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Potential of built environment interventions involving deployment of public bicycles to increase utilitarian cycling:

The case of BIXI© in Montreal, Quebec

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Potential of built environment interventions involving deployment of public bicycles to increase utilitarian cycling : The case of BIXI© in Montreal, Quebec

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Résumé

Contexte : Les interventions sur l'environnement bâti reliées au transport peuvent contribuer à l'augmentation de la pratique de l'activité physique. En tant qu'intervention, les programmes de vélos en libre-service (PVLS) peuvent contribuer à l'utilisation du vélo. BIXI© (nom qui fusionne les mots BIcyclette et taXI) est un programme de vélos en libre-service implanté à Montréal, au Canada, en mai 2009. Le programme BIXI© met à la disposition des gens 5050 vélos à 405 bornes d'ancrage.

Objectif : L'objectif général de cette thèse est d'étudier l'impact d'un programme de vélos en libre-service sur l'utilisation du vélo. Les objectifs spécifiques de la thèse sont de :

1) Estimer la prévalence populationnelle et identifier des variables environnementales, sociodémographiques et comportementales associées à l'utilisation des vélos en libre-service.

2) Estimer l'impact populationnel de l'implantation des vélos en libre-service sur l'utilisation du vélo et les contributions respectives de l'utilisation du vélo pour des fins utilitaires et récréatives à l'utilisation totale du vélo.

3) Estimer l'impact local de l'implantation des vélos en libre-service sur l'utilisation du vélo.

Méthodes : Un devis populationnel transversal avec mesures répétées. Des enquêtes ont été réalisées au moment du lancement du programme de vélos en libre-service (4 mai au 10 juin, 2009), à la fin de la première année d'implantation (8 octobre au 12 décembre, 2009), et à la fin de la deuxième année d'implantation (8 novembre au 12 décembre, 2010). Les échantillons se composaient de 2001 (âge moyen = 49,4 années, 56,7 % de femmes), 2502 (âge moyen = 47,8 ans, 61,8 % de femmes) et 2509 (âge moyen = 48,9 années, 59,0 % de femmes) adultes à chaque période de mesure respectivement.

Résultats : Globalement, les résultats démontrent le potentiel des PVLS pour augmenter l'utilisation du vélo. Les résultats suggèrent que près de 128 744 habitants ou 8,1 % de la population adulte ont utilisé les vélos BIXI© au moins une fois dans la première saison. Après deux ans d'implantation, ceux qui sont exposés à BIXI© dans leur milieu résidentiel avaient une probabilité significativement plus élevée d'utiliser le vélo par rapport à ceux non exposés. Par contre, il n'y avait aucun impact local de l’implantation du programme BIXI© sur l’utilisation du vélo.

Conclusions : L’implantation d'un PVLS à Montréal a augmenté la probabilité d’utiliser le vélo chez les individus habitant près d'une borne d'ancrage.

Mots clés : programme de vélos en libre-service, expérience naturelle, santé des populations.

Summary

Background: Interventions in transportation and the built environment have the potential to increasing physical activity. Public bicycle share programs (PBSP) are one such intervention which may contribute to increasing cycling and physical activity. BIXI© (name merges the words BIcycle and taXI) is a public bicycle share programs launched in Montreal, Canada in May 2009. BIXI© makes available 5050 bicycles at 405 docking stations.

Purpose: The overarching aim of this dissertation is to estimate the impact of a built environment intervention on cycling using. The specific research objectives are:

1) To estimate the population prevalence and identify built environment, sociodemographic and behavioural correlates of public bicycle share program use.

2) To estimate the population level impact of implementing a public bicycle share program on cycling and the contribution of utilitarian and recreational cycling to overall cycling.

3) To estimate the local impact of implementing a public bicycle share program on cycling.

Methods: A population-based repeat, cross sectional time series design was used. The population of the Island of Montreal was sampled at three time points. Surveys were conducted at launch of the public bicycle share program (May 4th - June 10th 2009), at the end of the first year of implementation (October 8th - December 12th 2009), and at the end of the second year 2 of implementation (November 8th - December 12th 2010). Samples consisted of 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) adults at the each time period.

Results: Overall the results provide a proof of concept for the potential of PBSPs to increase cycling. Approximately 128,744 inhabitants or 8.1% of the adult population used BIXI© bicycles at least once in the first season. Respondents exposed to BIXI© at their residence after two years had a significantly greater likelihood of all forms cycling. However, there was no local impact of the BIXI© intervention on cycling.

Conclusions: The implementation of a PBSP in Montreal had increased all forms of cycling in areas where it was deployed.

Key Words: public bicycle share program, natural experiment, population health.

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List of Abbreviations

CI .... **Confidence interval**

DD .... **Difference in differences**

GEE .... **Generalized estimating equations**

GIS .... **Geographic information systems**

GPS .... **Global positioning system**

IPAQ .... **International physical activity questionnaire**

IV .... **Instrumental Variable**

LTAP .... **Leisure time physical activity**

MEGAPHONE ....

Montreal Epidemiological and Geographical Analysis of Population Health Outcomes and Neighborhood Effects

PA .... **Physical activity**

PBSP .... **Public bicycle share program**

PVLS .... **Programme de vélo en libre-service**

RC .... **Recreational cycling**

RD .... **Regression discontinuity**

STM .... **Societé de Transport de Montréal**

UC .... **Utilitarian cycling**

UT .... **Utilitarian transportation**

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"The highest returns can be reaped by imagination in combination with a logical and critical mind, a spice of ingenuity coupled with an eye for the simple and humdrum, and a width of vision in the pursuit of facts that is allied with an attention to detail that is almost nauseating."

Sir Austin Bradford Hill, 1953

Preamble

A colleague told me she used to be a social activist. She used to protest against injustice, participate in marches, ride in critical mass. She used to… until she became an epidemiologist. Epidemiology is concerned with the distribution of diseases within populations, with identifying the causes of a disease, and curing and preventing diseases in populations. In epidemiology, the philosophical basis for substantiating causal claims requires the elimination (or testing) of any and all sources of bias, including the removal of values from research questions.[1] In contrast, health promotion is explicitly value-laden. One of the fundamental conditions for health in the Ottawa Charter is social justice. Often the contrasting views of epidemiology and health promotion are characterised as forming a value-fact dichotomy, a strict distinction between the context of discovery and context of justification.[2] I argue that this dichotomy is false. Attempts at making causal claims and explicit values are both part of my philosophical view.

How do people become interested in disease X and its relationship with exposure Y? Methods give us little indication of the questions to ask. Nor do they inspire the passion and dedication required to ask the questions, to pursue knowledge. The questions we ask are value-laden and these values are important. This is the context of discovery. My context of discovery is based on principles of health promotion including social justice, equity, and sustainability. In the context of justification the research question is unimportant. In epidemiology, agreed upon methods can support or refute a causal claim for any relationship between X and Y. This is the context of justification. My context of justification is epidemiological methods.

As stated by J. Michael Oakes, "real world programs and their implementations are literally tested, hopefully with dispassionate and unforgiving rigor (p. 1943)."[3] In my view researchers conduct research that is consistent with their values, using theory based on *a priori* hypotheses, agreed upon methods, *a priori* analysis plans and cautious interpretation. What I hope to avoid, is confusing dispassionate and unforgiving methodological rigor, with dispassionate and value free questions. I have strived to avoid this confusion in my dissertation. If nothing else at least you know where I stand.

Chapter 1: Introduction

Interventions to improve health

The World Health Organization (WHO) defines health as "a state of complete physical, mental and social well-being and not merely the absence of disease or infirmity."[4] To achieve the WHO definition of health the Public Health Agency of Canada adopts a public health strategy involving four pillars: surveillance, risk factor identification, intervention, and knowledge translation. Since 1854 when John Snow removed the handle from the Broad Street pump, intervention has played a key role in public health research and practice.[5] Recent examples of public health intervention in Canada include the re-emergence of the ParticipACTION program[6] and the AH1N1 vaccination campaign in 2009.[7, 8] Although interventions in the health sector are important, achieving the WHO definition of health requires public health to look beyond health sector interventions to other sectors that have important impacts on health, this idea is the foundation of the population health approach.[9, 10]

The 1974 Lalonde report was a fundamental step in acknowledging the influence on health of interventions occurring outside of the health sector.[10] Since the Lalonde report a number of documents including the Ottawa Charter for Health Promotion have outlined the importance of determinants of health outside of the health sector.[9, 11-14] In September 2010, the declaration on prevention and promotion from Canada's Ministers of Health and Health Promotion/Healthy Living renewed the original commitment of the Lalonde report, "while it is clear that health services are a determinant of health, they are just one among many. Others include: environmental, social and economic conditions; access to education; the quality of the places where people live, learn, work and play; and community resilience and capacity. Because many of these determinants of health lie outside the reach of the health sector, many of the actions to improve health also lie outside the health sector, both within and beyond government (p. 2)."[15] There is a recognized need for public health researchers to evaluate how interventions occurring outside the health sector influence the health of the population.[16]

Natural Experiments

The randomized controlled trial design (RCT) is the gold standard for establishing the efficacy of an intervention. That is, to determine whether an intervention caused a change in participant responses under ideal (i.e., researcher controlled) conditions. The generic term randomized controlled trials represents a suite of designs where the primary feature of the study design is randomization of individuals or groups to treatment conditions. These include parallel, cluster and crossover randomized studies among others. Random assignment to treatment conditions (placebo or no intervention are intervention conditions) serves primarily as a methodological tool to control for unmeasured confounding but also facilitates control for a number of other potential sources of bias including researcher manipulation (via blinding).[17-19] Two consequences of randomization control unmeasured confounding of the relationship between the exposure and outcome of interest. First, the mean level for all intervention conditions is equal, on average, on any measured or unmeasured participant background variable at the beginning of the experiment. Second, intervention condition assignment is, on average, unrelated to any participant background variable. Despite the strengths of the randomization for controlling unmeasured confounding and obtaining unbiased estimation of intervention effects in clinical interventions, there is considerable debate about the appropriateness of randomized designs for population health interventions.[20-26] This debate goes well beyond the interests of public health and is occurring in multiple disciplines as evidenced by recent special issues dedicated to discussing the potential and pitfalls of the randomized designs in *Psychological Methods* [27-31] and the *Journal of Epidemiology and Community Health.*[32-35]

When environmental or policy interventions that affect groups or populations are examined there can be ethical, methodological, and practical problems in conducting randomized studies. For example, in large scale interventions distributed over an entire city it may be difficult to ensure that the consequences of randomization are true.[26] For example, it is difficult to state with confidence that randomizing the 100 largest cities in the world would result in the mean level for each intervention condition to be equal, on average, on all city background characteristics prior to the beginning of the experiment. Would the mean level of cultural diversity be equal between groups? As well, studies employing randomization generally use researcher designed interventions that may not be feasible to implement in real world settings. Given the applied nature of public health and the need to evaluate interventions occurring outside the health sector a natural experiment approach is an important complement to randomized studies when studying population health interventions.[20, 36]

In a natural experiment “the objective is to study the causal effects of certain agents, procedures, treatments, or programs… but for one reason or another the investigator cannot impose on a subject or withhold from the subject, a procedure or treatment whose effects he desires to discover, or cannot assign subjects at random to different procedures (p. 1)."[37] In a natural experiment the researchers attempts to exploit natural variation in exposure to examine a causal link. The recent case of smoking bans in public places offers a good example. It is neither ethical nor feasible to randomly assign public places to different smoking ban conditions. However, after the introduction of smoking bans natural experiment studies documented large decreases in cigarette consumption and second hand smoke exposure.[38-40] The archetypal example of intervention in public health, the removal of the Broad Street pump, was the result of a natural experiment study.[5] John Snow examined deaths in two 'natural' treatment conditions where water either contained or did not contain *vibrio cholerae* depending on the water company. The results of this natural experiment, the variation in exposure to cholera by water company, allowed Snow to make causal inferences about the transmission of cholera and were the basis for his actions. Natural experiments are particularly useful when randomized designs are not ethical or feasible.[21, 23, 26, 32] They may be particularly relevant when examining changes in government policies that are applicable to some groups but not others or when large scale policy or infrastructure changes occur.[41] Areas where natural experiments are relevant for understanding the influence of interventions occurring outside the health sector on health include housing[42-44] and transportation, [45-47] among many others.

Evaluating Natural Experiments in Transportation

Natural interventions play an important role in advancing knowledge in a number of disciplines including transportation.[45-47] In urban environments, transportation interventions involving changes to the built environment such as building subway systems or highway reconstruction are particularly amenable to study using natural experiments. Health Canada defines the built environment as "our homes, schools, workplaces, parks/recreation areas, business areas and roads. It extends over-head in the form of electric transmission lines, underground in the form of waste disposal sites and subway trains, and across the country in the form of highways. The built environment encompasses all buildings, spaces and products that are created or modified by people. It impacts indoor and outdoor physical environments (e.g. climate conditions and indoor/outdoor air quality), as well as social environments (e.g. civic participation, community capacity and investment) and subsequently our health and quality of life."[48] An example of a natural built environment intervention in transportation is the reconstruction of the Turcot Interchange in Montreal. Proposed plans for rebuilding the Interchange resulted in considerable public debate about the health, economic, and social consequences of rebuilding a major highway.[49-52] To estimate the potential impacts of such changes, transportation planners and public health officials often rely on modelling studies[53, 54] (e.g., health impact assessments) rather than evidence from evaluations of the health impacts of actual major highway reconstruction projects. This is problematic because modelling studies often make strong (yet possibly untenable) assumptions about effect sizes, causal pathways related to health and may not capture unintended health and other consequences.

Despite some methodological limitations with research in this area, it is generally agreed that transportation infrastructure (and the multitude of vehicles using these infrastructure) have health impacts.[55] This is particularly the case for the transportation infrastructure of roads and motor vehicles.[47] Numerous studies show that motor vehicles (and their infrastructure, primarily roads) are related to a number of negative health consequences. There are also positive impacts of road networks and motor vehicles, particularly as they relate to accessibility and speed of long distance transportation. Related to health, reducing motor vehicle use is important for achieving the WHO definition of health.[56-59] For example, road collisions cause 1.3 million deaths per year and are one of the top 3 causes of death worldwide for those aged 5-44 years.[60] Time spent in cars is positively associated with overweight and obesity, one of the major public health concerns in Canada today.[61, 62] One method to reduce motor vehicle use is to promote walking and cycling for transportation (i.e., utilitarian transportation) as viable alternatives to motor vehicle travel. Multiple cross-sectional studies show associations between a high prevalence of utilitarian cycling and reduced traffic congestion, noise and air pollution, traffic related injuries, and obesity, as well as increases in physical activity.[54, 63-69]

Benefits and Prevalence of Cycling

Cycling is a common activity. A majority of children in Canada learn to cycle at a young age. Declining prevalence of cycling throughout childhood[70] lead to the expression "it's just like riding a bike." Outcomes of interest in the present dissertation include cycling in general and cycling for two specific motives, namely utilitarian and recreational. Utilitarian cycling is defined as cycling performed as a means of achieving other ends, that is, not strictly for leisure or for cumulating health-enhancing physical activity.[71] Utilitarian cycling can be performed to get to a work site, for shopping, or to reach locations to socialize with friends and family. Utilitarian cycling contrasts with recreational cycling in that recreational cycling is performed for its own sake or for achieving health or leisure benefits. Like recreational cycling, increasing utilitarian cycling has the potential to increase population levels of physical activity because it results in energy expenditure.

In 2001 Canadian adults made, on average, six trips per day by car of a distance of less than three kilometres (i.e., equivalent to a 15 minute cycle or less).[72] Making only one of those six trips per day using cycling would be sufficient for the population to meet half of the recommended dose of physical activity for health benefits. Health benefits of achieving the recommended daily dose of physical activity include reduced likelihood of obesity, hypertension, osteoporosis, and depression, among others.[73] Furthermore, for adults, cycling can contribute an important proportion of total physical activity, which reduces body mass index (BMI), waist circumference, and blood lipid profiles (i.e., total cholesterol, low density lipoprotein cholesterol, and triglycerides).[74-78] Cycling appears to be an effective means of increasing the proportion of the population achieving the recommended dose of physical activity. The plausibility of increasing cycling to increase population level physical activity is also evidenced, in part, by its low prevalence. In Canada, according to the 2006 census, the proportion of individuals who cycled to work was 0.6%,[79] while the proportion who regularly cycled for recreation was 26% in the past three months during summer.[80] In Montreal the proportion of individuals who cycle to work in 2006 was 0.7%.[79] Low prevalence of cycling and health benefits associated with increasing cycling are part of the reason why increasing levels of physical activity via cycling has become a public health priority.

Thus, to address the obesity epidemic and negative impacts of nearly exclusive use of motor vehicle transportation, the overarching aim of this dissertation is to estimate the impact of a built environment intervention on cycling using methods which reduce bias in estimation of intervention effects and improve the plausibility of making causal claims.

Literature Review

The built environment intervention under study is a public bicycle share program (PBSP). Public bicycle share programs increase accessibility to bicycles by deploying bicycles at docking stations throughout a city or area within a city.[81] PBSPs have been implemented in approximately 100 cities worldwide, particularly in Western Europe. The world's largest program is in Hangzhou, China with 60,000 bicycles at 2500 stations.[82] Despite being widely implemented there is relatively little empirical and grey literature examining population health outcomes of PBSPs. The literature review will consist of two sections. The first section will present grey and empirical literature on PBSPs. Because there is a dearth of literature examining PBSPs a second section will present results from interventions to increase cycling in general.

Public bicycle share programs (see Appendix I (p. xvi)):

Grey literature suggests that PBSPs are well used and can increase cycling.[71] *Vélo'v* was the first PBSP of its kind (i.e., third generation, an information technology based system[81]) in the world beginning in Lyon, France in June, 2005.[83] In Lyon, bicycle use is estimated to have increased by 80% since the implementation of *Vélo'v*.[84] Bicycle use in Lyon is measured using manual and automatic counting,[84] which are done once a month during a four hour period at 16 fixed locations. In February 2009, *Vélo'v* estimated a total distance travelled of 625,250 km in 315,712 *Vélo'v* bicycle uses[85], an average distance of 2km per use. Distances are calculated using Euclidian (i.e., as the crow flies) estimates between origin and destination points of *Vélo'v* docking stations.[84] These calculations underestimate trip distances because they do not consider the road network.[86] As well, *Vélo'v* does not provide data on socio-demographic characteristics or multiple uses by individual users and cannot distinguish between recreational and utilitarian cycling. As such, little can be inferred about changes in specific forms of cycling. Results from PBSP user surveys allow for some estimation of socio-demographic characteristics of users. For example, a volunteer sample of 848 *Vélib'* (Paris, France) users shows that 40% of *Vélib'* users are aged between 26-35 years, 58% are male, and average trip duration is 18 minutes.[87]

Researchers from a number of disciplines including health and transportation are beginning to empirically study PBSPs. The first study of this dissertation shows that approximately 128,744 inhabitants or 8.1% of the adult population of Montreal used BIXI© bicycles at least once in the first season of implementation. Significant correlates of BIXI© use were exposure to BIXI© docking stations and age. There was no difference in BIXI©

use between men and women.[88] Results from study 2 of this dissertation show that for individuals exposed to the BIXI© program the likelihood of using any form of cycling was greater after one year of implementation (OR=1.47, 95% CI: 0.99, 2.19) and significantly greater after two years of implementation (OR=2.86, 95% CI: 1.85, 4.42) while controlling for overall cycling usage in the entire city, weather, built environment, and socio-demographic characteristics.[89] A recent health impact and environmental assessment of the *Bicing*© PBSP in Barcelona estimated the annual change in mortality and carbon dioxide emissions attributable to the program. Results showed the annual change in mortality for the 181,982 *Bicing*© users was an additional 0.03 deaths from road traffic collisions, 0.13 deaths from air pollution, and 12.46 deaths avoided as a result of physical activity.[90] Thus a net benefit of 12.3 deaths avoided annually. Authors estimated an annual carbon dioxide emissions reduction of 9 062 344 kg or nearly 1% of all emissions for motor vehicles in Barcelona. A recently published study using publicly available data from the Boris PBSP in London, England estimated the impact of two large scale public transportation strikes on the use of the PBSP using an interrupted time series design. The results show that PBSP use nearly doubled increasing from 16 000 to 24000 trips per day and 7600 to 23000 trips per day, during the respective strikes.[91] Another recent study from London estimated changes in use of the London PBSP resulting from a policy change, which made the program available to casual users. The results show greater weekend usage and more stable weekday commuting patterns with large flows into centre London in the morning and flows out in the afternoon. The results also showed that the geographic distribution of PBSP use at individual stations forms concentric circles around central London.[92] A study in Hangzhou, China compared the travel patterns of 666 PBSP members to 140 non-members. The results showed that approximately 30% of members incorporated the PBSP into their most common commute. The majority of trips using the PBSP, 40%, occurred at station closest to respondents home or work, respectively. Results examining modal shift suggest that PBSPs compete with and complement other forms of public transportation.[93]

Taken together, the results of these six studies show preliminary evidence that PBSPs have the potential to increase cycling and possibly improve health and this, in different implementation contexts (i.e., Hangzhou, Barcelona, Montreal, and London). Similar to grey literature, empirical research is still limited in terms of its ability to make causal claims about the impact of PBSPs. As well, the majority of the studies rely on cross-sectional designs.

Cycling interventions: Other (see Appendix II (p. xvii) - reprinted from Pucher, Dill and Handy (2009) with permission from Elsevier: Preventive Medicine):

Beyond PBSP research two important literature reviews have examined interventions to increase cycling. Yang et al.,[94] examined 25 controlled intervention studies designed to increase cycling. The review screened abstracts from 27,696 scientific publications and assessed the full text of 118 documents in four languages. Searches were limited to interventions with cycling as the outcome and studies including pre-post measurement and a control group (i.e., basic requirements for internal validity in a true experimental study). The authors of the review suggest that few controlled studies have examined specific built environment interventions to increase cycling. The majority of controlled studies used individual approaches. Taken together the results from these intervention studies applied at a population level were associated with a mean increase of 0.5% in the population prevalence of cycling.

Pucher, Dill and Handy[71] conducted a broad review of 153 studies examining interventions designed to increase cycling. Methods for the review included electronic searches in academic (e.g., PUBMED) and non-academic (e.g., Streetsblogs) literature and peer-reviewed and non peer-reviewed (i.e., grey literature) studies. Searches were limited to interventions with cycling as the outcome. Results showed that built environment interventions are the most common type of intervention to increase cycling (n=135). Pucher, Dill and Handy[71] categorized built environment interventions as; 1) travel related infrastructure, 2) end of trip facilities, and 3) integrated case studies. Travel related infrastructure interventions add cycling lanes and paths designed to improve connectivity and security of the cycling transportation network. End of trip facilities are designed to make arrival at a destination more comfortable and include adding showers and bicycle parking. Integrated case studies examine the association between a number of cycling friendly policies and programs and cycling at the city level. Studies related to each of these intervention categories is briefly reviewed and critiqued.

Travel related infrastructure: The most common cycling intervention is travel related infrastructure such as painted cycling lanes on roadways and separated cycling paths.[71] The effect of travel related infrastructure on cycling differs by level of analysis (i.e., individual or city). Cross-sectional and longitudinal studies using the city as the unit of analysis show positive associations between the presence of cycling lanes (measured as number or distance covered) and prevalence of cycling.[63, 95-99] For example, a study of 35 large US cities using data from the Census 2000 Supplemental Survey showed that cities with higher levels of bicycle infrastructure (lanes and paths) also had a higher prevalence of bicycle commuting.[96] At the individual level, results from a study in Portland, Oregon following 166 regular cyclists for one week using global positioning systems (GPS) found that 50% of cycling occurred on streets with bicycle lanes or separated paths while these infrastructure represent only 8% of the combined road and cycle path network.[100] Studies of the self-reported influence of cycling infrastructure on cycling behaviour are equivocal. In these studies, individuals are presented with images of different cycling infrastructures and are asked on which infrastructure (e.g., lanes, paths, on street) they prefer to cycle. Multiple studies using self-reported change in hypothetical behaviour resulting from cycling infrastructure suggests that people living within 400 meters of a cycling lane are more likely than those living more than 400 meters from a cycling lane to cycle.[101-103] A study of 1653 residents of Minneapolis/St. Paul, Minnesota demonstrated that individual odds of bicycle use did not differ significantly by proximity to any bicycling facility.[104] Stated preference studies are subject to a number of biases and there is limited evidence from revealed preference studies (i.e., where actual behaviour is observed) of associations between travel related infrastructure and cycling.

End of trip facilities: End of trip cycling facilities include bicycle parking, repair facilities, and showers. Stated preference studies demonstrate that secure bicycle parking and showers have the potential to increase the number of people who cycle to a given destination.[105, 106] Stated preference studies require individuals to self-report if they would cycle if a service (e.g., showers) was available at their destination. For example, in a study conducted in Edmonton, Canada, 1128 respondents showed that the typical cyclist reported one minute of cycling on a road without any cycling infrastructure being equivalent to four minutes on separated cycling lanes and 2.8 minutes on shared paths with painted lanes.[105] The results showed that the sensitivity to cycling facility varied with cyclists experience with more experienced cyclists not necessarily preferring separated cycling lanes. As well, the potential for secure parking at the destination was reported to be equivalent to a 26.5

minute cycle on a road without any cycling infrastructure. Few studies have used revealed preference methods to examine the associations between implementation of end of trip facilities and behaviour.

Integrated case studies: Integrated case studies examine the combined effect of a number of cycling friendly policies and interventions by relating multiple sources of data (e.g., policy documents, cycling network) to explain changes in cycling.[99, 107, 108] These studies have been conducted primarily in European cities, and a small number of North American cities. For example, a case study of Paris, France showed a 1.5% increase in cycling between 2001 and 2007 associated with the implementation of multiple policies and interventions including, 280 km of new bike lanes, 4300 new bicycle parking spaces, eliminating free automobile parking, and bicycling training in schools.[109, 110] An important challenge with integrated case studies is the difficulty in isolating the effect of specific intervention components. It is speculated that the implementation of *Vélib'* may have had the strongest association with increases in cycling.[111] Bicycling trips in Paris increased by 46% between June and October 2007, the year of the *Vélib'* launch. However, because the evaluation methods are not known it is impossible to attribute the 46% increase in cycling specifically to *Vélib'*.

Research examining PBSPs and other cycling interventions suggest that built environment interventions have the potential to increase cycling. However, there are relatively few studies examining PBSPs. Of these studies there are a number of theoretical and methodological limitations that should be addressed in order to improve the causal claims of the impact of implementing a PBSP on cycling.

BIXI© and the Cycling Context in North America

As discussed public bicycle share programs (PBSP), widely implemented in Western Europe,[81] increase population access to bicycles by deploying bicycles at docking stations throughout an area within a city.[81] Compared to Europe, North American cities have been slower to adopt public bicycle share programs.[81] North America's first public bicycle share program was launched in Washington D.C. in 2008. This small pilot project offered 120 bicycles at 10 docking stations. Since 2008, there has been a growing interest in their implementation.

BIXI© (name merges the words BIcycle and taXI) is, for the time being, the largest PBSP in North America. It was implemented in Montreal, Canada, by an organization operating outside of the health sector, *Stationnement de Montréal,* who was awarded a contract by the City of Montreal to conceptualize and design the intervention. BIXI© was modelled after *Vélib'*© (Paris, France) and *Vélo'v*© (Lyon, France). Launched in 2009, BIXI© currently makes available 5050 bicycles at 405 docking stations from May through November. Individuals aged 16 years or older can rent and drop off bicycles for a subscription fee of $5 for 24 hours, $28 for a month, or $78 for a season. After paying the subscription fee, users can access bicycles as many times as they wish, within the subscription period, for usage periods of 45 minutes or less at no additional charge. Any single usage period beyond 45 minutes costs approximately $1.50 extra per 30 minutes. Phase 1 involved the deployment of ~3500 bicycles at ~300 docking stations in the Ville-Marie, Plateau Mont-Royal, and Rosemont-Petite-Patrie neighbourhoods in Montreal from May through November of 2009. Phased 2 involved the deployment of an additional ~1500 bicycles at ~100 stations in the Hochelaga-Maisonneuve, Westmount, Outremont, Côtes-des-Neiges, and Notre-Dame-de-Grace neighbourhoods. Phase 2, originally scheduled for the summer of 2010, was implemented in July 2009 because BIXI© uptake was so extensive (see Figure 1 (p. 121) for the phasing locations). The BIXI© intervention includes both built environment (i.e., implementation of bicycles at docking stations) and media (i.e., advertising the program) components. For the purpose of the dissertation it is assumed that the built environment component is the primary 'active ingredient' of the intervention and that any observed effects are attributable primarily to changes in the built environment.

Despite limited evaluation of PBSPs implemented in Europe, North American cities wanting to encourage cycling have launch PBSP. The BIXI© program has been extended to Washington DC, and Minneapolis Minnesota in 2010, Boston Massachusetts and Toronto Ontario in 2011, and New York New York and Vancouver British-Columbia in 2012.[112]

Challenges for Evaluating Natural Experiments

Reviews by Yang et al.,[94] and Pucher, Dill and Handy[71] suggest that although built environment studies are common they often do not meet scientific criteria for internal validity. As such, important research challenges remain when evaluating natural interventions to increase cycling. Limited data are available to examine the implementation of such interventions. One reason for this is that interventions are generally implemented outside of the research sector, without consultation with researchers, let alone health researchers. It is difficult for researchers to undertake the necessary steps (i.e., study design, ethics, funding) for evaluation prior to the implementation of these interventions.[71, 81, 113-115] As a result, the overall validity, and particularly the internal validity, required for evaluation are low and lead to poor quality data. "The crucial limitation, is that most studies fall far short of the ideal research design for evaluating interventions, involving before-and-after measurements of a "treatment or intervention" group and a "control" group.[46] In addition, many of the studies cited come from "grey literature" and have not undergone a peer-review process that would provide some assurance of their rigor (p. 17)."[71]

A number of recent articles in public health discuss the challenges of studying population health interventions and propose solutions that enable researchers to strengthen the causal claims of their evaluations.[20, 36, 115] Different randomized designs could be used to evaluate the population level impact of built environment interventions. For example the Moving to Opportunity study randomized housing subsidies for families residing in low-income neighbourhoods with one group receiving a subsidy but remaining in the same neighbourhood, one group receiving a subsidy and being encouraged to move to a higher income neighbourhood and one group receiving no subsidy. The results show that at 10 to 15 years after randomization the opportunity to move from a neighborhood with a high poverty to one with lower poverty was associated with modest reductions in extreme obesity and diabetes.[116] Other potentially useful randomized designs for examining the population effect of built environment interventions include stepped wedge, and preference designs. A stepped wedge design of a built environment intervention would randomly allocate changes to the built environment in neighbourhoods over a series of years with all neighbourhoods eventually receiving the treatment and examine changes in cycling and physical activity. This would be feasible given the time required to implement built environment changes and potential lag in intervention effects. A preference trial could be conducted where neighbourhoods with a strong preference for a certain treatment (e.g., bicycle infrastructure) are given their preferred choice while other neighbourhoods are randomized. This analysis allows areas with strong preferences to be included in the study while maintaining the benefits of randomization among the other areas. The designs described above are examples of important adaptations to randomized designs that address the limitations of individual parallel groups designs when used to study population level health interventions. However, the evidence base justifying the use of randomized designs for examining the impact of built environment changes on cycling is weak.[71, 81, 113-115] Research exploiting natural experiments and attempting to control measured and unmeasured confounders contributes to the building an evidence base that can justifying the need for randomized studies to examine the impact of the built environment of cycling.

When researchers have used randomized designs or natural experiments to examine the effect of changes to the built environment on behaviour the mechanisms that could explain observed intervention effects have not been well conceptualized using theory (see Appendix III (p. xxix).[117-120] The poor conceptualization leads to hypotheses about mechanisms that are oversimplified and not defined *a priori*.[46, 118] Studies examining the effect of the built environment changes on cycling generally rely on ecological models[121-124] as a theoretical foundation. However, the broad nature of ecological models limits researchers' ability to formulate plausible mechanism to explain intervention effects. For example, Northridge et al.[118] suggest that it is important to study "interactive and dynamic relationships among the various domains, between the fundamental and intermediate factors, as well as between the intermediate and proximate factors (p. 560)." Given the nebulous formulation for generating specific mechanisms that explain intervention effects from the work of Northridge et al.,[118] and others, the results of built environment studies are often limited to simplified hypotheses about mechanisms. The simplified hypotheses propose that a direct relationship exists between the environment and behaviour. Because of this simplified formulation hypotheses are often not defined *a priori* and mechanisms are undefined. The *a priori* definition of hypotheses is of primary importance in intervention studies of any kind. "An intervention study must be hypothesis-driven. Failure to specify a set of specific hypotheses leads to a muddled design and uninterpretable results (p. 290)"[125] For example, MacDonald et al.,[126] used a pre-post design to study the effect of implementing a light rail system on walking, vigorous physical activity, and BMI. The authors make no explicit hypothesis regarding the mechanism of the intervention on the outcomes. The results of the study show no significant increases in walking or vigorous physical activity while significant reductions in BMI are observed for people using the light rail system. The assumed causal pathway in this study is that implementation of the light rail system increases physical activity, which in turn reduces BMI. The results do not support the assumed causal pathway and the lack of hypotheses about mechanisms is unable to explain the change in BMI. A more explicit conceptualization of the mechanism underlying intervention effects is required to help move beyond the simplified formulation of the ecological model in order to advance research.

Addressing Limitations of Past Research

Solutions are needed to control for unmeasured confounding in evaluations of natural built environment interventions, which are often critiqued for using designs that are not internally valid, while simultaneously improving the conceptualisation of mechanisms that can explain the effects of such interventions. Research designs and analysis methods developed in psychology and formalized by economists propose a number of solutions to controlling for unmeasured confounding of natural interventions studies and attempting to approximate randomization when randomized data are not available. These methods collectively known as 'causal modelling' include propensity score matching,[127] instrumental variables,[128] difference in differences,[129, 130] and regression discontinuity.[131] All of these methods are based on counterfactual theory (also known as potential outcomes or Rubin's causal model). To date, however, few researchers in public health have used such designs. A general discussion of counterfactual theory will be followed by discussion of difference in differences and regression discontinuity, which were used in the present dissertation.

The concept of the counterfactual attempts to capture a conditional comparison between what is observed in a given individual u following an event and what would have occurred (i.e., is not observed) in the same unit u had the event not occurred.[132] For Rubin[133] there is a fundamental problem of causal inference. Each individual u in a population is potentially exposable to a treatment t or its absence c. For each individual there exists a treatment effect variable Y (u) that will take the value of Y_t (u) if the individual is treated and Y_c (u) if the individual is not treated.

$$\mathbf{Y}\ (\boldsymbol{u}) = \mathbf{Y_t}\ (\boldsymbol{u}) - \mathbf{Y_c}\ (\boldsymbol{u}) \qquad \mathbf{(1)}$$

The fundamental problem is that it is impossible to observe the values of Y_t (u) and Y_c (u) on the same unit at the same time. Without observing both treatment and no treatment at the same time it is impossible to estimate a true treatment effect. Thus, the challenge of all intervention research becomes estimating the value of Y_c (u), the counterfactual.[134] To estimate the counterfactual researchers typically compare the average value on a given outcome in a treated population to the average value in an untreated population and assume that the two populations are exchangeable. That is, the control population would respond to the treatment exactly as the treatment population had they been treated and the treatment population would respond to the treatment exactly as the control population had they not been treated. Random assignment makes the exchangeability assumption highly plausible and equally distributes any unmeasured variables that could be related to both the treatment and outcome and bias effect estimates between assignment groups. In natural experiments, treatment assignment is unknown and both measured and unmeasured variables could be related to both the treatment and outcome. It is not much less plausible that the untreated group represents a good counterfactual for the treated group. As a result, if we do not control for measured variables and attempt to control unmeasured confounders intervention effect estimates are likely biased. Difference in differences and regression discontinuity are two methods that attempt to control for unmeasured confounders and reduce bias in natural experiment studies.

Difference in differences (DD) estimation is an analysis method commonly used for evaluation of natural interventions in economics.[41] In order to apply the analysis method, a specific intervention, which can be thought of as a source of natural variation (in our case the BIXI© PBSP) is required. Analysis compares the difference in outcomes pre and post intervention for the treated (the treatment) while controlling for difference in outcomes pre and post intervention for the untreated (an estimate of the counterfactual). The DD approach is appealing because of its ability to estimate population level effects and potential to address a number of threats to internal validity. Difference in differences controls for existing differences in outcomes prior to the intervention and any common time trends occurring in both treatment and control groups.[41] There are two primary limitations of the DD approach.[135] First, it cannot control for differential time trends occurring in one group but not the other. Second, DD cannot control for phenomenon occurring simultaneously with the intervention of interest that could influence the outcome. The researcher must attempt to examine these primary limitations using secondary data and subject matter knowledge.

Thistlewaite and Campbell originally developed the regression discontinuity (RD) design in the 1960's.[136] Since that time it has been formalized by econometricians and used in economics.[131, 137, 138] In a recent review Lee and Lemieux found that only 7 of 77 studies using RD designs were related to health and none evaluated a natural built environment intervention. The basic logic of the RD design is as follows. If treatment assignment is based on a cut off or discontinuity (e.g., those <60 years do not receive a pension while those ≥60 years do) then assuming that the discontinuity is somewhat arbitrary and that individuals cannot manipulate their position on one side or the other of the discontinuity, then comparing those near the discontinuity improves the exchangeability assumption between treatment and control groups. In more practical terms, we can estimate the effect of receiving a pension on all cause mortality comparing those aged 59 and 61 years because, 1) we assume that there are no differences between these two groups other than the treatment variable, age, and 2) the discontinuity is based on being aged 60 years and nothing else. The two previous assumptions are similar to the two assumptions of random assignment. First, the mean level for all treatment conditions is equal, on average, on any participant background variable at the beginning of the experiment (i.e., there are no differences except the treatment variable, age for those 59 and 61 years). Second, treatment assignment is, on average, unrelated to any participant background variable (i.e., the only criteria used for allocating a pension is age). The strength of the RD design is that, if the assumptions hold, the RD design improves the exchangeability assumption between the treatment and control groups.. This is not to say that RD designs should be favoured over randomized designs because the randomization offers benefits beyond the two assumptions presented including the possibility for blinding. However, the RD design represents an important methodological alternative in cases where randomized data is unobtainable. An important limitation of the RD design is that it estimates a local effect (in the above example ages 59-61 years). RD can only estimate the direct effect of the intervention and cannot estimate indirect or total population effects. Practically, applying RD designs requires large data sets with sufficient sample sizes near the discontinuity.

