

# TRANSLATING RISK TO PREVENTABLE BURDEN BY ESTIMATING NUMBERS OF BICYCLING INJURIES PREVENTABLE BY SEPARATED INFRASTRUCTURE ON A TORONTO, ONTARIO CORRIDOR

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## Abstract

**Objectives:** Bicycling is a form of active transportation with several health benefits but carries a high risk of injury compared to other transportation modes. Safety intervention evaluations often produce results in the form of ratios, which can be difficult to communicate to policy-makers. The primary objective of this study was to estimate the number of preventable bicycling injuries on an urban corridor by separating bicycling infrastructure.

**Methods:** Stakeholders identified a key corridor with multiple segments having bicycling infrastructure but most of the corridor lacking similar infrastructure. We counted bicyclist volume along this route and used secondary data to supplement counts missing due to COVID-19. We used two reference studies conducted in Toronto, Ontario to estimate benefit of separated bicycling infrastructure and applied this to a city-wide estimate of baseline risk of injury per kilometre bicycled, which used a combination of secondary data sources including police, health care, and health and travel survey data. We adjusted estimates to account for increased bicyclist volume during and following the COVID-19 pandemic. We constructed “plausible intervals” (PI) to express uncertainty in estimates, calculated from upper and lower bounds estimated from the secondary data inputs.

**Results:** We estimated installation of fully separated cycle tracks along one Toronto corridor would prevent approximately 152.9 [PI: 61.2–212.7] injuries and 0.9 fatalities over a 10-year period for current ridership. As ridership increases, fully separated cycle tracks would prevent between approximately 159.3 [PI: 63.8–221.6] to 411.5 [PI: 253.3–572.6] injuries, and 1.0 [PI: 0.2–2.2] to 2.4 [PI: 0.5–5.7] fatalities over a 10-year period.

**Discussion:** Our results underscore the benefits of separated bicycling infrastructure. We identify several caveats for our results, including the limitations of studies used to estimate relative risk of infrastructure. Our method could be adapted for use in other cities or along other corridors. Finally, we discuss the role of preventable burden estimates as a knowledge translation tool.

**Keywords:** Bicycling; Injuries; Risk, Prevention; Transportation; COVID-19

## Introduction

The COVID-19 pandemic has placed new focus on bicycling as a physically distanced, active form of travel.<sup>1</sup> Safety concerns can deter bicycling,<sup>2</sup> as injuries per kilometre are higher than other modes.<sup>3–5</sup> Prior reviews evaluated the benefits of physically separated infrastructure in reducing injury or collision risk for bicyclists.<sup>6–8</sup> Inconsistencies in methodology

can make interpretation and comparison of different infrastructure types challenging. Overall, literature reviews have concluded that physically separated cycle tracks reduce injury and collision risk for bicyclists.<sup>9</sup> Reviews have also reported protective effects of painted cycle lanes (i.e., a painted lane along a roadway designated exclusively for bicyclists)<sup>9</sup> in reducing injury and collision risk compared to streets without bicycling infrastructure.<sup>8</sup> From a

public health perspective, physically separated bicycling infrastructure has numerous advantages because it is population-based, can be passively engaged by users, and can accrue benefits over time following implementation.<sup>10,11</sup>

Prior reviews have recommended the adoption of consistent terminology for bicycling infrastructure (e.g.,<sup>9, 10</sup>). In 2020, Winters et al.<sup>12</sup> introduced the Canadian Bikeway Comfort and Safety (Can-BICS) classification system to ensure consistent nomenclature. In this analysis, we use terminology consistent with Can-BICS, with *cycle tracks* used to denote physical separation and *bicycle lanes* or *cycle lanes* to indicate permeable infrastructure (e.g., painted lines).<sup>12</sup> Where local convention uses terminology not fully consistent with this nomenclature, we indicate local usage in quotes (e.g., “cycle tracks” that are not physically separated).

Few peer-reviewed studies have analyzed the burden of bicycling injury in Toronto, Ontario. More than two decades ago, Aultman-Hall et al. conducted a survey of 1360 Toronto bicyclists, who reported 666 collisions in the preceding 3 years and 482 falls in the preceding twelve months.<sup>3</sup> This study concluded that Toronto bicyclists had rates of collision 26–68 times higher than motor vehicles,<sup>3</sup> and indicated that the built environment contributed to this increased risk. In the intervening years, the built environment and the bicycling population of Toronto continue to evolve.

