Are Child Pedestrians at Increased Risk of Injury on One-way Compared to Two-way Streets?

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ABSTRACT

Objectives: To compare child pedestrian injury rates on one-way versus two-way streets in Hamilton, and examine whether the characteristics of child pedestrian injuries differ across street types.

Methods: The rates of injury per child population, per kilometre, per year were calculated by age, sex and socio-economic status (SES). Child, environment and driver characteristics were investigated by street type.

Results: The injury rate was 2.5 times higher on one-way streets than on two-way streets and 3 times higher for children from the poorest neighbourhoods than for those from wealthier neighbourhoods. SES, injury severity, number of lanes, collision location and type of traffic control were also found to be significantly different across street types.

Conclusions: One-way streets have higher rates of child pedestrian injuries than two-way streets in this community. Future risk factor and intervention studies should include the directionality of streets to further investigate its contribution to child pedestrian injuries.

ABRÉGÉ

Objectifs : Comparer les taux de blessures chez les enfants-piétons dans les rues à sens unique par opposition aux rues à double sens à Hamilton, et voir si les caractéristiques de ces blessures varient en fonction du type de rue.

Méthodes : On a calculé les taux de blessures par enfant, par kilomètre et par année en fonction de l'âge, du sexe et de la situation socio-économique. On a examiné les caractéristiques des enfants, de l'environnement et des conducteurs en fonction du type de rue.

Résultats : Le taux de blessures est apparu 2,5 fois plus élevé dans les rues à sens unique que dans les rues à double sens, et 3 fois plus élevé chez les enfants vivant dans les quartiers pauvres par opposition à ceux habitant les quartiers riches. Selon le type de rue, on a constaté des différences significatives aux plans de la situation socio-économique, de la gravité des blessures, du nombre de voies, de l'endroit de la collision et de la réglementation de la circulation.

Conclusions : À Hamilton, les taux de blessures chez les enfants-piétons sont plus élevés dans les rues à sens unique que dans les rues à double sens. Les prochaines études sur les facteurs de risque et les interventions devraient prendre en considération le sens des rues pour voir quelle influence cela a sur les blessures des enfants-piétons.

Child pedestrian injuries are a very important cause of childhood mortality globally.[1,2] Motor vehicle injuries lead the list of injury deaths at all ages during childhood and adolescence;[3] and among the five- to nine-year-old age group, pedestrian injuries overshadow occupant injuries as a cause of death and are in fact the leading cause of death from unintentional injuries in this age group.[2,4]

The city of Hamilton has a significant percentage (7%) of kilometres of one-way streets. We reviewed the literature and found that environmental risk factors not only contribute highly to child pedestrian injuries but also that countries that have had the largest decrease and have the lowest absolute rates of injuries have emphasized their modification.[5-9] We found five[10-14] studies that addressed the directionality of the street to the risk of injury, none of which were peer reviewed. Zeeger et al.[12] found the presence of one-way streets to be the geometric feature most related to low pedestrian injuries at signalized intersections in 15 U.S. cities (although less than traffic and pedestrian volume). However only injuries occurring at signalized intersections were included and since one-way and two-way intersections were not sampled representatively (only signal timing schemes were), the importance of one-way directionality might be confounded by oversampling of that intersection type. Two studies[10,11] found a decrease in injury count after conversion to a one-way street: Ewens[10] also looked at injuries on two-way streets and did not see a similar decrease, while Bruce[11] did not have a control of injuries on non-converted two-way streets. Both failed to include exposure variables (e.g., kilometres of streets) to assess rates of injury.

This study aims to contribute to the developing literature on the role of directionality. The objectives were to identify if there is a difference in child pedestrian injury rates on one-way and two-way streets, and to examine whether the characteristics of child pedestrian injuries differ between one-way and two-way streets.