As discussed, natural built environment interventions often do not define *a priori* hypotheses about mechanisms that could explain intervention effects. Using theory for evaluating natural built environment interventions offers potential for knowledge advancement. The present dissertation is guided by two theoretical ideas: Rose's strategy of preventive medicine[139, 140] and social cognitive theory (SCT).[141] The basic principle of Geoffrey Rose's strategy of preventive medicine is that the causes of cases (i.e., why an individual cycles for transportation) are different from the causes of incidence (i.e., why

0.6% of the Canadian population regularly cycle to work). The interest in the present application of Rose's strategy is whether the BIXI© intervention can shift the distribution of cycling at the population, rather than the individual level. This approach contrasts with individual level interventions to promote cycling, which given the current state of research have less biased estimates of intervention effects. However, individual interventions may not result in population shifts in levels of cycling because current cyclists may stop cycling and the interventions may not reach a sufficiently large proportion of the population.[142-144] Rose's strategy suggests that intervention approaches are best to address the causes of the incidence rather than the causes of cases.

Rose's strategy implies that we are interested in population and not individual level changes in an outcome. Thus, a necessary condition for applying Rose's strategy is population based data. My dissertation includes three cross-sectional population based surveys. A repeat cross sectional design is analogous to epidemiology's more traditional individual based longitudinal samples applied to a population. Consistent with Rose the repeated cross-sectional design allows for examining population rather than individual level changes in an outcome. The methodological strengths of these surveys, when compared to longitudinal surveys, include population representativeness and no attrition.[145, 146] Thus, applying Rose's strategy and a difference in differences approach allows for a population based evaluation of the PBSP that is able to control for unmeasured confounding .

In its simplified formulation Rose's strategy is often used to critique the equally simplified formulation of individual level psychological interventions proposed by SCT. The simplified critique suggest that environmental interventions are more effective because 'a change in the physical environment would have long-term effects and may reach many in society (p. 1)'.[147] However, Rose's strategy may not be sufficient to explain why population level changes in behaviour occurred beyond the simplified formulation of the ecological model, that is, a direct relationship between environment and behaviour. The critique of individual approaches is valid but it does not completely discount the use of so called individual level theories such as social cognitive theory (SCT).[142, 148] SCT is a promising theory to study built environment interventions and behaviour change because one of its basic premises is that individuals are not automatically shaped and controlled by the environment (the simplified formulation of the ecological model) nor are they solely motivated to pursue behaviour by individual factors (the simplified formulation of individual level theories).[149] Rather, according to the principle of triadic reciprocality, behavioural, environmental, and personal factors act as reciprocal, interacting determinants. For example, our results show that individuals who used cycling as their primary mode of transportation were more likely to use the program in the first year compared to those using other modes of transportation.[88] This suggests that those who are already cyclists may be more influenced (susceptible) to the environmental change than those who do not cycle. Beyond the direct relationship between environments and behaviour, the SCT concept of modelling suggests that one of the primary ways individuals learn behaviour is through observing others. In particular, observation of similar individuals in the urban context (e.g., age, sex, dress, etc) is more likely to result in adoption of a given behaviour. Initial intervention effects may be explained by uptake due to a direct relationship between the environment and behaviour while subsequent uptake is more likely the result of modelling.

Based on the Rose's strategy and social cognitive theory, the hypothesized mechanisms that can explain intervention effects are a direct effect of the environment on behaviour and an indirect effect of behavioural modelling on unexposed or less susceptible individuals. The concept of dependent happenings from the vaccination literature suggests that changes to the population prevalence of a given vaccine have direct effects on individuals who are vaccinated (treated) but changes in prevalence also have indirect protective effects on those who are not vaccinated (commonly known as heard immunity).[150] Translated to the current intervention, those who are directly exposed to BIXI© (i.e., reside in an areas where BIXI© is implemented) cycle more as a result of a direct influence of the intervention while those who are indirectly exposed (e.g., don't live in a implementation area but work in the implementation area) may also cycle more because they see more cyclists on the road. The 'safety in numbers' concept in the cycling literature assumes direct and indirect effects.[151-153] Rose's strategy emphasizes total effects of the intervention on both exposed and unexposed groups. The total effect is the sum of direct and indirect effects. The current dissertation estimates total and direct effects but is unable to capture indirect effects. Figure 2 (page 131) presents an intervention model including the proposed mechanisms, the analysis method and the estimated effect.

Summary and Objectives

Increasing the prevalence of cycling is an important public health strategy for increasing physical activity. A variety of intervention strategies have been used to increase cycling, some of which show promise. However, there are methodological and conceptual challenges in making causal claims about the impact of these interventions. Well conceptualized and internally valid intervention evaluations are an important step to advancing knowledge and increasing the prevalence of cycling.[69, 71, 114, 119, 154]

The overarching aim of this dissertation is to estimate the impact of a built environment intervention on cycling using methods which reduce bias in estimation of intervention effects and improve the plausibility of making causal claims.

The present dissertation is couched within a larger research project designed to assess the impact of BIXI© on physical activity, transportation, and collisions with motor vehicles (see Appendix IV (p. xxxii): CIHR Grant awarded to Gauvin, Fuller, Daniel, Kestens, Drouin, & Morency, 2009-2012). The present doctoral dissertation differs from the CIHR grant in two important ways. First, its focus is narrowed to examining the impact of the intervention on cycling, rather than on a broader set of outcomes such as collisions or walking. The outcome for the dissertation is limited to cycling because the effects of built environment interventions are small or moderate.[71, 94] In order to detect population level changes, the intervention and outcome must be closely related.[125] Second, the use of difference in differences and regression discontinuity designs was not part of the original study design and thus extends the work proposed in the grant.

Specific Objectives

1) To estimate the population prevalence and identify built environment, sociodemographic and behavioural correlates of public bicycle share program use.

2) To estimate the population level impact of implementing a public bicycle share program on cycling and the contribution of utilitarian and recreational cycling to overall cycling.

3) To estimate the local impact of implementing a public bicycle share program on cycling.

1. To estimate the population prevalence and identify built environment, sociodemographic and behavioural correlates of public bicycle share program use.

Summary: BIXI© is a newly implemented PBSP in Montreal, Canada. Grey literature shows that PBSPs are widely used, however few studies have estimated the prevalence of use and little is known about what built environment, sociodemographic and behavioural characteristics are associated with PBSP use. Results from a volunteer sample of 848 Vélib' users showed that 40% were aged between 26-35 years and 58% were male.[87] However, only 2% of Vélib' users were surveyed in a non-representative sample. Information pertaining to the prevalence and predictors of PBSP use can inform the implementation of future PBSPs.

Hypotheses: It is hypothesized that greater exposure to the PBSP and more favourable personal factors will increase the likelihood of using PBSP bicycles. Further it is hypothesized that a substantial proportion of the population will try BIXI© at least once in the first season of implementation. These hypotheses are based on the idea from Rose that "a large number of people exposed to a small risk may generate may generate many more cases than a small number exposed to a high risk (p. 59)."[139] This idea is reinterpreted as a positive intervention effect rather than a risk factor approach and suggests that a large number of persons exposed to a built environment intervention may generate more cyclists than a small number exposed to an intensive individual intervention to promote cycling. From SCT, personal factors, being a cyclist for example, are hypothesized to increase the likelihood of program adoption.

2. To determine the population level impact of implementing a public bicycle share program on utilitarian cycling and the contribution of utilitarian and recreational cycling to overall cycling.

Summary: BIXI© is a newly implemented PBSP in Montreal, Canada. Grey literature shows that PBSPs are widely used and have the potential to increase cycling. For example, in February 2009, Vélo'v estimated a total distance travelled of 625,250 km in 315,712 uses.[85] Despite PBSPs being implemented in a large number of cities, few studies have taken advantage of this natural experiment to evaluate the impact of this type of intervention. Lack of empirical evidence limits causal inferences about the impact of PBSPs for increasing cycling.

Hypotheses: It is hypothesized that the implementation of BIXI© will be associated with an increased likelihood of cycling for those exposed. It was further hypothesized that utilitarian cycling will contribute more to the hypothesized increases in total cycling than recreational cycling because the PBSP is implemented in an urban area with high densities of workplaces and shopping locations and targets utilitarian cycling (i.e., 45 minute free period). The hypothesis of overall impact for cycling is based on Rose's strategy from study 1 and the SCT concept that once a sufficient uptake is achieved modelling will further increase adoption of cycling through observation of similar peers. The hypothesis about utilitarian cycling relates to intervention specificity, which suggest that the more specific the relationship between and intervention and outcome the more likely a relationship exist between the two.

3. To determine the local impact of implementing a public bicycle share program on cycling.

Summary: Study 2 examines the population level impact of a PBSP on cycling. In study 3, the aim is to estimate the local impact of the PBSP using an RD design. The RD design best approximates an RCT. If the results of study 2 and 3 are consistent it provides good evidence for making the causal claim that the PBSP increased cycling in Montreal.

Hypotheses: It is hypothesized that there will be no local impact of the PBSP at the pre-implementation because the program was being launched. At season 1 and season 2 of implementation of the PBSP, it is hypothesized that persons on the inside of the discontinuity will self-report more cycling than those on the outside of the discontinuity because they are exposed. The hypotheses of a local impact tests the strength of the built environment intervention for those very near the implementation area and is based on a direct relationship existing between the environment and behaviour.

Chapter 2: Methods

Design

A population based repeat cross sectional design was used. The population of the Island of Montreal was sampled at three time points. Surveys were conducted during the launch of BIXI© (May 4th - June 10th, 2009), at the end of the first season of implementation (October 8th - December 12th, 2009), and at the end of the second season of implementation (November 8th - December 12th, 2010). BIXI© launched on May 12th, 2009 and closed for season 1 and season 2 on November 30th, 2009 and 2010, respectively. The sampling occurred during the launch and the phase out of implementation of each season. In the pre-implementation sample 1188 respondents completed the survey between May 4th, 2009 and May 11th, 2009, prior to the implementation of BIXI©, while 823 completed the survey between May 12th, 2009 and June 10th, 2009 after the initial implementation. In the pre-implementation sample 11 (0.5% of sample) respondents reported using BIXI©. At the end of season one 2212 respondents completed the survey while the program was deployed (October 8th to November 30th, 2009) while 290 completed the survey when the program had closed for the season (December 1st to 8th, 2009). At the end of season two 2215 of the sample completed the survey while the program was deployed (November 8th to November 30th, 2010) while 384 completed the survey when the program had closed for the season (December 1st to 8th, 2010). For each time period if a respondent completed the survey when the program was not deployed their exposure was considered null.

The sampling frame for each survey was individuals residing on the Island of Montreal with a landline telephone. Within contacted households the individual to next celebrate a birthday and aged over 18 years was targeted to respond. Within the sampling frame a two strata sampling plan was used to recruit sufficient numbers of respondents residing in neighbourhoods where BIXI© docking stations were available. In the first stratum, random digit dialling (method provided by http://www.surveysampler.com) 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 neighbourhoods were BIXI© was available (see Figure on p. 76 for detail on random and oversampling and implementation timelines). Sampling fractions were 0.0013, 0.0016 and 0.0016 for the pre-implementation, season 1 and season 2 surveys, respectively, and there was no overlap (i.e., participants responding to more than one survey).

Participants

A total of 7013 participants were recruited. Samples consisted of pre-implementation (n = 2001, unweighted mean age=49.4 years, 56.7% female), Season 1 (n = 2502, unweighted mean age=47.8 years, 61.8% female), and Season 2 (n = 2509, unweighted mean age=48.9 years, 59.0% female) adult respondents, respectively.

Procedures

Ethical approval was obtained from the ethics committee of the CRCHUM (*Centre de Recherche du Centre Hospitalier de l'Université de Montréal*) (See Appendix V (p. xlvi)). Participants were recruited via a polling firm. Verbal informed consent was obtained prior to 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. To properly account for surveying time and up to 5 callbacks to improve response rate, recruitment began 4-5 weeks prior to intended start and end dates of BIXI© for each season.

Measures

For operational definitions see Appendix VI (p. xlviii). For the complete questionnaire see Appendix VII (p. li).

Dependent variables:

BIXI use: BIXI© use was measured by self-report. Participants indicated whether or not they had used BIXI© , reported an estimate of the total number of BIXI© uses in the season and reported their usual trip type when using BIXI© e.g., getting to work, for leisure). BIXI© use was operationalized in two ways: a dichotomous indicator of use (Yes had tried BIXI© bicycles vs. No had not tried) and, for those indicating 'yes', a dichotomous indicator of regular or non-regular BIXI© bicycle use. Regular BIXI© users were those reporting using BIXI© bicycles at least 10 times during the 2009 or 2010 BIXI© season.

Total, utilitarian, and recreational cycling: Total, utilitarian, and recreational cycling were operationalized using a modified version of the International Physical Activity Questionnaire (IPAQ).[155] Respondents reported the number of days and minutes of total and recreational cycling in the past week using the long form of the IPAQ. The IPAQ data were dichotomized according to whether the respondent was or was not a regular cyclist (i.e., respondents reporting any cycling for at least 10 minutes per week) or non-cyclist. To determine recreational cycling the IPAQ data were dichotomized as either recreational cyclist (i.e., respondents reporting any recreational cycling for at least 10 minutes per week) or non-recreational cyclist. The number of minutes of utilitarian cycling per week was estimated by subtracting recreational from total cycling. To determine utilitarian cycling the IPAQ data were dichotomized as either utilitarian cyclist (i.e., subtraction of recreational from total cycling was at least 10 minutes per week) or non-utilitarian cyclist. The IPAQ has shown good reliability and validity.[155] Test retest using spearman's correlation for all versions of the IPAQ was 0.81 (95% 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.[155-157]

Exposure/treatment variables:

***Exposure to** BIXI©*: Individual level exposure to PBSP was operationalized in two ways. First, based on the home postal code, the distance to the nearest PBSP station will be estimated based on the road network. Second, the number of PBSP stations within 500 meters of participant's homes, calculated using road network, was estimated.[158] Five hundred meters was chosen as a buffer distance because it is a walkable distance and the average distance between PBSP stations is 300 meters. The number of BIXI© stations at the end of season 1 was 267 and 391 at the end of season 2. Data for the number and location of stations was obtained from the BIXI© website on May 24th, 2009 to define season 1 exposure and on May 12th, 2010 to define season 2 exposure. Appendix VIII shows the distribution of BIXI© stations in season 1 and 2.

Environmental variables:

Density of destinations: Density of destinations was operationalized 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.

Street connectivity: Street connectivity was operationalized as a count of the number of intersections within a 500 metre road network buffer of respondent's homes.

Both density of destinations and street connectivity measures have been used in past research as measures of urban form.[157, 159]

Weather: The weather was operationalized as the mean weekly temperature and days of precipitation. Mean temperature and number of days of precipitation (i.e., rain or snow) in the week preceding participant responses to the survey were calculated using data from Environment Canada.[160]

Socio-Demographic Characteristics:

Standard socio-demographic questions modelled from the Statistics Canada Census questionnaire were collected. Information described participants, determine home/work locations, capture potential covariates, and ensure sample representativity. Participants were asked their ***year of birth*** and ***sex***.

Marital status was measured by asking "which situation best describes your marital status?" Potential responses were 1) married/common law, 2) single, 3) separated, 4) divorced, 5) widowed, 6) other.

Employment/student status was measured by asking "what is your main activity (occupation)?" Potential responses were 1) student, 2) homemaker, 3) unemployed seeking work, 4) on disability leave, 5) on parental leave, 6) self-employed, 7) part-time employed, 8) full-time employed, 9) retired.

Education was measured by asking "what is the highest level of education you have completed?" Potential responses were 1) no degree, certificate, or diploma, 2) high school graduation certificate or equivalent, 3) trades certificate or diploma, 4) university certificate or diploma below bachelor level, 5) bachelor's degree, 6) university certificate or diploma above bachelor level, 7) degree in medicine, dentistry, veterinary medicine or optometry, 8) master's degree, 9) earned doctorate, 10) college diploma, 11) other.

Income was measured by asking participants to report their annual household income in four categories, less than \$20000, \$20000-\$49999, \$50000-\$100000, and more than \$100000.

Usual mode of transportation to work was measured by asking "which mode of transportation do you normally use to get to your main occupation?" Potential responses were 1) personal bike, 2) BIXI©, 3) walk, 4) public transportation, 5) taxi, 6) personal motor vehicle, 7) work at home.

Home postal code was estimated in two steps. First, based on the phone number the survey company was able to obtain postal codes for approximately 60% of the sample. Second, regardless of availability of postal codes participants were asked to confirm or provide their home postal code.

Work neighbourhood was measured by asking participants their work postal codes. If participants did not know their work postal code, they were asked to provide their work neighbourhood. This variable was used to determine secondary exposure to BIXI© while at work.

Health variables:

Self-rated health was measured by asking "In comparison to other persons your age, would you say that your health in general is…" Potential responses were 1) excellent, 2) very good, 3) good, 4) average, 5) bad.

Body Mass Index **(BMI)** was calculated using self-reported height and weight data and the standard equation for adults (weight (kg)/height (m^2)).

Analyses

All data were screened and cleaned according to standardized procedures.[161] For the entire data set descriptive analysis of socio-demographic variables was conducted and compared with the 2006 Canadian census. To improve the representativeness the sample data were weighted for age and sex using 2006 Canadian census data.

Objective 1:

Two elements were of interest. First, different operationalizations of exposure to the BIXI© intervention were tested. Two individual measures of exposure to the BIXI© intervention were examined. The reason for including multiple exposures was to determine which operationalization of exposure had the strongest association with BIXI© use. Chaix et al.,[162] suggest an approach based on model fit criteria in order to select a geographical measure of exposure when no common standard exists for defining exposure.[163] The exposure measure with the strongest association informed the selection of BIXI© intervention exposure indicators. Second, predictors of BIXI© program use were examined. Use of BIXI© was operationalized in two ways in order to estimate whether differences existed between BIXI© users/non-users and regular users/non-regular users.

The model building approach was conducted in 3 steps. First, bivariate relationships were estimated between independent variables and BIXI© use. Variables significantly associated at the $p<0.25$ level with BIXI© were retained for multivariable analysis. Second, multivariable analysis was conducted using a step up approach. The different measures of exposure to the BIXI© intervention were entered in separate steps in the model. The exposure measure with the strongest association to BIXI© use was retained. Next, blocks of environmental and sociodemographic were entered. Significant predictors were retained in the analysis. Analysis was performed using logistic (BIXI© use y/n) and poisson (count of number of BIXI© uses) dependent variables.

These steps were performed, however, upon submission to the *American Journal of Preventive Medicine* the editor and reviewers required a 'short report' of 1600 words rather than a full paper. As a result, many of the analyses are not presented due to requirements of the journal. For the full length version of the manuscript see Appendix VIII (p. lxix).

Objective 2:

Difference in differences estimation was conducted for separate logistic regression and generalized estimating equations (GEE) models examining associations between time and residential exposure to BIXI© docking stations with likelihood of total, utilitarian, and recreational cycling while adjusting for covariates. Difference in differences estimation is commonly used for evaluating natural interventions in economics.[41, 164] Figure 3 (p. 122) shows the graphical representation of the difference in differences method including the counterfactual. The counterfactual for the difference in differences method was that all forms of cycling would continue the steady increase observed since 1994[165] if BIXI© were not implemented. Variables associated with the dependent variable at $p<0.1$ in bivariate analyses were entered into multivariable analysis. Multivariable analysis consisted of a five step logistic regression. In step 1, time was entered 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, exposure to BIXI© docking stations was entered. In step 3, the interaction term between time and exposure to BIXI© docking stations was entered. The main effect of time allowed for an initial test of the hypothesis that implementation of BIXI© would result in greater likelihood of cycling on the entire Island of Montreal whereas the interaction terms tested the hypothesis that the implementation of BIXI©

would be associated with a greater frequency of cycling amongst respondents exposed to BIXI©. In step 4 and 5 weather and other covariates (i.e., density of destinations, street connectivity, age, sex, education, employment status, income, BMI and self-rated health) were entered into each model.

Objective 3:

Study 3 includes methodological and inferential objectives. Methodologically, the study presents a practical application of RD and suggests it as a promising approach for researchers interested in evaluating the local impact of natural built environment interventions. Key concepts of the approach including the assumptions, defining the discontinuity, the assignment and treatment variables, covariates and model specificity are presented in detail. Inferentially, the design was used to estimate the local impact of BIXI© implementation. Figure 4 (p. 123) shows the graphical representation of the regression discontinuity method including the counterfactual. The counterfactual for the regression discontinuity method was that those residing immediately outside the BIXI© implementation area were exchangeable with those residing immediately inside the implementation area and any changes in cycling are attributable to the BIXI© program.

Chapter 3: Articles

Article 1: Use of a New Public Bicycle Share Program in Montreal, Canada

Daniel Fuller, Lise Gauvin, Yan Kestens, Mark Daniel, Michel Fournier, Patrick Morency, Louis Drouin

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Title: Use of a new public bicycle share program in Montreal, Canada

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Role of authors: Article 1

Daniel Fuller conceptualized the article, conducted all data analysis and did the majority of writing.

Lise Gauvin contributed to conceptualizing the article, contributed to the data analysis and to writing and reviewing the article.

Yan Kestens contributed to conceptualizing the spatial component of the article, contributed to the data analysis and to writing and reviewing the article.

Mark Daniel contributed to writing and reviewing the article.

Michel Fournier contributed to all data analysis, particularly the weighting, and to writing and reviewing the article.

Patrick Morency contributed to writing and reviewing the article.

Louis Drouin contributed to writing and reviewing the article.

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Abstract

Background: Cycling contributes to physical activity and health. Public bicycle share programs (PBSPs) increase population access to bicycles by deploying bicycles at docking stations throughout a city. Minimal research has systematically examined the prevalence and correlates of PBSP use.

Purpose: To determine the prevalence and correlates of use of a new public bicycle share program called BIXI© (name merges the word BIcycle and taXI) implemented in May 2009 in Montreal, Canada.

Methods: A total of 2502 adults were recruited to a telephone survey in autumn 2009 via random- digit dialing according to a stratified random sampling design. The prevalence of BIXI© bicycle use was estimated. Multivariate logistic regression allowed for identification of correlates of use. Data analysis was conducted in spring and summer 2010.

Results: The unweighted mean age of respondents was 47.4 (SD 16.8) years and 61.4% were female. The weighted prevalence for use of BIXI© bicycles at least once was 8.1%. Significant correlates of BIXI© bicycle use were having a BIXI© docking station within 250 m of home, being aged 18 –24 years, being university educated, being on work leave, and using cycling as the primary mode of transportation to work.

Conclusions: A newly implemented public bicycle share program attracts a substantial fraction of the population and is more likely to attract younger and more educated people who currently use cycling as a primary transportation mode.

Introduction

Public bicycle share programs (PBSP), widely implemented in Western Europe,[81] increase population access to bicycles by deploying bicycles at docking stations throughout an area within a city.[81] Grey literature suggests that PBSP are well used and have the potential to increase cycling for transportation.[71] Bicycle use was reported to have increased by 80% in Lyon since the implementation of Vélo'v.[84] However, minimal research has examined the prevalence and correlates of PBSP use.[71, 81]

North American cities have been slower to adopt PBSP.[81] The largest PBSP in North America is BIXI© (named from BIcycle and taXI) in Montreal, Canada. Launched in 2009, BIXI© made available 5000 bicycles at 450 docking stations from May through November (see Figure 1 (p. 54)). Individuals aged 16 years or older can rent and drop off bicycles for a subscription fee of CAD$5 for 24 hours, CAD$28 for a month, or CAD$78 for a season. After paying the subscription fee, users can access bicycles as many times as they wish, within the subscription period, for usage periods of 30 minutes or less at no addition charge. Any single usage period beyond 30 minutes costs approximately CAD$1.50 per 30 minutes. Of interest, the BIXI© PBSP was extended to Washington DC and Minneapolis in 2010.[112] This study examines the prevalence and correlates of PBSP use during the first season of implementation in Montreal, Canada.

Design

A stratified random sampling design was used. The sampling frame was individuals residing on the Island of Montreal. To sample within contacted households the individual to next celebrate a birthday and aged over 18 years was invited to respond. The sampling frame was stratified according to the presence or absence of BIXI© docking stations. In the stratum without BIXI© docking stations, the sampling used random digit dialing to landlines. In the stratum with BIXI© docking stations, a 25% oversampling was conducted by randomly selecting landlines with Montreal postal codes matched to areas with BIXI© docking stations. Persons having moved in the previous year were excluded.

Procedures

Ethical approval was obtained from the ethics committee of *Centre de Recherche du Centre Hospitalier de l'Université de Montréal*. Participants provided verbal informed consent and could respond to the survey in French or English.

Measures

The outcome variable was self-reported use of BIXI© bicycles. Participants indicated whether or not they had ever used BIXI© and estimated the total number of BIXI© uses since implementation. Use of BIXI© was operationalized in two ways: a dichotomous indicator of use (Yes, had tried BIXI© bicycles vs. No, had not tried) and, a dichotomous indicator of regular (≥10 usages) or non-regular (<10 usages) BIXI© bicycle use in the first season.

The main exposure was a count of the number of BIXI© docking stations within a 250 meter road network buffer from participants' home postal code.[158] The 250 meter buffer was chosen as an indicator of exposure because it is a walkable distance and because BIXI© docking stations were installed on approximately 300 meters apart.

Exposure at work, a secondary exposure, was operationalized as a dichotomous variable indicating whether or not an individuals' primary occupation was in a neighborhood where BIXI© docking stations were available.

Sociodemographic variables included age, sex, education, employment status, and usual mode of transportation to work. Education was categorized as high school or less, trade school or college, and university. Employment/student status was categorized as employed full time, employed part time, student, retired or other (e.g., work from home). Usual mode of transportation to work was categorized as cycling (not including BIXI©), walking, public transportation, personal motor vehicle, and other (i.e., taxi, work at home, or skateboard).

Data analysis

Data analysis was conducted to estimate the prevalence of BIXI© use, and to examine the correlates of BIXI© use using SPSS version 17. Weighting via inverse probability of selection (correction for oversampling) and post stratification for age and sex using data from the 2006 Canadian census (ensure representativeness to the population residing on the Island of Montreal) was applied to prevalence estimates.[166,8] Weighted logistic regression were used to examine correlates of BIXI© bicycle use.[161]

Ancillary analyses compared socio-demographic characteristics across regular and non-regular BIXI© bicycle users (n=152) and whether exposure to BIXI© docking stations from home and work (in a subset of 1065 with worksite postcode) independently predicted BIXI© use.

Results

The final sample included 2502 respondents and the response rate was 34.6%. The current study was based on a subset of 2133 (85% of the final sample of 2502) respondents. Of 369 respondents excluded, 150 (6%) had moved in the previous year and 219 (9%) had missing data. The unweighted mean age of participants was 47.4 (*SD* = 16.8) years; 61.4% of the sample was female (see Table 1 (p. 52)).

The unweighted prevalence of having used BIXI© at least once for those aged 15 years and older was 7.1% (95% CI: 6.0, 8.2) whereas the weighted prevalence estimate was 8.1% (95% CI: 6.5, 9.7; 128,744). Weighted estimates showed that 14.8% (95% CI: 11.6, 18.0; 53,975) and 6.2% (95% CI: 4.3, 9.0; 75,891) of residents living respectively where BIXI© docking stations were, and were not, available had used BIXI© at least once.

Table 2 (p. 53) shows the results from logistic regression on weighted data. Results show that having one station (OR = 2.03; 95% CI: 1.31, 3.16) or more than one station (OR = 1.73; 95% CI: 1.04, 2.88) within a 250m road network buffer of home was related to greater likelihood of BIXI© use. Compared to participants aged 18-24 years, those aged 35 and older were significantly less likely to use BIXI© bicycles. Males and females did not differ in their likelihood of BIXI© use and those cycling to work were significantly more like to have used BIXI© at least once compared to walk, driving and public transit.

Ancillary analysis comparing regular and non-regular BIXI© users indicated no difference between participants aged 18-24 years and those older than 24 years (OR = 0.69; 95% CI: 0.19, 2.47). Regular BIXI© users were as likely to have a high school diploma or more than a high school education (OR = 0.77; 95% CI: 0.15, 4.08). Students and males were as likely to be regular BIXI© users compared to non students (OR = 0.87; 95% CI: 0.32, 2.41) and females (OR = 1.91; 95% CI: 0.91, 4.01), respectively. Exposure to BIXI© stations at work (OR = 1.56; 95% CI: 1.01, 2.31) was related to BIXI© use, once exposure at home was controlled.

Discussion

This study examined the prevalence and correlates of use of a PBSP in its first season, BIXI© in Montreal, Canada. Results show that BIXI© bicycles were used by approximately 128,744 inhabitants (8.1%) of the population age 15 years an older living on the Island of Montreal. Prevalence estimates of cycling for transportation in Montreal range from 1.6% to 8%,[79, 167]. In the first year of implementation, BIXI© has been tried at a level comparable to that of cycling for transportation in Montreal. Prevalence estimates stratified by proximity to docking stations showed that approximately 53,975 (14.8%) of the population where BIXI© bicycles were available had used them at least once compared to approximately 75,891 (6.2%) of residents where BIXI© bicycles were not available. Although the prevalence of BIXI© use was higher where docking stations were available, approximately two thirds of those reporting BIXI© use at least once resided in areas where BIXI© bicycles were not available.

Results also suggest that having a docking station within a 250m road network buffer of an individual's home was related to greater likelihood of BIXI© bicycle use. Being male and a student were not statistically significant predictors of using BIXI© bicycles, a result inconsistent with North American cycling literature.[99, 103, 168-170]

The present study creates a framework for studying the outcomes of implementation of PBSPs. Replication of findings is warranted in other cities as is examination of whether PBSPs can create a modal shift from motor vehicles to bicycles and thus result in health benefits.

Limitations

Limitations include a low power to examine differences between regular BIXI© bicycle users from occasional or one time users and potential self-selection of individuals who already cycle into neighborhoods where BIXI© was implemented.

Conclusion

A proportion of the population similar to that already cycling for transportation has tried a newly implemented PBSP called BIXI© in Montreal, Canada. Individuals residing in close proximity to BIXI© docking stations had a higher likelihood of having tried BIXI©, however, individuals residing where BIXI© bicycles were not available contributed greatly to total usage.

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Table 1. Socio-demographic characteristics of 2133 survey respondents residing on the Island of Montreal, Canada in 2009.

Characteristic	Unweighted percentage (n)	Weighted percentage (95% CI)
Age (N=2133)		
18-24 years	7.4 (n=158)	18.6 (15.4; 21.9)
25-34 years	19.1 (n=407)	22.0 (19.8; 24.1)
35-44 years	18.7 (n=399)	16.3 (14.6; 18.0)
45-54 years	20.4 (n=436)	16.6 (15.0; 18.3)
55-64 years	17.2 (n=367)	12.2 (10.8; 13.5)
65+ years	17.2 (n=366)	14.3 (12.7; 15.9)
Transportation to work (N=2133)		
Cycle	5.2 (n=110)	4.8 (3.8; 5.8)
Walk	13.5 (n=287)	13.0 (11.1; 14.9)
Car	38.5 (n=821)	34.9 (32.4; 37.4)
Public Transportation	39.2 (n=837)	44.1 (41.2; 47.0)
Other	3.7 (n=78)	3.2
Education (N=2133)		
High School or less	27.2 (n=581)	30.2 (27.5; 33.0)
Trade School	6.4 (n=136)	7.1 (5.5; 8.6)
College Degree	14.4 (n=308)	15.4 (13.4; 17.5)
University Degree	51.9 (n=1108)	47.3 (44.5; 50.0)
Employment (N=2133)		
Full time	52.9 (n=1129)	48.4 (45.6; 51.1)
Part time	6.9 (n=148)	7.3 (5.8; 8.8)
Student	9.8 (n=210)	18.8 (15.8; 21.8)
Retired	19.4 (n=413)	15.6 (13.9; 17.2)
Other	10.9 (n=233)	9.9 (8.4; 11.4)
Sex (N=2133)		
Male	38.6 (n=824)	44.8 (42.0; 47.7)
Female	61.4 (n=1309)	55.2 (52.3; 58.0)
BIXI© stations with 250m (N=2133)		
None	79.3 (n=1691)	84.5 (82.9; 86.1)
One station	12.8 (n=273)	9.2 (8.0; 10.5)
More than one station	7.9 (n=168)	6.3 (5.2; 7.4)

Table 2. Associations between BIXI© use, presence of BIXI© bicycle docking stations, and socio-demographic characteristics

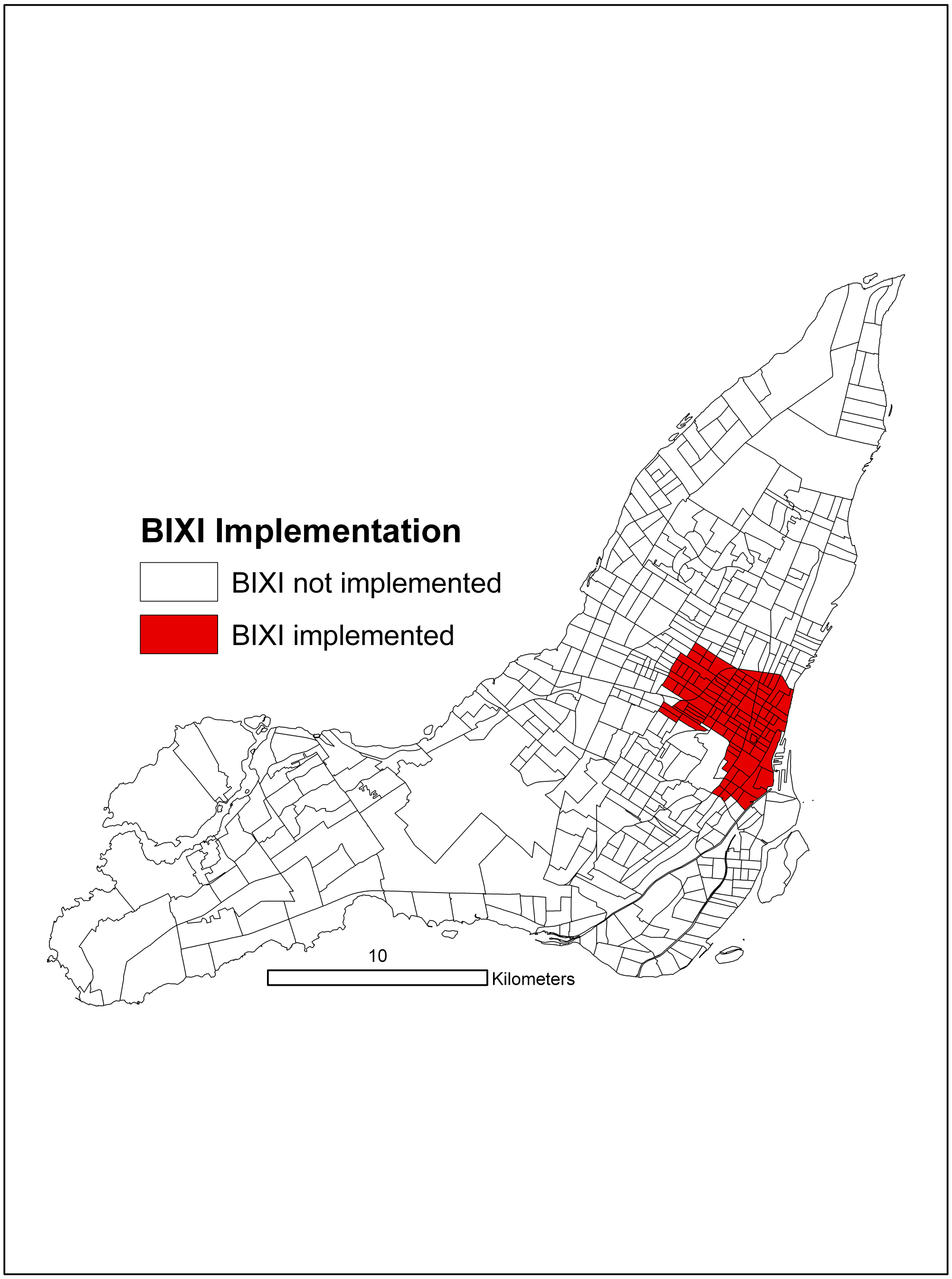
Variable	Unadjusted OR (95% CI)[a]	Adjusted OR (95% CI)[b]
Stations within 250m		
No stations (Ref)	1.00	1.00
1 station	**3.68 (2.49, 5.43)**	**2.03 (1.31, 3.16)**
More than 1 station	**2.19 (1.96, 5.18)**	**1.73 (1.04, 2.88)**
Age		
18-24 years (Ref)	1.00	1.00
25-34 years	1.11 (0.66, 1.88)	0.74 (0.44, 1.22)
35-44 years	0.73 (0.42, 1.26)	**0.41 (0.23, 0.75)**
45-54 years	**0.25 (0.13, 0.49)**	**0.14 (0.07, 0.29)**
55-64 years	**0.14 (0.06, 0.32)**	**0.11 (0.04, 0.29)**
65+ years	**0.02 (0.02, 0.13)**	**0.02 (0.01, 0.36)**
Sex		
Female (Ref)	1.00	1.00
Male	1.17 (0.84, 1.63)	1.26 (0.92, 1.72)
Education		
High school or less (Ref)	1.00	1.00
Trade school	1.29 (0.35, 4.74)	0.31 (0.08, 1.17)
College degree	2.52 (1.09, 5.81)	**0.49 (0.26, 0.91)**
University degree	**7.33 (3.82, 14.06)**	**2.27 (1.49, 3.44)**
Employment		
Full time (Ref)	1.00	1.00
Part time	0.69 (0.36, 1.37)	1.64 (0.96, 2.80)
Student	**1.67 (1.09, 2.57)**	0.63 (0.39, 1.01)
Retired	**0.05 (0.01, 0.19)**	0.42 (0.06, 2.84)
Other	**0.13 (0.04, 0.40)**	**0.09 (0.02, 0.36)**
Transportation to work		
Cycle (Ref)	1.00	1.00
Walk	**0.22 (0.12, 0.40)**	**0.12 (0.06, 0.24)**
Car	**0.10 (0.06, 0.17)**	**0.12 (0.06, 0.23)**
Public transportation	**0.19 (0.12, 0.31)**	**0.23 (0.13, 0.41)**
Other	**0.29 (0.13, 0.67)**	0.45 (0.17, 1.17)

* Bolded values are significant at $p<0.05$

[a] Unadjusted results are estimated using unweighted bivariate logistic regression

[a] Adjusted results are estimated using weighted multivariate logistic regression

Figure 1. Spatial distribution of BIXI© stations on the Island of Montreal in 2009 by census tract. For detailed station information (http://montreal.bixi.com/the-stations)



Black lines represent census tracts for Montreal based on data from the 2006 Canadian Census.

