PEDESTRIANS AND THEIR SURVIVABILITY AT DIFFERENT IMPACT SPEEDS

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ASTRACT

The UK's On The Spot (OTS) accident data collection project started in 2000 and continues to investigate 500 crashes per year. Investigations are undertaken minutes after the collision has occurred to gather all the perishable information. At the time of writing over 3,000 crashes involving all road users and all injury severities have been examined. The OTS database provides a unique insight into the prevailing factors that have been seen to cause crashes and the associated human injuries and vehicle and infrastructure damage that have been witnessed by the crash investigation teams.

The research objective of this paper is to outline the pre and post-crash circumstances of 108 pedestrian crashes. The nature of the events that led to the collision, including the respective travelling speeds, time and distance from the moment the impact was inevitable are described. The information provided can be used to begin to outline the potential effectiveness of future crash mitigation systems. Further, the impact speeds are correlated to the injuries the pedestrians suffered with respect to the impact partner. Lower limb and head injuries are highlighted to be the most frequently injured body regions. The risk of injury for pedestrians with respect to the cars' speed at the point of impact is outlined and comparison made with the literature.

The small sample size is a limitation to the work, which has not at this stage been proven to be representative of the UK pedestrian accident population. Further, the nature of real world crash investigation means that some of the calculated speed values have reasonably large ranges. However, the work does offer an up to date review of the risk and type of injury versus impact speed for modern vehicles. In addition, the study starts to describe the in-depth pre-crash circumstances witnessed in real life crashes.

INTRODUCTION

Significant numbers of pedestrians are injured or killed as a result of being struck by motor vehicles every year. The relative importance of pedestrians with respect to all traffic casualties varies between different countries, but typically the most common crash scenario involves them being struck by the front of a passenger car. One major factor that influences pedestrian injury outcome during a collision is the vehicle speed at the point of impact. This study provides a comparative review of real world casualty injury severity for pedestrians who were struck by the front of a car with respect to the speed at impact.

BACKGROUND

Vehicle speed affects both the risk of an accident and the associated injury severity. It has been observed that a reduction of the speed limit on a road from 60 kph to 50 kph produced a 20 % drop in pedestrian accidents, and a 50 % drop in pedestrian fatalities [1]. Also, pedestrian accidents are known to occur at a wide variety of speeds [2], although the majority (about 85 %) are believed to be below 50 kph [3]. Pedestrians are usually hit from the side, and are 3 to 4 times more likely to be crossing the path of the vehicle than travelling in a parallel direction to it. Cases where the vehicle runs over the pedestrian (where the wheels travel over the pedestrian as they lie in the road) are rare, with estimates varying between 2 % and 10 % [4] of pedestrian casualties.

The body parts with the highest risk of injury (frequency x severity) for a pedestrian struck by a vehicle are the head, followed by the lower extremities, the thorax, and the pelvis [4]. For non-fatal injuries, the lower extremities have been seen as the most frequently injured. These injuries tended to be to the knee ligaments for impact speeds around 20-30 kph, and to be fractures for accidents around 40 kph [5].

The head is often subject to two impacts, the first with the car itself, and the second with the ground as the pedestrian is thrown from the car. In relation to the relative severity of these two impacts, the literature is divided. Some observe that the primary impact (with the car) is the most severe impact [4]. This is in line with papers suggesting that the injuries caused by secondary impact are fewer and less serious than those caused by primary impact [6]. However, others claim that the secondary impact is often a source of injury comparable to the primary impact [3].

Euro NCAP undertakes pedestrian sub-system impactor tests that are designed to rate new car models on the protection they offer to pedestrians in a frontal impact. In order to produce repeatable and scientific measurements leg forms and head forms are used to represent the pedestrian's associated body regions. The leg and head forms are projected towards the vehicle at 40 kph. The leg forms impact with the bumper and the bonnet leading edge and the head forms strike the bonnet at a variety of locations. The impactors are instrumented and the resulting measurements are used to predict the risk of injury.

While speed is certainly a factor directly linked to the severity of injury during pedestrian-vehicle collisions, other factors also come into play, making a pure assessment of the effects of speed very difficult. For example one study has shown that a long bonnet on a car reduces the injury risk of pedestrians in collision with that car [4]. This difficulty is exacerbated by the varied nature of pedestrians, who will be of all ages, and have very different biomechanical tolerances [2]. As people age their biomechanical strength decreases leaving them more vulnerable to injury for a given loading condition.

For several reasons, including those noted above, it is impossible to predict solely from the speed of an accident what the injury outcome of a given pedestrian will be. Fatal accidents have occurred at very low speeds, under 20 kph and as low as 12 kph; and slight injuries have been seen at much higher speeds (above 40 kph) [2] [4]. However, it is possible to identify boundary speeds, where the proportion of accidents changes from being mainly slight accidents to mainly severe accidents, and where the proportion changes from mainly survivable accidents to mainly fatal accidents.

In 1979 these boundary speeds were observed by Ashton and Mackay as being 30 kph for the transition from mostly slight to mostly severe (AIS 2+), and between 50 and 60 kph for the transition from mostly survivable to mostly fatal [2]. Ashton and Mackay determined the impact speed distribution of cars involved in pedestrian accidents where the pedestrian was contacted by the front of the car. This data was taken from at-the-scene studies at the Accident Research Unit, University of Birmingham. They weighted the data so it matched the proportions of slight, serious and fatal casualties seen in the national UK data.

