Traveling by Bus Instead of Car on Urban Major Roads: Safety Benefits for Vehicle Occupants, Pedestrians and Cyclists

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ABSTRACT

Some studies have estimated fatality and injury rates for bus occupants, but data was aggregated at the country level and made no distinction between bus types. Also, injured pedestrians and cyclists, as a result of bus travel, were overlooked. We compared injury rates for car and city bus occupants on specific urban major roads, as well as the pedestrian and cyclist injuries associated with car and bus travel. We selected ten bus routes along major urban arterials (Montreal, Canada). Passenger-kilometres travelled were estimated from vehicle counts at intersections (2002-2010) and from bus passenger counts (2008). Police accident reports (2001-2010) provided injury data for all modes. Injury rates associated with car and bus travel were calculated for vehicle occupants, pedestrians and cyclists. Injury rate ratios were computed to compare the safety of travel by car and by bus. For all ten routes, the injury rate ratio is over three times greater (3.7, 95% CI [3.4, 4.0]) for car occupants than for bus occupants. The rate of pedestrian (4.1, 95% CI [3.5,4.9]) and cyclist (5.3, 95% CI [3.8, 7.6]) injuries, per hundred million passenger-kilometres travelled by car versus by bus, is significantly greater for car travel than for bus travel. Similar results were observed for fatally and severely injured vehicle occupants, pedestrians and cyclists. Results show that city bus is a safer mode than car, for bus passengers but also for pedestrians and cyclists travelling alongside these bus routes. On urban major roads, a modal shift from car to public transit may greatly improve road safety for all modes.

Keywords: road injuries, public transit and car safety, pedestrian and cyclist safety, injury rates and rate ratios.

INTRODUCTION

Road traffic is associated with several public health problems including urban air pollution, noise, physical inactivity and injury. A modal shift towards public transit and active modes of transportation could reduce traffic volumes and as a result reduce transportation-related health problems, not only in terms of reducing chronic diseases such as ischaemic heart disease, cerebrovascular disease, and diabetes, but also in reducing the number of traffic injuries and fatalities *(1)*.

According to several studies, the rate of death is lower for travel on public transport than in cars. For example, in the United States, fatality rates for car occupants are 23 times higher than for bus occupants, per 100 million person-trips *(2)*. Similarly in Australia, car occupants have 9 times greater rate of death than bus occupants, per hour travelled *(3)*. In Europe, car occupants have 10 times greater rate of death compared to bus occupants and 20 times greater rate of death than train occupants, per kilometre travelled *(4)*. The non-fatal injury rate is also higher for car occupants compared to bus occupants: 4.3 times higher per kilometer travelled in Norway *(5)* and 5.0 times higher per person-trips in the United States *(2)*.

Existing studies have focused on entire countries or groups of countries. However, the rate of traffic injury and death can vary widely by region, context (e.g. urban vs. rural), road type, and configuration of the road network *(6)*. A comparison of the safety of transportation modes at the country level may not apply at the local level. Furthermore, in most published studies, no distinction was made between different types of buses (ex. school bus, intercity, urban transit) *(2,4,7)*. Yet, understanding the safety benefits of public transit at the city level and for specific transport routes is likely to provide valuable information for mobilising city and transportation planners.

Few studies considered other injured road users (pedestrians, cyclists) in the comparative analysis of public transit versus cars and light vehicles. According to Litman, in the US the overall fatality rate (deaths per passenger-kilometres) associated with transit bus use - including deaths of bus occupants and other road users - is much lower than for passenger car and light truck travel *(8)*. Another country-level study found that buses were more likely to kill pedestrians than cars and light trucks *(9)*, but it used a measure of exposure based on vehicles (vehicle-miles) instead of passengers (passengers-miles) or individual trips, includes all types of bus travel, and it did not control for the volume of pedestrians, which might be greater on urban bus routes.

This work has two main objectives, to compare i) the rate of injury for car and city bus occupants on specific urban major roads and ii) pedestrian and cyclist injuries associated with car and bus travel.