Communicating findings is a challenge for public health intervention research. Studies

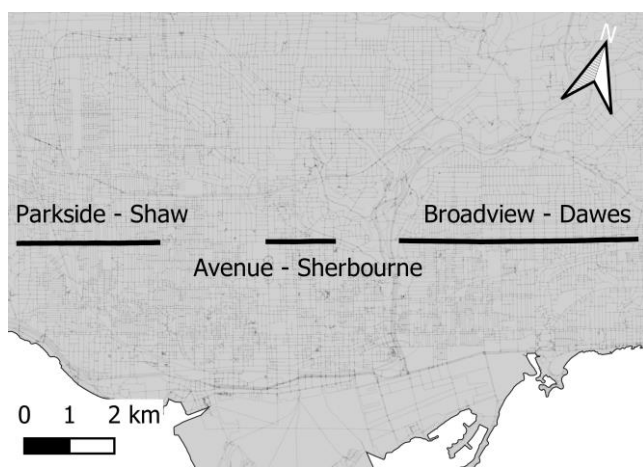
evaluating the effectiveness of interventions often report ratios, including odds ratios (e.g.,<sup>6,7,13,14</sup> [OR]) and others (e.g., rates<sup>15</sup> or risk ratios<sup>16,17</sup>). These can be difficult to interpret for potential policy- and decision-makers. Expressing ratio findings in different ways may improve understanding. Raw count estimates and percentages, including analyses of burden, can illustrate the magnitude of risk effects and communicate these in a way that may be more vivid than ratios.<sup>18-20</sup> However, these estimates are often constructed at the national and international scale and there are few examples of simplified burden calculations employed at the local (e.g., individual city) level.

The current study responded to stakeholder need (City Building Ryerson and Metcalf Foundation) for data on numbers of preventable injuries by separating bicycling infrastructure in Toronto. The primary objective was to estimate absolute numbers of bicycling injuries on an urban corridor preventable by bicycling infrastructure over ten years following a complete implementation, using previously published intervention evaluations and a combination of primary and secondary data.<sup>21</sup>

## Methods

To select a Toronto corridor for evaluation, we consulted with local advocacy and municipal government stakeholders in mid-2019.<sup>21</sup> The process identified Bloor St. to Danforth Ave. from Parkside Dr. in the West to Dawes Ave. in the East (**Figure 1**) as a high priority for intervention. At the time, bicycling infrastructure was limited

and intermittent on this corridor, and our analyses included only those segments without infrastructure. To estimate the expected burden of injury on target segments, and the alleviated burden preventable with infrastructure intervention, we collected primary data on bicycle volumes and compiled data from eight distinct secondary and literature sources. **Table 1** summarizes the calculations and data sources used. Below, we detail special methodological considerations and details of calculations.



**Figure 1.** Study area (Bloor Street to Danforth Avenue) with included street segments (Parkside Drive to Shaw Street, Avenue Road to Sherbourne Street, Broadview Avenue to Dawes Road) highlighted. Manual counts were conducted at the endpoints of each segment from September 2019 to March 2020

### ***Bicycle volumes: modelling automated count data to supplement primary collection***

Our research assistant conducted 20-minute counts at segment endpoints along the corridor between September 11, 2019 and March 13, 2020, at which point COVID-19 interrupted data collection. To impute ridership for seasons and times of day without manual data collection, we used the City of

Toronto's Open Data Bicycling Volume dataset containing automatic counts at three locations.<sup>22</sup> We modeled daily count data based on hour of the day, season, and day of the week, and modeled annual volumes from average daily volumes. Because the count stations are adjacent to those we modeled, we used a LOESS smoother<sup>23</sup> as it can capture the complex, nonlinear patterns present in the automatic counter data when aggregated and stratified by different time periods and temporal conditions.<sup>23</sup> The technical component of our public report provides additional details about modeled volumes.<sup>21</sup> Total segment bicycle rider counts were derived from the extrapolated count model for each respective segment, by calculating the mean of segment endpoints. Bicycle rider counts from our model indicated Bloor-Danforth supports 1,463,626 bicyclists annually.<sup>21</sup>

We considered bicycle volume increases resulting from the COVID-19 pandemic. Early survey reports indicated substantial public transit hesitancy in response to the COVID-19 pandemic, with 23% of public transit users indicating they would avoid Toronto transit until a vaccine is available.<sup>24</sup> Some of these users may divert to other modes, including bicycling. We also anticipated that new bicycling infrastructure along Bloor-Danforth installed in summer of 2020<sup>21</sup> would attract additional riders. To account for this expected increase, we applied four increased bicycle ridership scenarios to our estimates: volume increases of 10%, 20%, 33%, and 50% of current ridership. As an outer threshold, a ridership increase of 1000% was considered given past reported volume increases

**Table 1.** Summary of calculations and data sources used to estimate bicycling injuries preventable by bicycling infrastructure on a target corridor in Toronto, Canada.

