Impact Evaluation of a Public Bicycle Share Program on Cycling: A Case Example of BIXI in Montreal, Quebec

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Objectives. We examined associations between residential exposure to BIXI (BIcycle-taXI)—a public bicycle share program implemented in Montreal, Quebec, in 2009, which increases accessibility to cycling by making available 5050 bicycles at 405 bicycle docking stations—and likelihood of cycling (BIXI and non-BIXI) in Montreal over the first 2 years of implementation.

Methods. Three population-based samples of adults participated in telephone surveys. Data collection occurred at the launch of the program (spring 2009), and at the end of the first (fall 2009) and second (fall 2010) seasons of implementation. Difference in differences models assessed whether greater cycling was observed for those exposed to BIXI compared with those not exposed at each time point.

Results. We observed a greater likelihood of cycling for those exposed to the public bicycle share program after the second season of implementation (odds ratio = 2.86; 95% confidence interval = 1.85, 4.42) after we controlled for weather, built environment, and individual variables.

Conclusions. The implementation of a public bicycle share program can lead to greater likelihood of cycling among persons living in areas where bicycles are made available. (*Am J Public Health.* 2013;103:e85–e92. doi:10.2105/AJPH.2012.300917)

The relationship between transportation and health is of growing interest in public health.[1,2] Studies show associations between high levels of cycling for transportation or utilitarian cycling and reduced traffic congestion,[3] noise and air pollution,[4] and obesity as well as increases in physical activity.[5–7] Cycling contributes to overall physical activity, which is associated with a number of health benefits including reduced body mass index (BMI; defined as weight in kilograms divided by the square of height in meters), reduced waist circumference, and improved blood lipid profiles (i.e., total cholesterol, low-density lipoprotein cholesterol, and triglycerides).[8–12] As well, modeling studies suggest that the health benefits of physical activity resulting from increased cycling would outweigh the risks of collisions and exposure to air pollution.[13,14]

In North America, the potential of cycling as a means to augment population levels of physical activity is also evidenced, at least in part, by its low prevalence even in densely built urban areas. In Canada, the proportion of individuals who cycled to work was 0.6% in 2006 and in the United States the share of bicycle commuters was 0.55% in 2008.[15,16] The current low prevalence and the positive health benefits of greater cycling explain why initiatives to promote cycling, particularly cycling for transportation, are now a major public health aim. To date, only a small number of built environment interventions to promote cycling have been evaluated.[17–23] These intervention studies have shown small but statistically significant associations between intervention implementation and self-reported cycling.[17–19] However, a variety of potentially effective built environment interventions have been implemented but not evaluated.

Public bicycle share programs (PBSPs), widely implemented in Western European cities, increase population access to bicycles by making bicycles available at docking stations throughout an area within a city for a fee.[22,24] For example, Montreal's BIXI (BIcycle-taXI) program, North America's largest in 2011, launched in May 2009, makes available 5050 bicycles at 405 docking stations within an area of approximately 46.5 square kilometers, encompassing about 380 000 inhabitants. Bicycles are available for a check-out fee of $5 for 24 hours, $48 for a month, or $78 for the season. After payment of the check-out fee, the first 30 minutes of usage is free. Users extending their usage beyond 30 minutes pay a usage fee of approximately $1.50 per 30 minutes.

Two recent studies have provided evidence that PBSPs have the potential to contribute to population levels of cycling and may, as a result, increase population levels of physical activity.[24] Approximately 8% of the population of Montreal had used BIXI at least once in the first year of implementation.[25] Cycling behavior before the implementation of the program and having a university education were positively correlated with likelihood of using the program at least once. A health impact assessment of the *Bicing* program in Barcelona showed that, compared with car users, the annual change in mortality for the 181 982 *Bicing* users was an additional 0.03 deaths from road traffic incidents, 0.13 deaths from air pollution, and 12.46 deaths avoided as a result of physical activity. The estimated annual number of deaths avoided as a result of *Bicing* was 12.28.[14] However, despite initial evidence showing adoption and positive health benefits, to date, there is limited evidence that PBSPs actually increase overall cycling rates in cities where they are deployed.[22,24]

The primary objective of the present study was to examine whether exposure to Montreal's BIXI program (a built environment intervention) would be associated with increases in total cycling, including cycling on BIXI and personal bicycles. We hypothesized that the implementation of BIXI would be associated with an increased likelihood of cycling for those exposed. Ancillary analyses examined whether increases in cycling are attributable to increases in utilitarian or recreational cycling. We hypothesized that utilitarian cycling would contribute more to the hypothesized increases in total cycling because BIXI is implemented in an urban area with high densities of destinations and targets utilitarian cycling (i.e., 30-minute free period). In sensitivity analyses, we examined whether associations for total cycling remained statistically significant for durations that could contribute to meeting public health recommendations for physical activity.

