PERGAMON

Accident Analysis and Prevention 927 (2003) 1–9

ACCIDENT
ANALYSIS
&
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Pedestrian injuries and vehicle type in Maryland, 1995–1999

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Received 19 April 2002; received in revised form 18 September 2002; accepted 30 October 2002

Abstract

Pedestrian deaths constitute the second largest category of motor vehicle deaths in the US. The present study examined how pedestrian injury is associated with vehicle type, while controlling for vehicle weight and speed.

Police, trauma registry, and autopsy data were linked for injured pedestrians. Logistic regression analyses were performed to control for vehicle weight and speed. Outcomes included pedestrian mortality, injury severity score, and injuries to specific body regions.

Compared to conventional cars, pedestrians hit by sport utility vehicles and pick-up trucks were more likely to have higher injury severity scores (odds ratio = 1.48; 95% confidence interval: 1.18–1.87) and to die (odds ratio = 1.72; 95% confidence interval: 1.31–2.28). These relationships diminished when vehicle weight and speed were controlled for. At lower speeds, pedestrians struck by sport utility vehicles, pick-up trucks, and vans were approximately two times as likely to have traumatic brain, thoracic, and abdominal injuries; at higher speeds, there was no such association.

The overall increased danger sport utility vehicles and pick-up trucks present to pedestrians may be explained by larger vehicle masses and faster speeds. At slower speeds being hit by sport utility vehicles, and pick-up trucks, and vans resulted in specific injuries, indicating that vehicle design may contribute to different injury patterns.

Keywords: Pedestrians; Crashes; Vehicle characteristics; Fatalities

1. Introduction

Pedestrian deaths constitute the second largest category of motor vehicle deaths in the US. This category includes almost half of the traffic deaths for ages 3–9 and more than one-fourth for ages 75 and older (Baker et al., 1992). Among all motor vehicle trauma, the case-admission ratio is highest for pedestrians (266 hospital admissions per 1000 cases) (Barancik et al., 1986). In 1999 in the US, there were 85,000 pedestrians injured in traffic crashes, and 4907 pedestrians killed. This accounted for 12% of all traffic fatalities, but only 3% of all traffic injuries. On the average, in the US a pedestrian is injured every 6 min and one is killed every 107 min (National Highway Traffic Safety Administration, 1999).

In 1999 the state of Maryland had a pedestrian fatality rate of 2.2 per 100,000 population., which is 22% above the national average and ranks as the eighth highest among states in the US (National Highway Traffic Safety Administration, 1999). Nearly one-fourth of people killed in traffic accidents in the Baltimore area are pedestrians, an urban rate that is among the highest in the nation (Meyers, 2000).

Compared to vehicle occupants, less attention is paid to reducing pedestrian deaths and injuries. When countermeasures are devised, the focus is mostly on pedestrians' behavior, even though drivers are often at fault (Insurance Institute for Highway Safety, 1999). While many issues including pedestrian and driver behavior, as well as environmental factors, influence the occurrence and severity of pedestrian injury, an important but often overlooked factor is the vehicle. With the recent rise in popularity of sport utility vehicles (SUVs) and minivans, the issue of vehicle type is becoming more relevant to pedestrian safety. The purpose of this study was to determine if pedestrian injury is

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PII: S0001-4575(02)00129-X

associated with vehicle type while controlling for vehicle weight and speed.

2. Methods

2.1. Inclusion/exclusion criteria

The present study involved pedestrians injured in the state of Maryland from 1995 to 1999. Pedestrians had to have been struck by either a conventional car (sedan, coupe, sports car, station wagon, and hatchback), sports utility vehicle, pick-up truck (PU), or van. In addition, pedestrians had to either have been treated at a Maryland trauma center or have died as a result of their injuries.

