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Mode substitution effect of urban cycle tracks: Case study of a downtown street in Toronto, Canada

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ABSTRACT

With the growing environmental and health concerns associated with automobile dependence, municipalities across the Western world are investing in cycling facilities to encourage drivers and transit users to take up cycling as a mode of transportation, a process that is known as the travel mode substitution. This study explored the potential impact of cycle tracks on short-term travel mode substitution behavior. We present a case study of Sherbourne Street, located in downtown Toronto, Canada, that was redeveloped in 2012 to include a cycle track that replaced an existing bicycle lane. A street intercept survey was conducted in Fall, 2014, to record quantitative data on current and retrospective travel behaviors of cyclists (n = 214). A mode substitution effect was observed, with 38% of the respondents reporting that they would use travel modes other than cycling before the Sherbourne Street redevelopment, for making a trip to their current destination; the majority of them were previously transit users. Binary logistic regression models indicated that younger cyclists were less likely to substitute a car trip for a cycling trip. Those who did not use Sherbourne Street previously were more likely to substitute their travel mode. Improved safety was the most commonly reported reason for mode substitution. This study contributes to a limited literature by providing much needed insights into the impacts of cycle tracks on travel behavior in a North American context. This paper can also inform the development of easy-to-implement survey/audit tools to be used by professionals at the community level.

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1. 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 driving a private automobile (Dill, 2009; Portland Bureau of Transportation, 2011). 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 are more likely to meet recommended fitness levels (Dill, 2009; Hartog, Boogaard, Nijland, & Hoek, 2010; Larsen & El-Geneidy, 2011). 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 (Burwell & Litman, 2006; Grabow et al., 2012; Hartog et al., 2010).

Arguably, a diverse range of interventions can be adopted to enable urban cycling, including education/promotion, law enforcement, and new infrastructure and facilities. However, across Western countries and particularly in North America, cycling facilities including painted bicycle lanes and physically separated bicycle lanes known as the cycle tracks are probably the most common approaches adopted by municipalities in promoting cycling in urban settings (Krizek et al., 2009a). The current literature has demonstrated an association between an increased supply of cycling facilities and higher cycling rates/cycling mode share (Dill & Carr, 2003; Pucher, Dill, & Handy, 2010). 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 citywide cycling ridership (Dill & Carr, 2003). The cause-effect relationship between cycling facilities and travel behavior is less clear (Buehler & Dill, 2016; Krizek et al., 2009b; Piatkowski, Krizek, & Handy, 2015; Rowangould & Tayarani, 2015). As Krizek et al. (2009a) pointed out, strong cycling advocacy may lead to construction of new cycling facilities. In other words, the higher cycling rates can sometimes be the "cause" behind the construction of cycling facilities, instead of the "effect" relating to new cycling facilities. In the absence of sufficient empirical evidence, 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 cycle track, which replaced a bicycle lane. Sherbourne Street, the focus of the study, is an arterial road that runs north-south

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parallel to and just 0.8 km east of Yonge Street, which is one of the most important downtown streets in Toronto. Further details of Sherbourne Street and its cycle track are provided in Section 3.

The goal of the research is to explore the short-term mode substitution effect of this newly built bicycle track. In the context of this study, a short-term mode substitution would occur when a road user switches their travel mode from driving, taking transit or walking, to cycling during the first few years of the construction of a cycling facility, for a particular trip that is being examined. The short-term substitution of travel mode for one specific trip may indicate a process of behavioral change that may lead to longer term changes in overall travel mode choice patterns (Piatkowski et al., 2015).

To our knowledge, this study is a first of its kind in that it specifically focuses on estimating the short-term mode substitution effect of cycle tracks. Although we focus on one facility in a particular context, results from this study begin to provide an in-depth understanding of the impacts of cycle tracks in general, which are becoming a more common feature of downtown streets in many North American cities including Toronto. Methodologically, this paper advances a very limited literature that has demonstrated the usefulness of using a street intercept survey approach in exploring the potential impact of a recently constructed cycling facility, and more specifically, in examining travel mode substitution behavior (i.e., Piatkowski et al., 2015; Rowangould & Tayarani, 2015), by demonstrating the usefulness of using a street intercept survey approach in exploring the potential impact of a recently constructed cycling facility. 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 facilities and related investments (Mitra, Winters, Smith Lea, & Hess, 2015; Piatkowski et al., 2015; Smart Growth America, 2015).