METHODS

Subjects and setting

We studied pedestrian motor vehicle injuries to children aged 0 to 14 years (0-4, 5-9 and 10-14) occurring in Hamilton, Ontario from 1978 to 1994. Hamilton is a medium-sized Canadian city of 320,000, with a mix of manufacturing (largest group) and service industry, and a major university. It is situated on the Niagara escarpment and on Lake Ontario, with homogeneous residential and commercial neighbourhoods on the plateau and hetero-

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TABLE I
Operational Definitions and Inclusion Criteria for Variables in the Analysis of Child Pedestrian Injuries in Hamilton, 1978-94

Variables	Inclusion Criteria for Variables Based on: Present in Police Accident Database	Found to be Statistically Significant in the Literature Review*	Advice During Development of Study†
Dependent Variable			
Total Number of Injuries Per Child Per Km Per Year Total number of injuries among children 0 to 14 years of age on one-way or two-way streets from 1978-1994 divided by the total number of children 0 to 14, the number of one-way or two-way km and the number of years.			✔
Independent Variables			
Child Variables			
Age of Child Reported as ages 0-4, 5-9 and 10-14	✔	✔	✔
Sex Reported as male or female	✔	✔	✔
Action Reported as crossing with right of way, crossing without right of way, crossing with no traffic control, crossing at a pedestrian crossover, crossing a marked crosswalk, walking on road with traffic, walking on road against traffic, on sidewalk or shoulder, coming from behind parked cars, running onto roadway, getting on/off a school bus, getting on/off a vehicle and other	✔	✔	
Condition Reported as unknown, normal, had been drinking, drinking with blood alcohol level >0.08, ability impaired by alcohol, ability impaired by drugs, fatigue, medical or physical disability, inattentive and other	✔		
Injury Reported as none, minimal, minor, major and fatal	✔		
Social Environment Variables			
Planning Unit Obtained by entering the intersection nearest to the site of injury into MapInfo Program at Regional Planning Department. In cases where injury fell in between two or more units, each possible unit was used and the case was weighted accordingly (1/2, 1/3 or 1/4).		✔	✔
Social Economic Status (SES) of Planning Unit Calculated using Census values for percent incidence of low income economic families. The incidence values for the planning units were stratified into three groups: SES 1 (richest), 2 (moderate) and 3 (poorest). Calculated separately for Census 1981 (injuries from 1978-83, 1986 (1984-88) and 1991 (1989-1994).		✔	✔
Population of Planning Unit Proxy variable for crowding as reported in Census for the census years 1981 (for injuries from 1978-83), 1986 (1984-88) and 1991 (1989-94).		✔	
Physical Environmental Variables			✔
Number of km of one-way and two-way streets in Hamilton Estimate from Department of Public Works and Traffic using the Roads Inventory Management System. Average of 1980 and 1994 estimates used.			
Year Police Database encompasses injuries from 1978 to 1994	✔	✔	
Month Reported as separate months, January to December	✔		
Day Reported as separate days, 0 to 31	✔		
Day of the Week Reported as Monday to Sunday	✔		
Time of Day Reported as 24 categories: 1(12-1AM), 2 (1-2AM) up to 24 (11PM-12AM)	✔	✔	
Accident Location Reported as non-intersection, intersection related, at intersection, at private drive, at railway crossing, underpass or tunnel, overpass or bridge, parking lot and other	✔	✔	✔
Number of Lanes Reported as one to seven	✔	✔	
Environmental Condition Reported as clear, rain, snow, freezing rain, drifting snow, strong wind and fog/mist/smoke/dust	✔	✔	
Lighting Condition Reported as daylight, dawn, dusk and dark	✔	✔	

* As a risk factor for incidence and/or severity of child pedestrian injury.
† Advice from H. Solomon, Manager of Traffic Operations, Hamilton Traffic Department and Dr. B. Pless, McGill University, Montreal.

TABLE I — continued

Type of Traffic Control Reported as traffic signal, stop sign, yield sign, pedestrian crossover, police control, school guard, school bus, traffic gate, traffic controller, no control and other	✔	✔	✔
Traffic Control Condition Reported as functioning, non-functioning, obscured and missing/damaged	✔		
Condition of Road Reported as good, poor and under repair/construction	✔		
Road Surface Condition Reported as dry, wet, loose snow, slush, packed snow, ice, mud, loose sand/gravel, spilled liquid and other	✔		
Posted Maximum Speed Limit Reported as 40, 50, 60 and 70 km/hr	✔	✔	
Driver Variables			
Age Reported as ages 0-15, 16, 17, 18, 19, 20, 21, 22, 23, 24, 25-34, 35-44, 45-54, 55-64, 65-74, 75+, none, unknown and SMV accident	✔		
Driver Condition Reporting same as for child condition	✔		
Driver Action Reported as driving properly, following too close, exceeding speed limit, speed too fast for conditions, speed too slow, improper turn, disobeyed traffic signal, failed to yield right of way, lost control, improper passing, wrong way on one-way and improper lane change	✔	✔	
Maneuver of Vehicle Reported as going ahead, slowing or stopping, overtaking, turning left, turning right, making U turn, changing lanes, merging, reversing, stopped, parked, disabled, pulling away from curb/shoulder, pulling onto curb/shoulder, other, and unknown	✔	✔	