METHODS

We used a repeated cross-sectional design. Three population-based samples of adults participated in telephone surveys. We conducted surveys at launch of BIXI (May 4–June 10, 2009); at the end of the first season of implementation, season 1 (October 8–December 12, 2009); and at the end of the second season of implementation, season 2 (November 8–December 12, 2010). The implementation season of the program is from May through November. The sampling frame for each survey was individuals residing on the Island of Montreal with a landline telephone. Within contacted households the available individual to next celebrate a birthday and aged 18 years and older was targeted to respond.

To recruit sufficient numbers of respondents reporting cycling, we stratified the sampling frame according to the presence or absence of BIXI docking stations in the neighborhood of residence. In the first stratum, random-digit dialing to landlines was used to contact those residing on the Island of Montreal. In the second stratum, oversampling was conducted by randomly selecting landlines with Montreal postal codes matched to neighborhoods where BIXI was available (Figure A, available as a supplement to the online version of this article at http://www.ajph.org, provides details on random and oversampling and implementation timelines). Sampling fractions were 0.0013, 0.0016, and 0.0016 for the preimplementation, season 1, and season 2 surveys, respectively, and there was no overlap between surveys.

We obtained ethical approval from the ethics committee of Centre de Recherche du Centre Hospitalier de l'Université de Montréal. Respondents were recruited via a polling firm who obtained verbal informed consent before participation. Respondents could respond to the survey in French or English. Researchers trained telephone interviewers and performed ongoing quality surveillance to ensure the survey was being conducted in accordance with researcher training.

Measures

The outcome variables were dichotomous indicators of cycling behavior—self-reported total, utilitarian, and recreational cycling for at least 10 minutes in the past week. We defined utilitarian cycling as cycling performed as a means of achieving other ends—that is, not strictly for leisure or for cumulating health-enhancing physical activity.[22] Recreational cycling is performed for its own sake. To calculate the dichotomous variables, respondents reported the number of days and minutes of total and recreational cycling in the past week by using the long form of the International Physical Activity Questionnaire (IPAQ).[26] We dichotomized the IPAQ data according to whether the respondent reported any cycling for at least 10 minutes in the past week or reported less than 10 minutes of cycling in the past week. For recreational cycling, we dichotomized the IPAQ data as either respondents reporting recreational cycling for at least 10 minutes in the past week or reporting less than 10 minutes of recreational cycling in the past week. We calculated utilitarian cycling by subtracting the number of minutes of recreational from the number of minutes total cycling. We dichotomized utilitarian cycling according to whether the respondent reported utilitarian cycling for at least 10 minutes in the past week or reported less than 10 minutes of utilitarian cycling in the past week.

The IPAQ has shown good reliability and validity in past research.[26] Test–retest analysis with Spearman's correlation for all versions of the IPAQ was 0.81 (95% confidence interval [CI] = 0.79, 0.82). Criterion validity between the long form of the IPAQ and accelerometer-measured physical activity was fair to moderate (0.33; 95% CI = 0.26, 0.39). The IPAQ and the method for computing total, recreational, and utilitarian cycling have been used in past research.[26–28]

The primary independent variables were survey period (i.e., time) and exposure to BIXI docking stations. We operationalized survey period as an ordinal variable with dummy variables distinguishing the preintervention, season 1, and season 2 surveys. We operationalized residential exposure to BIXI docking stations by using a dichotomous variable contrasting respondents with 1 or more BIXI docking stations within a 500-meter road network buffer of their home (i.e., exposed) from those with no BIXI docking stations available within a 500-meter buffer (i.e., not exposed). For a map of station locations visit https://montreal.bixi.com. We used geographic information systems to calculate road network buffers. We chose a 500-meter buffer because this represents an easily walkable distance.[25,29] Some respondents completed the questionnaire before BIXI (n = 1188) was actually launched or after it was removed for the season in season 1 (n = 290) and season 2 (n = 384). We categorized those respondents as not exposed.

