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TRL Insight Report
INS009

The characteristics of pedestrian road traffic accidents and the resulting injuries

R E Cookson, D C Richards and R W Cuerden

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CONTENTS

List of figures

List of tables

Abstract

This Insight Report explores the characteristics of pedestrian road traffic accidents, and the injuries received by the pedestrian casualties. These are often the most vulnerable members of society, so an understanding of the causes and consequences of pedestrian accidents is important as the demographics of the population changes in the coming years. Recent changes in vehicle design, including the recent legislation on pedestrian protection, may also affect the consequences of pedestrian accidents.

This report has used a number of different sources of information. These include medical data collected by all hospitals in England (the Hospital Episode Statistics) and more in-depth data collected by the Helicopter Emergency Medical Service, which operates from the Royal London Hospital. More traditional sources of accident data have also been used, including the national police STATS19 database, in-depth accident studies (On The Spot and the Co-operative Crash Injury Study) and police fatal file reports.

This Insight Report provides a snapshot of the causes and consequences of pedestrian traffic accidents, which shows the most important considerations for reducing pedestrian casualties. Continuous monitoring is required to determine the results of changing vehicle design and pedestrian demographics.

Executive summary

This Insight Report explores the characteristics of pedestrian road traffic accidents, and the injuries received by the pedestrian casualties. These are often the most vulnerable members of society, so an understanding of the causes and consequences of pedestrian accidents is important as the demographics of the population changes in the coming years. Recent changes in vehicle design, including the recent legislation on pedestrian protection, may also affect the consequences of pedestrian accidents.

This report has used a number of different sources of information. These include medical data collected by all hospitals in England (the Hospital Episode Statistics) and more in-depth data collected by the Helicopter Emergency Medical Service, which operates from the Royal London Hospital. More traditional sources of accident data have also been used, including the national police STATS19 database, in-depth accident studies (On The Spot and the Co-operative Crash Injury Study) and police fatal file reports.

Analysis of the characteristics of pedestrian accidents showed that 80% involved cars, and a high proportion of pedestrian accidents with larger vehicles result in a fatal outcome for the pedestrian. Age of pedestrians was found to be related to the accident configuration where adults are most often involved in accidents involving pedestrian crossings, suicide, reversing vehicles and vehicles leaving the carriageway. Whereas accidents where the view of the pedestrian or the driver was obscured by another vehicle or object are more frequent for child pedestrians. The level of deprivation in the areas pedestrians came from was also investigated and it was found that a large proportion of pedestrians involved in road traffic accidents come from the most deprived areas.

The risk of a pedestrian being killed at an impact speed of 30 mph is approximately 7%. Above this speed the risk increases rapidly – the increase is more than 4 times from 30 mph to 40 mph. Although the risk at 30 mph is relatively low, approximately half of pedestrian fatalities occur at this impact speed or below.

Hospital data was used to determine the frequency and types of injury received by pedestrian casualties, and found the most frequent injuries were to the head and leg. Although head injuries were the most frequent, leg injuries were found to be the most costly. This is because, on average, pedestrians with leg injuries had a longer stay in hospital.

Reports created by the police for 49 fatal pedestrian accidents were analysed to determine the causes of the injuries received by the pedestrians. This showed that the majority of the severe leg injuries were caused by the initial impact between the pedestrian and the car bumper, or bonnet leading edge. The majority of head injuries were caused by impacts with the windscreen and surrounding frame. A large number of severe thorax injuries were also seen for these pedestrians.

This Insight Report provides a snapshot of the causes and consequences of pedestrian traffic accidents, which shows the most important considerations for reducing pedestrian casualties. Continuous monitoring is required to determine the results of changing vehicle design and pedestrian demographics.

1 Introduction

Every year in the UK thousands of people are killed and tens of thousands are seriously injured in road traffic accidents. As well as the personal tragedy of these events, road traffic accidents have economic implications. An understanding of how injuries occur in accidents is sought in order to implement ideas to try and mitigate them, and a major part of gaining this understanding is looking at national level statistics. The importance of these statistics is such that they can affect government and local authority initiatives, policy, spending and legislation, and even vehicle manufacturing decisions. Hence the need for them to be accurate and reliable is prevalent.

This report combines the use of these national level statistics (macro studies) with the more localised statistics of smaller, but more in-depth, databases (micro studies). These studies will be explained in more detail in Section 2 and are as follows:

- National police data from STATS19
- National hospital data from the Hospital Episode Statistics (HES)
- Localised data from the On The Spot (OTS) study run at TRL
- Local hospital data from the Helicopter Emergency Medical Service (HEMS) based in London
- Police fatal files

Apart from being a large group of the road casualties in Great Britain, there are a number of reasons for investigating pedestrians. Arguably, compared to car occupants, the injury epidemiology and characteristics of pedestrians are less well understood, because of the lack of large pedestrian-focused accident studies. Also, new European Union pedestrian regulations have meant that the design of cars has changed, so it is important to find any corresponding change seen in pedestrian casualties.

Pedestrian casualties are often the most vulnerable members of society. Children have a large exposure to traffic as pedestrians, especially on their journey to and from school. Elderly people, who may not have another form of transport available to them, are also exposed and at greatest risk of serious injuries if they are involved in an accident. These are also the two groups of pedestrians who are least well equipped for the road-crossing task.

This Insight Report investigates many aspects of pedestrian collisions. The structure of this report is as follows:

- Section 2 – Methodology. This describes the sources of information which were used to explore pedestrian traffic accidents. These include data recorded by hospitals, and traffic accident databases. This chapter also details the methodology used to determine the causes and costs of pedestrian injury, and the relationship between pedestrian injury and impact speed.
- Section 3 – Pedestrian accident characteristics. This chapter explores the range of variables that are related to pedestrian accidents, to determine how and why they occur, and what the consequences are. This begins with variables that are related to the accident, such as date, time, location and the vehicles involved. Contributory factors are also examined, relating to either the pedestrian casualty or the driver of the vehicle that hit the pedestrian. The characteristics of the pedestrian are then explored in more detail, such as their age and injury severity. Finally, the relationship between impact speed and pedestrian injury severity is determined.
- Section 4 – Pattern and costs of injury. This chapter explores the injuries which are received by pedestrian casualties in traffic accidents. The type and frequency of injuries is determined, then the cost of these injuries is estimated using a model that is based on the duration of stay of these pedestrians in hospital.
- Section 5 – Injury causation. This chapter explores 49 fatal pedestrian accidents, and investigates the causes of the injuries received by these casualties. The injury causations of pedestrians hit by new cars are compared to those hit by old cars to see if recent changes in vehicle design have had any discernible effect.

1.1 Overview of accidents in Great Britain

In 2008 there were 2,538 road traffic fatalities in Great Britain, and 26,034 seriously injured casualties (Department for Transport, 2009). These road casualties included 572 pedestrian fatalities (23% of all road fatalities) and 6,070 seriously injured pedestrians (23% of all seriously injured casualties on the road).

The reported number of killed and seriously injured road casualties per year has been decreasing for pedestrians from 1996 to 2008 (see Figure 1.1); however this decrease has been less from 2004 to 2008. This trend is the same for car user casualties. Motorcyclist casualties increased between 1996 and 2003, decreasing back to the 1994-98 average by 2006 with a sharp decrease from 2007 to 2008.

Although the total reported pedestrian casualties have decreased by 6% from 2007 to 2008 and fatalities have fallen by 11%, for the ages of 2 to 15 and from 80 onwards, most KSI casualties are still pedestrians.

The national statistics show that pedestrians are a significant number of road user casualties, and in recent years have not decreased, unlike other casualty types.

1.2 Pedestrian protection legislation

Pedestrian protection test procedures were not enforced by legislation until 2005 and until this point it was only the manufacturer's duty of care and consumer testing programmes such as EuroNCAP that encouraged the development of pedestrian protection. The aim initially was to reduce lower limb injuries such as fractures to the tibia and fibula bones and also reduce injuries to the knee ligaments which are potentially debilitating and were both common in bumper impacts. With the developments of pedestrian protection and the use of impact test tools, the acceleration of the tibia (related to fracture risk) and knee bending angles have been reduced. However, by reducing the tibia fracture it is possible that knee injuries may be increasing due to the fracture of the tibia alleviating some of the load in the knee. Tibia fractures are in most cases easier, cheaper and quicker to recover from than knee ligament injuries.

The head impact tests use the Head Injury Criterion (HIC) as an assessment of the performance of the vehicle; however, as HIC is related to life-threatening injuries, it may not fully

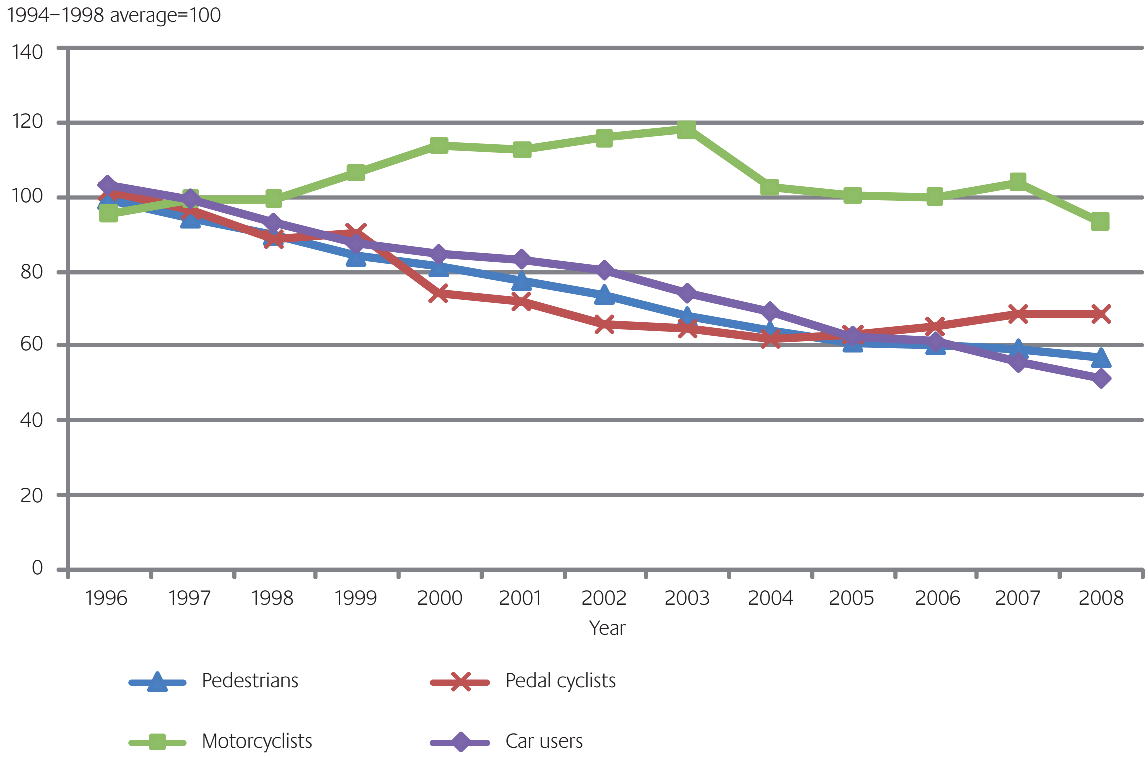

Figure 1.1 Trend of road casualties in Great Britain by road user type

consider the effect of more moderate injuries. From an impact testing perspective, this is difficult to assess, however a comprehensive study of "real-life" pedestrian collisions would enable a correlation of the consequences of head impacts with the bonnet top, windscreen, A-pillars and other structures for all injury severities, to be assessed.

To achieve the performance levels in the EC Regulation and in particular in Phase Two (discussed in the following sections) it is likely that deployable active safety pedestrian systems, such as pop-up bonnets, are going to become more common.

The EC Directive on pedestrian protection (2003/102/EC) was originally written in two phases. Phase One came into force in October 2005 and was applicable to new type-approvals, with the intention that all old type-approved vehicles that are still in production must be approved to the Phase One requirements by the end of 2012. Originally, Phase Two of the EC Directive was to come into force for new type-approvals in September 2010 and new vehicles by September 2015. However, it was suggested that Phase Two of the EC Directive was not achievable and consequently TRL were commissioned to conduct a feasibility study. As a result of the feasibility study, Phase Two of the European legislation was revised; the revised Phase Two was included in EC Regulation Number 78/2009, which was published in February 2009. This supersedes the EC Directive and also brings together the Frontal Protection Systems (Bull-bar) legislation and adds requirements for Brake Assist Systems (the latter being required to compensate for the pedestrian protection feasibility adjustments). Table 1.1 outlines the effective dates for each of the pedestrian protection phases of the EC Regulation and for the Brake Assist System (BAS) requirement.

1.2.1 Phase One of EC Pedestrian Directive

Phase One of the EC Directive and Phase One of the EC Regulation are similar and involve lower legform to bumper tests (for bumper heights ≤ 500 mm, otherwise there is a choice of upper leg impactor or lower leg impactor for high bumpers) for which the performance limits are:

- knee bending angle 21°
- tibia acceleration 250 g, and
- knee shear displacement 6 mm

Phase One also includes bonnet top headform impact tests. Normally 18 tests are performed at 35 kph using a child/small adult headform, with a mass of 3.5 kg. The test area corresponds to the combined child and adult areas of the Phase Two tests. The performance requirements are:

- Head Injury Criterion (HIC) values of 1000 and below for two thirds of the bonnet and HIC values of no more than 2000 for the remaining third (which is specified by the manufacturer).

As part of Phase One, there are monitoring tests performed using the upper leg to the bonnet leading edge and also adult head impact tests to the centre of the windscreen using the 4.8 kg headform. As these are for monitoring purposes only, there is no immediate incentive for the manufacturers to achieve an exceptional pedestrian protection performance in these regions.

Table 1.1 Outline of dates from when each phase of the Regulation is effective

Vehicles	*EC Regulation (78/2009)*					
	Phase One		*Phase Two*		*Brake Assist System*	
	New types	*New vehicles*	*New types*	*New vehicles*	*New types*	*New vehicles*
M1 ≤ 2500 kg and N1 derived from M1 ≤ 2500 kg	11/2009	12/2012	2/2013	2/2018	11/2009	2/2011
M1 > 2500 kg			2/2015	8/2019	11/2009	2/2011
N1 other (not derived and/or > 2500 kg)			2/2015	8/2019	2/2015	8/2015

1.2.2 Phase Two of EC Pedestrian Directive

The Phase Two of the original EC Directive has now been superseded by Phase Two in the EC Regulation. Currently, no vehicle is required to pass Phase Two. However, due to the development time it is likely that certain aspects of the protection performance requirements will gradually be seen to filter into the vehicle fleet prior to its effective date. The main tests, such as the lower leg test, high bumper test and the headform impact test, are performed in Phase Two, however the performance limits are modified. For the lower leg tests, they are performed using the lower legform impactor for bumpers with a height below 425 mm. For a bumper height ≥ 425 mm and < 500 mm the manufacturer has the option of an upper leg or lower leg impactor test, for heights ≥ 500 mm the upper leg only is used. In addition to these changes the lower legform impactor is raised by 25 mm from the ground level to take into account the height of a shoe of a pedestrian. The performance limits for Phase Two are:

- knee bending angle 19°;
- tibia acceleration 170 g; and
- knee shear displacement 6 mm.

In addition, there is also the inclusion of a "reduced protection zone" which can be applied to the vehicle bumper. There are no limits to the number of low performance zones as long as the total width of these does not exceed 264 mm. The performance criteria for the reduced protection zone remain the same except that the tibia acceleration limit increases to 250 g.

For the headform impact tests, two impactors are used at 35 kph. These headforms have a mass of 3.5 kg and 4.5 kg respectively and in the test area there is a transition line at 1700 mm wrap around distance between the child/small adult zone and the adult zone. These tests are only performed on the bonnet top, not in the windscreen area, and consequently some vehicles will have the transition line further rearward than the rear of the bonnet and would only require the 3.5 kg headform test. The performance criteria are:

- Head Injury Criterion (HIC) values of 1000 and below for two thirds of the bonnet and HIC values of no more than 1700 for the remaining third and no more than 50% of the child zone can be above HIC 1000.

An upper leg to bonnet leading edge test (similar to Phase One) is performed but is again only for monitoring purposes.

2 Methodology

In order to undertake a detailed review of pedestrian accidents and their resulting injuries, a number of databases were chosen, each of which can be used to explore a certain aspect of pedestrian accidents. To provide an overview of the characteristics of all the pedestrian accidents in Great Britain, the STATS19 database was analysed. The Hospital Episode Statistics (HES) were then used to identify the injuries received by a subset of these pedestrians, their deprivation levels and injuries received. In order to calculate costs of injuries, data from the Helicopter Emergency Medical Service (HEMS) was used. In-depth data from on-scene investigations was required in order to investigate the specifics of the pedestrian accidents, such as impact speeds and accident configurations. For this, data from the On The Spot (OTS) study was analysed. This study did not collect information on or take photographs of vehicle damage caused by pedestrians, or match vehicle damage to pedestrian injuries, therefore STATS19 was used to identify police fatal files where pedestrians were struck by cars. Fatal files with good photos and post mortems gave an insight into the injuries to different body parts received by pedestrians, which were then matched to damage seen on vehicles. Each of the data sources and further details on the methodologies used are described in the following sections.

2.1 STATS19

STATS19 data is comprised of the details of road traffic accidents attended by the police in Great Britain. In theory the police are required to attend every road traffic accident that involves an injury and while on scene officers fill out a series of standard forms. Details of the nature of the accident, the location, a crude classification of injuries and the overall accident severity are all collected. Officers make a judgement, often without further information from hospitals, and record the severity of the injured casualties and the overall accident as “slight”, “serious” or “killed”. This data is then collected, collated and analysed by the Department for Transport (DfT).

STATS19 is, in principle, the national database in which all traffic accidents that result in injury to at least one person are recorded, although it is acknowledged that some injury accidents are missing from the database and a few non-injury accidents are included (Ward, Lyons, and Thoreau, 2006). The database primarily records information on where the accident took place, when the accident occurred, the conditions at the time and location of the accident, details of the vehicles involved and information about the casualties. Approximately 50 pieces of information are collected for each accident (Department for Transport, 2007a).

The contributory factor system was adopted by STATS19 in 2005 (Department for Transport, 2007a). Up to six contributory factors can be recorded for each accident, from a list of 77 options. These 77 contributory factors are grouped into nine categories: road environment contributed, vehicle defects, injudicious action, driver/rider error or reaction, impairment or distraction, behaviour or inexperience, vision affected by, pedestrian only, and special codes.

Each contributory factor chosen for the accident can be given a confidence of “very likely” or “possible”, and can be allocated to a particular person or vehicle involved in the accident. The analysis of contributory factors in this report combines the “very likely” and “possible” factors into one dataset.

The accidents that are recorded in STATS19, including the contributory factors, are summarised annually in the DfT “Reported Road Casualties Great Britain” (RRCGB) series.

The pedestrian casualties used for analysis in STATS19 were selected to be only those who were killed or seriously injured as only these pedestrians could have been admitted to hospital and therefore be in the HES dataset. In the same 1998 to 2007 time period there were 64,233 pedestrian accidents in England recorded in STATS19. This consisted of 64,253 vehicles and 65,526 pedestrian KSI casualties. Contributory factors were also analysed for STATS19. There were 29,229 contributory factors recorded for these accidents.

2.2 Hospital Episode Statistics (HES)

Hospital Episode Statistics are compiled by the Department of Health and record details of all hospital admissions, finished consultant episodes (FCEs) and hospital discharges for England. Data of this type has been collected since 1989, with its main purpose being to ensure correct funding of hospitals from their Primary Care Trust (PCT) (Department for Transport, 2007b). HES contains data such as age, sex, dates of admission and discharge, diagnoses, operations and procedures, place of residence and ethnicity, with approximately 12 million new records being added each year. Information regarding the diagnosis of injury and its causation is coded using the “International Classification of Diseases” (ICD), of which the latest version, ICD-10, has been used since 1995. Injuries sustained in road traffic accidents can easily be identified when coded in this way. It should be noted that HES do not include details of any casualties treated in Accident and Emergency (A&E) that are not admitted to hospital (Department for Transport, 2006). For this work the HES data was obtained through the South East Public Health Observatory.

In this dataset there were 82,811 unique admissions for 80,116 patients. These admissions were then broken down by their accident type classification, using their 4-digit causation code. From these codes the admissions which were described as “non-traffic” or “unspecified non-traffic” were eliminated for comparison with the other datasets. This resulted in 72,878 admissions for analysis.

The Hospital Episode Statistics include a measure of the deprivation of the area where each casualty lives. This project uses the index of multiple deprivation (IMD) decile group for deprivation analyses; this uses the IMD overall ranking to identify which one of ten groups an area belongs to, from most deprived through to least deprived. The IMD overall ranking is made by combining the seven IMD Domain scores using the following weights (HESOnline, 2008):

- Income (22.5%)
- Employment (22.5%)
- Health Deprivation and Disability (13.5%)
- Education, Skills and Training (13.5%)
- Barriers to Housing and Services (9.3%)
- Crime (9.3%)
- Living Environment (9.3%)

2.3 Helicopter Emergency Medical Service (HEMS)

A report was produced in the 1980s by the Royal College of Surgeons which documented cases of patients dying unnecessarily because of the delay in receiving prompt and appropriate medical care. London's Air Ambulance was established to address the findings of this report and to find a way to respond quickly in London's increasingly congested roads. London's Air Ambulance began operations in 1989 from a temporary base at Biggin Hill Airport and in 1990 moved to a permanent base in central London. This is at the Royal London Hospital, which was successful in its bid due to being the only multidisciplinary hospital with a site where it would be safe to build a rooftop helipad. The Helicopter Emergency Medical Service (HEMS) began to fly from the rooftop at the Royal London on 30 August 1990 and to date has flown over 17,000 missions.

HEMS primarily deals with major trauma accidents of all varieties including serious road traffic accidents. The patient is then seen as quickly as possible by a specialist trauma doctor and paramedic team to provide the greatest chance of survival. The paramedic team at the London Ambulance Service control room decides which of the 3,500 calls they receive a day are appropriate for the HEMS to attend. The paramedic team can also request for HEMS to attend if they require further medical resources in the field.

There are a number of criteria which determine whether an emergency call is appropriate for the HEMS. For pedestrian accidents, there would be immediate dispatch (in less than three minutes) if the pedestrian was trapped underneath a vehicle, had received traumatic amputation above the wrist or ankle, or was involved in a collision which already contained a confirmed fatality. The HEMS team would also be dispatched immediately if requested to do so by another crew or emergency service.

If the details of the incident do not meet the criteria for immediate dispatch, then the calls are interrogated, to determine whether the call is appropriate for HEMS. This leads to an "interrogation dispatch" in less than seven minutes. The calls are interrogated to determine whether there is any loss of consciousness, airway compromise, breathing difficulties, head/spinal/chest/abdomen/pelvic/limb injuries, or burns/scalds covering the body surface. The result of this interrogation will be a decision as to whether the call is appropriate for the HEMS.

The data from the accidents attended by the HEMS team is entered into a database which is then used for various analyses. This database holds information on the age and gender of the patient as well as their injuries and the treatment they received both en route to the hospital and during their stay. This includes information on operations, who treated them, outcome (i.e. whether they lived and if not then the area of the hospital in which they died) and their length of stay in hospital (both on wards and in intensive care).

In total, the HEMS data consisted of 746 pedestrian struck by motor vehicle accidents from 2000 to 2007, with 2,974 injuries received in total. Of the 746 pedestrians, 616 survived (83%).

2.4 On The Spot (OTS)

The On The Spot (OTS) study began in 2000 and ran until March 2010. It was funded by the Department for Transport and the Highways Agency. It aimed to establish an in-depth database that could be used to improve the understanding of the causes and consequences of road traffic accidents, and thus aid the government in reducing road accident casualties.

There were two OTS teams: TRL covering the Thames Valley area, and Loughborough University's Vehicle Safety Research Centre (VSRC) covering Nottinghamshire. Expert investigators from these teams attended the scenes of accidents, usually within 15 minutes of an incident occurring, using dedicated response vehicles and equipment. In total, the teams make in-depth investigations of about 500 crashes per year, and record in excess of 3,000 data fields for each accident.