The causes of the pedestrian injuries were also discussed by Ashton and Mackay. The at-the-scene studies showed that contact with the vehicle was responsible for more life-threatening or fatal head injuries than contact with the ground, and also that the windscreen frame was more likely to give a serious head injury than contact with the windscreen glass or the bonnet. There were other trends in the type of injuries suffered: head injuries were the most frequent injury sustained by those having non-minor injuries, with leg injuries being the second most common. The likelihood of injury for all the body regions increased with injury severity.

Their work has been used in the "Think! Road Safety" campaign by the Department for Transport, and is also a good basis for comparison with the results of this report. With changes in medical technology, population demographics and vehicle design, the boundary speeds, causes and distribution of injuries may now have changed.

METHOD

OTS Methodology

The On-The-Spot (OTS) Accident Data Collection Study has been developed to overcome a number of limitations encountered in earlier and current research. Most accident studies (such as the UK Co-operative Crash Injury Study, CCIS) are entirely retrospective, in that investigations take place a matter of days after the accident and are therefore limited in scope to factors which are relatively permanent, such as vehicle deformation and occupant injuries. They do not, in general, record information relating to evidence existing at the crash site, such as post-impact locations of vehicles, weather and road surface conditions, nor do they consider events leading up to the accident, such as the driving conditions encountered as the protagonists approached the crash site and their behaviour. It is these factors which give an insight into why the accident happened. The police, who do attend the scenes of accidents while such "volatile" data are still available to be collected, tend to have other priorities, such as ensuring the injured receive help, clearing the scene to restore the flow of traffic and looking for indications that any of the parties involved has broken the law.

The philosophy of the OTS project was to put experienced accident researchers at the crash scene at the same time as the police and other emergency services. The Study is thus still retrospective, in that the accident has already happened, but the timing is such that it should be possible to gather information on the environmental and behavioural conditions prevailing just before the crash. This provides valuable in-depth data on the causes as well as the consequences of crashes, and allows countermeasures to be developed in the fields of human behaviour and highway engineering as well as vehicle crashworthiness. This is potentially a major improvement on the data currently available from other studies. A study of this type had not been conducted in the UK for over 20 years, and comparison of the results of the current study with those of the previous one should provide interesting insights into the changes which have taken place over that period.

The Study involves two teams, from the Vehicle Safety Research Centre at Loughborough University (VSRC) and the Transport Research Laboratory Limited (TRL), working in close co-operation to produce a joint dataset. Work on the development of the Study design and procedures began in 1998. Protocols were developed to be consistent with recent international activities. These include the EC proposals for the development of a Pan-European Accident Database based on recommendations from the Standardisation of Accident and Injury Registration Systems (STAIRS) project.

Funding for the project came from the Road Safety Division at the Department for Transport and from the Highways Agency. Full data collection began in 2000 with a requirement to collect detailed information on 500 accidents per year. This was a large and complex activity, involving close collaboration between two geographically remote research teams operating from TRL in Berkshire and VSRC in Nottinghamshire. Both teams developed the project using common protocols and liaison techniques with the emergency services, hospitals, HM Coroners and local authorities and including routine technical links with the expertise available at the two institutes.

The Study has seen a very close working relationship between the research teams and their respective local police in Nottinghamshire and Thames Valley. This link was strengthened by the inclusion of a serving police officer on each team, which provided a secure, direct and reliable link with the local police command and control systems, thus ensuring immediate crash notifications. Response vehicles, fitted with blue lights and driven by seconded police officers, were used to transport each research team safely to the scene. In this way it was possible to cover a larger area than in previous studies. The response technique ensured that the combination of a relatively large area and increased traffic densities on modern roads allowed larger samples of crashes to be investigated than were attained in some earlier studies.

Given the attention to detail in establishing the necessary infrastructure, the well designed sampling plan and conformity to common investigation protocols, the DfT/HA OTS project provides an example of “best practice” in this field. As far as the authors are aware, no other country is systematically collecting on-scene data, to a pre-defined sampling plan and with such effective co-operation from all relevant public services contributing to the necessary input data.

It takes many years to establish useful databases and it is essential to have continuity to gain the best value from the database over the long term. The OTS project has two main strengths, compared with more conventional studies. The first is having access to volatile scene data including transient highway factors and climatic conditions, which are particularly important for determining accident circumstances, especially when investigating vulnerable road user accidents. The second is the ability to interview witnesses at the scene, thus gaining an insight into behavioural characteristics, and how these may have been influenced by the transient factors referred to above.

Terminology and Definitions of Key Variables

Impact Speed - The collision or impact severity is determined by the OTS investigation team. Wherever possible, physical scene evidence is used to derive estimates of the speed of the vehicle at the point of impact. These techniques include mathematical reconstructions based on the trace marks which vehicle tyres leave on the road surface due to heavy braking and evaluation of the pedestrians’ throw distance correlated to the probable impact speed.

Often there is very little physical evidence either on the road surface or vehicle that can be used to calculate an impact speed. Sometimes the only evidence of pedestrian impact with the vehicle are faint cleaning marks on the bumper or bonnet surface. In such cases it is still possible to estimate impact speeds, but the level of accuracy is clearly lower. The OTS team collates information from witnesses, crash participants and the characteristics of traffic flow along with other scene related information to validate and help inform any vehicle to pedestrian impact speed measures.

Police Injury Severity - The casualties’ injury severity is classified by Road Casualties Great Britain (RCGB) [7] and by OTS according to the UK government’s definitions of Fatal (Killed), Serious or Slight.

