Pedestrian Injuries By Source: Serious and Disabling Injuries in US and European Cases

Ann Mallory
Transportation Research Center Inc.

Rikard Fredriksson
Erik Rosén
Autoliv Research

Bruce Donnelly
NHTSA

ABSTRACT – US and European pedestrian crash cases were analyzed to determine frequency of injury by body region and by the vehicle component identified as the injury source. US pedestrian data was drawn from the Pedestrian Crash Data Study (PCDS). European pedestrian data was drawn from the German In-Depth Accident Study (GIDAS). Results were analyzed in terms of both serious injury (AIS 3+) and disabling injury estimated with the Functional Capacity Index (FCI). The results are presented in parallel for a more complete international perspective on injuries and injury sources.Lower extremity injury from bumper impact and head&face injury from windshield impact were the most frequent combinations for both serious and disabling injuries. Serious lower extremity injuries from bumper contact occurred in 43% of seriously injured pedestrian cases in US PCDS data and 35% of European GIDAS cases. Lower-extremity bumper injuries also account for more than 20% of disability in both datasets. Serious head &face injuries from windshield contact occur in 27% of PCDS and 15% of GIDAS serious injury cases. While bumper impacts primarily result in lower extremity injury and windshield impacts are most often associated with head & face injuries, the hood and hood leading edge are responsible for serious and disabling injuries to a number of different body regions.Therefore, while it is appropriate to focus on lower extremity injury when studying bumper performance and on head injury risk when studying windshield impact, pedestrian performance of other components may require better understanding of injury risk for multiple body regions.

INTRODUCTION

Internationally, pedestrians account for more road traffic fatalities than any other group of road users with approximately 400 000 deaths per year [Naci, Chisholm and Baker, 2009]. Previous studieshave shown differences in the characteristics of pedestrian crashes internationally: US data has shown that the head is most frequently injured followed by the lower extremity and torso [Longhitano, Ivarsson, Henary et al., 2005, Zhang, Cao, Hu et al., 2008], while Japanese data indicates that lower extremity injury is most common followed by head injury[Maki, Asai and Kajzer, 2003]. Fatal injuries in both German and Japanese studies are most frequently head injuries when considering only single causes[Ehrlich, Tischer and Maxeiner, 2009, Maki et al., 2003]. However, head, chest, and pelvis polytrauma was reported as the most common overall cause of fatality. Differences in pedestrian crashes have been attributed to variations in vehicle shape and type[Lefler and Gabler, 2004, Longhitano et al., 2005, Roudsari, Mock and Kaufman, 2005]and international differences in traffic patterns[Mohan, 2002].

Determination of pedestrian injury risk by body region is complicated by the variability of the interaction between vehicles and pedestrians: each body region can interact with a number of different vehicle components. Roudsari et al. [2005]reported on the most frequent sources for injuries in each body region in US cases, but included injuries of all severity levels. Studies limited to serious injuries only have focused on injury risk to specific body regions[Klinich and Schneider, 2003, Mallory and Stammen, 2006a, Mallory and Stammen, 2006b, Okamoto, Sugimoto, Enomoto et al., 2003, Yao, Yang and Otte, 2008].However, a comprehensive understanding of pedestrian injury risk requires a broader look at the frequency and severity of injuries by body region *and* by vehicle component.

CORRESPONDING AUTHOR:
Ann Mallory, Transportation Research Center Inc., 10820 State Route 347, East Liberty OH, USA, Ann.Mallory.CTR@gov.

The current study reports on parallel investigations of US and European pedestrian cases to identify the most frequent combinations of body region and vehicle contact source. To better understand the importance of individual combinations of injuries, this assessment was performed based on expected long-term disability from sustained injuries as well as on overall injury severity.

METHODS

US pedestrian cases were drawn from the 549 cases in the Pedestrian Crash Data Study (PCDS). Case investigations were performed between 1994 and 1998, targeting vehicles of model year 1990 and newer[NCSA, 1996]. PCDS inclusion criteria were as follows:

- pedestrian impact by forward-moving vehicle,
- striking vehicle waspassenger car, light truck, van or utility vehicle,
- pedestrian was not lying or sitting,
- striking portion of the vehicle was previously undamaged original-equipment parts,
- pedestrian impact was vehicle's only impact, and
- first point of pedestrian contact was forward of the top of the A-pillar.

