Association Between Neighbourhood Marginalization and Pedestrian and Cyclist Collisions in Toronto Intersections

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ABSTRACT

OBJECTIVE: Pedestrian and cyclist collisions comprise a significant proportion of preventable injury. In urban settings, collision rates have been linked to various socio-demographic factors. We sought to determine whether neighbourhood marginalization affects pedestrian and cyclist collisions in the Greater Toronto Area.

METHODS: For 114 intersections, pedestrian and cyclist collisions were extracted from the Toronto Traffic Data Centre database. We used a geographic information system approach to determine census Dissemination Areas and an associated Ontario Marginalization Index (ON-Marg) for each intersection. We performed a logistic regression to examine the associations between the four ON-Marg dimensions (residential instability, material deprivation, dependency, ethnic concentration) and pedestrian and cyclist collisions.

RESULTS: The odds of sustaining a collision were independently associated with residential instability for both pedestrians (OR 1.84, 95% CI 1.21-2.84, p=0.006) and cyclists (OR 2.04, 95% CI 1.34-3.16, p=0.001). Higher overall collision rates (both pedestrian and cyclist) were associated with both ethnic concentration (OR 1.56, 95% CI 1.05-2.37, p=0.033) and residential instability (OR 2.16, 95% CI 1.43-3.38, p=0.001). Material deprivation and dependency were not significant risk factors for intersection collisions in this model.

CONCLUSIONS: Collisions involving pedestrians and cyclists are more common in areas of increased residential instability and ethnic concentration in Toronto. Intersections in neighbourhoods with these characteristics could be targeted for strategies to reduce pedestrian and cyclist injury risk in urban settings.

KEY WORDS: Pedestrian collisions; cyclist collisions; neighbourhood; social marginalization; risk factors; ON-Marg

La traduction du résumé se trouve à la fin de l'article.

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Traffic-related collisions comprise a significant proportion of preventable injury. In 2009 the World Health Organization ranked road traffic accidents the ninth leading cause of death, accounting for 1.21 million deaths and up to 50 million injuries per year.[1,2] Worldwide, nearly half of people who die in traffic collisions are vulnerable road users: pedestrians, cyclists and motorized 2-wheeler users.[2] In Canada, there were 199,337 road-traffic-related injuries and 2,889 fatalities in 2006; pedestrians comprised 13% and cyclists 3% of these deaths.[1] Though fatalities are fewer in developed countries and have decreased significantly over the last three decades, the physical, financial and psychosocial costs for the over 30,000 pedestrians and cyclists injured in Canada per year remain high. There is particular concern in large urban centres, where pedestrian and cyclist collisions may occur at higher rates due to increased vehicle and pedestrian traffic.

Intersections are complex geographical entities with high potential for road traffic collisions; two thirds of Ontario cyclist–motorist collisions occur in intersections.[3,4] Preston and colleagues[5] found that 55% of accidents and 80% of fatal crashes in Minnesota occurred at stop-controlled intersections. Characteristics that increase the complexity of intersections include vehicle turning, pedestrian and traffic volumes, and built infrastructure, including number of lanes, presence of traffic-slowing methods (e.g., speed humps), roundabouts, bicycle lanes, paths or shared lanes, crosswalks, and transit stop usage.[6-8]

Several studies have considered environmental, behavioural and socio-demographic risk factors for collisions in urban intersections. Environmental factors that increased collision risk included speed limits exceeding 50 km/h and lack of pedestrian signals.[9,10] Behavioural factors included alcohol intoxication, total driver violations, and lack of pedestrian supervision.[9,10] With respect to socio-demographic factors, injured pedestrians tend to be children and the elderly, predominantly male, Aboriginal, from low-income families or residing in neighbourhoods with low median home values.[9,10] Similar environmental, behavioural and demographic trends are expected for cyclists, but evidence is minimal in the literature to date.