METHODS

The study environment is the island of Montreal (Canada), with a population of 1.8 million. Travel by bus and metro (around 1.2 million trips per day) are managed by the Société de transport de Montreal (STM).

Traffic Routes

Figure 1 shows the density of accidents involving a bus from which the STM professionals identified ten routes with the highest number of injuries involving a bus (2007-2010). These ten routes were selected for analysis and were divided into road sections, defined by entry and exit points of bus routes. Road sections which did not form part of a STM bus route were excluded.

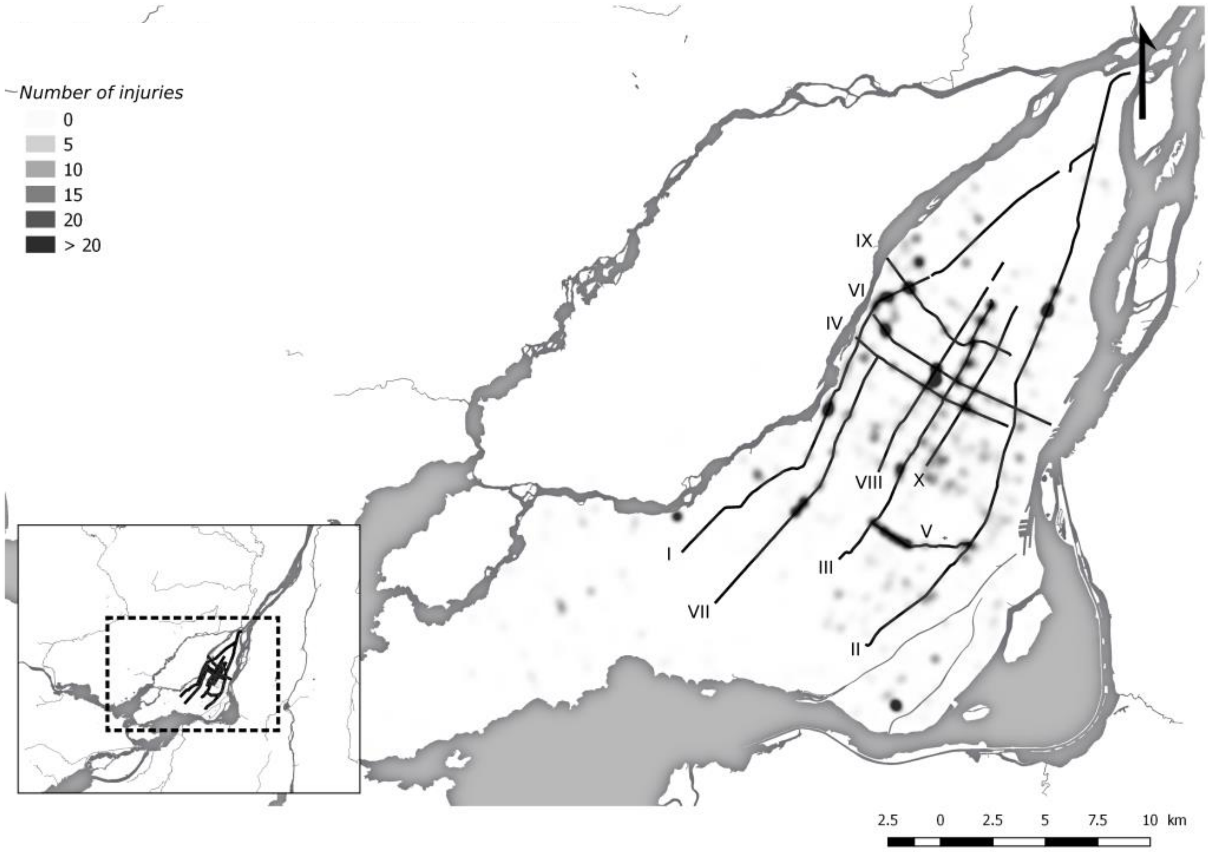

FIGURE 1 Density of injuries associated with a city bus (Montreal).

For every STM bus line, the number of persons entering and exiting the bus were counted for all stops over a 24-hour period, with automatic sensors installed on buses on a weekday, between September and December 2008 (data provided by STM). The daily number of bus passengers per road section was obtained by adding the number of passengers for each bus line traveling along the same road section.

