.75 (0.51-1.11)
Age (years)			
≥50 (ref)	1.00	1.00	1.00
30-49	2.26 (1.32-3.87)**	2.31(1.33-4.00)**	2.28(1.30-4.00)**
<30	2.23 (1.18-4.21)*	2.11 (1.10-4.07)*	1.92 (0.99-3.74)
Education			
University and above (ref)	1.00	1.00	1.00
Junior college	0.95 (0.57-1.59)	0.91 (0.53-1.54)	0.86 (0.50-1.48)
High school/ Technical secondary school	1.31 (0.79-2.17)	1.30 (0.77-2.18)	1.26 (0.74-2.13)
Junior high school	0.88 (0.45-1.72)	0.83 (0.42-1.66)	0.75 (0.38-1.52)
Marital status			
Unmarried/Divorced/ Widowed (ref)	1.00	1.00	1.00
Married	0.85 (0.53-1.37)	0.85 (0.52-1.39)	0.83 (0.50-1.37)
Personal monthly income (RMB)			
≥10000 (ref)	1.00	1.00	1.00
5000-9999	1.26(0.70-2.27)	1.25 (0.68-2.30)	1.29 (0.70-2.41)
2000-4999	1.45 (0.78-2.69)	1.39 (0.74-2.64)	1.43 (0.75-2.74)
<2000	0.94 (0.41-2.15)	0.86 (0.37-2.02)	1.01 (0.42-2.41)
Area			
Within the inner ring (ref)	1.00	1.00	1.00
Between the inner and middle ring	0.52 (0.29-0.93)*	0.45 (0.25-0.84)*	0.44 (0.24-0.82)**
Between the middle and outer ring	0.92 (0.56-1.51)	0.78 (0.46-1.31)	0.72 (0.43-1.23)
Beyond the outer ring	0.69 (0.42-1.15)	0.59 (0.33-1.05)	0.56 (0.31-1.01)
Ownership of motor vehicle			
No (ref)	1.00	1.00	1.00
Yes	1.37 (0.95-1.98)	1.45 (0.99-2.12)	1.53 (1.04-2.25)*
Ownership of bicycle			
No (ref)	1.00	1.00	1.00
Yes	0.85 (0.54-1.33)	0.84 (0.53-1.35)	0.92 (0.57-1.48)

Distance from work/college/university			
≤1.5km (ref)	1.00	1.00	1.00
1.5-5km	1.28 (0.73-2.24)	1.27 (0.71-2.27)	1.33 (0.73-2.39)
>5km	2.04 (1.07-3.90)*	2.22 (1.13-4.33)*	2.58 (1.30-5.12)**
Commuting time (one way)			
≤15min (ref)	1.00	1.00	1.00
15-30min	0.96 (0.57-1.61)	0.97 (0.57-1.65)	0.93 (0.54-1.60)
>30min	0.84 (0.45-1.58)	0.91 (0.48-1.73)	0.83 (0.43-1.62)
Perceived bikeability			
Presence of dedicated bicycle lane		1.38 (1.12-1.68)**	1.37 (1.12-1.68)**
Access to a public transportation stop/station		0.83 (0.68-1.01)	0.82 (0.67-0.99)*
Access to destinations		0.85 (0.66-1.10)	0.81 (0.63-1.06)
Physical condition of bicycle lanes		1.19 (0.89-1.59)	1.15 (0.85-1.54)
Maintenance of lanes		0.81 (0.60-1.08)	0.82 (0.61-1.11)
Vegetation/shades along the bicycle lanes		1.29 (0.97-1.71)	1.23 (0.91,1.65)
Traffic violation as a barrier		1.01 (0.79-1.29)	1.01 (0.79-1.29)
Traffic volume as a barrier		1.14 (0.87-1.49)	1.18 (0.90-1.56)
Motor bikes/electronic scooters as barriers		0.99 (0.76-1.29)	0.96 (0.74-1.26)
Social norms			
Riding dock-less shared bicycles perceived as fashionable			1.46 (1.21-1.76)**
Riding dock-less shared bicycles represents low socioeconomic status			0.91 (0.76-1.08)

All analyses are restricted to those who did not report cycling as the main mode of transport at baseline.