2.2. Sources of data

Vehicle type was determined using the Maryland Automated Accident Reporting System (MAARS) database (police data). This database consists of all police-reported motor vehicle traffic crashes that occur on the Maryland traffic ways involving at least one motor vehicle in transport and resulting in either a tow-away, injury, fatality, or hit and run. The computerized police records contained data on crash, driver, vehicle, and pedestrian characteristics, but not the investigating police officer's narrative, which described what actually occurred, nor did it capture the accident diagram. Driver and pedestrian names were not computerized.

Specific pedestrian injuries were determined using the Maryland Trauma Registry (TR). The TR, which is maintained by the Maryland Institute of Emergency Medical Services Systems, collects and tracks trauma incidence information and compiles patient-specific trauma utilization data from the nine Maryland trauma centers. TR data contained E-codes that were used to identify pedestrian patients (Centers for Disease Control and Prevention, 1994). For each patient up to 27 individual Abbreviated Injury Scale (AIS) injury codes were listed as well as an overall injury severity score (ISS) (McGinnis, 1989; Greenspan et al., 1985).

Pedestrians who died as a result of their injuries were identified using records from the Maryland Office of the Chief Medical Examiner (OCME). The total number of fatal cases from the OCME was used to determine the annual mortality rate. The OCME data were not computerized; hence these data were manually abstracted. Data on pedestrians who died at the crash scene or who were seen at a non-trauma center hospital were captured by reviewing autopsy reports. OCME data included pathological injury diagnoses.

2.3. Data linkage

Each database described contains invaluable information, but individually they are limited. By linking these databases (MAARS, TR, and OCME) together, it is possible to identify those factors which increase risk of serious and fatal injuries (National Highway Traffic Safety Administration, 1996). Linkage enables injured pedestrians to be traced from the scene of the crash to their final medical outcomes.

In the MAARS database, unique identifiers such as name and social security number were not available, so linkage was accomplished by initially merging the MAARS and TR using crash date and time, crash county, pedestrian age, and gender. For cases to match, the pedestrian gender and the county of the crash had to be the same in both the MAARS and TR databases. The crash date in both databases had to either match exactly (with time within 5 h) or the difference in crash times had to be within 5 h across midnight; the pedestrian age had to be within 3 years. Pedestrians who died but were not seen at a Maryland trauma center (e.g. died at the scene, treated at a non-trauma center hospital) had their OCME data added to the linked database.

2.4. Measures and variables

The main outcome variables were pedestrian mortality, pedestrian ISS, and pedestrian injuries to specific body regions. Pedestrian mortality was defined as a dichotomous (fatal or non-fatal) variable. Only pedestrians with death certificates in the OCME were considered to have died.

Pedestrian ISS as well as pedestrian injuries to specific body regions were determined using AIS codes from the TR or pathological injury diagnoses from the OCME. For each injured pedestrian, individual injuries were grouped into body regions (head, face, neck, thorax, abdomen, spine, upper extremity, and lower extremity). Lower extremity injuries were divided into three areas: above the knee, at the knee, and below the knee. Only non-superficial injuries (at least one injury with AIS severity score greater than one) were included. Simple skin lacerations, scrapes, and bruises (AIS severity codes equal to one) were excluded.

The main independent variables were vehicle type, vehicle speed, and weight. Each vehicle that hit a pedestrian was classified as a conventional automobile, SUV, PU, or van. Classification was based on police report data which documented vehicle type as well as vehicle identification number (VIN), make, model, and year of manufacture. Motorcycles, mopeds, large goods trucks, buses, fire vehicles, and tractor trucks were excluded. To improve statistical power, SUVs and PUs were combined into one category for many injury specific analyses.

Exact vehicle speed at impact was not routinely documented by investigating police officers. Thus, the speed limit of crash area as recorded on MAARS reports was used as a proxy. Vehicle weight was determined using Expert AutoStats® by 4N6XPRT Systems®. This DOS-based program translated the automobile's make, model, and year into a curb weight. This weight is for the vehicle with full fluids, as it would sit as a new car at the curb of a new car dealer (no cargo and no passengers).