In contrast to other accident studies which are based on evidence gathered after incidents, or based on secondary evidence, OTS investigations allowed "perishable" accident data to be gathered. These included trace marks on the highway, pedestrian contact marks on vehicles, the final resting places of the vehicles involved, weather at the time of the incident, visibility and traffic conditions. Medical data and questionnaires were also collected. Full details of the methodology of OTS are given in Cuerden, Pittman, Dodson, and Hill (2008).

OTS aimed to record the speeds of the vehicles involved in each accident for every different phase of the accident. This includes travelling speeds before the accident occurred, impact speeds with other vehicles or objects, and other relevant speeds, e.g. the speed at which a vehicle lost control. These speeds are recorded in the "phase data" for the accident, and are based on evidence at the scene, witness statements, and the expert judgement of experienced accident investigators.

Initial inspection of the OTS database showed that the details of 202 pedestrians were recorded. Of these, 193 had been struck by a moving vehicle, and it is these pedestrians which are used in this report.

2.5 Police fatal files

In 1992, TRL was commissioned by the Department for Transport (DfT) to set up and manage the police fatal road traffic accident reports project. The purpose of this project was to institute a scheme whereby police forces in England and Wales would routinely send fatal road traffic accident reports to TRL when they were no longer of use for legal purposes.

The fatal reports provide a unique insight into how and why fatal accidents occur and the detailed information contained within them is not available from any other source. The reports provide a unique opportunity to learn from these tragic accidents, so that we can work towards reducing the number of fatal accidents which occur in the UK and in the rest of the world. The current archive contains over 34,000 police fatal accident reports.

Police fatal file accident reports are recognised as an important source of information for accident research. They can provide detailed information on the events leading up to an accident, as well as giving details of driver errors and/or vehicle defects which may have contributed to the accident and to the injuries that resulted in the fatality.

These fatal accident reports cost a great deal to produce both in terms of police and pathologists' time. The reports are produced, even where no criminal prosecution is envisaged, for presentation in evidence at the coroner's inquest.

Each report is given a unique TRL number which is linked to its corresponding STATS19 number. By linking each fatal accident to its STATS19 number, groups of accidents, which meet certain criteria, can be quickly identified. These accident reports can then be retrieved from the central archive, so that further details of the accident can be obtained and analysed.

Post-mortems are ordered by the coroner for road traffic fatalities. The post-mortems are carried out by pathologists, who will record the details of the internal and external injuries received by the casualty. These details are put into a report, which will include what the pathologist considered to be the cause of death. These reports are often included in the police fatal files. For this project, the post mortems were coded into AIS 2005 codes (see Section 2.6.2 for an explanation of the AIS coding system).

Police fatal files were examined in this report to investigate the causes of pedestrian injuries. In order to select relevant fatal files from the archive, analysis was carried out on the STATS19 database to identify pedestrian collisions involving cars registered in 2000 or newer. From this analysis, 1008 pedestrian collisions were identified, 211 of which were in the fatal file archive. Out of the 70 cases extracted, 49 were found to have good photographs of the damage and post mortems, which were required for the analysis. This resulted in a sample of 49 vehicles which struck 49 pedestrians. It should be noted that some post mortems available included much more detail than others depending on the type of report; therefore, the number of injuries which could be AIS coded per person varied greatly. Also in some cases the body was not examined in as much detail; for example, in one case the brain was not examined in order to avoid further distress to the families.

The information from the police fatal files was recorded using a number of different forms, which were created for this project. These forms collected data about the accident, the vehicles involved, the damage on the vehicles, the drivers and pedestrians, the injuries received by the pedestrians and the causes of those injuries.

For the analysis, the forms were put together and the results punched into a database. The vehicles involved in collisions with pedestrians were split into 70 zones, shown in Figure 2.1. The AIS 2+ injuries received by each pedestrian were attributed to the various zones on the vehicle that were damaged or to other causation factors such as acceleration injuries, or secondary impacts with the ground or other objects. If two or more injuries to a body region were due to the same zone on the vehicle, the zone was counted only once as having caused an injury in that accident.

The injury causation of some of these pedestrians was discussed with the HEMS team in a TRL-HEMS workshop.

2.6 Recording injuries

Many of these different sources of data use different methods of recording injuries and causes of injuries. The HES data uses ICD-10 to record the cause of injury, and the individual injuries. The HEMS data uses the older ICD-9 system to record injuries. STATS19 does not record individual injuries, but does give each casualty an injury severity of "slight", "serious" or "fatal". The post mortems describe injuries, and for this project these descriptions have been translated using the Abbreviated Injury Scale.

It is important to know exactly how these different methods of recording injuries relate to each other. The following section explores each method in turn.

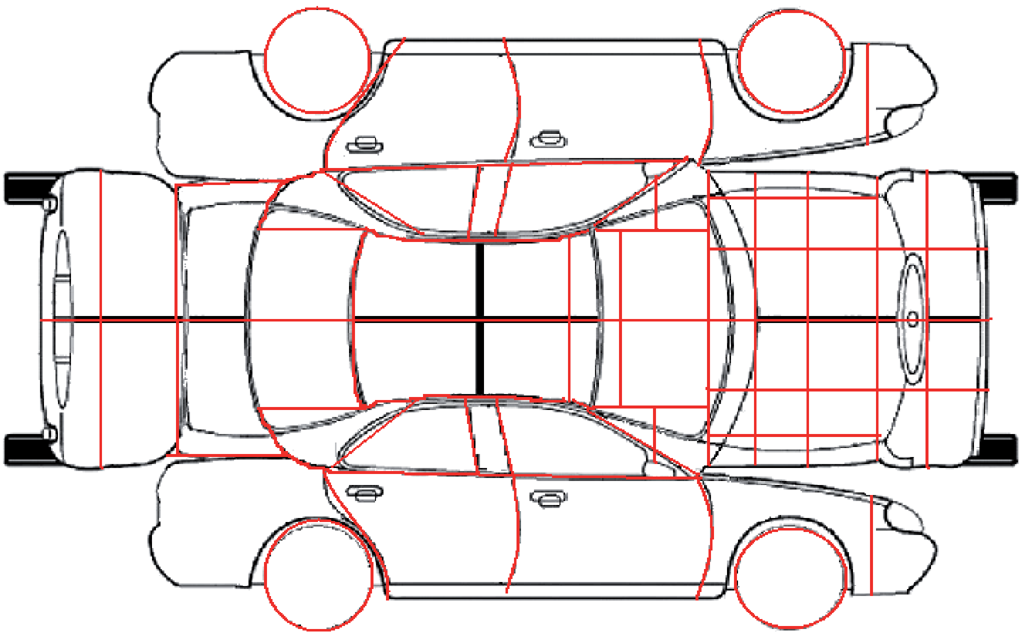

Figure 2.1 Location of zones on the vehicle

2.6.1 International Statistical Classification of Diseases (ICD)

The International Statistical Classification of Diseases and Related Health Problems, Ninth Revision (ICD-9, 2008), is used to record the injuries in the HEMS database. This is a coding system developed by the World Health Organization in 1975 (World Health Organization, 2008), where each possible injury has a unique four-character ICD-9 code associated with it. There are dictionaries of ICD-9 codes freely available on the internet (ICD-9, 2008). This code describes what the injury is, but does not include a measure of the severity of the injury. The HEMS team use AIS to give a measure of the severity of each injury.

The Tenth Revision of the ICD was developed in 1989. The major difference between ICD-9 and ICD-10 is that the codes changed from numeric to alphanumeric in ICD-10, enabling a far greater number of codes to be assigned (World Health Organization, 1992). This has been used to record the injuries in HES since 1995. Diagnosis codes start with a letter and are followed by two or three digits.

The ICD-10 codes are recorded in HES in both their three-character and four-character formats. The first three characters of the ICD-10 code provide the core classification of the injury, whereas the first four characters of the code provide a more specific injury description. An example of this would be a three-character code of "S01 – an open wound of the head" (World Health Organization, 1992). When split into its four-character codes it could be any of the following:

- S01.1 – Open wound of eyelid and periocular area
- S01.2 – Open wound of nose
- S01.3 – Open wound of ear
- S01.4 – Open wound of cheek and temporomandibular
- S01.5 – Open wound of lip and oral cavity
- S01.7 – Multiple open wounds of head
- S01.8 – Open wound of parts of head
- S01.9 – Open wound of head, part unspecified

In HES, injuries are recorded in 14 fields (seven fields before April 2002), which contain information about a patient's illness or condition (HESOnline, 2008). The first of these fields contains the primary diagnosis and the other fields contain secondary/subsidiary diagnoses.

2.6.2 Abbreviated Injury Scale (AIS)

The severity of the injuries is recorded by the HEMS team using the Abbreviated Injury Scale (AIS). This was also used to record the injuries from the post mortems in the police fatal files. The AIS scores in HEMS are recorded using the 1990 revision of AIS, while the post mortems were recorded using the 2005 revision.

In the AIS system, each injury description is assigned a unique six-digit numerical code in addition to the AIS severity score. The AIS severity score is a consensus-derived anatomically-based system that classifies individual injuries by body region on a six-point ordinal severity scale ranging from AIS 1 (minor) to AIS 6 (currently untreatable), shown in Table 2.1 (Association for the Advancement of Automotive Medicine, 1990).

MAIS denotes the maximum AIS score of all injuries sustained by a particular occupant. It is a single number that attempts to describe the seriousness of the injuries suffered by that occupant.

Table 2.1 Possible values of AIS

AIS score	*Description*
1	Minor
2	Moderate
3	Serious
4	Severe
5	Critical
6	Maximum
9	Unknown

Because AIS gives each injury a severity score and the severity of each casualty can be easily calculated using the maximum severity score, AIS is very useful in accident research, much more so than ICD.

2.6.3 Fatal, serious and slight

Although the police do not record individual injuries, they do record an overall severity for each casualty of slight, serious and fatal. The definitions of these are given in the STATS20 manual (Department for Transport, 2004). This states the following:

"Fatal" injury includes only those cases where death occurs in less than 30 days as a result of the accident. "Fatal" does not include death from ***natural causes or suicide****.*

Examples of "Serious" injury are:

- *Fracture*
- *Internal injury*
- *Severe cuts*
- *Crushing*
- *Burns (excluding friction burns)*
- *Concussion*
- *Severe general shock requiring hospital treatment*
- *Detention in hospital as an in-patient, either immediately or later*
- *Injuries to casualties who die 30 or more days after the accident from injuries sustained in that accident.*

Examples of "Slight" injury are:

- *Sprains, not necessarily requiring medical treatment*
- *Neck whiplash injury*
- *Bruises*
- *Slight cuts*
- *Slight shock requiring roadside attention.*
- *(Persons who are merely shaken and who have no other injury should not be included unless they receive or appear to need medical treatment).*

It is important to know the precise definition of a "serious" injury, because government targets are based on the reduction of the number of fatally and seriously injured casualties. These definitions also help to explain the relationship between the police STATS19 data and that of the hospitals. Because seriously injured casualties include those who are an in-patient in hospital, every road traffic casualty who is recorded as being an in-patient in hospital data should be present in the police STATS19 data as a serious (or fatal) casualty.

2.7 Creating speed-injury curves

The speed-injury curves were created using a combination of data from OTS and police fatal files. The purpose of the speed-injury curves was to estimate the probability of fatal or serious injury at different impact speeds for pedestrians in impacts with the front of a car.

The data for the speed curves was obtained from OTS for casualties of all severities, supplemented by fatally injured pedestrians recorded in the police fatal files, to increase the sample size at the highest severity.

The data was weighted to reflect the proportions of different casualty severities in STATS19. This process is shown in Table 2.2. The weighting was particularly important for this sample because of the large proportion of fatalities (many of these cases came from the police fatal files, which provided fatally injured pedestrians only). As the sample only included pedestrians hit by the front of cars, it was weighted using the number of pedestrians reported to have been hit by the front of cars nationally. The measure of speed used to draw the pedestrian speed-injury curves was the speed of the vehicle at the moment of impact.

It should be noted that there are some slight and serious accidents which are not reported to the police, and are therefore not present in the national statistics (Department for Transport, 2009). This means that once the results are weighted, they are likely to give an over-estimate of the risk of fatality.

The speed-injury risk curves for fatal injury were drawn using logistic regression. This process predicts how a variable with only two possible values (in this case “fatal” or “not fatal”) is dependent on a continuous variable (in this case impact speed) (Pallant, 2005). Confidence intervals were also drawn, which show the area within which the true speed-injury curve is likely to lie. In this study, the confidence intervals given are at 95%, i.e. they show the range of values where there is a 95% chance of the true value lying.

More details on these pedestrian injury curves, including comparisons to previously made estimates, can be found in Richards (2010).

2.8 The cost model

The cost of the pedestrian injuries in the HEMS data was estimated using a model based on the duration of stay on a ward and in intensive care. This costing was not performed with HES because HES only contains the total duration of stay in hospital. The Intensive Care Society (2008) state that the cost of a day in an ICU is approximately six times as costly to the hospital as a day spent on a ward. Christensen, Ridley, Lecky, Munro, and Morris (2008) cite the Department of Health statistics (Department of Health, 2005) which say that the mean cost per patient per day on a general ward is £281, and the mean cost per patient per day in a critical care unit is £1,328 (approximately 4.7 times more costly than the ward).

The information in the HEMS database includes the number of days spent by each patient on the ward and in the ICU, so this has been used to calculate a cost of each patient to the hospital. It should be noted that this cost only accounts for the length of time each pedestrian was in hospital, and does not account for the differing costs of surgical operations and procedures carried out during their stay or other pertinent factors. This is partially because this information could not readily be provided by the HEMS for this study, but also because the length of stay in hospital makes up a large proportion of the cost for each patient. In a study of blunt trauma patients Christensen *et al.* (2008) calculated that approximately 75% of the total costs were accounted for by the length of stay in hospital.

2.8.1 Weighting results to national level

The nature of the accidents attended by the HEMS team makes it likely that the pedestrians in the HEMS dataset will generally have more severe injuries than the pedestrians in the national accident population. Therefore the cost of the pedestrian injuries determined using the HEMS dataset alone will not be representative of the general cost of pedestrian injuries, and needs to be weighted to reflect the national population of pedestrian injuries. Because the HES dataset does not separate the duration of stay on the ward and in intensive care, the same method of costing could not be used to calculate costs at a national level using HES. Instead, the relationship between the injuries in HES and HEMS was determined in order to weight the costs calculated using the HEMS data to the national level. Weighting to the national level in this report means weighting to the pedestrian casualties in England, as this is the area covered by HES.

Table 2.2 Calculating weighting factors for pedestrians in impacts with front of cars

Pedestrian casualties with the front of cars in Great Britain 2005-2007 mean			*Pedestrian casualties in sample*	*Weighting factors*
Injury severity	*Number*	*Proportion*		
Fatal	347	2.4%	66	5.26
Serious	3171	21.7%	74	42.9
Slight	11116	76.0%	57	195.0

For a given body region the weighted annual cost was estimated using equation 1:

$$C_{weighted} = wC_{HEMS} \qquad [1]$$

where C_{HEMS} was the annual cost for the pedestrians in the HEMS dataset with an AIS 2+ injury to that body region, and w was a weighting factor calculated using equation 2:

$$w = \frac{N_{HES}\bar{D}_{HES}}{N_{HEMS}\bar{D}_{HEMS}} \qquad [2]$$

where N_{HES} was the number of pedestrians with a primary injury to that region in HES, N_{HEMS} was the number of pedestrians with an AIS 2+ injury to that region in HEMS, $\bar{D}_{HES}$ was the average duration of stay of the pedestrians with a primary injury to that region in HES, and $\bar{D}_{HEMS}$ was the average duration of stay of the pedestrians with an AIS 2+ injury to that body region in the HEMS dataset.

The same weighting factors were used to weight the costs determined for individual injuries; for example, the total cost of individual head injuries in the HEMS dataset was multiplied by the same weighting factor to give an estimate of the national cost of those injuries.

3 Pedestrian accident characteristics

This section explores the range of variables that are related to pedestrian accidents, to determine how and why they occur, and what the consequences are.

This begins with variables that are related to the accident, such as date, time, location, and the vehicles involved. Contributory factors are also examined, relating to either the pedestrian casualty, or the driver of the vehicle that hit the pedestrian. The characteristics of the pedestrian are then explored in more detail, such as their age and injury severity.

Finally, the relationship between impact speed and pedestrian injury severity is determined.

3.1 Accident date

The year in which the patient was admitted is recorded in HES and can be compared to the year of accident in STATS19. Figure 3.1 shows the number of HES admissions per year split by the type of accident as recorded by the four-digit causation code. From this figure it can be seen that the number of pedestrians recorded in HES who were selected for analysis decreased from almost 8,907 admissions in 1998/99 to 7,726 in 2003/04 but has been at a fairly constant level of around 7,800 admissions from 2003/04 to 2006/07. STATS19 data shows pedestrian accidents to have steadily decreased in this time frame, from 8,888 in 1998/99 to 6,132 in 2006/07.

This shows that at the beginning of the years analysed, the numbers of pedestrian accidents recorded were very similar in both datasets. However, in recent years the numbers have become less similar. These fluctuations could be due to a number of reasons, including under-reporting in STATS19. It should be noted that a warning is given on the HES website about the admission date data stating:

"Fluctuations in the data can occur for a number of reasons, e.g. organisational changes, reviews of best practice within the medical community, the adoption of new coding schemes and data quality problems that are often year specific. These variations can lead to false assumptions about trends." (HESOnline, 2008)

3.2 Time of day

Figure 3.2 shows the distribution of the killed and seriously injured (KSI) pedestrian accidents in STATS19 as a percentage of the hour of the day they occurred in. It can clearly be seen that there was a peak in accidents from 3pm to 7pm and a smaller peak at 8am to 9am which relates to the times that people travel to and from work/school, the time of highest exposure of pedestrians to traffic.

3.3 Day of the week

The day of the week on which the accidents occurred in STATS19 increased throughout the week with the lowest frequency on Sunday (11%), peaking on Friday (18%). When the time of day for accidents on Fridays and Saturdays was analysed it was found that there were more casualties towards the later hours up to 11pm.

3.4 Vehicle type

The distribution of the vehicle types impacting pedestrians as found in STATS19 are shown in Figure 3.3. It was found that the majority, 81%, of the pedestrians reported to have been involved in road traffic accidents were struck by vehicles in the car/taxi category. The next most frequent striking vehicle type was a heavy transport vehicle (over 3.5 tonnes) or a bus, accounting for 8% of pedestrians. The percentage of pedestrians struck by minibuses and LCVs (3.5 tonnes and under) was 5%, and 1% were struck by pedal cycles.

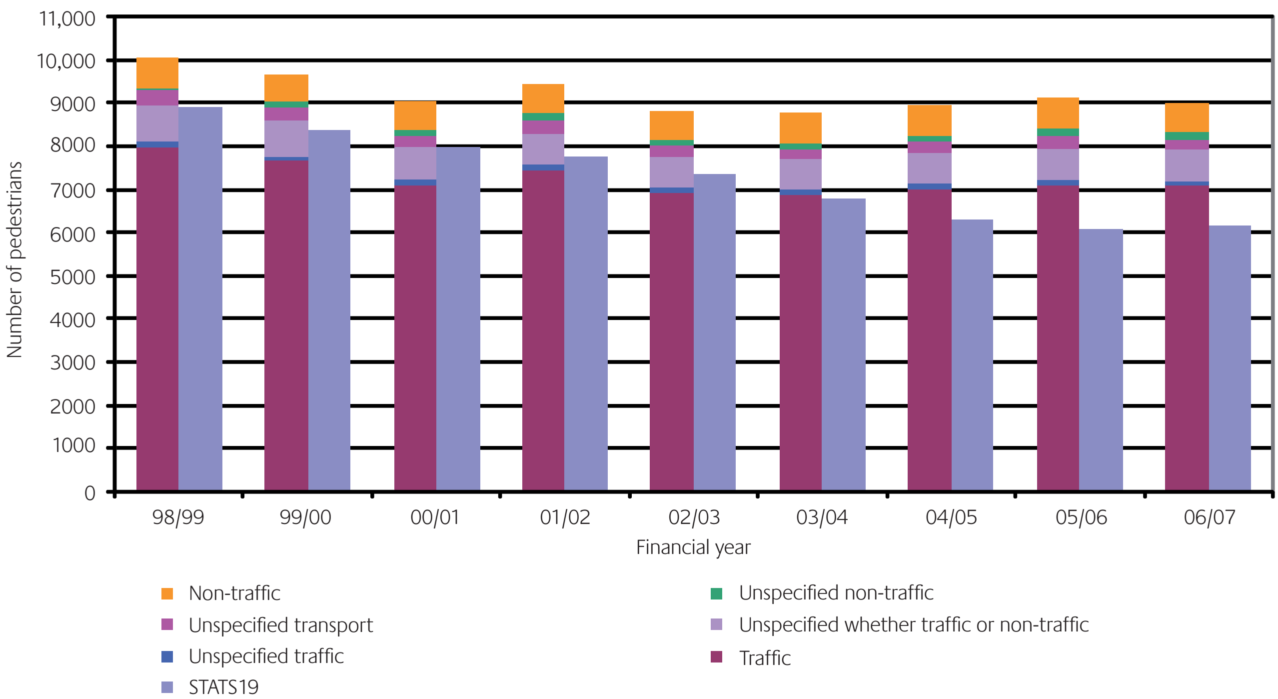

Figure 3.1 Number of pedestrian casualties from 1998 to 2007 in HES and STATS19

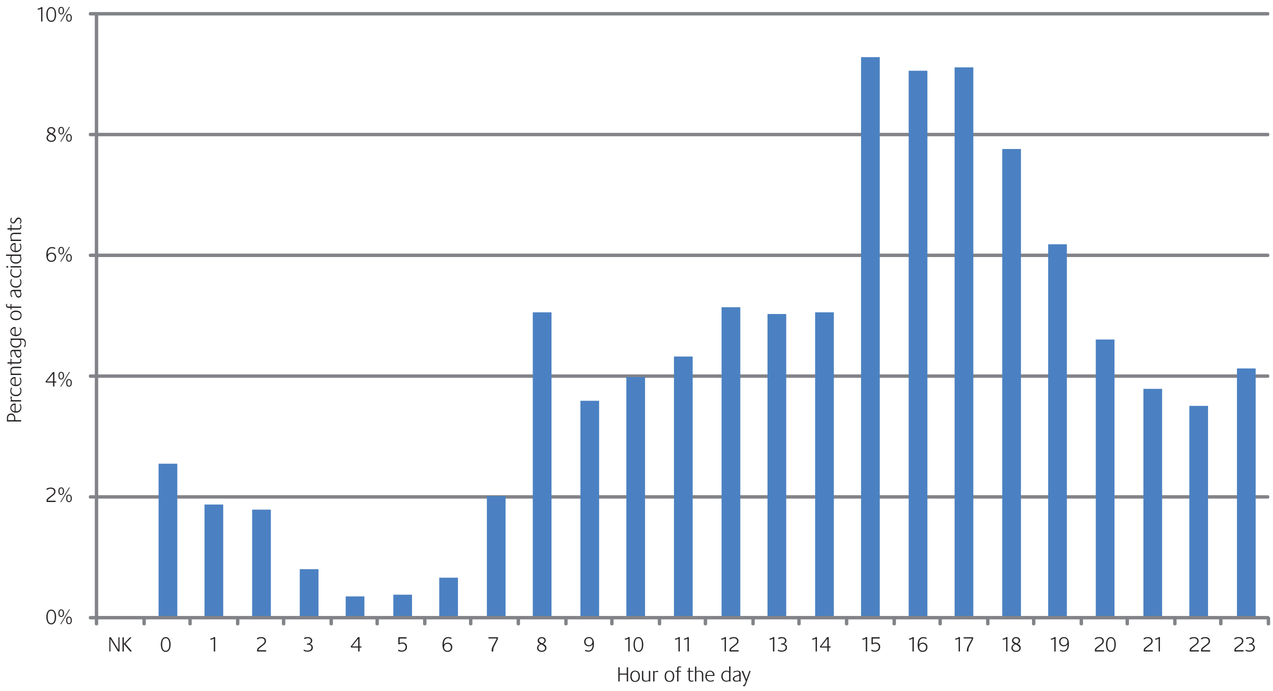

Figure 3.2 Distribution of time of day of KSI pedestrian accidents in STATS19

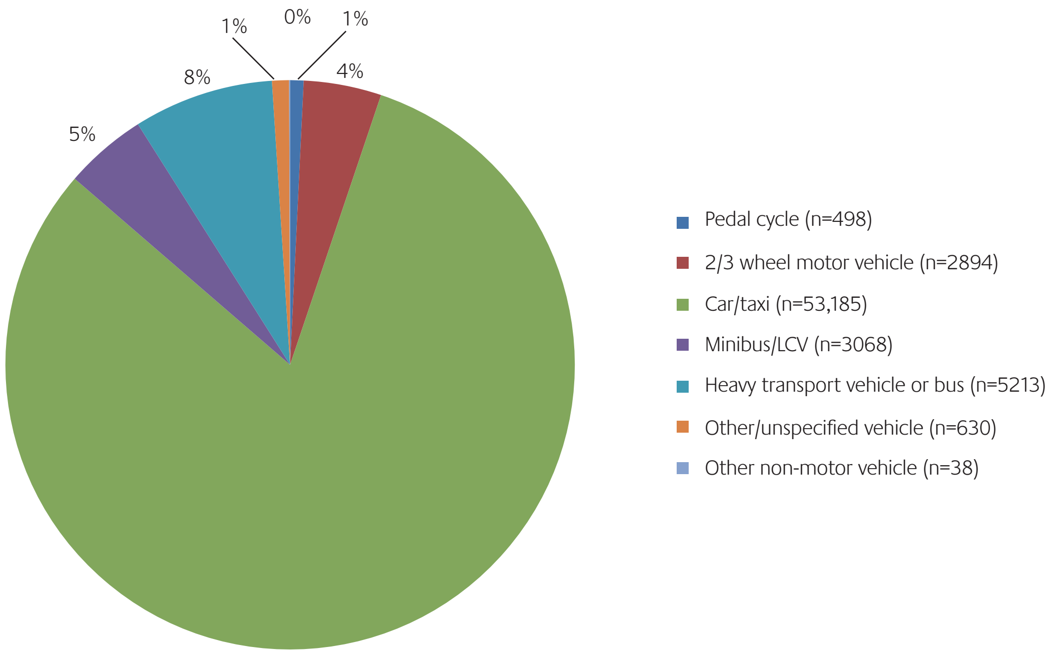

Figure 3.3 Type of vehicle involved in pedestrian accidents in STATS19

3.5 Location

STATS19 data showed that the pedestrian accidents mostly occurred on A-roads and unclassified roads with 42% and 36% of the casualties respectively. Analysis of these two groups can be seen in Figure 3.4 and it was found that 55% of fatal pedestrian accidents occurred on A-roads compared to 41% of serious accidents, and 37% of serious accidents occurred on unclassified roads compared to 22% of fatal. It is likely that this difference in injury severity was, at least in part, due to the higher travelling speed of vehicles on A-roads than unclassified roads.