2. Cycling facilities and travel behavior: A brief literature review

An emerging literature has explored the relationship between cycling facilities and travel behavior. A recent study conducted in Portland, Oregon, U.S., indicated that the majority (56%) of the people surveyed were "interested but concerned" cyclists (Dill & McNeil, 2013)—a group who are curious and interested in cycling but are afraid to do so and as a result do not regularly cycle. This group can, however, be a key target market for cycling-related capital investment (Dill & McNeil, 2013; Geller, 2012). Dill & McNeil (2013) also reported that physically separated cycle tracks may increase the level of comfort and enable cycling uptake among this population group. Recent cross-sectional research supports this finding and suggests that for cyclists sharing a road with automobiles, the perceived risk attributed to the possibility of collision is typically higher (Garrard, Rose, & Lo, 2008; Heinen, vanWee, & Maat, 2010; Larsen, Patterson, & El-Geneidy, 2013). Moreover, surveys of cycling preference have indicated that cyclists and noncyclists alike prefer separated cycling facilitates, in comparison to a scenario where a cyclist has to share roadway with an automobile (Akar & Clifton, 2009; Buehler & Dill, 2016; Gossling, 2013). Not surprisingly, researchers have repeatedly emphasized that separated cycling facilities may overcome these perceived risks and attract new and inexperienced riders, who report being more concerned for their safety when cycling (Dill, 2009; Garrard et al., 2008; Hood, Sall, & Charlton, 2011; Larsen & El-Geneidy, 2011; Parker, Gustat, & Rice, 2011; Parkin, Wardman, & Page, 2006).

The existing literature also suggests that cyclists may travel greater distances to use routes with cycling facilities that are perceived to provide improved safety and efficiency for users (Larsen & El-Geneidy, 2011; Howard & Burns, 2001). In particular, inexperienced cyclists are more likely to add to their trip length in order to use physically separated cycling facilities such as cycle tracks (Larsen & El-Geneidy, 2011). Other recent research indicates that off-street paths and "bicycle boulevards" may have a stronger influence on route choice compared to bicycle lanes (Broach, Dill, & Gliebe, 2012). However, Broach et al. (2012) also reported that commuters were less sensitive of the characteristics of the cycling facilities, compared to those cycling to nonwork destinations.

While there appears to be some statistical association between physically separated cycling facility and user perceptions of traffic safety, particularly in a North American context, the actual impact of this separation on improved safety may be moderate. Arguably, only a small proportion of collisions involving cyclists also involve a motor vehicle driving in the same direction (Forester, 2001), and poor design of cycling facilities potentially increases the risk of collision at intersections (McClintock & Cleary, 1996; Parkin & Koorey, 2012). However, physical separation would reduce the theoretical risk of mid-block collision between a bicycle and an automobile, particularly in contexts where relative difference in travel speed between these two types of travel modes is high (e.g., roads with high traffic speed limits) (Parkin & Koorey, 2012).

A limited literature has explored the direct/causal relationship between cycling facilities and a change in mode choice. For example, Piatkowski et al. (2015) examined trip substitution and mode substitution behaviors in Denver, Colorado, and Sacramento, California in the U. S. Survey data were largely collected from streets with active transportation facilities, but the study did not directly measure the impact of specific infrastructure(s). 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; age was not associated with travel mode substitution. A more recent study focusing on the use of off-street multiuse trails for commuting trips in Albuquerque, New Mexico, U. S., found that 25% of cyclists would have commuted by car had the trail not been present (Rowangould & Tayarani, 2015). The study also found that a desire to exercise was a significant predicator for continuing to cycle without a multiuse trail, indicating that the opportunity to participate in a healthier lifestyle was a major motivation for a potential mode substitution (Rowangould & Tayarani, 2015). In none of these aforementioned studies was the impact of cycle track, or on-street cycling facility in general, directly explored, highlighting the need for empirical research related to the direct impact of cycling facilities on behavioral change (Buehler & Dill, 2016).