geneous residential, commercial and industrial zoning on the plain. The plain also extends to the waterfront and includes the downtown area. There are 74 and 936 km of one-way and two-way streets respectively, and a speed limit of 50 kph.

Data sources

Four sources were used to obtain our variables (see Table I for inclusion criteria). One, injury data were obtained from the City of Hamilton Traffic Department. The database, which details the injured, the road and the driver, is compiled from Motor Vehicle Accident Reports collected by police officers at the scene of motor vehicle collisions.

Two, a commercial geographic information system[15] coded the site of each collision, as identified by the nearest intersection, to a planning unit for the city. When an injury occurred at an intersection bordering two or more planning units, the record of the injury was repeated for each planning unit and then weighted accordingly, for example, one half if the injury site bordered on two units, one third if it bordered on three. In cases where the child was injured on the boundaries of the city, only the weighted records pertaining to Hamilton were retained. When more than one child was injured in one event, then the injury record was repeated for each child, since children were our unit of analysis.

Three, 1981, 1986 and 1991 census data from Statistics Canada were used to obtain neighbourhood information. Statistics Canada's low income cut-offs[16] were used to assign socio-economic status (SES) levels to each planning unit: SES 1 (units with smallest Percent-Low-Income, i.e., the wealthiest neighbourhoods), SES 2 (units with moderate Percent-Low-Income) and SES 3 (units with the highest Percent-Low-Income). As the injured child's home address was not available, children were assigned the SES of the planning unit in which the injury occurred since studies have reported that 96% of child pedestrians are injured in their own census tract.[17] Less than 1.5% of injuries were not analyzed because the population of the planning unit was too small, the return on the census survey was inadequate or the planning unit was classified as "Parks and/or Industrial Area."

Four, Roads Inventory Management Software was used to calculate the number of kilometres. Kilometres for one-way streets were unchanged from 1978 to 1994 (74 km), the two-way streets estimate increased by 11% (to 936 km). An average was calculated for two-way streets.

Statistical analysis

Injury rates were calculated for each age-sex group by street type or SES. For injury rates by street type, the number of children injured on one-way and two-way streets was divided by the population of children of that age and sex group and the number of kilometres of that street type. For injury rates by SES, the number of injured in each SES group was divided by the population of children of that age, sex and SES group.

The characteristics of child pedestrian injuries on one-way and two-way streets were described. Chi-square tests for independence were performed on nominal categorical variables and chi-square tests for trends were performed on ordinal variables for all variables.

RESULTS

From 1978 to 1994, there were 2,091 children aged 0 to 14 years in Hamilton injured in pedestrian-vehicle collisions; 344 were injured on one-way streets and 1,747 on two-way streets.

The rate of injury for children ages 0 to 14 years was 2.5 times higher on one-way streets than on two-way streets (46.4 vs 19.6 per 100,000 children, per 100 km, per year). This finding was consistent across all age groups (0-4, 5-9, 10-14) and

TABLE II
Child Pedestrian Injury Rates (per 100,000, per 100 km, per year) on One-way and Two-way Streets by Age and Sex for Hamilton, 1978-1994

Street Type	Both Sexes				Age Groups Boys*				Girls*			
	0-4	5-9	10-14	Total	0-4	5-9	10-14	Total	0-4	5-9	10-14	Total
One-way (n=345)	19.1	76.1	46.1	46.4	26.0	114.8	59.0	65.8	16.5	58.1	37.1	36.9
Two-way (n=1747)	7.0	32.5	20.2	19.6	10.5	51.4	21.7	27.5	6.7	26.7	18.5	17.2

* Data for 1978 to 1987

TABLE III
Child Pedestrian Injury Rates (per 100,000, per 100 km, per year) on One-way and Two-way Streets by Age and Sex for Hamilton, 1978-1994