‘Fatal’ injury includes only those 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 of bone
- 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’ injuries are:

- Sprains, not necessarily requiring medical treatment
- Neck whiplash injury
- Bruises
- Slight cuts
- Slight shock requiring roadside attention

Abbreviated Injury Scale (AIS) - The OTS casualties’ injuries and characteristics (gender, age, height, weight etc.) are obtained from police reports, questionnaires, hospital records or HM coroner reports depending on the casualties’ injury severity. The injuries sustained are coded using ‘The Abbreviated Injury Scale (AIS) 1990 Revision’ (Association for the Advancement of Automotive Medicine, AAAM).

Each injury description is assigned a unique six digit numerical code in addition to the AIS severity score. The first digit summarises the body region; the second digit identifies the type of anatomical structure; the third and fourth digits identify the specific anatomical structure or, in the case of injuries to the external region, the specific nature of the injury; the fifth and sixth digits identify the level of injury within a specific body region or anatomical structure. Finally, the digit to the right of the decimal point is the AIS severity score. This study specifically uses the AIS code for the body region injured and the AIS severity score. The body regions injured are classified by:

- Head
- Face
- Neck
- Thorax
- Abdomen
- Spine (cervical, thoracic and lumbar)
- Upper Extremity
- Lower Extremity
- Unspecified

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 1.

Table 1.
Possible values of AIS

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

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.

HAIS denotes the highest AIS score of all injuries to a given body region sustained by an occupant. It is a single number that attempts to describe the seriousness of the injuries to a given body region suffered by that occupant.

The AIS system therefore allows injuries to be coded by their type and severity in terms of threat to life. In OTS, the injuries are then correlated with the associated vehicle damage to try to determine the ultimate cause of each individual injury.

The research undertaken by Ashton and Mackay used an earlier version of the AIS dictionary (1976 Revision). In summary the two dictionaries can not be directly compared for specific injuries, but like the AIS 1990 Revision, this version had six injury scores per injury ranging from 1 to 6. There were however, far fewer injury descriptions and the overall evaluation was much simpler than that documented later in AIS 1990. The severities of some individual injuries have also changed between the two versions, with some now having a higher AIS severity score, but others a lower score. Therefore, direct comparisons between Ashton and Mackay are not necessarily ‘like by like’ for the different AIS scores for the body regions injured.

OTS Sample Selection

OTS crashes involving pedestrians were selected and further filtering applied to identify cases with all the pertinent data available. Each case was reviewed in detail and where appropriate enhancements were made to the information available with respect to the injury severity, type and causation and the vehicle impact speed. The case reviews were undertaken by researchers working at the VSRC and TRL. The work was coordinated to ensure harmonisation between the two research centres and a common database was populated. All OTS crashes involving pedestrian casualties that were available in July 2006 were reviewed.

A separate database was created from the data for the use of this project, including all the details which would be required for a study of pedestrian casualties. This consisted of data on 175 pedestrians struck by vehicles, and for each pedestrian the best estimate of the impact speed was given. The impact speed was calculated using physical evidence if present, and other means of estimating the speed if the physical evidence was inconclusive. Of the 175 pedestrians, 41 % had an impact speed based on robust physical evidence, with the remaining 59 % having an impact speed estimated with other methods, sometimes including some physical evidence and on other occasions relying more on subjective opinion.

Physical evidence which was used to estimate impact speed includes the length of skid, and the distance the pedestrian was thrown after impact. Other methods used for estimating the impact speed include the speed limit of the road and the likely speed given the conditions, damage to parts of the car such as the windscreen, and the estimates of witnesses and the investigation team at the scene. Figure 1 shows a photograph of a car involved in a pedestrian impact. The impacts with the bonnet and windscreen can clearly be seen, and such evidence can be used to estimate the impact speed.

Figure 1. Car involved in a pedestrian impact.

Of these 175 pedestrians, only those involved in frontal impacts with cars were used. In addition, only those whose injury severity (both MAIS and police injury classification, slight, serious or fatal) was known were included in the study. This reduced the sample to 108 pedestrians. Of these 108, 49 % had impact speed calculated using physical evidence, while the remaining 51 % of impact speeds were estimated using other methods. Figure 2 shows how the methods of determining the impact speed were distributed.

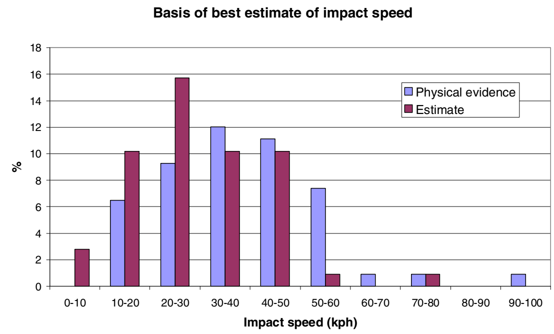

Figure 2. Basis of impact speed measurements for the 108 pedestrians.

RESULTS

Pre-Crash Characteristics

<u>Braking Before Impact</u> - The OTS pedestrian database recorded details of any braking believed to be performed by each car before it struck the pedestrian. Table 2 shows these details for the 108 pedestrian casualties in the sample.

Table 2.
Braking before impact for the vehicles striking the 108 pedestrians

	Number of pedestrians			
	Fatal	**Serious**	**Slight**	**Total**
Braking Unknown	1	7	26	34
Locked Wheels	2	10	9	21
No Braking	2	8	11	21
Some Braking	2	11	19	32
Total	7	36	65	108

For about a third of the pedestrians it was not known whether the car attempted to brake before the impact. The effect of braking on the impact speed is shown in figure 3, which shows the cumulative impact speeds for the 108 pedestrians.