2.5. Data analysis

Annual incidence and mortality rates were calculated for each year from 1995 to 1999. Total annual incidence cases were determined from total MAARS cases for each year. Total annual pedestrian deaths were determined from the total number of death certificate records stored at the OCME. Population denominators were obtained from the United States Bureau of Census. Case-fatality rates were calculated by dividing the total number of pedestrian deaths by the total number of incident cases.

Crude bivariate associations between outcome variables (pedestrian mortality, ISS, and injury to specific body region) and independent variables (vehicle type, speed, and mass) were assessed using χ^2-tests. ISS was operationalized into five categories: ≤ 3, 4–8, 9–15, 16–24, >25. Vehicle speeds (less than or equal to 25, 30–35, >40 mph) and weight (quartiles: less than or equal to 2454, 2455–2906, 2907–3394, >3395 lbs) were also categorized.

Analyses addressing the relationships of interest while controlling for vehicle speed and mass were accomplished using logistic regression. Separate logistic regression analyses were conducted for each outcome variable of interest. To assess potential effect modification, interaction terms for vehicle speed and mass with vehicle type were created and included in the initial model. Statistically significant interaction coefficients signified effect modification. Covariates that were not effect modifiers were evaluated as potential confounders by comparing regression models with and without potential confounders in the model. Potential confounding variables (variables associated with both the main independent variable, vehicle type, and the outcome variable, pedestrian injury) which changed the coefficient of the main independent variables by at least 10% or which decreased their standard error were left in the model.

All analyses and data linkage were conducted using PC SAS 6.12 (Cary, NC).

3. Results

From 1995 to 1999, there were an annual average of 3368 Maryland pedestrians involved in police-reported traffic collisions and 107 pedestrians who died as a result of their injuries. This resulted in a case incidence rate of 66.1 pedestrians hit per 100,000 population, case fatality rate of 2.1 per 100,000 population (or 3.17%), and a case fatality rate of 3.17%. Across this 5-year study period, there was an 8.9% decrease in the incidence rate and a 20.1% decrease in death rate.

3.1. Linkage

From 1995 to 1999 there were 16,838 pedestrians involved in a police reported vehicle–pedestrian collision. This encompassed 16,067 crashes, of which 6.9% involved multiple vehicles. During the same time period, there were 4294 pedestrians treated at a Maryland trauma center and 534 were killed, according to the OCME.

Using the linking criteria described, there were 2600 matches or 60.5% of all police-reported pedestrians found in the trauma registry. Of the 534 pedestrians who were killed from 1995 to 1999, only 192 were seen at a trauma center. The remaining 342 were added to the 2600 in the linked dataset resulting in a final dataset with a total of 2942 pedestrians. The 342 pedestrian fatalities included individuals who died at the scene (62.3%); were seen at a non-trauma center hospital (24.2%); or who according to the medical examiner's office were seen at a trauma center, but not captured using the trauma registry (13.5%).

Of the pedestrians in the linked database, there were 1194 for whom the actual police report hardcopy was available. Of these, in 93.9% the pedestrian name on both the police report hardcopy and in the TR matched, indicating that almost all the cases which linked were true matches.

In addition, cases that linked were compared to cases which did not; only very minor differences were seen. The linked cases were slightly more likely to be female (36.0% versus 32.5%) and were slightly younger (mean age 29.1 versus 32.0). Although linked cases were more likely to have died (5.7% versus 2.7%), the distributions of the overall injury severity scores were not significantly different. In addition, the pedestrians' race, the year, month, time of day, and county of injury were not significantly different between cases that did and did not link.

3.2. Pedestrian and crash characteristics

Among the linked cases, the largest proportion of pedestrian crashes occurred in the fall months (28.3% from September to November) with the smallest proportion occurring in the summer months (22.4% from June to August). These crashes tended to occur in the late afternoon/early evening hours, with 47.6% occurring between 3:00 and 8:59 p.m. Only 8.8% of crashes occurred between 12:00 and 5:59 a.m. Forty-one percent (41.4%) of the pedestrian crashes occurred in Baltimore City. The majority of the crashes (60.6%) occurred in clear weather conditions.