Covariates included mean weekly temperature, days of precipitation, density of destinations, street connectivity, and individual-level sociodemographic characteristics. We calculated mean temperature and number of days of precipitation (i.e., rain or snow) in the week preceding participant responses to the survey with data from Environment Canada.[30] We operationalized density of destinations as a count of the number of services (i.e., parks, grocery stores, banks, pharmacies, and medical services) within a 500-meter road network buffer of respondent's homes. We operationalized street connectivity as a count of the number of intersections within a 500-meter road network buffer of respondent's homes. Both measures have been used in past research as measures of urban form.[28,31] We measured sociodemographic and health variables of age, gender, education, employment status, income, BMI, and self-rated health by using questions from the 2006 Canadian Census[15] or with other standard questions.

Data Analysis

We conducted descriptive analysis of sociodemographic variables and compared them with the 2006 Canadian census. To improve representativeness, we weighted the sample survey data for age and gender with 2006 Canadian census data.

We used difference in differences estimation with logistic regression and generalized estimating equations. Difference in differences estimation is commonly used for evaluating nonrandomized interventions in economics.[32,33] The analysis compares the difference in outcomes (i.e., total cycling, utilitarian cycling, and recreational cycling) before and after the intervention for the unexposed by the difference in outcomes before and after the intervention for the exposed by using an interaction between time and exposure. The difference in differences approach is appealing because of its simplicity and potential to address a number of threats to internal validity including common time trends in outcomes.[33]

Separate logistic regression and generalized estimating equations models examined associations between time and residential exposure to BIXI docking stations with total, utilitarian, and recreational cycling while adjusting for covariates. We entered variables associated with the dependent variable at $P < .1$ in bivariate analyses into multivariate analysis. Multivariable analysis consisted of a 5-step logistic regression. In step 1, we entered time to assess changes across time in total, utilitarian, or recreational cycling (each outcome assessed in a separate analysis) on the Island of Montreal. In step 2, we entered exposure to BIXI docking stations to assess whether likelihood of cycling was higher in areas where bicycles were implemented. In step 3, we entered the interaction terms between time and exposure to BIXI docking stations. The main effect of time allowed for a test of the hypothesis that implementation of BIXI would result in greater likelihood of cycling on the entire Island of Montreal. The interaction terms test the hypothesis that the likelihood of cycling would be greater among respondents exposed to BIXI following its implementation compared with respondents not exposed following BIXI implementation. In step 4, we entered mean weekly temperature and days of precipitation per week for the 7-day period before participation. Finally, in step 5, we entered covariates (i.e., density of destinations, street connectivity, age, gender, education, employment status, income, BMI, and self-rated health) into each model. Our comparison of the results between logistic regression and generalized estimating equations (to control for neighborhood-level characteristics) showed similar odds ratios (ORs) and CIs and did not change the interpretation of the results. Logistic regression results are presented.

We conducted sensitivity analyses by using logistic regression described previously using 30 and 45 minutes per week of total cycling as outcomes to ensure the results were robust for durations of cycling that contribute to meeting public health recommendations for physical activity.

RESULTS

The pooled sample included 7012 respondents with 2001 (mean age = 49.4 years; 56.7% female), 2502 (mean age = 47.8 years; 61.8% female), and 2509 (mean age = 48.9 years; 59.0% female) adult respondents in each survey, respectively. Response rates for the samples were 36.9%, 34.6%, and 35.7%, respectively. The analysis sample was 6418 (91.5% of the final sample of 7012). Excluded respondents numbering 594 (8.5%) had missing postal code data and 146 (25% of 594) had missing postal code and sociodemographic data. Table 1 presents the unweighted and weighted descriptive results for cycling, weather, and sociodemographic variables. Descriptive analyses for the 3 surveys showed that over time 17.8%, 10.9%, and 8.7% of respondents, respectively, had engaged in cycling (including cycling on BIXI or personal bicycles) at least once in the past 7 days. Of those who reported cycling in the past week in season 1 and season 2, 26% (n = 63) and 27% (n = 56) used BIXI for at least 1 trip. For utilitarian cycling, proportions of BIXI use were 31% (n = 44) for season 1 and 31% (n = 46) for season 2. For recreational cycling, proportions of BIXI use were 21% (n = 25) and 18% (n = 14), respectively, for season 1 and season 2.