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Table 1. Dimensions of Marginalization (ON-Marg) Terms

ON-Marg Dimension	Description	Factors That Increase Marginalization Score
Residential Instability (RI)	Tendency of neighbourhood inhabitants to fluctuate over time	Proportion of population >16 years old Proportion of population not married Proportion of population living alone Proportion of population recently moved (within last 5 years) Proportion of homes that are apartments Proportion of homes that are not owned Average number of persons per residence
Material Deprivation (MD)	Socio-economic privilege, including housing, education, income and employment	Proportion of lone-parent families Proportion of homes needing major repair Proportion of population without certificate, diploma or degree Proportion considered low-income Proportion unemployed Proportion receiving government transfer payments
Dependency (DP)	Reliance on the workforce	Proportion of population >65 years old Proportion of population participating in labour force Ratio of population 15-65 years old to population <15 and >65
Ethnic Concentration (EC)	Community make-up of immigrant populations	Proportion who are recent immigrants (within last 5 years) Proportion who self-identify as visible minority

Adapted from Matheson et al. ON-Marg User Guide.[16]

Socio-demographic trends are associated with significant variations in road collision rates. Globally, 90% of road traffic fatalities, including vulnerable road user deaths, occur in low- and middle-income countries, which possess only 48% of the world's vehicles.[1] A cross-Canada study from 2001-2005 showed a graded inverse relationship between neighbourhood socio-economic status and hospitalization among child pedestrians and cyclists.[11] Similarly, a large study in a Southern California County identified several socio-demographic risk factors for neighbourhoods at high risk for pedestrian injuries: high population density, and percentage of residents who are under 14, did not complete high school, spoke English less than "very well", spoke another language at home, or had low income.[12]

Socio-demographic factors have been linked to various health outcomes by the Ontario Marginalization Index (ON-Marg), developed by Matheson and colleagues.[13] The ON-Marg is a validated census- and geographically-based index that highlights differences in marginalization between geographical regions and explores inequalities in social well-being and health.[14,15] ON-Marg 2006 was derived from responses to the 2006 extended census and quantifies four dimensions of marginalization: Residential Instability (RI), Material Deprivation (MD), Dependency (DP), and Ethnic Concentration (EC).[16] These dimensions provide a comprehensive definition of marginalization in comparison to individual census parameters alone. To date, ON-Marg has not been studied in association with road-traffic safety.

The purpose of the current study was to utilize the ON-Marg in conjunction with traffic collision data to explore the relationship between neighbourhood socio-demographic factors and pedestrian and cyclist collisions in intersections in Toronto.

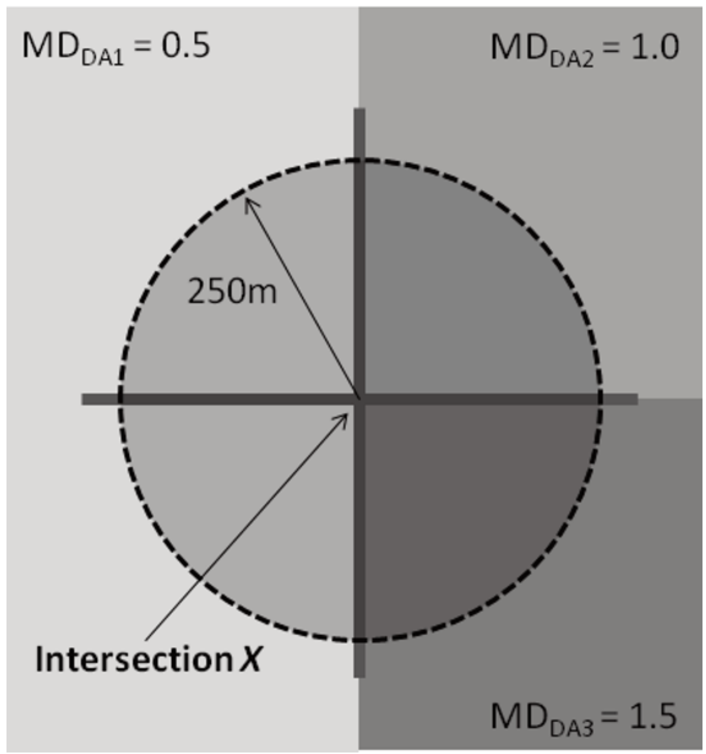
METHODS

A Geographical Information System (GIS)-based approach was used to extract socio-demographic characteristics derived from the 2006 Canadian census. The Ethics Review Board of the Office of Research Services at St. Michael's Hospital approved the study.