Calculation		Components	Estimation data sources
Baseline injuries (BI)	$BI = SSL \times SBR \times IR$	Street segment length (SSL), in km  Segment bicycle riders (SBR), persons  Injury risk (IR), injuries per person-km	Google Maps™ distance measuring tool  Manual (human) research assistant counts at segment endpoints, September 2019-March 2020.  Automated counter data in Toronto Open Data at adjacent count locations.  Hypothesized volume/ridership increase scenarios due to COVID-19 and attraction to infrastructure  Numerator: Police-reported crashes from the Toronto Police Killed or Seriously Injured (KSI) database, corrected for under-reporting using data from provincial (Ministry of Transportation, MTO) bicycle collision data and National Ambulatory Care Reporting System (NACRS) data on emergency department visits for bicycling injury  Denominator: Trips derived from Canadian Community Health Survey (CCHS) data on times bicycling, mean distance per trip estimated from Transportation Tomorrow Survey (TTS)
Lowest baseline injuries ( $BI_{low}$ )	$BI_{low} = SSL \times SBR_{low} \times IR_{low}$	Segment bicycle riders ( $SBR_{low}$ ), persons  Injury risk ( $IR_{low}$ ), injuries per person-km	Lowest estimate of street segment ridership volumes based on using the lower bound of a 95% confidence interval around expansion factors for both daily and annual volumes.  Lower 95% confidence interval of injury rate using Poisson exact method
Highest baseline injuries ( $BI_{high}$ )	$BI_{high} = SSL \times SBR_{high} \times IR_{high}$	Segment bicycle riders ( $SBR_{high}$ ), persons  Injury risk ( $IR_{high}$ ), injuries per person-km	Highest estimate of street segment ridership volumes based on using the upper bound of a 95% confidence interval around expansion factors for both daily and annual volumes.  Upper 95% confidence interval of injury rate using Poisson exact method
Post intervention burden (PIB)	$PIB = BI \times RR$	Relative risk of intervention (RR)	Teschke et al.* for higher protection cycle tracks and lower protection painted bicycle lanes, Ling et al.† for benefit of lower protection “cycle tracks” that may be semipermeable.
Post intervention burden lower plausible interval ( $PIB_{LPI}$ )	$PIB_{LPI} = BI_{low} \times RR_{low}$	Relative risk of intervention using lower confidence interval of study estimate ( $RR_{low}$ )	Assume the most protective effect of intervention by using the lower confidence interval for relative risk estimates in each study including Teschke et al.* for higher protection cycle tracks and lower protection painted bicycle lanes, and Ling et al.† for benefit of lower protection “cycle tracks” that may be semipermeable.
Post intervention burden upper plausible interval ( $PIB_{UPI}$ )	$PIB_{UPI} = BI_{high} \times RR_{high}$	Relative risk of intervention using lower confidence interval of study estimate ( $RR_{high}$ )	Assume the least protective effect of intervention by using the lower confidence interval for relative risk estimates in each study including Teschke et al.* for higher protection cycle tracks and lower protection painted bicycle lanes, and Ling et al.† for benefit of lower protection “cycle tracks” that may be semipermeable.
Prevented injury burden (B)	$B = BI - PIB$	Components as calculated above	
Prevented injury burden lower plausible interval ( $B_{LPI}$ )	$B_{LPI} = BI_{low} - (BI_{low} \times RR_{high})$		
Prevented injury burden upper plausible interval ( $B_{UPI}$ )	$B_{UPI} = BI_{high} - (BI_{high} \times RR_{low})$		

\*Teschke et al. 2012. American Journal of Public Health. Vol 102 (12), pp 2336-2343.

