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Association between bike-sharing systems and the blood pressure of local citizens: a cross-sectional study in China

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ABSTRACT

Introduction Globally, hypertension stands as the foremost preventable risk factor for cardiovascular disease and premature death. However, scalable approach to lowering blood pressure (BP) at the population level remains lacking. We investigated whether shared bikes, a sustainable method of transportation gaining increasing popularity across the world, can serve as a supplemental instrument to combat the increasing prevalence of hypertension.

Methods Based on 8 107 363 physical examination visits to one of the largest medical examination centres in China during the period of June 2016 to August 2017, we perfermed a staggered difference-in-differences (DiD) analysis that exploited the roll-out of bike-sharing systems across different cities. The main outcome was the blood pressure among adult participants who were likely to adopt shared bikes (age <45), measured by (1) systolic blood pressure (SBP), (2) diastolic blood pressure (DBP) and (3) a binary indicator of hypertension status (SBP≥130 or DBP≥80 mm Hg).

Results Blood pressure showed a decreasing trend after a bike-sharing platform entered the local city. After 6 months post an entry event, SBP reduced by 0.67 mm Hg (β (SE), −0.672 (0.245); 95% CI, −1.154 to −0.191); the prevalence of hypertension reduced by 1.4 percentage points (β (SE), −0.014 (0.007); 95% CI, −0.027 to −0.000); the reduction in DBP was statistically insignificant (β (SE), −0.193 (0.193); 95% CI, −0.572 to 0.187). Participants less likely to adopt shared bikes (age ≥45) showed no significant response. The number of visits and the age of participants were also unaffected by the entry events. Reduction in blood pressure was more pronounced in male, younger and non-obese participants.

Conclusion The findings of this study suggest that bike-sharing systems in China may be associated with lowered blood pressure, and thus may serve as a supplemental instrument to combat the increasing prevalence of hypertension, especially among young adults.

WHAT IS ALREADY KNOWN ON THIS TOPIC

⇒ Shared bikes are a sustainable method of transportation gaining increasing popularity across the world. By encouraging physical activity, they may offer additional health benefits.
⇒ However, the empirical evidence on the association between shared bikes and health outcomes is scarce, especially evidence based on large-scale individual-level data.

WHAT THIS STUDY ADDS

⇒ To the best of our knowledge, this study is the first to quantify the health benefits of bike-sharing systems based on large-scale individual-level data.
⇒ We took advantage of an administrative dataset of physical examinations from one of the largest medical examination centres in China, covering 8 107 363 visits from 47 cities scattered across 27 out of the 31 provinces in mainland China.
⇒ The use of the rollout of bike-sharing platforms across cities as a quasi-natural experiment, along with a battery of falsification, heterogeneity and robustness tests, facilitated a preliminary causal interpretation.
⇒ The introduction of bike-sharing systems was associated with reduced blood pressure of local citizens, especially among male, younger and non-obese participants.

HOW THIS STUDY MIGHT AFFECT RESEARCH, PRACTICE OR POLICY

⇒ The promotion of bike-sharing systems may serve as a supplemental instrument to combat the increasing prevalence of hypertension, especially among young adults.

INTRODUCTION

Globally, hypertension stands as the foremost preventable risk factor for cardiovascular disease and premature death.[1] Researchers have proposed various types of programmes aiming to control the prevalence of hypertension, which involves (a combination of) health education, house visits, medication prescription and support for lifestyle change.[2–8] Although effective within the analysis sample, these programmes generally entailed significant personnel (eg, recruitment or training of community health workers) and financial resources by the public sector, which limited their feasibility and sustainability for widespread implementation.

A scalable, community-level approach to lowering blood pressure (BP) at the population level remains necessary.

In this study, we evaluated whether the increased accessibility of cycling due to the introduction of bike-sharing systems can help reduce the BP of local citizens. Shared bikes have emerged as a sustainable alternative to traditional urban transportation, gaining immense popularity worldwide. As of August 2022, bike-sharing systems were present in 1590 cities from 92 countries, with the total number of bikes amounting to 9 million.[9] In China, the largest bike-sharing market in the world, there were 1.3 billion shared-bike accounts as of September 2022, facilitating 45 million trips per day.[10] These systems not only provide an economical means of commuting while encouraging physical activity among the local citizens.[11 12]

The health benefits of active commuting through the channel of increased physical activity have been well-established.[13–18] Building on this body of research, previous studies on bike sharing provided initial investigations on the health implications of bike-sharing systems. Some studies simulated the health benefits without directly observing the health outcomes of shared bike users.[19–22] Among studies that exploited real-world health information (eg, body mass index (BMI)), some relied on aggregate-level (eg, county-level) data, which makes it hard to capture the nuanced response heterogeneity at the individual level.[23] Generally, there is still insufficient empirical evidence on the implication of bike-sharing systems on BP, especially evidence based on large-scale individual-level data.