PCDS cases were collected and reported by the US National Highway Traffic Safety Administration (NHTSA) and the PCDS dataset is publicly available at *ftp://ftp.nhtsa.dot.gov/PED*.

European pedestrian data came from the 933 pedestrians included in the German In-Depth Accident Study (GIDAS) between 1999 and 2008.The inclusion criteria for the GIDAS cases in this study were the following:

- pedestrian impact by vehicle front,
- striking vehicle is passenger car or van,
- pedestrian was upright (not lying),
- striking portion of the vehicle was previously undamagedoriginal-equipment parts,
- pedestrian only struck by one vehicle, and
- both pedestrian and vehicle information available.

GIDAS is a collaborative research effort of the Federal Highway Research Institute (BASt) and the German Association for Research in Automobile Technology (FAT). Case access is limited to partners in these organizations.

All included injuries were categorized by pedestrian body region and by the identified injury source. Pedestrian body regions were classified into 7 regions using the 7-digit Abbreviated Injury Scale (AIS)codes in each dataset. A pelvis & hip injury category included all hip and bony pelvis injuries, as well as femur fractures coded as head, neck, or

intertrochanteric fractures. Injuries coded in the AIS spine region were re-grouped by spinal level so that cervical injuries were classified in the neck region, thoracic spine injuries in the thorax, and lumbar injuries with the pelvis and hip. Vehicle and environment injury sources were identified using the injury source variables, which are named "PINJSOU" in PCDS and "VTEIL" in GIDAS (Appendix Table A1).

To compare the similarity of the PCDS and GIDAS cases, the distribution of vehicle type, model year, pedestrian age, and vehicle impact speed were compared for the two datasets. In both databases, the vehicle impact speed at the time of pedestrian contact was estimatedusingon-scene investigation data (collision point, pedestrian and vehicle points of rest, vehicle skid marks) and interviews with the driver, pedestrian and witnesses.

Serious Injury Analysis

For the analysis of serious injuries, all pedestrian injuries of AIS level 3 to 6 were selected from both the PCDS and GIDAS datasets. Injuries from fatal and non-fatal cases were included. Pedestrians of all ages were included. The AIS codes used in the PCDS were based on the Association for Automotive Medicine's AIS-90 [AAAM, 1990]. The AIS codes in the GIDAS dataset were coded using the AIS-90/98 Update[AAAM, 1998]. No weighting was applied for the serious injury analysis.

Disabling Injury Analysis

To analyze disabling injuries, all AIS-coded injuries in non-fatal pedestrian cases in the two datasets were classified using the Functional Capacity Index (FCI) to estimate expected pedestrian disability. In the FCI system, each AIS code is assigned an FCI value from 0 to 100%, where 0 is no disability and 100 is total disability [MacKenzie, Damiano, Ditunno et al., 1994]. These values were developed by expert panels based on evaluation of how each injury affects 10categories of function (e.g. mobility, cognition) along with the relative importance of each category of function. They reflect the expected disability at one year following injury for initially healthy adults between age 18 and 34. Thus, each pedestrian's disability is *estimated* based on the corresponding FCI for that pedestrian's AIS-coded injuries rather than on documented disability for the case. The FCI codes used in this analysis were based on those developed for the National Automotive Sampling System Crashworthiness Data System (NASS CDS)[Segui-Gomez, 1996]. To accommodate injury codes that appeared in PCDS and in GIDAS that

were not included in the NASS CDS FCI codes, FCI was estimated based on Segui-Gomez's calculated FCI for similar injuries (Appendix Table A2).

A pedestrian's total long-term disability is estimated as the maximum FCI value for all disabling injuries sustained in each case. In this analysis of disabling pedestrian injuries, the disability attributable to injuries to specific body regions or to specific vehicle components was estimated using the methods developed for "attributable fatalities" byHasija, Martin and Ridella (personal communication with Peter Martin). The calculated attributable disability represents the total disability that would be prevented if disabling injuries to a particular body region were completely eliminated. For each pedestrian, the attributable disability for injuries associated with a given body region or vehicle component is the difference between the pedestrian's maximum FCI injury, and the maximum FCI injury excluding injuries to the given body region or vehicle component. Thus, if a pedestrian has disabling injuries to multiple body regions, this method reflects the incremental improvement in FCI that would be expected if injuries to only one body region were eliminated. Results for disability attributed to a given injury source or body region/injury source combination are presented as percentages of the total disability estimated for the dataset.