Article 2: Impact evaluation of a public bicycle share program on cycling: A case example of BIXI© in Montreal, Canada

Daniel Fuller, Lise Gauvin, Yan Kestens, Mark Daniel, Michel Fournier, Patrick Morency, Louis Drouin

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Daniel Fuller conceptualized the article, conducted all data analysis and did the majority of writing.

Lise Gauvin contributed to conceptualizing the article, contributed to the data analysis and to writing and reviewing the article.

Yan Kestens contributed to conceptualizing the spatial component of the article, contributed to the data analysis and to writing and reviewing the article.

Mark Daniel contributed to writing and reviewing the article.

Michel Fournier contributed to all data analysis, particularly the weighting, and to writing and reviewing the article.

Patrick Morency contributed to writing and reviewing the article.

Louis Drouin contributed to writing and reviewing the article.

Abstract

Objectives: BIXI© (BIcycle-taXI) is a public bicycle share program implemented in Montreal, Canada in 2009. BIXI©increases accessibility to cycling by making available 5050 bicycles at 405 bicycle docking stations. This study examines associations between residential exposure to the BIXI©public bicycle share program and likelihood of cycling (BIXI©and non- BIXI©) in Montreal over the first two 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), at the end of the first (fall 2009), and second (fall 2010) seasons of implementation. Difference in differences models assessed whether or not greater cycling was observed for those exposed to BIXI© compared to those not exposed at each time point.

Results: A greater likelihood of cycling was observed for those exposed to the public bicycle share program after the second season of implementation (OR=2.86, 95% CI: 1.85, 4.42) while controlling 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.

Key words: bicycling, transportation, intervention studies, urban health

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), waist circumference, and improved blood lipid profiles (i.e., total cholesterol, low density lipoprotein cholesterol, and triglycerides).[8-12] As well, modelling 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 (PBSP), 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 ~46.5km^2, encompassing ~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 paying 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 provide 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 prior to 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 to 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 or not 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 due 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 for durations that could contribute to meeting public health recommendations for physical activity.

METHODS

Design

A repeated cross sectional design was used. Three population-based samples of adults participated in telephone surveys. Surveys were conducted at launch of BIXI© (May 4th - June 10th 2009), at the end of the first season of implementation, season 1 (October 8th - December 12th 2009), and at the end of the second season of implementation, season 2 (November 8th - December 12th 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 over 18 years was targeted to respond. To recruit sufficient numbers of respondents reporting cycling, the sampling frame was stratified 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 (see Figure 1 for details on random and oversampling and implementation timelines). Sampling fractions were 0.002 for all surveys and there was no overlap between surveys.

Procedures

Ethical approval was obtained 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 prior to 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 last week. Utilitarian cycling is defined 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 using the long form of the International Physical Activity Questionnaire (IPAQ).[26] The IPAQ data were dichotomized according to whether the respondent reporting any cycling for at least 10 minutes in the last week or reporting less than 10 minutes of cycling in the past week. For recreational cycling the IPAQ data were dichotomized 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. Utilitarian cycling was calculated by subtracting the number of minutes of recreational from the number of minutes total cycling. Utilitarian cycling was dichotomized according to whether the respondent reported utilitarian cycling for at least 10 minutes in the last week or reporting 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 using Spearman's correlation for all versions of the IPAQ was 0.81 (95% 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. Survey period was operationalized as an ordinal variable with dummy variables distinguishing the pre-intervention, season 1, and season 2 surveys. Residential exposure to BIXI© docking stations was operationalized using a dichotomous variable contrasting respondents with one or more BIXI© docking stations within a 500m road network buffer of their home (i.e., exposed) from those with no BIXI© docking stations available within a 500m buffer (i.e., not exposed). For a map of station locations visit https://montreal.bixi.com/. Road network buffers were calculated using geographic information systems. A 500m buffer was chosen 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). Those respondents were categorized as not exposed.

Covariates included mean weekly temperature, days of precipitation, density of destinations, street connectivity, and individual level socio-demographic characteristics. Mean temperature and number of days of precipitation (i.e., rain or snow) in the week preceding participant responses to the survey were calculated using data from Environment Canada.[30] Density of destinations was operationalized as a count of the number of services (i.e., parks, grocery stores, banks, pharmacies, and medical services) within a 500m road network buffer of respondent’s homes. Street connectivity was operationalized as a count of the number of intersections within a 500m road network buffer of respondent’s homes.

Both measures have been used in past research as measures of urban form.[28, 31] Socio-demographic and health variables of age, sex, education, employment status, income, body mass index (BMI) and self-rated health were measured using questions from the 2006 Canadian Census[15] or with other standard questions.

Data analysis

Descriptive analysis of socio-demographic variables was conducted and compared with the 2006 Canadian census. To improve representativeness, the sample survey data were weighted for age and sex using 2006 Canadian census data.

Difference in differences (DD) estimation using logistic regression and generalized estimating equations (GEE) was used. DD estimation is commonly used for evaluating non-randomized interventions in economics.[32, 33] The analysis compares the difference in outcomes (i.e., cycling, utilitarian, and recreational cycling) before and after the intervention for the unexposed by the difference in outcomes before and after the intervention for the exposed using an interaction between time and exposure. The DD 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 GEE models examined associations between time and residential exposure to BIXI© docking stations with total, utilitarian, and recreational cycling while adjusting for covariates. Variables associated with the dependent variable at $p<0.1$ in bivariate analyses were entered into multivariate analysis. Multivariable analysis consisted of a five step logistic regression. In step 1, time was entered 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, exposure to BIXI© docking stations was entered to assess whether or not likelihood of cycling was higher in areas where bicycles were implemented. In step 3, the interaction terms between time and exposure to BIXI© docking stations was entered. 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 amongst respondents exposed to BIXI© following its implementation in comparison to respondents not exposed following BIXI© implementation. In step 4, mean weekly temperature and days of precipitation per week for the seven day period prior to participation were entered. Finally, in step 5, covariates (i.e., density of destinations, street connectivity, age, sex, education, employment status, and income, BMI and self-rated health) were entered into each model. Comparing the results between logistic regression and GEE (to control for neighborhood level characteristics) showed similar odds ratio and confidence intervals and did not change the interpretation of the results. Logistic regression results are presented.

Sensitivity analyses using logistic regression described above were conducted 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 while 146 (25% of 594) had missing postal code and socio-demographic data. Table 1 presents the unweighted and weighted descriptive results for cycling, weather, and socio-demographic variables. Descriptive analyses for the three 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 last seven 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 one 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 $p<0.1$. Income was not included 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 to pre intervention. 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 to 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 (Season 1 OR=1.57, 95% CI: 1.09, 2.27) and season 2

(OR=2.97, 95% CI: 1.97, 4.46) compared to those not exposed to BIXI© (see Figure 2 for a graphical representation of the interaction term). Controlling for the weather in step 4 rendered the differences between pre-implementation, season 1, and season 2 survey periods non-significant, while exposure and interaction terms remained statistically significant. The addition of the socio-demographic variables in step 5 attenuated to non significance 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) compared to pre-intervention. Compared to pre-intervention 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 to 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 non-significant for season 2. The addition of socio-demographic variables in step 5 did not change the associations between survey period, exposure or the interactions terms and the likelihood of utilitarian cycling.

Recreational cycling

Examining the results for recreational cycling 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 to pre-intervention. 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 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 exposure at season 1 (OR=2.24, 95% CI: 1.36, 3.59) and exposure at season 2 (OR=3.26, 95% CI: 1.83, 5.80) was associated with an increased likelihood of recreational cycling compared to 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. Socio-demographic variables entered in step 5 did not change the associations between survey period, exposure or the interactions terms and the likelihood of recreational cycling.

Sensitivity Analyses

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 or not 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 pre-intervention, season 1, and season 2 on the Island of Montreal. This association can be explained by seasonality and is evident when examining 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 pre-intervention, 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 non-significant 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.

Examining whether or not 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 due to limited control. Limitations include, selection bias, confounding, and the repeat cross sectional design which does not control for all omitted variables.[46] Not including cellular telephones in the sampling could under represent younger people, while women are more likely respond to landline telephones. The sample may over represent 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.[47] 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.[48] Secular trends toward increased cycling be explained by media campaigns[49] or a lagged effect of implementing a number of different cycling infrastructures since 2000.[50, 51] Between the pre implementation 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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Table 1. Unweighted and weighted sociodemographic characteristics of residents of the Island of Montreal, Canada surveyed prior to (n=1803), at the of the first season (n=2223) and second season (n=2392) of implementation of the BIXI public bicycle share program.

	Pre-implementation Observed percent (n)	Weighted estimate Pre-implementation percent (n)	Season 1 Observed percentage (n)	Weighted estimate Season 1 percent (n)	Season 2 Observed percentage (n)	Weighted estimate Season 2 percent (n)
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	58.6 (1056)	58.3	64.7 (1438)	51.6	66.5 (1590)	49.2
No exposed	41.4 (747)	41.7	35.3 (785)	31.8	33.5 (802)	30.8
Exposed						
Mean Weekly Temperature	12.9°C (55.2°F)	12.9°C (55.2°F)	4.1°C (39.4°F)	4.0°C (39.2°F)	1.2°C (34.2°F)	1.1°C (33.9°F)
Days of Precipitation per week	4.1	4.1	3.5	3.5	3.6	3.6
Age						
18-29 years	14.8 (266)	27.2	16.6 (370)	30.9	14.0 (334)	28.4
30-59 years	56.2 (1015)	50.9	57.8 (1286)	48.3	57.5 (1375)	50.5
60+ years	29.0 (522)	21.9	25.5 (567)	20.9	28.6 (683)	21.7
Sex						
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	9.2 (166)	9.9	14.3 (318)	15.0	15.3 (365)	15.8
University Degree	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						
Normal/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

Table 2. Associations between total, utilitarian, and recreational cycling, survey period, exposure to docking stations, and their interactions controlling for built environment and socio-demographic characteristics among respondents sampled at prior to (n=1803), at the end of the first season (n=2223) and second season (n=2393) of implementation of the BIXI public bicycle share program in Montreal, Canada.

Cycling	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]
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)*

Notes: [a]Models controlling for mean weekly temperature, days of precipitation. [b]Models controlling for mean weekly temperature, days of precipitation, density of destinations, street connectivity, age, sex, education, employment, body mass index and self-rated health. OR=Odds Ratio; CI=Confidence Interval.*p<.05;†p<.10

Table 3. Sensitivity analyses using total cycling for 10, 30, and 45 minutes per week and associations with survey period, exposure to docking stations, and their interactions controlling for built environment and socio-demographic characteristics among respondents sampled at prior to (n=1803), at the end of the first season (n=2223) and second season (n=2393) of implementation of the BIXI© **public bicycle share program in Montreal, Canada.**

Cycling	10 minutes per week[a]	30 minutes per week[a]	45 minutes per week[a]
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)*

Notes: [a]Models controlling for mean weekly temperature, days of precipitation. [b]Models controlling for mean weekly temperature, days of precipitation, density of destinations, street connectivity, age, sex, education, employment, body mass index and self-rated health. Number (Percent) of cyclists for each analysis, 10 minutes 771 (12%), 30 minutes, 704 (11%), 45 minutes, 617 (9.6%). OR=Odds Ratio; CI=Confidence Interval. *p<.05;[†]p<.10

Figure 1. Timeline for implementation of the BIXI© public bicycle share program and BIXI© study in Montreal, Canada, 2009-2010.

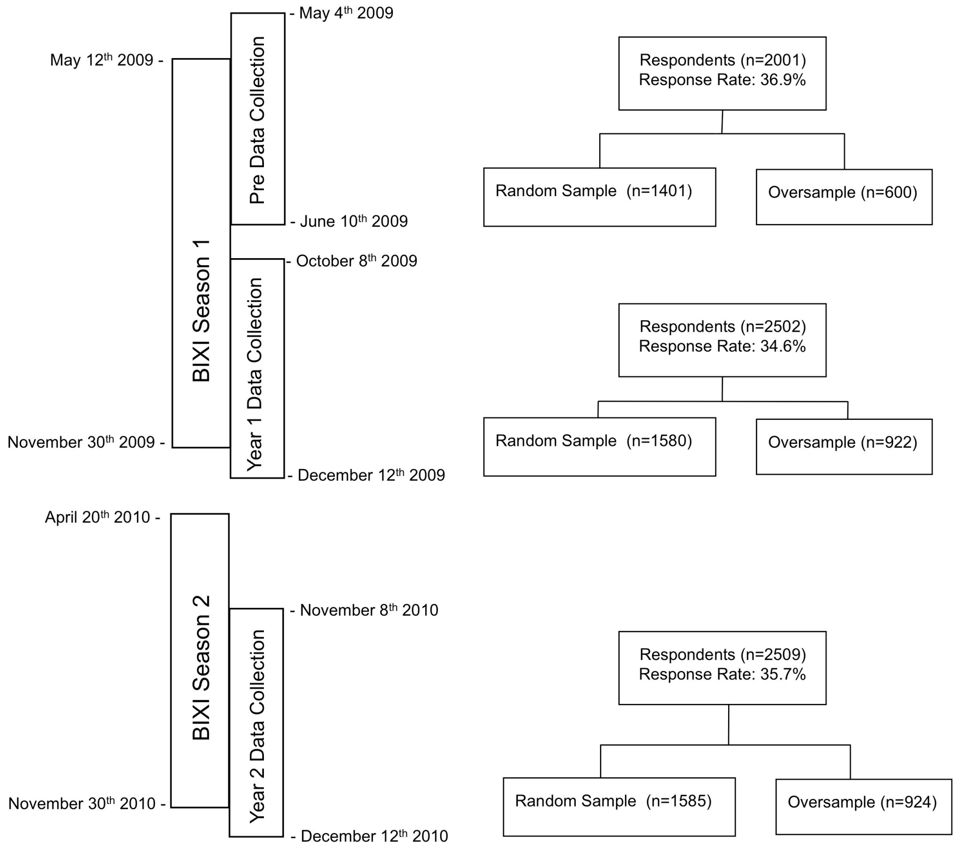
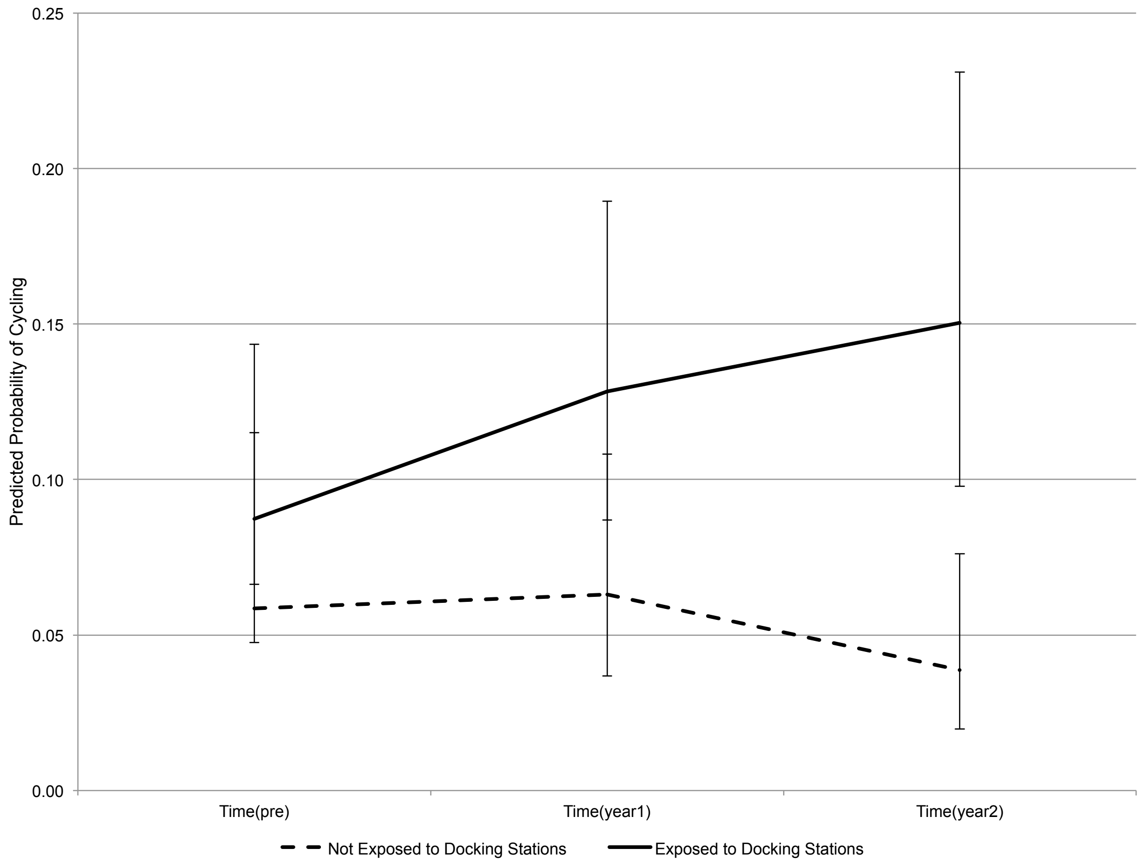


Figure 2. Fully adjusted predicted probability of cycling in areas where BIXI© dockings stations were deployed and not deployed in the pre-intervention, season 1 and season 2 survey periods in Montreal, Canada, 2009-2010.



Note. Error bars are confidence intervals.

Article 3: Studying the impact of natural built environment interventions: Approximating a randomized controlled trial using a regression discontinuity design.

Daniel Fuller, Lise Gauvin, Geetanjali Datta, Erin Strumpf, Yan Kestens, Guy Lacroix, Slim Haddad

Unsubmitted manuscript

Title: Studying the impact of population health interventions: Improving exchangeability assumptions between treatment and control groups using a regression discontinuity design.

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Daniel Fuller conceptualized the article, conducted all data analysis and did the majority of writing.

Lise Gauvin contributed to conceptualizing the article, contributed to the data analysis and to writing and reviewing the article.

Geetanjali Datta contributed to the conceptualisation of the analysis and to writing and reviewing the article.

Erin Strumpf contributed to the conceptualisation of the analysis and to writing and reviewing the article.

Yan Kestens contributed to conceptualizing the spatial component of the article, contributed to the data analysis and to writing and reviewing the article.

Guy Lacroix contributed to the conceptualisation of the analysis and to writing and reviewing the article.

Slim Haddad contributed to writing and reviewing the article.

Absract

Evaluating the impact of population health interventions is a priority for public health. A key challenge for researchers is to control for unmeasured confounding in studies examining the impact of population health interventions. Causal modelling approaches, particularly the regression discontinuity design, provide useful methodological tools for advancing this research agenda yet are underused. The regression discontinuity design improves the exchangeability assumption between treatment and control groups in observational studies. If exchangeability assumptions are met the regression discontinuity design can provide estimates of interventions effects that are not biased by selection. We apply the regression discontinuity design to study outcomes of a public bicycle share program in Montreal, Canada.

There is considerable debate about appropriate research methods for evaluating population and public health interventions.[1-3] The debate generally centres on the strengths versus limitations of randomized study designs (e.g., parallel, cluster) and alternative methods that can produce unbiased estimates of intervention effects. Yet, randomized studies examining population health interventions are rare and most population health intervention studies are pre- or quasi-experimental.[4] A key challenge for the field is to strengthen causal claims about intervention effects, which are often evaluated with non-randomized studies, using methods that can produce estimates unbiased by unmeasured confounders.[5-10] One solution lies in analysis methods collectively known as causal modeling.[11] These methods can improve causal claims about the effects of non-randomized population health interventions. Causal modeling approaches include propensity score matching, instrumental variables, difference in differences, and regression discontinuity. To date, despite general discussions about causal modeling in the public health literature, limited research has presented applications of causal modeling to actual population health interventions.[2]

The regression discontinuity (RD) design is particularly promising for studying population health interventions and is underused in public health research. Lee and Lemieux[12] found that of 77 studies using an RD design, 7 were related to health. None evaluated a population health intervention. The RD design was originally developed by psychologists in the 1960's[13] and has since been applied in numerous disciplines, particularly economics.[14-16] The logic of the RD design is that if treatment assignment is based on a cut off or discontinuity (age, neighborhood) and assuming: [a] that the discontinuity is somewhat arbitrary, (independent of expected outcomes) and [b] that individuals cannot manipulate their position on either side of the discontinuity, then comparing the outcomes of those near the discontinuity threshold improves exchangeability assumptions between treatment and control groups, because there is no reason to think that those on either side of the discontinuity differ. Assuming [a] and [b] is equivalent to the two assumptions of randomization which ensure exchangeability. That is, assuming that the discontinuity is arbitrary (assumption [a]) is equivalent to saying that the mean level for each treatment condition is equal, on average, on all participant background variables prior to the beginning of the intervention. And, assuming that individuals cannot manipulate their position (assumption [b]) is equivalent to saying that the treatment assignment is, on average, unrelated to all participant background variables, either observed or unobserved. The strengths of the RD design are that it approximates randomizations exchangeability assumptions and assumptions can be somewhat verified statistically.[17] For example, the RD design has been used to study the effect of breast cancer screening guidelines on screening rates where screening is recommended for all women aged 50 and over (a discontinuity at age 50).[18] The results show that mammography screening increased from 47% at age 49 to 57% at age 50 and 66% at age 51.

The purpose of this study is to present a practical application of the RD design and evaluate a population health intervention using data from a study of the BIXI© (name merges BIcycle and taXI) public bicycle share program (PBSP).[19] A recent RD 'user guide'[15] and study of the spatial distribution of employment benefits in Austria were used as a framework for the present paper.[20] Because the purpose of this study is to present an example of the concepts and application of RD in evaluating outcomes of population health interventions, technical mathematical details are not presented (consult Lee and Lemieux 2010[12] for a detail mathematical presentation).

CONCEPTS IN REGRESSION DISCONTINUITY DESIGN

Defining the discontinuity

The RD design requires a discontinuity in the assignment of a treatment. A continuous variable known as the assignment variable (also known as forcing or running variable) operationalizes the discontinuity. In the breast cancer example above, the assignment variable was age with the discontinuity occurring at age 50 years. Any continuous variable were a discontinuity in treatment occurs can be used as an assignment variable.

Once the discontinuity and assignment variable have been defined there are two ways to conceptualize the discontinuity: sharp or fuzzy. In a sharp RD design, the treatment assignment at the discontinuity is strictly applied to the entire population, you fall on one side or the other of the discontinuity. In a sharp design the treatment variable is operationalized by creating a dichotomous indicator of the assignment variable that indicates treatment or no treatment. In a fuzzy design, the discontinuity is not strict and the probability of treatment can vary at the discontinuity. The treatment variable in a fuzzy design can be operationalized as a dichotomous or ordinal variable indicating the probability of treatment. For example, Angrist and Lavy[21] exploited a class size rule, which states that a class of 40 or more must always be split into two, to study the effect of class size on scholastic achievement. Classes comprising 39 students were compared with classes of about 20 students because in the latter case the classroom size was more then 40 students and was split in two. Conceptually, this is a sharp design, however, in practice the class size rule was not applied strictly and the probability of treatment was fuzzy.

Distribution of the outcome variable and covariates

When using the RD design, visualizing the data is of primary importance.[15] This allows the examination of the relationship between the outcome and the assignment variable prior to conducting formal tests. Analyses should also examine covariates on either side of the discontinuity. These analyses support, but cannot confirm, the assumption that those on one side or the other of the discontinuity are exchangeable. Selection of covariates should be based on subject matter knowledge. In a fuzzy design the probability of treatment should also be graphed to ensure that it is continuous in relation to the assignment variable.

The regression

The RD design uses regression to estimate the effect of interest. This regression compares the average level of a given outcome at the discontinuity between participants on either side of the discontinuity. In a sharp RD, the estimand is the difference of two regression functions at the cutoff, a local average treatment effect (LATE). In principle (if the discontinuity is truly exogenous) there is no need for regression analysis or control for observed covariates in a sharp RD. Comparing means on either side of the discontinuity can be sufficient to provide an unbiased estimator of the treatment effect. In a fuzzy RD, the estimand is a local average effect of the treatment, divided by the probability of treatment.

In practice, in both sharp and fuzzy RD designs the analyst often has to deal with too few observations around the discontinuity and must test multiple specifications of 'either side' of the discontinuity (known as a bandwidth). Conceptually, the more observations the regression includes that are far away from the discontinuity (the larger the bandwidth), the less likely the assumption of exchangeability on all measured or unmeasured variables will hold. The narrower the bandwidth the smaller the sample size used for the estimate, which decreases power. Methods proposed for estimating bandwidths include optimization algorithms and cross-validation.[22 23] Regardless of the method of bandwidth selection, the estimated effect should not be sensitive to bandwidth size.

Other considerations when conducting the regression are the distribution of the outcome variable and functional form of the relationship between the outcome and assignment variable. RD analysis can be conducted with nearly any distribution of the outcome variable. All in one RD packages 'RD'[24] and 'RDOB'[25] are available in Stata for normally distributed outcome variables. For non-normally distributed outcome variables researchers will be required to manually create the necessary variables (assignment, treatment, discontinuity, left and right regression lines). However, manually creating variables is a recommended exercise to enhance understanding,[15] particularly for applied users, even if all in one RD packages are available. As well, researchers should test multiple functional forms of the relationship between the outcome and assignment variable. Fitting a line to a non-linear relationship can mask or overestimate effects.

METHODS

Data

Data from the BIXI© public bicycle share program study were used.[26] This ongoing study is examining the impact of implementing a PBSP on cycling, physical activity, and collisions in Montreal. The data consist of three population based repeat cross sectional samples of residents of the Island of Montreal. Surveys were conducted prior to the implementation of BIXI© (May 4th - June 10th 2009), at the end of the first season of implementation (October 8th - December 12th 2009), and at the end of the second season 2 of implementation (November 8th - December 12th 2010). Samples consisted of 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, respectively. Details on survey methods and procedures have been previously published.[19]

Measures

The outcome variable was self-reported cycling (on a BIXI© or personal bicycle). Respondents reported the number of days of cycling for at least 10 minutes in the past week using the long form of the International Physical Activity Questionnaire (IPAQ).[27] Covariates included income, age, body mass index, sex, and self-rated health measured using questions from the 2006 Canadian Census and population density, density of destinations, road network density, and street connectivity.[28]

Analysis

Regression discontinuity analysis was conducted using geographic information systems (GIS) and Stata. To encourage the use of these methods by other researchers the syntax files for analyses are included in Appendix 1. The outcome variable was highly skewed and negative binomial regressions were fitted using the count of the number of days of cycling per week. It is hypothesized that there should be no local impact of the PBSP during implementation because the program was being launched. At season 1 and season 2 implementations the PBSP is hypothesized to increase self-reported cycling.

APPLYING THE REGRESSION DISCONTINUITY DESIGN

Defining the discontinuity

The BIXI© program is implemented in certain areas of the city and not others. There is spatial discontinuity. The assignment variable was calculated using GIS which mapped the PBSP stations and participant home addresses for each survey period. The border of the implementation area (the discontinuity) was established by manually selecting stations at the outer limit of the implementation area. After defining the discontinuity, the network distance from the discontinuity to participant home addresses was calculated. In calculating the assignment variable, participants residing more than 10 kilometers from the discontinuity were excluded. Figure 1 maps the participants' distance from the discontinuity. Excluding these participants and those with missing data resulted in the loss of 307 (final sample n=1694), 354 (final sample n=2148) and 272 (final sample n=2237) participants from pre-implementation, season 1 and season 2, respectively. For participants residing inside the implementation area the distance values were transformed to negative. The discontinuity occurred at a value of zero. Participants residing inside the PBSP implementation had values ranging from -2 to 0, those outside the implementation are had values ranging from 0 to 10. The assignment variable was estimated for each survey period because the implementation area expanded each season.

In the present example, the treatment is fuzzy. Residing inside the implementation zone does not require individuals to cycle and people residing on both sides of the discontinuity can use the PBSP. The treatment variable was dichotomous and distinguished those not residing from those residing in a neighborhood where the PBSP was implemented. Figure 2 shows the predicted probability, estimated using logistic regression, of residing in a neighborhood where the PBSP was implemented during the pre-implementation, season 1 and season 2 surveys periods.

Distribution of the outcome variable and covariates

Figure 3 graphs the assignment variable by outcome variable at each survey period. The assignment variable is not normally distributed. This non-normality has implications for estimation and interpretation which will be discussed. Table 1 shows averages on either side of the discontinuity for selected covariates at each survey period. Socio-demographic, environmental, behavioral, and health characteristics related to cycling were chosen.[29-33] Given the importance of the comparability assumption to the strength of the RD design selected covariates should be judiciously chosen based on subject matter knowledge. Examining the mean level for each variable on either side of the discontinuity suggests that the values of population density and density of destinations are higher inside compared to outside the discontinuity. Variables that violate the assumptions of RD researchers should be controlled in analysis.

The regression

Figure 4 graphs the negative binomial regression estimates, while table 2 shows the estimated results for the change in number of days per week of cycling at the discontinuity of implementation for each survey period. The estimates show a local impact of the implementation of the PBSP on cycling at pre-implementation period, -1.29 days (95% CI: -2.65; -0.06), and expansions at season 1, -2.56 days (95% CI: -4.91; -0.21), with no difference in cycling at the discontinuity at season 2, -2.76 days (95% CI: -7.01; 1.49). Table 2 examines sensitivity of the models to bandwidths of 1.5 and 1 kilometer. Smaller bandwidths and small sample sizes increase the range of confidence intervals and significant differences in cycling at the discontinuity become non-significant. Finally, population density and density of destinations were included in the full models. These variables were highly collinear and only population density was included. Adding population density to the models with no bandwidth limits attenuated the local impact of the PBSP on cycling at pre-implementation, -0.36 days (95% CI: -1.41; 0.69), at season 1, -1.92 days (95% CI: -5.26; 1.42), and did not change the results at season 2, -2.67 days (95% CI: -9.62; 4.28).

DISCUSSION

This study presented a practical application of the RD design, which in theory approximates a randomized controlled trial, using data from a built environment intervention. The results show that the assumptions of exchangeability fail because implementation of the program was not exogenous. There was no local impact of implementing of a PBSP on cycling. This result is contrary to our research examining the overall impact of the BIXI© program[34] and past research examining other natural built environment interventions.[35-37] The finding of no local impact does not invalidate our research examining the overall impact because the LATE and average treatment effect (ATE) are distinct.[34] However, the different results do bring up relevant discussion points. There is a need for population health researchers to better hypothesize intervention effects when using causal modeling approaches. Our hypotheses for a LATE may have been weak because the effect of large scale interventions should occur over the entire population and not necessarily at the discontinuity, a lagged effect between implementation and uptake[39, 40] which was masked by the seasonal program expansion and fewer bicycles and docking stations available at the discontinuity in implementation. When using causal modeling approaches, there is a need for detailed hypotheses of intervention effects while simultaneously considering the relationship between the research question and methods.

The assumptions of RD were tested. The discontinuity of the PBSP was not exogenous and was related to population density. Population density was statistically controlled for in analyses. Conceptually, this control weakens the design considerably because, like a randomized study, if one variable is different between treatment and control groups it is difficult to justify exchangeability on all other measure and unmeasured variables. For example, individuals could choose to move to homes in order to live within the BIXI©

implementation area. The regression results were also sensitive to bandwidth size. RD requires large enough sample sizes at the discontinuity in order to balance bandwidth size and design assumptions. The importance of the assumptions for the strength of the RD method cannot be overstated. The RD design improves exchangeability assumptions and can approximate a randomized design only if the assumptions hold.

The spatial (versus an age or income based discontinuity) nature of the discontinuity poses interesting questions related to the RD design. The discontinuity was defined based on a single exposure (i.e., residential location) however individuals are highly mobile and defining the discontinuity based solely on residential exposure does not completely capture individuals daily mobility and their relationship with the discontinuity.[38] Spatial auto-correlation is not considered in the current analysis but may impact the results. Integrating geographical methods, such as geographically weighted regression,[39] into RD analyses is one potential approach which is being explored to improve estimates when discontinuities are spatial.[40]

Limitations

Despite the strengths of the RD design if the assumptions of the method hold there are practical and conceptual limitations that must be considered. In the present case, those residing more than 10 kilometers from the discontinuity were excluded. This exclusion could influence the results. More generally, limitations include the ‘fuzziness,’ external validity and the relationship with other causal modeling methods. For spatially distributed interventions, the question of ‘how fuzzy can fuzzy be?’ is relevant. In the case of the BIXI© intervention, people can easily move in and out of the implementation area using multiple modes of transportation. This is a case of weak identification where the discontinuity is of small magnitude which can bias results.[41] RD designs estimate a LATE, as a result external validity must be considered. It is tempting to extrapolate the findings of studies using RD designs to the population as a whole. However, assuming that LATE and ATE are the same requires strong assumptions. "Without strong assumptions justifying extrapolation to other subpopulations (e.g., homogeneity of the treatment effect), the designs never allow the researcher to estimate the overall average effect of the treatment (p. 622)."[15] Finally, RD is not completely separate from other causal modeling approaches. In fact, the RD design is a case of instrumental variable estimation.[21] An instrumental variable (IV) is related to the exposure of interest but unrelated to the outcome except through its relationship with the exposure.[42] IV estimates rely on the assumption that the only reason for an association between the instrumental variable and outcome of interest is the association between the instrumental variable and exposure of interest. Brought back to the fuzzy RD design, the instrument is the discontinuity and the exposure is the treatment variable. IV assumptions are equivalent to fuzzy RD assumptions (for more detail see Angrist and Lavy[21]).

Conclusion

The regression discontinuity design is an important, yet underused, methodological tool for studying population health interventions. This study presented the application, promise and challenges using of the regression discontinuity design to study effect of implementing a public bicycle share program on cycling. The results show that there was no local impact of implementing the public bicycle share program. Causal modelling approaches represent an important methodological advancement in cases where more research is necessary before randomized studies of population health interventions can be conducted.

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Figure 1. Network distance in meters from participants home to the discontinuity in public bicycle share program implementation by season in Montreal, Canada.

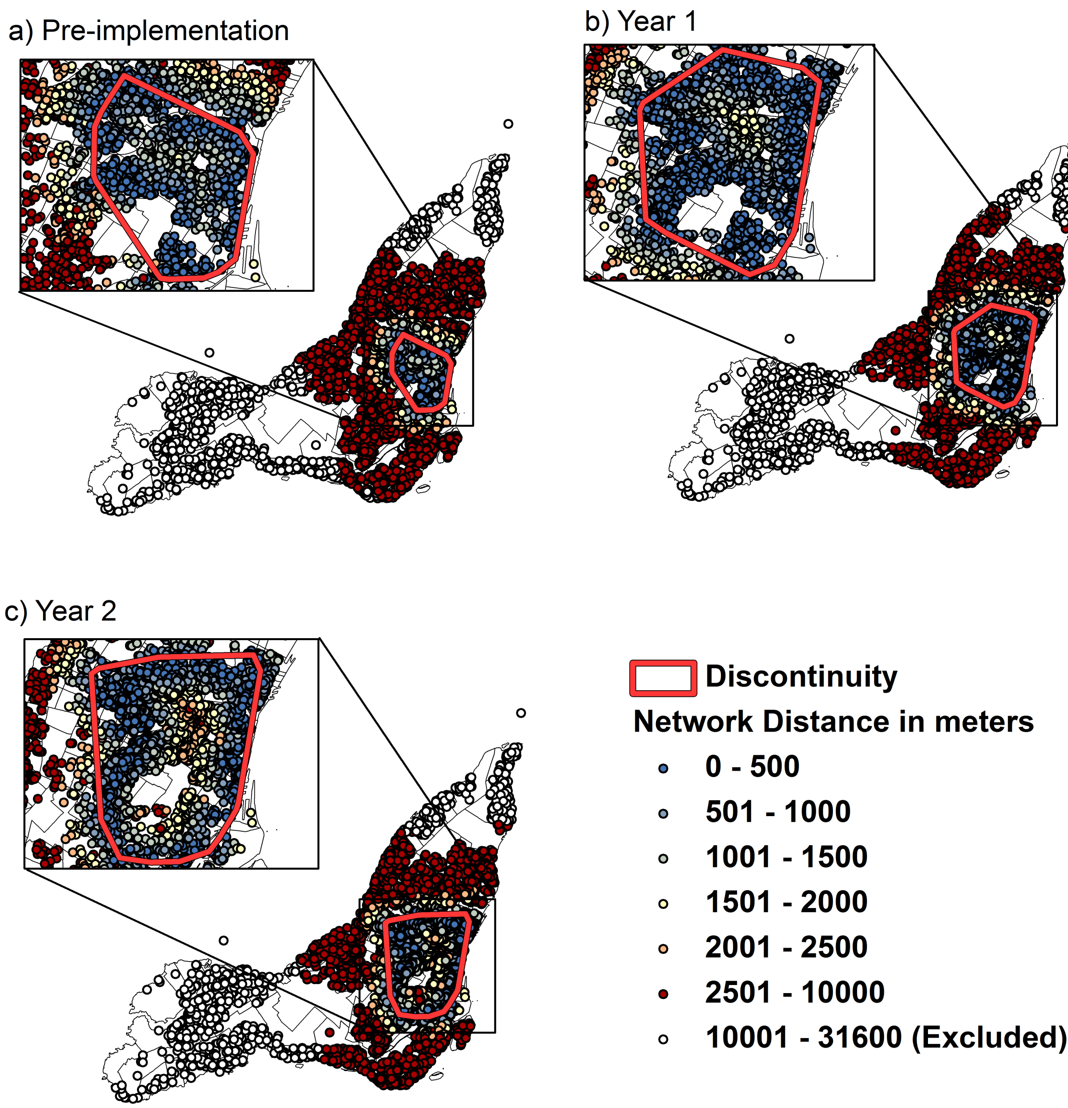

Figure 2. Probability of treatment by distance to implementation of the BIXI© public bicycle share program estimated using logistic regression during the implementation, season 1 and season 2 surveys periods in Montreal, Canada.

