Mode Substitution Effect of Urban Cycle Tracks: Case Study of a Downtown Street in Toronto, Canada

by

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ABSTRACT

With the growing environmental and health concerns associated with automobiles, municipalities across North America are investing in cycling infrastructure. These new infrastructures are often assumed to facilitate a mode substitution effect, i.e., encourage drivers to take up cycling as a mode of transportation. This study explored the potential impact of cycle tracks (i.e., physically separated bicycle lane within a street right-of-way) on short-term travel mode substitution behaviour. We present a quasi-experimental case study of Sherbourne Street, located in downtown Toronto, Canada, that was redeveloped in 2012 to include cycle tracks. The study used a street intercept survey method to record quantitative data on current and retrospective travel behavior. A short-term mode substitution effect was observed, with 38% of the sample reporting that they would use other travel modes than cycling before the Sherbourne Street redevelopment for making a trip to their current destination; the majority of them were previously transit users. Binomial logistic regressions indicated that younger cyclists were less likely to substitute a car trip for a cycling trip. Those who did not use Sherbourne Street previously to reach their current destination were more likely to substitute their travel mode. Improved safety was the most commonly reported reason for mode substitution. This study contributes to a very limited literature by providing much needed insights into impacts of cycle tracks on travel behaviour. Methodologically, this paper can inform the development of easy to implement survey/audit tools to be used by professionals at the community level.

INTRODUCTION

In recent decades, researchers, practitioners and advocacy groups across North America have taken notice of cycling as a more sustainable and healthier alternative to the private automobile (*1, 2*). As the popularity of cycling continues to grow, more research has focused on the benefits of cycling. Numerous cross sectional studies have reported an association between cycling and improved health outcomes, and that those cycling regularly meet the recommended fitness levels (*1, 3, 4*). Moreover, individuals choosing to travel by bicycle instead of driving assist in decreasing the number of automobiles in use, which may lead to a reduction in the harmful emissions (*3, 5, 6*).

Cycling facilities including bicycle lanes and bicycle tracks (i.e., physically separated bicycle lanes within the street right of way) remain the most common approaches to promote cycling in urban settings (*7*). The research literature has demonstrated an association between an increased supply of bicycle lanes and/or cycle tracks and higher cycling rates/ cycling mode share (*8-10*). For example, a cross sectional study, using data from 42 major US cities, found that the addition of one linear mile (1.6 km) of bicycle lane per square mile within cities was associated with a rise of approximately one percent in city-wide cycling ridership (*8*). However, the direct effects of these cycling infrastructure on travel mode switch (i.e., from other alternative modes to cycling) remains an understudied topic in current literature (*11, 12*). In the absence sufficient evidence of the role of cycling infrastructure in generating “new” cycling trips, the true impact of cycling lanes/tracks on healthy and sustainable travel behavior remains unclear.

This paper builds on this limited literature, and presents results from a case study of one street located in downtown Toronto, Canada, that was redeveloped in 2012 to include a bicycle track. The goal of the research is to explore the short term mode substitution effects. It was hypothesized that the cycle tracks would enable some road users (who were driving, using transit, walking or were using other travel modes than cycling) to switch their travel modes to cycling during the first few years of implementation. This short term substitution of travel mode for one specific trip may indicate a process of behavioural change that may lead to longer term substitution behaviour, and a change in overall travel mode choice patterns (*11*).

To our knowledge, the study is first of its kind in that it specifically focuses on the short term mode substitution effect of cycle tracks. It presents a quasi-experimental research on the nature and extent of travel substitution from other modes to cycling a few years after the implementation of a transportation project. Results from this study begin to provide in-depth understanding of the impacts of cycle tracks, which are becoming more common feature of downtown streets in many North American cities including the City of Toronto. Methodologically, this paper advances a very limited literature that has attempted to examine travel mode substitution behaviour (i.e., *11, 12*). More broadly then, pilot studies such as the one presented here may provide a framework for conducting future research on this topic, as well as contribute to the development of survey/audit instruments that can be used by professionals to measure the impact of cycling infrastructure and related investments (*11, 13, 14*).