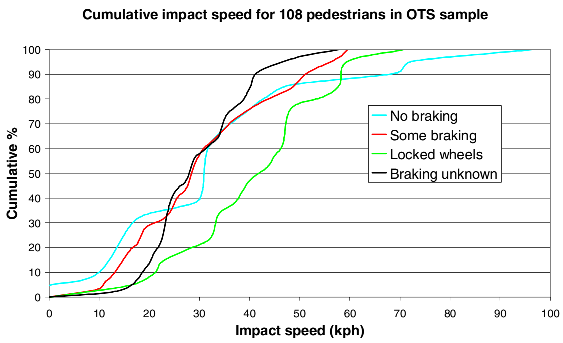

Figure 3. Variation of cumulative impact speed with braking.

Accidents where the car locked wheels before the accident tend to have larger impact speeds than accidents where there was some or no braking. But the cases with the highest impact speeds occur when there is no braking.

Causes and Contributory Factors - The OTS database records the likely causes of each accident in a number of different ways. The first method is to select a "precipitating factor" for each accident. The 108 pedestrians in the OTS sample were from 107 accidents, 99 of which had a "definite" precipitating factor. These precipitating factors are shown in table 3.

Table 3.
Precipitating factors in pedestrian impacts

Precipitating factor	No. of cases	% of cases
Pedestrian entered carriageway without due care (driver not to blame)	78	72.9
Failed to avoid pedestrian (pedestrian not to blame)	10	9.3
Failed to stop	3	2.8
Pedestrian fell in road	3	2.8
Loss of control of vehicle	2	1.9
Failed to avoid object or vehicle on carriageway	1	0.9
Failure to signal or gave misleading signal	1	0.9
Other	1	0.9
No definite factor	8	7.5

This shows that in the vast majority of cases the precipitating factor was the pedestrian stepping into the carriageway without due care.

For each of the precipitating factors, one or more contributory factors can be given which are deemed to have contributed to the precipitating factor. The 11 most frequent contributory factors for the 107 pedestrian accidents are shown in table 4.

Failure to look is the most frequent contributory factor recorded here, although it does not distinguish between failure of the driver or pedestrian.

Table 4.
Contributory factors to pedestrian impacts

Contributory factor	No. of cases	% of cases
Failed to look	23	21.5
Inattention	21	19.6
Carelessness, reckless or thoughtless	20	18.7
Cross from behind parked car	16	15.0
Ignored lights at crossing	10	9.3
Surroundings obscured by stationary or parked car	10	9.3
Failure to judge other persons path or speed	8	7.5
Impairment through alcohol	7	6.5
In a hurry	7	6.5
Person hit wore dark or inconspicuous clothing	3	2.8
Lack of judgement of own path	3	2.8

In 2005, another method of recording the contributory factors toward the accident was introduced in OTS (and the older cases were retrospectively coded to the new standard). This does not give the contributory factors towards the precipitating factor, but rather the contributory factors to the accident itself. The 8 most frequent contributory factors to the 107 pedestrian accidents in the OTS sample are detailed in table 5.

Table 5.
Contributory factors (2005) in pedestrian impacts

Contributory factor	No. of cases	% of cases
Pedestrian: Failed to look properly	43	40.2
Pedestrian: Crossing road masked by stationary or parked vehicle	20	18.7
Pedestrian: Wrong use of pedestrian crossing facility	6	5.6
Injudicious Action: Exceeding speed limit	5	4.7
Injudicious Action: Disobeyed automatic traffic signal	4	3.7
Pedestrian: Failed to judge vehicle's path or speed	4	3.7
Pedestrian: Impaired by alcohol	4	3.7
Error or Reaction: Failed to look properly	3	2.8

Once again, the majority of the accidents are deemed to have been caused by the pedestrian.

Injury Causation

<u>Risk of injury by impact speed</u> – Ashton and Mackay produced risk curves which attempted to show the risk of injury to a pedestrian for a given impact speed. The following graphs compare the findings from the OTS sample of pedestrians to those in Ashton and Mackay.

Figure 4 shows the cumulative impact speed for the 108 pedestrians in the OTS sample. Figure 5 shows the cumulative impact speed for the pedestrians with non-minor (MAIS > 1) injuries, and Figure 6 shows the cumulative impact speed for the fatalities. The equivalent curves from Ashton and Mackay are also shown.

In the OTS data, pedestrians tend to be struck at higher speeds than those seen in the Ashton & Mackay paper. The 50th percentile for all the casualties is about 30 kph for the OTS pedestrians, compared to only 20-25 kph for the Ashton & Mackay dataset. It also appears that a greater proportion of non-minor injuries are caused at higher speeds for the OTS data. The 25th percentile impact speed for non-minor injuries in OTS is approximately 25 kph compared to about 30 kph for the Ashton and Mackay data, while the 75th percentile impact speed is approximately 7 kph faster for OTS.

Although there are very few fatalities in the OTS data (only 7), these follow a similar trend to the non-minor injuries. However it should be noted that while fewer non-minor injuries and fatalities are occurring at high speeds, more fatalities and non-minor injuries are occurring at lower speeds, even though overall the number of casualties injured at a given speed has reduced. This trend of injuries occurring over a wider speed range than shown by Ashton and Mackay is true for both non-minor and fatal injuries.