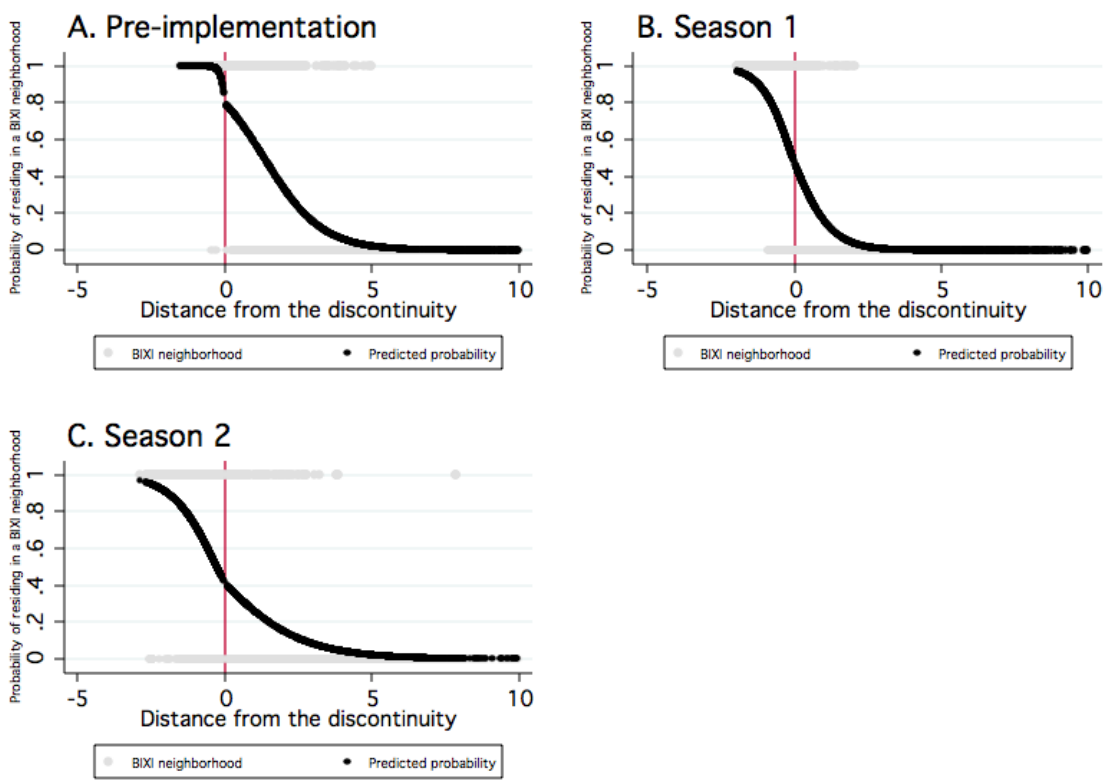

Figure 3. Density of number of days of cycling per week by distance to implementation of the BIXI© public bicycle share program during the implementation, season 1 and season 2 surveys periods in Montreal, Canada.

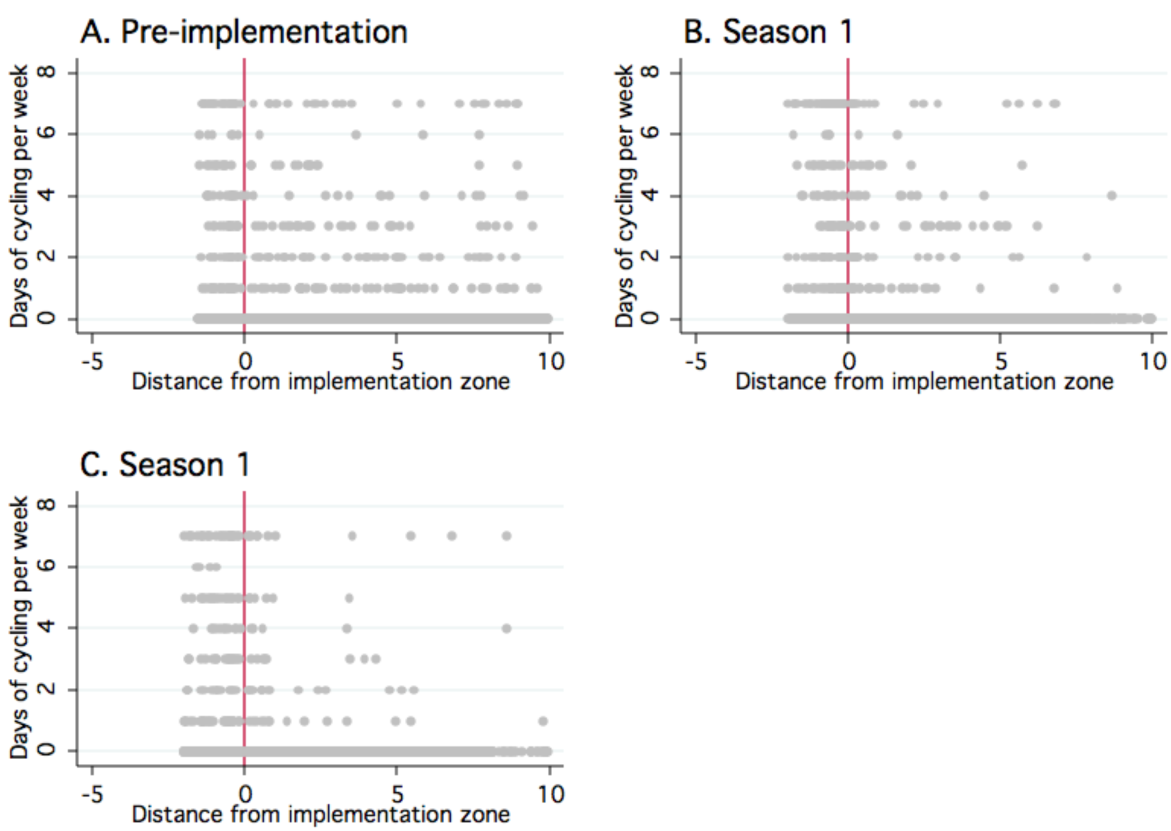

Table 1. Means inside and outside of the discontinuity area for selected covariates at the discontinuity of implementation of the BIXI public bicycle share program during the implementation, season 1 and season 2 survey periods in Montreal, Canada.

	Pre-implementation		Season 1		Season 2	
	Mean Inside BIXI area	Mean Outside BIXI area	Mean Inside BIXI area	Mean Outside BIXI area	Mean Inside BIXI area	Mean Outside BIXI area
Income	4.33	4.39	4.39	4.42	4.46	4.21
Age	44.91	49.64	44.04	48.03	45.63	48.83
Body Mass Index	24.33	25.45	24.61	25.16	24.52	25.55
Sex	49.71	55.49	60.75	59.80	54.51	59.80
Population density	75.72	26.36	72.76	24.56	66.85	25.84
Self-rated health	2.87	2.92	2.86	2.86	2.86	2.89
Density of destinations	10.78	5.48	9.44	5.73	9.45	6.09
Road density	6.478	5.53	6.20	5.42	6.15	5.59
Street connectivity	11.61	8.78	9.68	9.03	10.54	9.22

Notes. Income measured on a 9 category scale ranging from under $10,000 to more than $200,000. Sex is percent female. Population density is a kernel density of the Montreal population. Self-rated health measured on a 5 category scale ranging from excellent to bad. Density of destinations measured as a count of the number of parks, grocery stores, banks, pharmacies, and medical services within a 500m network buffer of respondent's homes. Road density measured as a kernel density of roads in Montreal. Street connectivity measured as a count of the number of intersections within a 500m network buffer of respondent's homes.

Figure 4. Negative binomial regression of days per week of cycling on either side of the discontinuity in public bicycle share deployment during the implementation, season 1 and season 2 surveys periods in Montreal, Canada.

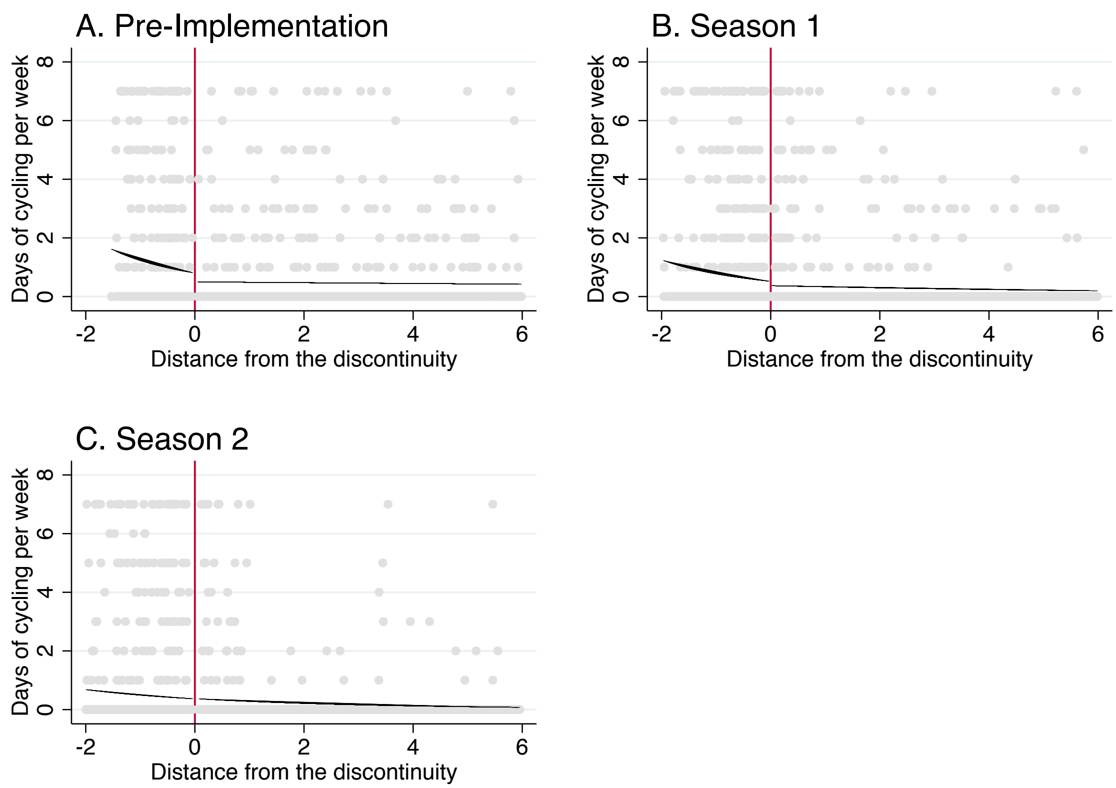

Table 2. Negative binomial regression coefficient for the change in number of days per week of cycling at the discontinuity of implementation of a public bicycle share program during the implementation, season 1 and season 2 survey periods in Montreal, Canada.

	Pre-Implementation Coefficient (95% CI)	Season 1 Coefficient (95% CI)	Season 2 Coefficient (95% CI)
Total cycling (Full sample)	-1.29 (-2.65; -0.06)*	-2.56 (-4.91; -0.21)*	-2.76 (-7.01; 1.49)
Total cycling (1.5km bandwidth)	-0.19 (-5.98; 5.60)	8.39 (-35.24; 52.03)	4.29 (-14.69; 23.26)
Total cycling (1km bandwidth)	-14.38 (-67.01; 38.25)	8.42 (-15.43; 32.25)	1.45 (-5.23; 8.13)

Notes: Sample sizes for full model are 1694, 2148 and 2237; 1.5km bandwidth are 689, 1347, 1180; 1km bandwidth are 503, 1169, 887 for the implementation, season 1 and season 2 survey periods, respectively. CI=Confidence Interval. *p<.05;†p<.10

Chapter 4: Discussion and Conclusion

The overarching aim of this dissertation was to estimate the impact of a built environment intervention on cycling using methods which reduce bias in estimation of intervention effects. This aim contributes to the Canadian Institutes of Health Research Institute of Population and Public Health objective to "foster research that examines the impact of population health interventions on health and health equity and to support the application of novel measures, research designs, and frameworks in studies of population health interventions."[171]

Summary of Results

In the exploratory first study, the prevalence and correlates of use of a PBSP in its first season were examined. Results show that approximately 125,626 inhabitants or 8.2% of the adult population of the Island of Montreal used BIXI© bicycles in the first season of implementation. Prevalence estimates stratified by proximity to docking stations showed that approximately 53,934 (14%) of the population where BIXI© bicycles were available had used them at least once compared to approximately 69,133 (6%) of residents where BIXI© bicycles were not available. Significant correlates of BIXI© use were exposure to BIXI© docking stations and age. There was no difference in BIXI© use between men and women.

In the second study, whether the PBSP was associated with an increased likelihood of cycling for those exposed was examined. The results showed that after the first year of implementation those exposed were not significantly more likely to cycle although the impact was in the hypothesized direction and neared statistical significance (OR=1.47, 95% CI: 0.99, 2.19). Those exposed at year 2 had a significantly greater likelihood of cycling (OR=2.86, 95% CI: 1.85, 4.42). The results show a lagged association between implementation of the PBSP intervention and greater cycling. This is consistent with discussions of natural built environmental interventions which suggest that it takes time for such interventions to achieve population uptake.[46, 125] Ancillary analysis 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. For recreational cycling, there was no significantly greater likelihood of cycling on the Island of Montreal but a significantly greater likelihood for those exposed to the PBSP.

Study 3 presented a practical application of the RD design, which can approximate the exchangeability assumptions of a randomized study and control unmeasured confounders, using data from a natural built environment intervention. The results showed that there was a local impact of the implementation of the PBSP on cycling at pre-implementation (-1.29, 95% CI: -2.65; -0.06), and expansions at season 1 (-2.56, 95% CI: -4.91; -0.21), while there was no impact at season 2 (-2.76, 95% CI: -7.01; 1.49). The result of a local impact at pre-implementation was unexpected because the program was not fully implemented at the end of data collection. The results for season 1 show a local impact. However, there is likely unmeasured confounding because effects were observed in the pre-implementation period. At the end of season 2 there was no local impact, which is contrary to the hypotheses and findings from the findings in study 2.

Taken together the results of this case study show that the PBSP in Montreal was successful in achieving population level changes overall, but no local effect was observed at the implementation area, in cycling in the first two years of implementation. This is, to my knowledge, the first in depth case study of a PBSP in North America. These results are important considering municipal and public health authorities desire to reduce motor vehicle use and increase cycling.

Contributions

Given the results of the dissertation and the current state of research examining natural built environment interventions in transportation there are three contributions of this dissertation; novelty, conceptualisation of interventions, and methods. For coherence each contribution is outlined with a heading, however, there are interactions between them.

1. Novelty

The BIXI© program is of interest to researchers in North America given the limited implementation of PBSPs and the lack of internally valid studies of the impact of more traditional built environment infrastructures (e.g., cycling lanes). BIXI© was the only large scale program in North America in 2009. Despite over 100 programs being implemented worldwide, only *Bicing*© in Barcelona, Spain has been extensively studied.[90, 172] The implementation of a PBSP in the context of North America is novel. Results from numerous studies comparing the North American and European cycling contexts show differences in terms of prevalence of cycling, presence of infrastructures (e.g., cycling lanes) and culture (e.g., positive attitudes toward use of bicycles for transportation).[173-175] Some authors suggest that PBSPs may have less impact in North America, compared to Europe, because cycling infrastructures and culture are not well established in North America.[81] This research contradicts the assertion that PBSPs may have less impact in North America and is important considering the expansion of programs to other North American cities. Since the beginning of this research in 2008 PBSPs have been implemented in Toronto, Washington DC, Minneapolis, Boston and Ottawa with planned programs in Vancouver and New York in 2012.

The novelty of studying a PBSP also relates to the ability to detect effects compared to other natural built environment interventions. Built environment interventions such as traffic calming or cycling lanes have been widely implemented in North America and Europe. The effect of these interventions is difficult to estimate. SCT hypothesizes a recursive relationship between individuals and the environment. Cycling lanes are implemented because the population judges them as necessary. As a result more people begin cycling and even more cycling lanes are built. An important challenge is designing a study that is sufficiently powered to detect the small hypothesized effect of implementing cycling lanes on cycling. PBSP are novel relative to other built environment interventions to increase cycling because they are implemented on a large scale and the hypothesized effect size is larger than other built environment interventions to increase cycling. The large scale provides a proof of concept for the potential of large scale built environment interventions.

2. Conceptualisation of Interventions

"Theories are causal explanations. The goal in every science is explanation, and explanation is always causal (p. 1177)."[176] This dissertation was guided by two ideas: Rose's strategy of preventive medicine[139, 140] and social cognitive theory (SCT).[141] The results of study 1 and 2 support Rose's strategy, which suggests that built environment interventions can plausibly bring about population level shifts in cycling. The present study adds to the evidence base supporting a population based approach to increase cycling.

Rose's strategy, though compelling in terms of public health implications, provides limited guidance for identifying specific mechanisms to explain why the intervention was or was not effective. SCT provides a theoretical basis for hypothesizing mechanisms of intervention effects. Results from study 2 support the proposed mechanism from SCT that the environment has a direct effect on behaviour which was observed in the nearly significant increase in cycling one season after the implementation of BIXI© Through further environmental exposure to BIXI© and the mechanism of behavioural modelling significant increases in cycling were observed after season 2.

The results of article 2 were not extended in article 3. Article 3 showed no local impact of implementing the PBSP on cycling. Although the hypotheses for article 2 were defined *a priori,* the results from article 3 call into question the sophistication of the proposed theorization. Assuming that the results from article 2 and 3 are both correct, why is there an overall impact in article 2 but no local impact in article 3? A *priori* theorization should provide mechanism that could explain differences in results. Lacking this, and with all its potential problems, *post hoc* theorization supported by the results from article 1 suggests four explanations for the differing results between article 2 and 3.[177] First, bias could explain the different result. Unmeasured confounders that were controlled in study 3 may not be controlled in study 2 and could be biasing the results. Second, Rose's strategy suggests that population intervention effects should be seen over the entire population and not specifically for those at the border of the implementation area. This is supported by the results of article 1 which shows that a similar absolute number of people use BIXI© who reside inside and outside the implementation area. Third, because the BIXI© implementation area increased in size each season, it is possible that the lagged uptake was not observable because each implementation area was subsumed by a larger implementation area the following season. Finally, fewer bicycles and docking stations may be available at the edge of the implementation zone resulting in a smaller effect of the environment and behaviour relationship. The key piece of this discussion is the need for *a priori* hypotheses, which can explain the estimated effects and, which consider the type of effect estimate, the strengths and the limitations of the method used. The researcher should ask, can the methods I'm applying answer my research question and does my hypothesis make the link between my question and methods?

3. Methods

> "A great part of clinical medicine, and of epidemiology, must still be observation. Nature makes the experiments, and we watch and understand them if we can. No one will deny that we should always aim at planned intervention and closer control. Here, as elsewhere, technique – the way we make our observations and check them – is half the battle, but to force experiment and observation into sharply separate categories is almost as dangerous a heresy as the science and art

> (of medicine) antithesis. It tends to make the clinician in the ward, the epidemiologist in the field, and the laboratory worker at his bench, think of themselves as doing different things, and bound by different rules. Actually they are all making experiments, some good, some bad. It is more difficult to make a good experiment in the ward than in the laboratory, because conditions are more difficult to control; but there is no other way of gaining knowledge… Controlled observation in the ward or in the field is an essential part of medical science, shading through almost imperceptible stages of increasing intervention into the fully developed experimental technique of the laboratory (p. 40)."[178]

This quote by William Topley suggests that we must, even in observational studies, keep the experimental method in mind. Keep causality at the forefront.[179] The methodological contribution of this dissertation is simple but has broad implications for how researchers theorize and conduct natural experiment evaluations. Stated simply, methods were borrowed from psychology and economics, which improve internal validity, and were applied to the study of a natural built environment intervention, which has the potential to increase cycling and physical activity. These methods can be applied to any number of natural experiments but to date have not been extensively used in public health research.[180]

The more complex question is then, why have researchers not applied such methods? I argue today, as was done in 1940, that researchers continue to "force experiment and observation into sharply separate categories (p. 40)"[178] The distinction between experiment and observation is characterized by the recommendations of Flay[181] for eight phases of research for the development of health promotion programs: 1) basic research, 2) hypothesis development, 3) pilot applied research, 4) prototype evaluation studies, 5) efficacy trials, 6) treatment effectiveness trials, 7) implementation effectiveness trials, and 8) demonstration evaluations. In proposing these phases Flay implies that evidence from basic (i.e., observational) and pilot test (i.e., quasi-experimental) studies as less able to make causal claims than evidence from randomized designs. The primary objective of both observational studies and randomised designs is to control for confounding and attempt to estimate an unbiased effect. This dissertation attempts to reconcile the artificially sharp distinction between observational and controlled experiments. The blurring of methods requires a new conception of hierarchies of evidence. Where evaluation of effect estimates is done on a based on control for confounding and the key feature of evaluation is the plausibility of the assumptions used to justify causal conclusions, be they in the context of a randomized study or an observational study.[181, 182]

Limitations

Limitations of the dissertation, beyond the limitations of each individual study, include insufficient theorization, coverage bias due to RDD sampling, low response rate, public health implications, exposure misclassification, alternative explanations, and general critiques of counterfactual theory. Despite the critique of insufficient theorization of mechanisms that can explain the effect of built environment interventions and an attempt to improve this theorization the present dissertation is still limited in terms explaining mechanisms. The relationship between the results and the ability to explain the findings theoretical emerged as a limitation throughout the process of the dissertation. For example, the *a priori* hypotheses developed for the dissertation assumed an average effect across the population. However, causal modelling approaches require specific hypotheses and assumptions. As discussed in paper 3, the RD design cannot estimate average treatment affects. If the *a priori* research questions and hypothesis assume an average treatment effect the RD design, no matter how internally valid, will be unable to answer the research question and the hypotheses will be flawed.

The RDD sampling to landlines telephones suffers from coverage bias. Two interrelated forms of coverage bias are likely, potential respondents not having any telephone (landline or cellular) and potential respondents having only cellular telephones. Ford et al., showed that respondents without a telephone were more likely to be smokers, to be less physically active, to have a poorer diet and to have lower screening rates for a number of health conditions including blood pressure and cholesterol.[183] Adults with only cellular telephones appear to fall into two categories, affluent young people residing in urban areas and low-income minority populations.[184, 185] The health characteristics of the low income minority populations are similar to the characteristics of individuals without any telephone.[184] The 2010 Residential Telephone Service Survey of Statistics Canada reports that the proportion of households without any phone service was 1.1% while 13% reported exclusively using a cellular telephone.[186] As well, volitional non-response using call screening and low response rates among contact individuals reduce the population representativeness of the sample.[187] Post-stratification weighting was an attempt to limit coverage bias due to exclusive cellular telephone use.

The public health implications of the results related to changes in physical activity due to increases in cycling are based on strong assumptions about addition versus substitution of different types of physical activity. The objective of the dissertation was to examine whether the PBSP could increase cycling. Extrapolating the findings assumes that increases in cycling lead to increases in total physical activity and subsequently to health benefits. For population increases in the physical activity to occur it is assumed that increases in cycling will be *added* to an individual's current level of physical activity. However, it is plausible that the individuals who adopt the PBSP do not increase their total physical activity. Rather they *substitute* one type of physical activity, say physical activity at an exercise facility for active transportation and thus do not change their total level of physical activity.

The operationalization of exposure in the dissertation was a count of BIXI© stations with a network buffer around respondents home postal code. This operationalization is limited in two ways. First, respondents could be exposed to BIXI© at multiple points depending on their daily travel pattern, particularly, during work hours for those who work in areas where BIXI© is implemented. Second, a simple count of stations does not consider the number of docking points or the number of available bicycles at any given point in time. A very small station with few available bicycles may represent a lower level exposure when compared to a large station with a considerable number of bicycles. In both cases, considering only exposure at home and not considering station characteristics, exposure is likely underestimated.

Despite the use of recently formalized causal modelling approaches, natural experiment studies are subject to multiple sources of bias. Unobserved confounders are the primary limitation of all causal modelling approaches. Unobserved confounders that could bias the findings from study 2 and explain the lack of consistency between study 2 and 3 include secular trends and self-selection. In Canada and Montreal specifically, there has been a trend of increasing levels of cycling since 1994.[165] Secular trends showing increasing cycling could be explained by media campaigns,[167] a lagged effect of cycling lanes and paths implemented since 2000,[188, 189] or the economic recession, which has been associated with increased gas prices and decreased driving in the United States.[190, 191] Residential self-selection may bias estimates because people who are already more likely to cycle are more likely to live and move into the BIXI© implementation area.[192]

There are two broad critiques of causal modelling approaches based on counterfactual theory.[193] The first is that nonmanipulable causes cannot be analyzed.[194] Questions about the effect of race and sex cannot be analyzed because comparing the observed condition, a black individual, to the counterfactual that the same black individual would simply change skin colour is not valid because this is not 'possible' in the real world. Counterfactual theorists retort that although race or sex may be nonmanipulable, race and sex are rarely a variable of interest. Race is most often used as a proxy for cultural practices, discrimination, or deprivation. Sex assumes some genetic differences that are often entangled with gender and socialization.[195] Thus, using better specified hypotheses, counterfactual theory is capable of imagining a world where cultural practices or gender are manipulable.[196] However, this approach is naturally reductionist. Second, the counterfactual is not an observable quantity; it is not real but an imagined alternative state or world. Some critique that science, rooted in real world observation, cannot require an unobserved quantity to confirm observed results.[197] This is a strict positivist perspective the critiques of which are well known.[198]

Future Directions and Recommendations

Future directions for this research include specific research questions about the impact of PBSPs and broad implications for all types of natural built environment interventions. Related to the impact of PBSPs, researchers should examine the effects of implementing such programs in different cities. Research questions that remain unanswered include potential interactions between the implementation and characteristics of cities. For example, there may be a threshold of density for PBSPs where a large-scale implementation will be effective for increasing cycling while a small scale implementation will not. It may also be the case that existing cycling infrastructure is a necessary pre-requisite for program uptake. These questions and detailed examination of the positive and negative health consequences of PBSPs require further investigation. More broadly related to intervention evaluation, researchers should use methods that improve internal validity of studies with non-randomized data. These causal modelling approaches are an important methodological advancement and should be adopted more widely by researchers interested in population health interventions of any kind. Study 3 of the dissertation is a first attempt at promotion causal modelling methods for population health intervention researchers. This study, as well one manuscript under review,[199] are a start at reminding researchers to keep causal questions at the forefront of their minds, regardless of methodology.

Conclusion

This dissertation shows empirically that interventions occurring outside the health sector do influence population health and merit study by health researchers. It also provides a proof of concept for the potential of population health interventions making changes to the built environment. The results show that a public bicycle share program did have an overall impact and increased cycling in Montreal. Broadly, the present dissertation examines the question of causality in non randomized studies. Directly addressing the causal question is an important contribution to natural built environment research which has implications for the conceptualisation and evaluation of these interventions. Evaluating and correctly estimating the impact of natural interventions occurring outside the health sector is important for structuring the environments where people live, learn, work and play and achieving the WHO definition of health.

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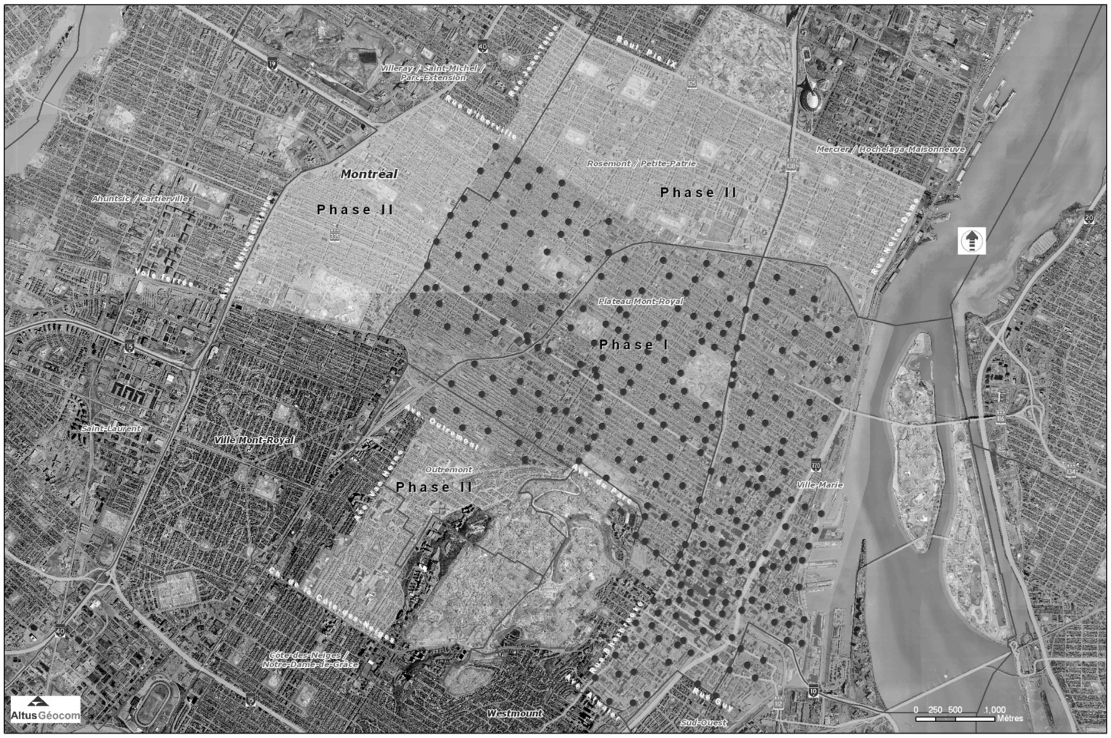
Figures

Figure 1. Phases of implementation of the public bicycle share program in Montreal, Canada, 2009-2010.



Note. Black dots are BIXI© stations implemented in Phase 1.

Figure 2. Intervention model for the evaluation of the BIXI© public bicycle share program

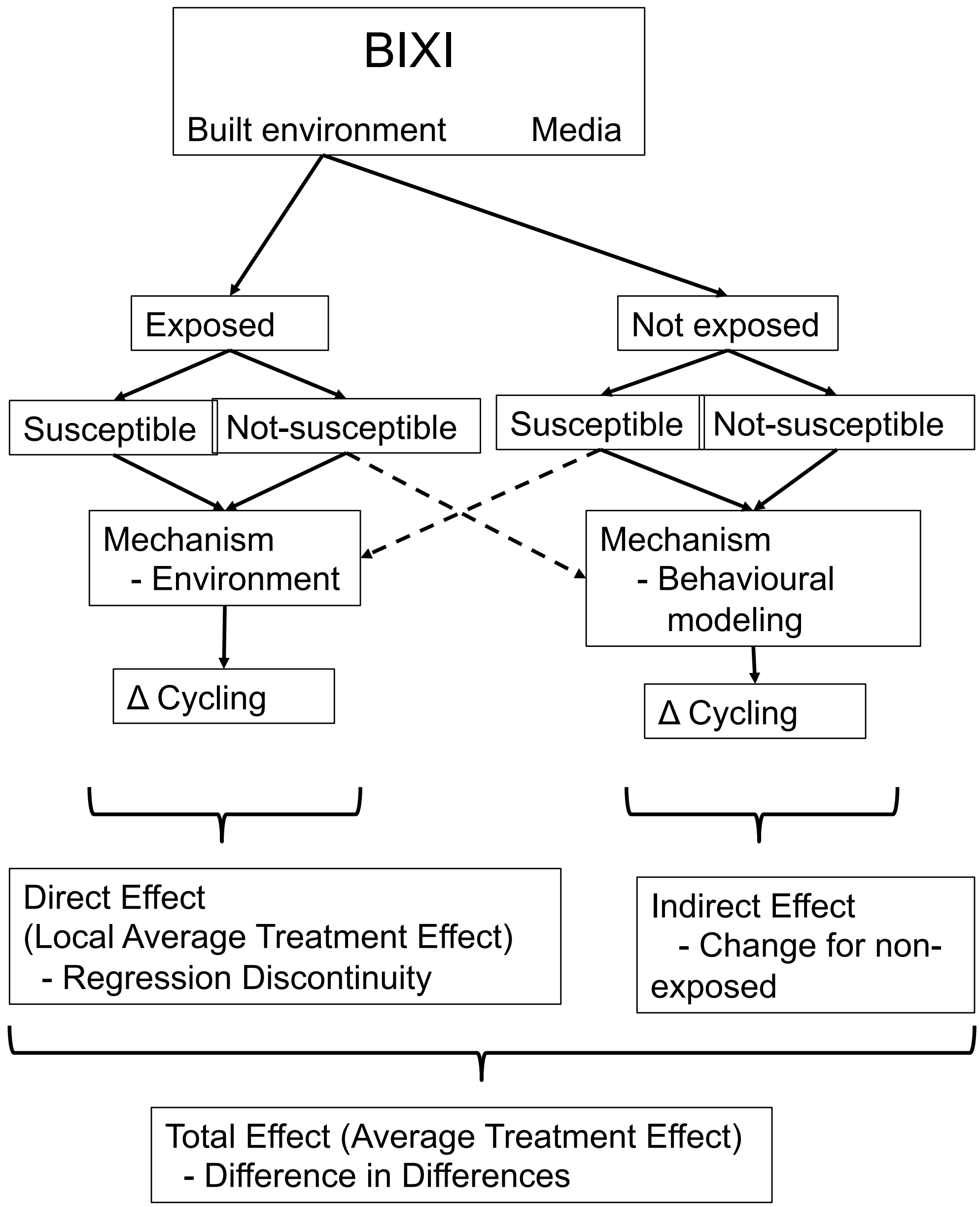


Figure 3. Graphical representation of the general difference in differences method including the counterfactual