Since published FCI values reflect outcome expected for adults age 18-34, the pedestrians included in the disability analysis were necessarily limited by age. In the current study, FCI analysis was performed on all non-fatal cases involving pedestrians of age 18 or older, although application of FCI values to pedestrians older than age 34 is expected to underestimate overall injury-related disability. No FCI codes have been reported for age-groups younger than 18 years, so although children were included in the serious injury analysis in this study, pedestrians under age 18 were excluded from the disability analysis.

*Weighting of PCDS and GIDAS cases.*Neither the PCDS nor GIDAS datasets are statistically sampled to be representative of all crashes in their respective countries. More seriously-injured pedestrians tend to be over-represented in both of these datasets.The serious injury analyses of the PCDS and GIDAS datasets included *only* serious (AIS 3+) injuries, so the overrepresentation ofserious injuries in those datasets was not expected to affect results significantly. The disabling injury analysis included all injuries, however, and was expected to be biased by the overrepresentation of serious injuries in these

two pedestrian datasets. Accordingly, cases used in the disabling injury analysis from PCDS and GIDAS were weighted to reflect the distribution of pedestrian cases by injury severity in statistically sampled national databases corresponding to each dataset. Pedestrian cases from the US National Automotive Sampling System General Estimates System (NASS GES)were used to weight PCDS cases and German national statistics on pedestrians crashes were used to weight GIDAS cases[Verkehrsunfälle, 2003-2007].

Following Rosén and Sander's weighting methods(2009) the final weighted sample of PCDS cases was developed by scaling each case relative to the proportion of pedestrians injured at each severity level in the PCDS and weighted NASS GES datasets. The police injury rating scale was used for weighting because it was available in both PCDS and NASS GES. The proportional scaling factor was set to 1 for cases where the pedestrian was listed as injured, with severity unknown. The final weighted sample of GIDAS cases was developed by determining a proportional scaling factor for each injury severity based on the number of pedestrians injured at each police-rated severity level in the GIDAS and national German pedestrian datasets. The proportional scaling factors for each injury severity level in the PCDS and GIDAS datasets were then normalized so that the total number of scaled adult non-fatal pedestrian cases was equal to the original number in each included dataset. The final, normalized case weight factors are shown inTable 1 and Table 2.

Table 1 - Scaling factors applied to PCDS cases based on distribution of injury severity in NASS GES pedestrian cases

US Injury Scale	Normalized Weight
No injury (0)	1.825
Possible injury (C)	1.279
Non-incapacitating (B)	1.180
Incapacitating (A)	0.628
Killed (K)	*Excluded in disability analysis*
Injured severity unknown	0.976

Table 2 - Scaling factors applied to GIDAS cases based on distribution of injury severity in national German pedestrian dataset

German Injury Scale	Normalized Weight
Ambulant	1.354
In-patient	0.677
Killed	*Excluded in disability analysis*

RESULTS

The 549 pedestrians in the PCDS dataset had 4,464 documented injuries. For the serious injury analysis, there were 193 seriously-injured pedestrians, who sustained 821 serious injuries.   For the disabling injury analysis, there were 323 adult pedestrians with non-fatal injuries.

The GIDAS dataset included 933 pedestrians with 3,468 injuries.   For the serious injury analysis, serious injuries were documented in 162 cases, which involved 451 AIS 3-6 injuries.   For the disabling injury analysis, there were 549 adult pedestrians with non-fatal injuries.

Vehicle type varied between the two datasets, reflecting differences in the US and European fleets. The PCDS dataset included 128 pedestrians struck by passenger cars, 32 by pickup trucks, 16 by minivans, 12 by sport utility vehicles, and 5 by full-size vans. In contrast, the GIDAS dataset had 157 passenger car pedestrian cases, 4 van cases, and 1 off-road vehicle case.

