THE RISK OF INJURY AND VEHICLE DAMAGE SEVERITY IN VEHICLE MISMATCHED SIDE IMPACT CRASHES IN BRITISH COLUMBIA

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As occupant protection offered by new passenger vehicles has improved, there has been growing concern about the harm that some vehicle designs may inflict on occupants of other vehicles with which they collide. Preceding analyses of crash statistics have clearly demonstrated the incompatibility between passenger sedan cars (PS) and pick-up trucks (PU) involved in side impact crashes in British Columbia. A comparison of light truck and passenger car crashes in previous literature reveals that light truck vehicles inflict greater harm than passenger cars for a number of reasons including their greater weight, stiffer structure, and higher ride height. These features place occupants of passenger cars at a disadvantage should they be involved in a collision with a light truck vehicle. The injury risk for passenger sedan car occupants is greater than the risk for pick-up truck occupants in two-vehicle crashes (Odds Ratio (OR) 1.87; 95% Confidence Interval (CI) 1.38-2.52). In addition, the risk of vehicle damage severity was increased for passenger cars compared with pick-up trucks (write off vehicle-OR 5.35; 95% CI 3.75-7.63, severely damaged vehicles-OR 5.87; 95% CI 4.79-7.19, moderately damaged vehicles-OR 2.86; 95% CI 2.44-3.36). There is strong justification for injury prevention experts and policy makers to step up motor vehicle crash injury prevention advocacy by implementing evidence-based policies to reduce rates of injury as a result of passenger sedan cars and pick-up trucks involved in side impact crashes in the province of British Columbia.

Key Words: Vehicle incompatibility, Crashworthiness, Side impact crashes, Risk of injury, Risk of vehicle damage

1. INTRODUCTION

Currently ranked ninth among the world's disease burdens, motor vehicle crashes are projected to rank third by 2020. Recent estimates of national economic loss due to road traffic injuries show that these range from 1 to 2% of the gross domestic product (GDP) of nations around the world[2]. The most recent Canadian study by Smart Risk using hospitalization data estimated that the total economic cost of motor vehicle collisions in Canada was approximately 1.7 billion annually[2]. The report estimates that a combined intervention strategy that involves proper restraint use, driving sober, marginal speed reductions and improved roadway design and maintenance could result in net savings of more than $500 million each year[2].

Potential years of life lost (PYLL), which highlights the loss resulting from early death, is suited to evaluating the impact of motor vehicle crash related death on population characterized by premature mortality. There were 1,588 deaths from accidents and violence among B.C. residents in 2002. Motor vehicle crashes accounted for approximately one in four of these deaths. Motor vehicle crashes were a major cause of death in the 15-24 age group responsible for 94 deaths and 5,135 potential years of life lost.

In the 25-44 year age group, there were 1,223 deaths in 2002, producing a total of 45,968 PYLL and a PYLL standardized rate of 12.51 PYLL per 1,000 standard population in this age group. Among the 832 male deaths, the highest PYLL standardized rates were for suicide (2.28) and motor vehicle crashes (2.21).

Death from road crashes and motor vehicle collisions constitute a major public health problem. Because so many of those killed and injured on the roads are young, the years of expected life lost as the result of motor vehicle crashes and collisions rival what occurs with the major modern epidemics of cardiovascular disease and cancer. The objective of PYLL is to rank major causes of premature death to help health planners define priorities.

Road traffic crashes occur on all continents, in every country of the world. Every year they take the lives of more than a million people and incapacitate many millions more. In a dramatic development in road safety philosophy, Sweden's "Vision Zero" offers a significant new paradigm for injury prevention. The underlying premise

Table 1 Potential years of life lost (PYLL) by age group and major causes of death (age under 75 years) in British Columbia 2002

