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Evaluation of the impact of a public bicycle share program on population bicycling in Vancouver, BC

Kate Hosford[a,b,*], Daniel Fuller[c,d], Scott A. Lear[a,e], Kay Teschke[f], Lise Gauvin[g,h], Michael Brauer[f], Meghan Winters[a,b]

[a] Faculty of Health Sciences, Simon Fraser University, 8888 University Drive, Burnaby, BC V5A1S6, Canada
[b] Centre for Hip Health and Mobility, 2635 Laurel Street, Vancouver, BC V5Z 1M9, Canada
[c] School of Human Kinetics and Recreation, Memorial University of Newfoundland, Physical Education Building, St. John's, Newfoundland A1C 5S7, Canada
[d] Department of Community Health and Humanities, Faculty of Medicine, Memorial University of Newfoundland, St. John's, Newfoundland A1B 3V6, Canada
[e] Division of Cardiology, Providence Health Care, 1081 Burrard Street, Vancouver, BC V6Z 1Y6, Canada
[f] School of Population and Public Health, University of British Columbia, 2206 East Mall, Vancouver, BC V6T 1Z3, Canada
[g] Centre de recherche du Centre Hospitalier de l'Université de Montréal (CRHCUM), 900, rue Saint-Denis, Pavillon R, Montréal, Québec H2X 0A9, Canada
[h] École de santé publique de l'Université de Montréal (ESPUM), 7101, Avenue du Parc, Montréal, Québec H3N 1X9, Canada

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ABSTRACT

Public bicycle share programs have been implemented in cities around the world to encourage bicycling. However, there are limited evaluations of the impact of these programs on bicycling at the population level. This study examined the impact of a public bicycle share program on bicycling amongst residents of Vancouver, BC. Using an online panel, we surveyed a population-based sample of Vancouver residents three times: prior to the implementation of the public bicycle share program (T0, October 2015, $n = 1111$); in the early phase of implementation (T1, October 2016, $n = 995$); and one-year post implementation (T2, October 2017, $n = 966$). We used difference in differences estimation to assess whether there was an increase in bicycling amongst those living and/or working in close proximity (≤500 m) to Vancouver's *Mobi by Shaw Go* public bicycle share program, compared to those living and working outside this area. Results suggest that only living or only working inside the bicycle share service area was not associated with increases in bicycling at T1 or T2 relative to those outside the service area. Both living and working inside the bicycle share service area was associated with increases in bicycling at T1 (OR: 2.26, 95% CI: 1.07, 4.80), however not at T2 (OR: 1.37, 95% CI: 0.67, 2.83). These findings indicate that the implementation of a public bicycle share program may have a greater effect on bicycling for residents who both live and work within the service area, although this effect may not be sustained over time.

1. Introduction

Public bicycle share programs are an example of a population-based intervention with potential to shift populations towards active transportation. Over the past decade, there has been a marked increase in the popularity and number of bicycle share programs operating globally, increasing access to bicycling in these cites (Meddin and DeMaio, 2018). Literature on public bicycle share programs covers the demographics of system users, motivators and barriers to use, usage and redistribution patterns, and equity considerations, however, there is limited evidence on the population level impacts of these programs on bicycling (Bauman et al., 2017; Fishman et al., 2013; Ricci, 2015). These programs have the potential to increase population-wide bicycling by increasing access to bicycling for those who do not own a personal bicycle, increasing the convenience of bicycling, and by normalizing bicycling as a form of transportation (Buck et al., 2013; Goodman et al., 2014a; Shaheen et al., 2010).

For interventions where randomization or experimental control is not possible, natural experiment studies can be used to study potential intervention effects (Craig et al., 2017). To date, there is one example of a natural experiment study of a bicycle share program in Montréal (Fuller et al., 2013). This study found increases in self-reported bicycling for those who lived close to a bicycle share docking station relative to those who were not in the bicycle share zone at the end of the second season of *BIXI Montréal* (Fuller et al., 2013). These findings provide evidence on the impacts of bicycle share on bicycling for those

* Corresponding author at: Faculty of Health Sciences, Simon Fraser University, 8888 University Drive, Burnaby, BC V5A1S6, Canada.
E-mail address: khosford@sfu.ca (K. Hosford).