The model-year distribution of vehicles in crashes included in each dataset was compared (Figure 1). PCDS cases in this study, collected between 1994 and 1998, targeted newer vehicles, with a resulting range of vehicle model years of 1988 to 1999 and a median model year of 1993 (mean 1993.1). Although the GIDAS cases in this study include more recent case investigations, those cases were not limited to late-model vehicles and covered a much wider range of model years so that there was substantial overlap in the model years covered by the two datasets. Median model year for GIDAS cases was 1995 (mean 1995.25).
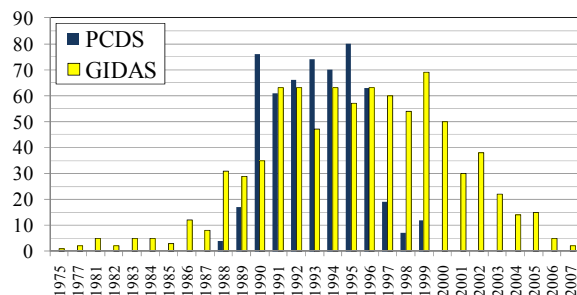

Figure 1 - Number of cases in each dataset by vehicle model year.

Vehicle speed at the time of first contact with the pedestrian was estimated in 84% of PCDS cases and 86% of GIDAS cases (Figure 2). Although mean impact speed was similar (28.4 km/h in PCDS and 29.8 km/h in GIDAS), the distribution of impactspeed varied between the datasets.   The $25^{th}/50^{th}/75^{th}$ percentile impact speeds were 13, 24, and 38 km/h for PCDS, compared to 17, 28, and 40 km/h in GIDAS. Age distribution of pedestrians also differed in the two datasets with GIDAS having proportionally more children and pedestrians over age 50 than PCDS, although the mean and median ages in the datasets were within one year of each other (Figure 3).
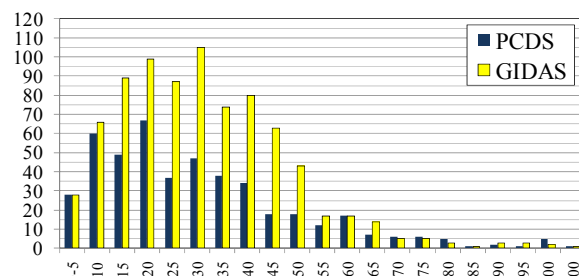

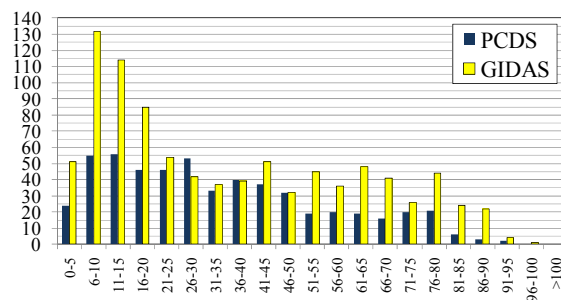Figure 2 - Number of cases in each dataset by vehicle impact speed (km/h)

Figure 3 - Number of cases in each dataset by pedestrian age (years)

Serious Injury Analysis

The percentage of seriously-injured pedestrians who sustained AIS 3 or greater injury from each combination of body region and vehicle injury source is shown in Figure 4 for PCDS and in Figure 5for GIDAS.

In both datasets, the most frequent combination of body region and vehicle source among serious injuries was lower extremity injuries attributed to the bumper or valence, documented in 43% of PCDS serious injury cases and 35% of GIDAS serious injury cases. The next most frequent injuries were head &face injuries from windshield or wiper contact (27% of PCDS cases and 15% of GIDAS cases) and thorax injuries from hood contact (17% of PCDS cases and 12% of GIDAS cases).   Head &face injuries from A-pillar/header contact were also frequent in both datasets, occurring in 10% and 11% of serious injury cases in PCDS and

