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QUANTITATIVE RESEARCH

Examining the association between area level deprivation and vehicle collisions that result in injury

Khrisha B. Alphonsus [1] · Cheryl Waldner [1,2] · Daniel Fuller [3]

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Abstract

Objective The objective of this study was to examine the association between area level deprivation and vehicle collisions resulting in either property damage or injury.

Methods A multilevel observational study was conducted using the 2000 to 2010 Saskatchewan Traffic Accident Information System (TAIS) ($n = 72{,}234$) and 2006 Census data at the Dissemination Area level ($n = 337$) for the city of Saskatoon.

Results Total area level deprivation was associated with severity of traffic collisions, but the association varied based on time of day and road repair status. Collisions were more likely to result in injury from the most deprived (Q5) versus the least deprived quintile (Q1) at all times of day; the difference was greatest in the evening (OR 1.7, 95% CI 1.3 to 2.3). However, there was no other evidence of a monotonic increase in risk associated with area level deprivation. When there were faded markings or potholes, the odds of a collision involving injury were 2.6 (95% CI 1.5 to 4.4) times greater for the most deprived quintile compared to the least deprived quintile. There were no significant differences in the risk of injury between area level deprivation quintiles when road conditions were good.

Conclusion While the association between area level deprivation and whether vehicle collisions result in injury in Saskatoon varies based on time of day and road repairs, under many circumstances the most deprived areas report more injuries from collisions compared to the least deprived.

Résumé

Objectif Examiner l'association entre la privation à l'échelle locale et les collisions entre véhicules automobiles causant des dommages matériels ou des blessures.

Méthode Nous avons mené une étude observationnelle multiniveau à l'aide des données du système d'information sur les accidents de la route de la Saskatchewan (TAIS) de 2000 à 2010 ($n = 72\,234$) et les données du Recensement de 2006 au niveau des aires de diffusion ($n = 337$) pour la ville de Saskatoon.

Résultats La privation totale à l'échelle locale était associée à la gravité des collisions de la route, mais cette association variait selon l'heure du jour et l'état de la chaussée. À toute heure du jour, les collisions étaient plus susceptibles de causer des blessures si elles se produisaient dans le quintile le plus défavorisé (Q5) que dans le quintile le moins défavorisé (Q1); l'écart était le plus

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✉ Daniel Fuller
dfuller@mun.ca

[1] School of Public Health, University of Saskatchewan, Saskatoon, SK, Canada

[2] Western College of Veterinary Medicine, University of Saskatchewan, Saskatoon, SK, Canada

[3] Canada Research Chair in Population Physical Activity, School of Human Kinetics and Recreation, Memorial University of Newfoundland, Physical Education Building, Room 2023, St. John's, NL A1C 5S7, Canada

prononcé en soirée (RC : 1,7, IC de 95%: 1,3 à 2,3). Nous n'avons cependant trouvé aucun autre signe d'augmentation monotone du risque associé à la privation à l'échelle locale. En présence de marquages délavés ou de nids-de-poule, la probabilité d'une collision avec blessés était 2,6 fois plus élevée (IC de 95% : 1,5 à 4,4) dans le quintile le plus défavorisé que dans le quintile le moins défavorisé. Il n'y avait aucun écart significatif dans le risque de blessures selon le quintile de privation à l'échelle locale quand la chaussée était en bon état.

Conclusion L'association entre la privation à l'échelle locale et la probabilité que les collisions entre véhicules automobiles causent ou non des blessures à Saskatoon varie selon l'heure du jour et l'état de la chaussée, mais dans de nombreuses situations, davantage de blessures dues aux collisions sont signalées dans les quartiers les plus défavorisés que dans les quartiers les moins défavorisés.

Keywords Total deprivation · Socioeconomic status · Vehicle collisions

Mots-clés Privation totale · Statut socioéconomique · Collisions entre véhicules automobiles

Introduction

Motor vehicle collisions are one of the leading causes of disability and death worldwide, and more than 1.2 million people die each year due to traffic collisions (Toroyan 2009). In Canada, injuries arising from motor vehicle collisions cost more than $100 million per day in total societal expenses (Redelmeier 2014). In fact, injuries arising from road collisions alone are ranked as the 7th leading cause of Years Lived with Disability (YLDs) (Rothman et al. 2015). The WHO and the World Bank urge all governments to address road safety (World Health Organization 2004).

The Haddon Matrix provides a model for examining phases of injury including pre-event, event, and post-event factors, along with human, vehicle, and environmental factors associated with collisions (Haddon 1980). Runyan expanded the conceptualization of the Haddon Matrix to include dimensions of effectiveness, freedom, and equity (Runyan 1998). Reviews of the association between individual and area level deprivation and road traffic injuries suggest that area level deprivation is a pre-event environmental factor that reflects material resources and community services in the area (Ameratunga et al. 2006; Cubbin and Smith 2002). Reviews suggest that examining the association between area level socio-economic status and injuries due to motor vehicle collisions is an important aspect of understanding and preventing injuries (Ameratunga et al. 2006; Cubbin and Smith 2002; Laflamme and Stephanie Burrows 2009; Ewing and Dumbaugh 2009).