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who live near a docking station, but there is limited evidence on the effects of working in the area. Moreover, bicycle share programs are implemented at different scales and program uptake varies widely across cities. Assessing the impacts of bicycle share in different cities can provide decision makers with evidence on potential changes in population bicycling associated with bicycle share programs implemented at different scales and in different contexts.

In July 2016, the City of Vancouver implemented a public bicycle share program, *Mobi by Shaw Go*, as part of their commitment to make bicycling more accessible to Vancouver residents. The program was implemented in Vancouver's most densely populated area, and as of October 2017, had over 1200 bicycles at 122 stations covering a land area of 17 km^2. The objective of this study was to examine whether there were increases in bicycling amongst those living or working in close proximity (≤500 m) to Vancouver's public bicycle share program relative to those living and working outside the program's service area.

2. Methods

2.1. Context

The City of Vancouver is home to > 631,000 residents (Statistics Canada, 2016). With over 320 km of bikeways and a mild climate, bicycling year-round is a viable option (City of Vancouver, 2018). In 2016, bicycling accounted for approximately 6.1% of all trips made to work, higher than most other Canadian cities (Statistics Canada, 2016). In the first year of Vancouver's public bicycle share program, 6400 memberships were purchased and approximately 436,000 trips were taken on *Mobi* bicycles (City of Vancouver, 2017). In 2017, the cost to use *Mobi* bicycles for unlimited 30-minute trips was $9.75 (Canadian dollars) for a day pass, $75 for a 3-month pass, and $129 for an annual pass.

2.2. Design

We used a repeated cross-sectional design. Vancouver residents (≥18 years) were recruited through an online panel using age and sex quotas to obtain representative samples. Surveys were conducted prior to the implementation of the public bicycle share program, (T0; October 13–28, 2015); in the early phase of implementation, (T1; October 13–31, 2016); and 15 months post implementation, (T2; October 13–31, 2017). The survey included questions on travel patterns in the past seven days, physical activity, bicycling behaviour, bicycle share knowledge and use (or potential use, pre-implementation), individual and household demographics, and place of residence and work or school. The number of bicycles and docking stations available during each survey period are shown in Fig. 1. All study procedures were approved by the Simon Fraser University Research Ethics Board and respondents provided informed consent.

2.3. Measures

The outcome was self-reported bicycling in the past week. Respondents were categorized according to whether they reported bicycling for any purpose (transportation or leisure) in the past week (> 0 min) or not (0 min).

The primary independent variables were survey period (i.e. year) and residing or working within the bicycle share service area (i.e., exposure to the bicycle share service area). Survey period was operationalized by using dummy variables to distinguish the three survey periods: T0 (2015), T1 (2016), and T2 (2017). Exposure to the bicycle share service area was based on respondent's home and work locations, where respondents with one or more *Mobi by Shaw Go* docking stations within a 500 m road network buffer of their home, work or school were considered to be within the service area. We picked a distance of 500 m because previous bicycle share studies use this distance to define bicycle share service areas (Fuller et al., 2013; Ogilvie and Goodman, 2012; Ursaki and Aultman-Hall, 2016), and because living within 500 m of a docking stations is associated with increased odds of using bicycle share (Bachand-Marleau et al., 2012). We asked survey respondents to provide a 6 digit postal code or the nearest intersection for their home and, if applicable, work or school location. We geocoded this information and the docking station locations (provided by *Mobi by Shaw Go*) in ArcGIS 10.5. In urban areas, postal codes correspond to approximately one city block. We assigned respondents to one of four groups: (1) not exposed, (2) exposed at work, (3) exposed at home, or (4) exposed at work and home. Even though there was no bicycle share program in 2015, we categorized 2015 respondents to one of the four exposure groups based on docking station locations in October 2016. This allows us to make a reasonable comparison of intervention and control groups over time.