GIDAS,respectively. Injuries from contact with non-vehicle sources in the environment were also documented in PCDS and GIDAS. The most frequent body regions injured in environment impacts were the head and face (7.2% of PCDS cases and 11.7% of GIDAS cases) and the thorax (7.4% of GIDAS cases).Full case counts for serious injuries in each body region and vehicle or environment injury source category are tabulated in Appendix Table A3.
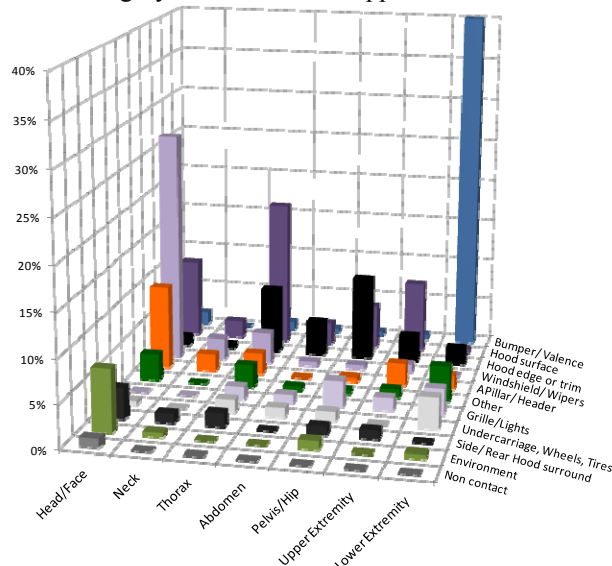

Figure 4- Percentage of seriously-injured pedestrians in PCDS (n=193) who sustained an AIS 3-6 injury in each body region/vehicle source category.
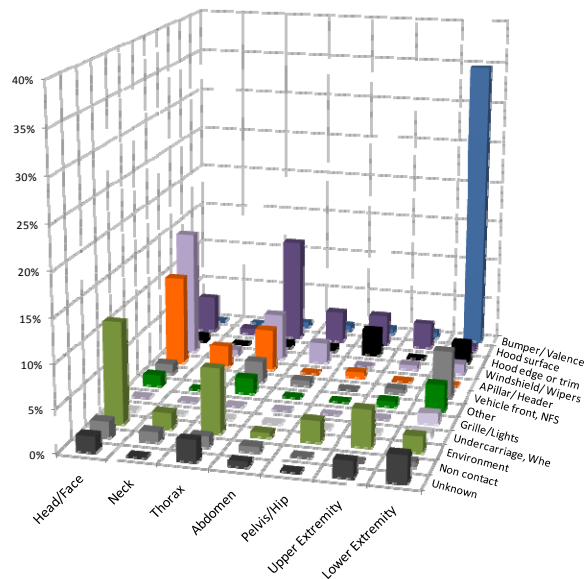

Figure 5 - Percentage of seriously-injured pedestrians in GIDAS (n=162) who sustained an AIS 3-6 injury in each body region/vehicle source category.

Among serious injuries in both datasets, more than 90% of pedestrians with injuries from bumper contact

had lower extremity injuries. More than half of pedestrians with injuries due to windshield and A-pillar/header contact sustained head injuries. Other vehicle components were responsible for a more diverse set of injuries. Hood surface contact was responsible for numerous serious injuries to the thorax, head & face, upper extremity and pelvis & hip. In PCDS, hood edge contact was responsible for injuries to the pelvis & hip, thorax, abdomen, and the extremities.

Injury combinations occurring more frequently in PCDS than in GIDAS included pelvis & hip and thorax injuries from the hood edge, head & face and upper extremity injuries from the hood, and lower extremity injuries from bumper contact. Injury sources identified more frequently in GIDAS than in PCDS included the environment, unspecified frontal vehicle structures, and unknown sources.

To understand how much of the difference between the two datasets resulted from a higher proportion of light trucks and vans in the US fleet, the frequency of injury/source combinations was calculated for cases involving only passenger cars. For the eight most common injury combinations from vehicle contacts (those that occurred in at least 7% of cases from either dataset), the difference between PCDS and GIDAS was compared for *all vehicles,* and then for *passenger cars only*(Figure 6).