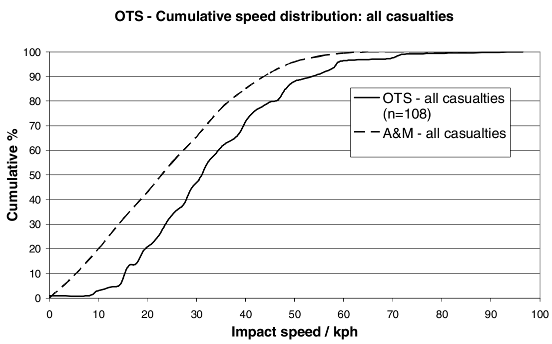

Figure 4. Cumulative impact speed for all pedestrian casualties.

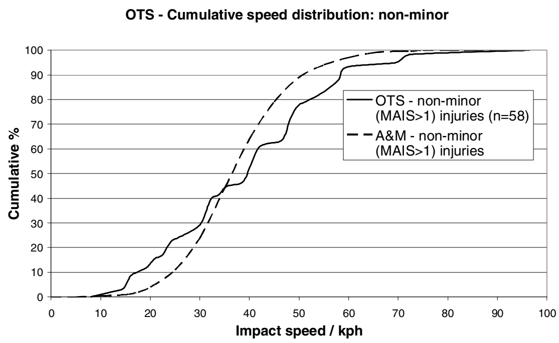

Figure 5. Cumulative impact speed for non-minor (MAIS > 1) casualties.

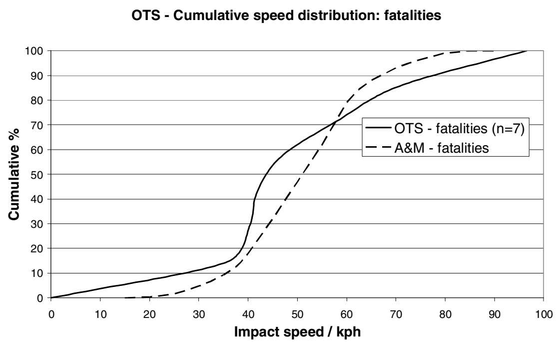

Figure 6. Cumulative impact speed for fatalities.

From the OTS data, figure 7 was produced which shows how the probability of suffering each severity of accident varies with impact speed. Note that the non-minor category no longer includes fatalities. This has been changed so that all injuries add up to 100 %.

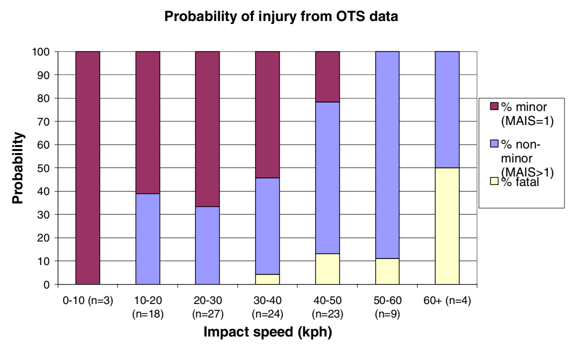

Figure 7. Probability of injury from OTS data, by MAIS.

As speed increases the probability of suffering a minor injury decreases, and the probability of suffering a serious injury or fatality increases. The number of cases at high speeds was very small, so the pedestrians with impact speeds above 60 kph have been combined. A second version of this figure is shown in figure 8 where the Police definitions of slight, serious and fatal are used to describe the casualties, rather than MAIS.

This can be compared with figure 9, which shows a reproduction of data in the Ashton & Mackay paper to produce a similar graph showing the probability of injury. Note that the Aston & Mackay paper does not give clear details of the number of casualties, so these have not been included. This figure was produced by estimating the area under the curves of a graph, and so is probably only accurate to about 10 %. But this is enough to compare the trend shown with that given by the OTS data.

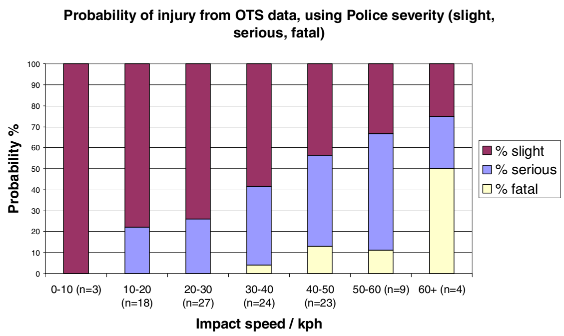

Figure 8. Probability of injury from OTS data, by Police severity.

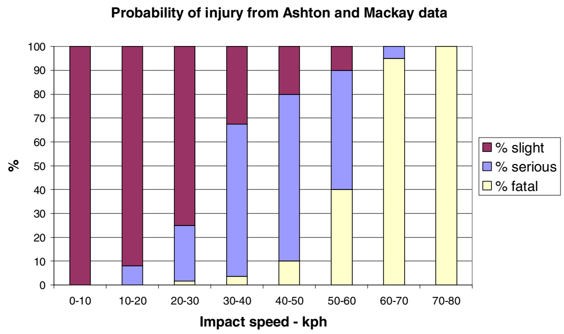

Figure 9. Probability of injury from Ashton and Mackay data, by Police severity.

Comparing these figures tells a similar story to the cumulative impact speed curves. At impacts below 30 kph, the incidence of serious injuries is the same or higher in the OTS data than in the Ashton & Mackay data. At speeds above this, pedestrians in the OTS data were less likely to suffer a serious or fatal injury than those in the Ashton & Mackay dataset.