Vehicle counts (2002-2010) at intersections along the ten selected routes were provided by the city of Montreal. The average daily number of vehicles was estimated for each vehicle direction (maximum 12 directions per intersection) using expansion factors (taking into account the time, day and month of the vehicles count) traditionally used to produce the average annual daily traffic (AADT) *(10)*. The daily number of vehicles on road sections - between intersections with vehicle counts - was calculated by taking the sum of all vehicles entering the section and subtracting all the vehicles exiting at the next intersection. For two-way road sections, this procedure was applied to both directions of vehicular traffic. The daily number of car occupants on a road section was obtained by multiplying the number of vehicles on this section by the average number (1.23) of car occupants in Montréal (based on the 2008 Origin-Destination Survey).

For car and bus travel, passenger-kilometres were obtained by multiplying the number of people traveling on a road section by the length of the section. Then, the passenger-kilometres on each road section were summed for the ten routes studied (Figure 2).

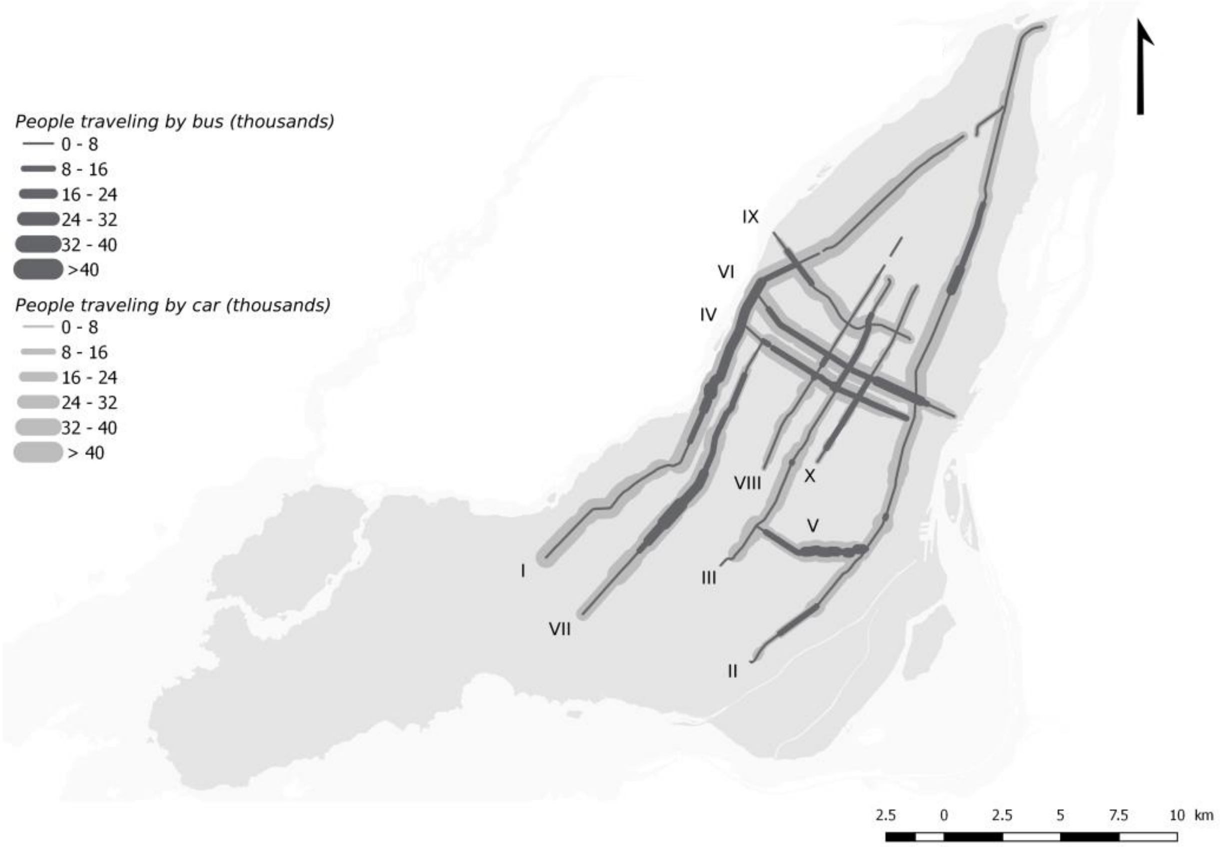

FIGURE 2 Daily number of people travelling by bus or car on ten bus routes (Montreal).