In bivariate analyses all variables except income were related to the dependent variables at $P < .1$. We did not include income in subsequent models. Table 2 shows the results from weighted logistic regression analyses examining the relationship between the implementation of BIXI and total, utilitarian, and recreational cycling.

Total Cycling

In step 1, the likelihood of cycling was lower at season 1 (OR = 0.56; 95% CI = 0.47, 0.67) and season 2 (OR = 0.40; 95% CI = 0.33, 0.49) compared with preintervention. In step 2, exposure to BIXI docking stations (OR = 2.62; 95% CI = 2.24, 3.07) was associated with greater likelihood of cycling compared with no exposure. In step 3, the addition of the interaction term (survey period × exposure to BIXI docking stations) showed that, in addition to the main effects of time and exposure, the likelihood of cycling was greater for those exposed to BIXI at season 1 (OR = 1.57; 95% CI = 1.09, 2.27) and season 2 (OR = 2.97; 95% CI = 1.97, 4.46) compared with those not exposed to BIXI (Figure 1).

When we controlled for the weather in step 4, the differences between preimplementation, season 1, and season 2 survey periods were rendered nonsignificant, whereas exposure and interaction terms remained statistically significant. The addition of the sociodemographic variables in step 5 attenuated to nonsignificance the association between the likelihood of cycling and the interaction term exposure at season 1 (OR = 1.47; 95% CI = 0.99, 2.19).

Utilitarian Cycling

In step 1 of analyses examining the relationship between survey period and utilitarian cycling, the likelihood of utilitarian cycling did not differ between season 1 (OR = 0.84; 95% CI = 0.66, 1.06) and preintervention. Compared with preintervention, at season 2, the likelihood of utilitarian cycling was lower (OR = 0.72; 95% CI = 0.56, 0.92). In step 2, exposure to BIXI docking stations (OR = 3.73; 95% CI = 3.03, 4.59) was associated with a greater likelihood of utilitarian cycling compared with no exposure. In step 3, the interaction term (survey period × exposure to BIXI docking stations) showed that, in addition to the main effects of time and exposure, exposure in season 1 (OR = 0.76; 95% CI = 0.46, 1.26) and exposure in season 2 (OR = 1.52; 95% CI = 0.89, 2.60) were not associated with an increased likelihood of utilitarian cycling.

Controlling for weather in step 4 made the relationship between survey period and cycling positive and significant for season 1, and positive and nonsignificant for season 2. The addition of sociodemographic variables in step 5 did not change the associations between survey period, exposure, or the interactions terms and the likelihood of utilitarian cycling.

TABLE 1—Unweighted and Weighted Sociodemographic Characteristics Before (n = 1803), and at the End of the First (n = 2223) and Second (n = 2392) Seasons of the BIXI Public Bicycle Share Program: Montreal, Quebec, 2009–2010

