A REVIEW OF THE CAUSES OF FATAL PEDESTRIANS’ INJURIES RESULTING FROM COLLISIONS WITH CAR FRONTS – COMPARING VEHICLES REGISTERED IN 2002 OR LATER WITH EARLIER MODELS.

R Cookson, R Cuerden, D Richards, J Manning
TRL, UK

ABSTRACT

This paper looked at a relatively small sample of Great Britain’s car accidents which resulted in pedestrian fatalities. 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) and “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.

It was found that 95% of fatally injured pedestrians received head or neck injuries when impacted by cars. Pedestrians struck by older cars received a lower percentage of AIS2+ injuries in all body regions except for legs. 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. Most AIS2+ head injuries were due to strikes to the windscreen both for old and new cars, but it was also found that strikes to the windscreen result in higher MAIS to the head in new car impacts than old.

It should be noted that the sample of 49 pedestrians is a relatively small sample size, however this paper 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.

Keywords: Pedestrians, injuries, accident investigations, bumpers, windshields

IN 2007 THERE WERE 646 PEDESTRIAN DEATHS ON BRITAIN’S ROADS. There were also 6,924 seriously injured pedestrian casualties. These killed and seriously injured (KSI) pedestrians were the largest group of casualties after car occupant, making up 23% of the KSI casualties in Great Britain (Department for Transport, 2008).

This paper focuses on pedestrian road traffic casualties as, when compared to car occupants, the injury epidemiology and characteristics of pedestrians are less well understood. This is because of the lack of large pedestrian-focused accident studies. In addition to this, the recent European pedestrian regulation (European Parliament, 2003) has or will influence the design of cars, so it is important to investigate the characteristics of pedestrian impacts with these newer cars and compare them to impacts with older vehicles. To improve vehicle safety design, engineers and legislators need to understand what are the causes and mechanisms that result in pedestrian injury.

This paper looked at a relatively small sample of Great Britain’s car accidents which resulted in pedestrian fatalities. 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) and “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 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 types of vehicles, 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 types in September 2010 and new vehicles by September 2015. However, Phase two of the European legislation was revised; the revised Phase two was included in Regulation (EC) No 78/2009, which was published in February 2009. This will supersede 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).

Phase one of the EC Directive and Phase one of the EC Regulation involve lower legform to bumper tests (for bumper heights \( \leq 500 \text{mm} \), otherwise choice of upper leg impactor or lower leg impactor for high bumpers). Phase one also includes bonnet top headform impact tests. Normally 18 tests are performed at 35kph using a child/small adult headform. The test area corresponds to the combined child and adult areas of the Phase two tests.

Phase two of the original EC Directive has now been superseded by the Phase two in the EC Regulation. Currently, no vehicle is required to pass Phase two. However, due to car 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. In addition, there is the inclusion of a ‘reduced protection zone’ which can be applied to the vehicle bumper which must not exceed a (combined) width of 264mm.

For the headform impact tests, two impactors are used at 35kph. 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 one headform test. An upper leg to bonnet leading edge test (similar to Phase one) is performed but is again only for monitoring purposes.

Pedestrian protection test procedures were not enforced by legislation in Europe until 2005 and until this point it was only manufacturers’ duty of care and 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 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, because fractures of the tibia alleviate some of the load in the knee. Tibia fractures are in most cases easier, cheaper and quicker to recover from than knee ligament injuries.

It is clearly important for the test procedures to be sufficiently valid, i.e. to take account of the range of impacts found in the real world, as manufactures will design their vehicles to meet the testing requirements. At present, these test procedures do not represent the range of impact speeds found in the real world or the full range of pedestrian physiques. Additionally, the test procedures define a limited test area on the car. It is not known whether this test area is adequate or whether, for example, impacts outside this tested area are more severe. It is certainly possible that this might be the case where:

- Changes in design have taken place to compensate for reduced stiffness within the tested area (such as the windscreen and A-pillars being moved forward, and potentially made stiffer);
- Areas outside the testing area are now impacted more severely or more frequently because of changes to the pedestrian’s kinematics resulting from vehicle stiffness or geometry changes;
• Changes to the pedestrian’s kinematics could also make impacts to the road surface more injurious. Although unknown, it is at least possible that cars being developed could therefore be failing to protect pedestrians as much as they could.