Socio-economic Status	Both Sexes				Age Groups Boys*				Girls*			
	0-4	5-9	10-14	Total	0-4	5-9	10-14	Total	0-4	5-9	10-14	Total
High (n=381)	3.5	17.9	15.5	12.2	4.9	27.9	17.3	16.7	3.6	13.6	13.5	10.3
Intermediate (n=593)	5.3	31.6	19.5	18.5	7.9	56.2	23.1	28.6	6.4	23.7	17.8	15.9
Low (n=1089)	14.5	57.3	30.1	33.3	22.5	83.4	32.1	45.4	12.0	50.2	27.5	29.0

* Data for 1978 to 1987

for both sexes. Children ages 5-9 had a higher injury rate than the other age groups, and boys were injured more often than girls overall (Table II).

The injury rate by neighbourhood SES was 2.7 times higher for children ages 0 to 14 years living in the poorest neighbourhoods than those living in the wealthiest (33.3 vs 12.2 per 100,000 children). This ratio, however, is much larger in younger children (4.15) than older children (1.95) and the injury rate for boys was higher across each SES group and/or age group (Table III).

The characteristics of child pedestrian injuries on one-way versus two-way streets along with the significance tests are shown (Table IV). Seventy-five percent of all child pedestrian injuries on one-way streets occurred in low SES neighbourhoods, while only 48% of all child pedestrian injuries on two-way streets occurred in low SES neighbourhoods ($p < 0.001$). Other characteristics of child pedestrian injuries, such as injury severity, number of lanes, accident location and type of traffic control, were also found to be significantly different across street types.

DISCUSSION

This study found that child pedestrian injuries occurred 2.5 times more frequently per kilometre of street on one-way streets than on two-way streets, a difference consistent across age groups.

Our study also confirmed the findings in the literature[18-23] of the contribution of SES to injury rates. Increased injury risk among poorer children has been found ranging from 2.4[19] to 7[18] times in case control studies and 6 times in a similar ecological design.[20]

There were limitations to our study, however. First, the Traffic Department database has shortcomings, the most significant of which is the sizeable portion of injuries not reported, with literature estimates ranging from 20 to 35%.[17,24-27] As the injuries more likely not to be reported involve children not injured in traffic (parking lots and driveways), this should not significantly affect our analysis. A second limitation relates to the Census database on children ages 0-4, which includes children who are too young to walk. The result is our underestimation of injury rates for exposed children ages 0 to 4. It seems unlikely though that there should be a differential underestimate across street type.

We must qualify the results of the present study because the relationship between street type and injuries was not adjusted using SES data for each individual child. However, in observing Tables II and III together, it is noteworthy that the pattern of rates by age and sex for the different levels of SES were identical to the pattern of rates by age and sex on one-way and two-way streets. We conclude that the one-way street rates therefore exceeded the main sources of variation due to SES, age and sex. This suggests that one-way streets represent an independent effect separate for these other variables. For example, the low SES group rate for all ages and both sexes was 33.3. The one-way street rate was 46.4 for all ages and both sexes suggesting that one-way street rates could account for a 12.1 excess rate of injury if we assume all other factors which might influence the rate are equal.

Other possible factors accounting for the increased injury rates can be divided into those that impact on *quantity* of exposure (i.e., the number of times a child is exposed to a street or vehicle) and those that impact on *quality* of the exposure. Regarding quantity, the downtown core of Hamilton consists almost entirely of one-way streets as does most of the surrounding and poorer neighbourhoods, although one-way streets also serve some of the wealthier neighbourhoods. Children who spend time downtown therefore are exposed to more multi-laned one-way street thoroughfares. Also, poorer kids are more likely to walk to school[28,29] and play on the streets and so they are exposed to more street crossings and vehicles. Finally there is higher volume

TABLE IV
Characteristics of Children with Injuries on One-way and Two-way Streets in Hamilton, 1978-1994