3. Case study: Sherbourne street

Sherbourne Street in Toronto, Canada, was examined as a case study for this research. In 2011, only 1.86% of all household trips in Toronto were taken using a bicycle (Mitra & Smith Lea, 2015). However, the past few years have seen a significant growth in advocacy and policy interest around cycling. The City of Toronto has currently undertaken a 10-year plan to grow the city's cycling network, which builds on the visions set out in the Toronto Bike Plan, 2000 (City of Toronto, 2016).

Sherbourne Street was the first in the City of Toronto to include cycle tracks on both sides of its right-of-way (Figure 1). The street is an arterial street located about 0.8 km (0.5 mile) east of the key north-south downtown street in Toronto-Yonge Street-and runs parallel to it through five different downtown neighborhoods: St. James Town, Cabbage Town, Moss Park, Corktown, and St. Lawrence. 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, to low-to-mid-rise commercial and residential uses toward the south-end. North- and south-bound buses run along the street, connecting transit riders to the Sherbourne Subway Station to the north, the waterfront to the south, and four east-west streetcar routes (Figure 1).

In 2011, Toronto City Council approved the construction of the Sherbourne Street Cycle Track, which was constructed in 2012. The cycle track replaced painted bicycle lanes that previously existed on the street since 1996, in order to "better separate cars and bikes and improve safety for cyclists" (City of Toronto, 2015a). The first phase of the project (from Bloor Street East to King Street) was constructed in 2012. The second phase, which continued south down to the waterfront, was completed in 2014. Overall, this project included a total of 2.44 km of cycle track on each side of the street, which fully separates cyclists from automobile traffic using low-height concrete dividers, except at intersections where the cycle track becomes a painted bicycle lane to facilitate right-turning of motor vehicles (Figure 1). The cycle track connects to existing bicycle lanes at Wellesley Street, Gerrard Street, Shuter Street, and Bloor Street East (City of Toronto, 2015a).

The redevelopment of the street focused on improving cycling facility only, whereas the public realm, automobile, and transit infrastructure remained the same. 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 (City of Toronto, 2015a). Following the completion of the project, the average daily cycle count on Sherbourne rose from 995 in 2011 to 2,827 by 2014 (City of Toronto, 2015a). This research asks how much of this increase can be attributed to short-term mode substitution versus other potential explanations.

4. Methods

4.1 *Data collection*

Short street intercept surveys were conducted to collect data from current cyclists on Sherbourne Street. Intercept surveys were previously used in other studies on cycling behavior (e.g., Downward, Lumsdon, & Weston, 2009; Piatkowski et al., 2015; Rose, 2007). In our research, this approach allowed a direct estimation of the short-term mode substitution effect for each

Figure 1. Sherbourne street cycle track. Note: Satellite Imagery from Google Earth (2015); photo taken by authors.

of the surveyed individuals, using retrospective questions. In addition, and similar to Piatkowski et al. (2015), a goal of this study was to explore the feasibility of a simple and easily implementable survey/audit instrument that professionals can use to evaluate active transportation projects. The application of this survey method was, then, novel and appropriate in the context of this study.

Two major intersections along Sherbourne Street were chosen as data collection points; cycle tracks on both locations were constructed in the first phase of the street redevelopment, in 2012. A student researcher stood near an intersection and utilized the "fixed line approach" (Graham et al., 2012) for recruiting road users aged >18 years who stopped at red lights. This method also included approaching the first cyclist who passed a predetermined feature along the street and near an intersection (e.g., a bus shelter, a pole), before coming to a complete stop at red lights (Graham et al., 2012). This approach, along with a short questionnaire designed to minimize the inconvenience or delay of the respondent during travel, was adopted to avoid potential selection bias in the survey.

A total of nine short questions were asked to cyclists; the survey typically took approximately 1 min to complete. Cyclists traveling on both directions were recruited. Surveys were conducted during October and November of 2014 before the onset of winter weather; one student researcher collected data on seven weekdays from 7:30 to 9:00 am in the morning and from 5:00 to 6:30 pm in the evening. Surveys were also conducted on three weekend afternoons from 4:30 to 6:00 pm. The surveyor made sure not to repeat interviews with the same cyclists. 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 behavior, sociodemographic characteristics, as well as on the characteristics of the trips. A total of 219 cyclists participated in the survey. The response rate was approximately 80%, which is similar to the response rate reported in a previous research (Rose, 2007).