Overall, 64.9% of the pedestrians in the linked database were male. They had a mean age of 30.7 years, and age had a bimodal distribution with a large peak at 5–9 year old (14.1% of population) and a smaller peak at 35–39 year old (8.8% of population). Pedestrian alcohol use (based on police perception) was 14.7%.

Of the 2942 pedestrians in the linked database, 91.2% had enough vehicle information in the MAARS database to determine the vehicle type. Overall, 66.0% of the pedestrians were hit by a conventional automobile, 9.3% by PUs, 7.0% by vans, and 4.5% by SUVs.

Table 1
Non-superficial pedestrian injuries to body regions by vehicle type, Maryland 1995–1999

	Head[a]	TBI	Non-superficial injury				Spine	Upper extremity	Lower extremity		
			Face	Neck	Thorax	Abdomen			Above knee	At knee	Below knee
Conventional autos	434 (22.4%)	377 (19.4%)	92 (4.7%)	4 (0.2%)	294 (15.1%)	170 (8.8%)	159 (8.2%)	312 (16.1%)	331 (17.0%)	73 (3.8%)	667 (34.4%)
SUV/pick-up	76 (18.6%)	103 (24.3%)	19 (4.7%)	2 (0.5%)	85 (20.8%)	61 (15.0%)	48 (11.8%)	79 (19.4%)	94 (23.0%)	15 (3.7%)	81 (19.9%)
P-value[b]	0.097	0.008	0.944	0.301	0.004	0.001	0.020	0.104	0.004	0.936	0.001
Vans	43 (21.0%)	45 (22.0%)	9 (4.4%)	1 (0.5%)	41 (20.0%)	33 (16.1%)	19 (9.3%)	29 (14.2%)	42 (20.5%)	6 (2.9%)	43 (21.0%)
P-value[b]	0.653	0.384	0.823	0.426	0.068	0.001	0.594	0.475	0.216	0.547	0.001

Linked database, total $N = 2942$.

[a] Non-brain head injuries.

[b] Chi-square *P*-values compared to conventional autos. There were no statistically significant differences between SUV/PUs and vans.

3.3. Pedestrian injury by vehicle type

Pedestrian mortality varied by the type of the vehicle involved in the crash. Pedestrians hit by a conventional automobile, SUV, PU, and van died 12.6, 24.1, 17.8, and 13.7% of the time, respectively. The differences in mortality compared to conventional automobiles were statistically significant for SUVs ($P = 0.001$) and PUs ($P = 0.016$), but not for vans ($P = 0.654$).

Similarly, being hit by a SUV or PU appeared to result in an overall higher pedestrian ISS score. Although the relationship between vehicle type and pedestrian ISS was not statistically significant, those pedestrians struck by an SUV, PU, or van had higher ISS scores compared to those struck by a conventional automobile (data not shown).

When non-superficial injuries were examined, different injury patterns emerged for different types of vehicles. Compared to conventional cars, SUVs and PUs resulted in a higher percentage of traumatic brain injuries (TBI), thoracic, abdominal, and spinal injuries, and injuries to the lower extremities above the knee, but a lower percentage of injuries below the knee. Vans differed from conventional cars with respect to more abdominal, and fewer below the knee injuries (Table 1). In general, pedestrian injury patterns caused by vans were not different from those caused by SUVs/PUs.

3.4. Pedestrian injury and vehicle speed and weight

Bivariate analyses showed that increasing vehicle curb weight was strongly associated with increased pedestrian mortality and increasing ISS. For example, when vehicles were divided into weight quartiles, pedestrians hit by vehicles in the upper quartile were almost twice as likely to die compared with those struck by vehicles in the lowest quartile, 20.9% versus 10.5%, respectively.