Cause of death	Number of deaths	PYLL*	PYLL %	PYLLSR**
Under 15 years old				
Perinatal conditions	90	6,698	34.1	2.57
Congenital anomalies	49	3,612	18.4	1.36
Cancer	18	1,212	6.2	0.37
Motor vehicle accidents	13	833	4.2	0.23
Sudden infant death syndrome (SIDS)	12	894	4.5	0.34
Nervous system diseases	10	731	3.7	0.27
Other causes	82	5,671	28.9	1.86
All causes	274	19,649	100	7.00
15-24 years old				
Motor vehicle accidents	94	5,135	31.0	1.39
Suicide	45	2,433	14.7	0.66
Cancer	20	1,095	6.6	0.30
Accidental poisoning	15	808	4.9	0.22
Nervous system diseases	8	435	2.6	0.12
Homicide	4	225	1.4	0.06
Other causes	117	6,418	38.8	1.73
All causes	303	16,548	100	4.47
25-44 years old				
Cancer	213	7,603	16.5	1.93
Suicide	141	5,338	11.6	1.46
Motor vehicle accidents	117	4,688	10.2	1.38
Accidental poisoning	105	4,078	8.9	1.15
HIV disease	59	2,143	4.7	0.56
Ischemic heart disease	36	1,255	2.7	0.31
Other causes	552	20,865	45.4	5.72
All causes	1,223	45,968	100	12.51
45-74 years old				
Cancer	4,029	43,753	42	9.32
Ischemic heart disease	1,283	12,878	12.4	2.76
Cerebrovascular disease	410	3,615	3.5	0.79
Diabetes	312	2,915	2.8	0.64
Chronic lung disease	334	2,500	2.4	0.57
Pneumonia/influenza	133	1,083	1.0	0.23
Other causes	2,892	37,395	35.9	7.65
All causes	9,393	104,138	100	21.97

Source: Vital statistics-2002[3]
* Potential Years of Life Lost (PYLL)
** Potential Years of Life Lost Standardized Rate (PYLLSR)

for "Vision Zero" is that 'no foreseeable accident should be more severe than the tolerance of the human in order not to receive an injury that causes long term health loss.' "Vision Zero" in Sweden and the Sustainable Safety Program in the Netherlands are both examples of good practices in road safety. Such good practices can also have other benefits. They can encourage healthier lifestyles involving more walking and cycling, and can reduce the noise and air pollution that result from motor vehicle traffic[4].

In the past decade, the crashworthiness of passenger cars for their occupants has improved considerably in many high-income countries, though there is substantial room for further improvement[4]. Despite the many safety improvements to new passenger vehicles, there is growing concern regarding an increased risk of injury to vehicle drivers and occupants during a collision between vehicles of differing size and mass.

Diversity in vehicle size may also be a factor affecting the risk of injury: Broyles et al[5] examined the extent of damage to vehicles involved in crashes with 4-wheel drive vehicles. Controlling for many characteristics of the vehicle, driver and environment in a regression model, they found that vehicles in side impact crashes sustained significantly more damage than vehicles involved in frontal or rear-end crashes. These authors did not look at injury as an outcome in crashes studied, although some of their recommendations (eg; improved lateral protection for vehicles) have implications for injury prevention.

Chief determinants for the degree of severity of injuries in motor vehicle collisions are vehicle size and weight. The European Commission (EC) has stated that if all cars were designed to be equal in standard to the best car currently available in each class, then an estimated 50 % of all fatal and disabling injuries could be avoided[4].

Among the many factors influencing the pattern of injuries in motor vehicle crashes, has been the popularity and high representation of sport utility vehicles (SUVs) and pick-up trucks (PU) in the BC vehicle fleet[6,7]. Between 1990 and 2001, PU ownership increased by 47% while passenger sedan cars (PS-both four- and two-door) ownership increased by 36 %[7]. It is estimated that PU accounted for approximately 28.4 % (636,631 vehicles) of the 2001 BC vehicle fleet[7,8].

Disparity in the size and mass of two vehicles colliding, especially when the struck vehicle is smaller and lighter, is a consistent risk factor for occupant injury[5-8]. Broyles et al. found in PU-PS collisions, that PS sustain significantly greater vehicular damage[5]. The Insurance Institute for Highway Safety estimates that the relative risk of death among occupants of passenger cars that are involved in crashes with light trucks is approximately 47:1 compared to crashes involving similar sized vehicles[9]. Vehicle incompatibility has been identified as an important influence in the outcomes of modern motor vehicle crashes[10].