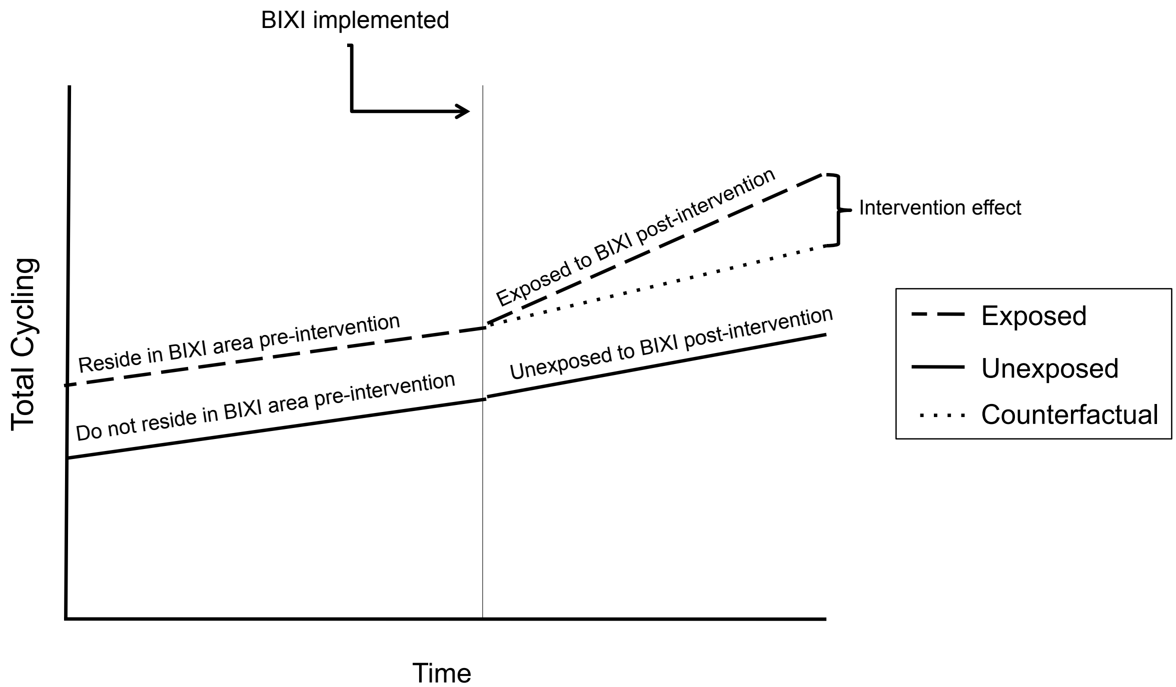
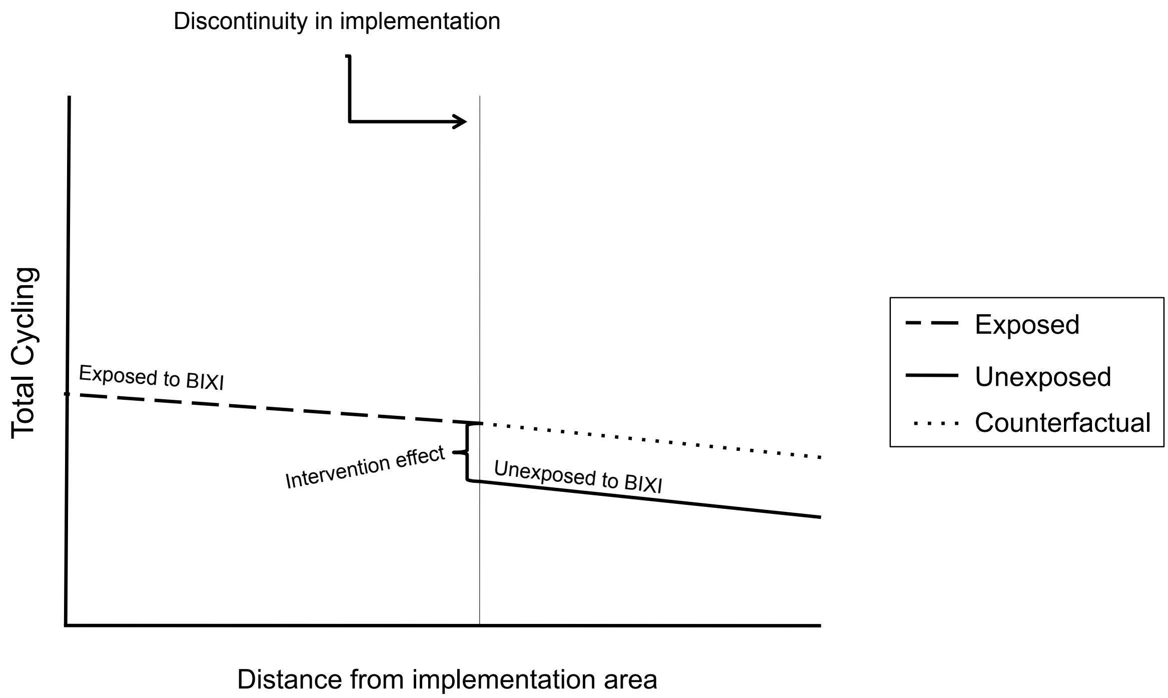


Figure 4. Graphical representation of the general regression discontinuity method including the counterfactual



Appendices

Appendix I: Public bicycle share programs

Authors/Location/Sample	Methods	Outcome variable	Results
D. Fuller, L. Gauvin, Y. Kestens, M. Daniel, M. Fournier, P. Morency, L. Drouin/Montreal, Canada/General population	Cross-sectional study of bicycle share use	Use of the bicycle share	125,626 inhabitants or 8.2% of the adult population of Montreal used BIXI©. Significant correlates of BIXI©use were exposure to BIXI©docking stations and age
D. Fuller, L. Gauvin, Y. Kestens, M. Daniel, M. Fournier, P. Morency, L. Drouin/Montreal, Canada/General population	Difference in differences impact evaluation of bicycle share on cycling	Cycling, utilitarian cycling, recreational cycling	Greater after one year of implementation (OR=1.47, 95% CI: 0.99, 2.17) and significantly greater after two years of implementation (OR=2.81, 95% CI: 1.83, 4.31)
D. Rojas-Rueda, A. de Nazelle, M. Tainio, M. J. Nieuwenhuijsen/Barcelona, Spain/Bicycle share users	Health impact assessment of air pollution, road collisions and physical activity. Carbon dioxide emissions.	Mortality/Carbon dioxide	Annual change in mortality for the 181,982 *Bicing* users was an additional 0.03 deaths from road traffic collisions, 0.13 deaths from air pollution, and 12.46 deaths avoided as a result of physical activity. Annual carbon dioxide emissions reduction of 9 062 344 kg.
D. Fuller, S. Sahlqvist, S. Cummins, D. Ogilvie/London, England/Bicycle share uses	Interrupted time series design of tube strikes in London on use of the PBSP	Use of the bicycle share	Significant increases in daily trip count were observed following strike 1 (3864: 95% CI 125 to 7604) and strike 2 (11293: 95% CI 5169 to 17416).
S. A. Shaheen, H. Zhang, E. Martin, S. Guzman/Hangzhou, China/Bicycle and non-bicycle share users	Comparison of users and non-users of the bicycle share program	Car ownership, transportation mode share, bicycle share use	30% of members incorporated the PBSP into their most common commute. 40%, occurred at station closest to respondents home or work.
N. Lathia, S. Ahmed, L. Capra/London, England/Bicycle share station usage	Evaluation of use of the program after implementation of casual usage	Use of the bicycle share	Greater weekend usage and more stable weekday commuting patterns. Distribution of PBSP forms concentric circles around central London
Barcelona, Spain	Unknown	Use of bicycle share, cycling	6 uses per day in Barcelona. Estimated trips generated per day 30,000. Bicycle share reportedly increased from 0.75% in 2005 to 1.76% in 2007 in Barcelona.
Paris, France	Unknown	Use of bicycle share, cycling	5-12 uses per day in Paris. Estimated trips generated per day 70,000-145,00. Bicycle share reportedly increased from 1.00% in 2001 to 1.5% in 2007 in Paris.
Lyon, France	Unknown	Use of bicycle share, cycling	6.4 uses per day in Lyon. Estimated trips generated per day 19,100. Bicycle share reportedly increased from 0.5% in 1995 to 2% in 2006 in Lyon.

Appendix II: Cycling interventions: Other

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Title: Infrastructure, programs, and policies to increase bicycling: An international review

Author: John Pucher, Jennifer Dill and Susan Handy

Publication: Preventive Medicine

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Travel related infrastructure			
Measure	**Description**	**Examples and extent of implementation**	**Measured effects on amount of bicycling**
Overall measures of "bikeability"	Some studies combine several infrastructure features into single indices or ask respondents to rate the overall environment for bicycling	Not applicable	One Austrian study found that people who agreed that there were bicycle "tracks" along their route and possible shortcuts were about twice as likely to bicycle as those who did not (Titze et al., 2008). One revealed preference (RP) survey of cyclists found a positive association between their overall rating of the quality of bicycle facilities and frequency of bicycle commuting (Sener et al., 2009). One study did not find a significant relationship between ratings for the bikeability on streets around elementary schools and the number of bicycles parked at the schools (Sisson et al., 2006).
On-road bicycle lanes	In the US, bicycle lanes are usually designated by a white stripe, a bicycle icon on the pavement, and signage. The lanes are on each side of the road, to the right of motor vehicle lanes, and are recommended to be at least five feet wide (American Association of State Highway and Transportation Officials (AASHTO), 1999).	Lanes are very common in US cities, though to varying degrees. Data for 43 of the 50 largest cities in the US found from 0 to 1.5 linear miles of bike lanes per square mile (Dill and Carr, 2003).	Cross-sectional studies at the city or district level show positive correlation between bike lanes or paths and levels of bicycle commuting (Dill and Carr, 2003; LeClerc, 2002; Nelson and Allen, 1997; Parkin et al., 2008; Pucher and Buehler, 2005). Two longitudinal studies found that new bike lanes and paths were associated with increases in bicycle commuting, though effects were sometimes mediated (Barnes et al., 2006; Cleaveland and Douma, 2009). Four of five RP studies conducted at the individual level did not show a positive correlation (Cervero et al., 2009; de Geus et al., 2008; Dill and Voros, 2007; Vernez- Moudon et al., 2005). Krizek and Johnson (2006) found that people living within 400 meters of a bike lane were
			more likely to bicycle. Two of the studies found positive association between the *perception* of having bike lanes and paths and bicycling (Dill and Voros, 2007; Vernez-Moudon et al., 2005). Some RP studies of route choices show that cyclists go out of their way to use bike lanes or paths (Dill, 2009; Dill and Gliebe, 2008; Howard and Burns, 2001; Krizek et al., 2007). Several stated preference (SP) studies show a preference for bike lanes over no facilities or that bike lanes would encourage more bicycling (Abraham et al., 2002; Akar and Clifton, 2009; Antonakos, 1994; Bureau of Transportation Statistics, 2004; Emond et al., 2009; Hunt and Abraham, 2007; Krizek, 2006; Landis et al., 1998; Madera, 2009; Parkin et al., 2007; Stinson and Bhat, 2003; Tilahun et al., 2007; Wardman et al., 2007). Experienced cyclists may prefer bike lanes to off-road paths (Akar and Clifton, 2009; Antonakos, 1994; Bureau of Transportation Statistics, 2004; Hunt and Abraham, 2007; Stinson and Bhat, 2003; Tilahun et al., 2007) or have little or no preference for striped lanes over no striping (Taylor and Mahmassani, 1996; Sener et al., in press). Before-and-after counts in several North American cities and London (UK) show increases in number of cyclists after bike lanes installed (City of San Francisco, 2004; City of Toronto, 2001; City of Vancouver, 1999; Federal Highway Administration, 1994; Sallaberry, 2000; San Francisco Department of Parking and Traffic, 2001; Transport for London, 2004a). However, only one city included counts on nearby streets, where it was found that cyclists were likely diverted to the bike lane (City of San Francisco, 2004). Four studies looked at the effect of bike lane markings on behavior related to safety, but did not include measures of changes in the amount of bicycling. (Hunter et al., 1999; Harkey and Stewart, 1998; Daff and Barton, 2005; Van Houton and Seiderman, 2005).

Two-way travel on one-way streets	**Contraflow bike lanes** allow bicyclists to travel in the opposite direction on one-way streets. **False one-way streets** use signage or barriers to allow cyclists to enter a street, but not motor vehicles. Two-way motor vehicle travel is allowed, but less common because of the entry restriction.	Contraflow lanes and similar treatments are common in many European cities, usually on urban residential streets with low traffic speeds. They are rare in the US (Nabti and Ridgway, 2002), where current guidance discourages the practice (AASHTO, 1999).	No studies were found that assessed changes in levels of bicycling. A study of six sites in the UK concluded that the treatments were safe when designed correctly. A large majority of surveyed cyclists felt safer with the treatments (Ryley and Davies, 1998). A German study found no negative effect on traffic safety (Alrutz et al., 2002). A before-after study of three locations in London found no significant change in the number of crashes. At a fourth location where bicycling flow rates were available, a significant decrease in the crash rate was found (Transport for London, 2005).
Shared bus/bike lanes	Bus-only lanes, usually in downtown environments, that allow bicycle travel.	Shared bus/bike lanes have been used in many European and Australian, and some North American, cities, including Toronto, Ontario; Santa Cruz, CA; Philadelphia, PA; and Washington, DC (Nabti	Surveys in the UK found that shared bus/bike lanes were popular with cyclists. For about one-quarter of the cyclists, the lane influenced their route choice, and few delays to buses were observed (Reid and Guthrie, 2004).
Off-street paths	Off-street paths are paved and separated from motor vehicle traffic. They usually accommodate two-direction bicycle traffic. The minimum recommended width is 10 feet (AASHTO, 1999). The term "trail" is sometimes used for this type of facility. However, transportation planners use the term trails to refer to unimproved (e.g., unpaved) recreational facilities (AASHTO, 1999). Paths can be mixed use (including pedestrians, rollerbladers, etc.) or limited to cyclists.	Off-street paths are common in US cities, though the number of miles is often limited. A survey of 50 large cities found a range of <0.1 to >3.0 linear miles of paths per square mile (Thunderhead Alliance, 2007). Most paths in the US are for mixed travel, though some have lane markings to separate cyclists from pedestrians and other users.	One RP study showed a positive correlation between likelihood of bicycling and proximity to separate paths (Vernez-Moudon et al., 2005), while another found no effect (Krizek and Johnson, 2006). RP studies have found conflicting evidence as to whether cyclists go out of their way to use paths (Aultman-Hall et al., 1998; Dill, 2009). One SP survey found that about 40% of cyclists preferred a longer route using a path to a shorter route using a motor vehicle lane (Shafizadeh and Niemeier, 1997). One observational study found that women cyclists preferred separate paths over bike lanes, and both facilities over no facilities (Garrard et al., 2008). One intercept survey of bicyclists on paths found that 20% stated they would change modes if off-road facilities were not available (Rose, 2007). Several SP studies found that less confident cyclists prefer separate paths over lanes (see above; Jackson and Ruehr, 1998). Respondents in one survey were more comfortable on a path compared to a four-lane local street with a bike lane, though there was no difference between the path and a two-lane local street with a bike lane (Emond et al., 2009). Five sources looked at paths before and after construction or the introduction of bicycles. Two did not show a change in levels of bicycling for nearby residents (Burbidge and Goulias, 2009; Evenson et al., 2005). One showed an increase in minutes of bicycling among residents living within 1.5 km, when combined with a marketing campaign (Merom et al., 2003). Two studies showed an increase in the number of cyclists (Cohen et al., 2008; Transport for London, 2004a).
Signed bicycle routes	"A shared roadway which has been designated by signing as a preferred route for bicycle use." (AASHTO, 1999) For this review, these routes do not include striped lanes or other pavement markings.	Signed bicycle routes are very common in US cities. They may be more common on residential streets or other streets with less motor vehicle traffic.	One RP survey found a positive correlation between cyclists' perception of facility quality and the presence of signed shared roadways, though not as strong as with bike lanes. Facility quality was then positively associated with the frequency of commuting by bicycle (Sener et al., 2009). One SP study found that cyclists preferred residential roads designated as a bicycle route slightly more than residential roads without such designation (Abraham et al., 2002).
Bicycle boulevards	Bicycle boulevards are signed bicycle routes, usually on low-traffic streets, that also include other traffic calming features that discourage motor vehicle traffic, such as diverters and traffic circles.	Bicycle boulevards are much less common in the US than bike lanes or paths. Portland, OR; Berkeley, CA; and Palo Alto, CA have implemented bicycle boulevards (Nabti and Ridgway, 2002).	One RP study found that cyclists went out of their way to use bicycle boulevards. Women and less-experienced cyclists demonstrated a particular attraction to the facilities, more so than to bike lanes on major streets (Dill and Gliebe, 2008). One survey found that respondents were most comfortable bicycling on a "quiet street" (Emond et al., 2009).

Cycletracks (sometimes referred to as sidepaths or raised bike lane)	Cycletracks are similar to bike lanes, but are physically more separated from motor vehicles, for example with a curb, vehicle parking, or other barriers. They are often wider than a typical US bike lane and usually do not allow pedestrian travel.	Cycletracks are common in European cities on major streets with higher volumes of motor vehicle traffic, but very rare in the US (Nabti and Ridgway, 2002).	One before-after study of new cycletracks in Copenhagen reported a 20% increase in bicycle and moped traffic and a 10% decrease in motor vehicle traffic. However, it was not known how much of the change was due to changes in route choice versus people shifting from driving or other modes to bicycling (Jensen, 2008a). An evaluation of a two-way cycletrack in London showed a decrease in the *rate* of bicycling crashes (Transport for London, 2005) and a 58% increase in the number of cyclists on the roadway in 3.5 years (Transport for London, 2004a). Surveys of Danish adults and German cyclists both found that respondents rated cycletracks higher than striped bike lanes (Bohle, 2000; Jensen, 2007).
Colored lanes	Paint or other methods are used to color bike lanes, making them more visible to motorists.	Colored on-street bike lanes are common in European cities, but rare in the US. Some US cities have used color to mark short segments of lanes at potential conflict points, such as intersections or on-ramps.	Two studies looked at raised and colored cycletracks through intersections in Sweden. One found that the volume of cyclists increased compared to two non-treatment intersections, and estimated that the safety risk declined (Garder et al., 1998). Several studies looked at various safety measures as outcomes, but not levels of bicycling (Konig, 2006; Jensen, 2008b; Hunter et al., 2000; Sadek et al., 2007; Hunter, 1998).
Shared lane markings (also known as sharrows)	Shared lane markings are used in lanes shared by motor vehicles and bicycles to alert drivers to the potential presence of cyclists and to show cyclists where to ride.	Shared lane markings are rare in the US, though use is expected to increase.	No studies were found that measured levels of bicycling. Two studies measured safety outcomes, such as distances between cyclists and parked cars and cyclists and passing motorists (Alta Planning + Design, 2004; Pein et al., 1999).
Bike boxes (also known as advanced stop lines)	Bike boxes are marked areas at a signalized intersection, in front of the motor vehicle lane, where cyclists can wait while the light is red. The boxes are intended to make cyclists more visible to motor vehicles and give them a head start through the intersection (depending on the design).	Bike boxes and advanced stop lines are used in many European cities. They have also been installed in Melbourne, Australia; Christchurch, New Zealand; and three cities in Canada (Toronto, Vancouver, Victoria). The concept is relatively new in the US, though at least eight US cities have installed bike boxes, including several in Portland, OR.	Studies show a wide range of results in terms of appropriate usage by cyclists and encroachment by motor vehicles (Allen et al., 2005; Atkins, 2005; Daff and Barton, 2005; Hunter, 2000; Newman, 2002; Rodgers, 2005; Wall et al., 2003). Four studies did not find a reduction in conflicts, because there were either no or too few conflicts observed (Allen et al., 2005; Atkins, 2005; Hunter, 2000; Wall et al., 2003). A London study concluded that advanced stop lines did not have a significant positive or negative effect on cyclist safety (Transport for London, 2005). Surveys of cyclists in three studies indicate that a majority felt safer with the bike box (Newman, 2002; Rodgers, 2005; Wall et al., 2003). One study found that a majority of cyclists did not understand the purpose of the bike box (Hunter, 2000).
Bicycle phases – traffic signals	Separate traffic signal phases for bicycles at intersections can provide time for cyclists to cross an intersection without motor vehicle traffic.	Bicycle phases for signals are common in European cities, particularly with cycletracks, but rare in the US. They have been used in Davis, CA; New York, NY; and Portland, OR (Nabti and Ridgway, 2002).	One study in Davis, CA estimated that the benefits (mainly reduced crashes) greatly outweighed the costs and potential harms (including changes in vehicle capacity) of a separate bicycle phase at an intersection with a high volume of bicycle traffic connecting to an off-street path. In the 35 months before installation there were 10 auto-bicycle collisions at or near the intersection, compared to none in the 35 months afterwards (Korve and Niemeier, 2002).
Maintenance of facilities	Pavement quality and the presence of debris on paths and in lanes could influence bicycling decisions and safety.	No data is available assessing the quality of bicycle facilities nationally.	One study found that pavement quality was negatively correlated with the share of residents in an area bicycling to work (Parkin et al., 2008). The number of cyclists on a path in London doubled after the path was resurfaced (Transport for London, 2004a). A US study found that pavement quality was a significant predictor of cyclists' rating of a road segment (Landis et al., 1998). In one survey, cyclists rated "smooth pavement" as high as having a direct route and higher than having a bike path, though lower than having a bike lane (Antonakos, 1994).
Wayfinding signage	Wayfinding signs for cyclists usually include common destinations and the distance or time to bicycle there.	Wayfinding signs are being used by more US cities.	No studies measured the effects of wayfinding signage on levels of bicycling.

Techniques to shorten cyclists' routes	**Cut-throughs** provide cyclists but not motor vehicles with a more direct connection. **Right-turn shortcuts** allow cyclists to turn before reaching an intersection.	Cut-throughs are sometimes used as a traffic calming technique in the US. We could not identify any examples in the US of right-turn shortcuts specifically for cyclists, not associated with separate from a path.	No studies measured the effects of cut-throughs or right-turn shortcuts.
Other traffic controls			A Netherlands study found that 0.3 fewer stops per km along a route meant a 4.9% higher share of bicycling (Rietveld and Daniel, 2004).
Traffic calming	"A combination of mainly physical measures that reduce the negative effects of motor vehicle use, alter driver behavior and improve conditions for non-motorized users" (Lockwood, 1997). Physical measures include vertical deflection (e.g., speed humps) or horizontal deflection (e.g., bulb-outs, neck-downs, or chicanes). Traffic calming techniques are used on bicycle boulevards, though programs tend to focus on pedestrians more than cyclists.	Traffic calming has its roots in neighborhood-based efforts in the Netherlands in the 1960s to tame traffic on residential streets (Clarke and Dornfeld, 1994). Officially endorsed by the Dutch government in 1976, the concept spread throughout Europe and to Japan, Australia, and North America over the next decade. In 1999, the Institute of Transportation Engineers (ITE) published a report on the state of traffic calming practice in the US (Institute of Transportation Engineers, 1999). Traffic calming programs for local streets are common throughout the US, though the scale and sophistication of the programs varies considerably.	Although a 1994 study concludes that "the experience from Europe clearly shows that bicycle use has been encouraged by traffic calming" (Clarke and Dornfeld, 1994), few rigorous studies are available to support this claim. The impact of traffic calming on vehicle speeds is well documented, but evidence on the degree to which reduced speeds lead to reductions in accidents or increases in bicycling is slim. Studies in Germany in the early 1980s showed a doubling of bicycling in the small town of Buxehude (Doldissen and Draeger, 1990) and a 50% increase in bicycle use in the Berlin-Moabit area (Commission of the European Communities, 1989). A study in Japan in the 1980s found that bicycle traffic volumes rose along most routes, though the magnitude of the increase was not reported (Clarke and Dornfeld, 1994). A Danish study noted a 20% increase in bicyclists crossing a major road after traffic calming in one of three towns (Herrstedt, 1992). In the 1990s, a traffic calming project in the city of Cambridge, Massachusetts led to an increase in perceived safety: 33% of residents reported that cyclist safety was better, while only 8% said it was worse (Watkins, 2000). In the Berlin-Moabit area, bicyclist accidents declined by 16% (Commission of the European Communities, 1989). Bicycle accidents rose in Buxtehude, but these were primarily non-injury accidents (Doldissen and Draeger, 1990).
Home zones	Home zones are a form of traffic calming that focuses on residential streets. Streets are designed or altered to serve as play areas as well as streets, and speed limits of 10 mph are enforced. Physical elements may include benches, flowerbeds, trees, lamp posts, play structures, and pavement treatments.	The home zone concept derives from the "woonerf" – or "living yard" – movement in the Netherlands in the 1960s. Home zones are common in the Netherlands, Germany, the UK, and other parts of Europe. The UK Department for Transport promotes the home zone concept. The concept has not been adopted in the US, though examples of streets that follow the principles of home zones can be found.	An evaluation of nine home zone schemes in the UK found no change in adult bicycle ownership. Among adults with bikes, 80% said the home zone made no difference in how often they bicycled within the zone, 10% said they bicycled more often, 10% said they bicycled less often. Among cyclists, 60% said bicycling in home zones was not different, 30% said more pleasant, 10% said less pleasant. Among children with bicycles, 57% used it with the same frequency, 22% used it more often, 21% used it less often; 28% thought bicycling more fun now, 10% less fun, and 62% about the same (Webster et al., 2006).

Car-free zones	Car-free zones generally take one of three forms: (1) Temporary closure of roads to motor vehicle traffic. In South America, these programs are called "ciclovias" (see Table 4). (2) Pedestrian malls, usually in central business districts, where several blocks have been closed to vehicle traffic, with limited exceptions. (3) Car-free neighborhoods, in which residents must park motor vehicles at a remote parking facility.	Although common in European cities, pedestrian malls are limited in the US. Well-known examples include Pearl Street in Boulder, CO; Third Street Promenade in Santa Monica, CA; Ithaca Commons, in Ithaca, NY; and Faneuil Hall/Quincy Market in Boston, MA. Many cities in the US experimented with pedestrian malls in the 1960s and 1970s but later removed them when businesses in the mall failed to thrive. Car-free neighborhoods are much less common than pedestrian malls. One of the most famous examples is Vaubon in Freiberg, Germany. In North America, examples are mostly limited to resort-oriented islands, such as Mackinac Island in Michigan.	Several case studies provide evidence of a shift in mode split for people entering the central business district after conversion to a pedestrian mall, though the impact on bicycling appears limited. In Bologna, Italy, vehicle traffic declined by 50%, and 8% of people arriving at the center came by bicycle after the conversion (Topp and Pharoah, 1994). In Lubeck, Germany, of those who used to drive, 12% switched to transit, walking, or bicycling; bicycling was not separately reported (Topp and Pharoah, 1994). In Aachen, Germany, car travel declined from 44% to 36%, but bicycling stayed constant at 3% (Topp and Pharoah, 1994).
Complete streets	The complete streets concept asserts that streets are not just for vehicles but for all potential users, including pedestrians, cyclists, transit users, wheelchair users, shopkeepers, and residents. Complete streets policies, taking many different forms, establish the complete streets concept as the guiding design principle for new and rebuilt streets.	Complete streets policies had been adopted by 25 local and regional governments in the US and by 10 states as of 2007 (Thunderhead Alliance, 2007). The US Congress is considering a federal complete streets policy. The number of projects built according to complete streets principles is growing.	No evidence on the impact of complete streets policies or projects on bicycling levels is publicly available at this time.

End of Trip Facilities

Measure	Description	Examples and extent of implementation	Measured effects on bicycling
Bike parking	**General**	Quantity and quality of bike parking rising sharply in many European, North American, and Australian cities, and in some Asian and South American cities. No comprehensive national data available, but selected city data show doubling or tripling of bike parking supply in many cities over past two decades (Pucher and Buehler 2005, 2007, 2008, and 2009; Fietsberaad, 2006; Litman, 2009; Thunderhead Alliance, 2007). Incomplete statistics generally include public bike parking but not privately provided parking at residences, workplaces, and commercial buildings, or at schools and universities. Increasingly, cities are requiring provision of specific levels of bike parking in newly constructed buildings and offer incentives via green building guidelines such as LEED (US), BREEAM (UK); CASBEE (Japan); and Green Star (Australia) (Litman, 2009; Kessler, 2008; US Green Building Council, 2005; Pucher, 2008).	Hunt and Abraham (2007) estimated large and statistically significant impacts on bicycling of secure parking at the destination, equivalent to a reduction of 27 minutes in in-route bicycling time. Noland and Kunreuther (1995) estimated that availability of safe bike parking at work significantly raised perception of bicycling convenience and raised likelihood of bicycling to work.
	Unsheltered/sheltered	Most parking is in unsheltered bike racks on sidewalks, plazas, or open parking lots. There is a trend toward sheltered parking, at least covered with a roof of some sort.	Multivariate analysis of UK National Travel Survey by Wardman et al. (2007) found significant impacts on bicycling to work. Compared to base bicycle mode share of 5.8% for work trips, outdoor parking would raise share to 6.3%, indoor secure parking to 6.6%, and indoor parking plus showers to 7.1%. Suggests that such end-of-trip facilities have important impact on decision to bicycle to work.
	Guarded	Trend in northern Europe (esp. Netherlands, Germany, Denmark) toward guarded parking to prevent theft, both in special facilities such as bike stations and in outdoor parking guarded by attendants.	
	Bike lockers	Usually at train or metro stations, especially in North America, where it is the main form of sheltered, secure bike parking.	Taylor and Mahmassani (1996) estimate significant impacts of secure bike lockers for cyclists at public transport stations.
Showers at workplaces	Usually combination of showers, clothes storage, and change facilities; often in conjunction with bike parking facilities.	Infrequent but increasing provision due to building codes in some cities that require such facilities, and encouraged by green building codes such as LEED and BREEAM, which award credit points for such facilities.	Wardman et al. (2007) estimated significant impact of shower facilities on bicycling to work; Abraham and Hunt (2007) estimate small but statistically significant impacts of shower facilities at the destination, equivalent to a reduction of 4 minutes in in-route bicycling time.
Bicycle stations	Full-service facilities offering secured, sheltered bike parking in addition to bicycle rentals, bicycle repairs, showers, accessories, bicycle washes, bicycle touring advice, etc. (Pucher and Buehler, 2007, 2008, and 2009; Pucher 2008; Litman, 2009; Martens, 2007). Stations are usually adjacent to train or metro stations as a key form of integration with public transport, but sometimes located in commercial districts of city centers.	In 2007, bike stations at 67 Dutch train stations and 70 German train stations, with capacity of up to 10,000 bikes; only 10 bike stations, mostly small (100–300 bikes) in North America in 2009; large bike stations in Tokyo and a few other Japanese cities (Martens, 2007; Harden, 2008).	Although no studies have measured impacts of bike stations on bicycling, they are presumably positive, because such bike stations are generally well utilized due to security, convenience, and wide range of services offered.

Integrated Case Studies

City (population)	Trends in bicycling levels and safety	Bicycling infrastructure and programs	References
London, UK (7,557,000)	Doubling in total number of bicycle trips from 2000 to 2008 (+99%); average annual growth of 17% between 2003 and 2006, after implementation of "congestion charging"; 75% increase in bicycle trips to school 2000–2008. Bicycle share of all trips (all trip purposes) rose from 1.2% in 2003 to 1.6% in 2006, an increase of 43; 12% reduction in serious bicycling injuries from 2000 to 2008.	x Development of London Bicycling Network since 2000, mainly through bike routes on lightly traveled streets, but also selective installation of bike lanes, bus-bike lanes, contraflow bike lanes, and mixed-use pedestrian/bike paths: 4,000 km total length, of which 550 km are special facilities of some sort, but not usually-separated from traffic x Traffic calming of some residential neighborhoods through roadway design modifications and 20 mph speed limit; installation of many pass-throughs (short-cuts) for cyclists and pedestrians to provide more convenient, faster connections x 640 intersections were modified via advance stop lines (bike boxes) for cyclists; some intersections offer bike turning lanes and special marking of lanes where crossing intersection; cyclist-activated traffic signals at some intersections x Installation of over 65,000 bike parking spaces since 2000, of which 15,000 have been at London schools, and over 5,000 additional spaces at public transport stops x Widespread introduction of bicycling training since 2000, now in all 33 boroughs, at over 600 schools in London in 2008 x Over 100 Transport for London (TfL) and London Cycling Campaign (LCC) community bicycling projects to promote bicycling among specific target groups x Over 3 million copies of TfL/LCC bike route maps distributed free of charge x Congestion charging in Central London, begun Feb 2003, imposing ğ5 per day fee for private cars, between 7:00 and 18:30 on workdays, raised to ğ8 in Feb 2005; expansion of charging zone in Feb 2007, 7:00–18:00	Transport for London (2004b, 2008a, 2008b)
Bogota, COL (7,881,000)	Increase from 0.8% of trips in 1995 to 3.2% in 2003; participation in ciclovia grew from 5,000 in 1974 to over 400,000 in 2005.	x From 1998 to 2000, 344 km of separate bike paths built, connecting to public transport and major destinations x Ciclovia: closure of 121 km of roadways to cars on Sundays and holidays, used mainly for bicycling x Car-free day, first Thursday of February, starting in 2000 x Restrictions on motor vehicles on certain days of the week depending on license plate numbers ("pico y plata") x Creation of extensive car-free zones and streets; removal of cars from many public spaces; restrictions on car parking x Extensive educational campaign to raise environmental awareness and improve motorist behavior toward cyclists and pedestrians	Parra et al. (2007); IDRD (2004); IDU (2009); Montezuma (2005); Despascio (2008); Cervero et al. (2009)
Berlin, GER (3,400,000)	Total number of bicycle trips almost quadrupled from 1975–2001 (275% increase); bicycle share increased from 5% of trips in 1990 to 10% in 2007; 38% decline in serious injuries 1992–2006.	x Network of separate bicycling facilities tripled from 271 km in 1970 to 920 km in 2008; also 70 km of bus-bike lanes and 100 km of shared-use paths x 3,800 km of residential streets (72% of all roads) are traffic calmed at 30 km/hr or less, including many home zones with 7 km/hr limit x Internet bicycle trip planning site tailors routes to range of preferences x 22,600 bike parking spots at regional rail and metro stations x Mandatory bicycling education for all schoolchildren x Call-a-bike program of German railways has over 3,000 bikes available for short-term rental at train stations, unlocked for use via mobile phones x Wide range of special bicycle rides, promotional events	City of Berlin (2003); Pucher and Buehler (2007)

Paris, FR (2,168,000)	Increase in bicycle share of trips within City of Paris from 1% in 2001 to 2.5% in 2007; 46% increase in bicycle trips from June to October 2007 after introduction o Velib' bicycle sharing program.	x Bike lane network more than tripled from 122 km in 1998 to 399 km in 2007 x Tripling of bicycle parking on sidewalks from 2,200 in 2000 to 6,500 in 2007 x Started Velib' in 2007, world's largest bicycle sharing program, now with over 20,000 short-term rental bikes x Introduction of 38 "quartiers verts" (green zones), extensive traffic calmed areas of the city with speed limits of 30 km/hr or less, car-free zones, narrowed roadways and widened sidewalks, and six "civilized travel corridors" of restricted motor vehicle access x National Ministry of Education and insurance companies cooperate to provide extensive bicycling training courses in many schools, with bicycle safety permits issued in 5th grade x Regular series of intensive bicycling training courses for adults offered twice a month in alternating arrondissements throughout Paris x Advance stop lines and priority traffic signals for cyclists at many intersections x Improved, uniform directional street signage for cyclists and special bicycle map and website to provide advice for best bicycle routes within Paris x Free program for engraving registration numbers on bikes to discourage theft x Elimination of free car parking throughout Paris	City of Paris (2007, 2009a, and 2009b); Nadal (2007)
Barcelona, SP (1,606,000)	Bicycle share more than doubled in only two years: 0.75% of trips in 2005 to 1.76% in 2007.	x Expansion of bike lane network from less than 10 km in 1990 to 155 km in 2008 (expanded by 28 km, 2007–2008) x Introduction of Bicing bicycle sharing program in 2005, since expanded to 6,000 short-term rental bikes in 2008, with over 400 bike rental stations x Extensive marketing in schools, combined with annual bike week with lots of special events, bicycle rides, informational workshops, etc. x Increased bike parking throughout city: 13,000 additional racks in 2007 and 2008, total of 20,392 in 2008 x Introduction of four traffic calmed zones with 30 km/hr speed limits x Free bicycle registration and engraving of numbers on bikes to prevent theft	Romero (2008)
Amsterdam, NL (735,000)	Bicycle share increased from 25% of trip in 1970 to 37% in 2005; 40% decline in serious injuries, 1985–2005.	x Doubling of separate bicycling facilities between 1980 and 2007, with 450 km in 2006, including construction of many bicycle bridges and short-cuts to create a complete network of separate bicycling facilities x Intersection improvements, advance stop lines and bike boxes, bicycle access lanes, priority traffic signals for cyclists x Bi-directional travel permitted for cyclists on many one-way streets x Extensive bike parking at all train stations; big expansion of guarded, sheltered bike parking x Ov-fiets (public transport bikes) for convenient, cheap, short-term rental at key train stations x Car-free zones in city center; many residential streets are traffic calmed at 30 km/hr, including some woonerfs ("living yards") with 7 km/hr limit x Sharp reduction in car parking in city center x Mandatory bicycling education for all schoolchildren	Fietsberaad (2006); Pucher and Buehler (2007)