Collisions and Injuries

Collision and injury data were extracted from police accident reports for 2001-2010 (source: SAAQ) containing: date, collision location (address, name and street type), road user class (driver, passenger, pedestrian, cyclist), injury severity (minor, severe, and fatal), vehicle(s) involved in the accident, vehicle occupied by the injured person(s) (weight, type, function). Collisions that occurred on highways, on a Saturday or Sunday, or having caused only property damage (without injuries) were excluded from this study.

The collision data was geo-coded (assigned geographic coordinates, x and y) using the police station number and the address (house number and street name) or, at intersections, the name of the two streets as reported by the police.

Cars and light vehicles include cars, vans, and light trucks under 3000 kilograms, and excludes heavier vehicles (greater than 3000 kilograms). Collisions involving city buses were identified by the SAAQ, using the vehicle type and the registration number of the vehicle (Owner: STM). Thus, intercity buses and school buses were not included.

Analysis

The number of injuries associated with car travel was compared to the number of injuries associated with bus travel. First, the injury rate for vehicle occupants (drivers and passengers) was computed (equation 1). Secondly, the rates of pedestrians and cyclists injured by cars were compared to those injured by buses (equation 2).

The injury rate for car occupants and injury rates for pedestrians and cyclists injured by a car were calculated using equation (1):

$$Injury\ Rate\ = \frac{Number\ of\ persons\ injured}{Passenger - kilometres\ by\ car} \quad (1)$$

The injury rate for city bus occupants and injury rates for pedestrians and cyclists injured by a bus were calculated using equation (2):

$$Injury\ Rate\ = \frac{Number\ of\ persons\ injured}{Passenger - kilometres\ by\ city\ bus} \quad (2)$$

To compare the safety of travel by car and by city bus, rate ratios were calculated for injured vehicle occupants (cars and city buses), and for pedestrians and cyclists using equation (3):

$$Ratio\ of\ injured\ = \frac{Rate\ of\ injuries\ associated\ with\ car}{Rate\ of\ injuries\ associated\ with\ city\ bus} \quad (3)$$

Confidence intervals (CI, 95% thresholds) associated with the rate ratios of car to bus occupant injuries as well as pedestrian and cyclist injuries associated with car and bus travel were calculated. The computations for obtaining confidence intervals is shown through the following example. The relative rate of car occupant injuries to bus occupant injuries is expressed as $R = \frac{I_{car}}{I_{bus}}$. This relative rate is then estimated as $\hat{R} = \frac{\hat{I}_{car}}{\hat{I}_{bus}}$. The logarithm of $\hat{R}$ approximately follows a normal distribution with variance:

$$s_{\log(\widehat{R})}{}^2 = \frac{1}{number\ of\ car\ occupants\ injured} + \frac{1}{number\ of\ bus\ occupants\ injured}$$

Therefore a 95% confidence interval of the ratio of injury rates is computed as shown in equation (4):

$$\text{Confidence interval} = \hat{R}\ \exp[\pm 1.96\ s_{\log(\widehat{R})}] \quad (4)$$

Separate analysis was performed for all injuries (including minor, severe, and fatal) and for major injuries only (severe and fatal injuries). For all injuries, the injury rates were estimated for each of the ten routes and overall for all ten routes. However, for major injuries the injury rates were estimated overall for all ten routes since the number of major injuries associated with city buses was insufficient at the route level.