It appears that differences in vehicle size and mass in a crash negate the ability of the present set of auto safety devices to maintain a reduced risk of injury for the occupants. Light truck vehicles differ from cars in three key areas. They have greater mass and stiffness, resulting in higher intrusion when striking smaller cars. Additionally, the geometry places bumpers above the frames of struck cars again resulting in greater intrusion. As a result, the safety designs that were effective ten or fifteen years ago are not adequate in today's incompatible vehicle collisions. New technology needs to be developed and implemented[10]. Whilst mass is an issue with respect to survivability in crashes, researchers are finding good vehicle geometry and energy absorbing interfaces to be key factors in developing a heavy vehicle that is crash compatible with the average car fleet.

Side impact crashes account for 25 to 40% of police reported traffic crashes in many jurisdictions. The etiology of these crashes and the prevention of injury have been attracting increased attention in the last decade. The main injury risks for car occupants arise from the way in which vehicles interact with each other, and with the roadside in front-on and side-impact crashes. The classic side impact crash is the T-bone: one vehicle strikes another in the occupant compartment at close to right angle. Crash test results of vehicles impacted on the side have shown that the interactions between vehicle and occupants in these crashes are qualitatively different from those in frontal crashes[11]. Unlike frontal crashes where the engine provides a crumple zone and passengers are positioned father away from the interior components, lateral crashes give little room to absorb energy and prevent the interior from intruding into the occupant. Potentially effective designs such as a central seating position would be unacceptable to most consumers[10].

This study examined two-vehicle side-impact crashes involving PS and PU in British Columbia for the year 2002. Injury rates and vehicle damage severity were compared in crashes between vehicles of differing size and mass.

2. DATA

Motor vehicle crash data was taken from 2002 Insurance Corporation of British Columbia (ICBC) traffic collision data[12]. In order for a crash to be eligible for the provincial police crash data files, it must involve at least one motor vehicle traveling on a traffic way, and the result must be property damage of more than $1,000 CAN, injury, or death. The police reports describe the type of crash, the characteristics of each vehicle and information about any injuries to occupants of each vehicle. For all occupant injuries the police specify (for what appears to be the most important injury), the location (head, abdomen etc.) and nature of the injury (concussion, laceration, fracture etc.). Police also specify the level of damage to each vehicle, from the most severe (e.g., 'demolished (write off)') to minor scratches or no visible damage. Severity is measured by material damage and injury to anyone involved in the crash.

3. METHODS

Traffic collision data for the year 2002[12] were reviewed for vehicle mismatch collisions. For the purpose of this review, mismatch collisions were defined as intersection right angle collisions between PS (defined as vehicles constructed on car frames) and PU (defined as vehicles constructed on truck frames). Crashes in which either vehicle was licensed in another jurisdiction or was a utility truck, bus or other large commercial vehicle were excluded. After applying the exclusion criteria to the initial data set, 363 two-vehicle PU-PS crashes (726 vehicles), 514 PS-PS crashes (1028 vehicles) and 127 PU-PU side impact crashes (254 vehicles) were identified. In this stage we have not developed our study to control any compounding factors that may influence the outcome of PU-PS crashes. Our next step is to analyze this data including the possible compounding factors that may influence the out come of the crash.

4. DATA ANALYSIS

Analyses were performed on crashes involving PS-PU vehicles. Odds Ratio (OR) with 95% Confidence Intervals (CI) were calculated to determine the magnitude of injury and vehicle damage severity in vehicle mismatch crashes. In this paper, results are shown as odds ratios comparing occupant injuries in the PS (case group) with occupant injuries in PU (control group).

5. RESULTS

5.1 Drivers and crash characteristics

(1) Driver age and gender

The mean age of PU drivers was 41.2 yr (SD = 16.8), and 85% of the PU drivers were male. The mean age of PS drivers was somewhat older at 46.9 yr (SD = 21.23), and the gender representation was evenly distributed among males and females (51% male, 49% females).

(2) Crash characteristics and information on restraint use

Seventy-two percent of PU-PS crashes occurred between 8 a.m. and 5 p.m., while 15% occurred between 6 p.m. and 10 p.m. Seatbelts were worn by 86% of PU occupants and drivers, compared to 88% of PS drivers and occupants. However, 4% of PU drivers and occupants did not wear seat belts, compared to 1.3% of PS drivers and occupants. For the remaining cases, information on seatbelt use was not reported.