Area level deprivation has been shown to be associated with greater risk of injury and death, when controlling for individual socio-demographic characteristics (Laflamme and Engstrom 2002; Zambon and Hasselberg 2006; Whitlock et al. 2003). A large Canadian study using the 1991–2001 Canadian Census Mortality Follow-up Study showed residing in a deprived area was associated with 1.8 times (95% CI 1.4 to 2.2) greater risk of a motor vehicle collision compared to less deprived areas while controlling for individual factors, age, marital status, visible minority, new immigrant, and urban/rural residence (Burrows et al. 2012). In the USA, a study of 472,364 adults including 1195 injury-related deaths over the follow-up period showed that area level deprivation was associated with an increased hazard ratio for motor vehicle-related deaths (Cubbin et al. 2000). Similarly, a study in South Korea used national death registry data to examine the association between area level deprivation and risk of death due to motor vehicle collisions. Results showed that those residing in deprived areas had a 1.3 times (95% CI 1.1 to 1.7) greater risk of death in a motor vehicle collision, compared to the high SES areas, controlling for individual level factors, gender, age, and education (Lee et al. 2014). Morency et al. (2012) found that intersections in the poorest areas had more injuries compared to those intersections in richer areas. The difference in injuries was explained by the combination of greater exposure to high traffic volumes and four-way intersections along with higher pedestrian and cyclist volumes in poorer areas.

Previous research studies suggest that area level deprivation may be associated with collisions resulting in injuries, but their methodologies have varied considerably. The majority of studies have used health administrative data and focused on controlling for individual factors, not road- or weather-specific factors (Zambon and Hasselberg 2006; Burrows et al. 2012; Lee et al. 2014), with a notable exception being Morency et al. (2012) who showed that increased risk in highly deprived areas was associated with four-way intersections and traffic volume. There are additional plausible mechanisms for the observed associations between area level deprivation and injuries that have not been examined. For example, low SES areas may be less likely to have traffic calming measures or, conversely, more likely to have an increased number of needed road repairs, which then leads to poorer quality roads and an increased risk of collisions that result in injuries (Bunn et al. 2009).

The primary objective of this study was to examine the association between area level deprivation and whether or not traffic collisions resulted in injury. We hypothesize that area level deprivation is associated with a greater likelihood of a collision resulting in an injury. As a secondary objective, we examined interactions between area level deprivation and additional pre-event environmental factors, light conditions, road repairs, and traffic volume, consistent with the hypothesis that area level deprivation is associated with material resources in the community.

Methods

The data for this analysis included collisions and covariates (time of day, vehicle type, road repair status, road surface condition, speed limit, season, traffic volume, road type) from 2000 to 2010 in Saskatoon, Saskatchewan, from the Saskatchewan Traffic Accident Information System (TAIS), weather data from Environment Canada, and area level deprivation data at the Census Dissemination Area level available from the *Institut national de santé publique du Québec* (INSPQ). The TAIS is the collision dataset used by the provincial government to report annual collision rates and trends. The TAIS collects variables from police reports and Saskatchewan Government Insurance claims. Weather data collected by Environment Canada from 2000 to 2010 were merged with the collision data from TAIS to examine the association between weather and collision severity. Area level deprivation at the dissemination area were joined to the x,y coordinates for each collision using a spatial join (see supplementary Appendix A).

Measures

The outcome measure was collision severity as defined by the TAIS data. Severity was measured using a categorical variable including property damage or injury (including personal and fatal injuries). Property damage as defined in TAIS is any collision that results in $1000 total damage or more. Personal injury and fatality was defined as any bodily harm or death of a driver or occupant within 30 days of the collision. The TAIS includes data on motor vehicles as well as bicycles.

The exposure of interest was area level deprivation that we defined using dissemination areas (DA). DAs are the smallest census geographic unit in Canada representing populations ranging from 400 to 700 persons. Area level SES was operationalized using the deprivation index developed at the INSPQ (Pampalon et al. 2009a, 2009b). The deprivation index is calculated for each DA using census data and includes two dimensions: material and social deprivation. The material deprivation dimension is composed of the proportion of people age 15 years and older without a high school diploma; employment/population ratio of people aged 15 years and older; and the average income of people ages 15 years and older. The social deprivation dimension is composed of the proportion of individuals aged 15 years and older living alone; the proportion of individuals aged 15 years and older who are separated, divorced, or widowed; and the proportion of single-parent families. We combined material and social deprivation into a total deprivation score for each DA using a matrix approach (Neudorf et al. 2015). The total deprivation index included 5 quintiles ranging from Q1 being a high privileged neighbourhood to Q5 being the most deprived neighbourhood. The deprivation index has been used extensively for area level socio-economic analysis in Canada (Burrows et al. 2012; Neudorf et al. 2015).

Covariates available from the TAIS and from Environment Canada included time of day, vehicle type, road repair status, road surface condition, speed, season, traffic volume, road type, and total precipitation (cm) on the day of collision (Jones and Jørgensen 2003). Time at which the collision took place was categorized as morning (6:01 a.m. to 12:00 p.m.), afternoon (12:01 p.m. to 6:00 p.m.), evening (6:01 p.m. to 12:00 a.m.), and night (12:01 a.m. to 6:00 a.m.). Vehicle type was categorized as automobile, van, pick-up truck, and other vehicle (ambulance/police/fire vehicles, bicycle, intercity bus, moped, motor homes, motorcycle, off-highway vehicles, other bus, other vehicle, power units for semi-trailers, school bus, snowmobile, trucks over 4500 kg, farm equipment, maintenance equipment, and bus). Road repair status was categorized into three categories as normal/good condition, obscured or faded markings/potholes, or under construction/repair. Road surface conditions were categorized as dry, snow/ice, or other conditions (fresh oil, loose gravel or sand, loose snow, muddy, slush, and wet). Speed limit was categorized as < 50, 50–60, and > 70 km/h. Season during which collision occurred was categorized as spring (March to May), summer (June to August), autumn (September to November), and winter (December to February). Traffic volume was categorized as low (0 to 10,000 average daily traffic) versus high (10,001 to 45,684 average daily traffic), consistent with City of Saskatoon street definition for residential and commercial collector streets. Total precipitation (both rain and snow) in centimetres was included as a continuous variable.