Conceivably, several types of road users may contribute to an increase in the number of cyclists on a street. The first group consists of individuals who previously were cyclists but did not use the street in question—Sherbourne Street—for traveling before the redevelopment. Some of them may switch/substitute their travel routes to use the newly constructed cycle tracks (Broach et al., 2012; Howard & Burns, 2001; Larsen & Geneidy, 2011). In this study, the focus was placed on a second group—those who were not previously cyclists. We explored the potential short-term mode substitution behavior among these "new cyclists" for traveling to the destinations of their current trip at the time of the survey.

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 (Dill & McNeil, 2013). Second, individuals who are more favorable to cycling may move to a bikeable neighborhood (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 (Krizek et al., 2009). Finally, individuals who previously used Sherbourne Street to reach the destinations of their current trips may switch/substitute their mode of transportation to cycling (from cars, transit or other alternatives to cycle) due to the presence of cycle tracks.

Potential travel behavior 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 reported that they would not cycle before the redevelopment and instead traveled by transit, car, walking, or other modes were identified as individuals who had made short-term mode substitutions in favor of cycling. Compared to a stated preference survey that relies on a respondent speculating about his or her mode choice (e.g. "what would you have done if you had not walked/cycled for this trip?"), the approach used here provides a direct retrospective account of an actual change in travel mode choice behavior in recent past (<2 years) and arguably captures the impact of a cycling facility more reliably.

Those who reported changing their travel modes were also queried about the potential reasons for switching. Another question in the survey asked if participants previously used Sherbourne Street before the installation of the cycle tracks. Answer to this was used to explore potential route substitution (which may also include changes in residential locations) within the sample.

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

4.2. *Statistical analysis*

Multivariate statistical analyses were performed to explore the correlates of short-term mode substitution by a current cyclist. Separate models were estimated that focused on factors associated with substitution (1) from all other modes to bicycle, (2) from private automobile to bicycle, and (3) from transit to bicycle. Due to binary discrete nature of these outcome variables, a set of three binomial logistical regression models were estimated. Multinomial logistic models were initially considered but were not used for multivariate analysis primarily because of a relatively small sample size.

5. Results and discussion

Current cyclists on Sherbourne Street in downtown Toronto were surveyed to explore the impacts of a recently built cycle track on short-term travel mode substitution. Table 1 summarizes the characteristics of 214 cyclists who used this street. Of the current cyclists, 61% were men and 39% were women (Table 1). This gender difference in cycling is representative of cycling behavior in Toronto, and more broadly, North America (Garrard et al., 2012; Mitra & Smith Lea, 2015; Pucher, Buehler, Merom, & Bauman, 2011). For example, in a resent exploration using data from a regional travel survey—the Transportation Tomorrow Survey—Mitra & Smith Lea (2015) reported that only 33% of current cyclists in Toronto were women in 2011. In a separate study using the same data, Ledsham, Liu, Watt, & Wittmann (2013) identified significant geographical variation in female participation in cycling, with much higher cycling rates among women in downtown neighborhoods such as the

Table 1. Summary of current cyclists and cycling trips.

Variables	All current cyclists (n = 214) %	Current cyclists who substituted their previous travel modes (n = 82) %	Current cyclists who would cycle before cycle track construction (n = 132) %
Demographics			
Gender			
Male	61.21	56.10	64.39
Female	38.79	43.90	35.61
Age			
<40 years	64.95	69.51	62.12
≥40 years	35.05	30.49	37.88
Previously used the road before the redevelopment			
Yes	37.85	9.76	55.30
No	62.15	90.24	44.70
Purpose and travel times			
Purpose of trip			
Commuting (work)	68.69	73.17	65.91
Commuting (school)	9.81	9.76	9.85
Social (shopping or social events)	15.89	10.98	19.94
Recreational (leisure or exercise)	4.67	4.88	4.55
Other	0.93	1.22	0.76
Total time to complete trip			
<15 min	14.49	15.85	13.64
15+	85.51	84.15	86.36
Time spent from trip origin to Sherbourne street			
<15 min	77.57	80.49	75.00
15+ min	23.43	19.51	25.00
Time spent from Sherbourne street to trip destination			
<15 min	86.92	90.24	84.85
15+ min	13.08	9.76	15.15
Travel mode substitution			
Changed to cycling since 2012 (after redevelopment)	38.32	—	—
Cycled before redevelopment	61.68	—	—

ones explored in this paper as a case study. With regard to age, our survey was restricted only to adult cyclists aged >18 years; 65% of the cyclists that were surveyed were <40 years old (Table 1). This proportion is not noticeably different from what was reported by Mitra & Smith Lea (2015) and is also consistent with findings from previous studies that reported an association between younger age and cycling (Buehler & Pucher, 2012; Saelens, Sallis, & Frank, 2003).