Step 1: Identify study intersections

One hundred fourteen intersections (n=114) in Toronto were criteria-selected and matched by various road characteristics.

Figure 1. Example factor score calculation for intersection bordering multiple dissemination areas



If $A_{DA1\text{-}overlap}$ = 100,000 m², $A_{DA2\text{-}overlap}$ = 50,000 m², $A_{DA3\text{-}overlap}$ = 50,000 m², *(i = X, j = 1:3)*: then, MD_X = (0.5 * 100,000 + 1.0 * 50,000 + 1.5 * 50,000) / (100,000 + 50,000 + 50,000) = 1.125. This means that intersection *X* has *MD* just over one standard deviation above the Ontario average.

Intersections were spread throughout the city and met the following criteria: road meetings signalized with traffic lights; where turning or crossing movements are possible for motorists; in which vehicular and pedestrian flow volume is available; excluding grade-separation (i.e., tunnels, overpass).

Step 2: Quantify number of collisions and flow of pedestrians and cyclists

Pedestrian and cyclist collision information was extracted from the Toronto Traffic Data Centre (TTDC) database which consolidates

Table 2. Logistic Regression Model: Risk Quartiles and Odds Ratios

	Pedestrian (ped)		Cyclist (cyc)		Total (ped+cyc)	
Risk Quartile	# coll	# int	# coll	# int	# coll	# int
1 (low)	0-2	28	0	23	0-3	22
2	3-5	32	1-2	34	4-7	36
3	6-8	24	3-4	26	8-12	26
4 (high)	9+	30	5+	31	13+	30
ON-Marg Index	OR	95% CI	OR	95% CI	OR	95% CI
RI	1.84*	1.21-2.84	2.04*	1.34-3.16	2.16*	1.43-3.38
MD	1.19	0.74-1.94	1.01	0.62-1.66	1.18	0.73-1.95
DP	1.28	0.66-2.53	0.89	0.45-1.73	1.19	0.62-2.33
EC	1.41†	0.96-2.11	1.42†	0.96-2.15	1.56*	1.05-2.37

Risk Quartiles: 1 = lowest risk to 4 = highest risk; # coll = number of collisions defining quartiles; # int = number of intersections per quartile; OR = odds ratio; CI = confidence interval; RI = residential instability; MD = material deprivation; DP = dependency; EC = ethnic concentration.
* Statistically significant ($p<0.05$).
† Marginally significant ($0.05<p<0.10$).

data from hospital records and Toronto Police Service Collision Reporting Centres. Collisions between a pedestrian or cyclist and a motorized vehicle occurring in or within 20 metres of the 114 intersections of interest from 2001 to 2006 were counted. The TTDC database provided intersection flow volumes for pedestrians, cyclists and total vehicular traffic. Eight-hour total flow counts were recorded on a random weekday from 07:30-09:30, 10:00-12:00, 12:30-14:30, and 15:00-17:00 between 2004 and 2006. The month and season of each count were also recorded. With access to flow count data, we applied Wachtel-Lewiston (WL) criterion to evaluate relative collision risk for pedestrians (R_{ped}) and cyclists (R_{cyc}) at each intersection.[17] The WL risk normalizes the number of collisions occurring in an intersection by vehicle flow (i.e., number of collisions divided by observed pedestrian or cyclist flow over an eight-hour period). However, our preliminary analysis revealed that eight-hour traffic tallies varied considerably by month of count and did not provide an accurate estimation of relative collision risk. Therefore, this report focuses on total pedestrian and cyclist collisions occurring in these intersections; total collisions were averaged uniformly over the six-year period and were thus not subject to systemic errors inherent in the flow data.

Step 3: Identify census regions near intersections and associated factor scores

ArcMap GIS software was used to extract neighbourhood socio-demographic characteristics. A 250-metre circular buffer was generated around each intersection using latitude-longitude coordinates to determine overlapping census Dissemination Areas (DAs). DAs are compact, relatively stable regions that respect boundaries of census subdivisions and other land features. DAs are designed to be uniform in population size and are the smallest geographical units with publicly available census data. The buffer zone captured average geographically-based properties of intersections bordering multiple DAs and its size was selected such that it did not exceed DA dimensions, consistent with buffers used in previous studies.[6] For each intersection, an area factor ($A_{DA\text{-}overlap}$) was assigned to nearby DAs based on land area (m^2) overlapping with the buffer zone.