Analysis

A two-level mixed effects logistic regression model, with collisions nested in DAs, was used to estimate the odds that a collision would result in injury, including a random intercept to estimate the similarity of collision severity within census dissemination areas. Bivariate analysis was carried out in which variables were screened one at a time in a null random intercept model using a p value < 0.20. The multivariable model was built using manual stepwise backwards selection. In addition to deprivation, other covariates, where $p < 0.05$, were retained in the full model. Cross-level interactions were assessed between total deprivation and time of day, road repair status, and traffic volume since these variables were hypothesized to have a differing effect on the likelihood of collisions resulting in injury in areas with different SES. Analysis was conducted using Stata IC 13.1.

Results

The dataset used for the analysis, with complete data for all variables of interest, included 71,259 collisions at level 1, nested in 337 DAs at level 2 in Saskatoon (Table 1). The average number of collisions in a DA was 212 (range 5 to 3124). The complete dataset included 185,328 observations. Data from Corman Park ($n = 560$), an adjacent municipality, were removed. Variables for road repairs, road surface condition, and vehicle type had considerable missing data, with 95,913, 31,711, and 12,024 observations removed

Table 1 Summary of bivariate and multivariate associations between potential covariates and the odds that a collision would result in injury in Saskatoon, Saskatchewan ($n = 71,259$ collisions, $N = 337$ dissemination areas)

Variable	Property damage n (%)	Injury, *n* (%)	Unadjusted OR null model	Adjusted OR
Level 2 (dissemination area)				
Total deprivation				
Quintile 1	5100 (9.3)	1354 (8.3)	Reference	Reference
Quintile 2	6849 (12.5)	2056 (12.5)	1.1 (0.9 to1.4)	1.1 (0.9 to 1.3)
Quintile 3	11,918 (21.8)	3290 (20.0)	1.2 (1.0 to 1.4)	1.1 (0.9 to 1.3)
Quintile 4	7914 (14.4)	2314 (14.1)	1.1 (0.9 to 1.3)	1.1 (0.9 to 1.3)
Quintile 5	23,073 (42.1)	7391 (45.1)	1.3 (1.1 to 1.5)	1.2 (1.0 to 1.4)
Level 1 (collision)				
Traffic volume				
Low traffic	19,990 (36.5)	4858 (29.6)	Reference	Reference
High traffic	34,864 (63.5)	11,547 (70.4)	1.3 (1.3 to 1.4)	1.3 (1.2 to 1.4)
Road repairs				
Normal/good road condition	51,295 (93.5)	15,799 (96.3)	Reference	Reference
Obscured or faded markings/potholes/ruts/bumps	2584 (4.7)	338 (2.1)	0.46 (0.41 to 0.52)	0.67 (0.60 to 0.76)
Under construction/repair/uneven payment/sharp drop-offs	975 (1.8)	268 (1.6)	0.9 (0.8 to 1.0)	0.96 (0.82 to 1.10)
Road surface condition				
Dry	29,887 (54.5)	10,343 (63.1)	Reference	Reference
Snow/ice	16,895 (30.1)	3421 (20.9)	0.60 (0.58 to 0.63)	0.78 (0.72 to 0.82)
Other (fresh oil, gravel, snow, mud, slush, wet)	8072 (14.7)	2641 (16.1)	0.94 (0.90 to 1.00)	1.02 (0.97 to 1.08)
Vehicle type				
Automobile	35,506 (64.7)	10,306 (62.8)	Reference	Reference
Panel van	8380 (15.3)	2725 (16.6)	1.11 (1.06 to 1.17)	1.1 (1.0 to 1.2)
Pick-up truck	8809 (16.1)	2287 (13.9)	0.89 (0.85 to 0.93)	0.90 (0.85 to 0.94)
Other	2159 (3.9)	1087 (6.6)	1.7 (1.6 to 1.9)	1.68 (1.56 to 1.82)
Speed limit				
< 50 km/h	2433 (4.4)	663 (4.0)	Reference	Reference
50–60 km/h	49,054 (89.4)	14,471 (88.2)	1.1 (1.0 to 1.3)	0.89 (0.80 to 0.98)
> 70 km/h	3367 (6.1)	1271 (7.8)	1.3 (1.2 to 1.5)	1.2 (1.0 to 1.4)
Road type				
Non-intersection	20,183 (36.8)	3750 (22.9)	Reference	Reference
Intersection	34,671 (63.2)	12,655 (77.1)	1.9 (1.9 to 2.0)	1.9 (1.8 to 2.0)
Time of day				
Morning	12,321 (22.5)	3484 (21.2)	Reference	Reference
Afternoon	24,873 (45.3)	8346 (50.9)	1.2 (1.1 to 1.2)	1.1 (1.0 to 1.2)
Evening	11,990 (21.9)	3564 (21.7)	1.0 (0.9 to 1.1)	1.0 (1.0 to 1.1)
Night	5670 (10.3)	1011 (6.2)	0.7 (0.6 to 0.7)	0.7 (0.6 to 0.8)
Season				
Spring	11,066 (20.2)	3311 (20.2)	Reference	Reference
Summer	11,522 (21.0)	4403 (26.8)	1.3 (1.2 to 1.3)	1.2 (1.2 to 1.3)
Autumn	14,518 (26.5)	4750 (28.9)	1.1 (1.0 to 1.1)	1.0 (1.0 to 1.1)
Winter	17,748 (32.4)	3941 (24.0)	0.7 (0.7 to 0.8)	0.9 (0.8 to 0.9)
Total precipitation (cm)	Mean = 0.24 SD = 0.62	Mean = 0.27 SD = 0.69	1.06 (1.03 to 1.09)	1.06 (1.02 to 1.08)
Variance of the random intercept for dissemination area			18.1%	10.5%
Intraclass correlation coefficient (ICC)			0.052 (0.041 to 0.066)	0.031 (0.024 to 0.041)

Q1 to Q5 (least deprived to most deprived) respectively. We conducted sensitivity analyses excluding road repairs and road surface condition (see supplementary Appendix B) to examine the impact of missing data. The results of the sensitivity analyses and the results presented did not differ substantively.