Potential confounders were identified a priori based on individual and environmental variables that could influence bicycling. Individual variables included sex, age, education, annual household income, place of birth (Canada or elsewhere), car ownership, and self-reported health. Environmental variables considered were mean weekly temperature and total precipitation in the week preceding survey completion, as differences in weather may affect bicycling rates across survey periods. Data on temperature and precipitation were obtained from Environment Canada (Government of Canada, 2017).

2.4. Analysis

We applied post-stratification weights based on age and sex strata in the 2016 Canadian census data to all analyses. We ran unadjusted and adjusted logistic regression models with difference in differences estimators to assess associations between bicycling, time, and exposure to the public bicycle share service area. This approach compares the difference in outcomes (i.e., bicycling) for a population that is exposed to

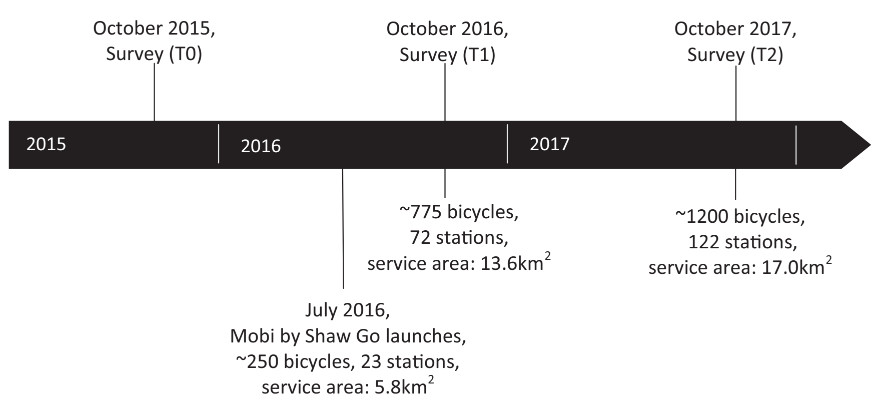

Fig. 1. Timeline of the *Mobi by Shaw Go* public bicycle share program implementation in Vancouver, BC and survey periods, 2015–2017.

the intervention (i.e., lives or works within the service area) and for a population that is not exposed (i.e., lives and works outside the service area) before and after the intervention (Craig et al., 2012; Fuller et al., 2013). Difference in differences models include 1) a time variable, which estimates the average change in the outcome over time, 2) a treatment variable, which estimates differences between the intervention and control group, and 3) an interaction term between time and treatment, which estimates the difference in the average change in outcome over time between the intervention and control group (Meyer, 1995). The interaction term is intended to estimate the effect of the intervention on the outcome over time and is therefore the primary effect of interest in this analysis. We included covariates associated with the dependent variable in bivariate analysis at a significance level of $p < 0.10$ in multiple logistic regression and used backward stepwise regression using the Akaike Information Criterion (AIC) to construct a model with the lowest AIC value. Independent variables typically associated with bicycling (age, sex, and income) were included in the multiple regression model, even if not statistically significant.

3. Results

The pooled sample included 3072 respondents (≥18 years) with 1111 respondents in 2015, 995 in 2016, and 966 in 2017. Cooperation rates were 21.0%, 19.8%, and 15.6%, by year. Of the 3072 respondents, 168 were excluded because they lived outside the study area, and 263 were excluded because of missing postal code ($n = 176$) or sociodemographic data ($n = 87$). Our final sample included 2641 participants (86% of the initial sample).

Weighted demographic characteristics and bicycling rates, by year, are in Table 1. The sample is reflective of the Vancouver population in terms of age and sex, however, respondents in the surveys had higher incomes and education levels and were more likely to be born in Canada compared to census data. The proportion of respondents that had bicycled (on a personal bicycle or *Mobi by Shaw Go* bicycle) at least once for any purpose in the past 7 days was 17.1% in 2015, 15.6% in 2016, and 17.4% in 2017. A larger proportion of respondents engaged in recreational bicycling as compared to utilitarian bicycling. The proportion that had used bicycle share increased from 3.2% in 2016 to 6.2% in 2017. Support for the public bicycle share program increased slightly from 70.4% of respondents reporting that the program was a good idea for Vancouver in 2015 to 75.0% in 2017.