Variable	Preimplementation, Observed % (No.), °C (°F), or Mean	Weighted Estimate Preimplementation, %, °C (°F), or Mean	Season 1, Observed % (No.), °C (°F), or Mean	Weighted Estimate Season 1, %, °C (°F), or Mean	Season 2, Observed % (No.), °C (°F), or Mean	Weighted Estimate Season 2, %, °C (°F), or Mean
Cycling						
No cycling	82.2 (1482)	80.3	89.1 (1981)	87.7	91.3 (2184)	91.2
Cycling	17.8 (321)	19.7	10.9 (242)	12.3	8.7 (208)	8.8
Utilitarian cycling						
No utilitarian cycling	92.1 (1660)	91.2	93.5 (2079)	92.4	93.7 (2242)	93.5
Utilitarian cycling	7.9 (143)	8.8	6.5 (144)	7.6	6.3 (150)	6.5
Recreational cycling						
No recreational cycling	88.7 (1599)	87.5	94.7 (2106)	94.3	96.7 (2313)	96.9
Recreational cycling	11.3 (204)	12.5	5.3 (117)	5.7	3.3 (79)	3.1
BIXI docking station exposure						
No exposed	58.6 (1056)	58.3	64.7 (1438)	51.6	66.5 (1590)	49.2
Exposed	41.4 (747)	41.7	35.3 (785)	31.8	33.5 (802)	30.8
Mean weekly temperature	12.9 (55.2)	12.9 (55.2)	4.1 (39.4)	4.0 (39.2)	1.2 (34.2)	1.1 (33.9)
Mean d of precipitation in past 7 d	4.1	4.1	3.5	3.5	3.6	3.6
Age						
18–29 y	14.8 (266)	27.2	16.6 (370)	30.9	14.0 (334)	28.4
30–59 y	56.2 (1015)	50.9	57.8 (1286)	48.3	57.5 (1375)	50.5
≥ 60 y	29.0 (522)	21.9	25.5 (567)	20.9	28.6 (683)	21.7
Gender						
Male	43.3 (781)	48.4	38.2 (849)	47.3	41.0 (980)	48.1
Female	56.7 (1022)	51.6	61.8 (1374)	52.7	59.0 (1412)	51.9
Education						
High school or less	30.4 (548)	31.2	27.5 (612)	30.5	24.5 (586)	27.0
Trade school	9.4 (169)	9.6	6.3 (141)	6.1	5.8 (138)	5.6
College degree[a]	9.2 (166)	9.9	14.3 (318)	15.0	15.3 (365)	15.8
University degree[a]	51.0 (920)	49.3	51.8 (1152)	48.3	53.3 (1276)	50.5
Employment						
Full time	48.5 (875)	47.4	52.3 (1162)	47.9	46.7 (1118)	45.1
Part time	6.8 (123)	6.3	6.9 (154)	7.3	7.7 (183)	7.0
Student	9.5 (171)	17.7	9.5 (211)	18.1	8.6 (205)	16.8
Retired	23.8 (429)	18.4	20.0 (445)	16.8	22.7 (542)	18.0
Other	11.4 (205)	10.3	11.3 (251)	9.9	12.8 (306)	11.4
Body mass index[b]						
Normal or underweight	54.5 (955)	56.4	58.9 (1273)	60.9	56.9 (1315)	59.7
Overweight	32.0 (561)	31.2	29.5 (639)	28.0	30.7 (709)	28.8
Obese	13.4 (235)	12.4	11.6 (251)	11.1	12.4 (286)	11.4
Self-rated health						
Excellent	23.9 (431)	23.7	26.6 (591)	25.5	22.3 (533)	22.8
Very good	33.7 (607)	34.8	32.9 (729)	32.7	34.5 (826)	34.7
Good	24.1 (435)	24.3	25.1 (557)	26.5	655 (27.4)	27.9
Average	14.1 (254)	13.8	12.3 (272)	12.6	12.1 (290)	11.4
Poor	4.2 (76)	3.5	3.1 (70)	2.7	3.6 (85)	3.1

Note. BIXI = BIcycle-taXI.
[a]In Quebec, college defined as grade 12 and first year university but is not considered a university degree.
[b]Body mass index defined as weight in kilograms divided by the square of height in meters.

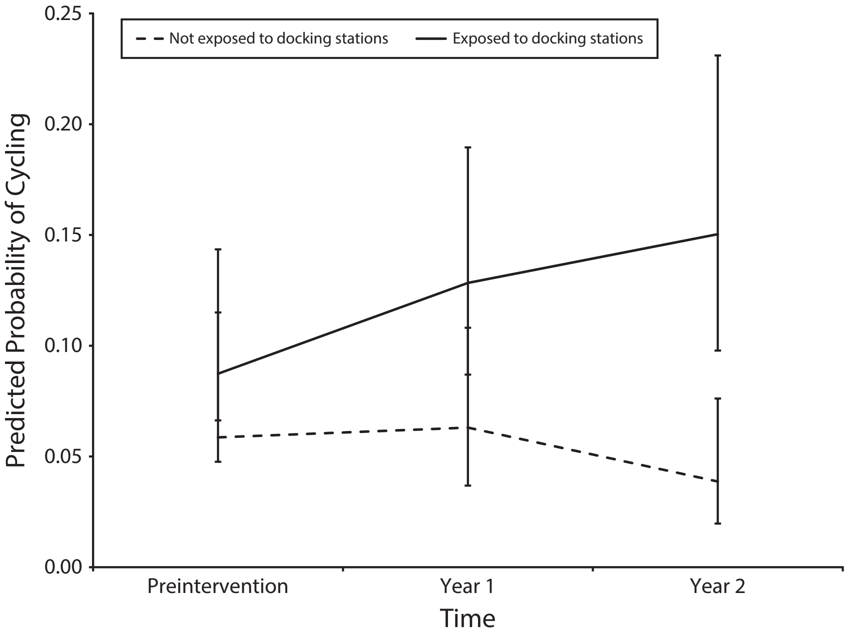
TABLE 2—Associations Between Cycling and Survey Period, Exposure to Docking Stations, and Their Interactions Before (n = 1803), and at the End of the First (n = 2223) and Second (n = 2393) Seasons of the BIXI Public Bicycle Share Program: Montreal, Quebec, 2009–2010