Descriptive statistics and bivariate associations between the variables of interest and collision severity are presented in Table 1. The majority (64%) of collisions were automobiles, with panel vans and pickup trucks representing 16% of collisions. The most deprived quintile had 30,464 collisions (42.8% of collisions) compared to 6454 collisions (9.1% of collisions) in the least deprived quintile. Total deprivation was associated with the odds of injury from traffic collisions. However, in the final multivariable model (Table 3), the association between total deprivation and injury from a traffic collision was modified by the time of day, road condition, and traffic volume after adjusting for season, vehicle type, road surface condition, and speed limit. In the final adjusted random intercept model, 11% of the variation in collision severity across DAs, as estimated from the null model, was accounted for by the final fixed effects model, including area level deprivation in Saskatoon (Table 3).

The cross-level interaction between deprivation quintile and time of day was significant (Table 2). When considering

Table 2 Cross tabulations describing sample size (*n*) and percent (%) between area level deprivation and covariates

Variable	Quintile 1 (least deprived), *n* (%)	Quintile 2, *n* (%)	Quintile 3, *n* (%)	Quintile 4, *n* (%)	Quintile 5 (most deprived), *n* (%)
Traffic volume					
Low traffic	2688 (10.8%)	3196 (12.9%)	4412 (17.8%)	4159 (16.7%)	10,393 (41.8%)
High traffic	3766 (8.1%)	5709 (12.3%)	10,796 (23.3%)	6069 (13.1%)	20,071 (43.2%)
Road repairs					
Normal/good road condition	5952 (8.9%)	8322 (12.4%)	14,358 (21.4%)	9586 (14.3%)	28,876 (43.0%)
Obscured or faded markings/potholes/ruts/bumps	383 (13.1%)	439 (15.0%)	590 (20.2%)	439 (15.0%)	1071 (36.7%)
Under construction/repair/uneven payment/sharp drop-offs	119 (9.6%)	144 (11.6%)	260 (20.9%)	203 (16.3%)	517 (41.6%)
Road surface condition					
Dry	3266 (8.1%)	4815 (12.0%)	8447 (21.0%)	5824 (14.5%)	17,878 (44.4%)
Snow/ice	2240 (11.0%)	2761 (13.6%)	4431 (21.8%)	2873 (14.1%)	8011 (39.4%)
Other (fresh oil, gravel, snow, mud, slush, wet)	948 (8.8%)	1329 (12.4%)	2330 (21.7%)	1531 (14.3%)	4575 (42.7%)
Vehicle type					
Automobile	4290 (9.4%)	5872 (12.8%)	9670 (21.1%)	6771 (14.8%)	19,209 (41.9%)
Panel van	1011 (9.1%)	1398 (12.6%)	2402 (21.6%)	1505 (13.6%)	4789 (43.1%)
Pick-up truck	887 (8.0%)	1279 (11.5%)	2416 (21.8%)	1523 (13.7%)	4991 (45.0%)
Other	266 (8.2%)	356 (11.0%)	720 (22.2%)	429 (13.2%)	1475 (45.4%)
Speed limit					
< 50 km/h	156 (5.0%)	555 (17.9%)	740 (23.9%)	461 (14.9%)	1184 (38.2%)
50–60 km/h	5646 (8.9%)	7283 (11.5%)	13,386 (21.1%)	9065 (14.3%)	28,145 (44.3%)
> 70 km/h	652 (14.1%)	1067 (23.0%)	1082 (23.3%)	702 (15.1%)	1135 (24.5%)
Road type					
Non-intersection	2179 (9.1%)	2805 (11.7%)	5510 (23.0%)	3436 (14.4%)	10,003 (41.8%)
Intersection	4275 (9.0%)	6100 (12.9%)	9698 (20.5%)	6792 (14.4%)	20,461 (43.2%)
Time of day					
Morning	1542 (9.8%)	2056 (13.0%)	3594 (22.7%)	2208 (14.0%)	6405 (40.5%)
Afternoon	2762 (8.3%)	4109 (12.4%)	7427 (22.4%)	4705 (14.2%)	14,216 (42.8%)
Evening	1536 (9.9%)	1945 (12.5%)	3019 (19.4%)	2282 (14.7%)	6772 (43.5%)
Night	614 (9.2%)	795 (11.9%)	1168 (17.5%)	1033 (15.5%)	3071 (46.0%)
Season					
Spring	1289 (9.0%)	1856 (12.9%)	2967 (20.6%)	2105 (14.6%)	6160 (42.8%)
Summer	1393 (8.7%)	1857 (11.7%)	3319 (20.8%)	2226 (14.0%)	7130 (44.8%)
Autumn	1728 (9.0%)	2351 (12.2%)	4019 (20.9%)	2873 (14.9%)	8297 (43.1%)
Winter	2044 (9.4%)	2841 (13.1%)	4903 (22.6%)	3024 (13.9%)	8877 (40.9%)

the average of all other risk conditions, the odds that a collision would result in an injury, compared to vehicle damage, were significantly greater in the most deprived quintile (Q5) compared to the least deprived quintile (Q1) in the morning 1.4 (95% CI 1.1 to 1.9), afternoon 1.6 (95% CI 1.2 to 2.1), evening 1.7 (95% CI 1.3 to 2.3), and night 1.6 (95% CI 1.1 to 2.3) (Table 3). However, there was no evidence of a monotonic relationship across the deprivation quintiles as there was a similar difference between the second and first deprivation quintile, but no difference between quintiles 3 or 4 and quintile 1. The relationship between time of day and the odds of a collision resulting in injury was not consistent across deprivation quintiles.