5.1 *Short-term mode substitution*

38% of all respondents (82 of a total of 214) potentially switched their travel mode to cycling between 2012 and 2014; they reported they would have used other travel modes for the same or a similar trip before the existence of Sherbourne Street cycle track. The others (62%) cycled before for traveling to the destinations of their current trips (Tables 1 and 2). A closer examination of the previous mode of transportation for the

Table 2. Reported mode of travel prior to the construction of cycle track, for traveling to the destination of current trip.

	All survey respondents (n = 214)					
	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
	Survey respondents who substituted their travel modes to cycling since 2012 (n = 82)					
	All trips (n = 82)		Commute (work or school) (n = 68)		Other (social, recreational, other) (n = 14)	
	Freq.	%	Freq.	%	Freq.	%
Private auto (i.e., car)	20	24.39	15	22.06[1]	5	35.71[1]
Transit	45	54.88	40	58.82[2]	5	35.71[2]
Walk	11	13.41	8	11.77	3	21.43
Other	6	7.32	5	7.35	1	7.15

Note: All survey respondents currently cycle to their destinations.
[1] χ^2 of the difference between commute and other trips is 1.174 (df = 1); p = 0.28.
[2] χ^2 of the difference between commute and other trips is 2.504 (df = 1); p = 0.11.

same or similar trip 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%) (Table 2). Some difference in mode substitution across trip purposes was also evident. Transit-to-cycle mode substitution was more common for commuting trips, while car-to-cycle substitution was more common for social, recreational or other trip purposes. These differences, however, were not statistically significant (Table 2).

For some time, academic research and professional practice on cycling have centered on understanding and enabling car-to-cycle mode substitution. Most people in the Western world, and particularly in North America, drive to fulfill their everyday travel needs. If the goal of promoting cycling is to improve environmental sustainability and population health, converting a car trip to a cycling trip would potentially deliver the most benefit and would be the most desired type of mode substitution outcome from a policy perspective. Some recent studies from the United States have linked cycling facilities with a potentially high car-to-cycle mode substitution (Piatkowski et al., 2015; Rowangould & Tayarani, 2015). Compared to these other observations, car-to-cycle mode substitution observed in our study was relatively lower (Table 2). However, within the context of downtown Toronto—an area that is served by subways, streetcars, and buses, and where the mode share for transit is already high—our results are not surprising. Instead, in the case of Sherbourne Street, our results suggest that cycle tracks may lead to the reduction in both public transit use and driving, 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. However, we could not test for this effect in this study.

In addition, our data suggest that 90% of those who potentially substituted their previous travel modes would not use Sherbourne Street for traveling to the destination of their current trips (Table 1). Moreover, of those who previously cycled, 45% did not ride on Sherbourne Street before the redevelopment. Together, these observations indicate a substantial route substitution effect after cycle tracks replaced a bicycle lane in 2012. While some researchers have challenged the traffic safety-related benefits of cycle tracks (e.g., Forester, 2001; Parkin & Koorey, 2012), findings from this study suggest that the Sherbourne cycle track may be attracting both existing and new cyclists, likely due to improved perceptions of safety offer by a cycle track compared to the painted bicycle lane that it replaced (Broach et al., 2012; Dill & McNeil, 2013; Larsen & El-Geneidy, 2011; McClintock & Cleary, 1996).

Figure 2 further emphasizes the importance of perceived safety in explaining short-term mode substitution behavior. Survey participants who had recently (i.e., since 2012) substituted their travel mode from any other mode to cycling were prompted to outline their reasons for switching modes. Respondents were able to choose multiple responses (i.e., "all that apply"). A total of 80 cyclists provided 155 responses, which are summarized in Figure 2. Improved safety (24%) was mentioned by most as a potential reason for a travel mode substitution, followed by a reduction in travel time (23%) and health benefits associated with cycling (17%). In contrast, the presence of other cyclists, positive environmental impact and attractive traveling environment were the least frequently mentioned reasons for travel mode substitution.