This study aimed to fill this gap by taking advantage of large-scale physical examination data from one of the largest medical examination centres in China. We obtained the administrative de-identified data of 8 107 363 visits over 15 months (June 2016 to August 2017) from 47 cities, which covered 27 out of the 31 provinces in mainland China. We evaluated and confirmed the representativeness of our data by comparing the key statistics (eg, the prevalence of hypertension or obesity) in our sample with those derived from nationally representative surveys. The granularity of our data allows us to better account for the heterogeneity across participants and evaluate the response dynamics at a higher frequency. In addition, all current studies examined the impact of bike sharing on public health using samples from developed countries (Europe and the USA). Our study is among the first ones sampling from a large developing country, in which the people may behave differently from those in the developed countries because of living standards.

METHODS

The Lingnan College, Sun Yat-sen University Ethics Review Committee deemed this study exempt from ethics review and waived the informed consent requirement because the study used existing, de-identified archival data and presented a low risk. We followed the Strengthening the Reporting of Observational Studies in Epidemiology reporting guidelines.[24] The patient and public were not involved in the study design or analysis.

Study population and data

Our analysis sample was routinely collected as part of the administrative records from one of the largest medical examination centres in China. We obtained the visit-level information for 159 examination centres from 47 cities, with participant identities anonymised. These cities were well scattered nationwide, covering 27 out of the 31 provinces in mainland China (excluding Tibet, Inner Mongolia, Qinghai and Gansu). The sample period was from June 2016 to August 2017.

For each visit, we were able to observe the timestamp and result of each test item, and each participant's gender, age and location. Our main outcome variable is BP, a required item for all visits. According to the bylaw of the medical examination centre, BP was measured on each participant's right upper arm at heart level using an electronic BP monitor after the participant was sitting at rest for 5 min.

While our full sample covered 8 107 363 visits by adult participants, our main analysis sample focused on the 5 554 284 visits by participants younger than 45. This sample filtering criterion was motivated by the low penetration rate of shared bikes for citizens older than 45 (accounting for only 10% of the total user base).[11] It may be due to the fact that older citizens in China during our sample period had a low adoption rate of smartphones, which were required for the usage of all bike-sharing platforms.[25] For this reason, older citizens were reserved for falsification tests in the later analysis.

Statistical analysis

Our empirical method exploited the roll-out of bike-sharing systems across different cities in China. The staggered entry events allow for a difference-in-differences (DiD) empirical framework. Therefore, our identification of causality boils down to comparing the changes in BP after the bike-sharing entry from cities that adopted bike-sharing earlier (ie, the treatment group) to the contemporaneous changes from cities that adopted bike-sharing later (ie, the control group). The DiD design allowed us to control for any confounding factors common to both groups. The validity of our empirical design hinged on the exogenous nature of these event events. That is, the exact timing of these events within our 15-month sample period did not correlate with such factors as the levels of health consciousness of the participants.

In online supplemental eTable 1, we reported the entry dates of bike-sharing systems for each city. These data were collected from public internet sites, the official websites of major bike-sharing systems and cross-validated with the data collected by existing studies.[26] One city experienced the entry of bike-sharing systems before our sample period began. Five cities introduced them after our sample period ended. For the remaining cities, the average timing of the entry events was February 2017,

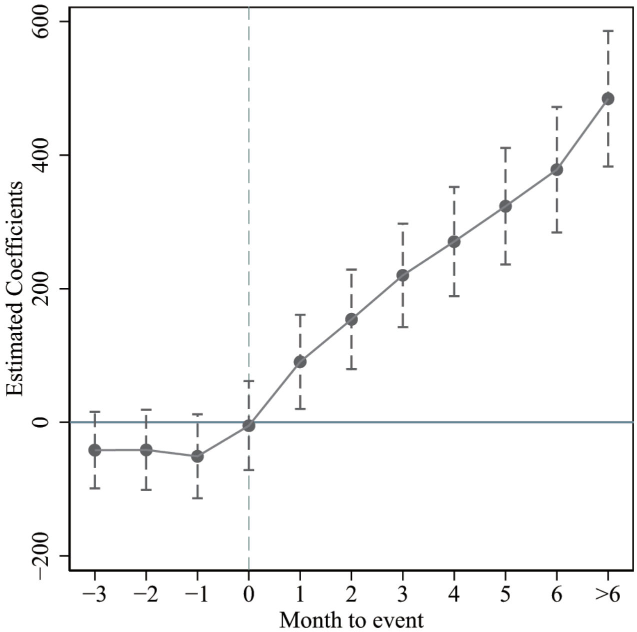

Figure 1 Association between bike-sharing platform entry and Search Volume Index of shared bikes. Note: city fixed effects and year-month fixed effects were controlled. Error bars represent 95% CIs.

which corresponds to the 9th month of our 15-month sample period.