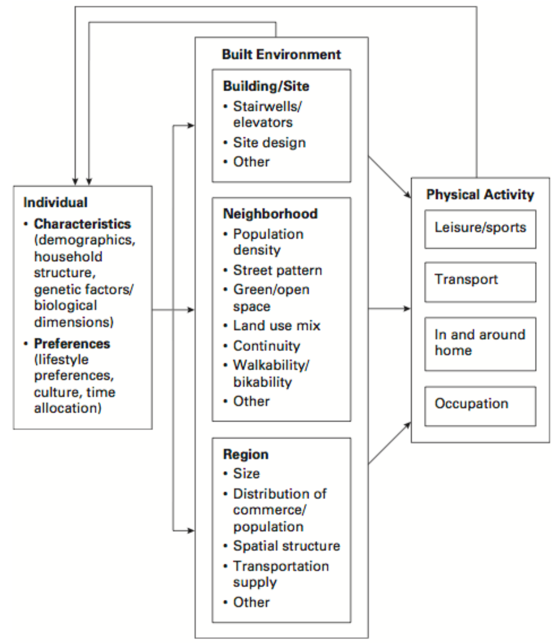
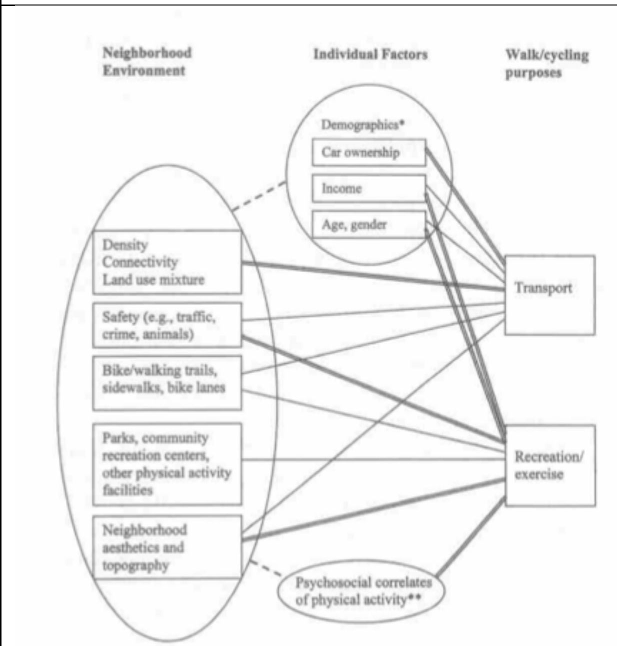
Portland, OR (576,000)	Share of workers commuting by bicycle rose from 1.1% in 1990 to 1.8% in 2000 and 3.9% in 2005–2007. Number of workers commuting by bicycle increased 329% from 1990, while the number of workers increased only 27%. The number of bicycles crossing four bridges into downtown increased 369% from 1992 to 2008. Number of reported crashes increased only 14% over same period.	x A 247% increase in the number of miles of bikeways (lanes, paths, and boulevards) from 79 in 1991 to 274 in 2008 x Colored bike lanes installed at several places of potential bicycle–motor vehicle conflict, assigning right of way to the cyclist x Special bicycle-only signals at four difficult intersections. Loop detectors for bicycles at all actuated traffic signals on bicycle routes. Bike boxes at 10 intersections. x Bicycle parking required in new development. City installs parking at other locations, including removing on-street parking for bicycle parking "corrals." x Bike racks on all transit buses, and bikes allowed on trains x First "Bike Sundays" held in 2008, closing city streets in one neighborhood to motor vehicles, similar to ciclovias x Education and marketing events conducted year-round and during SmartTrips program each summer. City-wide and neighborhood bicycle maps provided for free.	US Census (2009), City of Portland (2008a and 2008b)
Copenhagen, DK (500,000)	Bicycle share increased from 25% of trips in 1998 to 38% in 2005 for 40+ age group; 70% increase in total bicycle trips 1970–2006 (36% of work trips in 2006); 60% decline in serious injuries 1995–2006.	x Since 1970s, massive expansion of fully separate bike paths and cycletracks protected by curb from motor vehicle traffic (345 km in 2004) plus 14 km of unprotected bicycle lanes x Special intersection modifications: advance stop lines and bike boxes, bicycle access lanes, priority traffic signals for cyclists, bright blue marking of bike lanes crossing intersections x Green wave for cyclists, with traffic signals timed to cyclist speeds x Bi-directional travel permitted for cyclists on one-way streets x Guarded parking facilities increased from one in 1982 to 30 in 2006; 15 schools had guarded bike parking x Car-free zones and reduced car parking in city center; many residential areas are traffic calmed at 30 km/hr or 20 km/hr x Mandatory bicycling education for all schoolchildren x Over 20,000 bike parking spaces (but not enough) x Innovative bi-annual survey of cyclists to evaluate bicycling conditions x Pioneered city bikes program, which places 2,000 free bikes at 110 locations throughout the city; only small deposit required	Pucher and Buehler (2007); Fietsberaad (2006)
Muenster, GER (278,000)	Bicycle share increased from 29% of trips in 1982 to 35% in 2001; one serious injury per 1.03 million bicycle trips in 2001.	x More than doubled network of separate bike paths and lanes from 145 km in 1975 to 320 km in 2005, including 5 km bicycle expressway and 12 bicycling streets x Large car-free zones in city center; almost all residential streets traffic calmed at 30 km/hr, including home zones calmed to 7 km/hr; many contraflow streets for cyclists x Intersections with advance stop lines and bike boxes for cyclists, advance green lights, bicycle turning lanes, and special bicycle access lanes, as well as special colored marking of lanes crossing intersection x Bike station at the main train station and bus terminal, with parking for 3,500 bikes plus bike rentals, repairs, accessories, washing, and touring information. Also, large amounts of bike parking at all suburban rail stations throughout the city and region; bike station with 300 spaces in shopping district. x Comprehensive system of directional signs x Mandatory bicycling education for all schoolchildren x Wide range of special bicycle rides, promotional events	Pucher (1997); Pucher and Buehler (2007); Fietsberaad (2006); Boehme (2005); City of Muenster (2004)

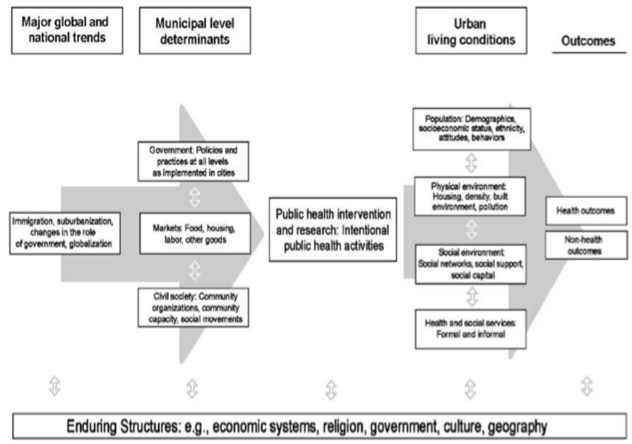
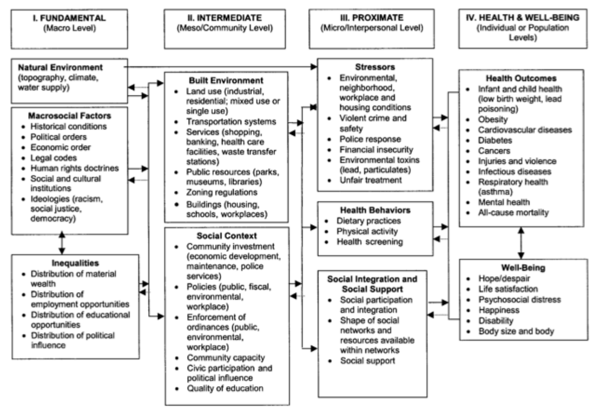
Freiburg, GER (220,000)	Bicycle share increased from 15% of trips in 1982 to 27% in 2007; 204% growth in bicycle trips 1976–2007; one serious injury per 896,000 bicycle trips in 2006.	x Expanded separate bicycle paths and lanes from 29 km in 1972 to 160 km in 2007, plus 120 km of bicycle paths through woods and agricultural areas; 2 km of special bicycling streets; 60 contraflow streets for cyclists x Entire city center turned into car-free zone in 1970s; all residential streets (400 km) traffic calmed, including 177 home zones with 7 km/hr limit; plus two car-free residential neighborhoods x Car parking restricted to fringe of city center; parking prices raised x Tripling in bike parking between 1987 and 2009 (2,200 to 6,040 spaces), including full service bike station (with 1,000 parking spaces) at main train station, plus 1,678 bike racks at train and bus stops x City requires new developments to facilitate mixed-use, compact development that generates trips short enough to walk or bicycle x Mandatory bicycling education for all schoolchildren	Pucher (1997); Pucher and Clore (1992); Buehler and Pucher (2009); Gutzmer (2006); Fietsberaad (2006)
Odense, DK (185,000)	Bicycle share increased from 23% of trips in 1994 to 25% in 2002; 80% increase in bicycle trips 1984–2002; 29% decline in injuries 1999–2004.	x National bicycling city pilot project, 1999–2002, financed huge range of innovative measures to promote bicycling and increase safety x Design improvements to 500 km of separate bike paths and lanes x Many intersections modified via advance stop lines and bike boxes for cyclists, advance green lights, bicycle turning lanes, and special bicycle access lanes, as well as special blue marking of lanes where crossing intersection x Improved signage, bicycle trip counters, bicycle air pumps, free bikes at work x Green wave for cyclists, with traffic signals timed to cyclist speeds x Improved maintenance of all bicycling facilities x Expansion and improvement of bike parking, especially at train station x Innovative Internet bicycle route planning, also via mobile phones x Car-free zones in city center and traffic calming of residential neighborhoods at 30 km/hr x Mandatory bicycling education for all schoolchildren x Wide range of promotional programs for all age groups, bicycling ambassador program, annual bicycle days, bicycling competitions, etc.	Andersen (2005); City of Odense (2007); Fietsberaad (2006); Pucher and Buehler (2007)
Groningen, NL (181,000)	Stable 40% bicycle share of trips since 1990; 50% decline in serious injuries 1997–2005.	x Separate bicycling facilities doubled between 1980 and 2006, to 220 km in 2006, including construction of bicycle bridges and short-cuts to create a complete network of separate bicycling facilities x Intersection modifications, advance stop lines and bike boxes, bicycle access lanes, priority traffic signals for cyclists; four-way green lights for cyclists at some intersections x Bi-directional travel permitted for cyclists on one-way streets x Increase in guarded parking facilities, from one in 1982 to 20 by 1995 and 30 in 2006; 15 schools with guarded bike parking x Extensive bike parking at all train stations and key bus stops; roughly 7,000 bike parking spaces at main station x Most residential streets are traffic calmed at 30 km/hr, including many woonerfs with 7 km/hr limit x Car-free zones in several parts of the city center; sharp reduction in car parking x Mandatory bicycling education for all schoolchildren	Fietsberaad (2006); Pucher and Buehler (2007)

Boulder, CO (92,000)	Share of workers commuting by bicycle more than doubled, from 3.8% in 1980 to 8.8% in 2006; bicycle share of all trips (all purposes) rose from 8% in 1990 to 14% in 2006.	x Over 100 miles of multi-use pathways with 74 underpasses and 2 overpasses, plus 74 miles of on-street bike lanes and 195 miles of signed routes and streets with paved shoulders; 95% of major arterials have bike lanes or adjacent pathways. x City regulations requiring bike parking (at least 3 bike parking spaces or 10% of off-street parking) x Bike-to-Work Day events since 2003; Safe Routes to School partnership with local school district x Interactive bicycle routing website and an individualized marketing program x Coordination of transportation coordinators at local businesses x Ambassador Community Outreach Program focused on improving bicycle safety	NRC (2007); Ratzel (2008); Roskowski and Ratzel (2008)
Davis, CA (63,000)	Drop in share of workers commuting by bicycle from 28% in 1980 to 14% in 2000; bicycle share of trips to campus by university students fell from 75% in 1970s to less than 50% in 2006.	x First city in the US to install bike lanes, in the 1960s x From 1970 to 2008, network expanded to over 50 miles of on-street bicycle lanes and 50 miles of off-street bicycle–pedestrian paths, including many bicycle tunnels and bridges x Intersection design improvements for cyclists, including bicycle-activated signals, special turn lanes, advance stop lines, etc. x During 1970s, city support for wide range of bicycling programs, including subsidized helmet programs, elementary school education programs, removal of abandoned bikes from racks, and strict enforcement of traffic laws x Gradual reduction in bicycling programs since mid-1980s	Buehler and Handy (2008); Xing and Handy (2009); Tal and Handy (2008): Pucher et al. (1999)

Notes: Reprinted with Permission from Pucher, J., Dill, J., Handy, S., 2009. Infrastructure, Programs, and Policies to Increase Bicycling: An International Review. Preventive Medicine 50, S106-S125.

Appendix III: Conceptualizations of the built environment

Reference	Definition of BE	Graphical Representation
Transportation Research Board, 2005. Does the built environment influence physical activity? Examining the evidence.	The built environment is broadly defined to include land use patterns, the transportation system, and design features that together generate needs and provide opportunities for travel and physical activity. It refers to physical environments that have been modified by humans and comprises public spaces, parks, and trails, as well as physical structures (e.g., homes, schools, workplaces) and transportation infrastructure (e.g., streets, sidewalks)	 **FIGURE 1-2 Detail on areas of interest to this study.**
Saelens, B.E., Sallis, J.F., Frank, L.D., 2003. Environmental correlates of walking and cycling: Findings from the transportation, urban design and planning literatures. Annals of Behavioral Medicine 25, 89-91.	Not provided	

Galea, S., Vlahov, D., 2005. Urban health: Evidence, challenges, and directions. Annual Review of Public Health 26, 341-365.	The urban physical environment includes the built environment: the air city dwellers breathe, the water they drink, the indoor and outdoor noise they hear, the park land inside and surrounding the city, and the geological and climate conditions of the site where the city is located.	
Northridge, M.E., Sclar, E.D., Biswas, P., 2003. Sorting out the connections between the built environment and health: A conceptual framework for navigating pathways and planning healthy cities. Journal of Urban Health 80, 556-568.	By the built environment, we mean that part of the physical environment made by people for people, including buildings, transportation systems, and open spaces. The remainder of the physical environment is the natural environment	 **FIGURE 1.** Social determinants of health and environmental health promotion. The model was developed for an article by AJ Schultz and ME Northridge.[5]
Frank, L.D., Engelke, P.O., Schmid, T.L., 2003. Health and Community Design: The impact of the built environment on physical activity. Island Press, Washington.	Denotes the form and character of communities. It is made up of the countless specific places-homes, streets, offices, parking lots, shopping malls, restaurants, parks, movie theaters-that constitute a city town or suburb.	INTRODUCTION  FIGURE 1-1. Model of linkages between the built environment, physical activity, and public health

Appendix IV: Impact of an Intervention Designed to Increase the Accessibility and User-Friendliness of an Active Mode of Transportation on Population Health: The Case of BIXI©Montreal

There is a growing body of literature suggesting that action on environmental determinants of active lifestyles holds promise for addressing the substantial individual and population burdens of sedentary living in contemporary societies. Numerous studies have shown that active modes of transportation contribute substantially to meeting public health recommendations for physical activity. Active transportation (i.e., walking or cycling for periods between 15 and 30 minutes a day) is associated with health benefits such as reduced body mass index, lower waist circumference, and improved blood lipid profiles (Barengoa et al., 2006; von Huth Smith et al., 2007; Wagner et al., 2001). Interventions aimed at increasing accessibility to, and user-friendliness of active transportation may contribute to increasing the proportion of persons meeting public health recommendations for physical activity (Dill & Carr, 2003). However, when using active transportation there are non-negligible risks of collisions between pedestrian/cyclists and motor vehicles. Beck et al. (2007) showed that the fatal traffic injury rate was 10.4 per 100 million person-trips for all transportation modes, but that rates were highest for pedestrians and cyclists. The nonfatal traffic injury rate was higher at 754.6 per 100 million person-trips for all transportation modes, but rates were highest for cyclists. In Montreal, on average 3-5 pedestrians and 3 cyclists per day are involved in collisions with motor vehicles although cyclists are severely injured more often than pedestrians with an ambulance being sent for an injured cyclist at more than one third of intersections in Montreal's central boroughs every year (Morency & Cloutier, 2005). The goal in promoting active transportation is to encourage active *yet safe* forms of transportation. To our knowledge, few if any studies have incorporated objectives related to both the promoting walking/cycling for transportation and preventing injuries due to collisions between pedestrians/cyclists and motor vehicles.

Studying naturally-occurring environmental interventions represents a unique opportunity for increasing knowledge of the effects of the built environment on physical activity and on likelihood of injurious collisions with motor vehicles. However, only limited data show the impact of implementation of sustained structured environmental interventions possibly because it is often difficult for researchers to know when environmental interventions are occurring as they are not well publicized (Ogilvie et al., 2006). As a result, collecting baseline data and planning for appropriate research designs is rendered difficult. Similarly, natural experiments do not always unfold as planned (Morrison et al., 2003; Ogilvie, et al., 2004). For example, Ogilvie et al., (2006) planned an evaluation of the impact of a new highway in Glasgow, Scotland that did not go forward because of citizen opposition to the project. Nonetheless, there is consensus that systematic evaluations of environmental interventions are warranted (Heath et al., 2006; Ogilvie et al., 2006; Sallis et al., 2004).

Given the limited number of intervention studies examining active transportation (Wells & Yang, 2008), ***the current application will advance knowledge of active transportation use and its impact on population health by evaluating an environmental intervention called BIXI***© (- name merges the words BIcycle and taXI) which increases the accessibility and user-friendliness of an active form of transportation. BIXI© is being implemented by an organization operating outside the health sector, namely *Stationnement de Montréal* () who was awarded a contract by the *City of Montreal* to conceptualize and design the intervention which consists of deploying a self-service bicycle rental program. The intervention is modeled after Vélib (Paris, France) and Vélo'v (Lyon, France) and will involve deployment of 3000 self-service bicycles available at minimal cost to individuals aged 18 years or older from May through mid-November of 2009 at 300 stations across the Ville-Marie, Plateau Mont-Royal, and Rosemont-Petite-Patrie boroughs of Montreal. Self-service bicycle users will be able to rent and drop off a bicycle at any of the 300 stations. Bicycles will be made available free of charge for a period of 30 minutes, for a day ($5), for a month ($28), or for the season ($78). The BIXI© program will offer residents and visitors to Montreal a chance to integrate active transportation into their travel patterns. In the month of October 2008, 40 prototypes of BIXI© bicycles were pilot tested to teach people to operate the rental system and to sensitized the public to the existence of BIXI©. A Web site promotes the intervention (www.bixi.ca). More publicity will be launched as the deployment of the bicycle rental system commences on May 1st 2009.

SUMMARY OF THE RELEVANT LITERATURE

PROPORTIONS OF THE POPULATION USING BICYCLES FOR TRANSPORTATION. Data on bicycle use from Quebec involving a sample of 1935 adults aged 18 to 74 years and from the USA involving a survey of 9616 participants weighted to represent the American population show that the majority of cycling trips are performed for recreation/exercise purposes (National Highway Transportation Safety Agency [NHTSA], 2008; Vélo Québec, 2005). In the USA, only 14% of bicycle trips are for errands and 5% for commuting to work or school (NHTSA, 2008). In Montreal, 66% and 1.5% of the population report that driving a motor vehicle and cycling were their primary transportation modes to get to work (Statistics Canada, 2001). More recent data show that 8% of Montrealers use cycling as their primary mode of transportation (Vélo Quebec, 2005). The potential for increasing active transportation exists as 15% of the population indicates an intention to increase their bicycle use in the next three years (Vélo Quebec, 2005). Overall, data examining population levels of cycling for transportation suggest that levels are low but that there is potential for increases (Statistics Canada, 2001; NHTSA, 2008; Vélo Québec, 2005). The role of a self-service bicycle program in potentiating increases has not been investigated.

CHARACTERISTICS OF THE POPULATION USING BICYCLES FOR TRANSPORTATION. Limited empirical research exists examining the socio-demographic characteristics, travel patterns, and accident risk of self-service bicycle users, and bicycle users in general. However, researchers have found that a social gradient exists for active transportation. People with lower income and education (Butler et al., 2007; McDonald, 2008), males, and those aged between 18 and 24 years old are more likely to use cycling for transportation (NHTSA, 2008; Vélo Québec, 2005).

INTERVENTIONS TO INCREASE ACCESSIBILITY AND USER-FRIENDLINESS OF CYCLING AS A MODE OF TRANSPORTATION. Limited empirical data exist examining citywide self-service bicycle interventions despite their deployment in a substantial number of Western European cities (see Appendix A). Given similarities between the operation of these programs, we will focus our attention on Vélo'v (Lyon, France) and Vélib (Paris, France). These self-service bicycle programs are the two largest in the world and served as models for BIXI©. The Vélo'v (www.velov.grandlyon.com) program was the first of its kind to be implemented on a large scale, beginning in June, 2005. Vélo'v counts 4000 bicycles available at 340 stations. In February 2009, Vélo'v bicycles were rented 315 712 times and travelled a total distance of 625 250 km (average 10 184 rentals/day, 2km/trip) (Vélo'v March Newsletter, 2009). Since its inception, Vélo'v estimates a total distance travelled of 42 120 000 km on their bicycles (Vélo'v March Newsletter, 2009). Using an average city cycling speed of 16 km/h (Dill, 2008), we estimate that Vélo'v has resulted in 2.6 million hours of active transportation over five years. In Lyon, bike use has increased by 80% since the launch of Vélo'v. The Vélib' () program incorporates 20000 bikes at 1450 stations. A recent survey conducted by TNS Sofres for JCDeceux surveyed 878 BIXI© users (Vélib May Newsletter, 2008). The results provide some data on Vélib' users' socio-demographic characteristics, travel patterns, and favourability to the program. That is, 40% of Vélib' users are aged between 26-35 years and 58% are male. The average trip duration is 18 minutes and 33% of users live in suburban areas. The three primary advantages of the program according to users are, 1) the simplicity of the rental system, 2) the freedom and enjoyment of the service, 3) the viability of the program as a transportation alternative. These data suggest that the uptake and impact of self-service bicycle programs are substantial.

GEOGRAPHY OF BICYCLE USE. As outlined above, general data on travel patterns are available from Vélo'v and Vélib, however the extent and focus of these data are limited. Research by Dill (2008), using GPS monitors to track cyclists' destination type, use of bike lanes, and cyclist type (male/female, frequent/infrequent) offers interesting insights. In a sample of 164 cyclists recruited in Portland Oregon, Dill (2008) demonstrated that the primary destinations for cyclists were work (26%) and home (32%). Cyclists made half of their trips on routes that included cycling infrastructure (lanes, paths). The majority (92%) of routes in the city did not include cycling infrastructures. Differential use of cycling infrastructure existed, with men and frequent cyclists preferring routes containing no cycling infrastructure (Dill, 2008). In Montreal, self-report data suggest that 78% of cyclists use cycling lanes at least sometimes (Vélo Quebec, 2008). Population data from the USA reveal that only 5% of cycling trips are made on cycling lanes (NHTSA, 2008). Individuals choosing not to use bicycle lanes say they are not convenient or do not lead to their destination (NHTSA, 2008).

COLLISIONS BETWEEN MOTOR VEHICLES AND CYCLISTS. Accident and injury data for self-service bicycle users are limited. Vélo'v reports no life threatening injuries or deaths since inception despite accidents involving cyclists increasing by 6% and cycling rates increasing by 80%. In 2006, 224 Vélo'v users were ticketed for traffic violations; primarily for riding through red lights and riding the wrong way down one way streets (La Gazette, 2007). In parallel, the Vélib' program reported three users killed in bicycle automobile collisions since 2007 (www.velib.paris.fr). In Montreal, data on collisions between cyclists and motor vehicles revealed that 761 cyclists/year are involved in accidents requiring an ambulance (Morency & Cloutier, 2005). Beck et al. (2007) showed that relative to passenger vehicle occupants, cyclists, and pedestrians are 2.3 and 1.5 times, respectively, more likely to be fatally injured. Interestingly, Jacobsen (2003) shows that the presence of a greater number of cyclists and pedestrians in an area reduces the likelihood of collisions, possibly due to motorists modifying their driving behavior as the number of pedestrians and cyclists increases. Like Montreal, neither Lyon nor Paris has mandatory bicycle helmet bylaws, however the BIXI© program encourages users to wear helmets. Self-report helmet use in Quebec for private bicycle use is 36% (Vélo Quebec, 2008).

SUMMARY. Levels of cycling for transportation are low but there is potential for increases (Statistics Canada, 2001; NHTSA, 2008; Vélo Québec, 2005). The role of bicycle rental programs in potentiating active transportation has not been investigated. The grey literature suggests, at least anecdotally, that self-service bicycle programs may be effective in increasing levels of cycling for active transportation. Some data show that the risk of collision with a motor vehicle while cycling is substantial but that the determinants of risk are poorly understood. There is a dearth of information on the impact of interventions that increase accessible and user-friendly active forms of transportation on cycling for transportation and on the risk of injuries. Evaluation of the impact of the BIXI© program offers a unique and compelling opportunity for gathering evidence on public health issues of physical activity and collisions between pedestrians and motor vehicles.

RESEARCH QUESTIONS AND HYPOTHESES.

The overriding goal of this environmental intervention research project is ***to provide empirical evidence of the reach, acceptability, and impact of a population-based intervention aimed at increasing the accessibility of cycling for transportation. The outcomes of interest are involvement in transportation physical activity, likelihood of injuries resulting from collisions with motor vehicles, and favourability toward active transportation-friendly policies***. Using the BIXI© intervention, the research project will focus on addressing objectives related to reach, acceptability, and impact of this type of population-based intervention.

REACH AND ACCEPTABILITY OBJECTIVES

OBJECTIVE 1: To estimate the proportion of the adult population in urban areas who have knowledge of BIXI© and who use BIXI©;

OBJECTIVE 2: To describe and compare socio-demographic, travel pattern, and health characteristics of individuals reporting BIXI© use;

OBJECTIVE 3: To compare the socio-demographic, travel pattern, and health characteristics of BIXI users to those of individuals reporting no BIXI© use;

OBJECTIVE 4: To determine the time and distance travelled by BIXI© users across travel episodes;

OBJECTIVE 5: To describe the geography of BIXI© use.

IMPACT OBJECTIVES

OBJECTIVE 6: To determine the impact of BIXI© on urban populations use of active transportation, physical activity, and favourability toward active transportation-friendly policies;

OBJECTIVE 7: To determine the impact of BIXI© on the use of active transportation, physical activity, and favourability toward active transportation-friendly policies on boroughs where BIXI© is implemented with those where BIXI© is not implemented;

OBJECTIVE 8: To determine the risk of collisions associated with BIXI© use.

GIVEN THE EXISTING LITERATURE, WE HYPOTHESIZE THAT:

1. BIXI© implementation will result in significant increases in bicycle use in Montreal.
2. BIXI© users will be more likely to be male, younger in age, and of lower SES when compared to residents of Montreal.
3. BIXI© users will travel on cycling infrastructure for approximately 50% of trips, however, differential travel patterns will exist for different sub-populations (i.e., cycling experience and gender).
4. BIXI© users will be at increased risk for collisions with motor vehicles.

Given the limited amount of information available on BIXI© programs, no further hypotheses are formulated. We will adopt an exploratory stance in addressing other objectives.

RESEARCH AND DATA COLLECTION PLAN: OVERALL METHODOLOGICAL APPROACH

In order to achieve the specific objectives, we will use three methodological approaches. First, we will adopt a repeated cross-sectional pre-test post-test design to collect population-level data on active transportation, physical activity, risk of collisions, and favourability toward active transportation-friendly policies (Campbell & Stanley, 1963, Koepsell et al., 1992). Second, we will use a cross-sectional design to collect data on the travel patterns, motives, and risk of collisions of BIXI© users. Third, we will use a travel behaviour survey involving a volunteer sample of BIXI© users recruited during the cross sectional design to assess how BIXI© is integrated into other travel patterns and daily activities. The use of three separate designs will allow for the creation of four population data sets ([1] Pre-deployment Population Data Set; [2] Post-deployment Population Data Set; [3] BIXI© User Data Set; [4] GPS Data Set) and to conduct advanced statistical analyses on single or combined data sets to meet the stated objectives. The creation of multiple data sets, triangulation of data, and analyses across data sets represent a strength of this proposal. We are evaluating a natural experiment on which we have no control and cannot implement specific design features, it is important to obtain multiple sources of information. Below, we describe the research design and measures of interest for each methodological approach. In a separate section we outline the proposed statistical analyses to meet each objective (Appendix B).

PRE-TEST POST-TEST DESIGN (POPULATION DATA SETS)

DESIGN. In order to assess the active transportation, physical activity, risk of collisions and favourability toward active transportation-friendly policies of individuals living in the city were BIXI© is being deployed, we will conduct a pre and post intervention cross sectional survey. This methodological approach will be employed over a three year period (August, 2009 – November, 2012). As well, we will determine if there are differences on active transportation, physical activity, risk of collisions, and favourability toward active transportation-friendly policies in BIXI© implementation versus non-implementation boroughs (for study design illustrations see appendix C). Given the time sensitive nature of this project, funds for the baseline measurement have already been secured and the baseline survey is currently underway (see Appendix D).

PARTICIPANTS AND PROCEDURES. In order to recruit participants, we will hire a local telephone polling firm. Approximately 3200 participants will be recruited for the pre (n=1600) and post (n=1600) population data sets. As well, in order to recruit a sufficient number of participants residing within the BIXI© boroughs we will oversample by 15% persons residing in boroughs BIXI© BIXI© is being deployed. Rather than having 17.2% of the sample (n=275 of 1600) residing in BIXI© boroughs, we will have 500 persons residing in BIXI© boroughs in the final sample. Our previous experience with telephone surveys indicates that participant characteristics are nicely aligned with Statistics Canada Census participant characteristics. Current estimates of response rates are 30-40% (Keeter et al., 2006; Kempf et al., 2007). The research team will train all interviewers and ongoing quality surveillance will be conducted (Gauvin et al., 2008). Our total sample, considering response rates, is estimated to be 1600 for the pre and post time data collection points, respectively.

VARIABLES & MEASUREMENT INSTRUMENT (Appendix E). The questionnaire includes 7 sections. *Section 1* addresses knowledge, experience, attitudes and intentions toward the

BIXI© program. These questions were drafted for the purposes of this investigation and were pilot tested for clarity and content validity. *Section 2* examines health status and includes items pertaining to self-rated health, stability of health status, presence of chronic disease conditions, and self-reported height and weight. These questions are widely used and have been found to provide a valid and reliable means of establishing health status in population based studies (Idler & Benyami, 1997; Krause & Jay, 1994). *Section 3* addresses questions pertaining to walking episodes, cycling episodes, and involvement in vigorous physical activity. The questions are adapted from the *International Physical Activity Questionnaire* (*IPAQ*, Craig et al., 2000) which has good concurrent, construct validity and test-retest reliability in population-based surveys. *Section 4* pertains to smoking and alcohol consumption. The standardized assessment procedures used for population surveillance in Quebec will be used. *Section 5* examines bicycle helmet use, history of accidents, close calls, and injuries while cycling. These questions were devised for this project and will be pilot tested for clarity and content validity. *Section 6* inquires about agreement with a series of policies and interventions designed to increase active transportation and reduce collisions between pedestrians/cyclists and motor vehicles. These questions were developed for the purposes of this project and will be pilot tested. *Section 7* includes a series of standard socio-demographic questions modeled from the Statistics Canada Census questionnaire.

CROSS SECTIONAL DESIGN (BIXI© USERS DATA SET)

DESIGN. Cross sectional sampling will allow us to determine the socio-demographic, travel pattern, and health characteristics of BIXI© users at randomly selected stations. Data will be collected by research assistants at BIXI© stations throughout the study period (i.e., August, September).

PARTICIPANTS AND PROCEDURES. Data will be collected from a volunteer sample of BIXI© users. In order to sample participants research assistants' will be deployed to randomly selected BIXI© stations for 5 consecutive days (3 week days and 2 weekend days) at the beginning of every month in August and September. We will station 20 interviewers for a period of 7 consecutive hours at 20 randomly selected bicycle stations throughout the three boroughs of BIXI© deployment. Interviewers will invite BIXI© users to complete the survey prior to departure or during arrival at a BIXI© station. Respondents will be able to immediately record their responses via palm pilot computers (palm pilot computers available through other funding). Interviewers will also record the number of BIXI© users agreeing or declining to complete the survey in order to allow for estimation of response rates. Based on Vélo'v usage of 33 rentals/station/day, and a response rate of 40% we estimate that each interviewer will recruit at least 13 respondents per day of data collection. With 20 interviewers working 5 days each month for 2 months the data set will include recording from approximately 2600 person-episodes.

VARIABLES & MEASUREMENT INSTRUMENT (Appendix F). The survey instrument is the same as the population data survey instrument. However, *section 1* of the population data survey will not be included because participants have experience with BIXI©. We replace this section, with a section on characteristics of the specific BIXI© travel episode the user is completing or embarking upon. Questions deal with prior experience with BIXI© bicycles, arrival/departure status for the current BIXI© episode, work vs. leisure purpose for BIXI© episode, whether or not the BIXI© episode represents a modal shift (from walking, personal bike, public transportation, motor vehicle), and use of cycling lanes while using BIXI©. These questions will be pilot tested for clarity and content validity.

TRAVEL BEHAVIOUR SURVEY (GPS DATA SET)

DESIGN. The travel behaviour survey will allow us to objectively determine travel behaviours of BIXI© users. BIXI© users will be invited to carry a cell-phone with integrated GPS receiver for a period of one week. The GPS will automatically collect GPS tracklog data for all trips. Online validation of objective travel will allow participants to provide important insights into their travel behaviour.

PARTICIPANTS AND PROCEDURES. A total sample of 120 BIXI© users, recruited as part of the cross sectional survey of BIXI© users, will be invited to volunteer for a real-time data capture study. These participants will carry a cell-phone with integrated GPS receiver for a period of one week. Prior to the data capture participants will be offered a two hour training course on GPS-enabled cell phones (equipment available through other funding) as well as on the travel behaviour website for daily validation and completion of trip data.

DATA COLLECTION: TRAVEL PATTERN DATA. GPS enabled cell phones will automatically collect GPS tracklogs for all trips. The cell-phones will be equipped with sensor licenses and programmed to automatically upload GPS tracking data to a central server hosted at the *Centre de recherche du CHUM* (CRCHUM) for transformation of tracklogs into meaningful travel information. GPS tracklogs received from cell phones will be automatically analysed based on secondary existing MEGAPHONE (Daniel & Kestens, 2005) spatial databases and heuristics so as to allow (1) split of tracklogs into distinct trips with precise origins and destinations; (2) alignment of signals along existing routes and entry/exit points of the built infrastructure (subway stations, shopping malls, offices, etc.); (3) estimation of modes of transportation based on speed, acceleration, and possible loss of signal.

DATA COLLECTION: ONLINE VALIDATION OF TRAVEL DATA. Using a confidential login and password, each participant will have access to a personalised, secured website to visualise and add information on their travel data as processed by the central server (trips, origins, destinations, modes, times). The website will display all trips for a given day and estimated transportation mode for each trip. Online functionalities will allow the participants to validate or modify information regarding each trip through interactive mapping (change of points of origin or destination, change of routes), and online forms to modify or add information on transportation mode, mode choice, trip motive and cycling lane use.

VARIABLES & MEASURES. The GPS dataset will allow us to derive measures needed to test hypotheses and to explore the impact of BIXI©. GPS and online recall collected data will be merged with existing spatial databases available through MEGAPHONE (Daniel & Kestens, 2005) allowing to further qualify BIXI© and non-BIXI© trips. BIXI© trip information will include: trip distance, trip speed, proportion of trips on bike lanes, local roads, and major roads, density of destinations (businesses, services) at point of origin and destination, shortest path ratio (ratio between shortest path and recorded path from origin to destination), greenness of route (using satellite-derived measures). Computation of similar information on non-BIXI© trips will allow further comparison of BIXI© and non-BIXI© trips and derive environmental and behavioural predictors of BIXI© use. Hourly climate data (temperature, wind, precipitation) from Dorval Airport will be merged to the database to control for climatic conditions.

DATA SETS TO ADDRESS DIFFERENT RESEARCH OBJECTIVES

DATA CLEANING AND SCREENING. Each data set will be screened and cleaned according to standardized procedures as described by Tabachnick and Fidell (2007).

REACH/ACCEPTABILITY OBJECTIVES

OBJECTIVE 1. Using the pre and post population data sets, we will compute estimates of the individuals having knowledge of, having tried and who use BIXI© regularly. Pre and post deployment estimates will be compared to produce an estimate of the proportion of the urban population in Montreal reached by the intervention.

OBJECTIVE 2. Using the pre and post population data sets, we will compute estimates of socio-demographic, health and travel pattern characteristics of participants reporting BIXI© use. In addition, using the BIXI© users data set we will produce descriptive statistics for the proportion of BIXI© users with different socio-demographic, health and travel patterns.

OBJECTIVE 3. Using the BIXI© users data set, we will compare socio-demographic, health, and travel pattern characteristics of BIXI© users to those of residents of the Island of Montreal by comparing descriptive estimates with socio-demographic data available from the 2006 Statistics Canada census (www.statcan.qc.ca) and health/travel data from the oversampling of residents of the Montreal Metropolitan Area from the Canadian Communities Health Survey of 2004 (CCHS; www.hc-sc.gc.ca/fn-an/surveill/nutrition/commun/index-eng.php). The census data set is available through the *Université de Montréal* Libraries, data from the CCHS data is available through the *Centre Inter-Québécois de Statistiques Sociales*. In addition, using the pre and post population data sets, we will examine whether or not the socio-demographic, travel pattern, and health characteristics differ for persons indicating that they have tried and not tried BIXI©.

OBJECTIVE 4. Using the GPS data set, we will compute the average durations and distances travelled on BIXI© and the extent to which time, speed, and distance travelled varied across episodes as a function of time of day, destination, and weather. Using the BIXI© user data set we will estimate perceived times, distances, and proportions of travel along cycling lanes for single episodes of travel.

OBJECTIVE 5. The BIXI© users data set and GPS data set will be used to describe the geography of BIXI© use. We will mesh both data sets with MEGAPHONE data to examine associations of BIXI© use to area of residence and BIXI© travel areas in the city. With the GPS data set, we will examine the proportion of time BIXI© users are on cycling paths. As well, travel mode choice will be modeled using individual, trip and environmental variables. Predictors of BIXI© or non-BIXI© travel mode will be assessed.

IMPACT OBJECTIVES

OBJECTIVE 6. Using the pre and post population data sets we will determine the impact of BIXI© on participants, use of active transportation, physical activity levels, collisions and degree of support for a variety of policy interventions aimed at increasing cycling and cyclist safety.

OBJECTIVE 7. Using the pre- and post population data sets we will cluster participants who reside or do not reside in BIXI© boroughs. We will determine the impact of BIXI© on participants, use of active transportation, physical activity levels, collisions and degree of support for a variety of policies aimed at increasing active transportation between BIXI© and non-BIXI© boroughs. In order to have sufficient power for the analysis this objective requires borough oversampling.

OBJECTIVE 8. To estimate the risk of collisions associated with BIXI© use we will use the BIXI© users data set and the GPS data set combined with MEGAPHONE data. Using the BIXI© users data set, we will estimate the proportion of users involved in a collision and having experienced "close calls". Proportions will also be examined as a function of socio-demographic, health, and travel characteristics. Extracting the BIXI© travel segments from the GPS data set, we will combine these data with geo-mapped data on accident risk

compiled in the context of ongoing investigation (Morency & Cloutier, 2005, 2006).
By combining the GPS travel data to accident risk data, we can obtain an overall and cumulative risk to which BIXI© users are exposed.

