Patterns in the incidence and consequences of pedestrian accidents

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Abstract

This paper presents data on factors related to the causes and consequences of collisions between pedestrians and motor vehicles. It is based on two in-depth studies of pedestrian accidents in Adelaide, Australia, police reports of road accidents in South Australia and Coroner's reports on fatal cases.

This paper describes the characteristics of the road environment, vehicles and the pedestrians in the cases. Further observations are made regarding the injuries sustained by the pedestrians in the collisions. A regression model was developed which describes the approximate probability of sustaining a serious injury (or worse) at a given impact speed. The model shows that newer cars are more likely to cause head injury, whereas newer cars are less likely to cause serious lower extremity injury. The probability of sustaining a severe head injury in a pedestrian accident involving a car built in 1990 is one in two at 50 km/h, compared to 1 in 4 for a car built in 1980. Possible limitations of the analysis are discussed

Introduction

The first paper to show that an adult pedestrian is run under, not run over, by the striking car was based on in-depth accident research conducted by the University of Adelaide in the 1960s [1]. During the past 30 years, through its crash investigation activities, the Road Accident Research Unit (now the Centre for Automotive Safety Research) has compiled many detailed investigations of pedestrian accidents, of all severities. This has given us the opportunity to characterise pedestrian accidents that occur in Adelaide, South Australia. Furthermore, the detailed injury data collected as part of the investigation allows us to look at patterns of injury in these accidents. The aim of the present analysis is to describe some general characteristics of the cases in the data and to look at the influence of vehicle characteristics, impact speed and pedestrian age on injury severity.

Data

The data used for this analysis have come from four sources: the Second Adelaide In-Depth Accident Study (henceforth called the ID series) [2], South Australian Coronial data from 1991 to 1997 (FP series), the South Australian Traffic Accident Reporting System (TARS), and data from a study entitled Vehicle Design and Operation for Pedestrian Protection (PED series). Each of these data sets is described briefly in an Appendix to this paper.

Pedestrian ages

The ages of pedestrians involved in accidents in Adelaide is illustrated in Figure 1. The data come from TARS records from the five years from 1999 to 2003. Figure 1 compares the distribution of ages among pedestrians with any injury requiring medical attention with the distribution of ages of fatally injured pedestrians. As expected, [3] elderly pedestrians (70+) appear to be over-represented in fatal cases whereas teenagers and young adults are under-represented; clearly age is closely related to the case fatality rate in pedestrian accidents.