3.6 Contributory factors

Since 2005, STATS19 has recorded contributory factors for each accident. In the sample 9,518 pedestrians had a contributory factor related to them. Of the 18,677 contributory factors recorded related to the pedestrian, 36% were “failed to look properly” and 16% were that the pedestrian was “careless, reckless or in a hurry”. The top nine contributory factors for pedestrians can be seen in Figure 3.5.

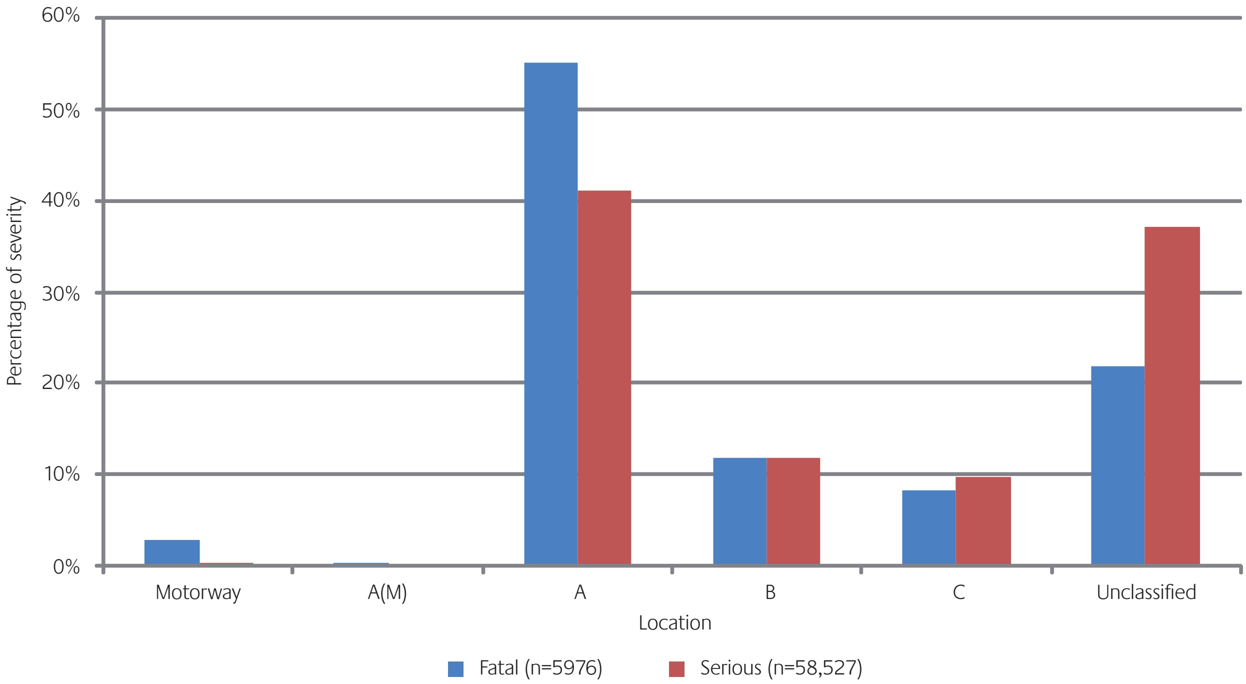

Figure 3.4 Location of KSI pedestrian accidents in STATS19

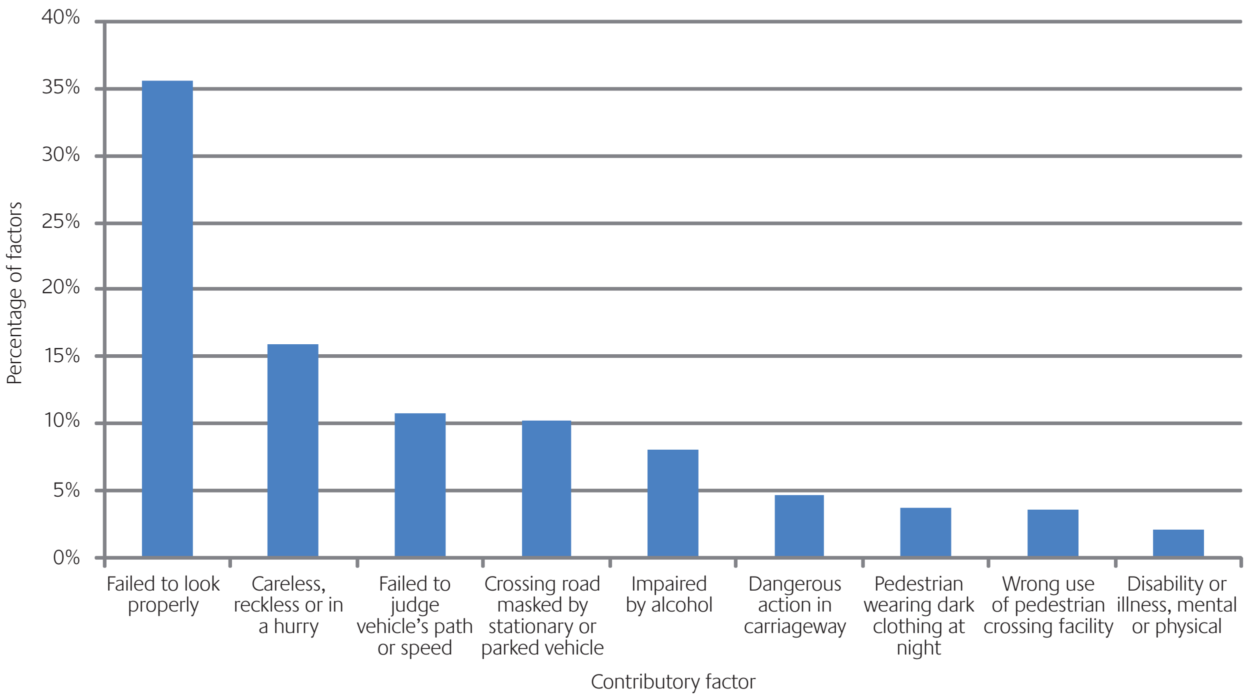

Figure 3.5 Pedestrian contributory factors in KSI accidents in STATS19

There were 10,552 contributory factors related to the driver of the vehicle. Of these, 21% were recorded as "failed to look properly" and 11% were "careless, reckless or in a hurry" followed by 7% "travelling too fast for conditions", as can be seen in Figure 3.6.

3.7 Age and gender

Male pedestrians are found to be more frequently involved in accidents than females with 61% of those in STATS19. The percentage of pedestrians involved in accidents split by age and gender is shown in Figure 3.7. This shows a peak in pedestrian accidents for those aged between 10 and 15 years. Female pedestrians over the age of 70 are shown to be more frequently involved in accidents than males in the same age group, whereas male pedestrians aged under 50 are generally more frequently involved in these accidents than female.

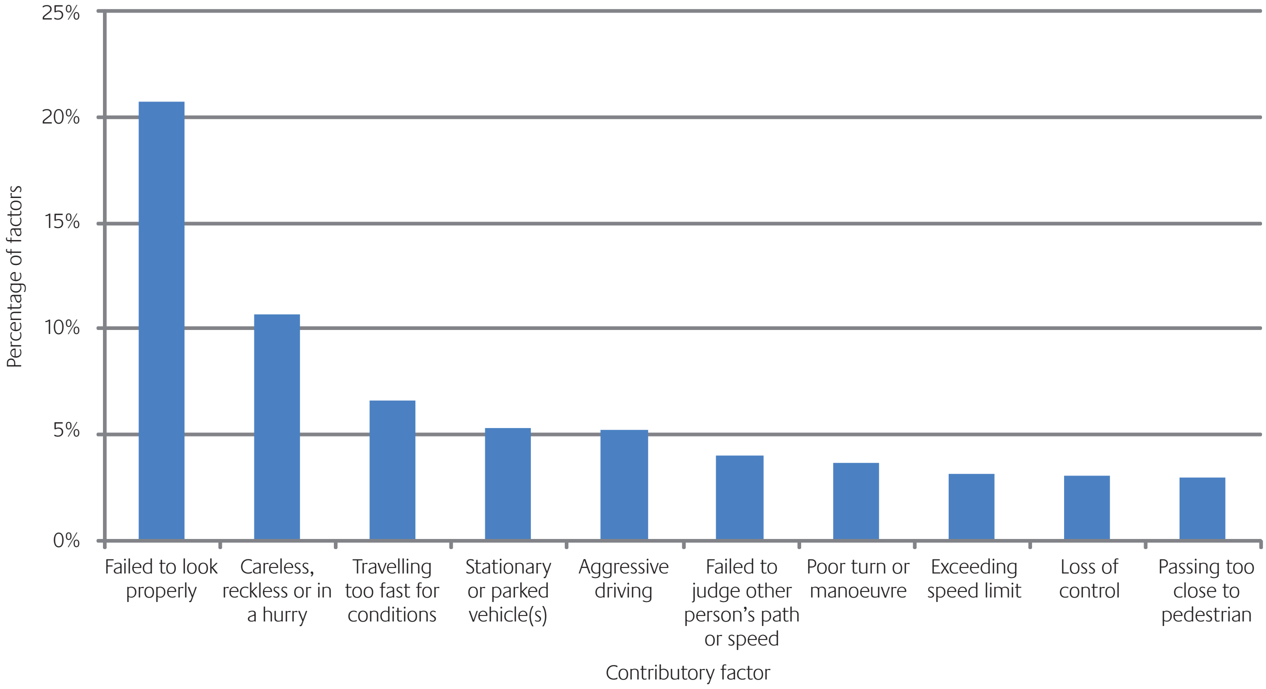

Figure 3.6 Driver contributory factors in KSI pedestrian accidents in STATS19

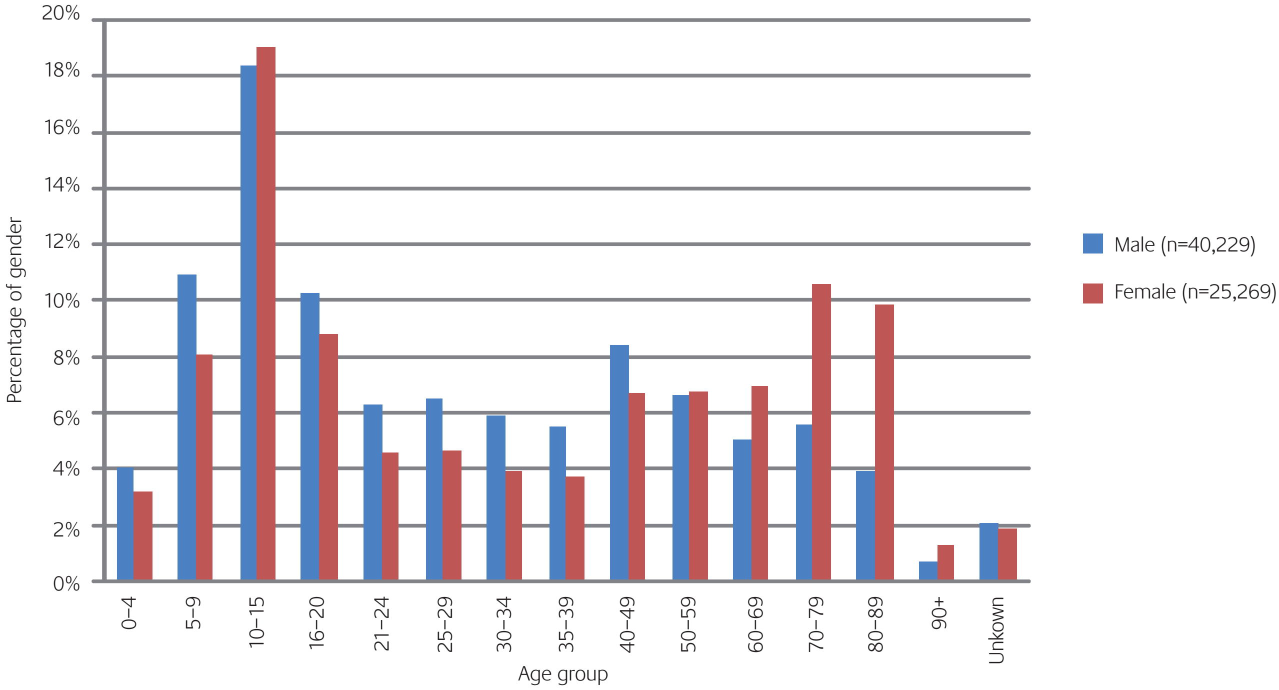

Figure 3.7 Pedestrian casualties split by age and gender in STATS19

3.8 Injury severity

Overall, 91% of KSI pedestrian casualties in STATS19 were recorded to be serious and 9% fatal. Males proportionally suffered more fatal injuries when involved in pedestrian accidents than females. Figure 3.8 shows that younger pedestrians received a higher proportion of serious injuries, with older pedestrians being those that were killed more frequently in pedestrian accidents.

3.9 Vehicle type vs severity

As would be expected, heavy transport vehicles are over-represented when the pedestrian was fatally injured. Cars/taxis were under-represented for fatal pedestrians (Figure 3.9).

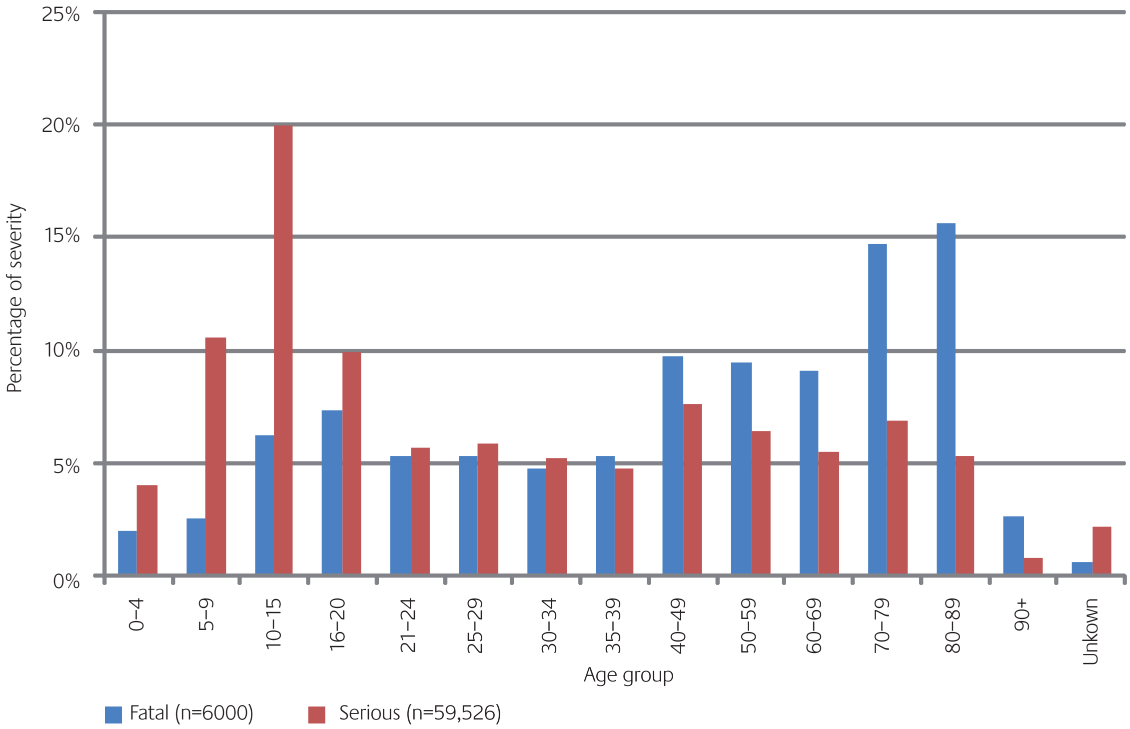

Figure 3.8 Severity split by age group for KSI pedestrians in STATS19

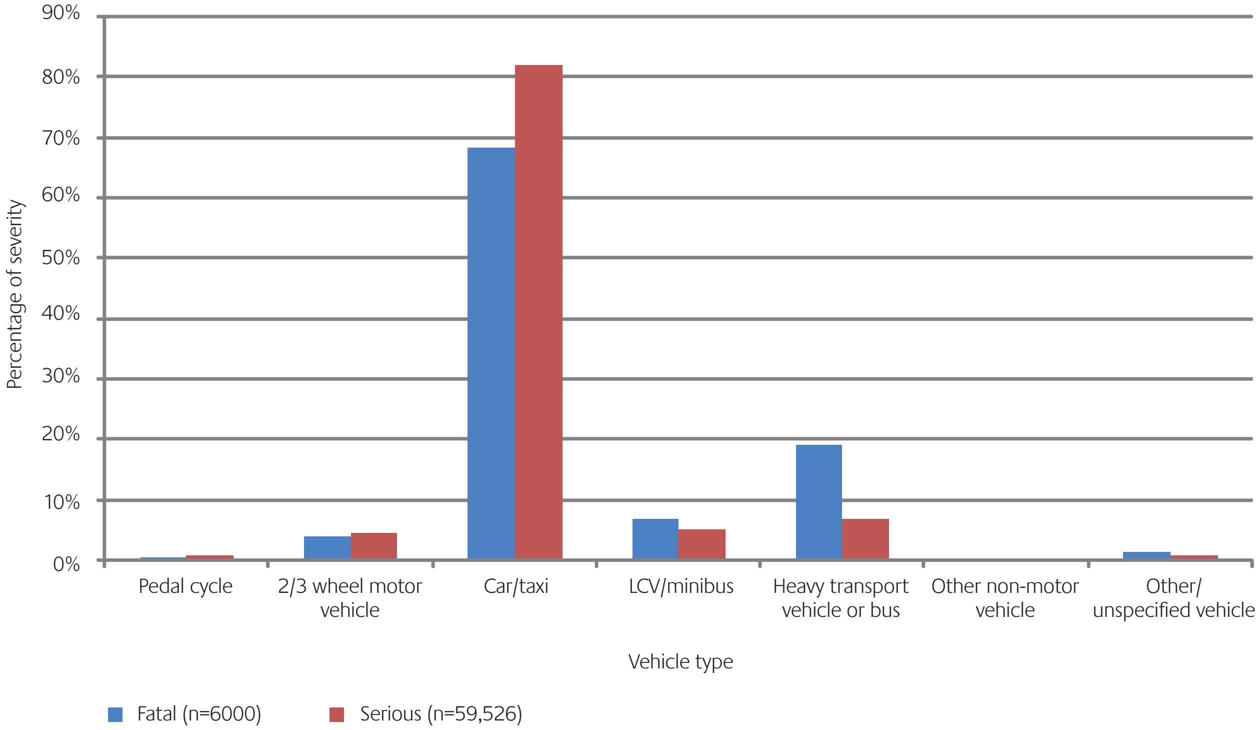

Figure 3.9 Vehicle type related to accident severity in STATS19 for KSI pedestrian accidents

3.10 Pedestrian manoeuvres

STATS19 also records the manoeuvre of the pedestrian at the time of the accident. The majority of the pedestrians were recorded to have been crossing the road from the driver's nearside (47%) or offside (30%). Approximately 18% of pedestrians were masked by a parked or stationary vehicle (Figure 3.10).

3.11 OTS accident configurations

All of the 193 pedestrians were examined in the OTS dataset (Cuerden and Richards, 2007), and a type of crash configuration was chosen for each one. Figure 3.11 shows these crash configurations, and the percentage of the 193 pedestrians who fell into each category. Some of these categories may require more explanation. This is included in Table 3.1.