Overall, almost half of the crashes (46.2%) in the linked database occurred in areas with low speed limits (less than or equal to 25 mph). Not surprisingly, as speed increased, pedestrian mortality and ISS also increased. Pedestrians hit in speed limit areas of $\leq$25 mph died 23.5% of the time, whereas, those hit in areas of 40 mph or greater died 39.4% of the time.

In general, SUVs, PUs, and vans weighed more than conventional cars. In the linked database, the mean weights of the conventional cars, SUVs, PUs, and vans were 2809, 3580, 3481, and 3719 lbs, respectively. In addition, SUVs and PUs tended to have their crashes in areas with higher speed limits. The proportion of crashes which occurred in areas with speed limits of 40 mph or greater was 12.9% for conventional cars, 22.9% ($P = 0.006$ compared to conventional cars) for SUVs, 18.7% ($P = 0.019$) for PUs, and 10.9% ($P = 0.085$) for vans.

Table 2
Odds ratios of mortality and injury severity score (≥16, < 16 as reference group) for Maryland pedestrians

	Parameter estimation	S.E.	*P*-value	OR (95% CI)
Outcome variable-mortality				
Crude model (mortality)				
Intercept	−1.940	0.069	0.0001	
Vehicle type				
Conventional car	Reference			
SUV/pick-up	0.545	0.142	0.0001	1.72 (1.31–2.28)
Van	0.096	0.215	0.65	1.10 (0.72–1.68)
Adjusted model (mortality)				
Intercept	−3.041	0.167	0.0001	
Vehicle type				
Conventional car	Reference			
SUV/pick-up	0.274	0.180	0.13	1.32 (0.92–1.87)
Van	0.260	0.257	0.31	1.30 (0.78–2.15)
Vehicle curb weight				
<3200 lbs	Reference			
>3200 lbs	0.326	0.147	0.03	1.39 (1.04–1.85)
Speed limit				
<30 mph	Reference			
30–35 mph	1.149	0.182	0.0001	3.16 (2.21–4.51)
>40 mph	2.465	0.195	0.0001	11.76 (8.03–17.22)
Outcome variable-ISS (<16 reference)				
Crude model (ISS)				
Intercept	−1.097	0.052	0.0001	
Vehicle type				
Conventional car	Reference			
SUV/pick-up	0.393	0.118	0.0008	1.48 (1.18–1.87)
Van	0.307	0.160	0.05	1.36 (1.00–1.86)
Adjusted model (ISS)				
Intercept	−1.955	0.111	0.0001	
Vehicle type				
Conventional car	Reference			
SUV/pick-up	0.140	0.151	0.35	1.15 (0.86–1.55)
Van	0.489	0.200	0.015	1.63 (1.10–2.42)
Vehicle curb weight				
<3200 lbs	Reference			
≥3200 lbs	0.338	0.119	0.004	1.40 (1.11–1.77)
Speed limit				
<30 mph	Reference			
30–35 mph	1.033	0.125	0.0001	2.81 (2.20–3.59)
>40 mph	2.073	0.155	0.0001	7.95 (5.87–10.76)

According to the type of vehicle, controlling for vehicle mass and speed 1995–1999.

3.5. Regression analysis: pedestrian mortality and injury severity score

Two models were created, one for pedestrian mortality as the outcome variable, and another with pedestrian ISS (dichotomous: <16 and ≥16) as the outcome variable (Table 2). In both outcomes, there were no significant interactions between vehicle type and vehicle mass or speed.

For pedestrian mortality, when no adjustment was made, pedestrians hit by SUVs and PUs had an odds ratio of 1.72 (95% CI: 1.31–2.28) of death compared to those struck by a conventional car. No such association was seen for vans. However, when vehicle weight and speed were controlled for, there was no statistically significant relationship between vehicle type and pedestrian mortality ($P = 0.13$).