An additional step was carried out to estimate the safety benefits of bus travel. Two modal shift scenarios are considered: I) all transit travel is shifted to car, and II) 50% of car travel is shifted to bus. For both scenarios, the overall number of passenger-kilometres (by bus and by car) is kept constant. In scenario I, which estimates the safety benefits of actual bus travel, the car travel injury rate is applied to the new passenger-kilometres by car. In scenario II, which estimates the theoretical safety benefit of a modal shift towards public transit, the bus travel injury rate is applied to the new passenger-kilometres by bus.

RESULTS

Kilometres Travelled and Injured Road Users

For each studied route, the number of car occupants, bus occupants, pedestrians and cyclists injured in a car crash or a bus crash over the ten years from 2001 to 2010 are shown in Table 1. Overall, there were 4 times more passenger-kilometres travelled by car than by bus (1,133 versus

257 million annual passenger-kilometres) and 16 times more injured car occupants (10,892) than bus occupants (668). Most pedestrians (95%) and cyclists (96%) were injured by a car.

TABLE 1 Car (a) and Bus (b) Passenger-Kilometres, Total Injuries and Major Injuries

a) Car Travel*

Corridor	Million Pass-Km**	All Injuries			Severe and Fatal Injuries		
		Car Driver and Occupant	Cyclist	Pedestrian	Car Driver and Occupant	Cyclist	Pedestrian
I-Henri-Bourassa	292	1937	75	277	68	3	28
II-Sherbrooke	247	2348	298	504	53	13	56
III-Jean-Talon	91	1393	102	387	29	6	38
IV-Saint-Michel	77	859	49	219	20	3	17
V-Côte-des-Neiges	45	364	42	162	13	2	13
VI-Pie-IX	112	1115	71	242	34	4	29
VII-Côte-Vertu/Sauvé	118	759	38	191	12	3	21
VIII-Jarry	46	860	63	218	16	4	16
IX-Lacordaire	68	791	35	147	20	1	19
X-Beaubien	36	466	67	190	13	3	17
Total	1133	10892	840	2537	278	42	254

* Only includes road users injured in a crash involving a car. Injured bus occupants (n=233) and other injured road users (n=636) are not included.

** Pass-Km stands for passenger-kilometres

b) Bus Travel*

Corridor	Million Pass-Km**	All Injuries			Severe and Fatal Injuries		
		Bus Occupant	Cyclist	Pedestrian	Bus Occupant	Cyclist	Pedestrian
I-Henri-Bourassa	49	105	6	19	3	0	7
II-Sherbrooke	41	86	7	18	4	1	1
III-Jean-Talon	16	73	4	18	1	0	0
IV-Saint-Michel	24	62	6	15	1	0	0
V-Côte-des-Neiges	18	53	2	8	1	0	0
VI-Pie-IX	31	75	2	21	0	0	6
VII-Côte-Vertu/Sauvé	40	67	2	15	0	0	0
VIII-Jarry	10	42	2	14	0	0	1
IX-Lacordaire	13	51	4	5	0	0	0
X-Beaubien	14	54	1	7	0	0	0
Total	257	668	36	140	10	1	15

* Only includes road users injured in a crash involving a city bus. Injured car occupants (n=229) and other injured road users (n=40) are not included.

** Pass-Km stands for passenger-kilometres

Looking at major injuries only (excluding minor injuries), there were 28 times more injured car occupants (n=278, including 19 deaths) than bus occupants (n=10, no deaths). Cars were associated with 3 cyclist deaths and 42 pedestrian deaths while buses were associated with no cyclist deaths and 4 pedestrian deaths.

Injury Rate for Vehicle Occupants

Overall, the injury rate for car occupants is 96.1 injured car drivers or passengers per hundred million passenger-kilometres (values range from 64.5 to 185.8 depending on the route) whereas the injury rate for bus occupants is 25.9 per hundred million passenger-kilometres (values range from 16.8 to 46.8 depending on the route) (Table 2).

Figure 3a shows the injury rate ratio for each route and overall, for all ten routes as another way to compare the rate of injury for car and bus occupants. Overall, the ratio between car and bus occupant injury rates is 3.7, showing that the rate of injury is greater for car occupants than for bus occupants per kilometre travelled. For each route, the injury rate ratio is significantly greater than one and, depending on the route, range from 2.7 to 4.6. The rate of fatally or severely injured vehicle occupants is 6 times greater for car occupants than for bus occupants (ratio=6.3, 95% CI [3.4, 13.3]) (Table 2).