ON-Marg factor scores for RI, MD, DP, and EC were recorded for all DAs overlapping 114 generated buffer zones. Table 1 summarizes the census factors associated with each ON-Marg dimension. DAs for which no census data were available (e.g., commercial, industrial, parkland space) were excluded from these calculations. ON-Marg dimension scores are derived based on standardized CAN-Marg scores, which have a mean of 0 and standard deviation of 1, with higher factor scores corresponding to more marginalized areas.

Step 4: Assign socio-demographic factor scores for each intersection

For each intersection, ON-Marg indices ($I = RI, MD, DP, EC$) were calculated by a weighted average based on DA area overlapping the buffer, $A_{DA\text{-}overlap}$.[6] Equation 1 calculates index I for a given intersection (i) with buffer zone overlapping multiple DAs.

$$I_i = \Sigma\,(1{:}j)\,[Ij * Ai_{DAj\text{-}overlap}] \,/\, \Sigma\,(1{:}j)\,[Ai_{DAj\text{-}overlap}] \qquad \text{(Eq. 1)}$$

where $I_i = RI, MD, DP$ or EC for intersection "i" (i=1:114), I_{DAj} = index for DA "j", and $A_{iDAj\text{-}overlap}$ = area of the circular buffer overlapping with DA_j. Note that the denominator is equivalent to the area of a circle of radius 250 m. Figure 1 illustrates a numerical example with an intersection near three DAs.

The ON-Marg factor scores averaged across intersections 1 to 114 were then compared to Ontario averages using an unpaired two-tailed t-test assuming a normal distribution of factor scores.

Step 5: Evaluate association between ON-Marg index and collision frequency

Ordered logistic regression was used to assess the extent to which ON-Marg indices were related to total pedestrian and bicycle collisions. Intersections were categorized into quartiles based on collision frequency. The odds ratios and 95% confidence intervals represent estimates of the likelihood of being in higher-collision categories based on unit increases in Ontario marginalization indices.

RESULTS

Collisions summary

In total, 1,194 pedestrian and cyclist collisions occurred at or within 20 m of the 114 intersections between 2001 and 2006. There were 738 pedestrian collisions: per-intersection median 5, range 0-32. There were 456 cyclist collisions: median 2.5, range 0-23.

Collision risk and socio-demographic characteristics

Ordered logistic regression was used to predict the odds of being in a collision based on the four ON-Marg dimensions as predictor(s) in the model, with total number of collisions at an intersection as outcome data. Convergence criteria were satisfied for all models and the proportional odds assumption was not violated ($p>0.05$).

Table 2 summarizes the breakdown of quartiles of pedestrian collisions, cyclist collisions, and total collisions used for each of the logistic regressions.

For pedestrian collisions, the multivariate model identified residential instability (OR 1.84, 95% CI 1.21-2.84) as an independently predictive variable for greater number of collisions at an intersection. RI was also predictive for cyclist collisions (OR 2.04, 95% CI 1.34-3.38). EC approached statistical significance when pedestrian or cyclist collisions were considered independently (pedestrians, OR 1.41, 95% CI 0.96-2.11; cyclists, OR 1.42, 95% CI 0.96-2.15). When considered together, total pedestrian and cyclist collisions were associated with higher EC (OR 1.56, 95% 1.05-2.37) and RI (OR 2.16, 95% 1.43-3.38). MD and DP were not associated with collision incidence.

ON-Marg of study intersections vs. Ontario average

When comparing ON-Marg averages of the 114 Toronto intersections in this study to the provincial average, the intersections included had significantly higher RI (1.08 ± 0.95 vs. -0.16 ± 0.95, p<0.001) and EC (1.22 ± 1.00 vs. 0.20 ± 1.13, p<0.001), as well as lower DP ratings (-0.29 ± 0.54 vs. -0.03 ± 0.94, p<0.001). No significant differences were found for MD (-0.21 ± 0.91 vs. -0.16 ± 0.89, p=0.57) between these intersections and the Ontario average.