The cross-level interaction between deprivation quintiles and road repair status was also significant (Table 4). The odds that a collision would result in an injury, compared to property damage alone, when there were faded markings or potholes were lowest in the least deprived quintile (Table 4). For example, the odds that a collision would result in injury, compared to property damage alone, were 2.6 (95% CI 1.5 to 4.4) times greater for the most deprived quintile (Q5) compared to the least deprived (Q1) when there were faded markings or potholes (Table 4). However, the odds of injury, compared to property damage alone, did not increase across deprivation quintiles in a monotonic fashion in the presence of obscured or faded markings or potholes. The difference between quintile 1 and quintile 2 was 4.3 (95% CI 2.4 to 7.5), greater than the difference between quintile 5 and 1. The odds that a collision would result in injury, compared to property damage alone, were also higher in the most deprived quintile compared to two less deprived quintiles (Q3 and Q4) when there was construction or uneven pavement, but not between the most and least deprived quintiles.

Collisions that resulted in injury, as compared to property damage alone, were more likely when road repair status was good as compared to when there were obscured or faded markings or potholes for quintiles 1, 4, and 5 (Table 4). Injury collisions, compared to property damage alone, were also more common for roads under construction than roads with obscured or faded markings or potholes in quintile 5 (Table 4).

There was an unclear cross-level interaction between deprivation quintiles and traffic volume (Table 3). The most deprived areas had 1.6 (95% CI 1.2 to 2.1) times greater odds of a collision resulting in injury, compared to the least deprived areas for both high and low traffic volume locations (Table 4). The odds that a collision would result in an injury, compared to property damage along, were greater on high traffic volume streets for all deprivation quintiles except quintile 2 (Table 4). The interaction between traffic volume and deprivation was only apparent in that there was a difference between the least and second least deprived quintiles when traffic volume was low, but not when it was high (Table 4).

Table 3 Final multivariable adjusted associations of total deprivation and other covariates measured at the time of the collision with the odds that a collision would result in injury in Saskatoon, Saskatchewan, from 2000 to 2010 ($n = 71{,}259$ collisions, $N = 337$ dissemination areas)

Variable	Adjusted model OR (95% CI)	*p* value
Total deprivation		0.0178
Quintile 1 (least deprived)	Reference	Reference
Quintile 2	1.1 (0.8 to 1.3)	0.69
Quintile 3	0.9 (0.7 to 1.1)	0.43
Quintile 4	0.8 (0.6 to 1.0)	0.04
Quintile 5 (most deprived)	1.1 (0.9 to 1.3)	0.54
Time of day (for total deprivation quintile 1)		0.0010
Morning	Reference	Reference
Afternoon	1.0 (0.9 to 1.1)	0.98
Evening	0.8 (0.7 to 1.0)	0.05
Night	0.6 (0.5 to 0.8)	0.00
Total deprivation*time of day comparing Q1 and morning		< 0.001
Q2 and afternoon	1.2 (1.0 to 1.4)	0.09
Q2 and evening	1.1 (0.8 to 1.4)	0.53
Q2 and night	1.5 (1.0 to 2.1)	0.02
Q3 and afternoon	1.1 (1.0 to 1.4)	0.14
Q3 and evening	1.3 (1.0 to 1.6)	0.02
Q3 and night	1.0 (0.7 to 1.5)	0.79
Q4 and afternoon	1.4 (1.1 to 1.7)	0.003
Q4 and evening	1.5 (1.2 to 1.9)	0.001
Q4 and night	1.3 (0.9 to 1.9)	0.10
Q5 and afternoon	1.1 (0.9 to 1.3)	0.37
Q5 and evening	1.2(1.0 to 1.5)	0.06
Q5 and night	1.1(0.8 to 1.4)	0.57
Road repairs (for total deprivation quintile 1)		< 0.001
Normal/good road condition	Reference	Reference
Obscured or faded markings/potholes	0.3 (0.2 to 0.4)	< 0.001
Under construction/repair	1.1 (0.7 to 1.6)	0.82
Total deprivation*road conditions		< 0.001
Q2 and obscured or faded markings/potholes	4.0 (2.3 to 7.0)	0.001
Q2 and under construction/repair	0.9 (0.5 to 1.7)	0.72
Q3 and obscured or faded markings/potholes	3.4 (2.0 to 6.0)	< 0.001
Q3 and under construction/repair	0.7 (0.4 to 1.2)	0.1
Q4 and obscured or faded markings/potholes	2.4 (1.3 to 4.3)	0.003
Q4 and under construction/repair	0.7 (0.4 to 1.3)	0.30
Q5 and obscured or faded markings/potholes	2.2 (1.3 to 4.0)	0.002
Q5 and under construction/repair	1.1 (0.7 to 1.8)	0.72
Traffic volume (for total deprivation quintile 1)		0.0003
Low traffic	Reference	Reference
High traffic	1.3 (1.1 to 1.5)	0.001
Total deprivation*traffic volume		< 0.001
Q2 and high traffic	0.8 (0.6 to 0.9)	0.007
Q3 and high traffic	1.0 (0.9 to 1.2)	0.70
Q4 and high traffic	1.1 (0.9 to 1.3)	0.56
Q5 and high traffic	1.0 (0.8 to 1.2)	0.97
Seasons		< 0.001
Spring	Reference	Reference
Summer	1.2 (1.1 to 1.3)	< 0.001
Autumn	1.0 (1.0 to 1.1)	0.11
Winter	0.9 (0.8 to 1.0)	< 0.001
Vehicle type		< 0.001
Automobile	Reference	Reference
Panel van	1.1 (1.1 to 1.2)	< 0.001