5.2 *Correlates of travel mode substitution*

Following the descriptive analysis, a set of binary logistic regression models were estimated to examine the statistical correlates of short-term mode substitution. A total of three models estimated mode substitution (1) from all other modes to bicycle, in reference to those who already cycled before 2012; (2) from private automobile to bicycle, in reference to those who would use transit, bicycle, walk, or other modes before 2012; and (3) from transit to bicycle, in reference to those who would use car, bicycle, walk, or other modes. The findings are summarized in Table 3.

Results from the regression analysis indicate that travel route substitution was probably the most important correlate of travel mode substitution, further emphasizing the results discussed in Section 5.1. The likelihood of a mode substitution to

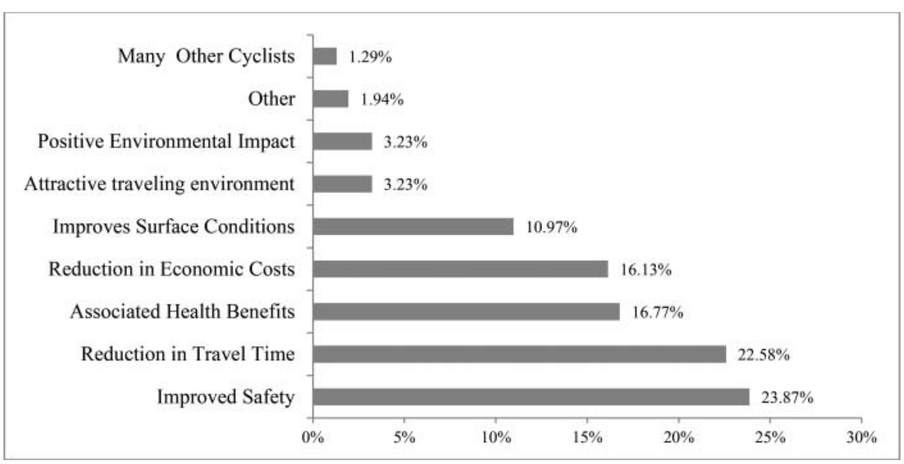

Figure 2. Reported reasons for substituting modes of transportation to cycling.

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

	From all modes to bicycle[1]		From car to bicycle[2]		From transit to bicycle[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 years)						
< 40 years	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 min)						
<15 min	−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 min	−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 min)						
>15 min	−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 min)						
>15 min	−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, bicycle, walk or "other"; [3]Ref: previous travel mode was car, bicycle, walk, or "other." ***Coefficients are significant at $\alpha = 0.01$; **coefficients are significant at $\alpha = 0.05$; *coefficients are significant at $\alpha = 0.10$.

cycling (from any other mode) was 11 times (Odds Ratio, OR = $e^{2.40}$ = 11.02) higher among those who had not traveled along Sherbourne Street for the same or similar trips before the 2012 redevelopment. A strong association between cycling facility and travel route change has been observed in previous studies. For example, Broach et al. (2012) emphasized that physically separated cycling infrastructure, such as a cycle track, may improve perceived comfort and safety, particularly among inexperienced and concerned cyclists. Our results indicate that improved cycling facilities may enable both travel route and mode substitution, adding new cyclists to urban streets. Moreover, improved safety was the most commonly reported reason behind travel mode substitution to cycling (Figure 2), further emphasizing the importance of cycle tracks in enabling cycling in an urban setting.

It should be noted here that the cause-effect relationship between travel route change and mode substitution could not be directly explored within the scope of this study. Part of the observed association between travel route change and cycling uptake may also relate to residential self-selection, as has been outlined in previous research (Krizek et al., 2009a). A more in-depth examination of this topic remains subject to our future research.