Before discussing the statistical analysis for the association between bike-sharing systems and BP, we first evaluated the assumption of our analysis that the introduction of bike-sharing systems significantly encouraged the usage of shared bikes. We proxied the prevalence of shared bike usage among local citizens by the Baidu Search Volume Index (SVI) of the keyword 'shared bike' ('Gong Xiang Dan Che' in Chinese). Based on the panel of SVIs at the city-year-month level, we estimated the following event-study specification:

$$SVI_{ct} = \Sigma_{m=-3}\beta_m \times 1_{post\_m} + City_c + YM_t + \varepsilon_{ct} \qquad (1)$$

The dependent variable was the SVI for 'shared bike' in city c year-month t. 1_{post_m} was a dummy equal to one for the mth month after city c introduced a bike-sharing system. Observations before the third month prior to bike-sharing entry were absorbed as benchmarks. $City_c$ and YM_t denoted the city and year-month fixed effects, respectively. ε_{ct} was the error term.

Figure 1 shows the coefficient estimates of equation 1, along with the 95% CIs. We observed a salient and persistently increasing trend in the SVI for 'shared bike' after the introduction of bike-sharing systems (m≥0), relative to the absorbed benchmark period. This finding suggests a significant rise in citizens' interest, and arguably, their usage of shared bikes. In addition, the estimated effects for periods before the entry of bike-sharing systems (m<0) were statistically insignificant and economically negligible, which confirms the parallel-trends assumption and thus the validity of the DiD method.

We estimated the association between bike-sharing systems and BP using the following equation:

$$BP_{ict} = \begin{array}{l}\beta_s \times 1_{post\_short\_term} + \beta_l \times 1_{post\_long\_term} + \\ X_i + City_c + Date_t + \varepsilon_{ict}\end{array} \qquad (2)$$

The dependent variable was the measure of BP for visit i in city c date t, including systolic blood pressure (SBP), diastolic blood pressure (DBP) and a dummy indicating the hypertension status (SBP≥130 mm Hg or DBP≥80 mm Hg, as defined in the 2017 American College of Cardiology/American Heart Association guidelines).[27] $1_{post\_short\_term}$ was a dummy equal to 1 within the 6 months after a bike-sharing system entered city c. Therefore, β_s captured the short-term effect of the bike-sharing system entry. $1_{post\_long\_term}$ was a dummy equal to one for the period beyond the sixth month after a bike-sharing system entered city c. Correspondingly, β_l captured the long-term effect of the bike-sharing system entry. City fixed effects ($City_c$) and date fixed effects ($Date_t$) were included, aiming to control for time-invariant city-specific characteristics and time-varying factors common to all cities. X_i donated a series of control variables at the visit level, including the participant's age, BMI and gender. ε_{ict} was the error term. Robust SEs were clustered at the city-by-year-month level.

Recent advance in econometrics suggests that the standard two-way fixed effect (TWFE) estimator may be biased if the treatments occur in a staggered fashion and if the treatment effect varies across cohorts (city in our data) and/or over time. To mitigate this concern, we conducted a robustness check that repeated our main analysis based on the Sun and Abraham estimator.[28] Intuitively, for each treatment cohort g (ie, participants from cities that experienced bike-sharing platform entry in the same month), we used never-treated cities (ie, participants from cities that experienced bike-sharing platform entry after the end of our sample period) to estimate β_{sg} and β_{lg}, then calculated the average of the β_{sg} and β_{lg} using the weight specified by Sun and Abraham.[28] We used the Stata package 'eventstudyinteract' to perform the estimation, controlling for the identical set of fixed effects (city and date) and covariates (age, BMI and gender) as in equation 2.

We also examined the dynamic responses to the introduction of bike-sharing systems using the event study strategy as shown in the equation below:

$$BP_{ict} = \Sigma_{m=-3}\beta_m \times 1_{post\_m} + X_i + City_c + Date_t + \varepsilon_{ict} \qquad (3)$$

Similar to equation 1, β_m captured the response of BP in the mth month after city c introduced a bike-sharing system, relative to the benchmark period (m<−3).

Before reporting our main findings, we first examined the validity of our identifying assumption (ie, the exogenous nature of the entry events), by evaluating whether the entry events (a dummy variable 1_{event_time} equal to one for the month of the entry of bike-sharing platform into the local city) could be predicted by proxies of health consciousness or health conditions in the local city, including the city-level number of visits, the prevalence of hypertension in the past 1–3 months and the age composition of the participants (ie, the proportion of participants with age below 45). As reported in online supplemental eTables 2–4, these variables showed no significant predictability for the entry of bike-share systems, suggesting that these platforms did not choose to enter a city earlier or later based on the overall health consciousness or levels of BP of the city.

In addition, we would further verify the identifying assumption by studying the parallel-trends assumption. That is, BP in the treated cities did not exhibit a differential trend before the entry events relative to cities in the control group, or equivalently, β_m estimated from equation 3 were economically small and statistically insignificant for m<0.