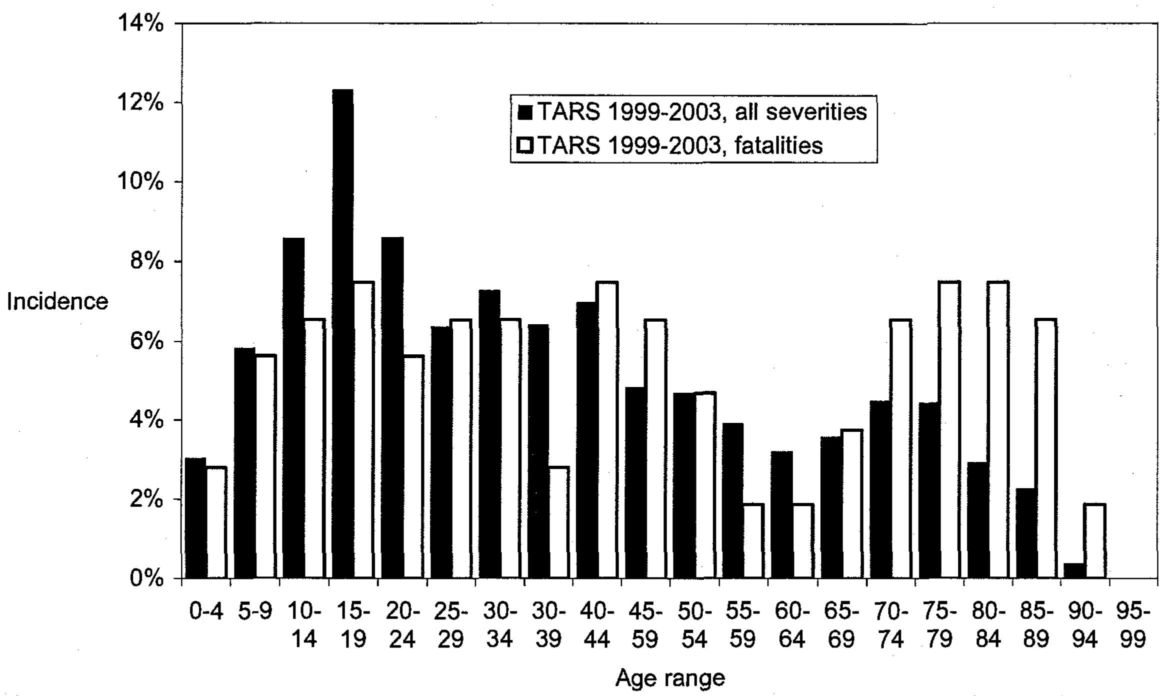

Figure 1 Distribution of the age of pedestrian casualties of all severities and of fatalities only. (TARS data 1999-2003)

Vehicle Characteristics

Approximately 75% of both nonfatal and fatal pedestrian accidents in the TARS data involved a passenger car or a car derivative such as a station wagon (Table 1). Not surprisingly, trucks and semi-trailers are the most dangerous types of vehicle in crashes. Taxicabs are also involved in a greater proportion of fatal pedestrian accidents, for reasons that are not apparent.

Table 1 Types of vehicles involved in pedestrian accidents in SA, TARS data 1999 - 2003

	Injured	Fatal	Total	Fatal accidents as a proportion of all accidents
Car	1449	55	1504	3.7%
Motor vehicle - type unknown	332	7	339	2.1%
Station wagon	302	8	310	2.6%
Utilities and 4WDs	113	3	116	2.6%
Panel van	80	4	84	4.8%
Taxi cab	55	4	59	6.8%
Truck	34	6	40	15.0%
Omnibus	36	1	37	2.7%
Pedal cycle	37	0	37	-
Motorcycle	32	3	35	8.6%
Semi trailer	11	8	19	42.1%
Other defined motor vehicle	11	2	13	15.4%
Forward control passenger van	1	0	1	-
Small wheel vehicle	1	0	1	-
Total	2494	101	2595	

Road and Environment

Figure 2 describes the accident location in terms of the distance from the nearest pedestrian crossing facility (of any kind), where relevant. The distribution of these distances shows that about one quarter of the 58 accidents occurred at a crossing (on roads where pedestrian crossings are commonly located) with another quarter within 50 metres of a crossing, about 30 per cent from 50 to 100 metres, and about one fifth more than 100 metres from a crossing.

One quarter of the total number of 77 accidents in this series of pedestrian accidents occurred in a location where there was no expectation that there would be a pedestrian crossing, or where the presence of a pedestrian crossing would not have prevented the collision. These cases included accidents that occurred on residential streets and rural roads, as well as collisions that occurred off the roadway.