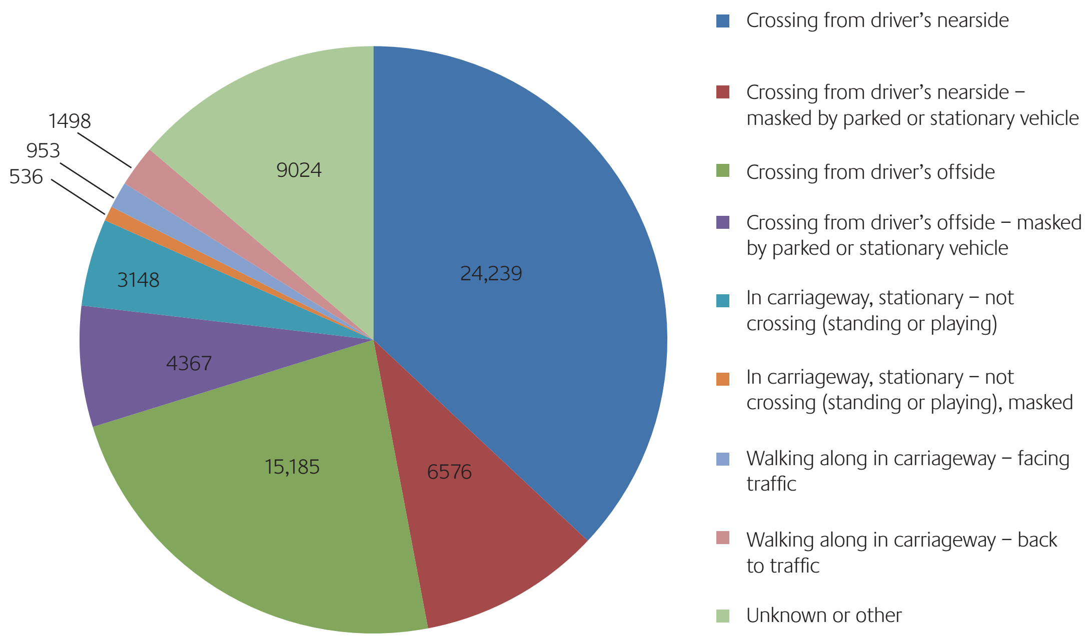

Figure 3.10 Manoeuvres of KSI pedestrians in accidents in STATS19

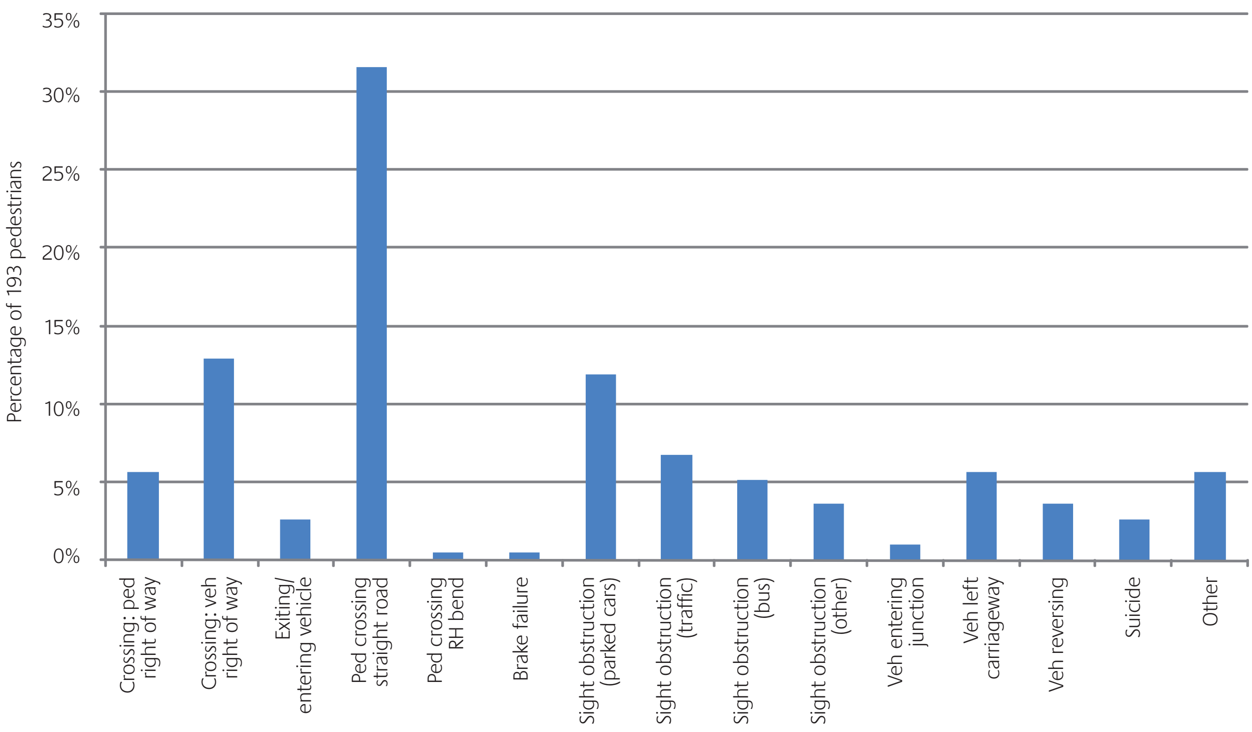

Figure 3.11 Accident configuration for 193 pedestrians in OTS dataset

Table 3.1 Possible accident configurations

Configuration	*No.*	*Explanation*
Crossing: ped right of way	11	The pedestrian was hit on a pedestrian crossing while the pedestrian had the right of way
Crossing: veh right of way	25	The pedestrian was hit on a pedestrian crossing while the vehicle had right of way
Exiting/entering vehicle	5	The pedestrian was (or had recently been) in the process of entering or exiting the vehicle
Ped crossing straight road	61	The pedestrian was crossing a straight road, with no obvious objects obscuring the view of the traffic or the pedestrian
Ped crossing RH bend	1	The pedestrian was hit while crossing a right-hand bend
Brake failure	1	The pedestrian was crossing the carriageway, and was hit by a vehicle whose brakes had failed
Sight obstruction (parked cars)	23	The view of the pedestrian / the vehicle was obscured by parked cars
Sight obstruction (traffic)	13	The view of the pedestrian / the vehicle was obscured by moving or stationary traffic
Sight obstruction (bus)	10	The view of the pedestrian / the vehicle was obscured by a stationary bus at a bus stop
Sight obstruction (other)	7	The view of the pedestrian / the vehicle was obscured by some other object
Veh entering junction	2	The vehicle entered a junction and struck a pedestrian on the new road
Veh left carriageway	11	The vehicle left the carriageway and struck the pedestrian off the carriageway (e.g. on the footway)
Veh reversing	7	The vehicle struck the pedestrian while reversing
Suicide	5	The pedestrian was attempting to commit suicide
Other	11	Any other accident configuration
Total	193	

The most frequent accident configuration (over 30% of accidents) involved a pedestrian crossing a straight road, which had no obvious obstruction of view for the pedestrian or the driver of the vehicle. This category included instances where the pedestrian did not look before they crossed the road, as well as pedestrians under the influence of alcohol running across the road.

Figure 3.12 investigates whether some of these accident configurations are more likely to occur if the pedestrian is a child. Some 166 pedestrians had a known age, and the percentage of each accident configuration where the pedestrian was under 16 or 16 and over is shown.

The final column shows that of all the 166 pedestrians for whom age was known, about 60% were 16 and over, and 40% were under 16. Accidents where the vision of the pedestrian or the traffic was obscured seem to be more frequent for child pedestrians. Accidents involving pedestrian crossings, suicide, reversing vehicles and vehicles leaving the carriageway are more frequent when the pedestrian is an adult.

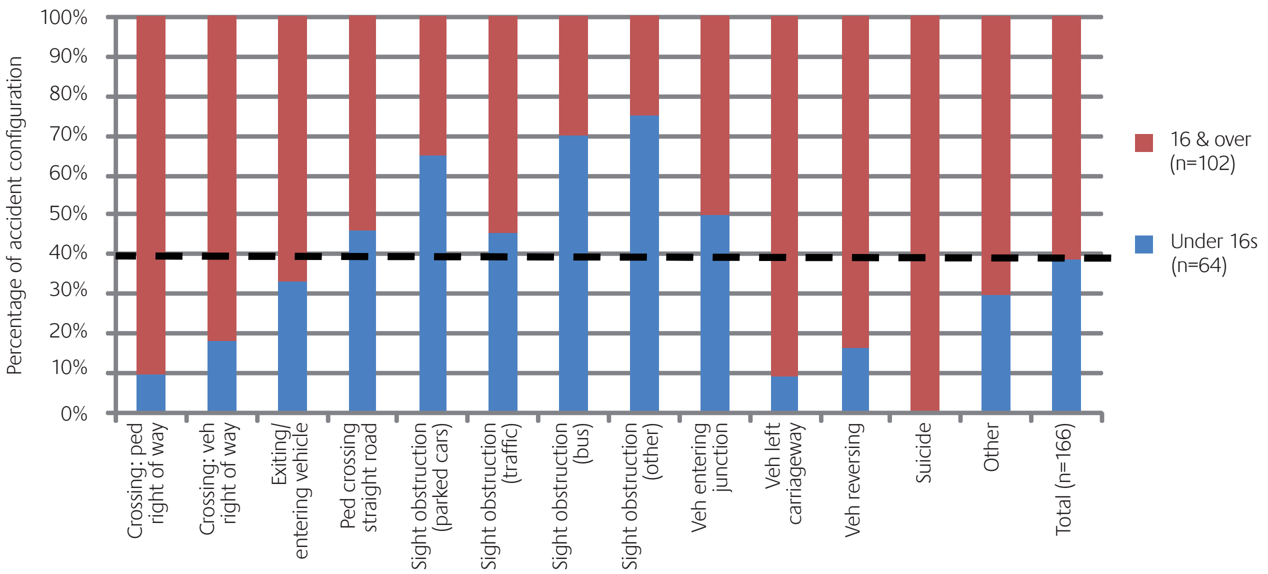

Figure 3.12 Relationship between accident configurations and pedestrian age in OTS

3.12 Deprivation data

The classification of deprivation groups was explained in Section 2.2. This section analyses this data in HES.

3.12.1 Overall IMD decile group

Overall, the pedestrians involved in road traffic accidents were found to be more frequent in the most deprived areas. Almost 50% of pedestrians were in the most deprived 30% of areas (Figure 3.13). These areas are likely to be urban/inner city areas and therefore more pedestrian accidents would be expected in these areas due to the higher exposure.

3.12.2 Age group related to IMD decile group

Figure 3.14 shows that younger pedestrians involved in collisions tended to be from the more deprived areas than the older age groups. Approximately 50% of under nine year olds were in the most deprived 20% of areas.

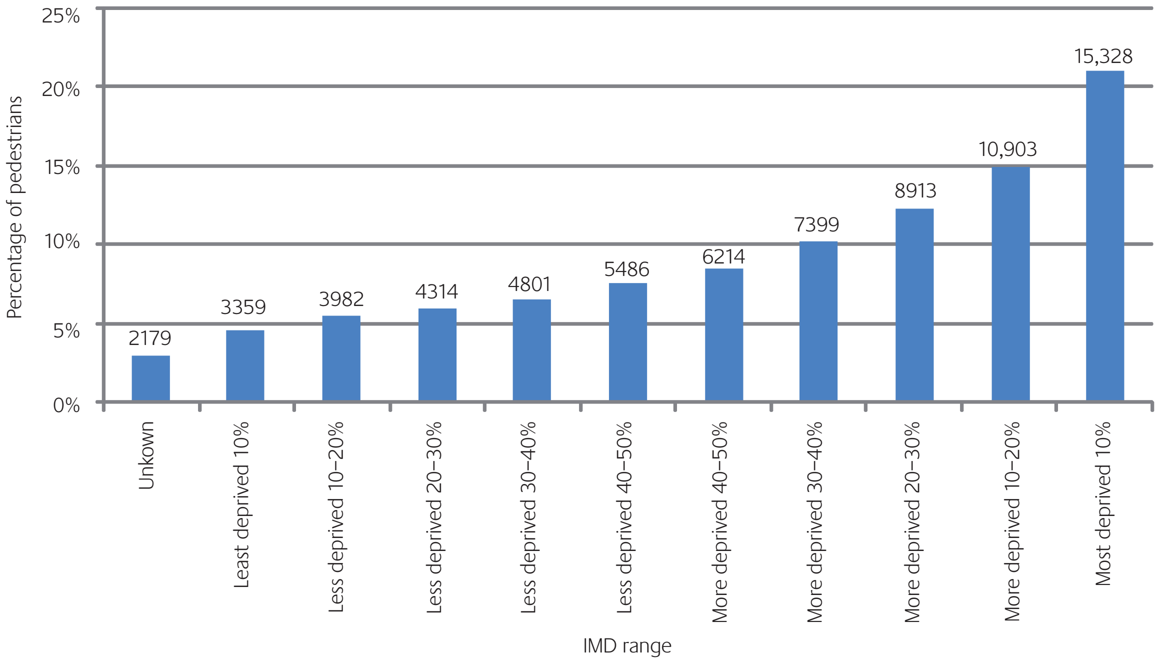

Figure 3.13 Index of Multiple Deprivation (IMD) range for pedestrian casualties in HES

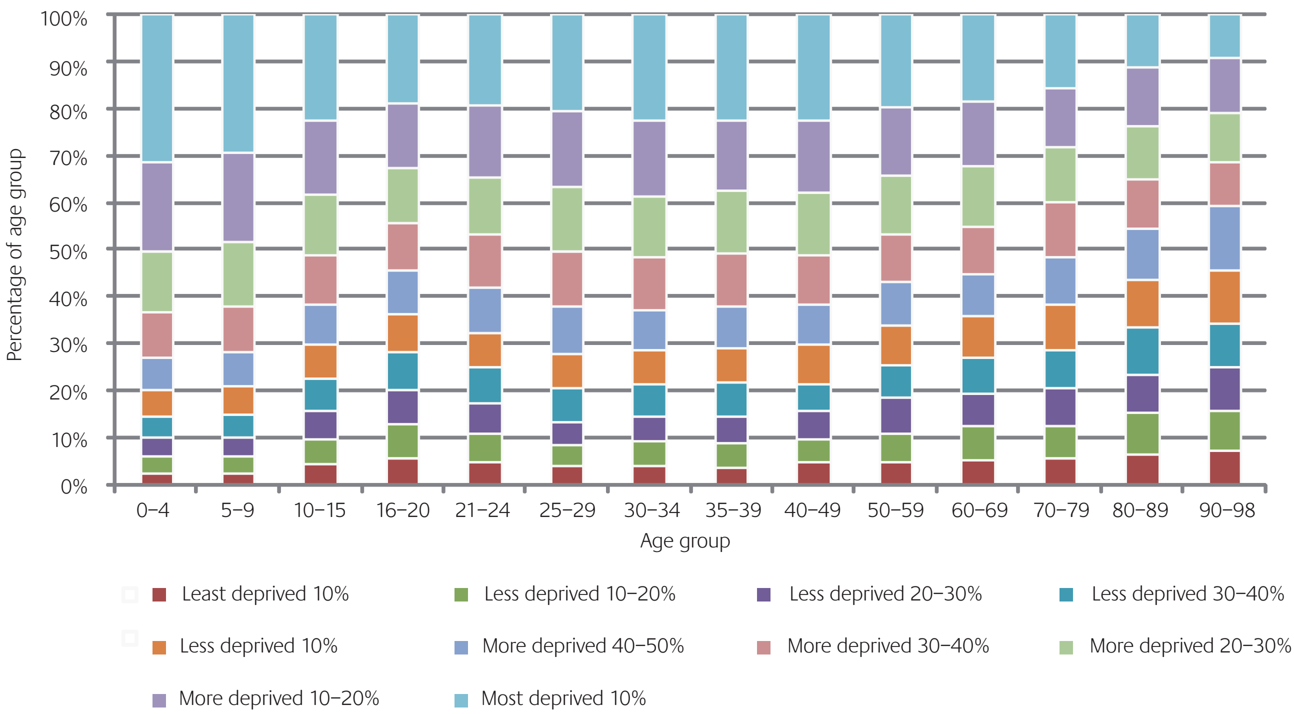

Figure 3.14 Relationship of pedestrian age to IMD range in HES

3.13 Speed and injury severity

As part of a study carried out for the Department for Transport (Richards, 2010), pedestrian casualties recorded in the On The Spot (OTS) study and police fatal files have been used to estimate the relationship between impact speed and pedestrian injury severity.

From the pedestrian accidents in OTS and the police fatal files, a sample of 197 pedestrian casualties was obtained, including 66 fatalities. These pedestrians were hit by the front of cars, in accidents occurring from 2000-2009. Accidents where the pedestrian was lying down or where the vehicle "sideswiped" the pedestrian were excluded. All ages of pedestrian casualty were included in the sample, including those of unknown age.

Figure 3.15 shows the cumulative impact speed of the pedestrians in the OTS and police fatal file dataset. This shows that approximately half of fatally injured pedestrians in the dataset were hit at an impact speed of 30 mph or less.

In order to perform the logistic regression, the number of slight, serious and fatal casualties in this dataset was weighted to match the number of pedestrian casualties in the national statistics (which was shown in Table 2.2). Figure 3.16 shows the relationship between impact speed and the risk of pedestrian fatality, calculated using the logistic regression method. The solid line shows the calculated relationship between speed and injury severity, and the dashed lines show the 95% confidence intervals. This figure gives the risk of pedestrian fatality at an impact speed of 30 mph as approximately 7%, and the risk at an impact speed of 40 mph as approximately 31% – an increase of 4.5 times.

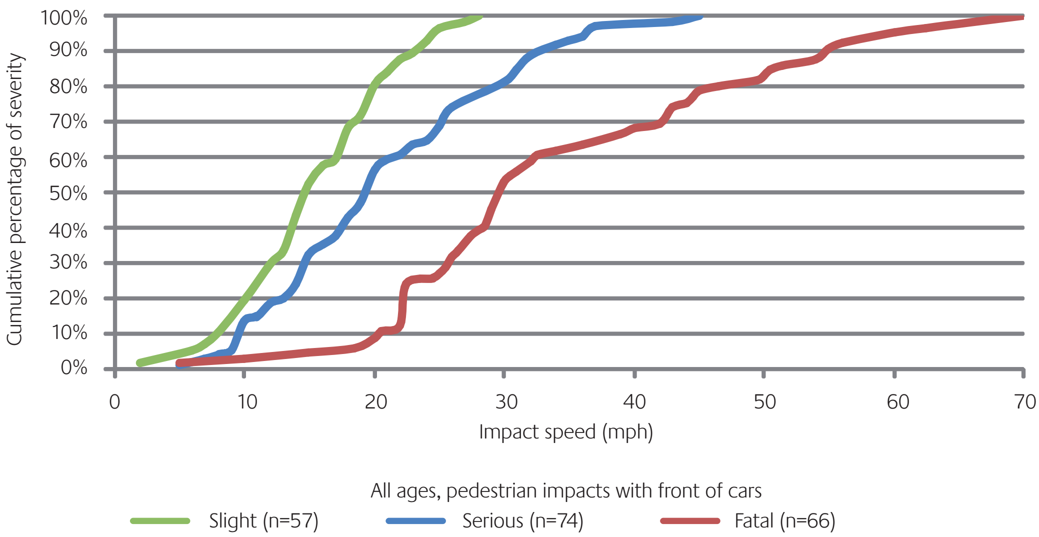

Figure 3.15 Cumulative impact speed for pedestrian casualties in the OTS and police fatal file dataset

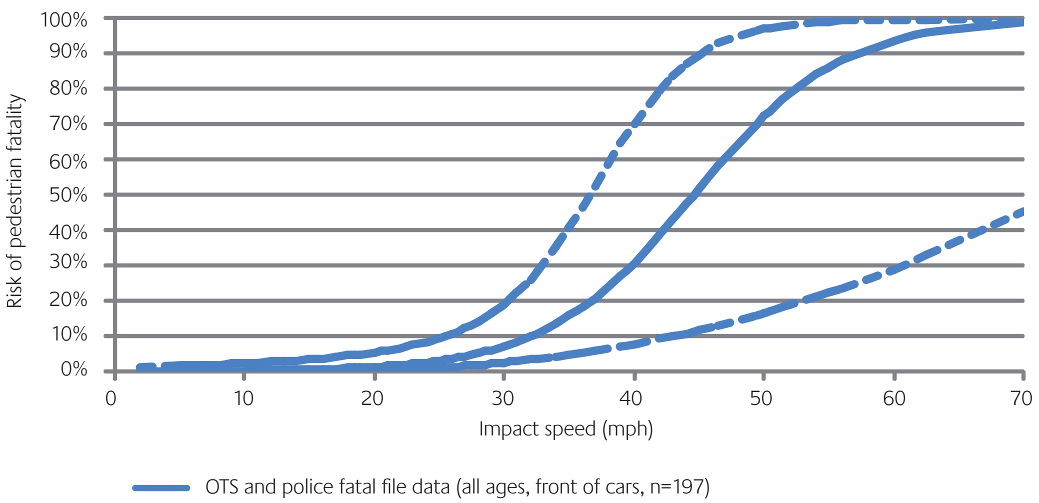

Figure 3.16 Risk of pedestrian fatality calculated using logistic regression from the OTS and police fatal file dataset

4 Pattern and costs of injury

This section begins by showing the pattern of injuries received by pedestrians in road traffic accidents. This information is taken from the Hospital Episode Statistics (HES), which record the injuries of pedestrian casualties who are admitted to hospital in England. The cost of these injuries is then estimated, using a model that is based on the amount of time each casualty spends on a hospital ward or in intensive care. This uses a combination of information from HES and the Helicopter Emergency Medical Service (HEMS).

4.1 Injury pattern

The following analysis used the ICD-10 diagnosis codes to analyse the most frequent injuries, injury regions and numbers of injuries received by pedestrians in HES. The more complicated injuries are explained in the glossary at the end of this report.

4.1.1 Number of injuries

The number of injuries recorded in HES for each pedestrian was calculated and is presented in Figure 4.1. It should be noted that the number of injuries which could be recorded in the HES dataset increased from seven to 14 in 2002 and therefore 3% had seven or more injuries. Pedestrians with only one injury made up 33% of the sample, the percentage of pedestrians then decreased with the increasing number of injuries.

4.1.2 ICD analysis

The most frequently injured regions coded as primary injuries in HES using three-character ICD10 codes are shown in Figure 4.2. The most frequent injury of the pedestrians in HES was a fracture to the lower leg including ankle, followed by unspecified injuries of the head. Of these most frequent injuries, a large proportion was other injuries to the head and legs.

The injuries coded using the four-character codes were then analysed and are shown in Figure 4.3. The most frequent primary injury in this field was an unspecified injury to the head. Next most frequent was pedestrians who had a fracture to the shaft of the tibia. The next two most frequent injuries were fractures to the lower end of the tibia and fractures to the upper end of the tibia, followed by fractures to other parts of the lower leg.