CYCLING INFRASTRUCTURE AND TRAVEL BEHAVIOUR: A BRIEF LITERATURE REVIEW

An emerging literature has explored the relationship between cycling infrastructure and travel behaviour. A recent study conducted in Portland, Oregon, U.S., indicated that the majority (56%) of the people surveyed were “interested but concerned” cyclists (*15*). This group, curious and interested in cycling, are afraid to do so and as a result not regularly cycling, is likely to be a key target market for cycling-related capital investment (*15, 16*). Dill and McNeil (*15*) also reported that physically separated cycle tracks may increase the level of comfort and enable cycling uptake among this population group. Recent research supports this finding, and suggests that for cyclists sharing a road with automobiles there is a perceived risk attributed to the possibility of collision (*17*). Not surprisingly, researchers have repeatedly emphasized that bicycle lanes may overcome these perceived risks and attract new inexperienced riders, particularly female riders who report being more concerned for their safety when cycling (*1, 4, 9, 18, 19*).

The existing literature also suggests that cyclists may travel greater distances to use routes that offer infrastructure that improved the safety and efficiency for users (*4*, *20*). In particular, inexperienced cyclists are more likely to add to their trip length in order to use physically separated cycling infrastructure (e.g., cycle tracks) (*4*). Other recent research indicates that physically separated cycling infrastructure (e.g., off-street paths and “bicycle boulevards”) may have a stronger influence on route choice compared to bicycle lanes (*21*). Travel behaviour may also vary across trip purpose; Broach et al (*21*) reported that commuters were less sensitive of the characteristics of the bicycle infrastructure, compared to those cycling to non-work destinations.

A limited literature has explored the direct relationship between cycling infrastructure and a change in mode choice behaviour (i.e., travel mode substitution). For example, Piatkowski et al. (*11*) explored trip and mode-substituion behaviour at five locations in Denver, Colorado, and Sacramanto, California in the U. S.. The surveys were typically collected at dedicated active transportation facilities, but the study did not directly measure the impact of specific infrastructure. The study identified that between 23.7% and 72.4% of the current cyclists would drive if they had not cycled. Frequency of car trips per week was positively associated with the likelihood of a car-to-cycle mode substitution. In a more recent study focusing on the use of multi-use trails (i.e., an off-street pathway separated from motor vehicles typically for pedestrian and cyclists only) for commuting trips in Albuquerque, New Mexico, U. S. found that 25% of cyclists would have made their commute trips by car had the trail not been present (*12*). The research also found that a desire to exercise was a significant predicator for continuing to cycle without a multi-use trail, indicating that the opportunity to participate in a healthier lifestyle presented was a major motivation for a potential mode substitution (*12*).

CASE STUDY: SHERBOURNE STREET

Sherbourne Street in downtown Toronto, Canada, was examined as a case study for this research. The street was the first in the city of Toronto to include cycle tracks on both sides of its right-of-way. Sherbourne Street was selected for redevelopment in 2012 based on its strategic location in Toronto’s existing bicycle network (*22*). The street runs through four different neighborhoods: North St. James Town, Cabbage Town, South James Town and Moss Park. It has varying densities and uses ranging from high-rise apartments in the north end near Bloor Street East, which is often considered as the northern border of downtown Toronto with a major concentration of high rise residential, office and high-end retail uses, to low-rise commercial and retail. Both north and south-bound buses run along the street, connecting transit riders to the Sherbourne Subway Station and the waterfront. The redevelopment of the street included a total of 2.44 km of cycle tracks extending from Bloor Street East to King Street, connecting to existing bicycle lanes at Wellesley Street, Gerrard Street, Shuter Street and Bloor Street East (*22*).

Bicycle boxes, which are painted boxes at intersections that enable cyclist to advance first, were added to major intersections such as Wellesley Street and Sherbourne Street. All on-street parking was removed, with additional spots being added on neighboring streets (*22*). Following its completion in 2012, the average daily cycle count rose from 995 in 2011 to 2,827 by 2014 (*23*).

METHOD

Data

Street intercept surveys were conducted to collect data from current cyclists on Sherbourne Street. Two major intersections along the cycle track were chosen as data collection points. A student researcher stood near an intersection, and utilized the ‘fixed line approach’ for recruiting road users stopped at red lights (*24*). Cyclists travelling on both directions, who were eighteen years of age and above, were recruited. Surveys were conducted during October and November 2014; one student researcher collected data on seven weekdays from 7:30am to 9:00am during the morning commute, and from 5:00pm to 6:30pm during the evening commute. Surveys were also conducted on three weekend afternoons from 4:30pm to 6:00pm.