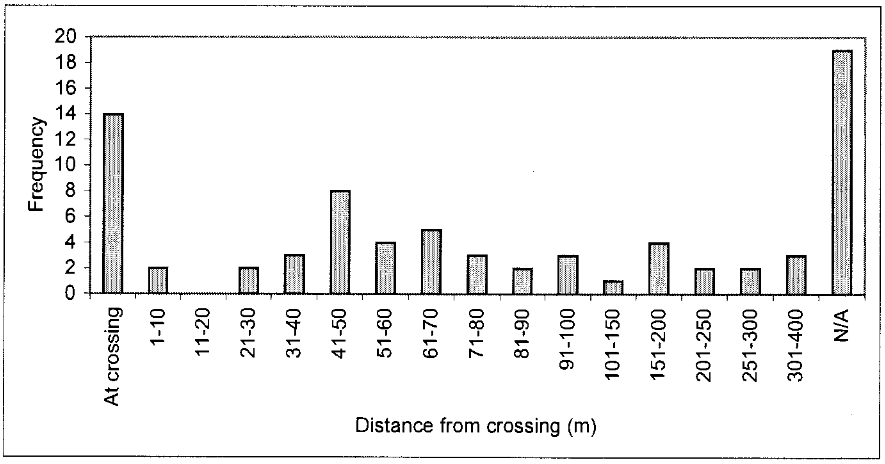

Figure 2 Distance of impact point from a pedestrian crossing facility: PED series. "N/A" in this context means that the environment was not one where one would normally expect to see a crossing facility: e.g. a residential street or a rural road, or where the collision took place off the roadway

A common perception of pedestrian accidents is that of a pedestrian who steps out from between parked cars, and a driver who could not see the pedestrian prior to the accident. Table 2 shows that most accidents occurred with no physical obstruction to vision between the pedestrian and the driver. However, parked vehicles and vehicles in a traffic lane were the most common obstruction to vision. They played a role in 22% of fatal accidents in the FP series and in 29% of pedestrian accidents of all severity in the PED series.

Table 2 Visual obstruction before the collision in the FP and PED series

Visual obstruction	FP series		PED series	
No obstruction	123	(72%)	50	(67%)
Parked vehicle(s)	15	(9%)	6	(8%)
Vehicle(s) in traffic lane – stationary	22	(13%)	15	(20%)
– moving			1	(1%)
Other physical obstruction	3	(2%)	-	-
Trees or bushes	8	(5%)	-	-
Sun	-	-	3	(4%)
Unknown	19	(-)	2	(-)
Total	190	(100%)	77	(100%)

Commonly injured body regions

In each case in the PED and ID series, the injuries sustained by the pedestrian(s) were coded according to the Abbreviated Injury Score, 1990 edition (AIS90, 98 update) and the 1976 edition (AIS76). The AIS severity and body region codes in the ID series were updated so that they could be combined with the PED series. Table 3 lists the body regions as defined by AIS90, in descending order of the incidence of AIS3+ injuries. As an impact may cause more than one serious-to-untreatable injury (skull fracture and a brain injury, for example), only the single most severe injury for each body region of each pedestrian was considered.

The head and the lower extremities (which by the AIS90 definition, includes the pelvis), accounted for 50% of the body regions having at least one serious injury (AIS 3+) in the PED and ID series (Table 3).

Table 3 Incidence of at least one AIS3+ injuries by body region: PED and ID series

Body region (by AIS code)	Body region count	
Head	25	(30%)
Lower extremity	17	(20%)
Thorax	12	(14%)
Abdomen	10	(12%)
Spine	10	(12%)
Upper extremity	5	(6%)
Face	2	(2%)
Neck (exc. Spine)	2	(2%)
Total	83	(100%)

The incidence of serious-to-untreatable (AIS3+) injuries to the head and lower extremities of the pedestrians is shown in Table 4, according to the data series. The were collected in 1999 and 2000. We noted large differences in the percentages of AIS3+ head injuries, and AIS3+ injuries to the pelvis or femur, between the two series. Although the numbers of cases are small, a comparison of the distribution of (head)/(pelvis & femur)/(knee & tibia) injuries approaches statistical significance (χ^2_{2df} = 5.92, p = 0.052). The vehicle fleet would have changed markedly between the two studies, indicating that vehicle year may be a relevant factor in the severity of injury. It is unlikely that any aspects of the vehicles in the samples were designed with pedestrians in mind.