5.2 General severity and types of injuries

Vehicle damage was found to be less severe for PU and more severe for PS in PS-PU crashes (Table 2). No significant differences were observed in damage severity rates or injury difference rates when comparing crashes involving vehicles of similar size (see Table 3 and 5).

Table 2 Vehicle damage severity in PS-PU crashes (n=726)

Vehicle Damage	PS	PU	Odds Ratio	Confidence Interval
Demolished	119	48	**5.35**	3.75–7.63
Severe	514	189	**5.87**	4.79–7.19
Moderate	731	551	**2.86**	2.44–3.36
Unknown	197	287	**1.48**	1.19–1.83
Light/no damage	419	905		

Highlighted odds ratios are statistical significant at the 95% level.

Table 3 Vehicle damage severity in PS-PS (n=1,028) and PU-PU (n=254) crashes

Vehicle Damage	PS-PS	PU-PU	Odds Ratio*	Confidence Interval
Demolished	49	14	0.65	0.32–1.29
Severe	283	71	0.74	0.48–1.14
Moderate	405	116	0.65	0.43–0.97
Unknown	87	15	1.43	0.81–2.52
Light/no damage	204	38		

* Odds ratio for the level of vehicle damage severity is not statistically significant at the 95% level in comparison of vehicle compatible crashes.

Overall, PS drivers/occupants experienced greater injuries than PU drivers/occupants in PU-PS collisions. Occupants in PS which collide with PU were at twice the risk of injuries (OR, 1.87; 95% CI, 1.38-2.52). Torso, head, face, nose, eye and neck injuries were more frequent in PS drivers/occupants. All other injuries are higher in PS drivers and occupants but not statistically significant.

Table 4 Comparison of injuries to different anatomical sites in PS-PU collisions (n=726)

Anatomical Site	PS	PU	Odds Ratio	Confidence Interval
Upper Extremity (Elbow, Lower/upper arm, Hand, Shoulder)	28	17	1.71	0.92-3.19
Lower Extremity (Hip, Upper/lower leg, Knee, Foot)	14	9	1.62	0.69-3.79
Torso (Chest, Abdomen, Pelvis)	26	11	2.46	1.19-5.06
Lower Torso (Back)	7	10	0.72	0.27-1.93
Entire Body	5	3	1.73	0.41-7.32
Head/Face, Nose, Eye	40	19	2.19	1.24-3.86
Neck	38	19	2.08	1.17-3.68
Total Injuries	158	88	1.87	1.38-2.52
No Injuries	351	366		

Highlighted odds ratios are statistical significant at the 95% level.

Table 5 Comparison of injuries to different anatomical sites in PS-PS versus (n=1,028) PU-PU (n=254) collisions

Anatomical Site	PS	PU	Odds Ratio*	Confidence Interval
Upper Extremity (Elbow, Lower/upper arm, Hand, Shoulder)	51	10	1.19	0.59-2.38
Lower Extremity (Hip, Upper/lower leg, Knee, Foot)	41	11	0.87	0.44-1.72
Torso (Chest, Abdomen, Pelvis)	59	6	2.30	0.98-5.39
Lower Torso(Back)	44	6	1.71	0.72-4.07
Entire Body	4	3	0.31	0.06-1.40
Head/Face, Nose, Eye	77	15	1.20	0.68-2.12
Neck	105	21	1.17	0.71-1.90
Total Injuries	381	72	1.24	0.93-1.65
No Injuries	1,071	251		

* Odds ratio for injuries are not statistically significant at the 95% level in comparison of vehicle compatible crashes