A total of nine short questions were asked to cyclists, which typically took approximately one minute (Table 1). The survey questions focused on cyclists’ current (i.e., on the day of the survey) and retrospective (i.e., before the redevelopment in 2012) travel behaviour, socio-demographic characteristics, as well as on the characteristics of the trips. A total of 219 cyclists participated in the survey.

Conceivably, several types of “new cyclists” may contribute to an increase in the cyclist volume on a street. The first group consists of individuals who previously were cyclists, but did not use the street in question (i.e., Sherbourne Street) for travelling. Some of them may switch their travel routes to use the newly constructed cycle tracks (*4*, *20, 21*). Some other cyclists may have changed their residential location and currently live near, and as a result use, the street with cycle tracks.

In this study, the focus was placed on the second group of “new cyclists”, who have recently substituted their previous travel modes for cycling. This short term mode-substitution can occur in three different ways. First, some individuals may switch their travel mode as well as the travel route to take advantage of the new cycle tracks (*15*). Second, individuals who are more favourable to cycling may move to a bikable neighbourhood (widely known as self-selection in urban planning literature), and some of them may take up cycling due to improved cycling infrastructure such as a cycle track (*7*). Lastly, individuals who previously used Sherbourne Street to reach the destination of their current trip may switch/ substitute their mode of transportation (from cars, transit or other alternatives to cycle) due to the presence of cycle tracks.

Potential travel behaviour change (i.e., short-term mode substitution) was captured in the survey by one key question: “Before the redevelopment of Sherbourne Street, what travel mode would you use to get to the destination of your current trip?” Those who did not (or rather, would not) cycle before the redevelopment and instead travelled by transit, car, walking or other modes were identified as individuals who substituted their previous trip with cycling. Those who potentially substituted their travel modes were investigated about the potential reasons for switching. Another question in the survey asked if participants previously used this street before the installation of the cycle tracks.

Adjusting for missing responses, the final dataset included trip records for n=214 individuals, including 183 weekday and 31 weekend trips.

Statistical Analysis

A logistic regression approach was adopted to explore mode substitution by a cyclist. Separate binomial logistic regression models were estimated to examine the factors associated with substitution (1) from all other modes to cycle, (2) from private automobile (i.e., car) to cycle and (3) from transit to cycle. Multinomial logistic regressions were initially considered, but were not used for multivariate analysis primarily because of a relatively small sample size.

TABLE 1 Summary of characteristics of cyclists and cycling trips (n = 214)

Variables	Percent
Demographics	
Gender	
Male	61.21
Female	38.79
Age	
<40 yrs	64.95
≥40 yrs	35.05
Previously used the road before the redevelopment	
Yes	37.85
No	62.15
Purpose and Travel Times	
Purpose of trip	
Commuting (work)	68.69
Commuting (school)	9.81
Social	15.89
Recreational	4.67
Other	0.93
Total time to complete trip	
<15 mins	14.49
15+	85.51
Time spent from trip origin to Sherbourne Street	
<15 mins	77.57
15+ mins	23.43
Time spent from Sherbourne Street to trip destination	
<15mins	86.92
15+ mins	13.08
Travel mode substitution	
Changed to cycling since 2012 (after redevelopment)	38.32
Cycling before redevelopment	61.68

RESULTS

Current cyclists on Sherbourne Street in downtown Toronto were surveyed to explore the impacts of a recently built cycle track on travel mode substitution. Table 1 summarizes the characteristics of cyclists who were surveyed, as well as the trips they took during the time of the survey. Of the cyclists who were surveyed, 61% were male, and 65% were between the ages of 18 and 40 years old. The majority surveyed are “new” users of Sherbourne Street; as only 38% of all current cyclists travelled along Sherbourne Street before the 2012 redevelopment that introduced a cycle track.

Between 2012 and 2015, 38% of all respondents potentially switched their travel mode to cycling (Table 1). The others (62%) cycled before, but did not use Sherbourne Street for travelling to the destination of their current trip. A closer examination of the previous mode of transportation for the same or similar trip (Table 2) revealed that the majority of those who substituted their travel modes to cycling would previously have used transit as their primary travel mode (55%), followed by driving (i.e., private automobiles, 24%) and walking (13%). While this transit-to-cycle mode substitution was more common for commuting trips (compared to social, recreational and other trips), the difference across trip purpose was not statistically significant (χ^2 =6.20 ; p = 0.1845).