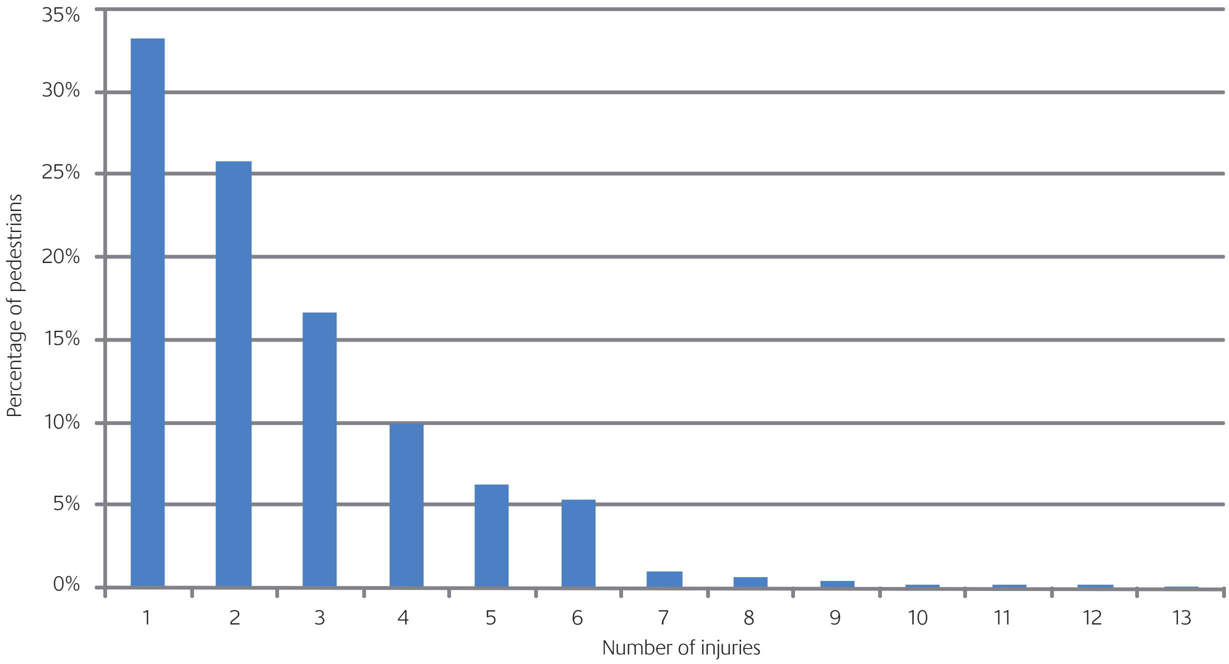

Figure 4.1 Number of recorded injuries for pedestrian casualties in HES

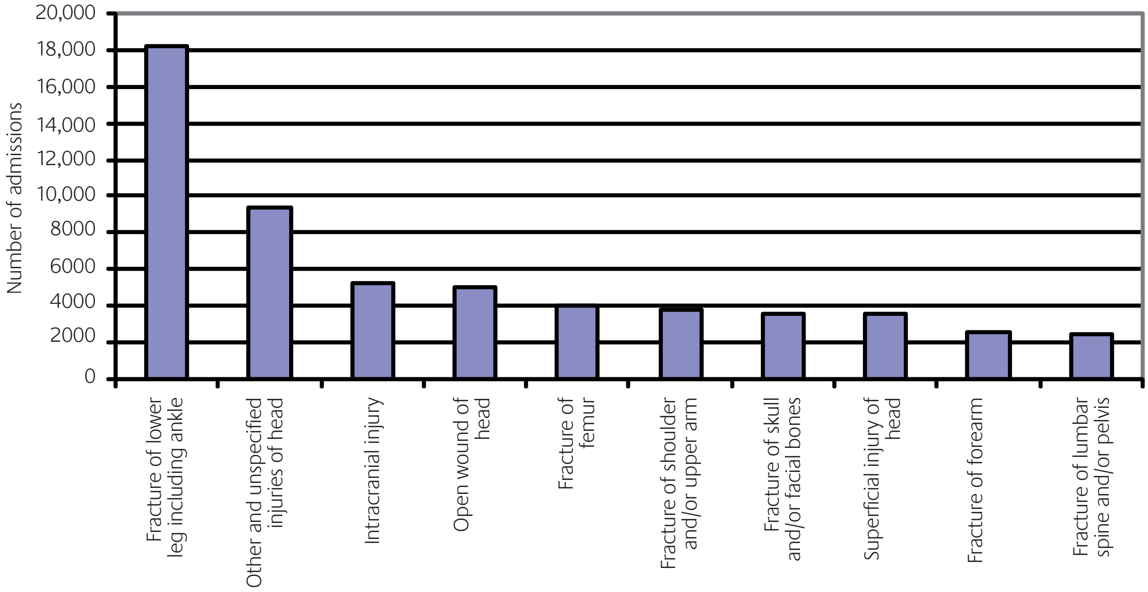

Figure 4.2 Most frequent primary injuries (using three-character code) in HES

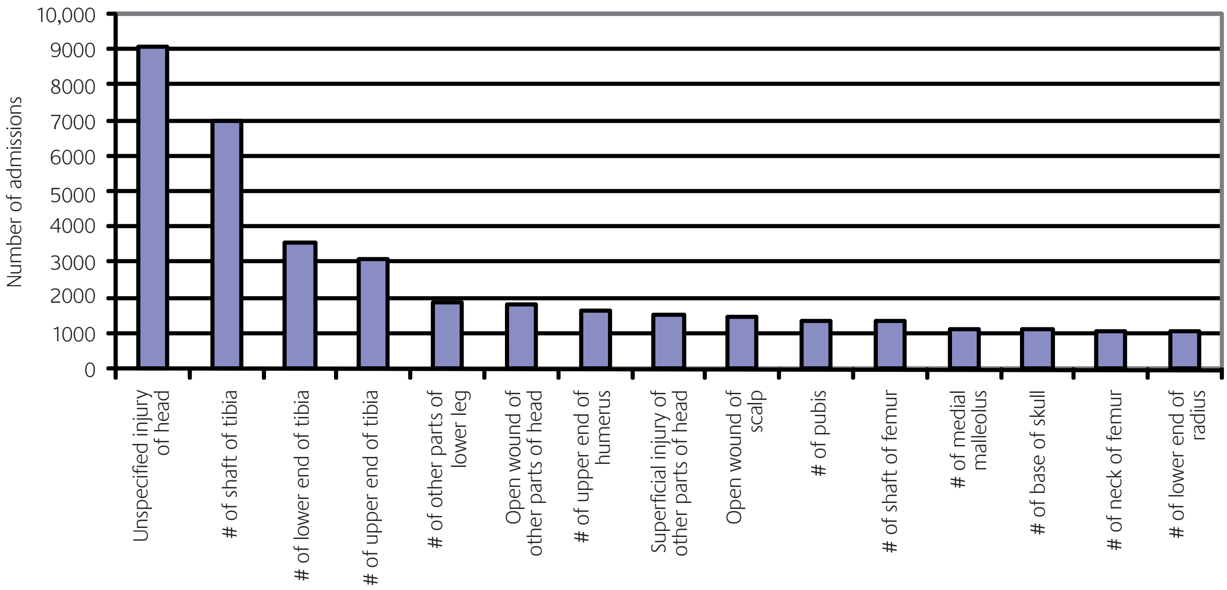

Figure 4.3 Most frequent primary injuries (using four-character code) in HES

4.1.3 Injury vs age and gender

The percentage of pedestrians with head injuries decreased with increasing age, as can be seen in Figure 4.4. Hip and thigh injuries were fairly constant for all ages until 59 years of age, after which the percentage of the age group with injuries in that region increased from 5% for 50-59 to 16% for those over 90. Knee and lower leg injuries had the opposite trend, decreasing from 30% for 60-69 year olds to 23% of over 90 year olds. Injuries in the shoulder and arm region were particularly low for those aged up to nine years, but were then fairly constant for all other age groups.

4.1.4 Injury vs vehicle type

Knee and lower leg injuries were the most common injury regions for all vehicle types apart from 2/3 wheel motor vehicles for which wrist and hand injuries were slightly more frequent (Figure 4.5). Pedestrians hit by heavy transport vehicles received the highest rate of injuries to multiple body regions, the abdominal region and the shoulder. Pedestrians struck by pedal cycles received the highest rate of ankle and foot, and thorax injuries.

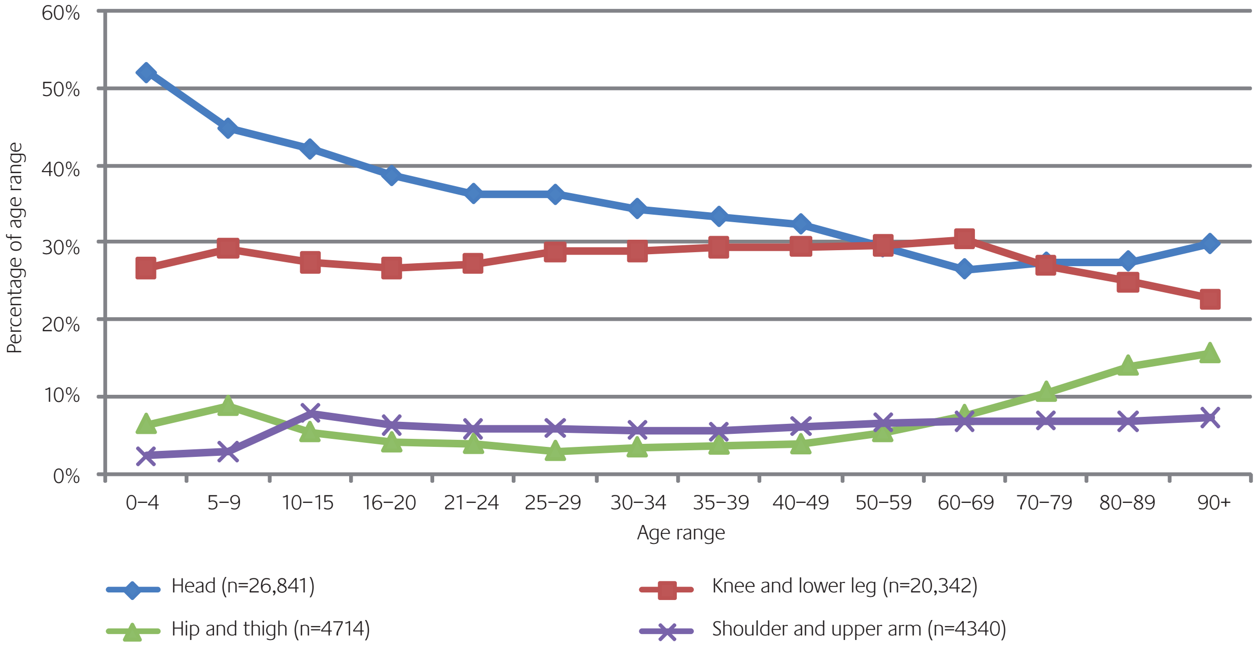

Figure 4.4 Relationship between the most frequent injuries and age of pedestrians, as a percentage of pedestrians in each age range in HES

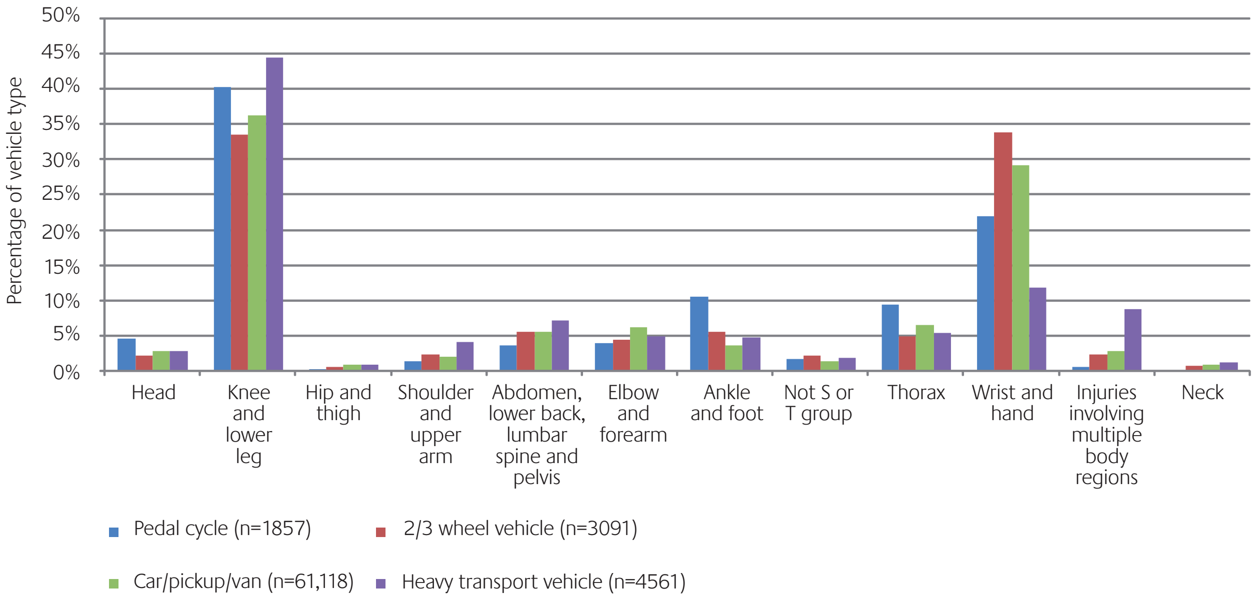

Figure 4.5 Pedestrian injuries caused by different vehicle types in HES

4.1.5 Injuries related to time in hospital

Figure 4.6 shows the duration of stay in hospital for the pedestrians in the HES dataset. The duration of stay for pedestrians peaked with 25% of pedestrians staying for one day. The next two most frequent lengths of stay were zero or two days, both accounting for 11% of pedestrians.

When comparing primary injury regions with duration of stay (Figure 4.7), it can be seen that the length of stay for those with head injuries peaked at one day, whereas those with knee and lower leg injuries peaked at two days. Patients who were admitted for two days or more most commonly had leg injuries compared to head injuries.

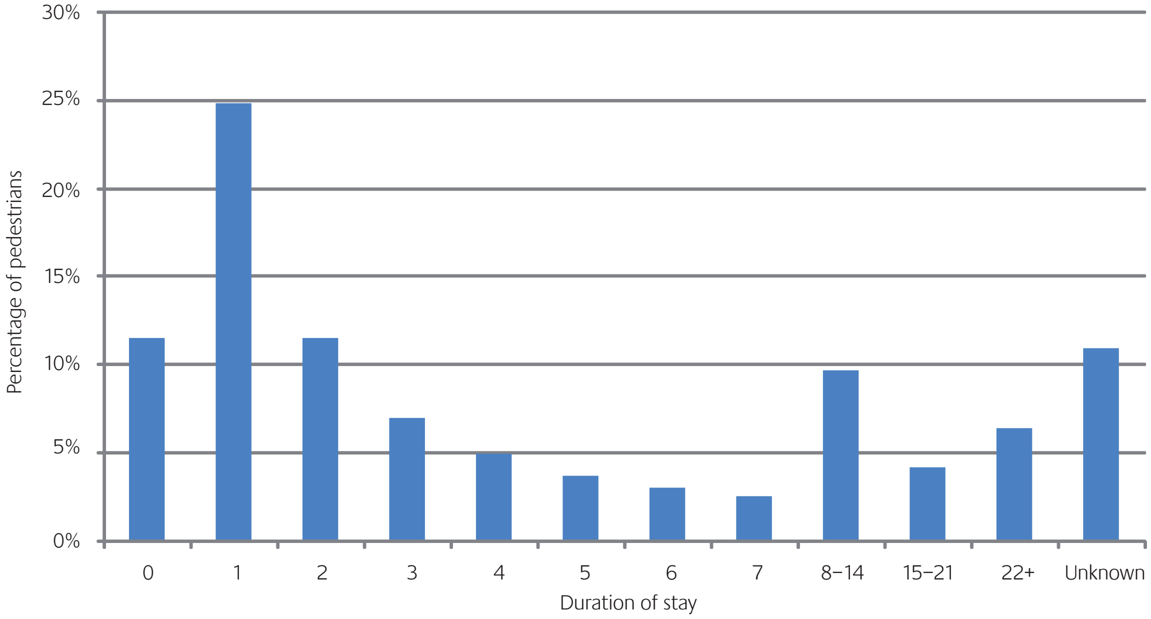

Figure 4.6 Duration of stay as a percentage of the number of pedestrians in HES

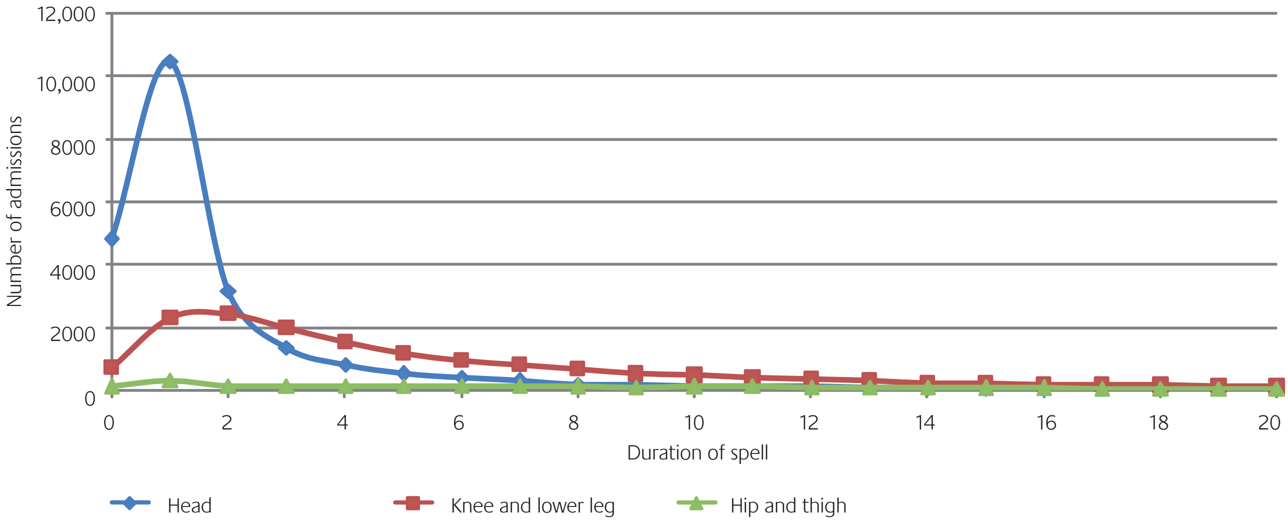

Figure 4.7 Duration of spell at hospital for pedestrians with the three most frequently injured regions in HES

Figure 4.8 presents a box plot which shows how primary injuries in different regions related to the length of time spent in hospital. The central horizontal line within the boxes gives the median duration of stay, and the boxes themselves give the upper and lower quartiles. The lines extending from the bars contain approximately 99% of the pedestrians. The circles are outliers (greater than 1.5 box lengths from the top or bottom of the box) and the stars are extreme values (greater than three box lengths from the top or bottom of the box). The body regions themselves are sorted by the mean duration of stay, descending from the left.

Primary injuries to the hip and thigh were associated with the longest mean and median duration of stay in hospital. There were a lot of outlying points for injuries to all body regions, where the pedestrian had been in hospital for a relatively long time. This was especially true for injuries to the head, where the quartiles of the duration of stay were close together, but there were a lot of outliers who were in hospital for much longer. This seems to be because a large number of pedestrians had relatively minor head injuries, and were only in hospital for one day, compared to a relatively small sub-set who spent over five days in hospital with serious or life threatening head injury.

These injuries were then broken down into the more specific injuries as shown in Figure 4.9, which gives the ten injuries with the highest mean duration of stay, received by at least 100 pedestrians. The injuries are coded using the four-character ICD code, the descriptions of which are given in Table 4.1. The longest mean duration of stay was 68 days for those pedestrians with fractured cervical vertebrae. This large mean duration was due to two pedestrians who received this injury and were in hospital for 1,082 and 2,878 days.

The majority of other injuries which led to long durations of stay were fractures of the legs. As with the body region injuries, there was a large spread in the duration of stay of the pedestrians suffering these injuries.

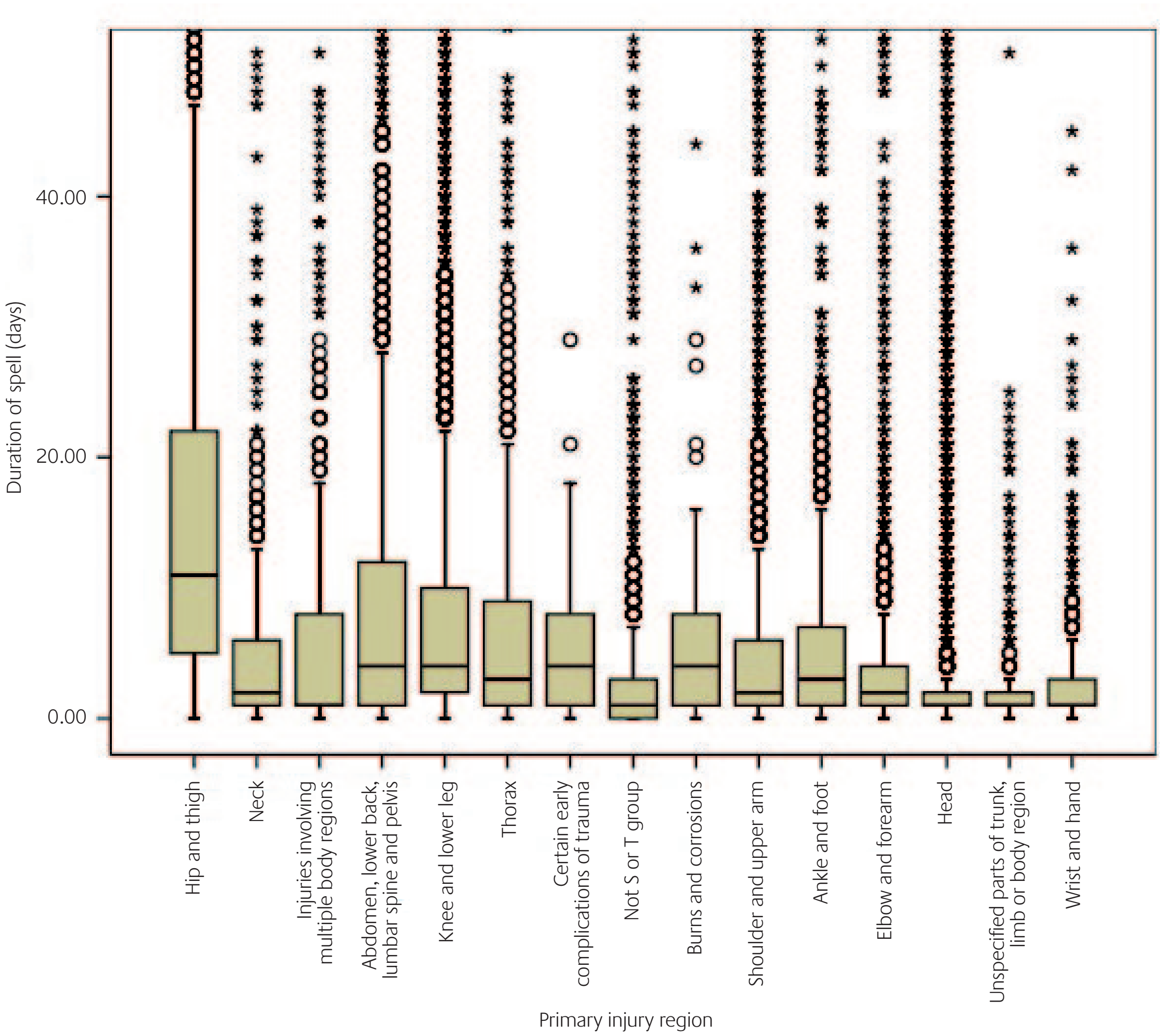

Figure 4.8 Mean duration of stay, by region of primary injury in HES

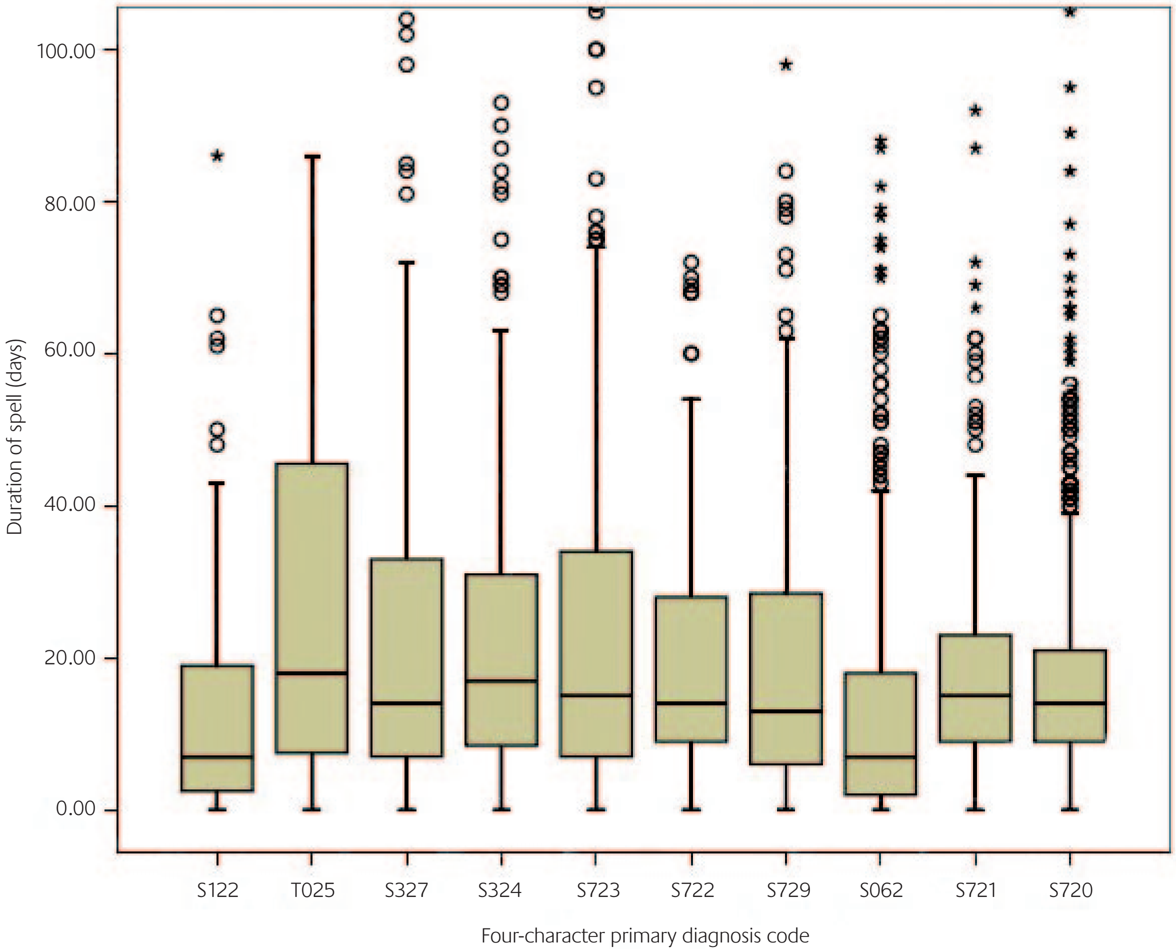

Figure 4.9 Mean duration of stay for injuries suffered by at least 100 pedestrians in HES

Table 4.1 Descriptions of four-character primary diagnosis codes in HES

Four-character code	*Injury description*	*No. of pedestrians*	*Mean duration of stay (days)*
S122	Fracture of other specified cervical vertebrae	101	67.5
T025	Fractures involving multiple regions of both lower limbs	100	33.9
S327	Multiple fractures of lumbar spine and pelvis	150	25.3
S324	Fracture of acetabulum	308	24.4
S723	Fracture of shaft of femur	1335	21.9
S722	Subtrochanteric fracture of femur	154	20.9
S729	Fracture of femur, part unspecified	336	20.3
S062	Diffuse brain injury	924	19.1
S721	Pertrochanteric fracture of femur	379	18.6
S720	Fracture of neck of femur	1067	17.5

4.2 Costs of injury

The HEMS dataset contained details of 746 pedestrians injured in accidents with motor vehicles from 2000-2007, who received a total of 2,974 recorded injuries. Table 4.2 shows the total number of days spent on a ward and in an intensive care unit (ICU) and the total cost for all the pedestrians in the HEMS dataset. It also shows the annual cost which was calculated by dividing the total cost by eight (the number of years covered by the HEMS dataset).