Furthermore, we performed a series of placebo tests based on (1) a subgroup of participants who were less likely to adopt shared bikes, including older or obese participants; (2) outcome variables that should not be affected by the entry of bike-sharing platforms, such as the number of visits, the age composition of the participants and the prevalence of a disease that should not be affected by the entry events.

Lastly, we evaluated whether our sample selection criteria (age <45) introduced selection bias, by examining the composition of participants' ages changed after the entries of bike-sharing platforms. As reported in online supplemental eTable 5, the ratio of younger participants (age <45) over the total number of visits did not respond significantly to the entry events.

Following existing studies,[29] continuous variables were winsorised at the 1% and 99% levels, aiming to mitigate the biases induced by outliers (eg, due to measurement errors) in linear regression models. Data analysis was performed using Stata, V.17.0 (StataCorp). We initiated the analysis on 1 January 2023.

RESULTS

In our main analysis sample (adult participants with ages below 45), the mean (SD) of the SBP was 117.4 (14.3) mm Hg. The mean (SD) of the DBP was 72.4 (10.5) mm Hg. The rate of hypertension (SBP≥130 or DBP≥80 mm Hg) was 31.0%. In addition, 55% of the participants were men, with a mean (SD) age of 31.0 (6.6) years and a mean (SD) BMI of 23.2 (3.6). Summary statistics for the full sample and participants with ages above 45 were separately reported in online supplemental eTable 6.

Estimation of the association between the entry of bike-sharing systems and local residents' BP, according to equation 2, is reported in table 1. As shown in Column 1, we observed a reduction in local participants' SBP by 0.26 mm Hg (β (SE), −0.264 (0.169); 95% CI, −0.596 to 0.067) within the 6 months after the entry of bike-sharing systems, although the estimate was statistically insignificant under the conventional level of significance. In the long run (≥6 months after the entry events), the reduction in SBP was economically larger and statistically more significant, by 0.67 mm Hg (β (SE), −0.672 (0.245); 95% CI, −1.154 to −0.191). The reduction of

Table 1 Bike-sharing platform entry and blood pressure

	Visit level (age <45), N=5 554 284			Visit level (age <45), N=5 554 284			Visit level (age <45), N=5 554 284		
	SBP (mm Hg)			DBP (mm Hg)			$1_{hypertension}$ (SBP≥130 or DBP≥80)		
Sample	Estimate	(95% CI)	P value	Estimate	(95% CI)	P value	Estimate	(95% CI)	P value
$1_{post\_short\_term}$	−0.2644	(−0.596, 0.067)	0.118	−0.0810	(−0.324, 0.162)	0.513	−0.0100	(−0.019, −0.001)	0.022
$1_{post\_long\_term}$	−0.6722	(−1.154, −0.191)	0.006	−0.1927	(−0.572, 0.187)	0.319	−0.0138	(−0.027, −0.000)	0.045
Age	0.0414	(0.030, 0.052)	<0.001	0.1617	(0.156, 0.167)	<0.001	0.0033	(0.003, 0.004)	<0.001
BMI	1.1572	(1.143, 1.172)	<0.001	0.7285	(0.718, 0.739)	<0.001	0.0295	(0.029, 0.030)	<0.001
Male	8.1358	(8.050, 8.222)	<0.001	4.6272	(4.550, 4.704)	<0.001	0.1826	(0.178, 0.187)	<0.001

Note: fixed effects of city and date were controlled.
BMI, body mass index; DBP, diastolic blood pressure; SBP, systolic blood pressure.

DBP showed a similar but weaker pattern, by 0.08 mm Hg (β (SE), −0.081 (0.124); 95% CI, −0.324 to 0.162) in the short-run and 0.19 mm Hg (β (SE), −0.193 (0.193); 95% CI, −0.572 to 0.187) in the long run. In order to provide a more unambiguous interpretation of BP reduction as an improvement in BP conditions (rather than leading to a BP level below the normal range), Column 3 reported the results of a dummy variable indicating the status of hypertension. We observed a significant reduction in the prevalence of hypertension by 1.0% point (β (SE), −0.010 (0.004); 95% CI, −0.019 to −0.001) within the 6 months after the entry events, and by 1.4% points (β (SE), −0.014 (0.007); 95% CI, −0.027 to −0.000) in the long run. Regarding the control variables, BP was significantly higher among participants who were older, who had higher BMI values or who were men. These findings are also consistent with those documented in previous studies based on national representative surveys.[30]

In online supplemental eTable 7, we further report the response of hypertension status by different stages, as specified by the American Heart Association. The association between bikeshare programmes and hypertension was mainly driven by the reduced prevalence of stage-1 hypertension (SBP between 130 and 140 mm Hg or DBP between 80 and 90 mm Hg). In contrast, the responses of more severe hypertension, especially stage-3 hypertension (SBP>180 mm Hg or DBP>120 mm Hg), were economically small and statistically less significant.