It is understood that in the Regulation 78/2009 the bonnet leading edge will be tested for monitoring purposes only; there are no mandated acceptance criteria, only target values. It should be noted that EuroNCAP will continue to test this zone and, with the introduction of the new whole vehicle rating system (combined score for adult and child occupant and pedestrian scores), this may drive safety improvements to this zone.

While injuries caused by contact with the bonnet leading edge are believed to have reduced in recent years (Cuerden et al. 2007), this may in part be because severe bumper impacts are forcing the pedestrians’ legs to move forward rapidly, reducing the impact with the bonnet leading edge structure. The study should investigate whether safer bumpers required by Phases 1 and 2 have resulted in a change to the severity and/or pattern of injuries caused by the bonnet leading edge.

In some cases, for example vehicles perhaps not expected to be tested by EuroNCAP but still within the Regulation constraints, manufacturers may opt to stiffen the bonnet leading edge area to reduce the knee bending angle obtained in the legform test. The bonnet leading edge is one area where the level of safety provided by manufacturers during Phase 1 could vary significantly.

Previous studies in this area (Cuerden 2007 and Ashton 1979) have highlighted the importance of head and leg impacts with cars which has led to the tests above being focussed on these body regions. This paper will identify body regions injured and the regions of the cars which caused these injuries. Cuerden et al. (2007) and Ashton (1979) found that contact with the window frame was more likely to result in a serious head injury than contact with the windscreen glass or top surface of the bonnet. Ashton (1979) found 60% of serious injuries to have resulted from vehicle impacts and 40% were impacts with the ground, whereas Cuerden et al. (2007) found 32% of AIS2+ head injuries to be due to impacts with the carriageway or footway. Otte (2001) found 36% of pedestrians to have suffered secondary impacts located on the head, a similar result. These previous studies, however, did not focus on fatalities as is the case in this paper, so direct comparisons are difficult to draw.

The sample of pedestrian casualties in this paper was obtained from Police fatal files. 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. The fatal reports highlight how and why accidents occur and provide the opportunity to learn from these tragic events, so that we can work towards preventing future incidents. TRL cooperates with Police forces in England and Wales and holds an archive of over 34,000 Police fatal accident reports, of all accident types. Each report is given a unique TRL number which is linked to its corresponding British road casualty injury accident report, commonly referred to as the STATS19 database. 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.

METHODOLOGY

Police fatal files were examined 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 which occurred in 2000 or later. There were 123 cases which met these criteria, 49 were randomly selected which were found to have good photographs of the vehicle
damage and post mortems, which were required for the analysis. This resulted in a random sample of 49 vehicles which struck 49 pedestrians.

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 using the Abbreviated Injury Scale (AIS) 2005 Revision (AAAM, 2005). In the AIS system, each injury description is assigned a unique six digit numerical code in addition to the AIS severity score. MAIS denotes the Maximum AIS score of all injuries sustained by a particular occupant.

It is well recognised that casualties with multiple injuries have a more difficult and challenging recovery period and a higher mortality rate. An alternative measure for the assessment of multiple injuries is the Injury Severity Score (ISS). The ISS is the sum of the squares of the three highest AIS codes in each of the three most severely injured ISS body regions. The six body regions used for ISS are:

- Head or neck
- Face
- Chest
- Abdominal or pelvic contents
- Extremities or pelvic girdle
- External

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 of a child was not examined in order to avoid further distress to the family of the deceased. Some AIS codes are uncodeable using post mortem records alone such as loss of consciousness. The differences between AIS coding using post mortems and clinical records was shown by Streat (1989) who found that the most major differences between clinical record deduced AIS scores and post mortem deduced AIS scores (two AIS grades or more) occurred in the head region. Injury scoring based on physiological features (e.g. coma) occurred without an anatomic injury of similar AIS grade, or in the thorax region where treatment had destroyed evidence of injury, or injuries were not discovered until post mortem. In an ideal situation, the post-mortems would have been specifically guided by the needs of injury scaling and with a full knowledge of the injuries recognised and treated clinically.

The files were reviewed by a multi-disciplinary team of researchers, including medics, engineers and physicists. 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.

The vehicles involved in collisions with pedestrians were split into 70 zones, shown in Figure 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.
RESULTS
This analysis of police fatal accident files held by TRL concentrated on pedestrian collisions with both old and new cars.