Variable	Step 1, OR (95% CI)	Step 2, OR (95% CI)	Step 3, OR (95% CI)	Step 4, OR (95% CI)[a]	Step 5, OR (95% CI)[b]
Cycling					
Survey period					
Pre (Ref)	1.00	1.00	1.00	1.00	1.00
Season 1	0.56* (0.47, 0.67)	0.59* (0.49, 0.71)	0.47* (0.36, 0.61)	1.04 (0.61, 1.77)	1.07 (0.62, 1.86)
Season 2	0.40* (0.33, 0.49)	0.42* (0.35, 0.52)	0.23* (0.17, 0.31)	0.65 (0.33, 1.27)	0.66 (0.33, 1.31)
Exposure to docking stations					
Not exposed (Ref)		1.00	1.00	1.00	1.00
Exposed		2.62* (2.24, 3.07)	1.69* (1.31, 2.16)	1.69* (1.32, 2.18)	1.35* (1.02, 1.78)
Survey × exposure					
Pre × not exposed (Ref)			1.00	1.00	1.00
Season 1 × exposed			1.57* (1.09, 2.27)	1.41 (0.96, 2.01)	1.47 (0.99, 2.19)
Season 2 × exposed			2.97* (1.97, 4.46)	2.55* (1.68, 3.88)	2.86* (1.85, 4.42)
Utilitarian cycling					
Survey period					
Pre (Ref)	1.00	1.00	1.00	1.00	1.00
Season 1	0.84 (0.66, 1.06)	0.92 (0.72, 1.17)	1.07 (0.72, 1.60)	2.34* (1.17, 4.67)	2.52* (1.24, 5.12)
Season 2	0.72* (0.56, 0.92)	0.79 (0.61, 1.01)	0.59* (0.38, 0.93)	1.63 (0.69, 3.40)	1.72 (0.71, 4.13)
Exposure to docking stations					
Not exposed (Ref)		1.00	1.00	1.00	1.00
Exposed		3.73* (3.03, 4.59)	3.63* (2.48, 5.29)	3.58* (2.45, 5.22)	2.59* (1.72, 3.91)
Survey × exposure					
Pre × not exposed (Ref)			1.00	1.00	1.00
Season 1 × exposed			0.76 (0.46, 1.26)	0.74 (0.44, 1.25)	0.79 (0.46, 1.35)
Season 2 × exposed			1.52 (0.89, 2.60)	1.45 (0.83, 2.52)	1.66 (0.94, 2.95)
Recreational cycling					
Survey period					
Pre (Ref)	1.00	1.00	1.00	1.00	1.00
Season 1	0.42* (0.33, 0.54)	0.44* (0.34, 0.56)	0.29* (0.21, 0.42)	0.71 (0.34, 1.49)	0.76 (0.36, 1.62)
Season 2	0.24* (0.18, 0.32)	0.25* (0.19, 0.33)	0.14* (0.09, 0.21)	0.43 (0.17, 1.09)	0.46 (0.18, 1.21)
Exposure to docking stations					
Not exposed (Ref)		1.00	1.00	1.00	1.00
Exposed		1.75* (1.87, 2.67)	1.08 (0.80, 1.46)	1.11 (0.82, 1.50)	0.98 (0.69, 1.38)
Survey × exposure					
Pre × not exposed (Ref)			1.00	1.00	1.00
Season 1 × exposed			2.24* (1.36, 3.59)	1.81* (1.10, 2.98)	1.87* (1.12, 3.13)
Season 2 × exposed			3.26* (1.83, 5.80)	2.55* (1.41, 4.59)	2.73* (1.49, 4.99)

Note. BIXI = BIcycle-taXI; CI = confidence interval; OR = odds ratio. With control for built environment and sociodemographic characteristics.
[a]Models with control for mean weekly temperature, and days of precipitation.
[b]Models with control for mean weekly temperature, days of precipitation, density of destinations, street connectivity, age, gender, education, employment, body mass index (weight in kilograms divided by the square of height in meters), and self-rated health.
*$P < .05$.