Results of the robustness tests are consistent with the baseline findings and are provided in online supplemental eTable 8. The Sun and Abraham estimators were quantitatively and qualitatively similar to the TWFE estimators as shown in table 1, suggesting that our findings were not significantly biased by the potential issue of heterogeneous treatment effects. In online supplemental eTable 9, we employed different strategies of winsorisation (ie, at the 0.1% and 99.9% levels, the 0.01% and 99.99% levels and the 0.001% and 99.999% levels). We find the specific scheme of winsorisation has little impact on the estimates.

Next, we employed an event study design (equation 3) and tested the dynamic association between the entry of bike-sharing systems and local citizens' BP (figure 2). Across all graphs, the estimated effects for periods before the introduction of bike-sharing systems (m<0) were statistically insignificant and economically negligible, which again verified the parallel-trends assumption and thus the validity of the DiD method. In addition, we found a salient decreasing trend of SBP (figure 2A) and the prevalence of hypertension (figure 2C) after the entry of bike-sharing systems (m≥0). These response dynamics tracked closely with the dynamics of the public's awareness of shared bikes (figure 1), offering further evidence that the reduction in BP was likely attributable to shared bikes. The response of DBP (figure 2B) showed a similar but weaker trend.

To further verify the validity of our empirical design, in table 2, we examined the response of three outcome variables that should not be associated with the entry of bike-sharing platforms, aiming to rule out the effect of unobservable factors that may confound our results. In Column 1, we demonstrated that the number of visits had no significant association with the entry of bike-sharing platforms. In addition, the ages of the participants were also not significantly affected by these entry events, as estimated in Column 2. Collectively, these results helped alleviate the concern that these entry events coincided with factors that attracted more (younger and potentially healthier) participants to conduct medical examinations. Lastly, among participants who were less likely to adopt shared bikes (age ≥45), their BP showed no significant association with platform entries. Therefore, our main findings were unlikely driven by confounding events that affected younger and older participants similarly.

In online supplemental eTable 10, we further examined the response of hepatitis B infection (ie, hepatitis B surface antigen (HBsAg) positive) as a falsification test. To the extent that the hepatitis B virus is transmitted through blood and sexual fluids, its prevalence should not be associated with the entry of bike-sharing platforms. Consistent with this argument, in column 1, we find the response of hepatitis B infection was statistically insignificant and economically close to zero. One caveat of this test is that the HBsAg test was not a mandatory test item: only 27% of the visits (1 513 525 out of 5 554 284) in our main analysis sample performed this test. However, the findings in Column 1 were unlikely confounded by selection issues given that the likelihood of a visit including the HBsAg test showed no significant association with the entry events of bike-sharing platforms, as reported in Column 2.

Next, we examined the response heterogeneity of bike-sharing platforms on BP. The first dimension of response heterogeneity is on participants' genders. As shown in figure 3A, while the effect trajectories of the two groups tracked each other closely before the entry events, male participants showed a more pronounced reduction in BP after the events. As reported in online supplemental eTable 11, the response differences between the two subgroups were statistically significant both in the short-term (p=0.015) and long-term (p=0.044). These results are consistent with the findings in the previous studies that bike-sharing programmes mainly promote bicycle ridership among men.[20]

The second dimension of response heterogeneity is on participants' BMI. As shown in figure 3B, participants who were underweight (BMI<18.5), normal (18.5≤BMI<25) and overweight (25≤BMI<30) enjoyed similarly significant improvements in blood pressure. Nevertheless, obese participants (BMI≥30) show almost no change in blood pressure. As shown in online supplemental eTable 12, the response differences between obese participants and the remaining participants were statistically significant both in the short-term (p=0.030) and long-term (p<0.001). These results are consistent with a negative association between obesity and the inclination of active