In bivariate analyses, all variables were associated with odds of bicycling at $p < 0.10$ with the exception of education, place of birth, and weather variables. The latter variables were excluded from adjusted models because they did not reach significance in bivariate models. Weighted logistic regression models examining the relationship between exposure to the bicycle share service area, time, and their interaction with bicycling in the past 7 days are shown in Table 2. In the full model, the coefficient for survey period is an estimate of the average change in bicycling over time in the unexposed group. We observed that for people not living or working inside the service area, the odds of bicycling was not different at T1 or T2, compared to T0. The coefficient for exposure is an estimate of baseline differences between the exposed (living and/or working in the service area) and unexposed groups. At baseline, relative to the unexposed group, the odds of bicycling were not different at any level of exposure.

The interaction term (time × exposure), the primary coefficient of interest, estimated the difference in the average change in the outcome over time between the exposed and unexposed groups. Over the study period, there was no evidence that the implementation of the bicycle share program increased the odds of bicycling for those who only work or only live within the service area, relative to those outside the service area. For those who both live and work within the service area, the odds of bicycling was greater at T1 (OR: 2.26, 95% CI: 1.07, 4.80) as compared with those outside the service area, and was also in the positive direction at T2, although the confidence interval crossed 1 (OR: 1.37, 95% CI: 0.67, 2.83). Due to relatively small sample sizes at each exposure level, the confidence intervals were wide for the interaction term.

4. Discussion

This study assessed whether there were greater increases in bicycling amongst those living or working in close proximity to Vancouver's public bicycle share program relative to those living and working outside the program's service area. The results show that over time, those only living or only working within the service area were not more likely to bicycle compared to those outside the service area. For those both living and working within the service area, we observed an increase in bicycling at three months following the implementation of the bicycle share program (T1), however this increase was not sustained at fifteen months following implementation (T2). This could be explained by an initial excitement surrounding program implementation that subsided over time.

Bicycle share programs can directly increase population bicycling from the use of the bicycle share program itself, and also indirectly, through increases from personal bicycle use. The second pathway, increases from personal bicycles, could arise if the use of public bicycle share motivates users to also ride their personal bicycles more frequently, or if having a public bicycle share program as part of the city normalizes bicycling and influences non-users to bicycle more frequently. It is plausible that residents who live and work within the service area might increase their bicycling more than those outside the service area, as they are exposed to the public bicycle share program on a regular basis, and therefore, may be more likely to use the program (pathway 1) or be influenced to ride their own personal bicycle (pathway 2).

The current findings differ from a similar study in Montréal that showed increases in overall bicycling for those who lived close to a docking station relative to those outside the service area, at the end of the second season of *BIXI Montréal* (Fuller et al., 2013). In the current study, we did observe a positive association for those who both lived and worked within the service area, but not for those who only lived in the area. Further, the observed effect estimate was larger in the first season, with confidence intervals of the effect estimate crossing 1 in the second season. Differences in scale and implementation timeline may be one explanation for differing results. Vancouver's program started modestly with 250 bicycles at 23 stations located in Vancouver's downtown core, and slowly built over the two years to 1200 bicycles at 122 stations. In comparison, the Montréal program launched with 3000 bicycles at 300 stations in the first year. In addition, only a small proportion of Vancouver residents had used bicycle share (3.2% of survey respondents in 2016, 6.2% in 2017), lower than the estimated 8.2% of Montréal residents that used bicycle share in the first season of the program's operation (May–Nov 2010) (Fuller et al., 2011).