Recreational Cycling

When we examined the results for recreational cycling, they showed that, in step 1, the likelihood of recreational cycling was lower at season 1 (OR = 0.42; 95% CI = 0.33, 0.54) and season 2 (OR = 0.24; 95% CI = 0.18, 0.32) compared with preintervention. In step 2, exposure to BIXI docking stations (OR = 1.75; 95% CI = 1.87, 2.67) was associated with a greater likelihood of recreational cycling compared with no exposure. In step 3, the addition of the interaction term (survey period × exposure to BIXI docking stations), in addition to the main effects of exposure at season 1 (OR = 2.24; 95% CI = 1.36, 3.59)



Note. Error bars are confidence intervals.

FIGURE 1—Fully adjusted predicted probability of cycling in areas where BIXI docking stations were deployed and not deployed in the preintervention, season 1, and season 2 survey periods in Montreal, Quebec, 2009–2010.

and exposure at season 2 (OR = 3.26; 95% CI = 1.83, 5.80), was associated with an increased likelihood of recreational cycling compared with those not exposed to BIXI.

In step 4, addition of the weather variables removed the associations between survey period and exposure and the likelihood of recreational cycling observed in step 3. Sociodemographic variables entered in step 5 did not change the associations between survey period, exposure, or the interaction terms and the likelihood of recreational cycling.

Sensitivity analyses presented in Table 3 show that the results for 30 and 45 minutes of total cycling per week were similar to those using 10 minutes of cycling per week as the outcome. Odds ratios for 10, 30, and 45 minutes of cycling per week at season 2 remained statistically significant and were of similar magnitude at 2.86 (95% CI = 1.85, 4.42), 2.54 (95% CI = 1.61, 4.01), and 2.39 (95% CI = 1.48, 3.86), respectively.

DISCUSSION

The primary objective of this study was to examine whether a built environment intervention involving the implementation of a PBSP would be associated with a behavioral change of an increased likelihood of cycling for 10 minutes per week for those exposed to BIXI. We hypothesized an increased likelihood of cycling. In ancillary analyses, we examined the contribution of utilitarian and recreational cycling to total cycling and whether the effects remained significant for longer durations of total cycling.

In bivariate analysis, results showed total, utilitarian, and recreational cycling decreased between preintervention, season 1, and season 2 on the Island of Montreal. This association can be explained by seasonality and is evident when we examined step 4 of our models adjusting for mean weekly temperature and days of precipitation.[34–36] In step 4 of our models the lower likelihood of cycling observed between preintervention, season 1, and season 2 was ameliorated, indicating that the weather variables accounted for seasonal differences in cycling.

In fully adjusted models, exposure to BIXI docking stations was significantly associated with increased likelihood of total and utilitarian cycling. Consistent with implementation of PBSPs in other cities,[24] BIXI in Montreal was implemented in areas with environmental characteristics (e.g., high population density, high workplace density, high mixed land use, and cycling lanes) associated with greater likelihood of utilitarian cycling.[37–40] The nonsignificant associations between the built environment characteristics (i.e., mixed land use, street connectivity) and cycling in fully adjusted models may in part be explained by exposure to BIXI docking stations being a proxy for these characteristics.

Examination of whether exposure to BIXI docking stations was associated with a greater likelihood of cycling across time (i.e., testing of interaction terms) showed that after season 1 those exposed were not significantly more likely to cycle although the impact was in the hypothesized direction and neared statistical significance. Those exposed at season 2 had a significantly greater likelihood of cycling. The results show a lagged association between implementation of the BIXI intervention and greater cycling. This is consistent with discussions of built environmental interventions, which suggest that this lagged effect may be the result of behavioral modeling.[41,42]

Examining the contributions of utilitarian and recreational cycling to the effects observed on total cycling showed that the likelihood of utilitarian cycling was significantly greater throughout the Island of Montreal but not specifically for those exposed to the BIXI program. Opposite associations were observed for recreational cycling with no significantly greater likelihood of cycling on the Island of Montreal but a significantly greater likelihood for those exposed to the BIXI program. This suggests that recreational cycling may contribute more to the observed increase in total cycling for respondents exposed to BIXI docking stations to the program in season 1 and season 2.