Table 3 (continued)

Variable	Adjusted model OR (95% CI)	*p* value
Pick-up truck	0.9 (0.9 to 0.9)	< 0.001
Other	1.7 (1.6 to 1.8)	< 0.001
Road surface condition		< 0.001
Dry	Reference	Reference
Snow/ice	0.8 (0.7 to 0.8)	< 0.001
Other	1.0 (1.0 to 1.1)	0.38
Speed limit		< 0.001
< 50 km/h	Reference	Reference
50–60 km/h	0.9 (0.8 to 1.0)	0.06
> 70 km/h	1.2 (1.1 to 1.4)	0.002
Road type		<0.001
Non-intersection	Reference	Reference
Intersection	1.9 (1.8 to 2.0)	< 0.001
Total precipitation (cm)	1.0 (1.0 to 1.1)	< 0.001
Variance of the random intercept for dissemination area	11%	
Intra-class correlation coefficient (ICC)	0.032 (0.2–0.4)	

Discussion

The objective of this study was to examine the association between area level SES and whether or not injuries result from traffic collisions. We also examined whether area level SES interacts with road characteristics in explaining whether injuries result from traffic collisions. We identified differences in whether injuries would result from traffic collisions between the most and least deprived quintiles in bivariate analysis. However, the results did not hold under all conditions in multivariate analysis and non-socio-economic differences were observed. Past research has shown similar results to our bivariate analysis when accounting for individual-level factors, like age and sex, with increased risk estimates for lowest area level SES ranging from 1.3 times greater (Lee et al. 2014) to 1.8 times greater (Burrows et al. 2012) when compared to the highest SES areas. There was no evidence of a consistent monotonic increase in risk associated with increasing deprivation when comparing the other quintiles in the current study.

Research from the USA has shown that social inequalities in road traffic deaths between 1995 and 2010 have persisted or worsened over time (Harper et al. 2015). The USA often shows a stronger social gradient than Canada, which could explain differences between our findings (The World Bank Group 2016). Additionally, approximately 11% of the variation in the severity of the collision across the dissemination areas was accounted by the final model, which included area level deprivation. Consequently, the percent of explained variation is consistent with, but larger than, the 1% variation in the risk of a fatality explained by geographic areas from previous research (Jones and Jørgensen 2003).

As a secondary objective, we examined the interactions between area level deprivation and mechanisms that could explain the observed differences in collisions involving injury between the most and least deprived areas (Zwerling et al. 2005; Valent et al. 2002). The odds of being in a collision resulting in injury in the most deprived quintile were higher in the morning, afternoon, and evening as compared to night. Collisions resulting in injury were also more likely the

Table 4 Summary of the significant pairwise differences among risk factor groups for simple effects resulting from the differences in effect of deprivation quintile based on road maintenance status, time of day, and traffic volume in the final multivariable model for the odds that a collision would result in injury (*n* = 71,259 collisions, *N* = 337 dissemination areas)

Contrasted variable	Baseline category of interacting variable	Adjusted model OR (95% CI)
Time of day*deprivation quintile		
Q5 vs Q1	Morning	1.4 (1.1 to 1.9)
Q5 vs Q1	Afternoon	1.6 (1.2 to 2.1)
Q5 vs Q1	Evening	1.7 (1.3 to 2.3)
Q5 vs Q1	Night	1.6 (1.1 to 2.3)
Q5 vs Q4	Morning	1.5 (1.2 to 1.9)
Q3 vs Q1	Evening	1.6 (1.1 to 2.2)
Q2 vs Q1	Afternoon	1.7 (1.2 to 2.3)
Q2 vs Q1	Evening	1.5 (1.1 to 2.1)
Q2 vs Q1	Night	2.1 (1.4 to 3.2)
Morning vs night	Q1	1.7 (1.25 to 2)
Afternoon vs night	Q1	1.7 (1.25 to 2)
Afternoon vs evening	Q2	1.3 (1.1 to 1.4)
Morning vs night	Q3	1.4 (1.3 to 2)
Afternoon vs night	Q3	1.7 (1.4 to 2)
Afternoon vs morning	Q4	1.4 (1.2 to 1.5)
Afternoon vs night	Q4	1.7 (1.4 to 2)
Evening vs morning	Q4	1.3 (1.1 to 1.5)
Evening vs night	Q4	1.4 (1.3 to 2)
Morning vs night	Q5	1.4 (1.3 to 1.7)
Afternoon vs night	Q5	1.7 (1.4 to 1.7)
Evening vs night	Q5	1.4 (1.3 to 1.7)
Road repairs*deprivation quintile		
Q5 vs Q1	Obscured or faded markings/potholes	2.6 (1.5 to 4.4)
Q4 vs Q1	Obscured or faded markings/potholes	2.5 (1.4 to 4.4)
Q3 vs Q1	Obscured or faded markings/potholes	3.5 (2.0 to 6.1)
Q2 vs Q1	Obscured or faded markings/potholes	4.3 (2.4 to 7.5)
Q5 vs Q3	Under construction/repair	1.9 (1.2 to 3.0)
Q5 vs Q4	Under construction/repair	1.7 (1.1 to 2.6)
Good vs obscured or faded markings/potholes	Q1	3.3 (2.5 to 5)
Good vs obscured or faded markings/potholes	Q4	1.7 (1.1 to 2)
Good vs obscured or faded markings/potholes	Q5	1.7 (1.4 to 2)
Under construction vs obscured or faded markings/potholes	Q5	2.0 (1.4 to 2.5)
Traffic volume*deprivation quintile		
Q5 vs Q1	High traffic	1.6 (1.2 to 2.1)
Q5 vs Q1	Low traffic	1.6 (1.2 to 2.1)
Q2 vs Q1	Low traffic	1.9 (1.4 to 2.6)
High traffic vs low traffic	Q1	1.3 (1.1 to 1.5)
High traffic vs low traffic	Q3	1.4 (1.2 to 1.5)
High traffic vs low traffic	Q4	1.4 (1.2 to 1.6)
High traffic vs low traffic	Q5	1.3 (1.2 to 1.4)