Moreover, trips made on bicycle share bicycles were only a small fraction of overall bicycling trips in Vancouver, which are estimated at 46 million trips per year based on daily estimates of 128,000 trips per day (City of Vancouver, 2016). In *Mobi by Shaw Go*'s first year of operation, approximately 436,000 trips were made on Mobi bicycles, and at the point of our 2017 survey (15 months of operation, including two summers), a total of over 680,000. Public bicycle share trips thus constituted < 1% of bicycling trips in the City. It is also worth noting that not all trips made by bicycle share are new bicycle trips because some trips would have been made by personal bicycle previously. Surveys with *Mobi by Shaw Go* members suggest that approximately 6–8% of bicycle share trips replace trips previously made by personal bicycles (Winters and Therrien, 2017).

Attributing increases in bicycling to a bicycle share program is difficult because the implementation of these programs often coincides with secular trends of increased bicycling, as cities typically make upgrades to bicycle infrastructure concurrently. Difference in differences

Table 1
Weighted sociodemographic characteristics of survey respondents' at three time points concurrent with the 2016 launch of the *Mobi by Shaw Go* Public Bicycle Share Program in Vancouver, BC (2015–2017).

Variable	Pre-implementation T0, Oct 2015 n = 939		T1, Oct 2016 n = 841		T2, Oct 2017 n = 862	
	Weighted n (%)		Weighted n (%)		Weighted n (%)	
Bicycling (any purpose) in the past 7 days						
Yes	160.8	(17.1)	131.6	(15.6)	149.7	(17.4)
No	778.0	(82.9)	709.8	(84.4)	712.2	(82.6)
Utilitarian bicycling in the past 7 days						
Yes	104.2	(11.1)	87.9	(10.4)	92.4	(10.7)
No	834.6	(88.9)	753.5	(89.6)	769.5	(89.3)
Recreational bicycling in the past 7 days						
Yes	115.9	(12.3)	99.9	(11.9)	117.6	(13.6)
No	822.9	(87.7)	741.5	(88.1)	744.3	(86.4)
Bicycle share service area[a]						
Outside	528.6	(56.3)	463.3	(55.1)	413.2	(47.9)
Work inside	132.1	(14.1)	114.1	(13.6)	94.3	(10.9)
Home inside	156.4	(16.7)	166.5	(19.8)	206.9	(24.0)
Home and work inside	121.8	(13.0)	97.6	(11.6)	147.4	(17.1)
Bicycle share use						
Yes	–	–	26.9	(3.2)	53.7	(6.2)
No	–	–	808.7	(96.1)	802.4	(93.1)
Don't know	–	–	5.8	(0.7)	5.8	(0.7)
Perception of bicycle share in Vancouver (good idea)	661.2	(70.4)	602.6	(71.6)	646.0	(75.0)
Perceived safety of bicycling in Vancouver (safe)	434.0	(46.2)	390.0	(46.4)	427.4	(49.6)
Sex						
Female	486.7	(51.8)	435.3	(51.7)	442.6	(51.4)
Male	452.1	(48.2)	406.1	(48.3)	419.3	(48.6)
Age (years)						
18–24	99.2	(10.6)	85.5	(10.2)	86.7	(10.1)
25–34	210.2	(22.4)	181.0	(21.5)	191.1	(22.2)
35–44	161.5	(17.2)	142.1	(16.9)	146.7	(17.0)
45–54	152.7	(16.3)	145.8	(17.3)	147.2	(17.1)
55–64	136.5	(14.5)	126.0	(15.0)	128.9	(15.0)
65 +	178.7	(19.0)	161.0	(19.1)	161.3	(18.7)
Annual household income						
< \$50,000	228.8	(24.4)	207.7	(24.7)	216.3	(25.1)
\$50,000–\$150,000	427.9	(45.6)	395.2	(47.0)	403.9	(46.9)
> \$150,000	79.8	(8.5)	84.6	(10.1)	96.4	(11.2)
No response	202.3	(21.5)	153.9	(18.3)	145.3	(16.9)
Car ownership						
Yes	749.6	(79.8)	665.1	(79.0)	645.0	(74.8)
No	189.2	(20.2)	176.3	(21.0)	217.0	(25.2)
Self-reported health						
Poor/fair	135.1	(14.4)	121.5	(14.4)	96.0	(11.1)
Good	292.9	(31.2)	279.4	(33.2)	267.3	(31.0)
Very good/excellent	510.8	(54.4)	440.6	(52.4)	498.6	(57.8)
Mean temperature	13.1 °C		11.5 °C		10.4 °C	
Mean daily rainfall	2.5 mm		8.1 mm		11.3 mm	