Table 4 Incidence of injuries scoring AIS3+ in the ID and Ped series (one per injury type per pedestrian)

3+ injury type	ID series	Proportion of sample (42)	PED series	Proportion of sample (81)	Total	Proportion of total sample
Head injury	5	12%	18	22%	23	19%
Fractured pelvis	4	10%	2	2%	6	5%
Fractured femur	3	7%	1	1%	4	3%
Ruptured ligament in knee	2	5%	1	1%	3	2%
Fractured tibia and /or fibula	3	7%	5	6%	8	7%

Vehicle year as a factor in injury severity

Although the PED series cases were collected in 1999 and 2000, vehicles from the 1970's were still represented in the sample. Therefore, the cases from the ID and PED series were combined to examine the effect of vehicle vintage on the incidence of severe injury. We speculate that if vehicle vintage is a factor in determining pedestrian injury severity, this effect is present because of differences in the frontal shape of the vehicles affecting the kinematics of a pedestrian struck by the vehicle, and possibly because of a decrease in the proportion of stiffer pedestrian head impact regions on the vehicle, and a decrease in the stiffness of structures likely to strike the legs. We restricted this analysis to those cases that involved a pedestrian of adult stature (approximated by pedestrians over the age of 12), and a vehicle bonnet leading edge height less than 900 mm. These criteria reduced the sample to 73 cases.

We then dichotomised the year of manufacture to produce two groups consisting of "older" (up to, and including 1984) and "newer" (1985 and later) cars. The break-year was chosen to produce two groups of similar size. The tabulation of head injury severity and lower extremity injury in these two groups is shown in Tables 5 and 6.

Table 5 Vehicle year and severity of injury to the lower extremities

		Vehicle year		
		1984 and older	1985 and newer	Total
Worst lower extremity injury	AIS < 3	25	37	62
	AIS ≥ 3	9	2	11
Total		34	39	73

Pearson chi-square = 6.465, p = 0.011

Table 6 Vehicle year and severity of injury to the head

		Vehicle year		
		1984 and older	1985 and newer	Total
Worst head injury	AIS < 3	31	30	61
	AIS ≥ 3	3	9	12
Total		34	39	73

Pearson chi-square = 2.687, p = 0.101

The newer groups of cars were far less likely to cause at least one AIS 3+ injury to the lower extremities of pedestrians (χ^2_{1df} = 6.456, p = 0.011). However, the data suggest that newer cars may be more likely to cause at least one AIS 3+ injury to the head. This result was not statistically significant (χ^2_{1df} = 2.687, p = 0.101).

Explanations for a possibly greater frequency of serious head injury among pedestrians struck by more recent cars are speculative, but there are some possibilities that we consider to be likely and that could be explored further. These are (a) that the collision kinematics are being altered due to changing car shapes and that this might affect head impact speed and the structures hit by the head in a collision, and (b) vehicle stiffness is effectively increasing as bonnet clearances with under bonnet components are reduced. The reduction in the severity of lower extremity injuries over time would almost certainly be accounted for by changes in vehicle design: the obsolescence of exposed steel bumpers and the changing profiles and structures of the bonnet leading edge.

The height of the bonnet leading edge of passenger cars and derivatives in the PED and ID cases is negatively correlated with age (R^2 = 0.461, p < 0.001). The height of the bonnet leading edge progressively decreased with changes in car design over time. This might explain the reduction in the incidence of serious fractures to the pelvis and femur. While this is a positive, if unintended, effect of design changes, a negative consequence might have been that head impact velocity has been increased. While we can only speculate on that effect being present in this sample, computer modelling has shown that a higher bonnet leading edge is associated with a lower head impact velocity. Comparisons of pedestrian head impact velocities in collisions with passenger cars and four-wheel drive type vehicles have been made by Anderson and McLean [4], who show that the head impact velocities are estimated to be 10-20 km/h lower in collisions with the higher vehicles. (This neglects any increase in the harmful effect of the higher leading edge on other critical body regions such as the neck, thorax and spine.)

As noted above, another possible explanation for the increase in the frequency of serious head injury is that later model vehicles may have less clearance between the bonnet and under bonnet components such as the engine and suspension towers, rendering a head impact with the bonnet more likely to result in a serious injury for a given head impact velocity. We have observed in reconstructions [5] and in tests for the Australian New Car Assessment Program that bonnet impacts are most serious when there is an engine or suspension component directly underneath and in close proximity to the bonnet. If there has been a trend to smaller volume engine-compartments, which we believe there has, and/or more engine and suspension components being installed into the compartment, this would entail an increase in the proportion of hard regions across the bonnet of the car.