KNOWLEDGE TRANSFER AND EXCHANGE

As indicated by the composition of the research team, we believe that knowledge transfer and exchange (KTE) activities are an integral part of this application. The partnership nature and goals of this research suggests two important avenues for extensive KTE activities. First, once each phase of data collection and analysis has been completed, we will hold meetings with *Stationnement de Montreal* and *Ville de Montreal* to discuss the results and exchange ideas. Second, when each phase of the project is complete, we will hold a media event in partnership with the *Montreal Public Health Department*, the *Centre de recherche Léa-Roback* (www.centrelearoback.ca), *Stationnement de Montreal*, and *Ville de Montreal*. During these events, findings will be presented and discussed. We will also hold public meetings to discuss the findings of the research with the public. We have also recently become aware of the fact that the City of Vancouver will be implementing a BIXI©-like system in that city in the summer of 2010. If we obtain funding, we will initiate contacts with colleagues at Vancouver Coastal Health (VCH, http://www.vch.ca/) to explore possibilities of sharing knowledge and conducting a parallel evaluation in Vancouver.

LISTING OF POPULATION-LEVEL MEASURES RELATING TO HEALTHY LIVING/CHRONIC DISEASE PREVENTION THAT WILL BE ASSESSED: 1) Physical activity: Total, recreational, and transportation. 2) Perceived health status: Self-rated health, stability of health status over the previous year, presence of chronic disease conditions, and self-reported height and weight. 3) Bicycle helmet use, accidents, close calls and injuries while cycling.

JUSTIFICATION FOR SIZE OF INTENDED SAMPLING. The population data sets are random samples of the Island of Montreal. With group sample sizes of 1600 the sampling achieves 81% power to detect a difference of 0.1 (confidence intervals ± 0.069) between group means with estimated group standard deviations of 1.0 (thus and effect-size [ES]=0.1) and a significance level of 0.05 using a two-sided t-test (PASS 2008; Kaysville, USA). The test of differences across boroughs with group sample sizes of 500 and 1100 achieves 96% power to detect a difference of 0.2 (ES=0.2, confidence intervals ± 0.106) between group means with estimated standard deviations of 1.0 and a significance level of 0.05 using a two-sided t-test (PASS 2008; Kaysville, USA). Given the low levels of cycling for transportation in the population (~8%) power to detect small changes in the population is necessary and available with the proposed data sets. Sampling of BIXI© users will occur at randomly selected stations. We believe that this procedure will provide a representative sample of BIXI© users. A sample size of 2600 (BIXI© user-episodes) will allow us to detect phenomena of a prevalence of 3% with a two-sided confidence interval of 1.5% - thus allowing for a rich description of episodes of BIXI© use. The GPS data set will involve a small volunteer sample. A sample size of 120 observations will allow us to describe phenomena with prevalence of 15% with a two-sided confidence interval of 13.5%. This data set has moderate power but will provide important preliminary evidence for the appropriateness of GPS data capture procedures for cyclists. One of the most interesting features of this project is that to adequately respond to the research questions, we will use different data sets and triangulate data.

DETAILS ON ANY EXISTING RESEARCH OR EVALUATION OF INTERVENTION. We have initiated contact with the Director of the BIXI© project at *Stationnement de Montréal* and are developing links. The Director outlined that they do not have plans to evaluate the impact of BIXI©. He stated that it was possible that they may collect general usage statistics (similar to Vélib' and Vélo'v) although plans were not concrete. Given the limitations of general usage statistics outlined in the literature review and our specific research questions, there is no overlap between possible data collected by *Stationnement de Montréal* and data collected by the research team. The director of BIXI© also confirmed that he had not been contacted by other researchers to study the intervention. In addition, we are currently commencing collection of baseline data as BIXI© is currently being deployed. The availability of these data will allow for appropriate comparisons and thus drawing inferences about the impact of BIXI©.

VERIFICATION THAT THE INTERVENTION IS OCCURRING OUTSIDE OF RESEARCHER CONTROL**.** No researcher control exists for the BIXI© intervention. Once in operation, BIXI© will be self-sustaining and will not require outside funding. The funding provided by this grant will not be used to bridge funding nor to study the adaption of researcher-developed programs. None of the researchers involved in the current project have funds for evaluating BIXI© other than to conducting the baseline survey and do not currently hold funding for similar projects. To our knowledge, no one else is evaluating BIXI©.

TIME LINES OF THE PROGRAM. This research project will span over 30 months starting August 1st 2009 and ending March 31st 2012. As well, the city of Vancouver has indicated that it plans to start a self-service bicycle program in the summer of 2010 (www.ctvbc.ca). If Vancouver implements a program, additional funding, would allow for comparison of two self-service bicycle programs in Canada.

LIST OF ORGANIZATIONS INVOLVED IN THE INTERVENTION**.** The *CRCHUM* (*Centre de recherche du CHUM*) will provide the space and research infrastructure for the conduct of this project. The *Direction de santé publique de Montréal* will provide links with policy-makers throughout the city and public health interventionists. The *Centre de recherche Léa-Roback* will provide in-kind support and infrastructure for the organization of knowledge transfer and exchange events. Lise Gauvin's CIHR/CRPO Applied Public Health Chair on Neighbourhoods, Lifestyle, and Healthy Body Weight will also provide support for KTE.

DECISION MAKERS (ONLY IF APPLICABLE):

Two decision-makers (Louis Drouin, Patrick Morency) are part of the research team. Together they have responsibility for actions and funding allocations at the Montreal Public Health Department that works with the City of Montreal and other Montreal-area partners in promoting active transportation.

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Appendix V: Ethical Approval

CHUM

COMITÉ D'ÉTHIQUE DE LA RECHERCHE
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EXPEDIE 22 AVR. 2009

Le 22 avril 2009

Docteure Lise Gauvin
Département de médecine sociale et préventive

A/s Mme Isabelle Thérien
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Objet : 09.014 – Approbation accélérée initiale et finale CÉR

Titre : Impact d'une intervention visant l'augmentation de l'accessibilité et la convivialité d'un mode de transport actif sur la santé des populations: le cas de BIXI Montréal.

Protocole : BIXI

Docteure ,

J'ai pris connaissance le 17 avril 2009 des documents datés du 2 avril 2009 concernant le projet mentionné ci-dessus :

- Formulaire de soumission d'un projet non-multicentrique
- Formulaire A – Annexe 2.1
- Attestation de recherche (datée du 22 août 2008)
- Échange de courriels relatif à la demande de fonds
- Résumé de la demande de subvention
- Protocole de recherche
- Bases de données populationnelles

Le tout est jugé satisfaisant. En vertu des pouvoirs qui me sont délégués par le Comité d'éthique de la recherche du CHUM pour procéder à une évaluation accélérée, il me fait plaisir de vous informer que j'approuver votre projet puisqu'il s'agit d'un projet se situant sous le seuil de risque minimal.

La présente constitue l'approbation finale du comité suite à une procédure d'évaluation accélérée. Elle est **valide pour un an à compter du 22 avril 2009**, date de l'approbation initiale. Je vous rappelle que toute modification au protocole en cours d'étude, doit être soumise pour approbation du comité d'éthique.

CHUM

3. à **conserver les dossiers de recherche** pour une période d'au moins deux ans suivant la fin du projets afin permettre leur éventuelle vérification par une instance déléguée par le comité;
4. à respecter les modalités arrêtées au regard du **mécanisme d'identification des sujets de recherche** dans l'établissement.

Le comité suit les règles de constitution et de fonctionnement de l'Énoncé de Politique des trois Conseils et des Bonnes pratiques cliniques de la CIH.

Vous souhaitant la meilleure des chances dans la poursuite de vos travaux, je vous prie d'accepter, Docteur(e), mes salutations distinguées.

B St-Pierre

Brigitte St-Pierre
Ajointe à la présidence
Comité d'éthique de la recherche

BSTP/kb

c.c. : Par télécopieur au Bureau des contrats/ Centre de recherche, Pavillon Masson, Hôtel-Dieu du CHUM, 514 – 412-7134

Voici les coordonnées de la personne ressource pour ce projet :

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Appendix VI: Operational definitions of variables

Variable Group	Variable name	Definition	Source	Scale
Dependent Variables	Total cycling	Self report number of 10 minute intervals of cycling per week	International Physical Activity Questionnaire: Pre-Post Survey	Continuous: Number of minutes/week
	Leisure cycling	Leisure time cycling	See total cycling	Continuous: Number of minutes/week
	Utilitarian cycling	Total cycling – leisure time cycling	See total cycling	Continuous: Number of minutes/week
	Use of BIXI©	Have you ever used BIXI©? How many times have you used BIXI©in the past year?	Pre-Post Survey	Dichotomous: Use vs. non use Count: Number of BIXI©uses
Exposure/treatment variables	Individual exposure to BIXI©	Distance from home to the nearest BIXI station based on the road the network	- Pre-Post Survey - Montreal and DMTI GIS files	Continuous: Distance in meters
	Individual exposure to BIXI©	500m radius of participants home calculated with road network	- Pre-Post Survey - Montreal and DMTI GIS files	Count: Number of BIXI©stations
Environmental variables	Density of destinations	Count of the number of services (i.e., parks, grocery stores, banks, pharmacies, and medical services) within a 500m road network buffer of respondent's homes.	- Pre-Post Survey - Montreal and DMTI GIS files	Count: Number of available services
	Street Connectivity	Count of the number of intersections within a 500m road network buffer of respondent's homes	- Pre-Post Survey - Montreal land use GIS files	Count: Number of intersections
	Work neighborhood	The neighourhood where the participant works.	- Pre-Post Survey - Montreal land use GIS files	Nominal: Neighbourhood
	Weather	The average temperature and number days of precipitation in the week prior to participant responses to surveys	Environment Canada	Continuous: Average temperature Count: Number of days of precipitation
Socio-demographic characteristics	Age	In what year were you born?	Pre-Post Survey	Continuous
	Sex	What is your sex?	Pre-Post Survey	Dichotomous: Male/Female

Marital Status	Which situation best describes your marital status?	Pre-Post Survey	Nominal: 1) Married/Common law 2) Single 3) Separated 4) Divorced 5) Widowed 6) Other 7) Refuse
Employment status	What is your main activity (occupation)?	Pre-Post Survey	Nominal: 1) Student 2) Homemaker 3) Unemployed seeking work 4) On disability leave 5) On parental leave 6) Self-employed 7) Part-time employed 8) Full-time employed 9) Retired 10) Other 11) Refuse
Education	What is the highest level of education you have completed?	Pre-Post Survey	Nominal: 1) No degree, certificate, or diploma 2) High school graduation certificate or equivalent 3) Trades Certificate or Diploma 4) University certificate or diploma below bachelor level 5) Bachelor's degree 6) University certificate or diploma above bachelor level 7) Degree in medicine, dentistry, veterinary medicine or optometry 8) Master's degree 9) Earned Doctorate 10) College Diploma 11) Other
Home postal code	What is you postal code?	Pre-Post Survey (reported or provided	

			by survey company)	
	Social position	In comparison to the 'middle class' in our society, in terms of life conditions and general wealth, would you say that you are?	Pre-Post Survey	Ordinal: 1) Significantly above the middle class 2) Slightly above the middle class 3) In the middle class 4) Below the middle class 5) Significantly below the middle class
	Income	Annual household income		Ordinal: 1) less than $20 000 2) $20 000-$49 999 3) $50 000-$100 000 4) more than $100 000
	Work postal code/neighbourhood	Can you provide postal code or neighbourhood of your place of work?	Pre-Post Survey	Nominal
	Usual mode of transportation to work	Which mode of transportation do you normally use to get to main occupation?	Pre-Post Survey	Nominal: 1) Personal bike 2) BIXI© 3) Walk 4) Public transportation 5) Taxi 6) Personal motor vehicle 7) Work at home
General Health	Self-rated health	In comparison to other persons your age, would you say that your health in general is…	Pre-Post Survey	1) Excellent 2) Very Good 3) Good 4) Average 5) Bad 6) Don't know
	Height	What is your current height?	Pre-Post Survey	BMI (weight/height^2)
	Weight	What is your current weight?	Pre-Post Survey	BMI (weight/height^2)

* Note: Variables are not necessarily included in all studies. Please refer to study descriptions for pertinent variables.

Appendix VII: Population based survey

We are working for a team of researchers headed by Dr Lise Gauvin of the Research Center of the University of Montreal Hospital Center. The researchers on this team want to know more about the health, transportation habits, and attitudes of people who live on the Island of Montreal. Rest assured that the information that you will provide will remain confidential. You are free to respond or not to any of the questions that are addressed to you. Please know that the project has received the approval of the Human Research Ethics Committee of the Research Center of the University of Montreal Hospital Center. Should you have any questions related to the scientific aspects of this project we can provide you with the telephone number and email of the principal investigator or to ethical aspects this project with the telephone number and email of the secretary to the ethics committee. Can I count on your collaboration for the next 20 minutes?

Thank you for agreeing to participate in this *SURVEY*. Please remember that your answers will remain confidential. Do not hesitate to ask questions. Can you confirm that the first three digits of your postal code are:

<u>Health Questions</u>

Q1A In this first series of questions, we ask about your current health status. Please indicate the answer that best describes your current state of health.
In comparison to other persons your age, would you say that your health in general is...

Excellent	1
Very good	2
Good	3
Average	4
Bad	5
DNK/DNA	9

Q2 In comparison to last year, how would you evaluate your health in general now? Is it...

Much better than last year	1
A bit better than last year	2
About the same as last year	3
A bit worse than last year	4
Much worse than last year	5
DNK/DNA	9

Q4 Below is a list of symptoms and conditions. For each one, please indicate whether or not a doctor has ever told you that you suffer from this symptom or condition.
Diabetes

Yes	1
No	2
DNK/DNA	9

Q7 Below is a list of symptoms and conditions. For each one, please indicate whether or not a doctor has ever told you that you suffer from this symptom or condition.
Cardiac problems (angina, heart attack/myocardial infarction, by-pass)

Yes	1

No 2
DNK/DNA 9

Q8
Below is a list of symptoms and conditions. For each one, please indicate whether or not a doctor has ever told you that you suffer from this symptom or condition.
Arthritis/ or rheumatism
Yes 1
No 2
DNK/DNA 9

Q9 Below is a list of symptoms and conditions. For each one, please indicate whether or not a doctor has ever told you that you suffer from this symptom or condition.
Respiratory illness (asthma, COPD-Chronic Obstructive Pulmonary Disease)
Yes 1
No 2
DNK/DNA 9

Q11 Below is a list of symptoms and conditions. For each one, please indicate whether or not a doctor has ever told you that you suffer from this symptom or condition.
Depression or Anxiety
Yes 1
No 2
DNK/DNA 9

Q14 Below is a list of symptoms and conditions. For each one, please indicate whether or not a doctor has ever told you that you suffer from this symptom or condition.
Back or neck problems
Yes 1
No 2
DNK/DNA 9

Lifestyle Questions
Q30 We now ask about your current and past smoking habits.
In the past 30 days, have you smoked?
Yes 1
No 2 ->Q31A

Q30A Are you currently a smoker?
Yes 1
No 2 ->Q31A

Q30B Do you smoke everyday?
Yes 1
No 2 ->Q31A

Q30C On average, how many cigarettes do you smoke per day?
Less than 10 cigarettes 1

Between 10 and 20 cigarettes	2
Between 21 and 30 cigarettes	3
Between 31 and 40 cigarettes	4
More than 40 cigarettes	5
DNA	9

Q31A We now ask about recent alcohol consumption.
During the last 7 days, on how many days did you have one or more drinks of beer, wine, liquor or any other alcoholic beverage?
Number of days ______
DNA 9

Q31B
Si... (AQ31A.GT.0)
On those days when you consume alcool, how many drink did you have per day?
Number of drinks ______
DNA 9

Questions related to BIXI©
Q40 In this next series of questions, we ask about your knowledge of a specific new amenity in Montreal.
Have you heard about the project called BIXI© in Montreal?
Yes 1
No 2

Q40A Si... (Q40=1)
What do you know about it? ______

Q40B Si... (Q40=1)
Have you ever used BIXI?
Yes, how many times have you used BIXI© in the past year? _____
No 2 ->Q40D

Q40C If BIXI© bikes had not been available, how would you have travelled to your destination?

Personal bike	1
Walking	2
Public transportation	3
Car	4

Q40C1 When you used BIXI© bicycles what is more often for?
1 Getting to work or school
2 For leisure or fun
3 For Exercise
4 For running errands
5 For social visits to family or friends
6 For trips for work
8 other

Q40C2 What was the mode of transportation you used to make the trips that you now make with BIXI© bicycles?
1 Personal bike
2 Walk
3 Public transportation
4 Taxi
5 Personal motor vehicle

Q40C3 Do you integrate other modes of transportation into your travel when you use BIXI© bicycles?
1 Yes, I take the bus at the beginning of my trip
2 Yes, I take the bus at the end of my trip
3 Yes, I take the subway at the beginning of my trip
4 Yes, I take the subway at the end of my trip
5 Yes, I take a taxi at the beginning of my trip
6 Yes, I take a taxi at the end of my trip
7 No, I walk to the BIXI© station at the beginning and end of my trip

Q40C4 What type of BIXI© membership do you have?
1 Yearly
2 Monthly
3 Pay per use

Q40C4 Do you have an integrated STM and BIXI© membership?
1 Yes
2 No
3 Don't know

Q40D Have you heard about projects called Vélib and Vélo'v in Paris and Lyon France?
Yes 1
No 2

Q40E What do you know about it? ______

Q40F Have you ever used Vélib or Vélo'v?
Yes, how many times have you used Vélib or Vélo'v in the past year? _____
No 2 ->Q40D

Q41A BIXI© , Vélib and Vélo'v are self-service bicycle rental programs that area available to the public. Bicycles are locked at stations throughout the city. Individuals can rent bicycles for a small fee and return them to any of the stations in the city. To what extent are you favourable to using BIXI© personally in the future?

Not at all	1	->Q41C
Somewhat	2	
Moderately	3	
Strongly	4	
DNK	9	->Q41C

Q41B Even if you do not use BIXI© bicycles yourself, has the availability of BIXI© bicycles made you change your habitual modes of transportation?

1 No
2 Personal bike
3 Walk
4 Public transportation
5 Taxi
6 Personal motor vehicle

Q41C Even if you do not use BIXI© bicycles yourself, has the availability of BIXI© bicycles encouraged you to make trips that you would not have made otherwise?

1 Work or school
2 For leisure of fun
3 Exercise
4 Shopping
5 Social visits to family or friends
6 Trips for work
8 Other
9 Non

Q41D How confident are you in your capability of using BIXI© if you chose to do so?

1 Not at all confident
2 Somewhat confident
3 Moderately confident
4 Very confident
9 NSP

Q40C3 In your opinion the implementation of BIXI© bicycles has had a…. impact on the image of Montréal? DEMANDER à TOUS

1 Very positive
2 Somewhat positive
3 Neutral
4 Somewhat negative
5 Very negative

Q40C4 In your opinion the implementation of BIXI© bicycles has had a…. impact on road safety in Montréal?

1 Very positive
2 Somewhat positive
3 Neutral
4 Somewhat negative
5 Very negative

Q40C5 In your opinion the implementation of BIXI© bicycles has had a…. impact on the ease of travelling within Montréal?

1 Very positive
2 Somewhat positive
3 Neutral

4 Somewhat negative
5 Very negative

Q40C3 In your opinion the implementation of BIXI© bicycles has had a…. impact on the promotion of active transportation in Montréal?
1 Very positive
2 Somewhat positive
3 Neutral
4 Somewhat negative
5 Very negative

Q40C3 In your opinion the implementation of BIXI© bicycles has had a…. impact on the health of the population of Montreal?
1 Very positive
2 Somewhat positive
3 Neutral
4 Somewhat negative
5 Very negative

Q41B To what extent do you have the intention to change your usual mode of transportation in favour of using BIXI© bicycles in the next year?
1 Not at all
2 Possibly
3 Probably
4 Definitely
9 NSP

Physical activity questions

Q20 We now ask about the walking you have done over the past 7 days. This includes walking to get around, or walking to maintain your health or for your leisure or walking for the pleasure of walking. In the past 7 days, how many days did you walk for at least 10 minutes at a time?
0 day ->Q20D
1 day
2 days
3 days
4 days
5 days
6 days
7 days
9 DNA

Q20A On those days that you walked at least 10 minutes, on average, approximately how much time per day did you spend walking?
Minutes 1
Hours 2
DNA 999

Q20B On those days that you walked for at least 10 minutes, on average, did you walk more often...

In your neighbourhood	1
Outside of your neighbourhood	2
About evenly split inside and outside of your neighbourhood	3
DNA	9

Q20C Among your walking activities, did you walk specifically to maintain your health or physical fitness, for your leisure or own pleasure?

Yes	1	
No	2	->Q21

Q20D In the past 7 days, how many days did you walk specifically to maintain your health, to stay fit, or for your leisure or pleasure?

0 day ->Q21
1 day
2 days
3 days
4 days
5 days
6 days
7 days
DNA 9

Q20E On average, approximately how much time per day did you spend walking specifically to maintain your health or fitness or for your leisure or pleasure?

Minutes	1
Hours	2
DNA	999

Q20F On those days that you walked for at least 10 minutes specifically to maintain your health or fitness or for your leisure or pleasure, on average, did you walk more often:

In your neighbourhood	1
Outside of your neighbourhood	2
About evenly split inside and outside of your neighbourhood	3
DNA	9

Q21 We now ask about the cycling you have done over the past 7 days. This includes cycling to get around, or cycling to maintain your health or for your leisure or cycling for the pleasure of cycling. In the past 7 days, how many days did you cycle for at least 10 minutes at a time?

0 day ->Q22
1 day
2 days
3 days
4 days
5 days
6 days

7 days
DNA 9

Q21A On those days that you cycled at least 10 minutes, on average, approximately how much time per day did you spend cycling?
Minutes 1
Hours 2
DNA 999

Q21B On those days that you cycled for at least 10 minutes, on average, did you cycle more often...

In your neighbourhood	1
Outside of your neighbourhood	2
About evenly split inside and outside of your neighbourhood	3
DNA	9

Q21C And, in the past 7 days, when you cycled, was it...

On your own bicycle	1
A BIXI© bycicle	2
A rental bicycle	3
With a borrowed bicycle	4
DNA	9

Q21D Among your cycling activities, did you cycle specifically to maintain your health or physical fitness or for your leisure or pleasure?
Yes 1
No 2 ->Q22

Q21E In the past 7 days, how many days did you cycle specifically to maintain your health, to stay fit, or for your leisure or pleasure?
0 day ->Q22
1 day
2 days
3 days
4 days
5 days
6 days
7 days
DNA 9

Q21F On average, approximately how much time per day did you spend cycling specifically to maintain your health or fitness or for your leisure or pleasure?
Minutes 1
Hours 2
DNA 999

Q21G And when you cycled specifically to maintain your health or fitness or for your leisure or pleasure, was it...

In your neighbourhood 1
Outside of your neighbourhood 2
About evenly split inside and outside of your neighbourhood 3
DNA 9

Q22 We will now ask about the vigorous physical activity that you perform in your leisure time. Walking and cycling do not count here. Vigorous physical activity causes you to breathe faster than normal and could include activities like lifting heavy weights, digging, doing aerobics, or playing sports. Think of the vigorous physical activities that you did for at least 10 minutes at a time.
In the past 7 days, on how many days did you do at least one vigorous physical activity for at least 10 minutes during your leisure time?
0 day ->Q22B
1 day
2 days
3 days
4 days
5 days
6 days
7 days
DNA 9

Q22A On average, how long do these physical activities last?
Minutes 1
Hours 2
DNA 999

Q22B Which of the following sentences best describes the work you do or the main activity that you perform on a daily basis? Is it...
I am usually seated during the day and I do not have to move around often 1
I am often standing or I often have to move around during the day but I do not have to lift or carry heavy objects very often 2
I usually lift or carry light objects or I must often go up stairs or inclines 3
I work hard physically or I carry very heavy objects 4
DNA 9

Questions related to your cycling experience
Q50 We now ask about experiences as a cyclist. In the previous 12 months, have you used a bicycle?
Yes 1
No 2 ->Q60A

Q50A How often have you worn a helmet while you cycled?
Always 1
Often 2
Seldom 3
Never 4

Q50A How often do you ride in the same direction as traffic?

Always 1
Often 2
Seldom 3
Never 4

Q50A How often do you use the appropriate hand signals when you are stopping or turning?
Always 1
Often 2
Seldom 3
Never 4

Q50A If you ride after sunset, how often do you turn on your light or wear light reflecting objets?
Always 1
Often 2
Seldom 3
Never 4
Does not apply 5

Q50B In the last 12 months has your personal bicycle been stolen?
1 Yes– was it found?
2 No

Q50B Have you been involved in a collision with a motor vehicle (including car, SUV, truck, bus, motorcycle) while cycling?
Yes 1 – How many times ? ______
No 2

Q50C During your most recent collision were you injured?
Yes 1
No 2

Q50D Did an ambulance come to the scene?
Yes 1
No 2

Q50E Were you cycling on a cycling lane?
Yes 1
No 2

Q50F Were you cycling in an area you know well or an area you were not familiar with?
Known area 1
Unfamiliar area 2

Q50G Were you cycling with your own bicycle, a BIXI© bicycle, or a rented/borrowed bicycle?
Own 1

BIXI© 2
Rented/borrowed 3

Q50H Which among the following factors could have allowed for the prevention of the collision:
Better physical layout of the location of the accident 1
More courteous behaviour on the part of the motor vehicle driver 2
More courteous behaviour on my part as a cyclist 3
More favourable weather conditions 4

Q51A In the previous 12 months, have you been involved in a 'near collision' (close call) with a motor vehicle (including car, SUV, truck, bus, motorcycle) while cycling?
Yes 1 – How many times
No 2

Q51B During your most recent close call were you cycling on a cycling lane?
Yes 1
No 2

Q51C Were you cycling in an area you know well or an area you were not familiar with?
Known area 1
Unfamiliar area 2

Q51D Were you cycling with your own bicycle, a BIXI© , or a rented/borrowed bicycle?
Own 1
BIXI© 2
Rented/borrowed 3

Q51E [1,4] Which among the following factors could have allowed for prevention of the near-collision:
Better physical layout of the location of the accident 1
More courteous behaviour on the part of the motor vehicle driver 2
More courteous behaviour on my part as a cyclist 3
More favourable weather conditions 4

Questions related to your opinions
Q60A Would you say that you completely agree, somewhat agree, somewhat disagree or completely disagree with the following potential changes municipal or government authorities might implement in your neighbourhood:
Allowing motor vehicule or bicycle to turn right when the traffic light is red...
I Completely agree 1
I Somewhat agree 2
I Somewhat disagree 3
I completely disagree 4
DNK 9

Q60B Would you say that you completely agree, somewhat agree, somewhat disagree or completely disagree with the following potential changes municipal or government

authorities might implement in your neighbourhood:
Implementing traffic calming measures such as making streets more narrow or blocking off street sections...

I Completely agree	1
I Somewhat agree	2
I Somewhat disagree	3
I completely disagree	4
DNK	9

Q60C Would you say that you completely agree, somewhat agree, somewhat disagree or completely disagree with the following potential changes municipal or government authorities might implement in your neighbourhood:
Allowing the construction of a major highway within 2km of your home...

I Completely agree	1
I Somewhat agree	2
I Somewhat disagree	3
I completely disagree	4
DNK	9

Q60D Would you say that you completely agree, somewhat agree, somewhat disagree or completely disagree with the following potential changes municipal or government authorities might implement in your neighbourhood:
Closing down a commercial street to motor vehicles...

I Completely agree	1
I Somewhat agree	2
I Somewhat disagree	3
I completely disagree	4
DNK	9

Q60E Would you say that you completely agree, somewhat agree, somewhat disagree or completely disagree with the following potential changes municipal or government authorities might implement in your neighbourhood:
Installing toll booths to enter the Island of Montreal...

I Completely agree	1
I Somewhat agree	2
I Somewhat disagree	3
I completely disagree	4
DNK	9

Q60F Would you say that you completely agree, somewhat agree, somewhat disagree or completely disagree with the following potential changes municipal or government authorities might implement in your neighbourhood:
Installing tramways on main boulevards on the Island of Montreal...

I Completely agree	1
I Somewhat agree	2
I Somewhat disagree	3
I completely disagree	4
DNK	9

Q60G Would you say that you completely agree, somewhat agree, somewhat disagree or completely disagree with the following potential changes municipal or government authorities might implement in your neighbourhood:
Extending the metro to the east and west ends of the Island...

I Completely agree	1
I Somewhat agree	2
I Somewhat disagree	3
I completely disagree	4
DNK	9

Q60H Would you say that you completely agree, somewhat agree, somewhat disagree or completely disagree with the following potential changes municipal or government authorities might implement in your neighbourhood:
Increase taxes on gasoline consumption to subsidize public transit...

I Completely agree	1
I Somewhat agree	2
I Somewhat disagree	3
I completely disagree	4
DNK	9

Q60I Would you say that you completely agree, somewhat agree, somewhat disagree or completely disagree with the following potential changes municipal or government authorities might implement in your neighbourhood:
Increasing the cost of parking to subsidize public transit...

I Completely agree	1
I Somewhat agree	2
I Somewhat disagree	3
I completely disagree	4
DNK	9

Q60J Would you say that you completely agree, somewhat agree, somewhat disagree or completely disagree with the following potential changes municipal or government authorities might implement in your neighbourhood:
Having more reserved lanes for cyclists...

I Completely agree	1
I Somewhat agree	2
I Somewhat disagree	3
I completely disagree	4
DNK	9

Q60K Would you say that you completely agree, somewhat agree, somewhat disagree or completely disagree with the following potential changes municipal or government authorities might implement in your neighbourhood:
Reducing automobile speed limits from 50 km/h to 30 km/h within a 3km radius around schools...

I Completely agree	1
I Somewhat agree	2

I Somewhat disagree	3
I completely disagree	4
DNK	9

Q60L Would you say that you completely agree, somewhat agree, somewhat disagree or completely disagree with the following potential changes municipal or government authorities might implement in your neighbourhood:
Stiffer fines for motorists caught speeding...

I Completely agree	1
I Somewhat agree	2
I Somewhat disagree	3
I completely disagree	4
DNK	9

Q60M Would you say that you completely agree, somewhat agree, somewhat disagree or completely disagree with the following potential changes municipal or government authorities might implement in your neighbourhood:
Stiffer fines for pedestrians caught jay walking...

I Completely agree	1
I Somewhat agree	2
I Somewhat disagree	3
I completely disagree	4
DNK	9

Q60N Would you say that you completely agree, somewhat agree, somewhat disagree or completely disagree with the following potential changes municipal or government authorities might implement in your neighbourhood:
Stiffer fines for cyclists not obeying the traffic code...

I Completely agree	1
I Somewhat agree	2
I Somewhat disagree	3
I completely disagree	4
DNK	9

Q60O Would you say that you completely agree, somewhat agree, somewhat disagree or completely disagree with the following potential changes municipal or government authorities might implement in your neighbourhood:
Allowing more commercial establishments du settle around subway stations...

I Completely agree	1
I Somewhat agree	2
I Somewhat disagree	3
I completely disagree	4
DNK	9

Q60P Would you say that you completely agree, somewhat agree, somewhat disagree or completely disagree with the following potential changes municipal or government authorities might implement in your neighbourhood:
Reducing speed limits in the city from 50km/h to 40km/h throughout the Island of

Montreal...

I Completely agree	1
I Somewhat agree	2
I Somewhat disagree	3
I completely disagree	4
DNK	9

Q60Q Would you say that you completely agree, somewhat agree, somewhat disagree or completely disagree with the following potential changes municipal or government authorities might implement in your neighbourhood:
Increasing the number of highways and the volume of traffic for motor vehicles coming in and out of the city...

I Completely agree	1
I Somewhat agree	2
I Somewhat disagree	3
I completely disagree	4
DNK	9

Q60Q Would you say that you completely agree, somewhat agree, somewhat disagree or completely disagree with the following potential changes municipal or government authorities might implement in your neighbourhood:
Reserving existing lanes on major Montreal highways, for example the 20 and 40 for buses….

I Completely agree	1
I Somewhat agree	2
I Somewhat disagree	3
I completely disagree	4
DNK	9

Descriptives

Q18 These final questions ask about your individual characteristics and will be used for comparison purposes only. All information will remain strictly anonymous. What is your CURRENT height?

In feet and inches	1
In meters	2
Refuse to answer	9

Q18C What is your CURRENT weigh?

In pounds	1
In kilograms	2
Refuse to answer	9

Q19C What weight you would PREFER to be at?

In pounds	1
In kilograms	2
His(here) weight is convenient for him(her)	8
Refuse to answer	9

Q70A In what year were you born? _____

Q70B [1,3] What language(s) do you most often speak at home? _____

Q70C Which situation best describes your marital status?

Married/Common law relationship	1
Single	2
Separated	3
Divorced	4
Widowed	5
Other, specify...	
Refuse	99

Q70D How many children do you have? _____

Q70E How many children live with you? _____

Q70F Including yourself, how many persons aged 18 or more are there in your household? ______

Q70G1 When did you move to your current home residence? ______

Q70H What is you postal code? ______

Q70I Have you moved to your present resident from another city or from another area of Montreal in the past year?

Yes, what is the postal code of your previous residence? ______	
Yes, but don't know the postal code	2
No	3

Q70J What country were you born in? ______

Q70K Do you have a valid driver's permit?

Yes	1
No	2

Q70KA Do you own a motor vehicle (including car, SUV, truck, motorcycle)?

Yes	1
No	2

Q70L Do you have access to a motor vehicle (including car, SUV, truck, motorcycle)?

Yes	1
No	2

Q70M What is the highest level of education you have completed?

No degree, certificate, or diploma	1
Secondary (high) school graduation certificate or equivalent	2

Trades Certificate or Diploma	3
University certificate or diploma below bachelor level	4
Bachelor’s degree	5
University certificate or diploma above bachelor level	6
Degree in medicine, dentistry, veterinary medicine or optometry	7
Master’s degree	8
Earned Doctorate	9
College Diploma	10
Other, please specify…	98
Refuse	99

Q70N What is your main activity(occupation)?

Student	1
Homemaker	2
Unemployed seeking work	3
On disability leave	4
On parental leave	5
Self-employed	6
Part-time employed	7
Full-time Employed	8
Retired	9
Other, specify	98
Refuse	99

Q40C Which mode of transportation do you normally use to get to main occupation?

1 Personal bike
2 BIXI©
3 Walk
4 Public transportation
5 Taxi
6 Personal motor vehicle
7 Work at home
8 Other

Q70O Can you provide postal code of your place of work? _____

Q70P In comparison to the 'middle class' in our society, in terms of life conditions and general wealth, would you say that you are:

Significantly above the middle class	1
Slightly above the middle class	2
In the middle class	3
Below the middle class	4
Significantly below the middle class	5
Refuse	99

Q70Q What is the total yearly income for your entire household?

Under $10000 per year	1

Between $10000 and $19999 per year	2
Between $20000 and $34999 per year	3
Between $35000 and $49999 per year	4
Between $50000 and $74999 per year	5
Between $75000 and $99999 per year	6
Between $100000 and $149999 per year	7
Between $150000 and $199999 per year	8
Over $200000 per year	9
Refuse	99

SEXE

1	Female
2	Male

Appendix VIII: Maps of the distribution of BIXI© stations for the first and second seasons of implementation on the Island of Montreal.

Season 1: 267 Stations. Data from www.bixi.com scrapped on May 24th, 2009.

Season 2: 391 Stations. Data scrapped from www.bixi.com on May 12th, 2010.

Appendix IX: First insights into the potential impact of a natural experiment on travel practices: Prevalence and predictors of use of a New Public Bicycle Share Program in Montreal, Canada

ABSTRACT

Objectives: Determine the prevalence and correlates of use of a new public bicycle share program called BIXI© implemented in May 2009 in Montreal, Canada.

Methods: A total of 2502 adults were recruited to a telephone survey in autumn 2009 via random digit dialing according to a stratified random sampling design. The prevalence of BIXI© bicycle use was estimated following inverse probability of selection weighting and post stratification weighting of data. Logistic regression allowed for identification of correlates of use.

Results: The unweighted mean age of respondents was 47.4 (SD = 16.8) years and 53.8% were female. The weighted prevalence for use of BIXI© bicycles at least once was 8.2%. Significant correlates of BIXI© bicycle use were having a BIXI© docking station within 250m of home, being aged 18-24 years, being university educated, being on work leave, and using cycling as primary mode of transportation to work.

Conclusions: A new public bicycle share program attracts a substantial fraction of the population and is more likely to attract younger and more educated people who currently use cycling as a primary transportation mode.

Over the past 15 years researchers in public health, geography, and urban planning have studied benefits of cycling as a mode of transportation for increasing levels of physical activity.[1,2] Cycling for transportation makes an independent contribution above that of leisure time physical activity to reducing body mass index (BMI), waist circumference, and blood lipid profiles (i.e., total cholesterol, low density lipoprotein cholesterol, and triglycerides).[3-7] According to the 2006 Canadian census, the proportion of individuals who cycled to work was 0.6% and in the United States the share of bicycle commuters was estimated at 0.55% in 2008,[8,9] although other estimates suggest that anywhere between 1.6% to 8% of the population of Montreal use cycling for transportation.[8] Low prevalence and potential population health benefits to be gained by increasing levels of physical activity via cycling for transportation explain why promoting cycling for transportation has become an important public health objective.

Public bicycle share programs (PBSP), widely implemented in Western Europe,[10] increase population access to bicycles by deploying bicycles at docking stations throughout a city or area within a city.[10] Grey-area literature suggests that public bicycle share programs are well used and have the potential to increase cycling for transportation.[11] For example, Vélo'v was the first PBSP of its kind (i.e., information technology based system[9]) initiated in Lyon, France in June, 2005.[12] The city of Lyon estimated that bicycle use had increased by 80% since the implementation of Vélo'v.[13] In Paris, data from a volunteer sample of 848 Vélib' users suggested that 40% of Vélib' users were aged between 26-35 years, 58% were male, and that the average trip duration was 18 minutes.[14]

North American cities have been slower to adopt public bicycle share programs as a means of increasing cycling for transportation.[10] However, in the past few years there has been growing interest in their implementation. In 2008, North America's first public bicycle share program was launched in Washington D.C. This small pilot project offered 120 bicycles at 10 docking stations. The largest public bicycle share program in North America is BIXI© (named from BIcycle and taXI, www.bixi.com) in Montreal, Canada. Launched in May 2009, BIXI© was modeled after Vélib' and Vélo'v. In the central, more urbanized areas of the Island of Montreal, BIXI© made available 5000 bicycles at 450 docking stations from May through November 2009 in it's first season of implementation. The BIXI© public bicycle share program was extended to Boston and Minneapolis in 2010.