DISCUSSION

The purpose of this study was to evaluate geographical variations in collision rates and to identify neighbourhood factors that impact injury risk for vulnerable road users. We examined the relationship between four dimensions of marginalization in Ontario and collision frequency for pedestrians and cyclists. Ethnic concentration and residential instability increased the odds of greater numbers of pedestrian and cyclist collisions.

Previous research[11] examining neighbourhood factors and motor vehicle incidents in Canada used raw census data (average income per single person equivalent) in their analyses. The benefit of the ON-Marg was its multidimensional nature, incorporating several census variables and considering various realms of neighbourhood marginalization. The ON-Marg dimensions were validated and specifically designed to assess regional differences in health outcomes. Previous research using ON-Marg has shown its utility in examining depression, stress, alcoholism and self-reported health.[14,15] The current study is the first of its kind to relate the ON-Marg to road traffic collisions in an urban setting.

The ordered logistic regression model identified high ethnic concentration and residential instability as predictive neighbourhood variables for increased pedestrian and cyclist collisions. The relationship between EC and collisions was consistent with previous studies that considered pedestrian victim characteristics.[12] This association may be related to: a higher child population in those areas; decreased familiarity with local road rules; differences in cultural norms; or language barriers to signage within these communities. Alternatively, this population may have a higher tendency to live in areas with poorer road safety infrastructure; interestingly, however, average EC did not differ between the 35 intersections in the downtown core and the 79 outside the core. On the other hand, RI was (1.5 units) higher downtown and collision rates were expectedly higher in these areas. This may be explained by more people living close enough to walk, cycle, or use public transit to get to work. Although many argue for safety in numbers due to increased motorist awareness, the current study shows that more collisions occurred in areas of high RI.

It is important to recognize that these results do not confer an increased individualized risk for a given pedestrian or cyclist in marginalized areas, but rather identify areas at high overall collision risk that may be targeted by policy-makers working in injury prevention. That is, the ON-Marg dimensions do not directly reflect the individuals involved in collisions but rather those living in surrounding neighbourhoods. From an injury prevention standpoint at the population level, this makes the ON-Marg an effective tool for studying regional variations in injury frequency as highly marginalized areas can be explored for mechanisms that increase collision rates.

We recognize physical infrastructure as an important variable that potentially confounds the effects of neighbourhood marginalization on collision frequency; therefore, future studies should consider the built infrastructure to provide additional insight to improve dangerous intersections in Toronto. For example, when considering its association with collisions, the ON-Marg may be a surrogate marker of physical infrastructure. While several studies have considered the environmental and socio-demographic risk factors for collisions, few have made suggestions about relationships between these factors. From the results in this study, we may suppose that in areas of high EC there should be clear and simple signage. As children are at increased risk in these areas, the addition and maintenance of sidewalks and well-marked crosswalks for drivers and pedestrians on busy streets may reduce collisions. In high-volume areas, such as those in high-RI neighbourhoods, separated bicycle tracks (which are popular in Ottawa) are associated with fewer collisions.[18] Beyond informed suggestions, however, few prospective studies exist that have examined the effects of such interventions. Moreover, physical infrastructure is unlikely to be the only factor ON-Marg measures, as evidenced by unpredictable distributions in marginalization scores in the downtown core versus outside the core (with the exception of the higher RI downtown owing to a larger population of young professionals living in rented apartments and commuting). With the ON-Marg validated for predicting vulnerable areas, targeted studies can employ the ON-Marg to compare characteristics of built infrastructure without requiring long study periods for accidents to occur. Municipal governments in large cities can then use the ON-Marg (or CAN-Marg) to predict neighbourhoods at high risk for collisions and provide targeted interventions to prevent collisions involving vulnerable road users.

We compared the neighbourhoods in this study to the provincial average to evaluate the extent to which these trends can be applied across the country. We would hypothesize that higher RI in Toronto (vs. Ontario) may be related to high cost of urban real estate which keeps many young professionals renting, especially in the downtown core. Higher EC was not surprising in a large multicultural centre with many employment and cultural opportunities for new immigrants. Similar trends are expected in other large urban settings in Canada, therefore we believe that the results of this study are applicable to major cities across the country.