† Ling et al. 2020. Accident Analysis &amp; Prevention. Vol 135 (2020)

following implementation of cycle tracks on Richmond and Adelaide streets (which may have particularly represented bicycle traffic diversion in addition to new riders).<sup>25</sup>

### ***Estimating baseline bicycling injury risk with numerators and denominators***

We calculated a city-wide estimate of baseline injury risk (**Table 1**) by compiling data on the number of bicyclist injuries or fatalities across Toronto (numerator) and the total number of kilometers travelled by bicyclists in Toronto during the same period (denominator). While there could be many ways to define injury severity sufficient to warrant public health concern, we targeted injuries that would require a visit to emergency departments.

### ***Injuries to cyclists: correcting for underreporting in police data***

Toronto Police Services (TPS) records summarize bicyclist collisions in their “Killed or Seriously Injured” (KSI) dataset.<sup>26</sup> This dataset is a subset of police-reported injuries where a major or fatal injury has occurred.<sup>26</sup> Even when they include broader range of injury severity, police-reported crashes systematically miss bicycling injuries, particularly when they are non-fatal and do not involve motor-vehicles.<sup>27</sup> To address the problem of unreported injuries requiring emergency department (ED) visits in the absence of Toronto-specific hospital data, we estimated a correction factor using provincial data. We examined the ratio between Ontario police-reported bicycle crashes from the Ontario

Ministry of Transportation (MTO) annual collision statistics (2014-2017)<sup>28</sup> and bicycle injuries treated in Ontario EDs during the same period, compiled by the Canadian Institute for Health Information.<sup>29</sup> The observed ratio between ED injuries and MTO summarized police-reported collisions was 11.2. We then assumed this Ontario-wide ratio would apply to Toronto. We multiplied the 2014–2017 total non-fatal TPS KSI bicycling crashes by the correction factor. Between 2014 and 2017 TPS recorded 181 injuries and 12 fatalities. After applying the correction factor, we estimated 2,019 bicyclist injuries in Toronto between 2014-2017, or 504 injuries each year.

### ***Risk denominators: trips and kilometres***

Denominator calculations were performed in R version 4.0.2,<sup>30</sup> using two data sources to estimate total kilometres bicycled annually in Toronto. We analyzed the Canadian Community Health Survey (CCHS) 2014 cycle<sup>31</sup> public use microdata file (PUMF), subset to respondents within the Toronto Public Health Unit, and tallied the number of bicycling trips to work/school and for leisure (defined as times bicycling “not for work”). We used CCHS survey weights to calculate a weighted sum, tallying 47,039,804 annual Toronto bicycle trips.

We used the Transportation Tomorrow Survey (TTS) to estimate average trip length for Toronto bicyclists.<sup>32</sup> TTS aggregates data for several Ontario municipalities,<sup>32</sup> but we assumed that mean bicycling trip length would be comparable in Toronto. Trip length was calculated using a

weighted mean for Manhattan lengths to simulate city blocks.<sup>33</sup> Average bicycle trip length was 4.3 km. Number of trips were multiplied by average trip length to yield an estimate of annual kilometres travelled by bicycle in Toronto: 202,318,197 km.

### ***Baseline injury risk per person-km***

Dividing 504 injuries by 202,318,197 km, we obtained a Toronto baseline injury risk estimate of 0.25 per 100,000 person-km. We applied a safety-in-numbers<sup>34,35</sup> effect to injury risk. The safety-in-numbers effect postulates that risk of injury declines with increasing volumes.<sup>34,35</sup>

### ***Relative risk of intervention***

We drew our ratio estimates from two prior studies<sup>13,16</sup> that collected data in Toronto. Teschke et al.<sup>13</sup> found cycle tracks (defined as physically separated cycle lanes) offered significant protection (OR = 0.11, 95% CI: 0.02, 0.54). They found painted cycle lanes, when implemented without parked cars, offered less protection (OR = 0.54, 95% CI: 0.29, 1.01).<sup>13</sup> Ling et al.<sup>16</sup> focused on local infrastructure labeled as “cycle tracks” (not consistently physically separated, compared to other jurisdictions)<sup>9,12</sup> recording a protective association (OR = 0.62, 95% CI: 0.44, 0.89).