6. DISCUSSION

An important determinant of the absolute level of road trauma in the population is the variance in vehicle size within the vehicle fleet, i.e. vehicle compatibility. This study provides estimates of relative injury and vehicle damage risk by size of vehicle in side impact crashes involving passenger sedan cars and pick-up trucks in British Columbia, Canada. The result suggests that drivers and occupants in smaller vehicles are more likely to be injured in PS-PU involved side impact crashes. Overall, PS drivers/occupants experienced greater injuries than PU drivers/occupants in PU-PS collisions. Occupants in PS which collide with PU were at twice the risk of injuries (OR, 1.87; 95% CI, 1.38-2.52). Occupants in PS which collide with PU were at twice the risk of torso injuries (OR, 2.46; 95% CI, 1.19-5.06). Occupants in PS which collide with PU were at twice the risk of head, face, nose and eye injuries (OR, 2.19; 95% CI, 1.24-3.86). Occupants in PS which collide with PU were at twice the risk of neck injuries (OR, 2.08; 95% CI, 1.17-3.68). Vehicle damage was found to be less severe for PU and more severe for PS in PS-PU crashes. Overall, PS vehicles experienced greater vehicular damage than PU vehicles in PU-PS collisions. PS vehicles which collide with PU were at five times the risk of severely damaged or demolished.

The Crash Injury Research and Engineering Network (CIREN) was developed under the National Highway Safety Administration (NHTSA) to provide detailed crash site analysis and specific occupant injury data to improve the prevention, treatment, and rehabilitation of motor vehicle crash injuries. A recent study has reviewed cases of vehicle mismatch collisions in the CIREN database to establish patterns and source of injury. In side impact collisions with vehicle mismatch, this study has examined injury outcomes for each vehicle. Whereas a majority (11/14) of the light truck vehicles (LTV) occupants sustained no injury or a non-disabling injury, 11 of the passenger car occupants sustained major injuries and 5 died (15/16). This study has found that the changing composition of vehicle fleets is having a considerable effect on crash types and injury severity. The injuries and vehicle damage identified in this study support the need for re-designing both PU and PS to improve vehicle compatibility[13]. According to the Insurance Institute of Highway Safety, LTV versus car collisions are four times more lethal than car versus car collisions in frontal crashes and twenty seven times more lethal in lateral impacts[14].

Previous studies investigating passenger cars and pick-up truck related crashes have confirmed that these two categories of vehicles are incompatible from a design point-of-view[5-7, 9-11,13,14]. Our results support this previous evidence that PU inflict significant vehicle body damage to PS vehicles, and that PS drivers/occupants experienced more injuries than PU drivers/occupants in PU-PS crashes. With increasing numbers of PU on our highways, design improvements to both PS and PU must be considered.

While there are many interventions that can reduce injuries, political will and commitment are essential and without them little can be achieved. Motor vehicles should be designed for crashworthiness to protect the occupants, with efforts to expand this concept to the design of the front of motor vehicles, so as to protect pedestrians and cyclists[4]. Safety standards for front-end construction which would make vehicles less hazardous to pedestrians and cyclists may be as important as standards that affect vehicle occupants. Political obstacles have made such standards difficult to implement[15].

A major design feature of heavy vehicles identified as significantly exacerbating the injury risk to pedestrians, cyclists and vehicle occupants, is the high stiffness and aggressiveness of the front structures. Many studies in North America and Europe have identified that the front, side and rear design of LTV can be effectively modified to significantly reduce the harm potential of heavy vehicle crashes[16-18].

A recent Australian research proposes a paradigm shift in road safety and crashworthiness thinking. It calls on the different industries to collaborate, exchange information and seek a compatible state for the benefit of the users of their particular subsystem. It suggests a systems approach should be used to design vehicles and infrastructure for the environment they have to operate in, i.e. the development of a crashworthy system. In other words, the whole road system including vehicles and occupants needs to be modeled by experts from a multi-disciplinary team using existing field data to help reduce the severity of a crash[16].

Road users everywhere deserve better and safer road travel[4,7,12]. To minimize the economic burden of vehicle body damage and road trauma, policy makers should promote the purchase of small cars with good occupant protection. Traffic safety literature indicates that larger vehicles and trucks inflict a larger external safety cost when involved in a collision, causing damage to other vehicles, road infrastructure, road side objects and road users. It is recommended that PU vehicles be taxed at higher rates than PS by incorporating a surcharge for safety into road use taxes, annual vehicle insurance fees or vehicle registration fees. We expect that these initiatives will result in improved traffic safety for British Columbians and Canadians.

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