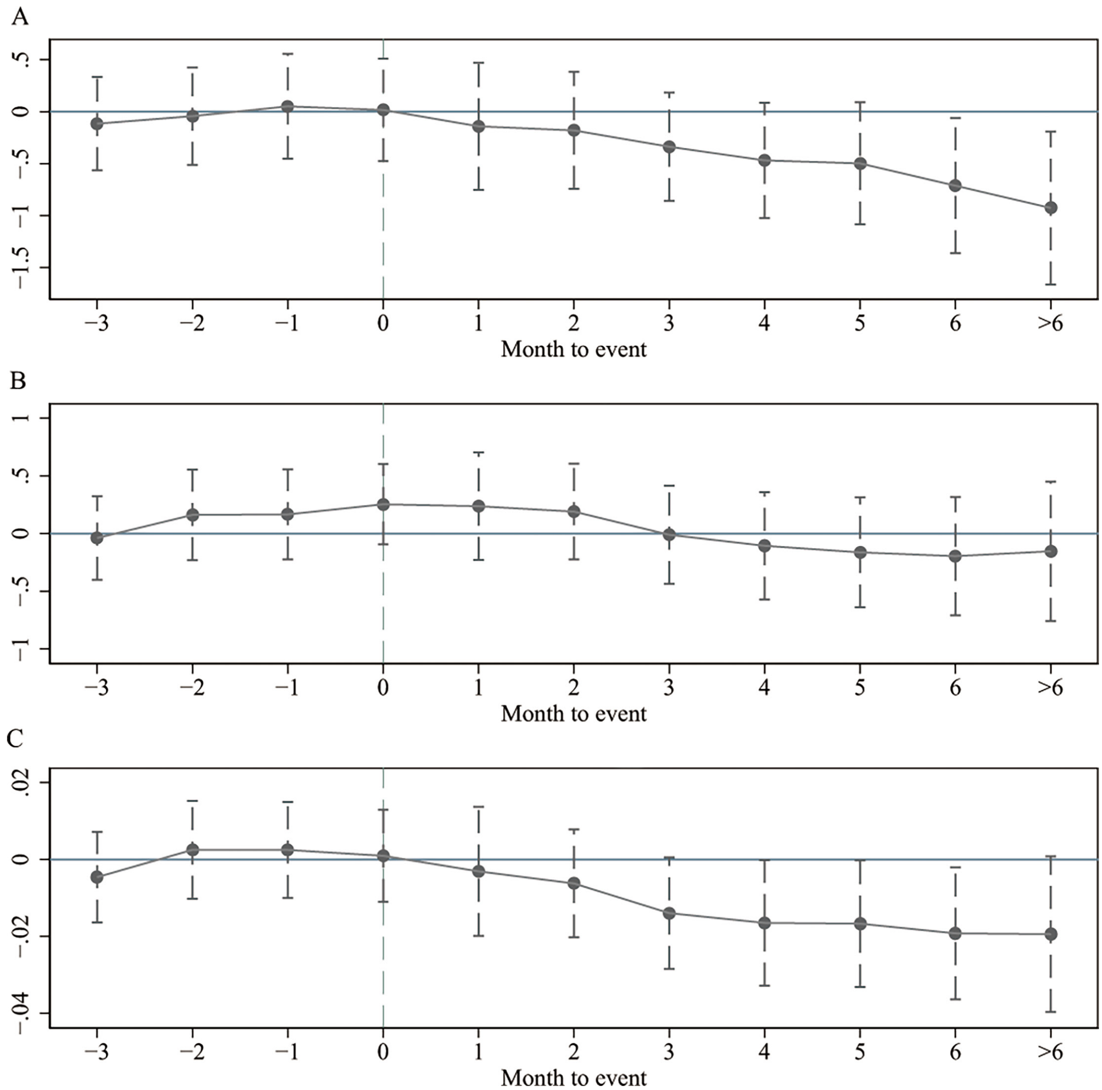

Figure 2 Association between bike-sharing platform entry and blood pressure. (A) Systolic blood pressure. (B) Diastolic blood pressure. (C) $1_{hypertension}$. Note: city fixed effects and date fixed effects were controlled. Error bars represent 95% CIs.

commuting, implying a lower rate of bike-sharing adoption among obese participants.[31]

The last dimension of response heterogeneity is on participants' ages. As shown in figure 3C, younger participants (age <30) showed a visually more salient reduction in BP after the entry events than older participants (30≤ age <45). This pattern is consistent with the higher penetration rate of shared bikes among the younger population.[11] That said, as shown in online supplemental eTable 13, the response differences between the two groups were not precisely estimated, and not statistically significant under the conventional level of significance (p=0.497 for $1_{young}*1_{post\_short\_term}$, and p=0.055 for $1_{young}*1_{post\_long\_term}$). Collectively, we documented a larger reduction in BP among men, younger and non-obese participants, who were more likely to experience an increase in bicycle ridership and thus physical activity in response to the entry of bike-sharing systems.

Lastly, we examined the response for each city. Specifically, for each city c, we estimated equation 2 by additionally including $1_{post\_short\_term}*1_{city\_c}$ and $1_{post\_long\_term}*1_{city\_c}$, where 1_{city_c} was a binary indicator for city c. Note that the coefficients of these two interaction terms cannot be identified if $1_{post\_short\_term}$ or $1_{post\_long\_term}$ did not vary in city c during our sample period. This may be the case if bike-sharing platforms entered city c too early or too late. The coefficients ($1_{post\_short\_term}+1_{post\_short\_term}*1_{city\_c}$) and ($1_{post\_long\_term}+1_{post\_long\_term}*1_{city\_c}$) thus captured the short-term and long-term response for city c. Results were reported in the online supplemental eFigure 1. We found that 26 out of the 39 cities with the coefficient $1_{post\_short\_term}*1_{city\_c}$ identified showed a reduction in SBP; 18 out of the 23 cities with the coefficient $1_{post\_long\_term}*1_{city\_c}$ identified showed a reduction in SBP. However, a direct, quantitative comparison of the estimates across cities needs caution, given that the treatment effect was time-varying (as shown in figure 2) and that cities were treated at different times.