We used the OR estimate for fully physically separated cycle tracks from Teschke et al.<sup>13</sup> (0.11) to approximate relative risk (or relative rate) for a “high protection scenario”. ORs are often used to approximate relative risk when the outcome is rare.<sup>36</sup> Bicycle collisions are very rare in Toronto

given the high bicycling volume. The OR (0.62) from Ling et al.’s<sup>16</sup> evaluation of Toronto-implemented “cycle tracks”<sup>13</sup> was used to approximate a “lower protection” scenario. Finally, painted cycle lanes with no parked cars were termed “lower protection 2” using the OR observed by Teschke et al. (0.54).<sup>13</sup> These interventions would result in an estimated 89%, 38%, or 46% reduction in risk of crash, respectively.

### ***Conveying uncertainty: plausible intervals***

In compiling a wide range of secondary data with a multipart calculation (**Table 1**), there is no standard methodology available to apply a measure of sampling error to our overall burden calculation. We thus presented only point estimates to stakeholders in our public report.<sup>21</sup> However, given the value of demonstrating the uncertainty inherent in estimation, we developed a “plausible interval” (PI) measure, detailed in **Table 1**, to summarize upper and lower bounds on estimates from the component data sources.

## **Results**

**Table 2** summarizes ten-year projections of injury burden along previously unprotected segments of the target corridor. Without intervention, hundreds of injuries requiring emergency department visits can be expected (**Table 2**). The burden of injuries and fatalities prevented by infrastructure interventions is shown in **Figures 2 and 3**, respectively. Overall, largest reduction in injury burden would occur by implementing high protection, fully separated

bicycling infrastructure,<sup>13</sup> preventing an estimated 152.9 [PI: 99.9–167.4] injuries at current ridership and as many as 411.5 [PI: 268.9–450.7] injuries with extremely increased ridership of 1000%. Similarly, high protection infrastructure could prevent 0.9 [PI: 0.8–0.9] fatalities over 10 years, and as many as 2.4 [PI: 2.1–2.5] with increased ridership of 1000%. Lower protection cycle tracks<sup>16</sup> could prevent as many as 175.7 [PI: 143.5–205.3] injuries

(**Figure 2**) and 1.0 [PI: 0.1–1.0] fatalities (**Figure 3**) over 10 years with this extremely high ridership increase, while lower protection painted lanes<sup>13</sup> could prevent 212.7 [PI: 100.5–293.0] injuries (**Figure 2**) and 1.2 [PI: 1.0–1.5] fatalities over 10 years (**Figure 3**).

**Table 2:** Ten-year estimated numbers of injuries and fatalities along Bloor Street to Danforth Avenue, with and without (baseline) installation of safer bicycling infrastructure over 10 years, with estimates of relative risk (RR) provided by interventions derived from literature sources.

10 Year Injury Burden [plausible interval]				
Ridership Projection	Baseline	High Protection (RR=0.11)* Fully Separated	Lower protection 1 (RR=0.62)† Intermittently Separated	Lower protection 2 (RR=0.54)** Painted lanes
Current	171.8 [133.1 – 217.1]	18.9 [2.7 – 117.2]	106.5 [58.6 – 193.2]	92.8 [38.6 – 219.2]
10% increase	179.0 [138.7 – 226.2]	19.7 [2.8 – 122.1]	111.0 [61.0 – 201.3]	96.7 [40.2 – 228.4]
25% increase	189.1 [146.5 – 238.9]	20.8 [2.9 – 129.0]	117.2 [64.5 – 212.7]	102.1 [42.5 – 241.3]
33% increase	194.2 [150.5 – 245.4]	21.4 [3.0 – 132.5]	120.4 [66.2 – 218.4]	104.9 [43.6 – 247.9]
50% increase	204.5 [158.5 – 258.4]	22.5 [3.2 – 139.6]	126.8 [69.7 – 230.0]	110.4 [46.0 – 261.0]
1000% increase	462.4 [358.3 – 584.3]	50.9 [7.2 – 315.5]	286.7 [157.7 – 520.0]	249.7 [103.9 – 590.1]
10 Year Fatality Burden [plausible interval]				
Ridership Projection	Baseline	High Protection (RR=0.11)* Fully Separated	Lower protection 1 (RR=0.62)† Intermittently Separated	Lower protection 2 (RR=0.54)** Painted lanes
Current	1.0 [0.4 – 2.2]	0.1 [0.0 – 1.2]	0.6 [0.2 – 1.9]	0.6 [0.1 – 2.2]
10% increase	1.1 [0.4 – 2.2]	0.1 [0.0 – 1.2]	0.7 [0.2 – 2.0]	0.6 [0.1 – 2.3]
25% increase	1.1 [0.5 – 2.4]	0.1 [0.0 – 1.3]	0.7 [0.2 – 2.1]	0.6 [0.1 – 2.4]
33% increase	1.2 [0.5 – 2.4]	0.1 [0.0 – 1.3]	0.7 [0.2 – 2.2]	0.6 [0.1 – 2.5]
50% increase	1.2 [0.5 – 2.6]	0.1 [0.0 – 1.4]	0.8 [0.2 – 2.3]	0.7 [0.1 – 2.6]
1000% increase	2.7 [1.1 – 5.8]	0.3 [0.0 – 3.1]	1.7 [0.5 – 5.2]	1.5 [0.3 – 5.9]