Regression of injury on impact speed, vehicle age and pedestrian age

Given the results obtained above, we estimated the size of the effect of vehicle year taking into account vehicle impact speed and pedestrian age. The data from the two series were combined, and logistic regression models were constructed in which the severity of the head and the lower extremity injuries were separately regressed on impact speed, pedestrian age and model year. Impact speeds could not be estimated in 23 cases and so regression was based on the remaining 50 cases. The results are shown in Tables 7 and 8.

Table 7 Incidence of head injury (MAIS ≥ 3) regressed on vehicle year, impact speed and pedestrian age.

	B	Sig.	Exp(B)	95% C.I. for Exp (B)	
				Lower	Upper
Year of manufacture	.100	.047	1.105	1.001	1.220
Impact speed	.084	.009	1.088	1.021	1.160
Pedestrian age	.006	.705	1.006	0.974	1.040
Constant	-5.260	.006	.005		

Table 8 Incidence of lower extremity injury (MAIS ≥ 3) regressed on vehicle year, impact speed and pedestrian age.

	B	Sig.	Exp(B)	95% C.I. for Exp (B)	
				Lower	Upper
Year of manufacture	-.120	.067	.887	0.780	1.008
Impact speed	.098	.005	1.103	1.030	1.182
Pedestrian age	.056	.037	1.057	1.003	1.114
Constant	-8.420	.001	.000		

Unsurprisingly, speed was revealed as a significant correlate of the incidence of at least one AIS 3+ injury to the lower extremities and to the head. Furthermore, pedestrian age was positively correlated with the incidence of at least one AIS 3+ injury to the lower extremities (age in years, odds ratio = 1.057, p = 0.037), but curiously not with the incidence of at least one AIS 3+ injury to the head (odds ratio = 1.006, p = 0.705).

The results were also consistent with Tables 5 and 6; newer cars were less likely to cause at least one AIS 3+ injury to the lower extremity but were more likely to cause at least one AIS 3+ injury to the head. The latter result implies that the odds of sustaining at lest one head injury of this severity increased by 11% per year of manufacture (odds ratio = 1.105, p = 0.047). Concomitantly, the odds of sustaining at least one AIS 3+ lower extremity injury decreased by 11% per year of manufacture (odds ratio = 0.887, p = 0.067).

Although there is no reason to expect a selection bias toward cases of less severe head injury in the earlier ID series, we repeated the regression of the incidence of head injury using PED cases only. The estimated size of the effect actually increased (odds ratio = 1.166) and statistical significance only marginally decreased (p = 0.052).

The implication of the model (PED and ID cases combined) is that on average the probability of sustaining a severe head injury in a pedestrian accident involving a car built in 1990 is one in two at 50 km/h, compared to 1 in 4 for a car built in 1980.

Summary and discussion

This paper has examined data on pedestrian accidents with the aim of describing some of the characteristics of the pedestrians, the vehicles, the collisions and the injury outcomes. The data sets were collected from the mid 1970's up to 2000.

The general characteristics of the accidents included the following:

- Older pedestrians have a higher case fatality rate than younger pedestrians.
- Approximately 75% of accidents that caused some level of injury involved a passenger car or passenger car derivative.
- Most accidents occurred without any visual obstruction between the driver and the pedestrian. In those that did have some visual obstruction, parked or stationary vehicles in traffic lanes were the most common, playing a role in 20% of fatal accidents and 27% of accidents overall.

The PED and ID series (those series which contain the most detailed data on pedestrian-vehicle collisions) were used to examine the severity and locations of injuries sustained by pedestrians in collisions with cars and car derivatives. In these series, the head and lower extremities accounted for approximately 50% of body regions having at least one serious injury. Thorax (14%), abdomen (12%) and spine (12%) followed head and lower extremity in the incidence of serious injury.