When a similar analysis was conducted with ISS (<16, ≥16) as the outcome variable, pedestrians hit by SUVs and PUs had an odds ratio of 1.48 (95% CI: 1.18–1.87) for having a higher ISS compared to a conventional auto when no adjustments were made. In addition, there was a borderline significant association between higher ISS scores and being hit by a van compared to a conventional car (OR = 1.36,

Table 3
Unadjusted and adjusted odd ratios for pedestrian injuries to specific body regions

	Unadjusted OR (95% CI)	Adjusted[a] OR (95% CI)
Traumatic brain injuries		
Conventional autos	Reference	Significant interaction with speed (see Table 4)
SUV/PU	1.40 (1.09–1.80)	
Van	1.17 (0.82–1.66)	
Thoracic injuries		
Conventional autos	Reference	Significant interaction with speed (see Table 4)
SUV/PU	1.48 (1.13–1.93)	
Van	1.40 (0.97–2.02)	
Abdominal injuries		
Conventional autos	Reference	Significant interaction with speed (see Table 4)
SUV/PU	1.83 (1.34–2.51)	
Van	2.00 (1.34–3.00)	
Spinal injuries		
Conventional autos	Reference	
SUV/PU	1.50 (1.06–2.11)	1.16 (0.77–1.77)
Van	1.15 (0.70–1.89)	1.09 (0.59–2.01)
Lower extremity above knee injuries		
Conventional autos	Reference	
SUV/PU	1.46 (1.13–1.89)	1.21 (0.88–1.66)
Van	1.25 (0.88–1.80)	1.02 (0.65–1.59)
Lower extremity below knee injuries		
Conventional autos	Reference	
SUV/PU	0.47 (0.37–0.62)	0.39 (0.28–0.54)
Van	0.51 (0.36–0.72)	0.52 (0.34–0.80)

[a] Adjusted for vehicle weight and speed limit of area of crash.

Table 4
Odds ratios for pedestrian traumatic brain, thoracic, and abdominal injuries by speed limit of area of crash, adjusted for vehicle weight

	OR (95% CI) speed limit <30 mph	OR (95% CI) speed limit 30–35 mph	OR (95% CI) speed limit >40 mph
Traumatic brain injury			
Conventional Autos	Reference		
SUV/PU	1.97 (1.08–3.59)	1.11 (0.70–1.74)	0.84 (0.48–1.46)
Van	2.45 (1.27–4.73)	1.22 (0.64–2.32)	1.49 (0.57–3.92)
Thoracic injury			
Conventional autos	Reference		
SUV/PU	2.00 (1.08–3.72)	1.35 (0.83–2.21)	0.76 (0.43–1.35)
Van	2.42 (1.22–4.79)	1.37 (0.69–2.75)	0.95 (0.35–2.55)
Abdominal injury			
Conventional autos	Reference		
SUV/PU	2.51 (1.20–5.27)	1.29 (0.73–2.27)	0.63 (0.31–1.28)
Van	3.00 (1.35–6.68)	1.17 (0.52–2.64)	1.33 (0.45–3.94)

95% CI: 1.00–1.86). When vehicle weight and speed were controlled for, being hit by an SUV or PU was not associated with a higher ISS score ($P = 0.35$), but being hit by a van had a significantly higher ISS score (OR = 1.63, 95% CI: 1.10–2.42).

3.6. Regression analysis: specific pedestrian injuries

Significant odds ratios for spinal and lower extremity above the knee injuries for SUVs and PUs compared to conventional autos became non-significant after adjustment for vehicle mass and speed. Injuries to the lower extremities below the knee were less common in SUVs and PUs compared to conventional autos. The crude odds ratio (OR = 0.47, 95% CI: 0.37–0.62) remained significant even after adjustment for vehicle mass and speed (adjusted OR = 0.39, 95% CI: 0.28–0.54). Similar trends were seen for vans versus conventional autos (Table 3).