<u>Body Regions Injured</u> - Figure 10 details the distribution of injuries suffered by all surviving pedestrians aged between 15-59. This age range is chosen to match that used by Ashton & Mackay to display the same data, and gives 43 pedestrians from the 108 in the OTS dataset. The injury distribution is demonstrated using the most severe injury suffered to a particular body region (HAIS), and is given as a percentage of the 43 pedestrians. For example, about 50 % of pedestrians had injuries to the head, with the highest injury being an AIS 1 injury. About 20 % of pedestrians had injuries to the head the worst of which has an AIS greater than 1. So in total, over 70 % of the pedestrians suffered an injury to their head.

Most of the pedestrians hit by the front part of a car suffer injuries to the head, arms and legs. This agrees with the Ashton and Mackay data.

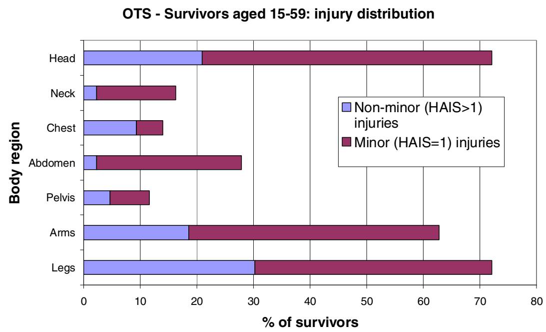

Figure 10. Injury distribution of OTS survivors aged 15-59.

Figure 11 shows the results for the 22 pedestrians with non-minor (MAIS > 1) injuries, who survived. The same data from the Ashton & Mackay paper is also included, which had 308 survivors suffering non-minor injuries.

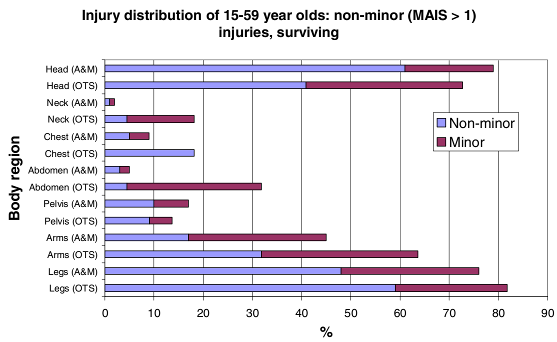

Figure 11. Injury distribution of non-minor (MAIS > 1) casualties from OTS and Ashton and Mackay.

For all body regions apart from the head and pelvis, a larger percentage of pedestrians in the OTS dataset suffered some kind of injury. In the arm, leg, and pelvis region the percentage suffering minor injuries is not very different between the two sets of data. There is a slight increase in minor head injuries to the OTS pedestrians, and a large increase in minor neck and abdomen injuries.

The OTS data shows large increases in non-minor injuries for the neck, chest, arm and leg regions, and a decrease in non-minor injuries to the head. The decrease in non-minor injuries to the head is possibly the most important change as far as fatalities are concerned. Ashton & Mackay showed that over 90 % of pedestrians who were fatally wounded had a non-minor injury to their head.

There were only two fatalities present in the OTS data for the age range 15-59, so the details of those cases have not been included here.

Causes of Injury - Figure 12 shows the causes of the head injuries sustained by pedestrians in the OTS dataset. This is shown as the percentage of injuries of that severity (all, non-minor (AIS > 1), and causing death) for which the cause was known, rather than the percentage of pedestrians. Of the 108 pedestrians in the dataset, there were 144 head injuries of known origin.

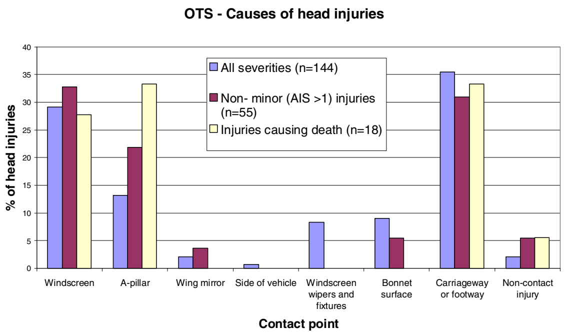

Figure 12. Causes of head injuries in OTS dataset.

The windscreen, A-pillar and contact with the ground cause the most head injuries, of all severities. Although contact with the vehicle does cause more injuries than contact with the ground (as stated by Ashton & Mackay), there is no single part of a car which causes as many injuries. While injuries caused by the A-pillar become increasingly important as the severity increases, contact with the windscreen and the ground causes more injuries of all severities.

Figure 13 shows the causes of the leg injuries suffered by pedestrians in the OTS sample.

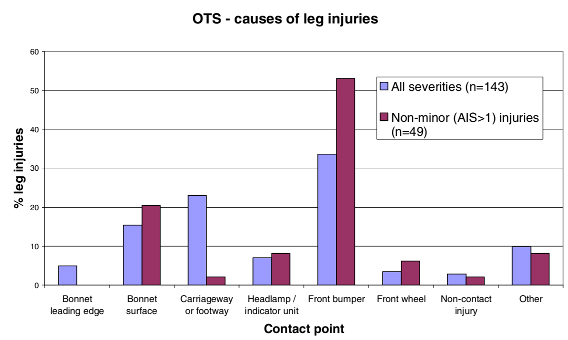

Figure 13. Causes of leg injuries in OTS dataset.