[a]Model 1 adjusted for demographic variables, including gender, age, education, marital status, personal monthly income, area, ownership of motor vehicle, ownership of bicycle, distance from work/college/university and commuting time (one way). [b]Model 2 adjusted for all variables in Model 1 + perceived environmental variables, including presence of dedicated bicycle lane, access to a public transportation stop/station, physical condition of bicycle lanes, maintenance of lanes, vegetation/shades along the bicycle lanes, traffic violation as a barrier, traffic volume as a barrier and motor bikes/electronic scooters as

barriers. [c]Model 3 adjusted for all variables in Model 2 + social norms variables. *$p<0.05$, **$p<0.01$

DISCUSSION

This is the first community-based study to evaluate the effect of new dock-less PBSPs on cycling for transport. Over the last 30 years, China has witnessed rapid economic development and a booming car industry and consequentially, a dramatic decrease in cycling.[12-14] With the introduction of dock-less PBSPs, e found that the proportion of participants that cycled for transport increased significantly from 33.3% to 48.3%. Nearly 30% of the participants who usually travelled by car/motorcycles/electric motorcycles adopted cycling after the launch of dock-less PBSPs. In comparison, a study that evaluated conventional PBSPs with docking stations showed that in Beijing, Shanghai and Hangzhou, 5.2%, 0.46% and 4% of car trips were replaced by bicycle.[33] Another study on members of bikesharing programs revealed that in Montreal, Toronto, Washington, DC, Minneapolis-Saint Paul, 40% of members reduced their number of car trips while only 0.4% of members increased their car trips.[34,35] Studies about PBSPs with docking stations in Barcelona, London, Montreal and Washington, DC have all reported low transfer rates from car journeys to shared bicycles.[18,36] It appears that dock-less PBSPs might have the potential to be more effective and to have a wider reach in promoting cycling than conventional PBSPs.[20,37] However, it is important to take into account that the effect sizes are not comparable because our study used individual-level data and previous evaluations used trip-level data. We offer several potential explanations for the potentially more effective dock-less PBSPs based on previous studies as follows. Firstly, enough bicycles per resident (more than 50 bicycles per 1,000 resident in

Shanghai) and the GPS positioning function allow for better access to bicycles.[38-40] Secondly, conventional PBSPs in China require local "HuKou" (a permanent residency system unique to China) and are therefore not available to visitors and temporary residents. Instead, dock-less PBSPs are available to all who have registered an account online.[38] Thirdly, a fully dock-less system makes it convenient for users to pick up and drop off bicycles wherever they want. Fourthly, the provided bicycles are durable, attractive and practical.[38,40] Lastly, mobile payment is instantaneous and convenient. However, it is important to note that a prerequisite for successful dock-less PBSPs is the ubiquity of mobile payment, as is the case in China.[41]

Based on our preliminary evidence, one may conclude that dock-less PBSPs have great potential for cycling promotion in China. Perhaps a key ingredient for the success of dock-less PBSPs in Shanghai is China's history of cycling as a social norm.[42] Another reason for the success of dock-less PBSPs is that they have been created and promoted by the private sector which has vested interest in the wide adoption of shared bicycles. Business competition stimulates continuous development and improvement of bicycle-sharing technology and promotion of cycling at the population level.[43]

However, dock-less PBSPs are not guaranteed to be more effective than conventional PBSPs in all settings. A report on bike share in the U.S. in 2017 showed that station-based systems produced an average of 1.7 rides per bike per day, while dock-less bike share systems nationally had an average of about 0.3 rides per bike per day.[44] Several factors might explain these differences. Firstly, it is difficult to control the distribution of dock-less shared bicycles, resulting in insufficient bicycles in some areas and overcrowding in others.[45] Secondly, nearly one-third of station-based bicycle share systems have income-based discount programs, making renting station-based bicycles cheaper and potentially more appealing for low-income groups.[44] Thirdly, station-based and dock-less BSPSs may appeal to different types of riders. Some evidence from U.S. suggests that station-based bicycle share trips are mainly for commuting, while dock-less bicycle share trips suggested more recreational use.[44]