Pedestrian and Cyclist Injury Rates Associated with Car and Bus Travel

We quantified and compared pedestrian and cyclist injury rates associated with car and bus travel (Table 2 and Figure 3).

Looking at the same ten routes, the rate of pedestrian injury associated with car travel is 22.4 injured pedestrians per hundred million car passenger-kilometres (values range from 9.5 to 52.9 depending on the route) whereas the rate associated with bus travel is 5.4 injured pedestrians per hundred million passenger-kilometres (values range from 3.8 to 13.4 depending on the route). Overall, for all ten routes, the rate of pedestrian injury is 4.1 (95% CI [3.5, 4.9]) times greater for car passenger-kilometres than for bus passenger-kilometres. Depending on the route, the rate ratios range from 2.5 to 10.8 (Figure 3b). The rate of pedestrians fatally or severely injured is almost 4 times greater for car passenger-kilometres than for bus passenger-kilometres (ratio=3.9, 95% CI [2.3, 6.99]) (Table 2).

On average, the rate of cyclist injury associated with car travel is 7.4 injured cyclists per hundred million passenger-kilometres (values range from 2.6 to 18.6 depending on the route) whereas the rate associated with buses is 1.4 per hundred million passenger-kilometres (values range from 0.5 to 3.0 depending on the route). Overall, the rate of cyclist injury is 5.3 (95% CI [3.8, 7.6]) times greater for car passenger-kilometres than bus passenger-kilometres. Depending on the route, the rate ratios range from 1.7 to 26.7 (Figure 3c).The rate of cyclists fatally or severely injured is over 9 times greater for car passenger-kilometres than for bus passenger-kilometres (ratio=9.3, 95% CI [1.6, 386.6]) (Table 2).

TABLE 2 Injury Rates Associated with Car and Bus Travel

a) All Injuries

Corridor	Car			Bus		
	Car driver and occupant	Cyclist	Pedestrian	Bus occupant	Cyclist	Pedestrian
I-Henri-Bourassa	66.4	2.6	9.5	21.3	1.2	3.9
II-Sherbrooke	95.0	12.1	20.4	20.7	1.7	4.3
III-Jean-Talon	152.8	11.2	42.4	46.8	2.6	11.5
IV-Saint-Michel	111.8	6.4	28.5	25.8	2.5	6.2
V-Côte-des-Neiges	80.3	9.3	35.7	29.6	1.1	4.5
VI-Pie-IX	99.1	6.3	21.5	23.9	0.6	6.7
VII-Côte-Vertu/Sauvé	64.5	3.2	16.2	16.8	0.5	3.8
VIII-Jarry	185.8	13.6	47.1	40.1	1.9	13.4
IX-Lacordaire	115.7	5.1	21.5	38.8	3.0	3.8
X-Beaubien	129.6	18.6	52.9	37.7	0.7	4.9
Total (all injuries)	96.1	7.4	22.4	25.9	1.4	5.4

b) Major Injuries

Corridor	Car			Bus		
	Car driver and occupant	Cyclist	Pedestrian	Bus occupant	Cyclist	Pedestrian
Severe injuries	2.29	0.34	1.87	0.39	0.04	0.43
Fatal injuries	0.17	0.03	0.37	0.00	0.00	0.16
Total (severe and fatal)	2.45	0.37	2.24	0.39	0.04	0.58