When potential effect modifications with vehicle mass and speed were explored, significant interactions were seen for pedestrian traumatic brain, thoracic, and abdominal injuries. Examining odds ratios comparing vehicle types stratified by speeds, helped to clarify the relationships. The associations for the three body regions of interest demonstrated similar patterns. In all instances, vehicle type was not associated with more injuries at speed limits 30 mph or higher. However, at speed limits less than 30 mph, being hit by SUVs, PUs, and vans was associated with more injuries to the brain, thorax, and abdomen compared to conventional autos (Table 4).

4. Discussion

While a few epidemiologic studies on pedestrian injuries have commented on vehicle type, the classifications have been extremely broad (e.g. motor vehicles, bicyclists, and other) (Galloway and Patel, 1982; Atkins et al., 1988; Harruff et al., 1998; Kingman, 1994). In general these studies only described the distribution of vehicles, rarely examined specific pedestrian injuries by vehicle type, and never studied the relationship between pedestrian injury and vehicle type while controlling for vehicle mass and speed.

Different vehicle types may be more dangerous for pedestrians for several reasons: (1) larger vehicle mass, (2) faster vehicle speeds, and (3) more dangerous front vehicle design.

The agent that causes injury in motor vehicle crashes is kinetic energy, which is dissipated in a collision by friction, heat, and the deformation of mass. In general, the more kinetic energy available in a collision, the greater the potential for injury. The formula that describes kinetic energy is:

$$\text{kinetic energy} = \tfrac{1}{2}(\text{mass} \times \text{velocity}^2)$$

Faster vehicle speeds or velocities are not only associated with an increased risk for crash occurrence (Moore et al., 1995; Zivot and Di Maio, 1993), but faster speeds are also related to more fatalities and more severe injuries among vehicle *occupants* (Ashton et al., 1978; Tolonen et al., 1984; Buzeman et al., 1998). Pedestrians, who do not have the benefit of vehicle safety devices (seat belts or air bags) or even the protection of the automobile's frame, are more vulnerable to injuries and death when struck. In car occupant studies, when vehicles with larger masses collide with smaller cars, the passengers in the smaller vehicles are more seriously injured (Grime and Hutchinson, 1979). Lower vehicle weight is associated with a higher net risk to occupants in collisions with substantially larger and stronger objects and also with a lower net risk for much smaller and more vulnerable entities such as pedestrians, bicycles, and motorcycles when struck (Insurance Institute for Highway Safety, 1998). In published pedestrian injury studies, it generally has been observed that larger cars result in more serious pedestrian injuries (Galloway and Patel, 1982; Atkins et al., 1988) and higher pedestrian fatality rates (Mizuno and Kajzer, 1999).

Since the majority of pedestrian–vehicle collisions involve the pedestrian being struck by the front of a car (58–94%) (Ashton et al., 1978; Lane et al., 1994; Ashton, 1982; Ashton, 1979), it stands to reason that pedestrian injuries are related to the vehicle's external frontal design. SUVs and conventional automobiles have drastically different frontal designs. For example, in general, SUVs have higher car heights and higher bumper heights. These dimensions are important because they dictate the initial contact points between pedestrian and vehicle and they influence secondary contacts between the pedestrian and vehicle and pedestrian and ground.

The present study found that SUVs and PUs were associated with more pedestrian deaths and a higher pedestrian ISS. However, when vehicle mass and vehicle speed were controlled for, the measure of effect was smaller and non-significant. Vans were not crudely associated with mortality, but the relationship with pedestrian ISS remained after adjustment. For SUVs and PUs this is evidence that the overall increased danger these vehicles present to pedestrians may be largely due to their larger masses and faster speeds. Both vehicle types generally weigh more and had their pedestrian collisions in areas with higher speed limits.

The larger cars were associated with more traumatic brain, thoracic, and abdominal injuries, but only at the lowest speeds. At higher speeds, there was no association with vehicle type. This suggests that there is a speed threshold above which the occurrence of these injuries is independent of vehicle type. However, as described previously, almost half of the crashes occurred in areas with low speed limits. The strong influence of speed was also seen in odds ratios for the associations of speed with mortality and ISS in Table 2. Compared to the lowest speed limits, crashes in highest speed limits areas (greater than or equal to 40 mph) had between 8 and 12 times the odds of resulting in a higher pedestrian ISS score or a pedestrian death. The discrepancies in traumatic brain, thoracic, and abdominal injuries by vehicle type at the lower speeds may indicate that vehicle design is more relevant to pedestrian injuries at these lower speeds.