Sensitivity analyses support the public health potential of the intervention for increasing physical activity. Estimates of the impact remained statistically significant for 30- and 45-minute bouts of physical activity representing 20% and 37.5% of the weekly recommended dose.

Limitations

Evaluations of built environment interventions are subject to multiple sources of bias

TABLE 3—Sensitivity Analyses Using Total Cycling and Associations With Survey Period, Exposure to Docking Stations, and Their Interactions Before (n = 1803), and at the End of the First (n = 2223) and Second (n = 2393) Seasons of the BIXI Public Bicycle Share Program: Montreal, Canada, 2009–2010

Cycling	10 Min/Wk,[a] OR (95% CI)	30 Min/Wk,[a] OR (95% CI)	45 Min/Wk,[a] OR (95% CI)
Survey period			
Pre (Ref)	1.00	1.00	1.00
Season 1	1.07 (0.62, 1.86)	1.05 (0.59, 1.86)	0.93 (0.51, 1.69)
Season 2	0.66 (0.33, 1.31)	0.64 (0.31, 1.32)	0.57 (0.27, 1.22)
Exposure to docking stations			
Not exposed (Ref)	1.00	1.00	1.00
Exposed	1.35* (1.02, 1.78)	1.41* (1.06, 1.89)	1.44* (1.06, 1.94)
Survey × exposure			
Pre × not exposed (Ref)	1.00	1.00	1.00
Season 1 × exposed	1.47 (0.99, 2.19)	1.39 (0.93, 2.11)	1.36 (0.88, 2.09)
Season 2 × exposed	2.86* (1.85, 4.42)	2.54* (1.61, 4.01)	2.39* (1.48, 3.86)

Note. BIXI = BIcycle-taXI; CI = confidence interval; OR = odds ratio. With control for built environment and sociodemographic characteristics.
[a]Models control for mean weekly temperature, days of precipitation, density of destinations, street connectivity, age, gender, education, employment, body mass index (weight in kilograms divided by the square of height in meters), and self-rated health. Number (%) of cyclists for each analysis, 10 min: 771 (12); 30 min: 704 (11); 45 min: 617 (9.6).
*$P < .05$.

because of limited control. Limitations include selection bias, confounding, and the repeat cross-sectional design, which does not control for all omitted variables.[43] Not including cellular telephones in the sampling could underrepresent younger people, and women are more likely respond to landline telephones. The sample may overrepresent older women who are less likely to cycle.[36] Selection could bias the results of the regressions models; however, weighting and including control variables in the logistic regression analysis are methods to control for this potential selection bias.[44] There are potentially other weather factors, such as hours of daylight and wind that could have biased the results. However, temperature and precipitation are the most commonly examined weather predictors of cycling and likely act as good proxies for any other potential weather confounders. This study indicates that exposure to BIXI docking stations across time is associated with greater likelihood of total and recreational cycling in Montreal. However, in Canada and Montreal specifically, there have been secular trends toward greater levels of population cycling since 1994.[45] Secular trends toward increased cycling could be explained by media campaigns[46] or a lagged effect of implementing a number of different cycling infrastructures since 2000.[47,48] Between the preimplementation and end of the second season, only minor changes were made to Montreal's cycle network. Differences between survey respondents across time points on measured or unmeasured variables not included in the modeling may also bias the results of comparisons between repeated cross-sectional surveys.

Conclusions

The BIXI public bicycle share program in Montreal was associated with greater likelihood of cycling after the second season of implementation for respondents exposed to the BIXI program. The present study adds to the growing consensus that built environment interventions can result in population-level behavior change. ■

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D. Fuller conceptualized the article, conducted all data analysis, and did the majority of writing. L. Gauvin and Y. Kestens contributed to conceptualizing the article, to data analysis, and to writing and reviewing the article. M. Fournier contributed to all data analysis, particularly the weighting, and to reviewing the article. M. Daniel, P. Morency, and L. Drouin contributed to writing and reviewing the article.

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