The front bumper is the most frequent cause of all leg injuries, and is by far the most important cause of non-minor leg injuries. Contact with the ground is the second most frequent cause of leg injuries, although the vast majority of these are minor, AIS 1 injuries. The bonnet surface is the second most important cause of non-minor leg injuries.

Figure 14 looks at leg injuries caused by contact with the front bumper (the most important cause of leg injuries), and shows how the injury severity depends on the impact speed.

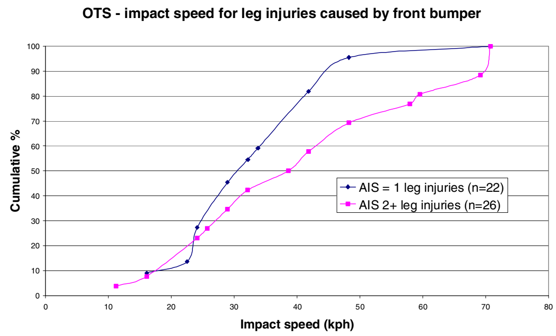

Figure 14. Cumulative impact speed of leg injuries caused by front bumper.

As would be expected, pedestrians struck at higher speeds receive more serious injuries. Above 30 mph (48 kph) all leg injuries caused by the front bumper are at least of severity AIS 2. A similar effect is seen between impact speed and head injury, which is shown in Figure 15.

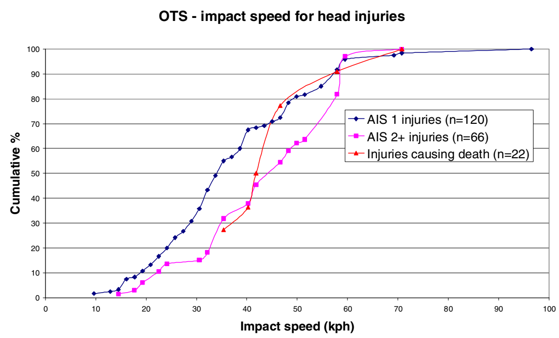

Figure 15. Cumulative impact speed for head injuries.

Non-minor head injuries occur at greater speeds than minor (AIS 1) head injuries. The 50th percentile is about 43 kph for AIS 2+ injuries, compared to about 34 kph for minor head injuries.

DISCUSSION

Pre-Crash Characteristics

Braking before the accident does seem to have an effect on the injury severity of the pedestrian. From the 108 pedestrian impacts studied in detail, 41 % of those where there was "some braking" were killed or seriously injured, compared to 48 % of those where there was "no braking". But of the pedestrians where the braking was recorded as "locked wheels", 57 % were killed or seriously injured.

The impact speeds for pedestrians where the car locked wheels seem to be higher than those for other braking conditions, which explains why these pedestrians were more often killed or seriously injured. But this does not explain why cars whose wheels had locked have higher impacts than those where there was no braking. This is likely to be due to statistical variation in the relatively small sample.

The majority of the pedestrian impacts seemed to be caused by poor judgement on the part of the pedestrian, with the 3 most frequent contributory factors (as used in OTS from 2005) relating to mistakes by the pedestrian. Of the causes attributed to the driver of the car, exceeding the speed limit was considered a contributory factor in only 5 % of cases (compared to 40 % of cases where the pedestrian did not look properly).

Impact Speed

Large differences are seen when the cumulative impact speed curves from the OTS data are compared to the equivalent curves from Ashton & Mackay. Firstly, the difference between the speeds at which fatalities occur compared to the impact speeds for all casualties is much greater in the Ashton and Mackay data. Taking the 50th percentile, there is a difference of about 28 kph between the fatalities and all the casualties, compared to about 12 kph for OTS. The impact speeds for all the casualties are also lower in Ashton & Mackay than in OTS, by about 8 kph.

There are also differences in the shape of the curves. The OTS curves change more gradually than the Ashton & Mackay curves, and the curves cross above the 50% line. This means that the Ashton & Mackay casualties are spread over a smaller speed range, and peak at lower speeds than the OTS casualties.

These relationships between impact speed and injury severity are complicated. The largest difference is that, in general, the impact speeds for all the casualties being hit in the OTS dataset are higher than those shown by Ashton and Mackay. Making the assumption that all pedestrians who are struck by a car are injured in some way, there are a few possible explanations for this: either pedestrians are, on average, struck at higher speeds; the datasets are biased to include more accidents at higher speeds; or the methods used to estimate the impact speeds tend to overestimate (or Ashton & Mackay under-estimated).

When the casualties are split by severity, it appears that the non-minor and fatalities in Ashton & Mackay were occurring at lower speeds, and over a smaller spread of speeds, than in the OTS data. The increase in speed required to inflict a non-minor injury would suggest that cars have become more pedestrian-friendly in some way since 1979, with higher impact speeds required to produce the same degree of injury. The increase in speed for a fatality agrees with this improvement in pedestrian friendliness, and could also suggest that pre-hospital and hospital trauma care has improved a pedestrian's chance of surviving.

These changes are also present in the graphs which attempt to show the probability of suffering a slight, serious or fatal injury at different speeds. For example, from the Ashton & Mackay paper the chance of a pedestrian being killed between 60-70 kph is approximately 95 %, whereas the probability of a fatality at impact speeds greater than 60 kph is about 50 % in OTS. Unfortunately, at these higher speeds the sample sizes are very small in the OTS data, but impacts between 50-60 kph also produce a lower percentage of fatalities in OTS.