Figure 4.10 shows the distribution of the costs of the pedestrian casualties to the hospital by their outcome: whether they survived, or where they died. The central horizontal line within the boxes gives the median cost, and the boxes themselves give the upper and lower quartiles. The lines extending from the bars contain approximately 99% of the pedestrians. The circles are outliers (greater than 1.5 box lengths from the top or bottom of the box) and the stars are extreme values (greater than 3 box lengths from the top or bottom of the box). All the pedestrians who died in Accident and Emergency (A&E) or in theatre did so within a day of admission, which means that the annual cost for these pedestrians was zero.

Table 4.2 Summary of costs for pedestrians in HEMS dataset

Number of pedestrians	746
Total days on ward	12,009
Total days in ICU	2,634
Total cost	£6,853,253
Annual cost	£856,657
Mean cost per patient	£9,187

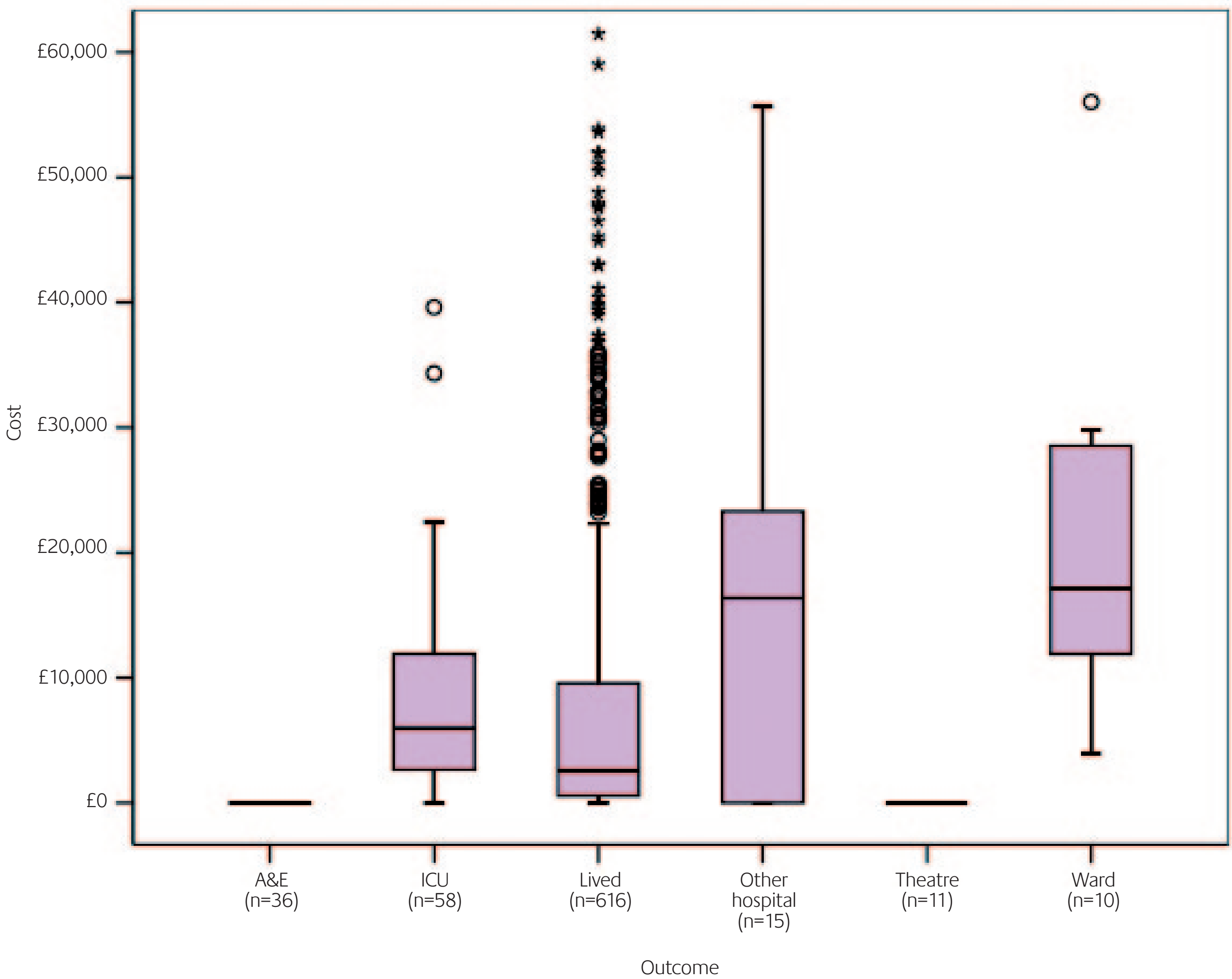

Figure 4.10 Distribution of pedestrian casualty cost by outcome from HEMS

The annual cost of the pedestrians for each outcome was calculated by summing the cost of each individual pedestrian with a given outcome, then dividing by the number of years covered by the HEMS data. The annual cost for pedestrians who died in intensive care was £89,639, for those who died on the ward it was £25,890, and for those who died in another hospital it was £28,539. The annual cost of the pedestrians who survived was £712,588.

Figure 4.11 shows the average cost of the pedestrians in the HEMS dataset by body region injured. This only includes the injuries with a severity of AIS 2 or greater. This figure shows that head injuries had a relatively low average cost (which agrees with the HES data in Figure 4.8 which shows that head injuries lead to a relatively short duration of stay compared to other injuries).

Figure 4.11 also shows the difference in the average cost of pedestrian injuries between 2000 and 2007. Head, lower limb and upper limb injuries showed a small decrease in the average cost, while abdomen and thorax injuries showed an increase (there were only two and four pedestrians with "multiple" region injuries in 2000 and 2007 respectively – i.e. one injury that includes multiple body regions, such as burns).

Figure 4.12 shows the annual cost of the pedestrian injuries by body region for the pedestrians in the HEMS dataset. Table 4.3 shows the ten individual injuries received by the pedestrians in the HEMS dataset which were calculated to be the most costly.

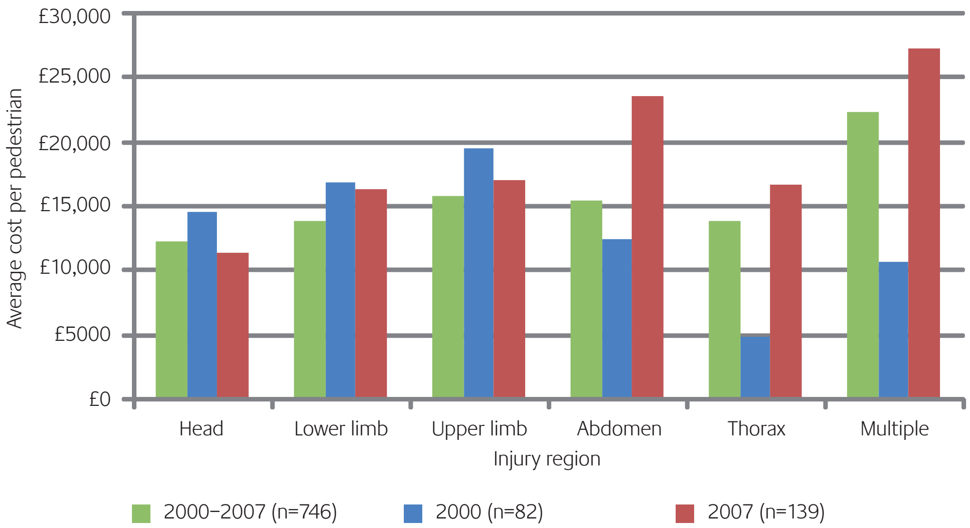

Figure 4.11 Average cost per pedestrian of pedestrians in HEMS dataset

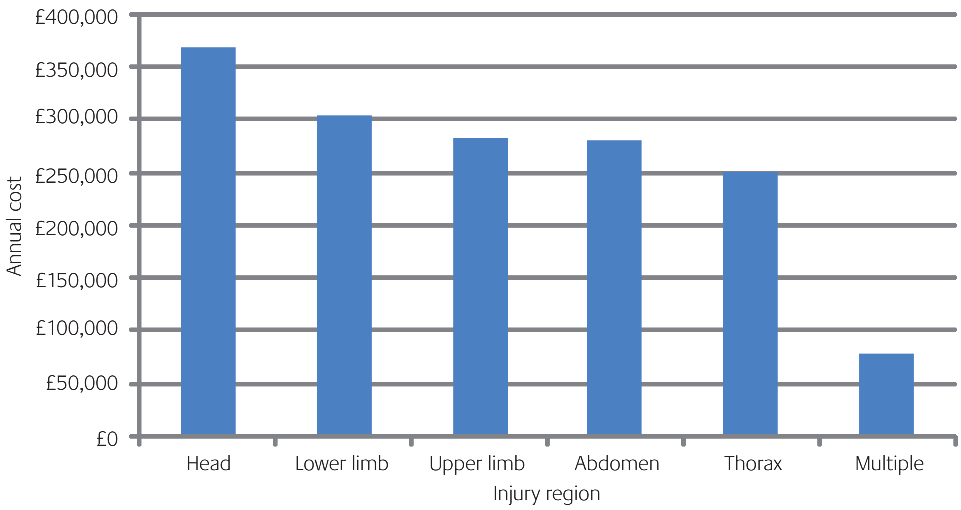

Figure 4.12 Annual cost of pedestrian injuries by body region injured in the HEMS dataset

Table 4.3 ICD-9 descriptions of the ten AIS 2+ injuries with the highest annual cost in the HEMS dataset, surviving pedestrians only

ICD-9 code	*ICD-9 description*	*Annual cost*
851	Cerebral contusion closed	£223,644
852.05	Generalised SAH IVH*	£197,136
852.04	Cerebral subdural haematoma	£147,423
807	Fracture of ribs closed	£127,802
860	Pneumothorax, without wound into thorax	£108,336
802.4	Fracture of malar and maxillary bones closed	£98,578
861.2	Injury to lung without wound into thorax	£88,132
801.1	Fracture of base of skull, closed with intracranial injury	£85,202
808.2	Fracture of pelvis, pubis closed	£82,431
810	Fracture of clavicle, closed	£77,503

* Generalised subarachnoid haemorrhage and intraventricular haemorrhage.

Head injuries accounted for the top three most costly individual injuries, and head injuries were also the injury region with the greatest annual cost for the pedestrians in the HEMS dataset. However, the larger HES dataset differed with respect to the relative proportions of head and leg (and other injuries) which were received by pedestrian casualties. For example, the proportion of pedestrians receiving their primary injury to the head or lower limb in HES was 39% and 39% respectively, compared to 32% and 24% for the AIS 2+ head and lower limb injuries in HEMS. For this reason the estimated costs calculated using the HEMS dataset were weighted using the larger national HES dataset.

Table 4.4 shows the process used to calculate the weighted annual costs for injuries to the different body regions, and Figure 4.13 shows the annual cost of pedestrians by injury region using the results from the weighting.

Table 4.4 Weighting cost of pedestrian injuries in HEMS dataset to national HES dataset

Body region injured	*Annual cost in HEMS*	*Annual number of pedestrians*		*Average duration of stay*		*Weighting factor*	*Weighted annual cost*
		HEMS	*HES*	*HEMS*	*HES*		
Head + neck	£369,023	30	3060	23.3	4.0	17.5	£6,446,118
Lower limb	£304,618	22	3046	28.7	9.9	47.7	£14,518,084
Upper limb	£282,985	17	946	29.0	5.1	9.2	£2,613,434
Abdomen, lower back, lumbar spine and pelvis	£281,232	18	454	30.3	10.2	8.4	£2,372,013
Thorax	£251,376	18	186	26.0	8.1	3.2	£794,129
Multiple / NS	£78,118	3.5	135	45.1	7.5	6.4	£501,518

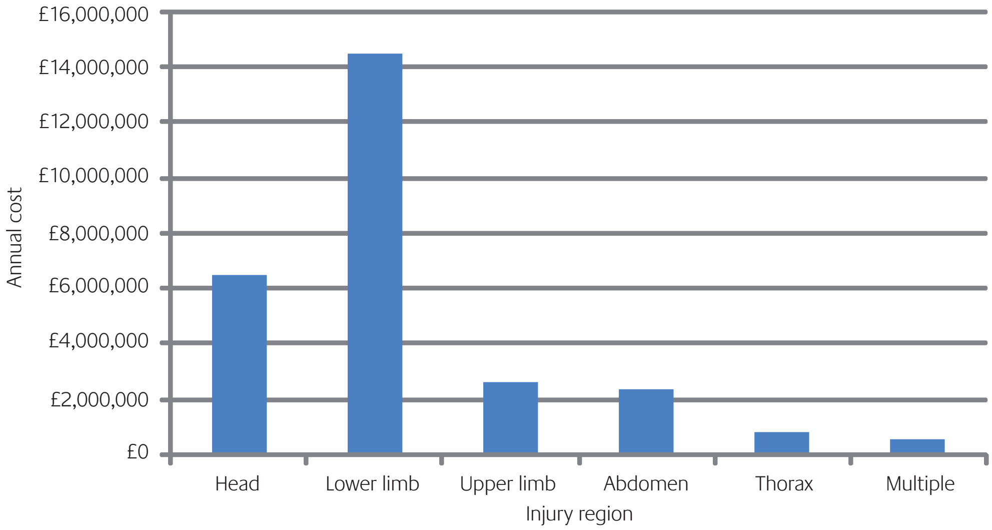

Figure 4.13 Weighted annual cost of pedestrian injuries by body region

The large total duration of stay associated with lower limb injuries in the HES dataset meant that, when the costs in the HEMS dataset were weighted using the HES dataset, lower limb injuries accounted for a larger annual cost than injuries to any other region. This was also reflected in the most costly individual injuries, shown in Table 4.5, as five of the ten most costly injuries were lower limb injuries (before the weighting none of the top ten injuries were to the lower limbs). However, the two most costly individual injuries were still head injuries.

The top ten most costly injuries, after the weighting using the HES data, were all either head or lower limb injuries. However, it should be noted that the weighted cost of the individual injuries is based on the weightings calculated by body region. This would be more accurate if the weightings could be calculated for the individual injuries; unfortunately, because of the limited sample size and the differences between ICD-9 and ICD-10, the weightings could not be calculated for individual injuries as part of this study.

Table 4.5 Weighted annual cost of the ten most costly individual injuries

ICD-9 code	*ICD-9 description*	*Annual cost*
851	Cerebral contusion closed	£3,907,067
852.05	Generalised SAH IVH	£3,443,958
823.1	Fracture of tibia and fibula, unspecified part, open	£2,711,806
852.04	Cerebral subdural haematoma	£2,575,482
823	Fracture of tibia and fibula, unspecified part, closed	£2,376,994
823.3	Fracture of tibia and fibula, shaft open	£2,009,706
802.4	Fracture of malar and maxillary bones closed	£1,722,163
801.1	Fracture of base of skull, closed with intracranial injury	£1,488,491
823.2	Fracture of tibia and fibula, shaft closed	£1,458,104
891	Open wound of knee, leg and ankle	£1,362,013

5 Injury causation

This analysis of police fatal accident files held by TRL concentrated on pedestrian collisions with both old and new cars. This analysis is based on Cookson, Cuerden, Richards, and Manning (2009).

5.1 New and old car sample comparison

Figure 5.1 shows the year of registration of the 49 vehicles which struck the 49 fatally injured pedestrians in the files selected for review. All of these vehicles were cars or car-derived vans. Of the 49 vehicles, 27 (55%) were registered in 2002 or later and 22 were registered before 2002. These will be referred to as "new" and "old" cars respectively. These two groups of vehicles were chosen as they split the sample into two relatively equal sized groups, the newer of which are likely to have been more influenced by EuroNCAP and EC regulations discussed in Section 1.2.

It should be noted that the sample of 49 pedestrians is a relatively small sample size, however this demonstrates the types of analysis that can be carried out on a larger scale and provides an indication of the types of patterns that may be found. In all of the analysis in this section, no evidence of significant differences was found, which is at least partly due to the small numbers in the sample. In other words, future work investigating a larger sample may highlight statistical differences between newer and older cars.

The sizes of the vehicles in the two groups were compared and there was no significant difference between the groups. The vehicles were grouped into size by their EuroNCAP class of supermini, small family car, large family car, executive, small MPV, large MPV, roadster sports, small off-road 4x4, large off-road 4x4 and pick-up. Small and large family cars were the most frequent vehicles in both groups: small family cars accounted for 36% of the old cars and 26% of the new cars; large family cars accounted for 32% of the old cars and 30% of the new cars.

The age and gender of the pedestrians and average impact speed of the collisions in the two vehicle registration groups were compared and chi-squared tests showed there to be no evidence of a difference between the old and new vehicle groups. The sample of 49 pedestrians was made up of 32 males (65%) and 17 females (35%). There were six children under the age of 15, 24 pedestrians aged 15-59 and 19 pedestrians aged 60 years or older. These can be split by those struck by old and new vehicles as shown in Figure 5.2.

From the skid marks left by the vehicles or using pedestrian throw calculations, the impact speed for the collisions could be estimated. Each vehicle had a minimum and a maximum impact speed recorded, which were calculated or estimated based on the information present in the police fatal files. There were five collisions in which the impact speed could not be calculated. The average of the minimum and maximum speeds was calculated and Figure 5.3 shows the cumulative average impact speed for the remaining 44 vehicles in the sample. The 50th percentiles of the average impact speed for the old and new vehicles were approximately 47 kph (29 mph) and 48 kph (30 mph) respectively. When chi-squared tested, there was no evidence of a statistical difference.

Table 5.1 shows the crash avoidance manoeuvres undertaken by the vehicles before they hit the pedestrians. This shows that for 21 (43%) of the vehicles there was no evidence of any avoidance manoeuvres, while 26 (53%) at least braked. For two of the vehicles, avoidance manoeuvres were unknown. As statements are not always reliable, driver-stated braking was only recorded where expert opinions of the analysis team thought that this was likely to be true from the fatal file reports and photographs. Very little difference can be seen between the two vehicle groups, and there was no evidence of a statistical difference.

Figure 5.1 Year of registration of the 49 vehicles in impacts with pedestrians from police fatal files

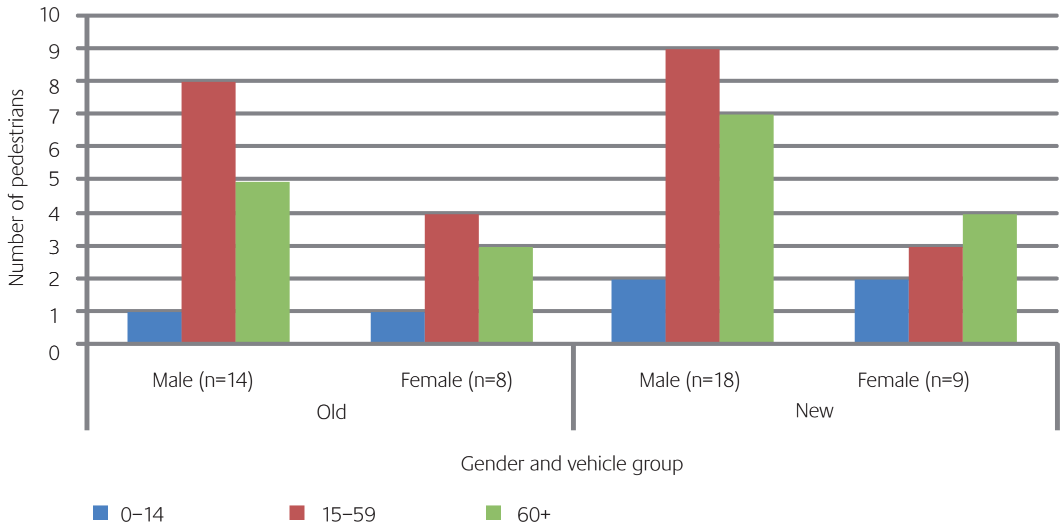

Figure 5.2 Distribution of pedestrians by age group in each gender for old and new cars from police fatal files

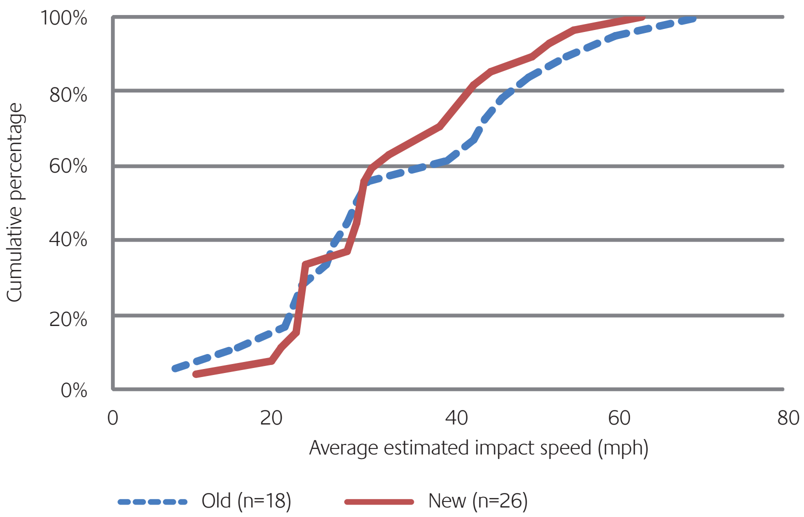

Figure 5.3 Cumulative impact speed of vehicles striking pedestrians from police fatal files

Table 5.1 Crash avoidance manoeuvres of vehicles striking pedestrians from police fatal files

Crash avoidance	*Old*	*New*	*Number of vehicles*
No avoidance manoeuvre reported	45%	41%	21
Braking (skid marks evident)	23%	26%	12
Braking (no skid marks; driver stated)	14%	19%	8
Braking (other reported evidence)	5%	0%	1
Steering and braking (evidence or stated)	9%	11%	5
Unknown	5%	4%	2

Figure 5.4 shows that the most frequently AIS 2+ injured region in the sample of fatal pedestrian accidents was the head and neck, followed by the thorax and legs. Many of the pedestrians had injuries to more than one body region. The percentages are given as a percentage of the total number of casualties in the old and new car groups, which were 22 and 27 respectively. It can also be seen that pedestrians who were struck by older cars received a lower percentage of AIS 2+ injuries in all body regions except for legs. The largest differences can be seen in the pelvis and thorax where 23% of those struck by old vehicles received pelvis injuries compared to 41% of those struck by new vehicles. Pedestrians struck by old vehicles also received thorax injuries in 55% of cases compared to 74% of new vehicle cases. When chi-squared tested, no evidence was found that there is a statistical difference.

Figure 5.5 shows the percentage of pedestrians who received AIS 3+ injuries by body region. These injuries are dominated by injuries to the head and thorax. With the exception of injuries to the abdomen, a higher percentage of pedestrians received AIS 3+ injuries in impacts with new cars. When chi-squared tested, no evidence was found of a statistical difference.