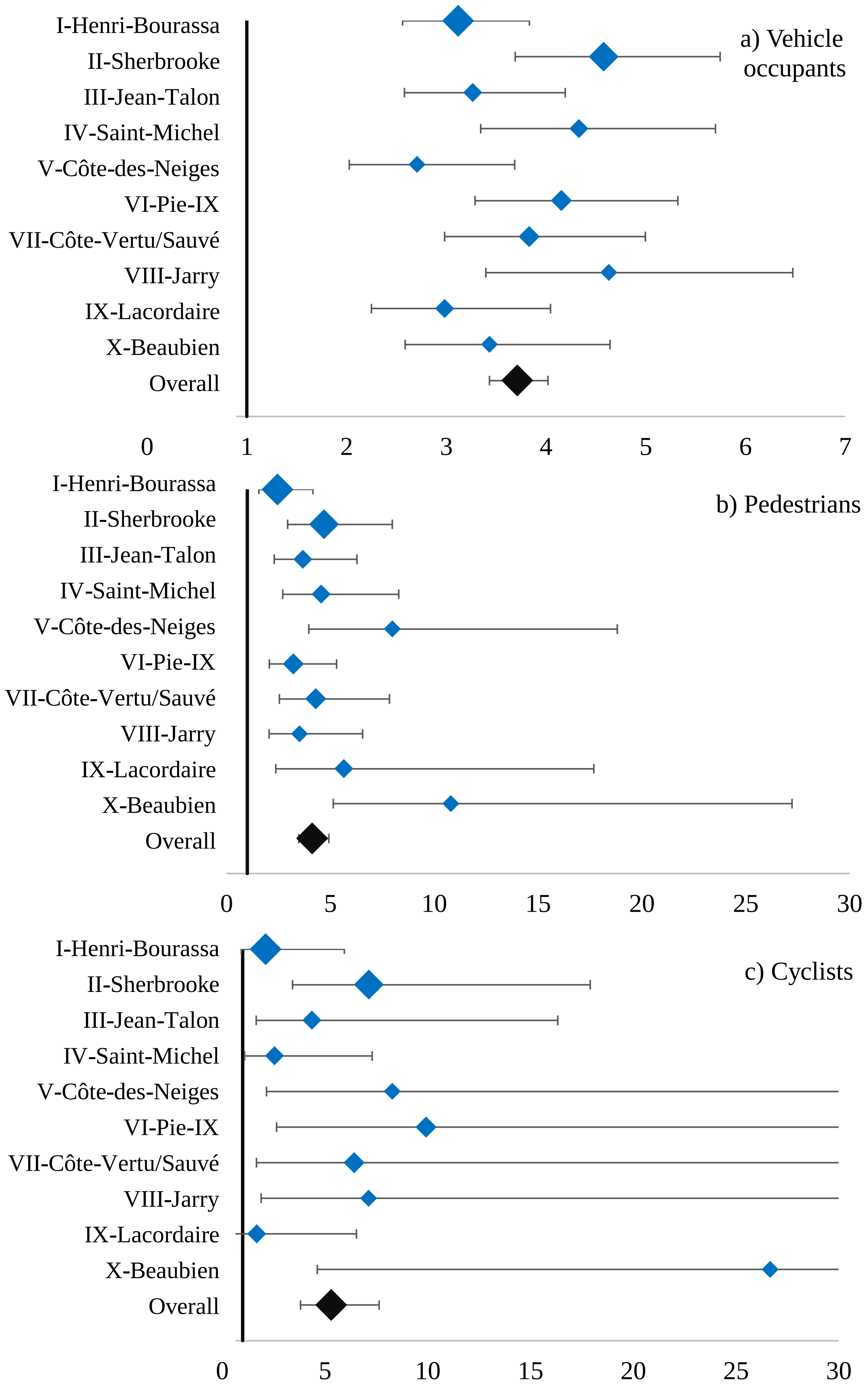

FIGURE 3 Injury rate ratio associated with car and bus travel (per 100 million passenger-kilometres) for a) vehicle occupants b) pedestrians, and c) cyclists.
(Marker size is proportional to the total number of passenger-kilometres (car and bus))

Expected Number of Injuries Resulting from Modal Shift Scenarios

Table 3 shows the estimated number of injuries for scenario I (all passenger-kilometres travelled by car) and scenario II (50% of car travel shifted to bus). According to scenario I, the kilometres travelled by bus (257 million passenger-kilometres) "saved" 1,803 vehicle occupant, 435 pedestrian and 155 cyclist injuries from 2001-2010. If 50% of car travel is shifted to bus, according to scenario II, this would represent 567 passenger-kilometres travelled by car and 824 passenger-kilometres travelled by bus and there would be 3,969 (-34%) less injured vehicle occupants, 340 (-39%) less injured pedestrians and 959 (-36%) less injured cyclists (Table 3).