TABLE 2 Reported mode of travel for same/ similar trip prior to the 2012 redevelopment

	All trips (n = 214)		Commute (work or school) (n = 168)		Other (Social, recreational, other) (n = 46)	
	Freq.	%	Freq.	%	Freq.	%
Private auto (i.e., car)	20	9.35	15	8.93	5	10.87
Transit	45	21.03	40	23.81	5	10.87
Cycle	132	61.68	100	59.52	32	69.57
Walk	11	5.14	8	4.76	3	6.52
Other	6	2.80	5	2.98	1	2.17

Note: $\chi^2$of the difference between commute and other trips is 6.20 (df = 4); p = 0.1845

Binomial logistic regressions were estimated for reported mode substitution (from all other modes to cycle, from car to cycle, and from transit to cycle); the findings are summarized in Table 3. Results from the regression analysis indicate that route substitution was probably the most important correlate of travel mode switch. The likelihood of a mode substitution to cycling (from any other mode) was 11 times (Odds Ratio, OR = $e^{2.40}$ = 11.02) higher among cyclists who had not travelled along Sherbourne Street for the same or similar trips before the 2012 redevelopment. In addition, a mode switch from driving to cycling was less likely to occur among individuals aged <40 years (α=0.10), and more likely to occur among those who had to travel > 15 minutes to get to Sherbourne Street (compared to those who travelled ≤15 minutes). In contrast, an individual was less likely to substitute a transit trip for cycling when the total trip length was < 15 minutes (compared to >30 minutes trip length; OR = 0.22).

TABLE 3 Binary logistic regression of mode substitution to cycling (n = 214)

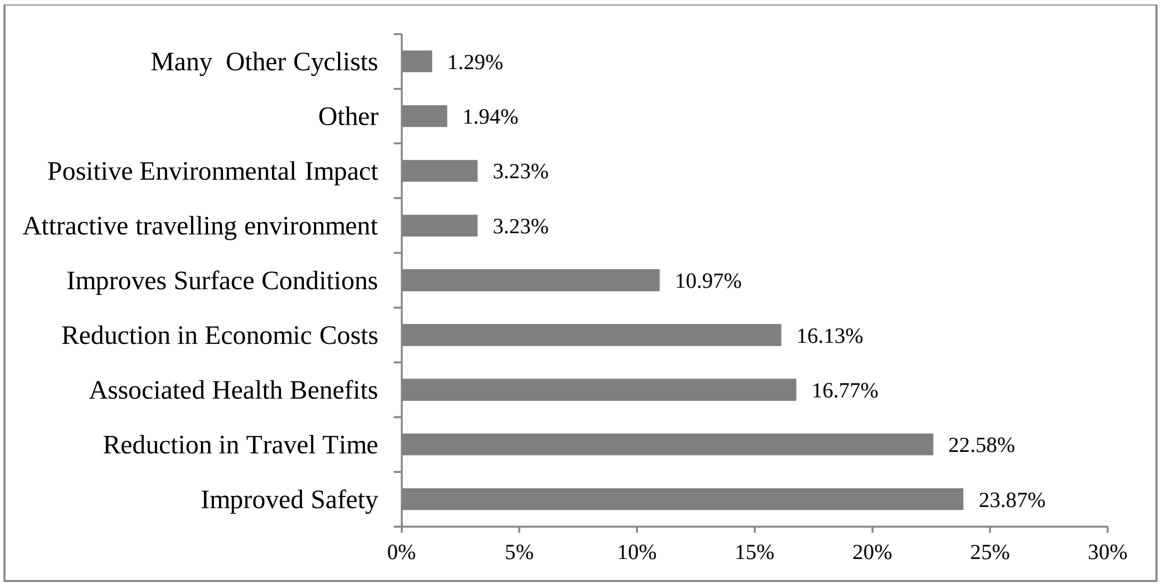
	From All Modes[1]		From Car[2]		From Transit[3]	
	Not adjusted for route substitution Coef (S. E.)	Adjusted for route substitution Coef (S. E.)	Not adjusted for route substitution Coef (S. E.)	Adjusted for route substitution Coef (S. E.)	Not adjusted for route substitution Coef (S. E.)	Adjusted for route substitution Coef (S. E.)
Gender (ref: Female)						
Male	-0.38 (0.30)	-0.19 (0.34)	-0.20 (0.50)	0.12 (0.54)	-0.54 (0.36)	-0.43 (0.38)
Age (ref : ≥40 yrs)						
< 40 yrs	0.36 (0.31)	0.22 (0.35)	-0.64 (0.49)	***-0.92 (0.52)***	0.20 (0.37)	0.10 (0.40)
Purpose (ref: Other)						
Commute	0.29 (0.42)	0.27 (0.47)	-0.48 (0.65)	-0.47(0.68)	0.81 (0.61)	0.78 (0.63)
Trip length (ref: >30 mins)						
< 15 mins	-0.40 (0.58)	0.07 (0.66)	0.41 (0.95)	0.86 (1.02)	**-1.74 (0.79)**	***-1.51 (0.82)***
15-30 mins	-0.55 (0.46)	-0.28 (0.51)	0.02 (0.71)	0.40 (1.23)	-0.84 (0.51)	-0.60 (0.55)
Dist from origin (ref: ≤15 mins)						
>15 mins	-0.61 (0.44)	-0.11 (0.50)	***1.14 (0.67)***	**0.85 (0.77)**	**-1.15 (0.54)**	-0.85 (0.57)
Dist from destination (ref: ≤15 mins)						
>15 mins	-0.72 (0.55)	-0.62 (0.62)	-1.40 (1.14)	-1.61 (1.23)	-0.14 (0.61)	0.19 (0.66)
Day of week (ref: weekday)						
Weekend	-0.13 (0.51)	-0.08 (0.58)	-0.60 (0.90)	-0.18 (0.94)	-0.05 (0.70)	-0.21 (0.74)
Route substitution (ref: no)						
Yes (i.e., did not use road before)		**2.40 (0.42)**		**2.36 (0.83)**		**2.04 (0.56)**
Constant	-0.11 (0.62)	**-2.17 (0.79)**	***-1.62 (0.93)***	**-4.00 (1.33)**	-0.89 (0.79)	**-2.67 (0.98)**
McFadden's ρ^2 (adj.)	0.03 (0.00)	0.19 (0.16)	0.07 (0.01)	0.16 (0.10)	0.07 (0.03)	0.16 (0.12)
AIC	294.79	251.45	141.78	131.2	222.6	205.23