[a] The bicycle share service area is defined as the area within 500 m of a bicycle share docking station.

analysis can partly, but not completely, account for some of these other factors. For example, between our baseline survey at T0 and follow-up survey at T2, a greater density of bicycle routes were added inside the bicycle share service area (0.44 km/km^2) compared to outside (0.09 km/km^2) (City of Vancouver, 2018). In addition, there are two crucial assumptions of the difference in differences method that should be met in order to obtain unbiased estimates of the intervention effect. First, the parallel trend assumption, which assumes that in the absence of the intervention the average outcomes for the intervention group and control group would follow parallel trends over time (Craig et al., 2017). This assumption is difficult to test because it would require multiple data points prior to the intervention and spatially resolved longitudinal data on overall cycling is not available. Second, difference in differences assumes no changes in relevant aspects of the population demographic structure over time (Craig et al., 2017). In our case, there are two possible ways this assumption could be violated: changes in the sociodemographic structure of the study area overall, or changes in the sociodemographic structure in the exposed and non-exposed groups due to the expansion of the bicycle share service area over time. We did not see any other major differences in the composition of our sample over time, with the exception of car access. The proportion of respondents with access to a car decreased over time from 79.8% (95% CI: 77.1–82.3) at T0 to 74.8% (95% CI: 71.8–77.7) at T2, and access decreased slightly more in the unexposed group compared to the exposed groups. This reflects an overall shift to sustainable modes of transportation amongst Vancouver residents, and could also influence bicycling over time.

Public bicycle share programs are just one example of an intervention that cities are employing to increase bicycling. Other interventions to increase bicycling include bicycle infrastructure development (i.e., protected bicycle lanes, traffic signals, bicycle parking at transit stations), marketing and educational programs (e.g., Bicycle to Work Week), and traffic calming. Studies examining specific bicycling interventions often show modest impacts on bicycling (Yang et al., 2010, Goodman et al., 2014b, Crane et al., 2017, Rissel et al., 2015), however, Pucher et al. suggest that the combined effect of all bicycling infrastructure in a city (e.g., bicycle lanes, traffic signals, bicycle share programs, etc.) may have a greater impact on bicycling than the sum of

Table 2
Results of weighted logistic regression analyses examining associations between bicycling and survey period, exposure to the bicycle share service area, and their interactions at three time points concurrent with the 2016 launch of the *Mobi by Shaw Go* public bicycle share program in Vancouver, BC (2015–2017).

	Bicycling	
	Unadjusted OR (95% CI)	Adjusted[a] OR (95% CI)
Survey period		
October 2015, T0 (Ref)	1.00	1.00
October 2016, T1	0.88 (0.62, 1.26)	0.90 (0.62, 1.29)
October 2017, T2	1.09 (0.77, 1.56)	1.04 (0.73, 1.50)
Exposure to bicycle share service area		
No exposure (Ref)	1.00	1.00
Work only	1.28 (0.78, 2.10)	1.07 (0.63, 1.81)
Home only	1.53 (0.98, 2.40)	1.52 (0.96, 2.43)
Home and work	1.08 (0.64, 1.84)	0.77 (0.44, 1.33)
Survey × exposure		
T0 × no exposure (Ref)	1.00	1.00
T1 × work	0.84 (0.39, 1.81)	0.82 (0.37, 1.81)
T2 × work	0.90 (0.42, 1.94)	0.94 (0.42, 2.08)
T1 × home	0.66 (0.33, 1.31)	0.59 (0.29, 1.20)
T2 × home	0.55 (0.29, 1.05)	0.48 (0.25, 0.94)
T1 × home and work	2.17 (1.04, 4.55)	2.26 (1.07, 4.80)
T2 × home and work	1.37 (0.68, 2.77)	1.37 (0.67, 2.83)