\*Cycle tracks and \*\*Painted cycle lanes, per Teschke et al. 2012. American Journal of Public Health. Vol 102 (12), pp 2336-2343.

†Cycle tracks, per Ling et al. 2020. Accident Analysis & Prevention. Vol 135 (2020).

## Discussion

This analysis showed that a substantial number of injuries can be prevented by implementation of physically separated bicycling infrastructure. During our analyses,

the City of Toronto rapidly implemented both separated and semi-permeable bicycle infrastructure along the Bloor-Danforth study route, in response to COVID-19.<sup>21,37</sup> As such, our calculated estimates may form a preliminary projection of the benefits of

this newly installed (and designated as “temporary”)<sup>37</sup> infrastructure, if it is made permanent. Ongoing data collection along the route will test the accuracy of projections. This project is unique in its attempt to quantify hypothetical benefits of preventive bicycling infrastructure intervention prior to implementation. Other studies have attempted to quantify benefits after implementation, including improved physical activity<sup>38</sup> and injuries prevented.<sup>8</sup> In studies projecting benefits of infrastructure, the focus has been on presenting an economic case for infrastructure interventions.<sup>39</sup> However, it may also support communication to incorporate injury and fatality burden impacts.

The methods outlined in this study could be adapted to other city corridors and geographic regions as our public report included a downloadable, modifiable spreadsheet.<sup>21</sup> Our risk calculations estimated baseline risk for Toronto as whole. While this will allow estimated risk per kilometre travelled to apply to other locations in the same city, it assumes risk is homogeneous throughout the municipality. In reality, crash and injury risk are heterogeneous over both space and time, but this variability is not discernible from the secondary data sources we relied on. Spatial analyses of Toronto bicycling crashes rely on police reported crashes.<sup>16</sup> We used secondary data to correct for the crucial problem of underreporting of bicycling injuries in police data.<sup>40</sup> This secondary data correction relied on provincial rather than municipal data because health care system data are summarized at the provincial rather than municipal level. Incorporation of health

care system utilization data to capture traffic injury, particularly of active transportation users, would strongly improve municipal road safety surveillance programs.<sup>41</sup> However, we note that there can be impacts of injury that do not require interaction with the health care system, and these injuries could be assessed by primary data collection and surveillance approaches.