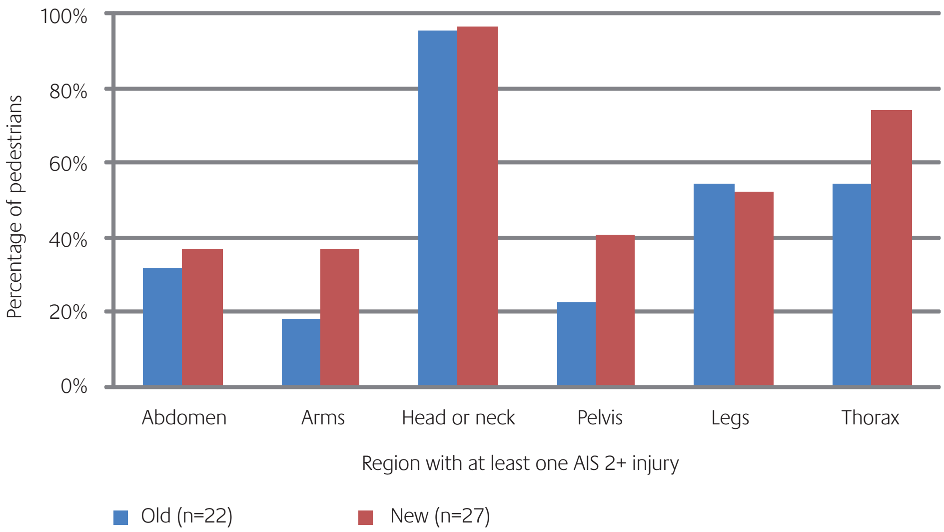

Figure 5.4 Percentage of pedestrians with at least one AIS 2+ injury to a body region from police fatal files

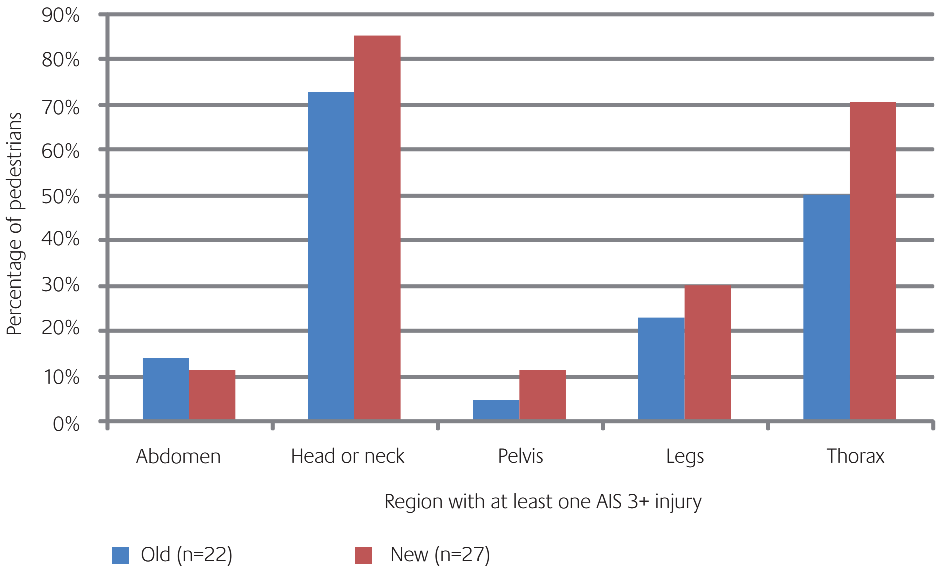

Figure 5.5 Percentage of pedestrians with at least one AIS 3+ injury to a body region from police fatal files

The locations with respect to body region of the maximum AIS for each pedestrian were calculated and are shown in Table 5.2. Some pedestrians had multiple body region injuries of equal AIS score, which were equal to their MAIS: all regions were recorded. Head and thorax injuries came out as the most frequent body regions to have an AIS score equal to the MAIS value for a pedestrian. It can be seen that impacts with new vehicles resulted in head injuries of a higher MAIS, whereas the opposite can be said for thorax injuries. Of the 27 pedestrians impacted by new vehicles, 11 had a MAIS of 5 including an AIS 5 head injury, compared to only three of the 22 struck by older cars.

The height of a pedestrian would affect the parts of the vehicles struck by different body regions; therefore this variable was checked before analysis was undertaken. For the pedestrians whose height was known (14 old, 23 new) the average heights were similar and the range of heights was larger for new vehicles than old as shown in Table 5.3. Also chi-squared tests showed there to be no evidence of significant differences between the distributions, therefore the impact region distributions can be compared.

Table 5.2 Location of maximum AIS for each pedestrian from police fatal files

Vehicle category	*Body region*	*MAIS*			
		2	3	4	5
Old	Head or neck	3	4	4	3
	Legs	2	2	0	0
	Pelvis	1	0	0	1
	Thorax	0	2	1	5
New	Abdomen	1	0	1	0
	Head or neck	1	4	6	11
	Legs	0	1	0	0
	Pelvis	1	0	0	0
	Thorax	0	6	3	3
	Arm	1	0	0	0

Table 5.3 Height distribution of the pedestrians from police fatal files

Height (cm)	*Old vehicles*	*New vehicles*
Average	168	166
Maximum	188	196
Minimum	142	135

5.2 Injury causation in impacts with new and old cars

The following section breaks down the injuries by body region and shows the areas of the vehicle that caused at least one AIS 2+ injury to that region. It should be noted that if two or more injuries to a body region were due to the same zone on the vehicle, the zone was counted only once as having caused an injury to that body region in that accident. The percentages given are the number of pedestrians who received an injury from that area of the vehicle as a percentage of the number of pedestrians in that group (i.e. old or new vehicles). It cannot be said that a certain area of the vehicle definitely caused a particular injury, however, an expert opinion was gained to ensure that the areas selected were the most likely. For this, evidence on the vehicle and scene shown in photographs and police descriptions were used.

Figure 5.6 and Figure 5.7 show the percentage of pedestrians who had an AIS 2+ head injury caused by each zone on the car. The most frequent impacts were those to the windscreen which accounted for AIS 2+ head injuries to 12 (55%) of the pedestrians hit by old cars and 10 (37%) of the pedestrians hit by new cars. Three (14%) of the pedestrians received AIS 2+ injuries to their heads from the A-pillars when struck by old cars compared with eight (30%) of those struck by new cars.

Table 5.4 below shows the severity of the head and neck injuries split by impacts to the windscreen and A-pillar. Head strikes to the windscreen resulted in higher MAIS in this region when the impacts involved new cars compared with older cars. A-pillars showed the opposite trend, but it should be noted that there were only three of these impacts causing AIS 2+ injuries for pedestrian impacts with old cars, therefore the results were less reliable. It can also be seen that for new vehicles, MAIS 4+ injuries to the head were more frequent in windscreen impacts than A-pillar impacts.

From the analysis of the damage to the vehicles it can also be seen that the head strikes with new vehicles resulted in a lower percentage of a hole being created in windscreens than old vehicles (50% of AIS 2+ windscreen head strikes compared to 75%).

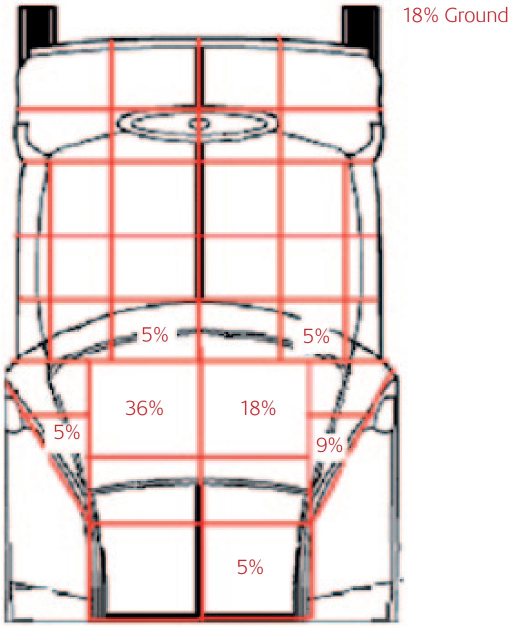

Figure 5.6 Location of AIS 2+ head and neck injuries for old cars

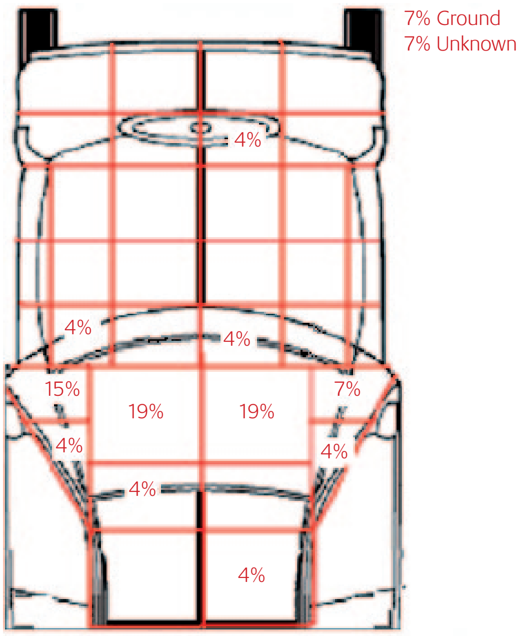

Figure 5.7 Location of AIS 2+ head and neck injuries for new cars

Table 5.4 Severity of head and neck injuries by location of impact from police fatal files

Vehicle group	*Impact location*	*MAIS of head and neck*			*Sample size*
		2	*3*	*4+*	
Old	Windscreen	25%	17%	57%	12
	A-pillar	0%	33%	66%	3
New	Windscreen	10%	20%	70%	10
	A-pillar	13%	25%	63%	8

Figure 5.8 and Figure 5.9 show the zones which caused one or more AIS 2+ injuries to a pedestrian's thorax. The most frequent impact zones were those to the rearmost half of the bonnet for both old and new vehicles. Older vehicles had a higher percentage of pedestrians receiving thorax injuries from the A-pillars. Newer vehicles had a higher percentage of pedestrians receiving thorax injuries from other objects such as the ground and walls. Overall, there was little difference between the severity of thorax injuries due to old and new cars. One of the pedestrian's thorax injuries was recorded as an acceleration injury. This was a transected aorta which is thought to have occurred when the pedestrian was suddenly accelerated by the impact with the car.

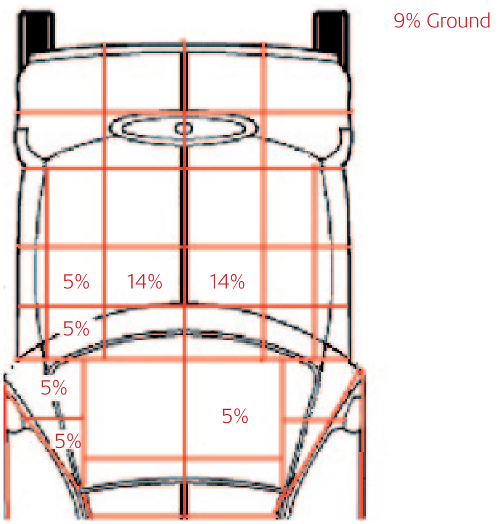

Figure 5.8 Location of AIS 2+ thorax injuries for old cars

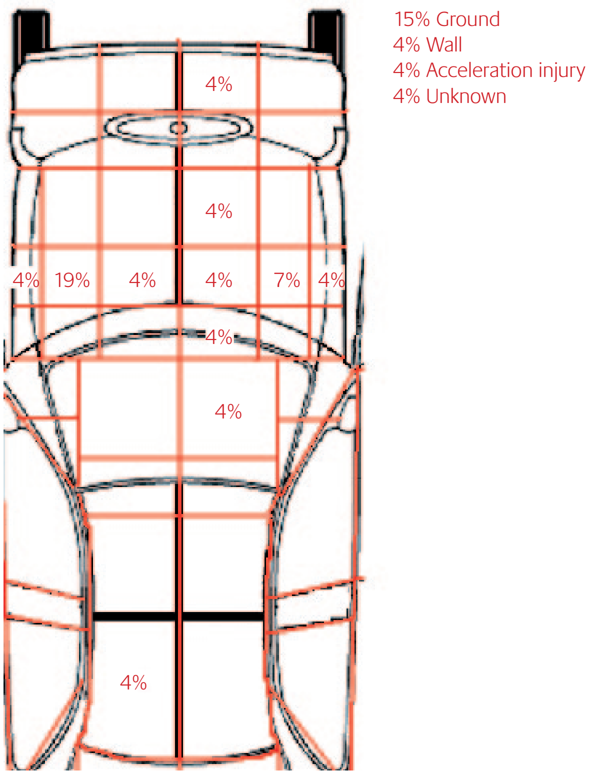

Figure 5.9 Location of AIS 2+ thorax injuries for new cars

Figure 5.10 and Figure 5.11 show the zones which caused one or more AIS 2+ injuries to a pedestrian's left or right leg. If both legs had AIS 2+ injuries from the same zone of the vehicle, the zone was counted once. The majority of the impacts were to the bumper or the leading edge of the bonnet, and the distribution was virtually the same for both old and new vehicles. For leg injuries resulting from impacts with older vehicles, 62% were MAIS 2 and 38% were MAIS 3, whereas with newer cars 47% were MAIS 2 and 53% were MAIS 3. However, when tested using a chi-squared test, no evidence was found that this difference is significant for this sample.

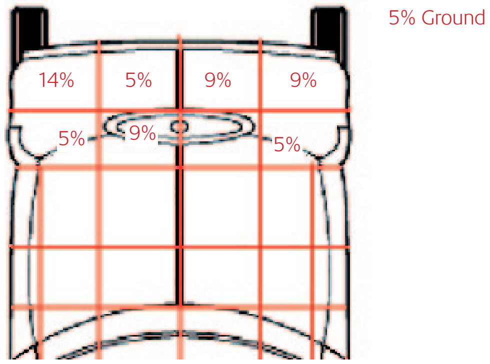

Figure 5.10 Location of AIS 2+ leg injuries for old cars

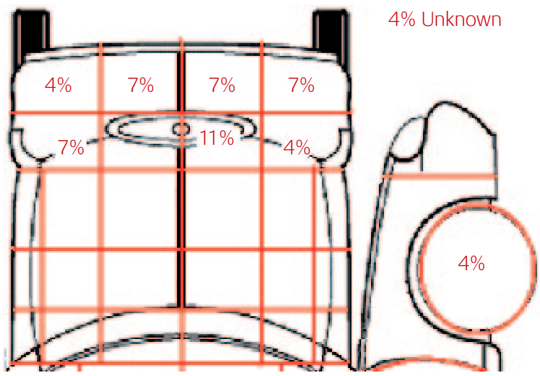

Figure 5.11 Location of AIS 2+ leg injuries for new cars

Figure 5.12 and Figure 5.13 show the zones which caused one or more AIS 2+ injuries to a pedestrian's abdomen. The majority of the impacts were to the bonnet. For older cars the areas causing abdominal injuries were mostly along the front half of the bonnet, whereas with newer cars the areas were more distributed along around the centre of the vehicle, on the bumper, bonnet leading edge and the front half of the bonnet.

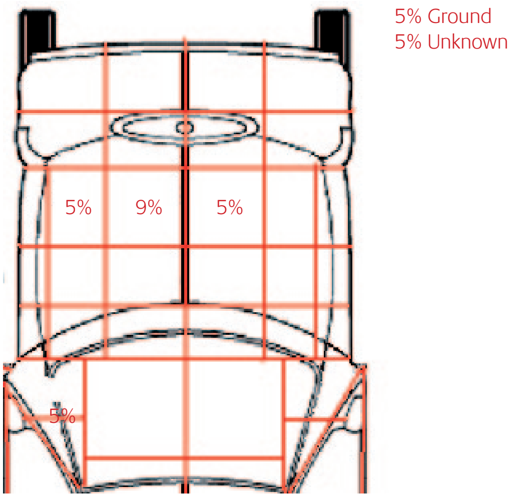

Figure 5.12 Location of AIS 2+ abdomen injuries for old cars

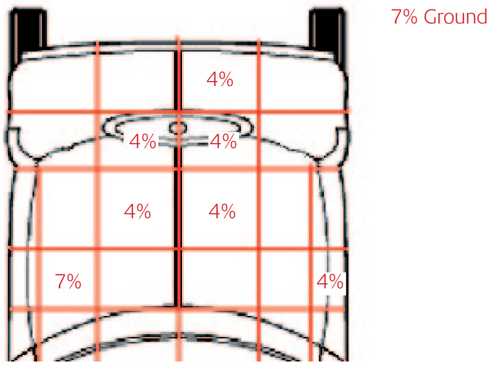

Figure 5.13 Location of AIS 2+ abdomen injuries for new cars

Figure 5.14 and Figure 5.15 show the zones which caused one or more AIS 2+ pelvic injuries. The majority of the impacts were to the front half of the bonnet for both sets of cars, with newer cars also showing pelvic injuries being due to the leading edge of the bonnet and bumper (child pedestrian).

The zones which caused one or more AIS 2+ arm injuries are not shown here as arm injuries were found to be the most difficult body region to assign an impact location due to the way they flail in an unpredictable way during the impact.

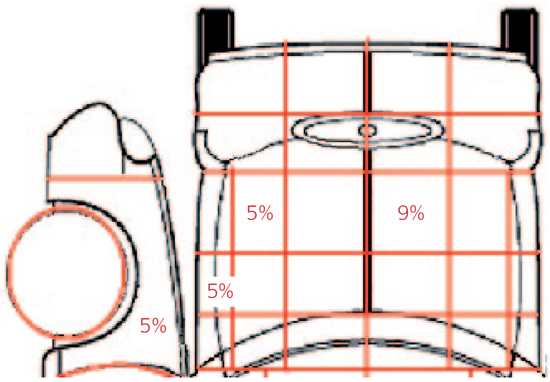

Figure 5.14 Location of AIS 2+ pelvis injuries for old cars

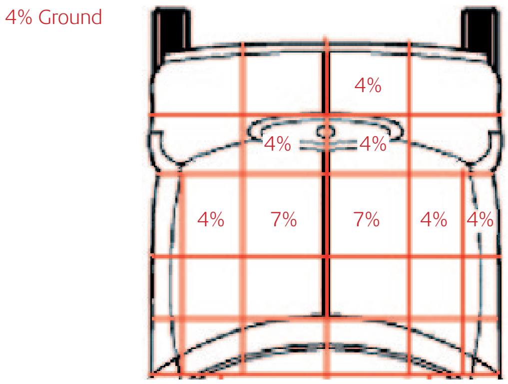

Figure 5.15 Location of AIS 2+ pelvis injuries for new cars

6 Discussion

Apart from being a large group of the road casualties in Great Britain, there are a number of reasons for investigating pedestrians. Arguably, compared to car occupants, the injury epidemiology and characteristics of pedestrians are less well understood, because of the lack of large pedestrian-focused accident studies. Also, new European Union pedestrian regulations have meant that the design of cars has changed, so it is important to find any corresponding change seen in pedestrian casualties.

For this report, five different databases were used to give an overview of pedestrian crashes and survivability. This demonstrates how each database provides its own unique attributes to crash analysis.

6.1 Accident characteristics

There is a strong relationship between the time of day and the number of pedestrian accidents which occur. Over all the days of the week, the number of pedestrian accidents peaks at 8am to 9am and 3pm to 6pm. These are the times when both pedestrians and drivers are travelling to and from work/school, so there is greater opportunity for them to come into conflict. At the weekends, there was an increase in the accidents occurring at later times up to 11pm, which again is a time when pedestrians and vehicles come into conflict with more social related travel.

When STATS19 was used to split pedestrian accidents by vehicle type, it was found that 81% of pedestrians were struck by cars/taxis. As these are the most frequent vehicle found on Britain's roads, this is to be expected. The next largest vehicle type striking pedestrians was heavy transport vehicles or buses. This may be related to the blind spots for the drivers of larger vehicles. It is found that a large proportion of accidents with these vehicles are due to pedestrians crossing in front of stationary large vehicles which then begin to move off without realising that there is a pedestrian in front (Smith, Broughton, and Knight, 2007). Impacts with these large vehicles often lead to fatal injury.

Most pedestrian accidents occurred on A-roads and unclassified roads, with A-roads accounting for a higher proportion of fatalities than of seriously injured pedestrians, and unclassified roads accounting for a higher proportion of serious casualties. This is most likely due to the higher speeds of vehicles on A-roads than unclassified roads.

6.2 Casualty characteristics

STATS19 was used to compare the characteristics of killed and seriously injured pedestrians. This shows that males were slightly more likely to be involved in fatal accidents, and that children were more likely to survive the impact than older pedestrians. This is believed to be because of their greater tolerance to injury and their different sizes and potentially crash types.

STATS19 showed that 47% of the pedestrians were crossing the road from the nearside of the vehicle. This is because both the pedestrian and the vehicle have very little time to react in this situation, assuming that the car is travelling adjacent to the footway on the nearside.

Of the contributory factors attributed to the pedestrian, "failed to look properly" was recorded for 35% of accidents. Ten percent of the pedestrians were recorded as "crossing road masked by parked or stationary vehicle" in the contributory factors, compared to the 22% who were recorded as "masked by parked or stationary vehicle" on the STATS19 casualty page.

6.3 Deprivation

The HES data includes a measure of the deprivation of the area where each pedestrian casualty lives. This shows that the rate of pedestrian injuries is much higher in areas which are more deprived: just under 5% of the pedestrian casualties were in the least deprived 10% of areas, while over 20% of pedestrian casualties were in the most deprived 10% of areas. This seems like a very strong relationship; however it is very difficult to separate the effect of deprivation from the location of the accident. Most accidents will occur near the home of the pedestrian, so pedestrians living in the most deprived areas (which are likely to be inner cities) are likely to have accidents in inner cities, where there is more exposure of pedestrians to traffic.

However, there does appear to be a relationship between age and deprivation, with younger children over-represented as pedestrian casualties in the more deprived areas.

6.4 Speed and injury severity

There is a gradual rise of risk up to impact speeds of around 30 mph. From 30 mph the risk of fatality increases more rapidly with respect to speed: in the OTS and police fatal file dataset the risk increases 4.5 times from 30-40 mph.

It should be noted that this is the risk of fatality provided that the pedestrian has been injured. This is because no details have been included of any pedestrians that were hit by vehicles but not injured. Although OTS does record details of road users who were not injured in accidents, the national statistics do not include this information. However, it is a good assumption that the vast majority of pedestrians hit by the front of a moving car will receive at least slight injuries (which can be as minor as a bruise), therefore these curves are a good approximation of the risk of fatality which could be calculated if the number of non-injured pedestrians was known.

It is known that there are some slight and serious road traffic accidents that are not reported to the police in Great Britain (Department for Transport, 2009) and are therefore not included in the national statistics. Because the risk of pedestrian fatality was calculated by weighting the OTS and police fatal file dataset to match the proportion of fatal, serious and slight casualties nationally, this under-reporting in the national statistics will have an effect on the calculated risk. The effect will be that the risk is overestimated.

Although this study suggests that the risk of pedestrian injury at an impact speed of 30 mph is approximately 7%, the cumulative impact speed curves show that approximately half of the fatally injured pedestrians in the OTS and police fatal file sample were hit at impact speeds of 30 mph or less. A recent analysis of STATS19 data shows that over 60% of pedestrian fatalities occur in an area where the speed limit was 30 mph or lower. Although the risk of pedestrian fatality may seem relatively low at 30 mph, the large number of pedestrian accidents at these speeds leads to a lot of pedestrian fatalities at 30 mph or less.

6.5 Injuries

Pedestrian injuries were dominated by injuries to two body regions, namely the head and the lower limbs. The majority of the injuries to the lower limbs would have been caused by the initial impact with the bumper or the bonnet edge in frontal impacts with cars. The causes of the head injuries are likely to be more widely distributed, including primary impacts with the vehicle (to the bonnet, windscreen, and A-pillars in a frontal impact) as well as secondary impacts with the ground (Appel, Strutz, and Gotzen, 1975; Otte and Pohlemann, 2001; Gavrila, Marchal, and Meinecke, 2003; Ashton and Mackay, 1979).

The most valuable part of the HES dataset is the injuries it records for pedestrians, data which is not available in any other database on such a large scale. The most frequent injuries recorded for the pedestrians in HES are head and lower leg injuries. This is true whether the three-character or the more detailed four-character ICD codes are used.

Using the four-character ICD codes, the most frequent injury is “unspecified injury of head”, however we do not know the severity of this injury due to the ICD coding system not including a measure of injury severity. This also means that the severity of different injuries cannot be compared.

The next four most frequent injuries are all fractures of the lower leg, and the majority of the top ten most frequent injuries are head and leg injuries. This agrees with previous studies on smaller samples of pedestrians (Cuerden, Richards, and Hill, 2007; Ashton and Mackay, 1979).