Minimal research has systematically examined the prevalence and correlates of PBSP use.[10,11] One reason is that PBSP are generally implemented outside of the research sector. Thus it is difficult for researchers to undertake the necessary steps (i.e., study design, ethics, funding) rapidly enough for evaluation.[10,11,16-19] As a result, internal validity required for evaluation is difficult to achieve.[11,16]

The present study examines the prevalence and correlates of PBSP use in Montreal, Canada and builds on past research in three important ways. First, the use of stratified random population based sampling and weighting via inverse probability of selection and post-stratification by age and sex increased representativeness of the sample and accuracy of estimates. Second, recent geographical literature suggests that researchers must begin to consider the influence of exposures in more than the home location.[20-22] Exposure to BIXI© docking stations in the vicinity of both the home and workplace of participants is considered in the present analysis. Finally, the study contributes to creating a framework for studying the outcomes of implementation of PBSP in other North American cities.

METHODS

Design

A stratified random sampling design was used. The sampling frame was individuals residing on the Island of Montreal. The two strata within the sampling frame were individuals residing where BIXI© docking stations were deployed and where docking stations were not deployed. BIXI© docking stations were deployed in central more urbanized locations in Montreal. The data collection period was October 8th to December 12th 2009. This period represents the post-implementation period of the first BIXI© season in Montreal. Unlike among European PBSP, BIXI© is removed during the winter months. A total of 7231 households were contacted via telephone for participation in the survey using random digit dialing. To sample within contacted households the individual to next celebrate a birthday and aged over 18 year was invited to respond to the survey. In the stratum where BIXI© docking stations were not deployed the sampling frame was landlines. To recruit sufficient numbers of participants in the stratum where BIXI© docking stations were available, 25% oversampling of respondents were applied in Montreal area codes where BIXI© docking stations were available and residences with landlines. Thus, based on 2006 Canadian census data, it was estimated that rather than 17.2% of the sample (n=430 of 2500) residing in the stratum where BIXI© docking stations were available, the sampling would recruit approximately 625 respondents residing in the stratum where BIXI© docking stations were implemented. Researchers trained telephone interviewers and performed ongoing quality surveillance. Inclusion criteria for the present investigation required respondents not to have changed residence in the previous year and to be aged 18 years or more.

Procedures

Ethical approval was obtained from the ethics committee of *Centre de Recherche du Centre Hospitalier de l'Université de Montréal*. Participants were recruited via a polling firm who obtained verbal informed consent prior to participation. Recruitment including up to five callbacks to improve response rate took 5 weeks. To properly account for surveying time, recruitment began 5 weeks prior to planned storage of BIXI© bicycles and docking stations for the winter (i.e., November 30th, 2010).

Measures

The outcome variable was self-reported use of BIXI© bicycles. Participants indicated whether or not they had ever used BIXI© and estimated the total number of BIXI© uses since implementation on May 12th, 2009. Use of BIXI© was operationalized in two ways: a dichotomous indicator of use (Yes had tried BIXI© bicycles vs. No had not tried) and, for those indicating 'yes', a dichotomous indicator of regular or non-regular BIXI© bicycle use. Regular BIXI© users were those who reported using BIXI© bicycles at least 10 times during the 2009 BIXI© season.

The main exposure was a count of the number of BIXI© docking stations within a 250 meter buffer, calculated using road networks, from participants' home postal code. The 250 meter buffer was chosen as an indicator of exposure because it is a walkable distance and also because BIXI© docking stations were installed on average 300 meters apart.

A secondary exposure of interest was having a primary occupation (i.e., full time, part time, or student) where BIXI© docking stations were implemented. Exposure to BIXI© bicycles at work was operationalized as a dichotomous variable indicating whether or not an individuals' main occupation was in a location where BIXI© docking stations were available.

Sociodemographic variables were measured using standard socio-demographic questions drawn from the Statistics Canada Census questionnaire. These questions concerned age, sex, education, employment status, income, and usual mode of transportation to work. Education was measured by asking "what is the highest level of education you have completed?" Responses were categorized as high school or less, trade school or college, and university. Employment/student status was measured by asking "what is your main activity (occupation)?" and responses were categorized as employed full time, employed part time, student, retired or other (i.e., work from home, maternity leave, sick leave, unemployed). Income was measured by asking participants to report their annual household income in four categories, less than \$20 000, \$20 000-\$49 999, \$50 000-\$100 000, and more than \$100 000. Usual mode of transportation to work for employed respondents was measured by asking "which mode of transportation do you normally use to get to your main occupation?" and responses were categorized as cycling (not including BIXI© bicycles), walking, public transportation, personal motor vehicle, and other (i.e., taxi, work at home, or skateboard).

Data analysis

Data analysis was conducted to first estimate the prevalence of BIXI© use, and second, to examine the correlates of BIXI© use. To estimate the prevalence and 95% confidence intervals (95% CI) of BIXI© use, inverse probability of selection weighting and post stratification weighting were applied. Inverse probability of selection weighting corrected for the oversampling of participants exposed to BIXI© docking stations close to home. Post stratification weighting for age and sex using data from the 2006 Canadian census, ensured that the sample was representative of the population residing on the Island of Montreal.[25] Final prevalence estimates and 95% CIs were computed for the entire Island of Montreal and stratified by locations where BIXI© docking stations were and were not available. Bivariate and logistic regression were used to examine correlates of BIXI© bicycle use.[26] Variables related with BIXI© bicycle use at $p<0.1$ in bivariate analyses were entered into multivariate analysis. In unweighted and weighted analyses, blocks of variables were entered in the model as follows: (1) exposure to BIXI© docking station from home, and (2) socio-demographic variables.

Ancillary analyses using logistic regression compared a limited number of socio-demographic characteristics across regular and non-regular BIXI© bicycle users (n=152). Because of limited statistical power, analyses were constrained to comparisons of age, education, employment status, and sex. Analyses involving logistic regression also examined the relationship between exposure to BIXI© docking stations from home (i.e., number of stations within a 250m buffer) and working where BIXI© bicycles were available, in a subset of the sample (n=1065) with data (i.e., persons working outside the home and knowing their work postal code).

RESULTS

The final sample included 2502 respondents with 634 residing where BIXI© docking stations were available. The response rate for the survey was 34.6%. The sample analyzed in the present study was 2133 (85% of the final sample of 2502). Of 350 respondents excluded, 150 (6%) had moved in the previous year. The remaining 219 participants (9%) were excluded because of missing data. The unweighted mean age of participants was 47.4 (*SD* = 16.8) years; 53.8% of the sample was female. Examining the unweighted sociodemographic characteristics of the sample showed that 51.9% of participants were university educated and 31% had a total household income between 20,000-50,000$ per year. Table 1 presents the unweighted and weighted socio-demographic characteristics of the sample.

The unweighted prevalence of BIXI© use at least once was 7.1% (95% CI: 4.1, 10.1) whereas the weighted prevalence estimate was 8.2% (95% CI: 8.1; 8.3) Considering a total population on the Island of Montreal of 1 853 001 inhabitants, 151 946 (weighted estimate) residents of the Island of Montreal have used BIXI© at least once. Unweighted prevalence estimates showed that where BIXI© docking stations were available 13.7% (95 CI: 7.9, 19.5) of the population had used BIXI©. Where BIXI© docking stations were not available prevalence estimates were 4.7% (95% CI: 2.7, 6.7). Weighted estimates showed that 14.3% (95% CI: 14.1, 14.5; n=47 033) and 6.0% (95% CI: 5.9, 6.1; n=98 658) of residents living respectively where BIXI bicycle docking stations were, and were not, available had used BIXI© at least once.

In bivariate analyses all variables except income were related to BIXI© use at $p<0.1$. As a result, income was not included in multivariate models. Table 2 shows the results from unweighted logistic regression. Adjusted results show that having one station (OR = 2.53; 95% CI: 1.61, 3.97) or more than one station (OR = 2.40; 95% CI: 1.40, 4.10) within a 250m road network buffer of home was related to greater likelihood of BIXI© use. Compared to participants aged 18-24 years those aged 34-45 years (OR = 0.35; 95% CI: 0.17, 0.70), 45-54 years (OR = 0.12; 95% CI: 0.05, 0.27), 55-64 years (OR = 0.10; 95% CI: 0.04, 0.26) and older than 65 years (OR = 0.03; 95% CI; 0.01, 0.28) were less likely to use

BIXI© bicycles. BIXI© users were more likely to be university educated (OR = 4.17; 95% CI: 2.08, 8.35) compared to participants with a high school diploma or less. Males and females did not differ in their likelihood of BIXI© bicycle use and those using a car, public transit, and walking to get to work were all less likely to have used BIXI© in comparison to those already cycling to get to work.

Table 3 shows results from logistic regression comparing regular and non-regular BIXI© users. Results indicate that compared to participants aged 18-24 years those older than 24 years were statistically as likely to be regular BIXI© users. Regular BIXI© users were not more likely to be have a high school diploma or less compared to more educated participants. Students and males were as likely to be regular BIXI© users compared to non students and females, respectively.

Among the subset of respondents working outside the home, logistic regression examining only the home and work exposure variables showed that exposure to one BIXI© station (OR = 3.27; 95% CI: 1.97, 5.41) or more than one station (OR = 3.18; 95% CI: 1.74, 5.79) were significantly associated with greater likelihood of BIXI© use, whereas once exposure at home was controlled, exposure at work (OR = 1.49; 95% CI: 0.97, 2.31) was not related to BIXI© use. The Spearman correlation coefficient between having one or more BIXI© stations at home and working were BIXI© stations were implemented was .27 ($p<0.01$) indicating limited collinearity.

DISCUSSION

The present study examined the prevalence and correlates of use of a newly implemented PBSP called BIXI© in Montreal, Canada. Results show that BIXI bicycles were used by 8.2% (151 946 inhabitants) of the population living on the Island of Montreal. Estimates of the prevalence of cycling for transportation prior to the implementation of BIXI© in Montreal range from 1.6% to 8%,[8, 27] suggesting that, although only its first year of implementation, BIXI© has been adopted at a level which is comparable to that of cycling for transportation in Montreal. Weighted prevalence estimates stratified by where BIXI© docking stations were and were not available showed that 14% (n=47 033) of the population where BIXI© bicycles were implemented had used them at least once compared to 6% (n=98 658) of residents where BIXI© bicycles were not available. Interestingly, although the prevalence of BIXI© use was higher where BIXI© docking stations were available, the absolute number of people residing where BIXI© bicycles were not available and who reported using BIXI© at least once was nearly double that of people residing where bicycles were available. This suggests an important contribution to total BIXI© use from individuals for whom the BIXI© public bicycle share program was not readily available and supports the potential of a population based approach to promote cycling through the availability of a PBSP.[28]

Examining correlates of BIXI© use suggests that having at least one docking station within a 250m road network buffer of an individual's home was related to greater likelihood of BIXI© bicycle use even when socio-demographic characteristics and usual mode of transportation to work were accounted for. There did not appear to be a dose response relationship between having one or more than one station within 250m of home. This suggests that availability, rather than extensive availability, may be sufficient to promote use of the bicycle service.

Limited research has examined correlates of PBSP use. However, the cycling literature from North America consistently shows that males, students, and younger individuals are more likely to cycle for transportation with their own bicycle.[29-33] The results of the present study were only somewhat consistent with this literature as being male and a student were not statistically significant predictors of using BIXI© bicycles. This suggests that taking other factors into account, a PBSP may be used equally by males and females and students and non-students. This is important because PBSP may, over time, increase the proportion of the female, non-student population who engage in utilitarian cycling. Conversely, in line with the North American cycling literature, results showed that older individuals, particularly those older than 35 years were less likely to have used BIXI© bicycles.[29]

Examining behavioral correlates of BIXI© bicycle use showed that those who use cycling as their primary mode of transportation to work are more likely to have tried BIXI© at least once. This suggests that the potential for PBSP to support changes in transportation mode away from motor vehicles may be limited, at least in the first year of implementation.

The secondary analysis comparing regular and non-regular BIXI© users suggests that there are no differences as a function of age, sex, education, and employment status. Again, the results are not consistent with cycling literature which suggest more cycling among younger people and males.[29]

Secondary analysis of exposure to BIXI© docking stations at home and at work showed that when controlling for exposure at home, exposure at work had a non significant association with BIXI© use. Hence, although availability of bicycles close to work has been thought to have an impact on active transportation[20-22], the current data do not support this assertion.

Limitations

Limitations include a low power to examine differences between regular BIXI© bicycle users from occasional or one time users. Results should be interpreted with caution. A second limitation is incomplete data on work location and thus a potential selection bias in analyses related to workplace exposure to BIXI©. In addition, the dichotomous indicator of working or not where BIXI© bicycles were implemented may not be sufficiently nuanced to capture how people use different modes of transportation to get about during a workday. A third limitation is the use of the 250m buffer. This buffer size is somewhat arbitrary and other distance thresholds could be tested.

Conclusion

The study suggests that a proportion of the population similar to that already cycling for transportation has tried a newly implemented PBSP called BIXI© in Montreal, Canada. Individuals residing where BIXI© docking stations were implemented were more likely to have used bicycles, however, individuals residing outside of where BIXI© bicycles were available contributed largely to total usage. Younger and university educated persons were more likely to have tried the PBSP. The use of the PBSP by the public supports the potential of implementing PBSP in other North America cities as the current research suggests PBSP can reach substantial numbers of people living in large urban centers. Additional research on the evolution of the prevalence and correlates of use of PBSP and on the likelihood of PBSP on modal shift from motorized transportation to cycling for transportation as well as additional research on health benefits (e.g., energy expenditure, body weight) and risks (e.g., collisions with motor vehicles) of PBSP use are warranted to fully grasp the potential of these interventions for improving population health.

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Table 1. Weighted and unweighted sociodemographic charateristics of 2133 residents of the Island of Montreal, Canada surveyed in the fall of 2009.

	Unweighted percentage (n)	Weighted percentage
Age (N=2133)		
18-24 years	7.4 (n=158)	18.6
25-34 years	19.1 (n=407)	22.0
35-44 years	18.7 (n=399)	16.3
45-54 years	20.4 (n=436)	16.6
55-64 years	17.2 (n=367)	12.2
65+ years	17.2 (n=366)	14.3
Transportation to work (N=2133)		
Cycle	5.2 (n=110)	4.8
Walk	13.5 (n=287)	13.0
Car	38.5 (n=821)	34.9
Public Transportation	39.2 (n=837)	44.1
Other	3.7 (n=78)	3.2
Education (N=2133)		
High School or less	27.2 (n=581)	30.2
Trade School	6.4 (n=136)	7.1
College Degree	14.4 (n=308)	15.4
University Degree	51.9 (n=1108)	47.3
Employment (N=2133)		
Full time	52.9 (n=1129)	48.4
Part time	6.9 (n=148)	7.3
Student	9.8 (n=210)	18.8
Retired	19.4 (n=413)	15.6
Other	10.9 (n=233)	9.9
Sex (N=2133)		
Male	38.6 (n=824)	44.8
Female	61.4 (n=1309)	55.2
BIXI stations with 250m (N=2133)		
None	79.3 (n=1691)	84.5
One station	12.8 (n=273)	9.2
More than one station	7.9 (n=168)	6.3

Table 2. Associations between BIXI© bicycle use, and the presence of BIXI© bicycle docking stations close to home, and socio-demographic characteristics among 2133 residents of the Island of Montreal, Canada surveyed in the fall of 2009

	Crude OR (95% CI)	Adjusted OR (95% CI)
Stations within 250m		
No stations (Ref)	1.00	1.00
1 station	3.68 (2.49, 5.43)	2.53 (1.61, 3.97)
More than 1 station	2.19 (1.96, 5.18)	2.40 (1.40, 4.10)
Age		
18-24 years (Ref)	1.00	1.00
25-34 years	1.11 (0.66, 1.88)	.57 (0.30, 1.07)
35-44 years	.73 (0.42, 1.26)	.35 (0.17, 0.70)
45-54 years	.25 (0.13, 0.49)	.12 (0.05, 0.27)
55-64 years	.14 (0.06, 0.32)	.10 (0.04, 0.26)
65+ years	.02 (0.02, 0.13)	.03 (0.01, 0.28)
Sex		
Female (Ref)	1.00	1.00
Male	1.17 (0.84, 1.63)	1.12 (0.77, 1.63)
Education		
High school or less (Ref)	1.00	1.00
Trade school	1.29 (0.35, 4.74)	1.19 (0.30, 4.64)
College degree	2.52 (1.09, 5.81)	1.14 (0.47, 2.72)
University degree	7.33 (3.82, 14.06)	4.17 (2.08, 8.35)
Employment		
Full time (Ref)	1.00	1.00
Part time	.69 (0.36, 1.37)	.84 (0.39, 1.79)
Student	1.67 (1.09, 2.57)	.78 (0.45, 1.35)
Retired	.05 (0.01, 0.19)	.33 (0.06, 1.69)
Other	.13 (0.04, 0.40)	.12 (0.04, 0.39)
Transportation to work		
Cycle (Ref)	1.00	1.00
Walk	.22 (0.12, 0.40)	.27 (0.14, 0.53)
Car	.10 (0.06, 0.17)	.15 (0.08, 0.29)
Public transportation	.19 (0.12, 0.31)	.21 (0.12, 0.38)
Other	.29 (0.13, 0.67)	.44 (0.17, 1.52)

Table 3. Socio-demographic characteristics associated with regular BIXI© bicycle use among 152 BIXI© users of the Island of Montreal, Canada surveyed in the fall of 2009

	Crude OR (95% CI)	Adjusted OR (95% CI)
Age		
18-24 years (Ref)	1.00	1.00
25-95 years	.60 (0.19, 1.91)	.69 (0.19, 2.47)
Sex		
Female (Ref)	1.00	1.00
Male	1.89 (0.91, 3.96)	1.91 (0.91, 4.01)
Education		
High school or less (Ref)	1.00	1.00
Other education	.67 (0.14, 3.49)	.77 (0.15, 4.08)
Employment		
Student (Ref)	1.00	1.00
Other	.81 (0.32, 2.06)	.87 (0.32, 2.41)

Appendix X: Curriculum Vitae

Curriculum Vitae

Daniel Fuller 406 Avenue E South Saskatoon, SK SJM 1S3	PhD Candidate College of Medicine Department of social and preventive medicine Université de Montréal

Education

Institution	Degree	Year	Field of Study	Supervisor
University of Saskatchewan	Bachelor of Science (Great Distinction, Honours)	2006	Exercise and Sport Studies	Dr. Kent Kowalski
University of Saskatchewan	Master of Science	2008	Exercise Psychology	Dr. Nancy Gyurcsik
Université de Montréal	Doctor of Philosophy	Current	Public Health & Health promotion	Dr. Lise Gauvin Dr. Yan Kestens

Languages

English and French (written and spoken)

A. Positions

- Teaching Assistant (2010-2011)
  - Biostatistics: Multilevel modeling (MSO 6068c)
    - June 2011
    - Faculty of Medicine, Université de Montréal
  - Thesis seminar in public health (MSO 6048)
    - November 2010 – February 2010
    - Faculty of Medicine, Université de Montréal
  - Individual behaviour and public health (MSO 6134)
    - January 2009 – April 2010
    - Faculty of Medicine, Université de Montréal
- Teaching Assistant (2006-2008)
  - Socio-behavioral Foundations of Physical Activity (Kin 122)
    - September 2007 – April 2008
    - College of Kinesiology, University of Saskatchewan
  - Sport in Society (Kin 232)
    - September 2007 – April 2008
    - College of Kinesiology, University of Saskatchewan
  - Theory of Coaching (Kin 334)
    - January 2006 – April 2006
    - College of Kinesiology, University of Saskatchewan
- Research Assistant (2005-2008)
  - TAME – Tempering Arthritis by Managing Exercise
    - September 2005 – June 2008
    - College of Kinesiology, University of Saskatchewan
  - Saskatchewan Access to the Cochrane Library
    - September 2005 – December 2006
    - College of Kinesiology, University of Saskatchewan

B. Honors and Awards

- 2012
  - Active Living Research Conference Publication Supplement in Annals of Behavioral Medicine
  - Student Travel Award – United Kingdom Medical Research Council for the 2012 Population Health Methods and Challenges Conference
- 2011
  - Dr. John Hastings Award - Canadian Public Health Association
  - Travel Award - Institute of Population and Public Health
- 2010
  - **Michael Smith Foreign Study Supplement** - **Social Science and Humanities Research Council of Canada**
  - Student Presentation Award **-** International Conference on Urban Health
  - International Conference Scholarship - Department of social and preventive medicine, Université de Montréal
- 2008
  - **Canadian Graduate Scholarship (Doctoral) ($35,000/year for 3 years) - Social Science and Humanities Research Council or Canada**
- 2007
  - First Place Poster – Life & Health Science Research Conference, University of Saskatchewan
  - **College of Kinesiology Graduate Scholarship ($15,000/year for 2 years)**, University of Saskatchewan
- 2005
  - Centennial Leadership Award - Government of Saskatchewan
  - Book Award - College of Kinesiology, University of Saskatchewan

C. International Internship

February 2011-April 2011

1) Queen Mary University of London: Dr. Steven Cummins
2) Medical Research Council – Epidemiology, Cambridge: Dr. David Ogilvie

D. Grants Received

Gauvin, L., **Fuller, D**., Drouin, L., Winters, M., Edwards, S., Teschke, K. (2009). A Multi-City Study of the Impact of Public Bicycle Share Programs on Active Transportation and Risk of Injury. Funded: CIHR Operating Grant- Population Health Intervention Research, December 2011 - ($200,000).

Winters, M., Edwards, S., Teschke, K., Brauer, M., Gauvin, L., **Fuller D.**, Frank, LDF., Kestens. Y. Health Promotion through Active Transportation – A Pre-Post Evaluation of a Vancouver-Based Public Bikeshare Program. Funded: CIHR Operating Grant- Population Health Intervention Research, December 2011 - ($200,000).

Gauvin, L., **Fuller, D**., Drouin, L., Morency, P., Kestens, Y. Impact of an Intervention Designed to Increase the Accessibility and User-Friendliness of an Active Mode of Transportation on Population Health: The Case of BIXI Montreal. CIHR Operating Grant- Population Health Intervention Research, April 2009 - ($240,000)

E. Publications

Fuller, D., Gauvin, L., Kestens, Y., Morency, P., Daniel, M., & Drouin, L. (In Press). Impact evaluation of a public bicycle share program on cycling: A case example of BIXI in Montreal, Canada. American Journal of Public Health.

Fuller, D., Gyurcsik, N.C., Spink, K.S., Brawley, L.R., (In Press). Prospective examination of self-regulatory efficacy in predicting walking for active transportation: A social cognitive theory approach. Journal of Applied Social Psychology.

Fuller, D., Potvin, L. (2012). Context by treatment interactions as the primary object of study in cluster randomized controlled trials of population health intervention. International Journal of Public Health, DOI: 10.1007/s00038-012-0357-x.

Fuller, D., Gauvin, L., Fournier, M., Kestens, Y., Daniel, M., Morency, P., & Drouin, L. (2012). Reliability and Validity of a Self-Report Measure of Favorability towards Active Living-Friendly Policies (ALF-P) in a Population-based, Cross-sectional Sample of Adults. Journal of Urban Health, 89(2), 258-269.

Fuller, D., Hobin, E. P., Hystad, P. & Shareck, M. (Joint Authorship) (2012). Challenges to interdisciplinary training for junior space, place and health researchers, Critical Public Health, 22(1), 1-7.

Fuller, D., Sahlqvist, S., Cummins, S., Ogilvie, D. (2012). The impact of public transportation strikes on use of a bicycle share program in London: interrupted time series design. Preventive Medicine, 54, 74–76.

Fuller, D., Gauvin, L., Kestens, Y., Daniel, M., Fournier, M., Morency, P., & Drouin, L. (2011). Use of a New Public Bicycle Share Program in Montreal, Canada. American Journal of Preventive Medicine, 41(1), 80–83.

Fuller, D., Sabiston, C., Karp, I., Barnett, T., O'Loughlin, J. (2011). School sport opportunities influence physical activity in secondary school and beyond. Journal of School Health, 81 (8), 449-454.

Meili, R., **Fuller, D.,** & Lydiate, J. (2011). Teaching Social Accountability by Making the Links: Qualitative evaluation of student experiences in a service-learning project. Medical Teacher, 33 (8), 659-666.

Fuller, D., Muhajarine, N., and Smart Cities, Healthy Kids Research Team (2010). Replication of the Neighborhood Active Living Potential Measure in Saskatoon, Canada. American Journal of Preventive Medicine, 39(4), 364-367.

Gyurcsik, N.C., Brawley, L.R., Spink, K.S., Brittain, D.R., **Fuller, D.L.,** & Chad, K. (2009). Physical activity in women with arthritis: Examining perceived barriers and self-regulatory efficacy to cope. Arthritis Care and Research, 61(8), 1087-1094.

Forbes, S., **Fuller, D.L.,** Little, J.P., Krentz, J. (2008). Anthropometric and physiological predictors of flat-water 1000 m kayak performance in young adolescents and the effectiveness of a high volume training camp. *International Journal of Exercise Science*, 2, 106-114.

Forbes, D. A., Bangma, J., Neilson, C., Forbes, J., **Fuller, D.,** & Furniss, S. (2007). Saskatchewan residents' access to the Cochrane Library. *Canadian Journal of Library and Information Practice and Research*, 2(2).

F. Published Abstracts

Fuller, D., Gauvin, L., Kestens, Y. (2012). Examining the spatial distribution and relationship between support for policies aimed at active living in transportation and transportation behavior. *Annals of Behavioral Medicine,* 43(S1), S153.

Fuller, D., Gauvin, L., Kestens, Y., Morency, P., Daniel, M., & Drouin, L. (2010). Validity

and Reliability of a Measure of Favorability to Active Living Friendly Policies. *Annals of Behavioral Medicine,* 39(S1), S62.

Fuller, D.L., Gyurcsik, N.C., Brawley, L.R., Spink, K.S. (2009). Walking for active transportation: Using social cognitive theory to examine differences between successful and less successful users. *Annals of Behavioral Medicine,* 37(S1), S85.

Fuller, D.L., Gyurcsik, N.C., Brawley, L.R., Spink, K.S. (2008). A prospective examination of social cognitive predictors of walking for active transportation. *Journal of Sport and Exercise Psychology*, 30, S146.

Bloomquist, C.D., **Fuller, D.L**., Gyurcsik, N.C., Brawley, L.R., Spink, K.S., & Bray, S.R. (2008). Active Transportation Use By Sufficiently and Insufficiently Active First-Year University Students. *Annals of Behavioral Medicine*, 35(S1), S218.

Gyurcsik, N.C., Brawley, L.R., Spink, K.S., Brittain, D.R., Chad, K., & **Fuller, D**. (2008). Managing arthritis using physical activity: Perceived barriers and self-regulatory efficacy predict activity in arthritic women. *Annals of Behavioral Medicine*, 35(S1), S28.

G. Presentations at Scholarly Conferences

Fuller, D., Gauvin, L., Kestens, Y., Morency, P., Daniel, M., & Drouin, L. (Accepted). Examining the impact of the BIXI public bicycle share program on the likelihood collisions and quasi-collisions. For presentation at the 2012 Velo City International Conference, Vancouver, June 26-29, 2012.

Fuller, D., Gauvin, L., Datta, T. Kestens, Y., Lacroix, G., Strumpf, E., Kestens, Y., Haddad, S. Studying the impact of natural built environment interventions: Approximating a randomised controlled trial using the regression discontinuity design. For presentation at the 2012 Population Health Methods and Challenges conference, Birmingham, England, April 24-26, 2012.

Fuller, D., Gauvin, L., Kestens, Y., Morency, P., Daniel, M., & Drouin, L. (Accepted). Examining the spatial distribution and relationship between support for policies aimed at active living in transportation and transportation behavior. For presentation at the 2012 Society of Behavioral Medicine Conference, New Orleans, April 11-14, 2012.

Fuller, D., Gauvin, L., Kestens, Y., Morency, P., Daniel, M., & Drouin, L. (Accepted, April 2012). Examining Individual and Neighborhood Level Disparities in Access to the Road Network, Public Transit, and a Public Bicycle Share Program in Montreal, Canada. For presentation at the 2012 Active Living Research Conference, San Diego, March 12-14.

Fuller, D., Gauvin, L., Kestens, Y., Fournier, M., Morency, P., Daniel, M., & Drouin, L. (2011, June).
From modal shift to multi-modal transportation – Complexity of transportation behaviours associated with implementation of the BIXI public bicycle share program in Montreal. Canadian Public Health Association, Montreal, Canada.

Fuller, D., Gauvin, L., Kestens, Y., Fournier, M., Morency, P., Daniel, M., & Drouin, L. (2011, February). Evaluating the impact of implementing a public bicycle share program on utilitarian cycling: The case of BIXI in Montreal, Canada. Active Living Research, San Diego, California.

Gauvin, L., **Fuller, D**., Kestens, Y., Fournier, M., Morency, P., Daniel, M., & Drouin, L. (2010, October). Association between use a city-sponsored public bicycle share program and risk of reporting a collision or quasi-collision with a motor vehicle in

Montreal, Canada: The case of BIXI. 9th International Conference on Urban Health, New York, New York.

Fuller, D., Gauvin, L., Kestens, Y., Fournier, M., Morency, P., Daniel, M., & Drouin, L. (2010, October). Prevalence and predictors of use a city-sponsored public bicycle share program in Montreal, Canada: The case of BIXI. 9th International Conference on Urban Health, New York, New York.

Fuller, D., Gauvin, L., Kestens, Y., Morency, P., Daniel, M., & Drouin, L. (2010, July). Tracking the reach of a cycling intervention : The case of a large-scale public bicycle share program. 20th World Conference of the International Union for Health Promotion and Education, Geneva, Switzerland.

Corbin, H., Bull, T., Huntington, J., Keshavarz Mohammadi, N., **Fuller, D**., Smith, J. (2010, July). What can health promotion learn from other social movements? 20th World Conference of the International Union for Health Promotion and Education, Geneva, Switzerland.

Fuller, D., Gauvin, L., Kestens, Y., Morency, P., Daniel, M., & Drouin, L. (2010, April). Validity and Reliability of a Measure of Favorability to Active Living Friendly Policies. Society of Behavioral Medicine, Seattle, Washington, 2010.

Fuller, D., Sabiston, C., Karp, I., Barnett, T., O'Loughlin, J. (2010, May). School sport opportunities influence physical activity in secondary school and beyond. 3rd International Congress on Physical Activity and Public Health, Toronto, Ontario, 2010.

Fuller, D., Gauvin, L., Kestens, Y., Morency, P., Daniel, M., & Drouin, L. (2010, February) Behavioral Correlates of Awareness of a Large-scale, Self-service Bicycle Program: Potential for a Modal Shift Toward Active Transportation. Active Living Research, San Diego, California.

Fuller, D., Gough, R., Meili, R. (2009, March). Evaluation of student experiences in the Making the Links project. Ninth International Research conference on Service-Learning and Community Engagement, Ottawa, Ontario. October, 2009.

Fuller, D.L., Gyurcsik, N.C., Brawley, L.R., Spink, K.S. (2009, April). Walking for active transportation: Using social cognitive theory to examine differences between successful and less successful users. 30th annual Society for Behavioral Medicine Conference, Montreal, QC.

Forbes, D. A., Bangma, J. Bingham, M., Forbes, J., **Fuller, D. L.,** Marshall, C., Furniss, S., & Clark, K. (2008, October). First Province in Canada to Provide Access to The Cochrane Library: Lessons Learned. XVI Cochrane Colloquium, Freiburg, Germany.

Fuller, D.L., Gyurcsik, N.C., Brawley, L.R., Spink, K.S. (2008, June). A prospective examination of social cognitive predictors of walking for active transportation. Abstract accepted for presentation at the annual conference of the North American Society for the Psychology of Sport and Physical Activity (NSPASPA), Niagra Falls, ON.

Bloomquist, C.D., **Fuller, D.L**., Gyurcsik, N.C., Brawley, L.R., Spink, K.S., & Bray, S.R. (2008, March). Active Transportation Use By Sufficiently and Insufficiently Active First-Year University Students. Annual conference of the Society of Behavioral Medicine (SBM), San Diego, CA.

Gyurcsik, N.C., Brawley, L.R., Spink, K.S., Brittain, D.R., Chad, K., & **Fuller, D.** (2008, March). Managing arthritis using physical activity: Perceived barriers and self-regulatory efficacy predict activity in arthritic women. Presented at the annual

conference of the Society of Behavioral Medicine (SBM), San Diego, CA.

Forbes, D. A., Bangma, J. Bingham, M., Forbes, J., **Fuller, D. L.,** Marshall, C., Furniss, S., & Clark, K.
(2007, October). Promoting and evaluating access to the Cochrane Library. XV Cochrane Colloquium, Sao Paulo, Brazil.

Bloomquist, C. D. & **Fuller, D.** (2007, March). Active Transportation: Sustainable physical activity options for university students. Fourteenth Annual Health & Life Sciences Research Conference, Saskatoon, Saskatchewan.

Forbes, D. A., Bangma, Neilson, C., **Fuller, D.,** Adamson, J.,Bingham, M. (2006, October). Strategies that promote the use of the Cochrane Library. XIV Cochrane Colloquium, Dublin, Ireland.

Fuller, D., & Gyurcsik, N. C. (2005, November). The coach-athlete relationship: Perceptions of coaching behaviour in individual sports. Abstract accepted for presentation at the Sport Leadership Conference, Quebec, Quebec.

Forbes, D. A., Bangma, J. Bingham, M., Adamson, J., **Fuller, D. L.,** Marshall, C., Furniss, S., & Clark, K. (2005, December). Do province-wide access to the Cochrane Library and training sessions make a difference? 4th Canadian Cochrane Symposium, Montreal, Quebec.

H. Articles submitted or under review

Fuller, D., Gauvin, L., Kestens, Y., Drouin, L. (Under Review). Individual- and Area-Level Disparities in Access to the Road Network, Subway System, and a Public Bicycle Share Program on the Island of Montreal, Canada. Annals of Behavioral Medicine.

Fuller, D., Cummins, S., Matthews, S. (Under Review). Does transportation mode moderate associations between distance to food store, fruit and vegetable consumption and BMI in low income neighborhoods? American Journal of Clinical Nutrition.

I. Invited Presentations

- Research Seminar - Medical Research Council Epidemiology, Cambridge, England. April 9th, 2011.
- Complex Interventions Seminar - London School of Hygiene and Tropical Medicine**,** March 30th, 2011.
- KIN 6848: Promotion de l'activité physique et de la santé. Modèle logique d'évaluation et l'évaluation axée sur l'utilistation. November 18th, 2010.
- TEDxMontrealQuartierLatin - BIXI is the new fixie: The public bike share explosion in North American. October 1st, 2010
- Neighbourhood Active Living Potential (NALP). Training session for the use of the NALP for Dr. Nazeem Muhajarine and the Smart Cities, Healthy Kids Project (CIHR, Heart and Stroke Foundation of Canada)
- The positive effect of active transportation on sustainability - University of Saskatchewan, Sustainability Department. June 11th, 2008.

J. Training Sessions Attended

- Journal Club – Université de Montréal, Public Health – Classic texts in Public Health.
- "Space, place and health." - Canadian Institute of Health Research Summer Institute. McMaster University, Hamilton, Ontario, July 9-12, 2009

- Graduate Studies and Research 987: Science, Scientists, and Science-Societal Interactions: An introduction to the dynamics of science - Gwena Moss Center for Teaching Effectiveness, University of Saskatchewan.
- Advanced ArcGIS – Geo-processing, Geostatistical Analysis, Spatial Analyst & 3D Analyst –Information Technology Services Training Group, University of Saskatchewan.
- Introduction to ArcGIS – Information Technology Services Training Group, University of Saskatchewan.
- Teaching Seminar: "What the best college teachers do" by Ken Bain - Gwena Moss Center for Teaching Effectiveness, University of Saskatchewan.
- Teaching Seminar: "Making Teaching Visible: Practical principles for peer review of teaching" - Gwena Moss Center for Teaching Effectiveness, University of Saskatchewan.
- Teaching Seminar: "Teaching… if only we knew the questions?" - Gwena Moss Center for Teaching Effectiveness, University of Saskatchewan.

K. Service

- Reviewer:
  - Journal of Epidemiology and Community Health
  - Transportation Research Board
  - Preventive Medicine
  - Annals of Behavioral Medicine
  - Social Science and Medicine
  - Chronic Disease in Canada
- Session Chair - 20th World Conference of the International Union for Health Promotion and Education, Geneva, Switzerland.
- Board Member - International Union of Health Promotion Student and Early Career Network (ISECN), September 2009-Current
- Scholarship Writing Mentorship Program – Université de Montréal, Department of Social and Preventive Medicine, September 2009 – Current
- Program Committee, Student Board Member– Université de Montréal, Department of Social and Preventive Medicine. September 2008 – September 2010
- Admissions Committee, Student Member – Université de Montréal, Department of Social and Preventive Medicine. September 2008 – September 2010
- Vice President - Université de Montréal Public Health Graduate Student Society (AEESPUM) September 2008 – September 2010
- Reviewer - Canadian Millennium Scholarship Foundation, November 2007 – March 2008

Board Member - College of Kinesiology