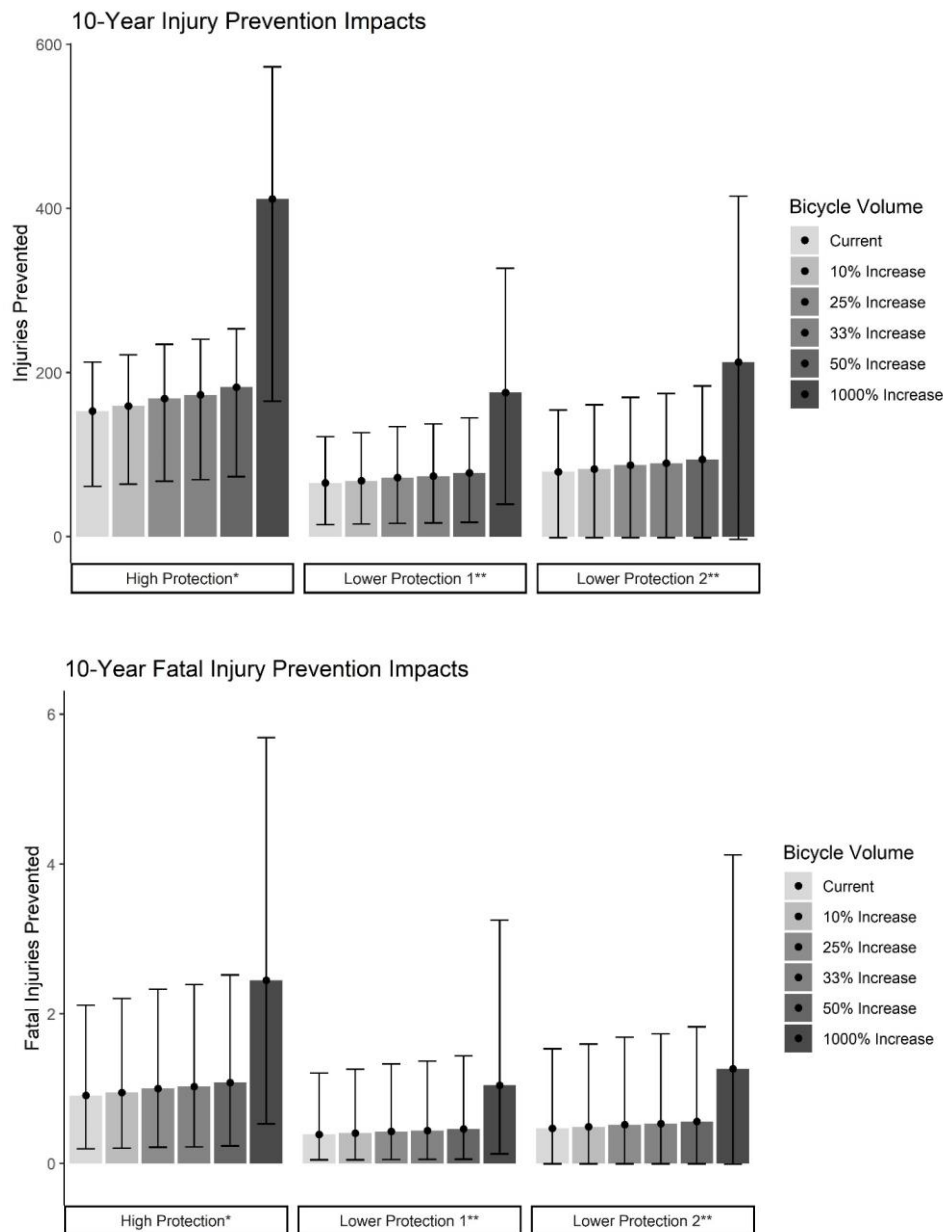
Our report presents decision-makers with absolute estimates of the number of injuries preventable with design intervention. There exists no standard method to evaluate knowledge translation interventions and it is difficult to assess their success.<sup>42</sup> One metric could be uptake of public-facing materials. We produced a webinar and a report, with 75 people attending the webinar and 72 downloads of the report between September 29 and November 18, 2020. Considering substantial portions of the newly implemented bicycle infrastructure on this corridor were designated as “temporary”,<sup>37</sup> an opportunity to evaluate this project as a knowledge translation product will arise when the permanency of the implemented infrastructure is debated by municipal government (anticipated for 2021). Testing reactions before and after reading the technical report could be a potential way to evaluate its impact.<sup>43</sup> We must acknowledge, however, that there may be an element of “study fatigue” on the part of community stakeholders when new studies are required each time safe infrastructure projects are considered.

Our analysis compiles multiple data sources collected across different years to derive high-level estimates. As such, there



are several limitations that must be acknowledged when interpreting our results. Our calculations assume that odds ratios (ORs) from reference studies<sup>13,16</sup> can

be used to approximate relative rates or risk ratios (RRs).



\* Cycle tracks, per Teschke et al. 2012. American Journal of Public Health. Vol 102 (12), pp 2336-2343.

\*\* Cycle tracks, per Ling et al. 2020. Accident Analysis & Prevention. Vol 135 (2020).

\*\*\* Painted cycle lanes, per Teschke et al. 2012. American Journal of Public Health. Vol 102 (12), pp 2336-2343

**Figure 2 (Top) and Figure 3 (Bottom).** Top: Ten-year estimates of injuries preventable by installing bicycling infrastructure along Bloor Street and Danforth Ave in Toronto, Canada. Whiskers represent “plausible intervals” estimated from upper and lower bounds of calculation inputs. Bottom: Ten-year estimates of fatalities preventable by installing bicycling infrastructure along Bloor Street and Danforth Ave in Toronto, Canada. Whiskers represent “plausible intervals” estimated from upper and lower bounds of calculation inputs.