[a] Model controls for age, sex, annual household income, car ownership, and self-reported health.

its individual parts (Pucher et al., 2010). Public bicycle share programs contribute to the overall efforts of a city to improve bicycling, and in time, may help shift a population towards bicycling.

5. Strengths & limitations

We employed rigorous methods to assess population-level impacts and are one of only two studies to use repeated cross-sectional surveys with independent samples, before and after the implementation of a public bicycle share program. In addition to considering exposure to the bicycle share service area based on home locations, we also consider exposure based on work locations, which is often not considered in evaluations of bicycling interventions.

Our study faces limitations common to natural experiment studies including bias from residual and unmeasured confounding, and selection bias. This analysis does not control explicitly for changes to the built environment (e.g., addition of bicycling infrastructure). A greater density of bicycle routes was added inside the bicycle share service area (0.44 km/km^2) compared to outside (0.09 km/km^2), which could positively bias the intervention effect. However, we do not believe that the slight differential increase in bicycle route length had a substantial impact on the results because the additional infrastructure was only a 5% increase in route length (+16 km, compared to the overall length of bicycle infrastructure at baseline of ~306 km). Second, our surveys were matched in time of year, but weather did vary by survey year. The weather during the 2015 survey period was somewhat warmer and dryer than in 2016 and 2017. In bivariate analyses temperature and rainfall were not associated with bicycling in the past week, and these were not included in final models. Third, selection bias could occur as respondents in our surveys had higher incomes and educations, and underrepresented immigrants as compared to the Vancouver population. This is common for both telephone and online surveys, but suggests that the estimates of bicycling in the general population may be overestimates as income, education status, and immigrant status are predictors of bicycling (Butler et al., 2007).

We assigned respondents to one of four exposure levels, to go beyond past work and consider exposures at both home and work. With this more nuanced consideration, confidence intervals are wide in some cases and some caution is warranted when interpreting the results. Additionally, within the service area, changes in bicycling may vary across neighbourhoods. Future work could consider assessing whether public bicycle share programs impact bicycling differently for neighbourhoods within the service area.

The cost and pricing structure for *Mobi by Shaw Go* use changed from 2016 to 2017, which could affect usage of the program. At T1, there were two pass options: a day pass ($7.50) and a monthly pass ($10–20 depending on plan). At T2, the cost for the day pass increased ($9.75), the monthly pass was replaced by a 3-month pass ($75), and there was an additional annual pass option ($129–159).

Finally, we used self-reported bicycling in the past week as our outcome measure, where respondents who reported at least one trip by bicycle were categorized as bicycling. Other metrics such as number of bicycle trips, % bicycling to work, minutes of bicycling, are also common in the literature (Pucher et al., 2010). In our survey we did collect minutes of bicycling in the past week. Descriptive results for minutes of bicycling over time show a similar trend to the results observed in this analysis. Moreover, future analyses could consider evaluating the impact of public bicycle share programs on changes in people's attitudes towards bicyclists and bicycling.

6. Conclusion

Using a natural experiment study design, we observed that the implementation of the public bicycle share program in Vancouver was associated with greater increases in bicycling for those living and working inside the bicycle share service area relative to those outside the service area in the early phase of implementation, but this effect did not sustain over time. We did not find an association between increased bicycling over time and only living or only working within the service area, relative to those outside the service area. It may be that the program is either too early in its implementation or was implemented at too small a scale to have a measurable effect over our study period for those exposed to the program at only home or work. These findings can be complemented by natural experiment studies that examine the impact of bicycle share programs implemented at different scales in other cities.

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Conflicts of interest

The authors declare there is no conflict of interest.

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