NOTE: 1: Ref: previous travel mode was bicycle; 2: Ref: previous travel mode was transit, cycle, walk or other; 3: Ref: precious travel mode was car, cycle, walk or other.

Coefficients in **bold** are significant at α=0.05; coefficients in ***bold italics*** are significant at α=0.10.

Those who had recently (i.e., since 2012) substituted their travel mode from any other mode to cycling were also prompted to outline their reasons for switching modes. Respondents were able to choose multiple responses (i.e., “all that applies”). A total of 80 respondents picked n=155 responses, which are summarized in Figure 1. Improved safety (24%), reduction in travel time (23%), and associated health benefits at 17% were the most commonly mentioned reasons for switching travel modes (Figure 1). Among the other potential reason, the presence of other cyclists, positive environmental impact and attractive travelling environment were the least frequently mentioned ones.

FIG 1 Reasons for substituting modes of transportation to cycling



DISCUSSION AND CONCLUSIONS

This paper presents a novel quasi-experimental study of the short-term mode substitution behaviour. Using a case study of Sherbourne Street in downtown Toronto, and a methodical approach that is somewhat similar to Piatkowski et al. (*11*), we specifically explored mode shift to cycling after the implementation of a cycle track.

The results indicate that 38% of the current cyclists on Sherbourne Street would have used other modes of travel for the same/ similar trip (i.e., to reach the destination of their current trip) before the redevelopment in 2012. We also found that more than half (55%) of these new cycling trips were previously made using transit (Table 2). Car to cycle mode substitution, which is perhaps the most desired type of mode substitution outcome from a policy perspective (*11*), was relatively low at 22%. Other recent studies have reported higher car- to- cycle mode substitution rates in the U.S. (*11, 12*). However, within the context of downtown Toronto, an area that is served by subways, streetcars and buses, and where the mode share for transit and cycling is already high, our results are not surprising. Instead, they suggest that the addition of cycle tracks may result in a reduction in both public transit users and private automobiles, contributing to some relief from transit and automobile congestion, both of which remain important topics of discussion among transportation engineers/ planners, politicians, civic engagement groups and popular media in Toronto. With transit lines running above design capacity, reducing transit congestion may also have indirect positive impacts encouraging other mode substitutions to transit (e.g., from cars to transit) across the district.