Variables	One-way Streets %	Two-way Streets %	p-value
Child Variables			
Age of Child			
0-4	14.1	12.2	0.420**
5-9	52.8	53.4	
10-14	33.2	34.4	
Sex†			
Boy	64.8	62.3	0.523*
Girl	35.2	37.7	
Injury Severity			
None	2.9	1.1	0.011*
Non-fatal	95.4	97.9	
Fatal	1.7	0.8	
Social Environment Variables			
Social Economic Status (SES) of Planning Unit (PU)			
High	5.6	21.0	<0.001**
Moderate	18.9	30.7	
Low	75.5	48.3	
Physical Environmental Variables			
Year			
1978-1981	28.4	32.3	0.114**
1982-1985	25.2	25.0	
1986-1989	22.3	21.7	
1990-1995	24.1	21.0	
Time of Day			
Before 9 AM	9.7	9.4	0.235**
9 AM to 3 PM	32.2	30.1	
3 to 7 PM	49.9	49.2	
After 7 PM	8.3	11.2	
Posted Maximum Speed Limit (kph)			
≤50	99.4	98.7	0.413*
≥60	0.6	1.3	
Number of Lanes			
≤2	20.4	45.5	<0.001**
3 to 4	70.0	50.4	
≥5	9.6	4.0	
Accident Location			
Non-intersection	41.8	56.4	<0.001*
Intersection and related	58.2	43.6	
Type of Traffic Control			
Traffic signal	57.1	43.0	0.002*
Stop sign	24.5	28.4	
Other signal	3.1	2.9	
No signal	15.3	25.8	
Condition of Road			
Good	98.3	98.4	0.854*
Poor or under repair/construction	1.7	1.6	
Environmental Condition			
Clear	90.6	86.8	0.062*
Rain, snow, other	9.4	13.2	
Lighting Condition			
Daylight	86.4	84.4	0.344*
Dawn, dusk, dark	13.6	15.6	
Road Surface Condition			
Dry	82.5	77.7	0.052*
Wet, snow, slush and other	17.5	22.3	
Driver Variables			
Age			
0-19	6.6	7.1	0.138**
20-24	15.7	14.3	
25-34	27.8	27.1	
35-44	21.6	19.1	
45-54	12.7	12.2	
55-64	9.4	10.9	
≥65	3.6	4.8	
None	2.7	4.6	
Driver Action			
Driving properly	81.5	83.6	0.318*
Driving improperly	18.5	16.4	
Driver Condition			
Normal	97.3	98.3	0.155*
Impaired and other	2.7	1.7	
Maneuver of Vehicle			
Going ahead	82.4	81.3	0.627*
Turning	11.1	10.7	
Other	6.5	8.0	

† only includes injuries from 1978 to 1987 * χ^2 test ** χ^2 test for trend

of traffic on one-way streets in Hamilton (documented as a 10 to 50% increase after the change[10]), a variable associated with up to a 13-fold increase in injury risk.[7,18]

Also possibly explaining the difference in injury rates could be differences in quality of exposure on one-way streets such as higher traffic speed (seen with a decrease in transit time ranging from 5 to 75% in Hamilton after the conversion),[10] a variable associated with up to a 6-fold increased injury risk.[18] It is also possible that on one-way streets, drivers are less attentive (due to the lack of traffic from the other direction) and that children are inexperienced at looking first to the right in situations where traffic flows from right to left. Unfortunately, our inability to adjust for many of these variables limits our ability to isolate the responsible factor which increases the risk on Hamilton's one-way streets.

Although this would be consistent with research demonstrating reduced injuries with alterations in the physical environment,[30-32] why does the literature seem to suggest otherwise? One possible reason is that Zeeger et al.[12] examined injuries only at signalized intersections, while in Hamilton, not only do more than half of all injuries not occur at intersections (and when they do occur at intersections, these intersections are more likely not to be signalized), but also one-way streets have more injuries at signalized intersections. Another explanation could be that using injury counts instead of adjusted rates (e.g., count divided by number of kilometres or number of intersections) leads to a misleading impression of the changes in injuries. This is evidenced by our findings of higher *rates* of injuries on one-way streets although previous authors had documented a *count* decrease with data from the same database.[11] Nonetheless, there remains a need for a study of all pedestrian injuries which would adjust for SES and all exposure variables. In the end, it might be, as Zeeger describes, that it is necessary that one-way streets are safer in some situations and two-ways streets in others.[33]

In conclusion, one-way streets have higher rates of child pedestrian injuries than two-way streets in this community. This increased risk is comparable to the increased risk in low SES communities in this study. Future risk factor and interven-

tion studies should include the directionality of streets to further elucidate its contribution to child pedestrian injuries.

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