A regression analysis showed that accidents involving cars manufactured recently were more likely to produce a head injury than cars of older vintages, while the risk of serious lower extremity injury has been reduced. The height of the leading edge of newer vehicles has consistently been lower than that of older vehicles. This and other differences in frontal shape might have led to different pedestrian kinematics during the collision, possibly increasing head impact velocity. It may also be that newer cars have less clearance between the bonnet and the under bonnet components of the car. In an impact between the head and the bonnet, this can be a critical factor in the severity of that impact.

Although the regression showed the year of vehicle was a statistically significant factor in the likelihood of head injury, some reservations must be borne in mind. First we assume that there is no factor, irrelevant to vehicle design, that we didn't account for and that is accidentally correlated with vehicle age. For example, it may be that more recent cars in our sample just happened to hit individuals more susceptible to head injury, or it just so happened by chance that our cases of serious head injury involving newer cars involved more aggressive structures on the cars. Effects of this type are more likely in smaller sample size and so repeating the analysis with another, preferably larger, sample would be desirable to eliminate the possibility of any such effect.

Furthermore, it is conceivable that the following mechanism might lead to a bias in the head injury results. If older cars are indeed more likely to cause leg injuries (which is plausible) then those injuries may well be the way in which a crash involving an older car entered our sample. If newer cars do not cause such lower extremity injuries then 'equivalent' cases involving newer cars may have not have been captured, creating a distortion in the selection of the sample. While the studies from which our data are drawn were carefully designed to capture accidents of all severity (and which they do) and our assessment is that no unintended censoring of cases took place, we must consider whether selection bias of the kind just described took place.

The novelty of this result is reason to carefully consider bias in the data, but it is also important to consider the implications if in fact there has been changes in the safety performance of vehicles described herein; while the reduction of leg injuries is to be welcomed, an increase in the risk of head injuries is of concern.

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Appendix A: Description of data sets

The Second Adelaide In-Depth Accident Study, 1976-1977 (ID series): 40 Cases

The Second Adelaide In-Depth Accident Study (1975-1979) was designed "to evaluate the effectiveness of many existing safety measures and to identify other factors related to accident or injury causation in road accidents in metropolitan

Adelaide." [6] This at-the-scene study was of a representative sample of accidents to which an ambulance was called in the Adelaide metropolitan area. It comprised 304 accidents including 40 pedestrian accidents of varying severity.

South Australian Coronial Data, 1991 – 1997 (FP series): 190 Cases

This data set, which consists of Coronial files on pedestrian accidents for the years 1991-1997, set has been characterised previously [7]. These files generally contain a large amount of information on the accident, including police accident report forms, a report by the Police Major Accident Investigators, interviews with participants and witnesses, autopsy reports, and blood alcohol analyses.

Traffic Accident Reporting System (TARS) Data, 1999-2003: 2,595 Cases

When a road accident occurs in South Australia, the operators of the motor vehicle/s involved are required to report the accident to the police, in all but minor property damage cases. These data are then entered into the Traffic Accident Reporting System (TARS). The TARS data file consists of three levels of information. Information on the accident is held in the accident file. Under this is the unit file which records information on each unit involved in the accident (a unit may be a vehicle, pedestrian, animal or a roadside hazard). Finally, the casualty file records information on each casualty for each unit.

Vehicle Design and Operation for Pedestrian Protection 1998-2000 (PED series): 77 Cases

Between 1998 and 2000, 77 pedestrian accidents were investigated at the scene for the Federal Department of Transport and Regional Services. The main aim of this project was to collect information on the physical interaction between the pedestrian and the vehicle. Consequently, the focus of the data collection was on items of information that would enable an estimate to be made of the vehicle travel and impact speeds, contacts between the pedestrian and the vehicle, injuries sustained in the accident and the likely source of those injuries. Additionally, road and traffic factors were also recorded.