At speeds lower than this, the percentages of fatalities in the two sets of data are similar. At speeds between 20-60 kph there tend to be fewer serious casualties in OTS compared to Ashton and Mackay, although at speeds lower than this there are more serious injuries in OTS.

It is possible that the methods used to estimate the impact speeds could have an effect on the results, for example if they consistently overestimated the impact speed. For the OTS data, it has been shown that estimates based on physical evidence tend to give larger impact speeds than estimates made using other methods. This is probably due to the fact that there is less likely to be suitable physical evidence (such as pedestrian throw or skid marks) at impacts of lower speed, so other methods of estimation need to be used. There is no evidence that these other methods under/over estimate compared to the estimates based on physical evidence.

The increase to the impact speed observed in the boundary condition between serious and fatal injury outcome is a very interesting finding. This could be due to many interrelated factors. Not least, in the 30 years since Ashton and Mackay completed their innovative research the standard of pre-hospital and hospital medical care has significantly improved with advances in technology and working practices. There have been significant road and vehicle design changes that have also occurred in this period. In addition, the exposure and associated pedestrian demographics have changed, resulting in different groups of people being more or less at risk of being struck by a car with respect to their age and even socio-economical status.

Injury Distribution

For all survivors the head, arms and legs are the body regions of pedestrians which most frequently suffer both minor (AIS = 1) and non-minor (AIS > 1) injuries. Unfortunately, because there are so few fatalities in the OTS dataset the difference in injury distribution between non-minor casualties and fatalities could not be investigated. The OTS data shows that increasing impact speed is related to increasing severity of both head and leg injuries. The most consistent difference between the data sets is that there are more head injuries in the Ashton & Mackay data for non-minor casualties and fatalities. This is one possible explanation for the greater percentage of fatalities in the Ashton & Mackay data, although the increase in head injuries is relatively small.

Apart from a small decrease in head injuries, the pedestrians who are hit by cars do not show any great reduction in injuries to separate body parts compared to those seen by Ashton & Mackay in 1979, even though it has been shown that higher speeds are required to produce the same injury severity. It is possible that this is related to the higher impact speeds compared to the 1979 data, where any possible improvement is being masked because pedestrians are being hit at higher speeds. To determine whether this is the case, the data would need to be split by both body region and speed, which unfortunately would leave the sample sizes too small to be meaningful.

Causes of injury

The two regions most frequently injured in a pedestrian impact are the legs and the head, and it is these regions where the causes have been investigated in more detail.

The majority of leg injuries are caused by the front bumper, as would be expected. This is shown in the OTS data, with 53 % of AIS 2+ leg injuries caused by the front bumper for the OTS pedestrians. Impact with the bonnet surface makes up another 20 % of the non-minor leg injuries.

Head injuries are the leading cause of fatalities to pedestrians, so determining the causes of these injuries is very important if cars are to be further adapted to be pedestrian friendly. For the pedestrians in the OTS dataset, the most common causes were contact with the windscreen, the A-pillar and the carriageway/footway. Ashton and Mackay identified contact with the A-pillar as causing more serious injuries than contact with the windscreen or bonnet, and for OTS the proportion of injuries caused by the A-pillar increases as the injury severity increases.

Although more injuries are caused by contact with the car than with the road, contact with the ground causes more injuries than any single region of a car. The bonnet, which has been the focus of many attempts to improve the results of pedestrian crashes, has been shown here to be one of the least import causes of fatalities. This could mean that improvements in bonnet design have been successful, but now efforts should probably be concentrated elsewhere.

CONCLUSIONS

- The majority of pedestrian impacts are caused by the actions of the pedestrian.
- In 1979, Ashton and Mackay reported that the boundary car impact speed for the transition from mostly slight to mostly severe (AIS 2+) pedestrian casualties was approximately 30kph. The OTS dataset mirrors this finding.
- Further, Ashton and Mackay reported that the boundary car impact speed for the transition from mostly severe to mostly fatal pedestrian casualties was between 50 and 60kph, whereas the OTS dataset shows this change to occur above 60 kph. However, the number of fatal cases in the OTS database above 60kph is very small and this is an important factor to note when presenting the data.
- The OTS pedestrian impact speeds are more distributed than reported by Ashton and Mackay with proportionally more at the lower and higher speed ranges respectively.
- Head and leg injuries are the most frequent in the OTS dataset, which agrees with the findings of Ashton and Mackay.
- Most head injuries in the OTS dataset are caused by contact with the A-pillar, windscreen or the ground. Contact with the bonnet seems to be relatively unimportant. The most frequent cause of leg injuries is impact with the front bumper.

In terms of future work, the following points should be considered.

OTS is a continuing project. As more pedestrian accidents are investigated, the greater numbers will allow more robust conclusions to be drawn from the results, and may also allow other factors to be investigated. Estimates of impact speed will also become more representative and reliable.

While this project has concentrated on pedestrian collisions with the front of cars, the OTS project investigates accidents involving all types of vehicles. It would be a simple extension to this project to consider these vehicles, although there are far fewer associated pedestrian injuries. A further study could also investigate collisions with other vulnerable road users, such as pedal cyclists and motor cyclists.

The OTS project investigates a representative sample of all traffic crashes, involving all road users and injury outcomes. There would be some merit in enhancing a percentage of crash investigations with additional reconstruction effort beyond the current scope of the OTS project to provide analysis projects, such as this study, with comparative cases that could be used to validate the wider database findings. Examples could include utilising specialist crash reconstruction software techniques to give a more in-depth understanding of the crash kinematics for a sub-sample of cases.

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