Q1 to Q5 (least deprived to most deprived) evening and night in quintiles 2 through 5, compared to quintile 1, the least deprived. The results are consistent with the findings from the Canadian Institute for Health Information, which state that traffic collisions resulting in hospitalization are more common in the afternoon and evening (Spitz 2013). A possible explanation for this result observed in Saskatoon is that high SES areas have limited traffic in the afternoon and evening compared to other areas (Pallagst 2010). However, our study was not able to address this question, and additional research would be needed to examine this hypothesis.

The effect of area level deprivation was also modified by road repairs and, to a less meaningful extent, traffic volume. The results suggest that less deprived areas have a lower likelihood of collisions resulting in injury compared to all other deprivation quintiles when obscured or faded markings or potholes are present on the road. A possible explanation for the lower likelihood of collisions resulting in injury in the least deprived neighbourhoods could be due to the reduced number of potholes in the area. Additionally, it is possible that the potholes present were not as severe or were more visible due to better signage warning drivers of risks. There were no differences in the odds of collisions resulting in injury among good road conditions across quintiles. The interaction between traffic volume and total deprivation did not show a monotonic relationship. A similar increased risk of injury associated with high traffic volume was apparent in all but the second least deprived quintile (Q2). These results were not consistent with the study done in Montreal where poorer neighbourhoods had higher exposure to traffic volume at intersections thereby increasing the risk of injury (Morency et al. 2012). We examined collisions resulting in injury at both intersections and non-intersections, which differed considerably from Morency et al. (2012), who only examined injuries at intersections. The association between traffic volume and injury in Morency et al. (2012) was examined using a continuous measure of traffic volume at the intersection level centred at 500 vehicles per day, and the association was statistically significant but very small 1.07 (95% CI 1.06 to 1.08).

The season in which the collision took place was significantly associated with collisions resulting in injury. Summer and autumn were found to have a greater odds of injury as opposed to collisions that occurred during the winter. These findings were consistent with an American study showing that summer and autumn had increased crash deaths as opposed to the winter due to increases in traffic volume and alcohol use (Farmer and Williams 2005).

Limitations

The primary limitation of this study was missing data. We conducted a complete case analysis with considerable missing data for road condition, road surface condition, and vehicle type variables. We quantified the impact of missing data and showed that the results did not differ substantively. Additionally, variables (such as wearing seat belts, and the number of vehicles involved in the collision) were not modelled due to the large number of missing values. Information bias is also possible as the data for collisions involving injury were based on information from both police reports and the individuals involved in the collision, while data from less severe collisions were based only on reports from those involved in the collision. Other limitations include not having the injury severity measured. Having an injury severity measure would have been beneficial because it would have given more context to the severity and type of injury that occurred. Overall, published validity and reliability data regarding the TAIS dataset are limited. We assume biases similar to police reports and insurance data, as the TAIS combines these two data sources. Finally, collisions near the census tract boundaries may have been assigned to the incorrect SES quintile, but this misclassification may be non-differential in relation to the other characteristics.

Conclusion

Our study suggests an increased risk of collisions resulting in injury in the most deprived compared to the least deprived areas of Saskatoon. The increased risk of collisions resulting in injury in the most deprived compared to the least deprived areas was found to be consistent at all times of day and under both high and low traffic volumes, but only where road conditions were compromised by potholes or faded markings. Approximately 11% of the variation in the severity of the collision across the dissemination areas was attributed to neighbourhood deprivation. However, there is no clear dose-response relationship between deprivation and collisions resulting in injury. These findings suggest that injury disparities may exist based on geographical and socio-economic context, but these associations are not straightforward to interpret and translate into policy recommendations. More work should be done in this area to clarify potential interactions between area level SES and road characteristics.

Compliance with Ethical Standards

Conflict of Interest The authors declare that they have no conflict of interest.

References

Ameratunga, S., Hijar, M., & Norton, R. (2006). Road-traffic injuries: confronting disparities to address a global-health problem. *Lancet, 367*(9521), 1533–1540. https://doi.org/10.1016/S0140-6736(06)68654-6.

Bunn, F., Collier, T., Frost, C., et al. (2009). Area-wide traffic calming for preventing traffic related injuries (Review) Area-wide traffic calming for preventing traffic related injuries. (1), 1–3. https://doi.org/10.1002/14651858.CD003110.Copyright.

Burrows, S., Auger, N., Gamache, P., & Hamel, D. (2012). Individual and area socioeconomic inequalities in cause-specific unintentional injury mortality: 11-year follow-up study of 2.7 million Canadians. *Accident Analysis and Prevention, 45*, 99–106. https://doi.org/10.1016/j.aap.2011.11.010.

Cubbin, C., LeClere, F. B., & Smith, G. S. (2000). Socioeconomic status and injury mortality: individual and neighbourhood determinants. *Journal of Epidemiology and Community Health, 54*(7), 517–524. https://doi.org/10.1136/jech.54.7.517.

Cubbin, C., & Smith, G. S. (2002). Socioeconomic inequalities in injury: critical issues in design and analysis. *Annual Review of Public Health, 23*(1), 349–375. https://doi.org/10.1146/annurev.publhealth.23.100901.140548.

Ewing, R., & Dumbaugh, E. (2009). The built environment and traffic safety a review of empirical evidence. *Journal of Planning Literature, 23*(4), 347–367.