This assumption depends on the generalizability of the original study population and the low incidence of the outcome.<sup>44</sup> Our use of studies collecting Toronto data and the overall low incidence of bicycling injury can address these assumptions.

The two reference studies<sup>13,16</sup> we relied on were designed differently, complicating comparison of resulting ORs. At the time of the Teschke et al (2012)<sup>13</sup> study, much of the current bicycling infrastructure found in Toronto had not been implemented. While guidance on “cycle track” nomenclature entails physical separation,<sup>12</sup> Toronto has a range of “cycle tracks” which are permeable or semipermeable. It was this variety of styles implemented in 2013 and 2014 that were assessed directly by Ling et al.<sup>16</sup> Given that effects of infrastructure can vary strongly by implementation and design,<sup>7,9,10</sup> it will be crucial to monitor impacts and problems with any implemented protected designs.

This project entailed consultation with local stakeholders to identify the target corridor. The corridor was considered a primary target for intervention, supported by the later street reallocation efforts during COVID-19 response. However, this process may not give sufficient attention to equity considerations<sup>45,46</sup> which must be considered along with existing ridership, safety, connectedness, and accessibility. Separated bicycling infrastructure may also confer injury protection benefits to other road users including motor vehicle occupants (e.g., reduced speed) and pedestrians through additional separation<sup>47</sup> not captured in this analysis. We were limited

in measuring safety effects in terms of injuries prevented and did not assess other aspects of safety including harassment, particularly as experienced by marginalized and racialized people.<sup>48</sup>

We used our city-wide estimates of injury risk as a baseline before applying relative risk of intervention at locations with no bicycling infrastructure. This does not factor in spatial variation in risk, and because some Toronto streets already have cycling infrastructure, a city-wide estimate may be an underestimate of local rates, if locations without infrastructure have higher injury risk. This limitation would tend to underestimate benefits of intervention. In contrast, our estimates of bicycling trip denominators may be an undercount because of incomplete data on bicycling for utilitarian purposes other than work or school (i.e., CCHS does not have a full accounting of all bicycling trips), which could tend to overestimate baseline risk and benefits of intervention.

Our approach to recognizing the impact of COVID-19 was to include projections of possible increases in bicycling volumes in response to the pandemic, in addition to overall attraction to improved infrastructure.<sup>25</sup> Ongoing volume counts will help assess whether these projections were reasonable. Our analysis only considered bicycle volume and does not incorporate possible changes in volume of other modes. It is not yet known if deterrence from public transit to personal motor vehicles<sup>49</sup> will persist into pandemic recovery, or whether this may lead to locally increased motor vehicle volumes on this target corridor. While

motor vehicle volumes declined during early COVID-19 interventions, possible increased speeds of motor vehicle traffic, resulting from decreased volumes might paradoxically have increased risk to vulnerable road users.<sup>50</sup>

Consideration of statistical error is challenging with this approach, and our method of constructing a plausible interval has limitations. The bounds we calculated represent scenarios which, based on our methodology, are the upper and lower bounds of estimated injuries prevented and should not be interpreted as a confidence interval around a statistical parameter in a frequentist framework.<sup>51</sup> The bounds may over- or underestimate true error depending on underlying distributions and variability. There may be other ways to impress upon knowledge users the uncertainty around estimates or what can be expected as a reasonable, plausible range. Future studies could attempt simulation (e.g.,<sup>52,53</sup>) to model error, but improving primary collection of data used for calculation inputs could be a better use of resources.

This analysis helps to identify data sources needed for ongoing assessment and surveillance of bicycling injury. We relied on a variety of data sources to approximate numerators and denominators of risk. For numerator data, inclusion of injuries requiring ED and hospital visits may enable a more complete assessment of injury impacts of interventions.<sup>54</sup> For denominator data, expanded locations of volume count data collection with more detailed demographic data for all modes of transportation will provide more accurate denominators

for risk estimates and enable more nuanced analyses of populations affected. Because automated counts do not entail demographic detail, these could be supplemented with manual counts, including those made with video footage.<sup>55</sup> We also advocate for the adoption of a national travel survey to improve overall estimates of injury risk and rates at the population level.<sup>56</sup>

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