The relationship between the age of the pedestrian and the rate of injury in the four most frequently injured regions was investigated. This showed that the rate of head injuries decreases with age, and the rate of hip and thigh injuries increases with age. The rate of hip and thigh injuries increases most above the age of 60, which would coincide with the decreasing bone density and strength of older people, especially women. This would help to explain why the number of female pedestrian casualties increases above the age of 70.

The rate of head injuries was greatest for young children, which is likely to be because they will receive a more direct contact to the head from the front of the vehicle, because of their height. From the age of 16 and older, the rate of head injury remains relatively constant. It might be expected that elderly pedestrians would also see an increase in head injuries because they are generally less tolerant to injury. However, it may be that these pedestrians are being seriously injured at lower impact speeds (receiving leg fractures), which may balance their reduced tolerance to head injuries. Some knowledge of impact speed would be required to determine whether this was true.

6.6 Duration of stay

The duration of the stay in hospital is one way in which the HES data can be used to estimate the cost to the hospital of different injuries. Overall the duration of stay in hospital of the pedestrian casualties in HES is a very skewed distribution, with a large number of pedestrians staying for only one day, and a very small number of pedestrians remaining in hospital for very long periods of time. This distribution is a similar shape when individual injuries are investigated. For this reason, the relationship between individual injuries and the duration of stay in hospital has been investigated using the mean stay in hospital, and box-plots showing the distribution of the length of stay for different injuries.

Measuring the mean duration of stay shows that injuries to the hip and thigh and the neck result in the longest average stay in hospital. Serious injuries to these regions have relatively long recovery times, can leave the patient immobile for a long period of time and are frequently associated with older women who generally stay in hospital longer.

Looking at individual injuries shows that a fracture of the cervical spine leads to the longest mean duration in hospital, but this is mainly due to one pedestrian who received this injury and remained in hospital for almost eight years. Apart from this spinal injury, multiple fractures of the lower legs led to the longest mean stay in hospital. The remainder of the ten longest mean durations of stay in hospital are mostly made up of fractures to the femur.

6.7 Costs of injuries

When the costs from the HEMS dataset were weighted to the national HES dataset, it was injuries to the lower limbs which dominated the cumulative cost of pedestrian injuries, accounting for double the cost of head injuries, and six times as much as the next most costly region injured.

This highlights one of the benefits of the cost model, as it can clearly distinguish between injuries that are the most frequent (such as head injuries), and injuries which are not as frequent but have a larger cost in terms of hospital-based recovery time (such as leg injuries).

The purpose of the weighting was to estimate the national cost of pedestrian injuries, at the same time removing the differences between the HEMS and the HES datasets. It is likely that the HEMS dataset contains pedestrians who are more severely injured than those in the HES dataset and who have a different injury distribution. In effect the weighting has used the proportion of days on the ward to days in intensive care for the pedestrians in the HEMS dataset, and weighted this proportion to the duration of stay of the pedestrians in the HES dataset. This means that the differences in the total duration of stay or injury distribution of the pedestrians in the HEMS dataset have no effect on the final results, which are calculated for the national population of pedestrian patients.

The results of the weighting suggest that pedestrian leg injuries should be prioritised over injuries to all other body regions. However, looking at individual injuries suggests that it is a combination of head and lower leg injuries which should be prioritised, especially the causes of contusions and haemorrhages in the brain and fractures of the lower legs.

There are a number of limitations to the costing model presented here. The first is associated with basing the model on the duration of stay in hospital alone, as this does not properly account for pedestrians who died after a short time in hospital. The HEMS and HES datasets also do not include pedestrians who died before they reached the hospital, although using this cost model these fatalities would have a cost of zero if they were included. The cost of fatalities needs to be added to the model in some other way. It is also difficult to estimate the cost of individual injuries, as the majority of pedestrians received more than one injury. This means that the cost of the individual injuries (and the cost of injuries by body region) cannot be combined to determine the cost for that pedestrian; there is not a linear relationship. Further, the model provides indicative costs which are consistent for all casualties, but does not include and sum the additional costs associated with different surgical procedures, outpatient clinic appointments, physiotherapy care or a more generic life impairment measure. Therefore, the costs given typically significantly underestimate the true health care costs.

Because the method of recording injuries in HES and HEMS differs, some assumptions have been made in order to use HES to scale the costing estimated from the HEMS dataset. HES does not include a measure of injury severity but it does record one injury as the "primary" injury. HEMS does record injury severity through AIS coding, but does not select a "primary" injury. In the weighting process, the frequency of "primary" injuries to each body region was used to scale the average cost of AIS 2+ injuries by body region determined from the HEMS data.

Because details of the vehicles are not included in the HES or HEMS data, these datasets alone cannot be used to investigate the cost of impacts with different types of vehicle (e.g. comparing old vehicles to new vehicles). However, these datasets could be linked in the future to national accident data such as that collected by the police, which would enable more detailed analysis to be performed. Indeed, some HES data has already been linked to police accident reports (Department for Transport, 2008).

The costing model, based on the duration of stay of pedestrians on the ward and/or in intensive care, is an example of one method which can be used to prioritise injuries using medical information. The costs of individual injuries could be refined if other information was included in the analysis, such as the operations and procedures performed on the patient while they were in hospital. The details of the operations and procedures were not available for both the medical datasets in this study, but the data is recorded and could be used in a future model. Costing road traffic injuries in a similar way has been carried out in the USA for car occupants (Miller, Romano, Zaloshnja, and Spicer, 2001), and is used when considering the cost-benefit of countermeasures designed to increase road safety.

The costing model presented in this paper is offered as an alternative to the willingness to pay models which are often used in the valuation of road traffic accidents (Hopkin and Simpson, 1995). While it does not include, for example, costs related to the patient's time off work, it is believed to be a good descriptor of the cost to the hospitals of treating pedestrian casualties. The cost of treatment should be considered when prioritising pedestrian injury prevention in the future, and can form part of other valuation methods to give a full picture of the cost of pedestrian injury.

6.8 Injury causation

From the police fatal files, a sample of 49 vehicle and pedestrian collisions were selected where the front of the car had impacted the pedestrian. The cars were categorised as "new" (registered in 2002 or later) or "old" (registered before 2002). The aim of the study was to investigate if the fatally injured pedestrians had different injury patterns when involved in collisions with the newer compared with the older cars. A working hypothesis was that EuroNCAP and/or the changing vehicle fleet could be influencing the injuries received by pedestrian fatalities. Further, given the introduction of EC Regulation 78/2009 it was considered important to document the current injury patterns and corresponding sources and mechanisms of fatal pedestrian injury, so potential future benefits could be benchmarked with respect to this sample.

The new and old sub-samples were compared with respect to the pedestrians' demographics and vehicle characteristics and no differences between the groups were identified. Due to the small numbers of pedestrians used for this analysis, no evidence was found that the differences between old and new vehicles were statistically significant. Therefore, this discussion details the findings and compares these to previous studies. It also highlights where the differences seen could arise from if further study was carried out and these differences were found to be significant.

European pedestrian protection legislation along with previous studies (Cuerden *et al*., 2007; Ashton and Mackay, 1979) have focussed on the protection of the pedestrians' legs and heads in impacts with cars. This analysis has highlighted the additional importance of thorax injuries, which are more common for the fatalities studied, more than leg injuries, particularly in impacts with new vehicles.

Overall it was found that 95% of the pedestrians in the study received AIS 2+ injuries to the head or neck. Previous studies have analysed pedestrian impacts focussing on comparing the injuries received in primary and secondary impacts. For example, Otte and Pohlemann (2001) found that only 59% of pedestrians in their study received head injuries. However, the sampling criteria in the Otte and Pohlemann (2001) paper included all injury severity pedestrians (not just fatalities), which indicates that in fatal pedestrian accidents head injuries are much more frequent. It is also understood that although this paper found head injuries to be most common for fatalities, in seriously injured pedestrians there will be a higher frequency of injuries to other body regions such as the lower limbs, resulting in impairment. It should also be noted that the analysis by Otte and Pohlemann (2001) was based on accident investigations carried out at the scene by a scientific team rather than a retrospective review of police reports and differences with respect to the information available and analysis techniques may contribute to some of these different findings. Also the small sample in this paper may have affected the results; further study would provide insight into whether the findings are significant.

Pedestrians struck by older cars received a lower percentage of AIS 2+ injuries in all body regions except for legs. This may be due to recent improvements in pedestrian leg protection design or technologies fitted to newer vehicles, but this is not proven. Pelvis, thorax and arm injuries demonstrated the largest difference between old and new car impacts with a much greater proportion of these injuries resulting from impacts with the new car group. Similar results were seen for AIS 3+ injuries, where only injuries to the abdomen were received in a greater proportion of impacts with old cars. The impacts with new vehicles resulted in the highest severity injury being mostly to the head with a high proportion of these being AIS 5 injuries, this proportion was much lower for the older car group. Thorax injuries were also a high severity group but the severity of the injuries was higher for the old vehicles. The reasons behind these findings are not fully understood, but could be related to different pedestrian impact kinematics associated with the newer vehicle design or due to the small numbers. The differing distributions between injury regions impacting areas of the new and old cars were thought to be associated with the changing geometry in the vehicle fleet, where newer cars were slightly taller and produced less focal loading on the legs, but rather distributed the initial impact between the legs, pelvis and abdomen. The heights of the pedestrians were not found to be statistically different.

Pedestrians who are fatally injured are likely to be in crashes with different characteristics to those who are less seriously injured, therefore it is difficult to say how representative these results may be of the population of pedestrian casualties, but the finding that the windscreen is the most frequent cause of serious head injuries has also been seen in pedestrian casualties, of all severities, recorded by the UK's On The Spot accident study (Cuerden *et al.*, 2007).

There were too few pedestrians with A-pillar strikes to analyse for old vehicles (only three), however for new vehicles it could be seen that windscreen strikes were more frequent for the more severe injuries (MAIS 4+) than A-pillar strikes, which is in contrast to previous studies. Ashton and Mackay (1979) and Cuerden *et al.* (2007) found that contact with the windscreen frame was more likely to result in serious injury than contact with the windscreen glass or top surface of the bonnet. Ashton also claimed that a reduction in the incidence of pedestrian head injuries could be expected if the vehicle exterior could be designed to reduce head contacts to the windscreen frame. However, the small sample presented in this paper should be borne in mind when interpreting these trends.

Ashton and Mackay (1979) found 60% of serious injuries to have resulted from vehicle impacts, the remaining 40% were from secondary impacts with the ground. Cuerden *et al.* (2007) found 32% of AIS 2+ head injuries to be due to impacts with the carriageway or footway. This study found that 13% of all the AIS 2+ injuries, and 12% of the AIS 2+ head injuries, were due to impacts with objects other than the vehicle, which is a much lower frequency than found in these previous studies. This is probably due to these previous papers collecting data at the scene in which objects other than the vehicle (e.g. carriageway, footway etc) could be more closely examined in order to see if any evidence of impact was here. This study used police fatal files which, while having good photographs of the vehicle damage, did not always have as much detail on the marks left at the scene.

For leg injuries resulting from impacts with older vehicles, 62% were MAIS 2 and 38% were MAIS 3, whereas with newer cars 47% were MAIS 2 and 53% were MAIS 3. This signifies that although the frequency of leg injuries has decreased, the severity of these injuries, at least for this small sample, has not changed and at worst has potentially risen. The European pedestrian protection legislation includes two tests, based on an impact of a leg with the front bumper, and the impact of a head with the bonnet. Interestingly, although the vast majority of the serious leg injuries in this study were caused by the front bumper, impacts with the windscreen are the most frequent cause of serious head injuries in both groups, and no head injuries were caused by the main surface of the bonnet at all, in either of the groups of vehicles. A large number of the serious leg injuries were caused by the area around the bonnet leading edge.

This study of police fatal files has presented evidence on the impact location for fatal pedestrian head injuries and finds that they are outside of the current consumer and impact test regulation strike zones. It should be borne in mind that the causes of all the injuries determined by the team of experts are informed judgements, the experts chose the source which seemed most likely to have caused the injury, however it is acknowledged that it is impossible to be 100% sure what caused every injury in this line of work. However, the investigation team reviewed old and new car impacts alike and so any bias would be consistent between the groups.

7 Conclusions and recommendations

This Insight Report has explored the frequency, causes and consequences of pedestrian road traffic accidents. The conclusions of this study are as follows:

- In Great Britain in 2008, pedestrian casualties made up 23% of reported deaths and serious injuries in road traffic accidents.
- Cars are by far the most frequent collision partner in pedestrian accidents, and are involved in over 80% of pedestrian accidents. However, a high proportion of pedestrian accidents with larger vehicles result in a fatal outcome for the pedestrian.
- Younger pedestrians are over-represented for serious casualties: approximately 20% of seriously injured casualties are aged 10-15 years. Older pedestrians are over-represented for fatal casualties. This highlights that pedestrian casualties are often the most vulnerable members of society.
- There is a relationship between the age of the pedestrian and the accident configuration. Children are most often involved in accidents where they have crossed from behind a parked car, or some other object that has obscured the view of the driver or pedestrian. Accidents involving pedestrian crossings, suicide, reversing vehicles and vehicles leaving the carriageway are more frequent when the pedestrian is an adult.
- A large proportion of pedestrians involved in road traffic accidents come from the most deprived areas. This is especially true for young child pedestrians. These areas are likely to be urban/inner city areas, where pedestrians have a high exposure to traffic.
- The risk of a pedestrian being killed at an impact speed of 30 mph is approximately 7%. Even though the *risk* of pedestrians being killed at 30 mph is relatively low, approximately half of pedestrian fatalities occur at this impact speed or below, due to the large number of pedestrian accidents that occur at these speeds.
- The most frequent injuries received by pedestrians in road traffic accidents are to the head and lower limbs. The rate of head injuries was greatest for young children due to their height.
- Using a cost model based on the duration of stay of the pedestrians in hospital, the most costly injuries were lower limb injuries, followed by head injuries. Injuries to the lower limbs accounted for double the costs of head injuries, and six times as much as the next most costly region injured.
- The study of 49 pedestrian fatalities enables the causes of their injuries to be determined. The majority of the severe leg injuries were caused by the initial impact between the pedestrian and the car bumper, or bonnet leading edge. The majority of head injuries were caused by impacts with the windscreen and surrounding frame, areas which are not covered in existing pedestrian protection legislation. A large number of severe thorax injuries were also seen for these pedestrians. The relationship between vehicle age and injury causation was explored, but no difference in causation was seen when new and old cars were compared. However, this may be because of the relatively small sample of cases.

The recommendations of this Insight Report are as follows:

- There is a need to monitor pedestrian casualty trends, in order to discern the effects of measures that have been introduced to protect pedestrians. These include reduced urban speed zones, and the 2009 European Regulation which covers pedestrian protection on vehicles.
- Consideration should also be given to monitoring other changes that may affect pedestrian accidents, including changing vehicle design and vehicle power. A larger number of small city cars, with relatively steep bonnets and steep windscreens, could change the injury distribution of pedestrian casualties. Also, the introduction of quiet electric vehicles has the potential to make some pedestrian accident configurations more likely.
- A better understanding is required of what exactly is meant by “failed to look properly”. This was by far the most frequent contributory factor recorded for both pedestrians and drivers involved in pedestrian accidents, and addressing this would give the largest benefit in reducing pedestrian accidents.
- Any countermeasure which is designed to protect pedestrians should consider the demographics of the pedestrian population. This report has shown that younger and older people have different types of pedestrian accident, which result in different patterns of injury. This means that different interventions may be required for different groups, for example modifications made to vehicle design as part of the pedestrian protection regulation may reduce injuries for young pedestrians but not for older pedestrians, or vice versa.
- There is a need for more feedback to other important stakeholders in traffic accidents, such as emergency care professionals. The monitoring of changes in injury patterns can form the basis of better evidence to inform diagnosis and treatment of injuries sustained in these accidents.

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Glossary of terms and abbreviations

Head

Diffuse brain injury – an injury to the brain which does not occur in one specific spot in the brain.
Intracranial injury – any injury which occurs within the skull (Oxford University Press, 1998).
Subdural haemorrhage – a form of traumatic brain injury in which blood gathers between the dura (the outer protective covering of the brain) and the arachnoid (the middle layer or the meninges). Subdural bleeding usually results from tears in the veins that cross the subdural space (Oxford University Press, 1998).

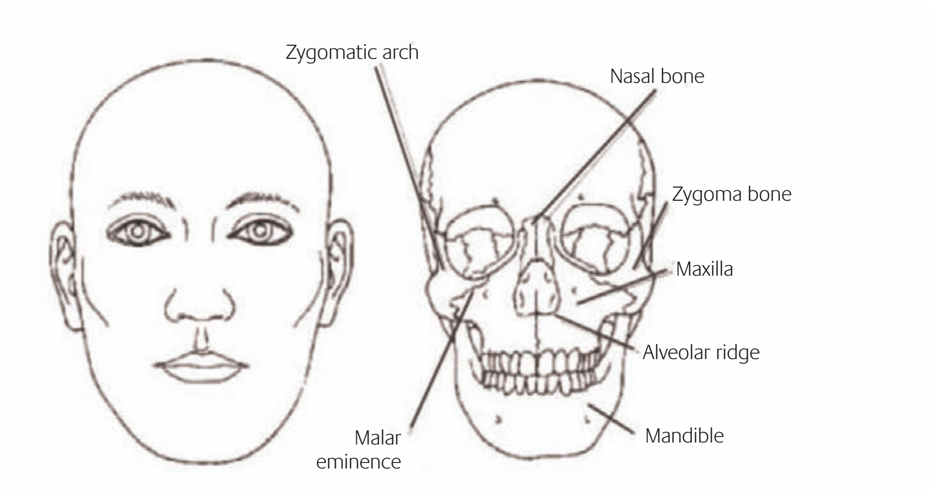

Figure G.1 The bones of the face (TARN, 2008)

Spine

Cervical spine – consists of the cervical vertebrae which are the seven bones making up the neck region of the backbone. The first vertebra supports the skull which rotates on the second vertebra, enabling the head to turn (Oxford University Press, 1998) (see Figure G.2).
Lumbar spine – consists of the lumbar vertebrae which are the five bones of the backbone that are situated between the thoracic vertebrae and the sacrum, in the lower part of the back (Oxford University Press, 1998) (see Figure G.2).

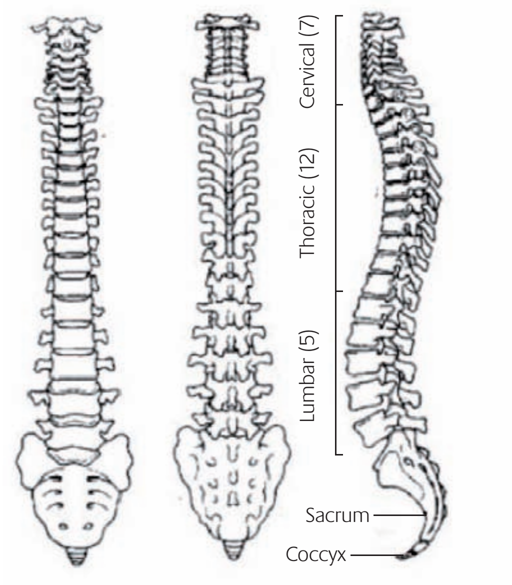

Figure G.2 The spine (TARN, 2008)

Limbs

Acetabulum – one of the two deep sockets either side of the hip bone where the head of the femur fits.

Femur (or thigh bone) – a long bone between the hip and the knee. The neck of the femur is the narrowed top end of the bone which carries the head of the femur. The shaft of the femur is the long central length of the bone (Oxford University Press, 1998) (see Figure G.3).

Humerus – the bone of the upper arm. The head of the humerus articulates with the scapular at the shoulder joint, and the lower end articulates with the ulna and the radius of the forearm (Oxford University Press, 1998) (see Figure G.3).

Malleolus – either of the two protuberances on each side of the ankle: the lateral malleolus at the lower end of the fibula or the medial malleolus at the lower end of the tibia (Oxford University Press, 1998).

Pelvis – the bony structure formed by the hip bones, sacrum and coccyx that protects the organs of the lower abdomen and provides attachment for the bones and muscles of the lower limbs.

Pertrochanteric fracture – a fracture of the great trochanter of the femur, which is at the top of the femur near the head.

Pubis – a bone which forms the lower front part of each side of the hip bone (Oxford University Press, 1998) (see Figure G.3).

Radius – the outer and shorter bone of the forearm. It partially revolves about the ulna, permitting pronation and supination of the hand. The head of the radius articulates with the humerus. The lower end articulates with the wrist bones and ulna (Oxford University Press, 1998) (see Figure G.3).

Subtrochanteric fracture – a fracture of the femur between the lesser trochanter (which is at the base of the greater trochanter) and a point approximately 5 cm further down the femur.

Tibia (or shin bone) – the inner larger bone of the lower leg. The shaft of the tibia is the long central section (Oxford University Press, 1998) (see Figure G.3).

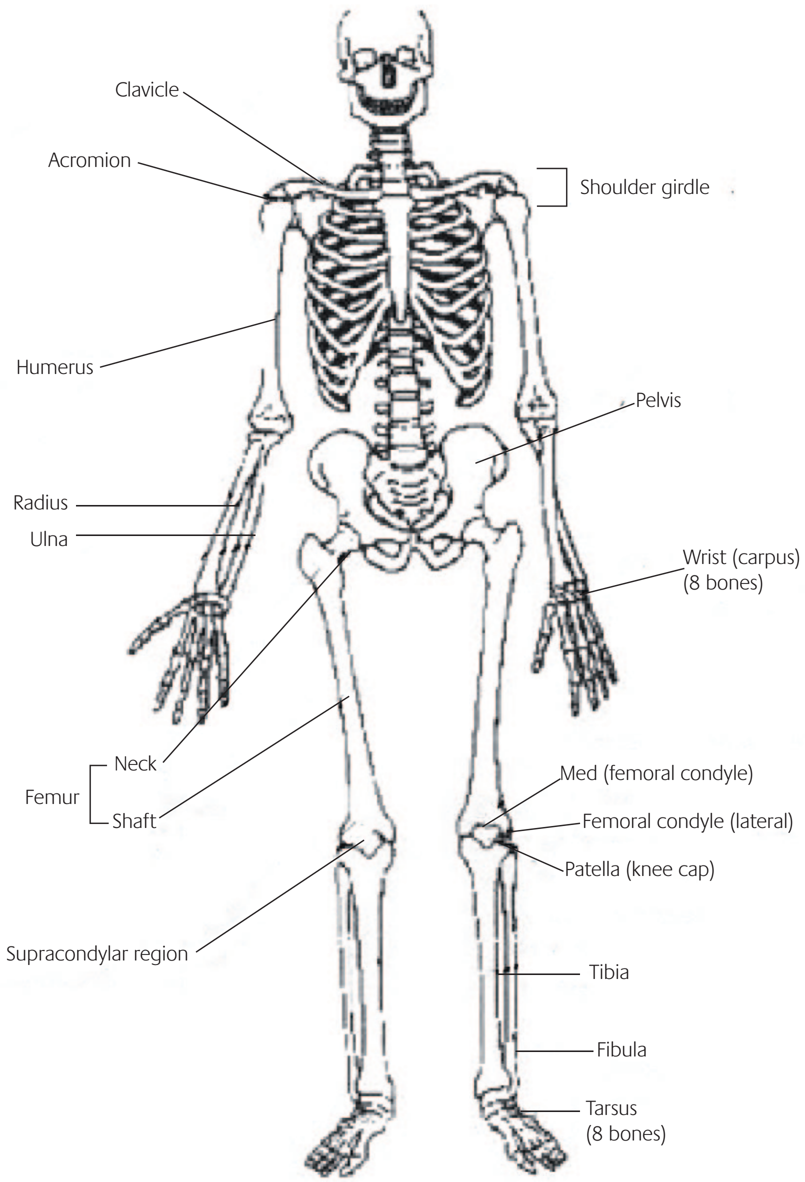

Figure G.3 The skeleton (TARN, 2008)

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This Insight Report explores the characteristics of pedestrian road traffic accidents, and the injuries received by the pedestrian casualties. These are often the most vulnerable members of society, so an understanding of the causes and consequences of pedestrian accidents is important as the demographics of the population changes in the coming years. Recent changes in vehicle design, including the recent legislation on pedestrian protection, may also affect the consequences of pedestrian accidents.

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