TABLE 3 Expected Number of Injuries Resulting from Modal Shift Scenarios

	All Injuries				Severe and Fatal Injuries			
	Vehicle occupant**	Cyclist	Pedestrian	Total	Vehicle occupant**	Cyclist	Pedestrian	Total
Observed car and bus injuries (2000-2010)	11560	876	2677	15113	288	43	269	600
Scenario I (all travel by car)*								
Total number of injuries	13363	1031	3112	17506	341	52	312	704
Difference w.r.t.*** observed number	1803	155	435	2393	53	9	43	104
(%)	(+16%)	(+18%)	(+16%)	(+16%)	(+18%)	(+20%)	(+16%)	(+17%)
Scenario II (50% of car travel shifted to bus)*								
Total number of injuries	7591	536	1718	9845	171	24	175	371
Difference w.r.t.*** observed number	-3969	-340	-959	-5268	-117	-19	-94	-229
(%)	(-34%)	(-39%)	(-36%)	(-35%)	(-41%)	(-44%)	(-35%)	(-38%)

* In scenario I, all 1390 million passenger-kilometres are made by car. In Scenario II, 50% of car travel (567 million passenger-kilometres) are shifted from car to bus, resulting in 824 and 567 million passenger-kilometres made by bus and car, respectively.
** Vehicle occupants includes injured car and bus occupants.
*** w.r.t stands for with respect to.

CONCLUSION AND FUTURE WORK

This study achieved its objectives of comparing vehicle occupant, pedestrian and cyclist injuries associated with car and city bus travel. Looking at ten routes with the most bus collisions, results reveal that, per kilometer travelled, bus travel is not only safer for vehicle occupants but also for pedestrians and cyclists on these routes. The rate ratio of injuries associated with car versus bus travel are consistent across the ten different routes and are quite similar to previously published estimates for non-fatal injuries.

We estimated that a 50% modal shift from car toward bus would prevent 35% of all injuries and 38% of severe injuries. The benefits may be underestimated, because we did not take into account the effect of having fewer vehicles on the road, the risk reduction - for all road users - associated with a reduction in traffic volume *(11)*. However, the benefits may also be overestimated, because a modal shift towards public transit would likely increase the number of pedestrians and which is associated with an increase in pedestrian casualties *(5)* or in the overall number of road casualties *(1)*. It is worth mentioning that in Canada's large metropolitan areas, transit access points are concentrated at intersections of wide major roads with the greatest rate of crashes *(12)* and pedestrian injuries *(13)*. To offset an increase in pedestrian exposure to crashes, a large reduction in traffic volume and the area-wide implementation of traffic calming measures and safer pedestrian crossings might be needed.

This study addressed some of the main shortcomings in the current literature. We only considered city buses and estimated car and bus passenger-kilometres along the ten chosen routes. To compare injury rates between bus and car travel, each route served as its own control therefore controlling, to some degree, for roadway environment, pedestrian and cyclist volumes. No previous studies have compared the rate of injury for car and bus occupants at such a disaggregate level. Also, no studies have considered the rate of cyclist and pedestrian injury associated with car and bus travel.

This study has some limitations. Injury rates were aggregated for each of the ten routes. Road typology as well as geometric design and built environment are likely to vary throughout the route and therefore the injury rate is also likely to vary along the route. Both car and bus injuries came from the same data source, but passenger-kilometers were estimated through different data sources. An overestimation of bus travel or an underestimation of car travel would partially explain the observed results, but this study is likely over-estimating the car passenger-kilometres. For car travel, all types of vehicles were considered by the vehicle counts - even heavy trucks and buses - while only injuries associated with vehicles under 3 000 kilogrqams were included. Future research may take into account the influence of geometric design of roads and include injuries associated with the walking portion of public transit trips.

This study suggests that there is great potential for road safety improvement if there is a modal shift from car to bus, since bus is the safer mode not only for vehicle occupants but also for pedestrians and cyclists.

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