Table 2 Additional tests

Sample	City-year-month level, n=684*			Visit level (full sample), n=8 107 363†			Visit level (age ≥45), n=2 553 079†		
	Log (# visits)			Age			SBP		
	Estimate	(95% CI)	P value	Estimate	(95% CI)	P value	Estimate	(95% CI)	P value
$1_{post\_short\_term}$	0.0214	(−0.117, 0.160)	0.762	0.0818	(−0.608, 0.771)	0.816	0.1106	(−0.504, 0.725)	0.719
$1_{post\_long\_term}$	−0.0180	(−0.260, 0.225)	0.886	0.3075	(−0.906, 1.521)	0.619	0.1810	(−0.857, 1.219)	0.727
Age							0.7127	(0.692, 0.733)	<0.001
BMI							1.4555	(1.428, 1.483)	<0.001
Male							2.2048	(1.792, 2.618)	<0.001

*Fixed effects of city and year-month were controlled.
†Fixed effects of city and date were controlled.
BMI, body mass index; SBP, systolic blood pressure.

DISCUSSION

In this study, we exploited a large-scale physical examination dataset covering over 8 million visits from 47 cities, to study the association between the introduction of bike-sharing platforms and the BP of local citizens. Baseline estimations indicated a reduction in SBP by 0.67 mm Hg and a reduction in the prevalence of hypertension by 1.4% points after bike-sharing platforms entered the local cities for more than 6 months. Compared with the literature on the effect of aerobic exercises on BP, our estimates are notably smaller. Specifically, based on a meta-analysis of 57 clinical trials of 2543 subjects, aerobic exercises were found to reduce SBP by 2 mm Hg (95% CI, −3 to −1).[32] The included training programmes had an average intensity of 67% VO_{2max} (SD=10%), and a length of 40 (SD=12) minutes for 3 (SD=1) times per week, generally comparable to the intensity of active commuting by cycling. Our smaller estimates are consistent with the fact that not all participants were shared-bike users. That being said, with the large user base of shared bikes, our study clearly showed the feasibility of bike-sharing systems as a supplemental community-level approach to lower BP at the population level.

Although our falsification tests and response heterogeneity suggested that the association between bike-share systems and BP was unlikely contaminated by other confounding factors, one may still be concerned about the exact channel that drove the association. For example, bike-sharing systems might affect the local air conditions, which could independently reduce the BP of local citizens.[33 34] However, our findings did not square with this interpretation. Specifically, we did not find participants whose BP conditions were more sensitive to air pollution (eg, obese or older participants) benefited more after the entry of bikeshare systems.[35 36] In contrast, because obese or older participants rarely adopt shared bikes, we observed close to zero association between their BP conditions and bikeshare systems (table 2 Column 3 and figure 3B). Collectively, while we cannot completely rule out the air condition channel, the reduction in BP we documented was more likely explained by bike-sharing systems promoting physical activity.

One may also be concerned that the results based on individuals who visited medical examination centres may not be generalisable to the population. Specifically, those who visited medical examination centres might be more health-conscious, and thus more likely to adopt shared bikes and enjoy the health benefits. However, this was unlikely the case in our sample. First, for the participants in our main analysis sample (adults aged below 45), their visits to health examination centres were mostly induced by pre-employment medical checks or complimentary health checks provided by employers, instead of voluntary visits due to a higher level of health consciousness. In contrast, we found little improvement in BP among older participants, whose visits were more likely self-selected. We further directly evaluated the representativeness of our data by looking at the summary statistics of our sample