Regarding other trip characteristics, previous research suggested that access to cycling facilities may have a more pronounced impact on noncommuting trips, compared to commuting trips (Broach et al., 2012; Piatkowski et al., 2015). Researchers have also found that those who lived near the cycling facilities would be more likely to use them, compared to others who lived farther from these facilities (Broach et al., 2012; Goodman, Sahlqvist, & Ogilvie, 2013; Larsen & El-Geneidy, 2011; Piatkowski et al., 2015). Our models indicated no such correlation. Most cyclists (86%) traveled >3.75 km, estimated based on a travel time of >15 min at an estimated speed of 15 km/h, to complete their trips (Table 1). Travel time did have some statistical association with mode substitution to cycle, either from a car or from transit (Table 3). Those who are currently traveling <15 min 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 traveling >30 min. In contrast, for those who traveled >15 min to Sherbourne Street from their trip origin (i.e., the cycle track was >15 min from trip origin), the likelihood of a car-to-cycle mode substitution was higher (OR = 2.34), compared to those who had to travel ≤15 min. These findings are at odds with the existing literature that emphasizes the importance of access to cycling facilities in enabling cycling (e.g., Larsen & El-Geneidy, 2011). However, when examined in the context of Sherbourne Street, such results may not be surprising. For example, for those trips where travel distance between trip origin and Sherbourne Street was >15 min, no one walked, and a high 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 construction of the cycle track.

With regard to the sociodemographic characteristics, a cyclist's gender did not correlate with short-term mode substitution. However, our model results indicate 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.

6. Conclusions

This study presents an easy-to-implement method of examining the short-term impact of a downtown cycle track on travel mode substitution. We used a street intercept survey for this purpose, which asked retrospective questions about behavioral change. Sherbourne Street in downtown Toronto was used a case study in this research, where a physically separated cycle track was built in 2012, replacing an older bicycle lane. The study begins to provide insights into the potential benefits of physically separated cycling facilities in downtown Toronto and perhaps in other similar urban situations. The results indicate that 38% of the current cyclists on Sherbourne Street would have previously used other modes of travel to reach the destination of their current trip at the time of the survey. We also found that more than half (55%) of these new cycling trips were previously made using transit. Binary logistic regression models indicated that younger cyclists were less likely to substitute a car trip for a cycling trip. The likelihood of travel mode substitution to cycling was also higher among those who had not traveled along Sherbourne Street for the same or similar trips before the construction of the cycle track.

The results from this study are only generalizable to the extent allowed by the data that was collected. First, the data captured potential short-term travel mode substitution among current cyclists and only for one of their daily trips. Our results do not capture a potential change in travel behavior at a population level. While travel mode substitution for one trip may indicate a potential change in overall travel mode choice patterns (Piatkowski et al., 2015), an examination of this topic was outside the scope of this work. Second, travel route change was one of the most important indicators of mode substitution, but the causal relationship between route substitution and mode choice could not be explored more directly. Third, existing literature has reported a cultural and attitudinal shift toward cycling in recent years across North America (Aldred & Jungnickel, 2014; Krizek et al., 2009a; Vivanco, 2013). Thus, some increase in cycling could be expected due to changes in the culture of mobility even without the new facility, and such effects could not be explored in this study. Last, and more broadly, our findings may not be generalizable to other urban and/or rural contexts that have less dense and diverse built form, lower transit use or a different urban cycling culture than Toronto.

Despite some limitations, the findings and the methodology from this study may have important implications for transportation policy and planning. During the past decade, we have seen significant policy, professional, and grass-roots interests around active transportation. As a result, cycling facilities have become an increasingly common feature in many urban streets across North America. However, the impacts of these cycling facilities remain less known. The absence of easy and cost-effective methods/tools to measure these impacts is a key challenge for practitioners (Mitra et al., 2015). Within this context, evidence presented in this study may enable transportation and urban planning practitioners in Toronto and similar urban municipalities/regions to better understand the impacts of cycle tracks on travel mode choice and enable them to make more informed decisions regarding future active transportation planning. The methods used in this and other similar studies (Piatkowski et al., 2015; Rowangould & Tayarani, 2015) may inform the development of evaluation tools that would help professionals to measure and monitor the success of infrastructure projects.

With very limited literature on this topic, there is also a great opportunity for conducting further research that would both refine the methodology and explore influences that could not be examined in this study. This future research would provide a clear understanding of the mode substitution effect that this study begins to uncover, and would enable urban planners, policy advisors, and politicians to plan for healthier and more sustainable communities.

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