To date, few studies have examined correlates of adopting cycling in the context of newly introduced PBSPs. With the rapid development and popularity of dock-less PBSPs, it is necessary to examine potential correlates of adopting commuting cycling. We found that younger participants were more likely to adopt cycling, which is consistent with previous studies.[46-48] Gender and education were not related to adopting cycling, which is consistent with a study conducted in Beijing, but different to results from other studies from the United States, Spain, and the UK which found that males and those with higher education were more likely to cycle.[28,47-49] Previous evidence on the associations between income and cycling was mixed, and our findings suggest no association between income and change in travel mode.[27,28,47,50] It is noteworthy that we found positive associations of commuting distance and car ownership with adopting cycling, which is counter-intuitive and different from previous findings.[47-49,51] A potential explanation is that those who lived within walking distance (<1.5 km) to work/college/university may not own a car or have considered cycling, so bicycle-sharing was most likely to affect those who lived relatively far away from work/college/university and previously traveled by car because they could not easily access public transportation stops/stations without shared bicycles. Among the perceived bikeability of the environment, presence of dedicated bicycle lanes were positively associated with change in travel mode which is in line with several other studies, including some from Beijing.[27,47,51-55] Among them, a study in India suggested that dedicated bicycle lanes were the most important attribute of bicycle infrastructure.[53] A study from Beijing found that the perception that bicycle lanes being taken over by motorized vehicles is a key deterrent for people to switch to cycling.[47] On the other hand, consistent with other studies, we found an inverse association between access to a public transportation stop/station and adopting cycling.[29,48,55] Unlike some previous studies, we did not find an association between other aspects of the bikeability of the environment, such as traffic safety and aesthetics, with adopting cycling.[27,46,49,51,52]

Another finding from our study relates to social norms. Although previous studies have found effects of attitudes towards cycling and other modes of transportation on mode choice, our study examined effects of both positive and negative attitudes toward cycling.[56-59] Our data showed that the perception that riding dock-less shared bicycles is fashionable was positively correlated with adopting cycling while considering riding dock-less shared bicycles representing low income was inversely correlated with switching to cycling. This finding highlights that promoting positive social norms may be critical to increasing cycling at the population level.

Dock-less PBSPs provide new opportunities for active travel, but also pose challenges for their management[21] Several related issues have been raised: such as road and pedestrian safety concerns, bicycle dumping, crowding footpath and vandalism.[21,60] We discuss a few suggestions for better management of PBSP planning and management, as follows. Firstly, public bikesharing operators and local governments should consider what types of systems are the most effective for linking bikesharing with public transit and vehicle-sharing systems according to population density and land use.[35,39,61] Secondly, local governments should assess the social and environmental impacts of new bikesharing programs.[61] Besides quantitative assessment, some in-depth qualitative evaluations should be encouraged.[62,63] Thirdly, companies that run dock-less bike share programs should be open to sharing more data about bike usage with local governments to facilitate evaluations, so that the local governments can better support the development of bikesharing programs to help achieve goals of safety, equity, and sustainable mobility.[44,64]

Strengths and limitations

There are some limitations to this study. First, all measures were based on self-report, however, the measures have been validated .[32] Second, this study applied a retrospective design due to practical reasons outlined earlier. This limits causal inference from the current study. Third, because we did not collect total physical activity levels at two time points, we could not determine whether those who have adopted cycling have become more physically active overall.

CONCLUSION

We found that dock-less bicycle-sharing can be effective in increasing bicycle use and might have the potential to be scaled up internationally. To maximize the impact of dock-less PBSPs at the population level, improving attributes of the built environment, such as dedicated bicycle lanes, and promoting positive social norms about cycling should be considered. The rapid development and popularity of dock-less PBSPs provides new opportunities for active travel, but also poses challenges for their management. Operators of dock-less PBSPs and local governments should work together to create better built environment and social norms for promoting active travel and physical activity.