Figure 2 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 in this paper as “new” and “old” cars respectively. These two groups of vehicles were chosen as they split the sample into two relatively equally sized groups, the newer of which are likely to have been more influenced by EuroNCAP and EEVC WG17 (European Parliament, 2003) factors discussed previously.

It should be noted that the sample of 49 pedestrians is a relatively small sample size, however this paper 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 some of the following analysis a chi-squared test is performed to see whether the differences between the “old” and “new” vehicles are statistically significant. A model is created using the combination of the two distributions in question, and the null hypothesis is that the two distributions are the same as the model. If the probability (p) of the null hypothesis being true is below 5% (p<0.05), the differences are said to be statistically significant. Where chi-squared tests are used, there is a statement as to whether the value of p was above or below 0.05. In all of the analysis in this report, 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 accounting for 31% of all the vehicles each.

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 6 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 3. It can be seen that there was a higher proportion of young females in the new vehicle group than the old with a lower proportion of those in the middle age group.

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 5 collisions in which the impact speed could not be calculated. The average of the minimum and maximum speeds was calculated and Figure 4 shows the cumulative average impact speed for the remaining 44 vehicles in the sample. The 50th percentile 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, no evidence was found that there is a statistical difference.
Table 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. There was no evidence of a statistical difference (p>0.05).

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

Figure 5 shows that the most frequently AIS2+ injured regions in the sample of fatal pedestrian accidents was the head and neck, 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 of the two groups, 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 head (including neck) region showed the smallest difference of only 1% of pedestrians. 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 6 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 that there is a statistical difference.
Figure 6. Percentage of pedestrians with at least one AIS 3+ injury to a body region

Figure 7 shows that overall the injury severity score of pedestrians struck by older cars was lower than for those struck by newer cars. Fifty percent of pedestrians struck by older cars received an ISS of 22 or less compared to 50% of those struck by newer cars had an ISS of 29 or less. The average ISS for pedestrians hit by new cars was 35 compared to 29 for old cars.

The locations with respect to body region of the maximum AIS for each pedestrian were calculated and are shown in Table 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 the 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 3 of the 22 struck by older cars.
Table 2. Location of maximum AIS for each pedestrian

<table>
<thead>
<tr>
<th>Vehicle Category</th>
<th>Body Region</th>
<th>MAIS</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>2</td>
</tr>
<tr>
<td>OLD</td>
<td>Head or neck</td>
<td>3</td>
</tr>
<tr>
<td></td>
<td>Legs</td>
<td>2</td>
</tr>
<tr>
<td></td>
<td>Pelvis</td>
<td>1</td>
</tr>
<tr>
<td></td>
<td>Thorax</td>
<td>0</td>
</tr>
<tr>
<td>NEW</td>
<td>Abdomen</td>
<td>1</td>
</tr>
<tr>
<td></td>
<td>Head or neck</td>
<td>1</td>
</tr>
<tr>
<td></td>
<td>Legs</td>
<td>0</td>
</tr>
<tr>
<td></td>
<td>Pelvis</td>
<td>1</td>
</tr>
<tr>
<td></td>
<td>Thorax</td>
<td>0</td>
</tr>
<tr>
<td></td>
<td>Arm</td>
<td>1</td>
</tr>
</tbody>
</table>

The following sections break down the injuries by body region and show the areas of the vehicle that caused at least one AIS2+ 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.

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 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 3. Height distribution of the pedestrians

<table>
<thead>
<tr>
<th>Height (cm)</th>
<th>Old vehicles</th>
<th>New Vehicles</th>
</tr>
</thead>
<tbody>
<tr>
<td>Average</td>
<td>168</td>
<td>166</td>
</tr>
<tr>
<td>Maximum</td>
<td>188</td>
<td>196</td>
</tr>
<tr>
<td>Minimum</td>
<td>142</td>
<td>135</td>
</tr>
</tbody>
</table>

Figure 8 and Figure 9 show the percentage of pedestrians who had an AIS2+ head injury caused by each zone on the car. The most frequent impacts were those to the windscreen which accounted for AIS2+ head injuries to 10 (37%) of the pedestrians hit by new cars and 12 (55%) of the pedestrians hit by old cars. Eight (30%) of the pedestrians received AIS 2+ injuries to their heads from the A-pillars when struck by new cars compared with only three (14%) of those struck by old cars.
Table 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 3 of these impacts causing AIS2+ injuries for pedestrian impacts with old cars, therefore the results were less reliable. It can also be seen that for new vehicles, MAIS4+ injuries to the head were more frequent in windscreen impacts than A-pillar impacts.