Even though many relationships were seen between vehicle type and injuries to other body regions, none was as notable as below-the-knee injuries. Injuries to the other body regions often diminished after adjustment. However, there were always fewer injuries below the knee when the pedestrian was hit by an SUV, PUs, or vans. Since SUVs, PUs, and vans have higher bumper heights, the initial contact point in frontal crashes would be higher on the leg (usually above the knee). For conventional cars, the initial contact point would be closer to the ground or below the knee. Also, as drivers brake to avoid a collision, the front of the vehicle tends to tilt downward, lowering the bumper height. For conventional cars, this tilting is more dramatic when compared with SUVs and pick-up trucks, hence the bumpers for these taller cars would remain more elevated.

A main independent variable examined was the vehicle speed. Since the actual vehicle speed was rarely available, the speed limit of the area of the collision was used as a surrogate. Although it was felt that the two measures are correlated, the study would have been enhanced if the precise speeds were available. For example, the actual speed of the vehicle would have been much less than the speed limit in crashes when the vehicle was turning or backing up, or if the driver was braking to avoid a collision.

Pedestrians could not be included in this analysis if their police data did not link with a TR record. This would occur if data on linking variables were missing or inaccurate. For cases involving a seriously injured pedestrian, the investigating police officers would tend to be more thorough in their recording of MAARS data, so it is safe to assume that overall, the pedestrians excluded were less severely injured than the ones included.

If in the two datasets (those excluded and those included with a similar level of injury severity) there were *similar* vehicle distributions, then the results seen in the present study would not be different. However, if the pedestrians excluded were hit *more* often by SUVs, PUs, and vans compared to pedestrians included (with a similar injury severity level), then the measures of effect would have been *overestimations*. Similarly, if the pedestrians excluded were hit *less* often by SUVs, PUs, and vans, then the measures of effects would have been *underestimations*. While it is not possible to know which of the three possibilities truly occurred, there is no reason to believe that the excluded cases had very different vehicle distributions from those included with a similar level of injury severity; hence, we suspect that estimates of effect would have been similar.

5. Conclusions

Pedestrians hit by SUVs and pick-up trucks were more likely to have more severe injuries and more likely to die, but the increase in danger may be explained primarily by larger vehicle weights and faster vehicle speeds. Regardless of vehicle weight, pedestrians struck at slower speeds by SUVs, pick-ups, and vans incurred a rate of brain, thoracic, and abdominal injuries twice that of those struck by conventional cars, indicating that vehicle design may contribute to different patterns of injuries at lower speeds. Fewer below the knee injuries were associated with SUVs, pick-up trucks, and vans. This suggests that specific pedestrian injuries may be mitigated with alterations to vehicle design.

Pedestrian injury is a complicated issue. Like most major injury issues, significant reductions in pedestrian deaths and injuries will only be achieved with multi-faceted interventions. Although the present project focused on an understudied area, the vehicle, countermeasures targeting the pedestrian's behavior and environmental characteristics have also proven to be effective.

Acknowledgements

We would like to thank John New and Claudine Woo from the Maryland Institute for Emergency Medical Services Systems; the late Dr. John Smialek, Dr. David Fowler, and Donna Hanson from the Office of the Chief Medical Examiner; Doris Byrne from the Maryland State Archives; Ida Williams from the Central Records Division of the Maryland State Police; Daniel Vomhof from 4N6XPRT Systems; Shiu Ho from the Charles McC. Mathias National Study Center for Trauma and EMS; and the late Dr. Trudy Bush, Dr. Paul Stolley, and Dr. Andrew Burgess from the University of Maryland, Baltimore.

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