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Contributors

YJ and HF conceived the idea, analyzed the data and drafted the paper. DD, KG, LC, SZ, and ZM contributed to the writing and assisted with the analysis and interpretation. YJ, LC, SZ, and ZM contributed to collecting the data. All authors have read and approved the final manuscript.

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Competing interests

The authors declare that they have no competing interests.

Abbreviations

PA: Physical activity; PBSP: Public bicycle-sharing program; GPS: Global Positioning System; CWES: Chinese Walkable Environment Scale; SPSS: Statistical Package for the Social Sciences.

Availability of data and material

Please contact authors for data requests.

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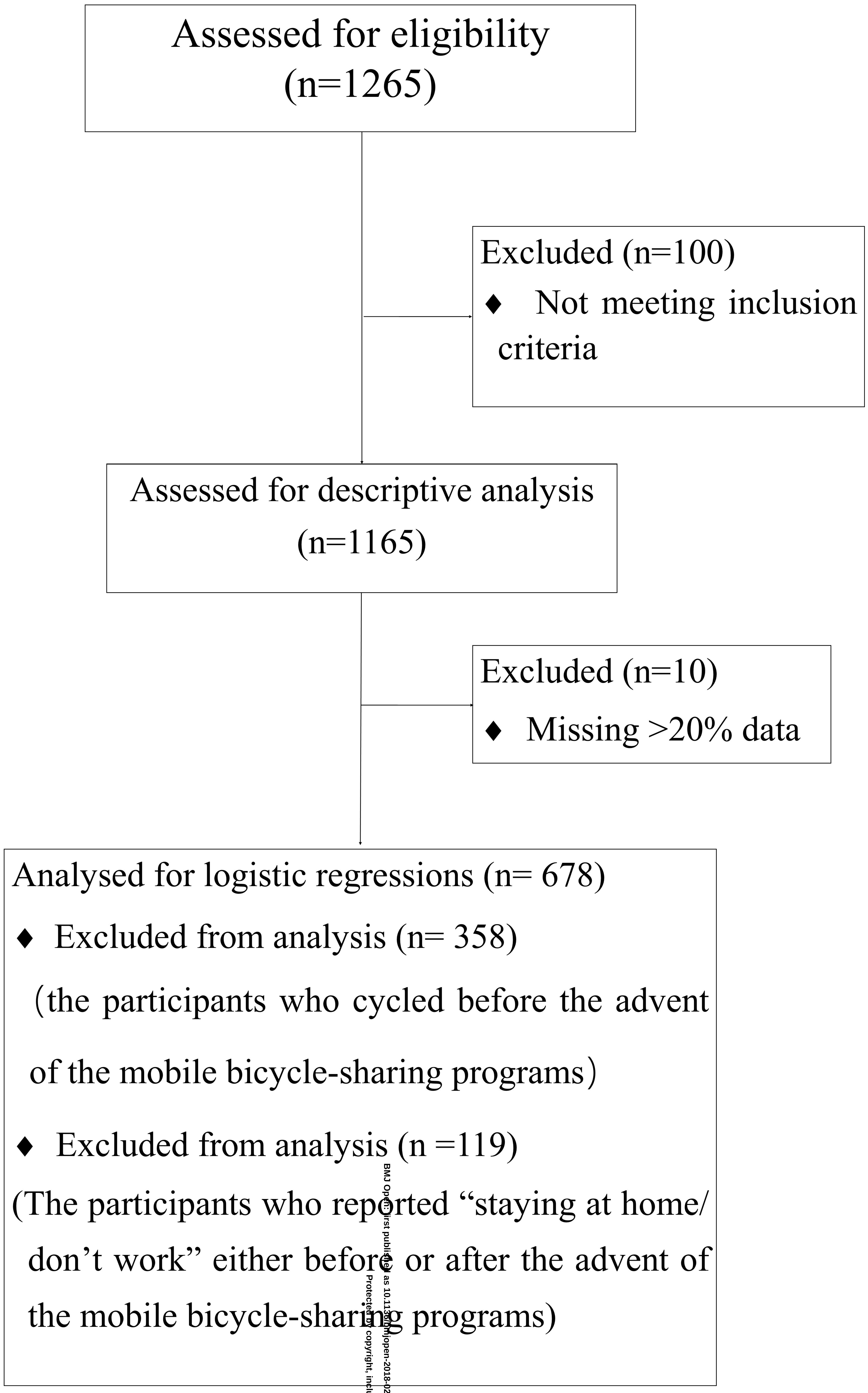
Figure 1. Participants flow