<table>
<thead>
<tr>
<th>Vehicle Group</th>
<th>Impact Location</th>
<th>MAIS of Head and Neck</th>
<th>Sample Size</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>2</td>
<td>3</td>
</tr>
<tr>
<td>Old</td>
<td>Windscreen</td>
<td>25%</td>
<td>17%</td>
</tr>
<tr>
<td></td>
<td>A-pillar</td>
<td>0%</td>
<td>33%</td>
</tr>
<tr>
<td>New</td>
<td>Windscreen</td>
<td>10%</td>
<td>20%</td>
</tr>
<tr>
<td></td>
<td>A-pillar</td>
<td>13%</td>
<td>25%</td>
</tr>
</tbody>
</table>

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 AIS2+ windscreen head strikes compared to 75%).

Figure 10 and Figure 11 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.
The zones which caused one or more AIS 2+ injuries to a pedestrian’s left or right leg were then investigated. 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 MAIS2, and 38% were MAIS3 whereas with newer cars 47% were MAIS2 and 53% were MAIS3. However, when tested using a chi-squared test, no evidence was found that this difference is significant for this sample.

Figure 12 and Figure 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 14 and Figure 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.

DISCUSSION
This paper looked at a relatively small sample of Great Britain’s car accidents which resulted in pedestrian fatalities. 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) and “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, 2007 and Ashton, 1979) have focussed on the protection of the pedestrians’ legs and heads in impacts with cars. This paper 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 (2001) found that only 59% of pedestrians in their study received head injuries. However, the sampling criteria in the Otte (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 (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 or just by chance.
Pedestrians struck by older cars received a lower percentage of AIS2+ 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 AIS5 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. This difference in injuries to most body regions also corresponds with the higher average ISS for the pedestrians struck by newer vehicles (34.8 compared to 28.8). 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.

When split down by the region of the vehicle impacted, it was found that the 22 pedestrians struck by old cars had a higher proportion of windscreen strikes causing AIS2+ head injuries than the 27 pedestrians struck by new cars, whereas new cars had a higher proportion of A-pillar strikes causing these injuries. This may be due to the changes in vehicle windscreen position and/or design, with the windscreens on modern cars often being larger and sweeping further forwards. 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 3), however for new vehicles it could be seen that windscreen strikes were more frequent for the more severe injuries (MAIS4+) than A-pillar strikes, which is in contrast to previous studies. Ashton (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 born in mind when interpreting these trends.

Ashton (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 AIS2+ head injuries to be due to impacts with the carriageway or footway. This study found that 13% of all the AIS2+ injuries, and 12% of the AIS2+ 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, whilst 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 MAIS2, and 38% were MAIS3 whereas with newer cars 47% were MAIS2 and 53% were MAIS3. 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 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 project 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.

CONCLUSIONS

Forty nine UK Police fatal files were used for this analysis, which had both post mortems and photographs of vehicle damage. Of these, 22 pedestrians were in impacts with a vehicle registered before 2002 and 27 registered in 2002 or later. 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. Further work stemming from this paper would be to extract and analyse many more fatal files in order to increase the statistical power of the analysis and validate the results presented. The conclusions of the analysis are as follows:

- 95% of the fatally injured pedestrians received head or neck injuries when impacted by cars
- The pedestrians struck by older cars received a lower percentage of AIS2+ injuries in all body regions except for legs
- 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 for this sample.
- The ISS for the pedestrians struck by older cars was also lower
- Most AIS2+ head injuries were due to strikes to the windscreen both for old and new cars, but it was also found that strikes to the windscreen result in higher MAIS to the head in new car impacts than old.
- Leg injuries had reduced in number from old car impacts to new, however, the severity of these injuries was greater in new car impacts.

It should be noted that the sample of 49 pedestrians is a relatively small sample size, however this paper 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.

ACKNOWLEDGEMENTS

This paper uses accident data from the Police fatal accident reports which are archived and stored for research purposes by a project funded by the Department for Transport.

REFERENCES