Of all the current cyclists on Sherbourne Street, 62% would cycle for travelling to their current destination before 2012. However, 45% of those who previously cycled did not ride on Sherbourne Street before the redevelopment, indicating a substantial route substitution after the introduction of the cycle tracks. The result is not surprising in the context of current evidence that suggests that inexperienced cyclists may add to their trip length in order to use physically separated cycling infrastructure (*4, 21*).

This potential route substitution was also the most important predictor of mode substitution in our models (Table 3). A strong association between travel route change and mode substitution, as observed in this study, indirectly supports the existing literature that has hypothesized that physically separated cycling infrastructure, such as the cycle tracks, may improve perceived comfort and safety among inexperienced and concerned cyclists, and may enable cycling uptake among some (*15*). Moreover, improved safety was the most commonly reported reason behind travel mode substitution to cycling (Fig. 1), further emphasizing the importance of cycle tracks in enabling cycling in an urban setting. Part of the observed association between travel route change and cycling uptake (i.e., short term mode substitution) may also relate to residential self-selection, as outlined in previous research (*7*) and was discussed in the Methods section of this paper. The cause-effect relationship between travel route change and mode substitution, however, could not be directly explored within the scope of this study, and a more in-depth examination of this topic remain subject to our future research.

With regard to the socio-demographic characteristics, only 39% of all cyclists that were surveyed were women, which is consistent with current literature that has consistently reported lower cycling rates among women (*25, 26*). Moreover, previous studies reported an association between younger age and cycling (*27, 28*), which is consistent with what was found in Toronto; 65% of the cyclists that were surveyed were <40 years old. However, our model results indicated that younger individuals (< 40 years old) were less likely to substitute a car trip for a cycling trip (Table 3; $\alpha = 0.10$). The result is not surprising particularly in the context of downtown Toronto, where many young adults do not own cars and/or drive less frequently, and perhaps as a result, not many of the new cyclists were drivers before the Sherbourne Street redevelopment. Current research has also reported a statistical association between higher female ridership and cycling infrastructure (*9*). No such association was found in our study.

Regarding the trip characteristics, previous research suggested that the impact of cycling infrastructure can be different on commuting trips versus other destinations (*11, 21*). Our models indicated no such difference. Most cyclists (86%) travelled >3.75 km (i.e., >15 mins at 15 km / hr) to complete their trips (Table 1). Travel time did have some statistical association with mode substitution to cycle, both from a car or from transit (Table 3). Those who are currently travelling <15 minutes to reach their destinations were less likely (Odds Ratio, OR = $e^{-1.51} = 0.22$) to substitute their mode of travel from transit to cycling, compared to those travelling >30 minutes. In contrast, for those who travelled >15 mins to Sherbourne Street from their trip origin, the likelihood of a car-to-cycle mode substitution was higher (OR = 2.34), compared to those who had to travel ≤15 mins. These findings are at odds with the existing literature that emphasizes the importance of access to cycling infrastructure in facilitating cycling (*4, 11, 29*). However, when examined in the context of Sherbourne Street, the results are not surprising. For example, for those trips where travel distance between trip origin and Sherbourne Street was >15 mins, no one walked, and higher proportion of respondents drove before the 2012 redevelopment. Not surprisingly then, the likelihood of substituting a car trip for a cycling trip was higher after the implementation of the cycle track.

Building on a very limited literature (*11*, *12*), this study presents an easy-to-implement method of using an intercept survey asking retrospective questions about behavioural change to examine the short term impact of cycling infrastructure. The results begin to provide insights into the cycling mode substitution behaviour in downtown Toronto and perhaps in other similar urban situations. However, the scope of this study was somewhat limited by the methodical approach (i.e., short intercept survey) that was adopted in this research. For example, travel route change was one of the most important indicators of mode substitution, but this relationship could not be explored more directly. Existing literature has also reported a cultural and attitudinal shift toward cycling in recent years across North America (*7*, *30*, *31*). Thus, some increase in cycling could be expected due to changes in attitudes even without the new facility and we acknowledge this potential confounding factor could not be accounted for in this study (*32*, *33*). More generally, our findings may not be generalizable to other urban and/or rural contexts that have a different (e.g., less dense and diverse) built form, lower transit use or a different urban cycling culture.

With very limited literature on this topic, there is great opportunity for further research both refining the methodology and exploring variables such as other socioeconomic factors and cycling attitude/ culture. This future research would provide a clearer understanding of the mode substitution effect that this study begins to uncover, and provide sound data on cycling infrastructure that would enable urban planners, policy advisors, and politicians to plan for healthier and more sustainable communities.

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