This study is not without limitations. First, a significant challenge was the inadequacy of flow data, which reduced the ability to accurately estimate risk to a single pedestrian or cyclist passing through an intersection. This necessitated use of raw collision statistics rather than proportions of vulnerable road users. This is frequently encountered in studies of pedestrian and cyclist collisions. This limitation did not significantly influence the current study design because interventions grounded in these results would still prevent the highest number of injuries. Nonetheless, transportation engineers at the TTDC and elsewhere continue to explore solutions to improve the accuracy of pedestrian and cyclist flow counts.

Second, the relative infrequency of collisions requires long study periods for accurate risk assessment and this is exacerbated by under-reporting of non-motorist collisions; as many as 88% of these collisions may go unreported, especially when there are no major injuries requiring hospitalization.[19] To manage this limitation, we examined six years of collision data to establish significant numbers and compiled both police and hospital records of accidents to reduce the effect of under-reporting of minor injuries. Injury severity is an important variable in collision reporting and may bias results. For example, in areas of high RI there are more pedestrians and cyclists but speed limits are generally slower, conferring a reduced severity of injury due to low-velocity impact and an increased tendency not to report. The relationship between RI and collisions may therefore be even stronger than that reported in this study. On the other hand, some areas with higher EC (immigrant populations) may have more children and reduced helmet use, factors which increase collision severity and the bias towards reporting.

Last, intersection pre-selection may have skewed spatial sampling of collision data, however this was preferred to using geographically equidistant intersections that were less uniform in road characteristics and could limit future study of confounding variables such as physical infrastructure. The current approach proved effective in analyzing relative trends in marginalization.

In summary, pedestrian and cyclist collisions were predicted by areas of increased residential instability and ethnic concentration. These results help to identify neighbourhoods where targeted interventions may effectively prevent injuries to vulnerable road users.

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RÉSUMÉ

OBJECTIF : Les collisions avec des piétons et des cyclistes représentent une proportion importante des blessures évitables. En milieu urbain, les taux de collision ont été liés à divers facteurs sociodémographiques. Nous avons voulu déterminer si la marginalisation du quartier a un effet sur les collisions avec des piétons et des cyclistes dans la région du Grand Toronto.

MÉTHODE : Pour 114 intersections, nous avons extrait les données sur les collisions avec des piétons et des cyclistes de la base du Centre de données sur la circulation de Toronto. Nous avons utilisé l'approche d'un système d'information géographique pour déterminer les aires de diffusion du Recensement et associer un indice de marginalisation ontarien (ON-Marg) à chaque intersection. Par régression logistique, nous avons examiné les associations entre les quatre dimensions de l'ON-Marg (instabilité résidentielle, défavorisation matérielle, dépendance, concentration ethnique) et les collisions avec des piétons et des cyclistes.

RÉSULTATS : La probabilité de subir une collision était indépendamment associée à l'instabilité résidentielle, tant pour les piétons (RC : 1,84, IC de 95 % : 1,21-2,84, p=0,006) que pour les cyclistes (RC : 2,04, IC de 95 % : 1,34-3,16, p=0,001). Les taux de collision globaux plus élevés (piétons et cyclistes) étaient associés à la fois à la concentration ethnique (RC : 1,56, IC de 95 % : 1,05-2,37, p=0,033) et à l'instabilité résidentielle (RC : 2,16, IC de 95 % : 1,43-3,38, p=0,001). La défavorisation matérielle et la dépendance n'étaient pas des facteurs de risque significatifs pour les collisions aux intersections dans ce modèle.

CONCLUSIONS : Les collisions avec des piétons et des cyclistes sont plus courantes dans les zones de Toronto où l'instabilité résidentielle et la concentration ethnique sont élevées. On pourrait cibler les intersections dans les quartiers possédant ces caractéristiques pour réduire les risques de blessures des piétons et des cyclistes en milieu urbain.

MOTS CLÉS : collisions avec des piétons; collisions avec des cyclistes; quartier; marginalisation sociale; facteurs de risque; ON-Marg