Assessed for eligibility
(n=1265)
Excluded (n=100)
♦ Not meeting inclusion criteria
Assessed for descriptive analysis
(n=1165)
Excluded (n=10)
♦ Missing >20% data
Analysed for logistic regressions (n= 678)
♦ Excluded from analysis (n= 358)
(the participants who cycled before the advent of the mobile bicycle-sharing programs)
♦ Excluded from analysis (n =119)
(The participants who reported "staying at home/ don't work" either before or after the advent of the mobile bicycle-sharing programs)

Appendix 1

Table 1. The questions measuring bikeable neighborhood environment.

Questions	Rating				
	1	2	3	4	5
1. Among the surrounding roads, how many dedicated bicycle lanes are set up?	none	a few	half	most	all
2. Distance from neighborhood to a public transportation stop/station (subway station/bus station)	>2km	1-2km	0.5-<1km	0.2 km - <0.5km	<0.2km
3. Access to destinations such as supermarkets, pharmacy, and small market	poor	a little poor	moderate	good	perfect
4. Physical condition of bicycle lanes	poor	a little poor	moderate	good	perfect
5. Maintenance of lanes	poor	a little poor	moderate	good	perfect
6. Vegetation/shade along bicycle lanes	poor	a little poor	moderate	good	perfect
7. Obstruction through traffic violation	serious	some	moderate	a little	little
8. Obstruction through motor vehicles	serious	some	moderate	a little	little
9. Obstruction through motorbikes / electric motorcycles	serious	some	moderate	a little	little

STROBE Statement—checklist of items that should be included in reports of observational studies

	Item No	Recommendation
Title and abstract	1	(*a*) Indicate the study's design with a commonly used term in the title or the abstract *– In the abstract we explicitly mentioned it is a retrospective natural experimental study*
		(*b*) Provide in the abstract an informative and balanced summary of what was done and what was found *– Clearly stated in abstract.*
Introduction		
Background/rationale	2	Explain the scientific background and rationale for the investigation being reported *– Clearly stated in the Introduction*
Objectives	3	State specific objectives, including any prespecified hypotheses *– Objective stated at the end of the Introduction*
Methods		
Study design	4	Present key elements of study design early in the paper *– Stated at the start of Methods*
Setting	5	Describe the setting, locations, and relevant dates, including periods of recruitment, exposure, follow-up, and data collection *– Stated in Methods*
Participants	6	(*a*) *Cohort study*—Give the eligibility criteria, and the sources and methods of selection of participants. Describe methods of follow-up *Case-control study*—Give the eligibility criteria, and the sources and methods of case ascertainment and control selection. Give the rationale for the choice of cases and controls *Cross-sectional study*—Give the eligibility criteria, and the sources and methods of selection of participants *– eligibility criteria, sources and methods of selection were stated in Methods(Study areas and recruitment of participants)*
		(*b*) *Cohort study*—For matched studies, give matching criteria and number of exposed and unexposed *Case-control study*—For matched studies, give matching criteria and the number of controls per case *– NA*
Variables	7	Clearly define all outcomes, exposures, predictors, potential confounders, and effect modifiers. Give diagnostic criteria, if applicable *– Clearly defined in Methods*
Data sources/ measurement	8*	For each variable of interest, give sources of data and details of methods of assessment (measurement). *– References for measures were provided* Describe comparability of assessment methods if there is more than one group *– NA*
Bias	9	Describe any efforts to address potential sources of bias *– Stated in discussion section*
Study size	10	Explain how the study size was arrived at *–Stated in Methods(Study areas and recruitment of participants)*