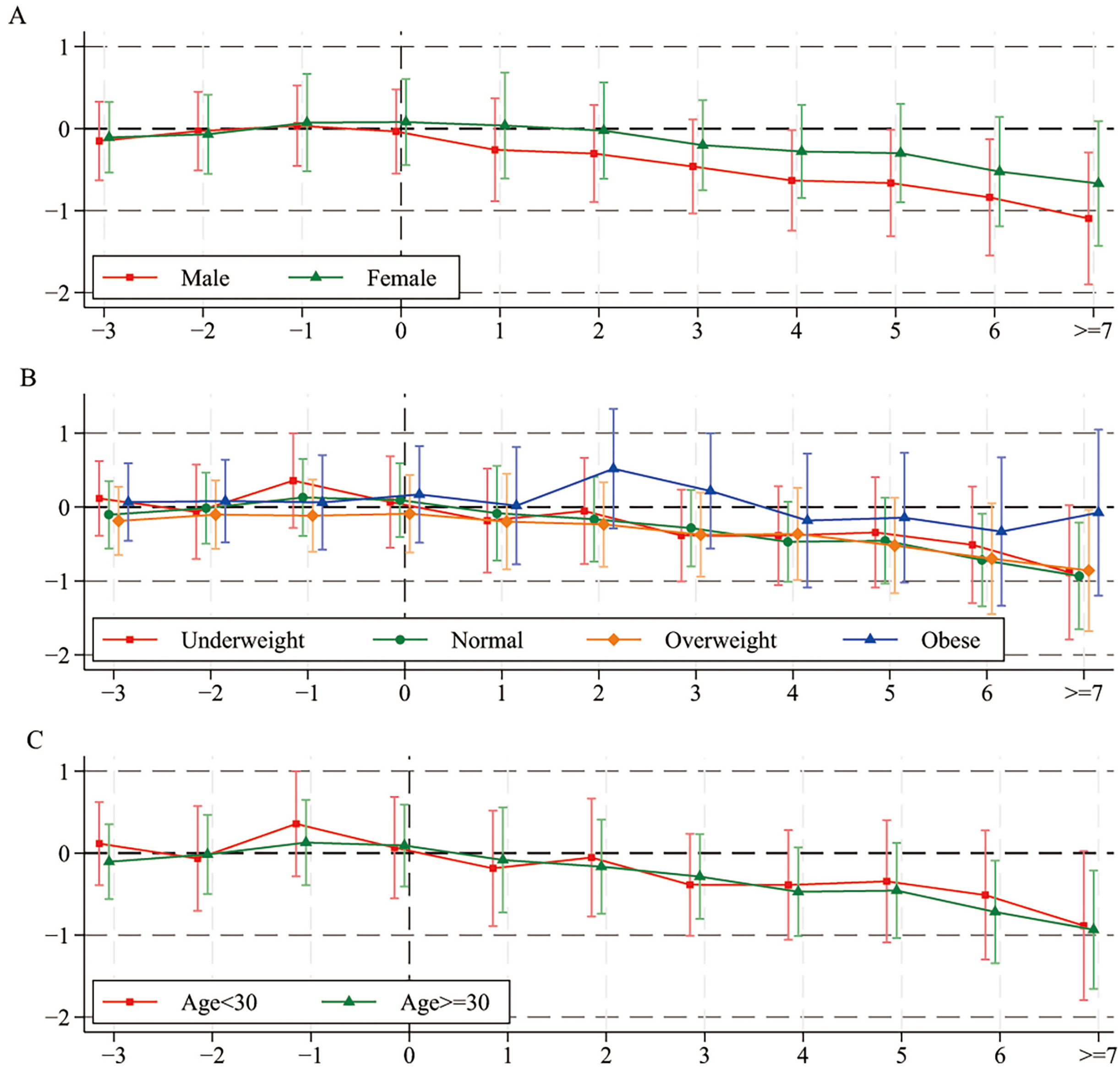

Figure 3 Response heterogeneity by gender, BMI and age. (A) SBP, by gender. (B) SBP, by BMI. (C) SBP, by age. Note: city fixed effects and date fixed effects were controlled. Error bars represent 95% CIs. BMI, body mass index; SBP, systolic blood pressure.

(shown in online supplemental eTable 6). The key statistics were generally comparable to the national average for the corresponding age cohorts. Specifically, the rate of hypertension (SBP≥130 or DBP≥80 mm Hg) was 31.0%, largely consistent with the findings in the China Hypertension Survey (2012–2015), which documented a rate of hypertension (SBP≥130 or DBP≥80 mm Hg) equal to 23.0%, 28.0% and 41.7% among the age group 18–24, 25–34 and 35–44.[30] Regarding other characteristics of the participants, the average BMI was 23.2, with rates of underweight, overweight and obesity equal to 7.7%, 24.3% and 4.8%, respectively. These statistics are also consistent with those derived from nationally representative surveys.[37 38]

This study has limitations. The city-level information on bike-sharing platform entry cannot directly correspond to the actual usage of shared bikes for each participant in our sample. We have attempted to mitigate this concern by showing that the response was stronger across subgroups with higher levels of shared bike adoption rates (male, younger and non-obese participants).

In addition, the information on BP (one-time measurement via an automated measurement system) may be subject to measurement errors, which we were unable to directly detect and manage due to the secondary nature of the data. However, such (random) error was unlikely to be systematically correlated to the entry events of bike-sharing platforms. Our large sample size (over 5 million in the main analysis sample) was likely sufficient to cancel out any random measurement errors in the regression analysis.

Lastly, our physical examination data only included the most basic demographic information (age, BMI and gender), all of which were controlled for in our empirical analysis. Other information such as socioeconomic status and pre-existing health conditions were unobservable in our data. We tried to mitigate this potential omitted variable bias by additionally controlling for the size of the physical examination plan (ie, log number of test items included). In online supplemental eTable 14 Column 1, we find a strong (p value<0.001) and negative correlation between the size of the examination plan and SBP. This finding is consistent with the negative association between income or health consciousness and BP,[30] suggesting that this variable was informative in terms of capturing the related omitted information. More importantly, including this new control variable had little effect on the estimates of our core variables. We also directly examined whether the entry of bike-sharing platforms affected our proxy for participants' socioeconomic status and pre-existing health conditions. As reported in Column 2, the size of physical examination plans showed no significant response to the entry events, which was also consistent with the random nature of the entry events. Therefore, omitting-related control variables should not significantly bias our estimates.

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