Farmer, C. M., & Williams, A. F. (2005). Temporal factors in motor vehicle crash deaths. *Injury Prevention, 11*(1), 18–23. https://doi.org/10.1136/ip.2004.005439.

Haddon, W. (1980). Advances in the epidemiology of injuries as a basis for public policy. *Public Health Report, 95*(5), 411–421. https://doi.org/10.2307/4596353.

Harper, S., Charters, T. J., & Strumpf, E. C. (2015). Trends in socioeconomic inequalities in motor vehicle accident deaths in the United States, 1995–2010. *American Journal of Epidemiology, 182*(7), 606–614. https://doi.org/10.1093/aje/kwv099.

Jones, A. P., & Jørgensen, S. H. (2003). The use of multilevel models for the prediction of road accident outcomes. *Accident Analysis and Prevention, 35*(1), 59–69. https://doi.org/10.1016/S0001-4575(01)00086-0.

Laflamme, L., & Engstrom, K. (2002). Socioeconomic differences in Swedish children and adolescents injured in road traffic accidents: cross sectional study. *British Medical Journal, 324*(February), 396–397.

Laflamme, L., & Stephanie Burrows, M. H. (2009). *Socioeconomic differences in injury risks*. a Review of Findings and a Discussion of Potential Countermeasures. (January).

Lee, J., Lee, W.-Y., Noh, M., & Khang, Y.-H. (2014). Does a geographical context of deprivation affect differences in injury mortality? A multilevel analysis in South Korean adults residing in metropolitan cities. *J Epidemiol Community Health, 68*(5), 457–465. https://doi.org/10.1136/jech-2013-203082.

Morency, P., Gauvin, L., Plante, C., Fournier, M., & Morency, C. (2012). Neighborhood social inequalities in road traffic injuries: the influence of traffic volume and road design. *American Journal of Public Health, 102*(6), 1112–1119. https://doi.org/10.2105/AJPH.2011.300528.

Neudorf, C., Fuller, D., Cushon, J., Glew, R., Turner, H., & Ugolini, C. (2015). An analytic approach for describing and prioritizing health inequalities at the local level in Canada: a descriptive study. *CMAJ Open, 3*(4), E366–E372. https://doi.org/10.9778/cmajo.20150049.

Pallagst, K. (2010). Viewpoint: the planning research agenda: shrinking cities—a challenge for planning cultures. *The Town Planning Review, 81*(5), i–vi.

Pampalon, R., Hamel, D., & Gamache, P. (2009b). A comparison of individual and area-based socio-economic data for monitoring social inequalities in health. *Heal Reports 20*(4), 85–94. http://www.ncbi.nlm.nih.gov/pubmed/20108609. Accessed 23 Jan 2016.

Pampalon, R., Hamel, D., Gamache, P., & Raymond, G. (2009a). A deprivation index for health planning in Canada. *Chronic Diseases in Canada 29*(4),178–191. http://www.ncbi.nlm.nih.gov/pubmed/19804682. Accessed 23 Jan 2016.

Redelmeier, D. A., & Tien, H. C. (2014). Medical interventions to reduce motor vehicle collisions. *CMAJ, 186*(2), 118–124. https://doi.org/10.1503/cmaj.122001.

Rothman, L., Macpherson, A., Buliung, R., et al. (2015). Installation of speed humps and pedestrian-motor vehicle collisions in Toronto, Canada: a quasi-experimental study. *BMC Public Health, 15*, 774. https://doi.org/10.1186/s12889-015-2116-4.

Runyan, C. W. (1998). Using the Haddon matrix: introducing the third dimension. *Injury Prevention, 4*(4), 302–307. https://doi.org/10.1136/ip.4.4.302.

Spitz, S. (2013). Hospitalizations from car collisions twice as likely during evening. *Canadian Medical Association Journal, 185*(6), E255–E255. https://doi.org/10.1503/cmaj.109-4427.

The World Bank Group. *GINI index World Bank estimate*. http://data.worldbank.org/indicator/SI.POV.GINI?end=2013&locations=US&start=2013&view=map. Published 2016. Accessed 29 Oct 2016.

Toroyan, T. (2009). Global status report on road safety. *Injury Prevention, 15*(4), 286. https://doi.org/10.1258/jrsm.2010.090426.

Valent, F., Schiava, F., Savonitto, C., Gallo, T., Brusaferro, S., & Barbone, F. (2002). Risk factors for fatal road traffic accidents in Udine, Italy. *Accident Analysis and Prevention, 34*(1), 71–84. https://doi.org/10.1016/S0001-4575(00)00104-4.

Whitlock, G., Norton, R., Clark, T., Pledger, M., Jackson, R., & MacMahon, S. (2003). Motor vehicle driver injury and socioeconomic status: a cohort study with prospective and retrospective driver injuries. *Journal of Epidemiology and Community Health, 57*(7), 512–516. https://doi.org/10.1136/jech.57.7.512.

World Health Organisation. (2004). World report on road traffic injury prevention. *World, 244*. https://doi.org/10.1016/j.puhe.2005.09.003.

Zambon, F., & Hasselberg, M. (2006). Socioeconomic differences and motorcycle injuries: age at risk and injury severity among young drivers. A Swedish nationwide cohort study. *Accident Analysis and Prevention, 38*(6), 1183–1189. https://doi.org/10.1016/j.aap.2006.05.005.

Zwerling, C., Peek-Asa, C., Whitten, P. S., Choi, S.-W., Sprince, N. L., & Jones, M. P. (2005). Fatal motor vehicle crashes in rural and urban areas: decomposing rates into contributing factors. *Injury Prevention, 11*(1), 24–28. https://doi.org/10.1136/ip.2004.005959.