Quantitative variables	11	Explain how quantitative variables were handled in the analyses. If applicable, describe which groupings were chosen and why *– Stated in Methods (Statistical Analysis)*
Statistical methods	12	(*a*) Describe all statistical methods, including those used to control for confounding *– Stated in Methods (Statistical Analysis)*
		(*b*) Describe any methods used to examine subgroups and interactions *– Stated in Methods (Statistical Analysis)*
		(*c*) Explain how missing data were addressed *– Stated in Methods (Statistical Analysis and Figure 1)*
		(*d*) *Cohort study*—If applicable, explain how loss to follow-up was addressed *Case-control study*—If applicable, explain how matching of cases and controls was addressed *Cross-sectional study*—If applicable, describe analytical methods taking account of sampling strategy *– Stated in Methods(Study areas and recruitment of participants)*
		(*e*) Describe any sensitivity analyses *– NA*

Continued on next page

Results		
Participants	13*	(a) Report numbers of individuals at each stage of study—eg numbers potentially eligible, examined for eligibility, confirmed eligible, included in the study, completing follow-up, and analysed *– Presented in Figure 1*
		(b) Give reasons for non-participation at each stage *– Presented in Figure 1*
		(c) Consider use of a flow diagram *– Presented in Figure 1*
Descriptive data	14*	(a) Give characteristics of study participants (eg demographic, clinical, social) and information on exposures and potential confounders *– Presented in Table 1*
		(b) Indicate number of participants with missing data for each variable of interest *– NA*
		(c) *Cohort study*—Summarise follow-up time (eg, average and total amount) *– NA*
Outcome data	15*	*Cohort study*—Report numbers of outcome events or summary measures over time *– NA*
		Case-control study—Report numbers in each exposure category, or summary measures of exposure *– NA*
		Cross-sectional study—Report numbers of outcome events or summary measures *– Presented in Table 1*
Main results	16	(*a*) Give unadjusted estimates and, if applicable, confounder-adjusted estimates and their precision (eg, 95% confidence interval). Make clear which confounders were adjusted for and why they were included *– Indicated in Results , Table 2*
		(*b*) Report category boundaries when continuous variables were categorized *– Indicated in Results , Table 1 and 2*
		(*c*) If relevant, consider translating estimates of relative risk into absolute risk for a meaningful time period *– NA*
Other analyses	17	Report other analyses done—eg analyses of subgroups and interactions, and sensitivity analyses *– Indicated in Results , Table 2*
Discussion		
Key results	18	Summarise key results with reference to study objectives *– Addressed*
Limitations	19	Discuss limitations of the study, taking into account sources of potential bias or imprecision. Discuss both direction and magnitude of any potential bias *– Extensively described in Discussion (Strengths and Limitations)*
Interpretation	20	Give a cautious overall interpretation of results considering objectives, limitations, multiplicity of analyses, results from similar studies, and other relevant evidence *– Addressed in Discussion*
Generalisability	21	Discuss the generalisability (external validity) of the study results *– Addressed in Discussion*

Other information

Funding	22	Give the source of funding and the role of the funders for the present study and, if applicable, for the original study on which the present article is based – *Funding and the role of the funder presented.*

*Give information separately for cases and controls in case-control studies and, if applicable, for exposed and unexposed groups in cohort and cross-sectional studies.

Note: An Explanation and Elaboration article discusses each checklist item and gives methodological background and published examples of transparent reporting. The STROBE checklist is best used in conjunction with this article (freely available on the Web sites of PLoS Medicine at http://www.plosmedicine.org/, Annals of Internal Medicine at http://www.annals.org/, and Epidemiology at http://www.epidem.com/). Information on the STROBE Initiative is available at www.strobe-statement.org.