After excluding light trucks and vans, the GIDAS results were relatively unchanged as a result of the very small number of light trucks or vans in that dataset. For both datasets, the three most frequent injuries for passenger car cases were the same as those for all vehicles: lower extremity injuries from bumper/valence contact, head & face injuries from windshield contact, and thorax injuries from hood contact. As in the analysis including all vehicle types, head & face injuries from windshield contact, upper extremity and thorax injuries from hood contact, and lower extremity injuries from bumper contactare more common in PCDS passenger car cases than in GIDAS passenger car cases. In contrast, when the search was limited to passenger cars, the higher percentage of hood leading edge injuries and the higher percentage of head & face to hood injuries observed in the PCDS database search including larger vehicles was diminished: among passenger car cases only, hood leading edge injuries and head & face to hood injuries occurred with similar frequency in PCDS and GIDAS. These results suggest that the elevated number of PCDS cases of head & face injuries from hood contact and thorax and pelvis & hip injuries from hood edge

contact are a result of the light trucks and vans included in the PCDS dataset and the US fleet. The injury combinations that are more prevalent in PCDS in both the all-vehicles dataset and the passenger-cars-only dataset may be a result of other differences in the PCDS and GIDAS datasets including impact speed and pedestrian age.
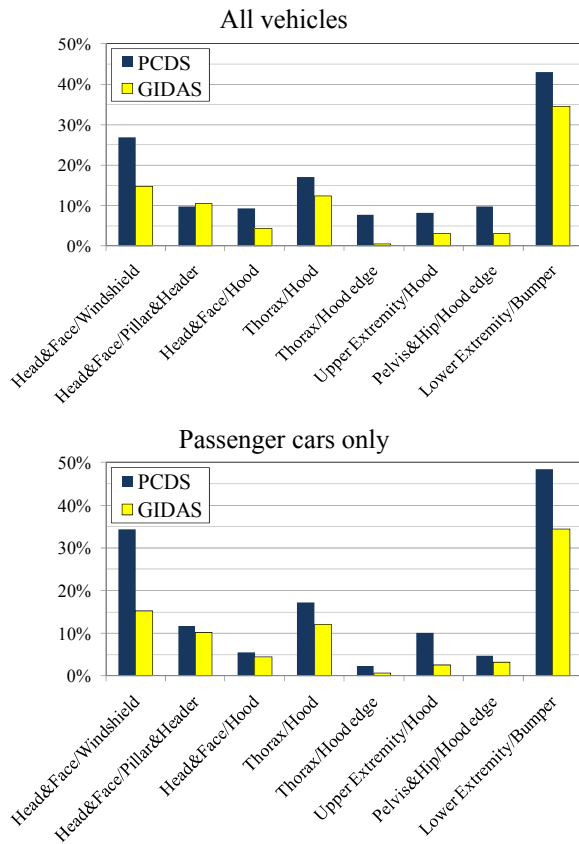

Figure 6 - Percentage of seriously-injured pedestrians with AIS 3-6 injury in each body region/vehicle source category for 8 most frequent combinations.

Disabling Injury Analysis

Each pedestrian's expected disability was estimatedusing the FCI based on their AIS-coded injuries. According to weighted results, 31% of the 323 adult, non-fatal pedestrian cases in PCDS had FCI greater than zero, consistent with disability at one year following injury. The mean FCI for all included pedestrians was 12% and the mean FCI for all pedestrians with FCI greater than zero was 39%. In GIDAS, the mean FCI among the 549 adult, non-fatal pedestrian cases was 6%. Among the 23% of pedestrians with FCI greater than zero, the mean FCI was 27%. Using the procedure outlined in the Methods section, the total disability attributable to specific vehicle components was calculated as a percentage of the total estimated disability (Figure 7).
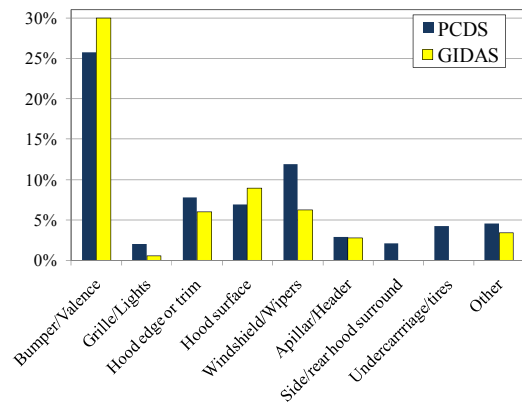

Figure 7 - Percentage of total disability attributable to contact with each vehicle component (i.e. percentage of disability prevented if all injuries to that vehicle component were eliminated).

The majority of disability from vehicle contact in both datasets is attributable to the bumper/valence, the hood surface, the hood edge/trim, and the windshield or wipers. The disability attributed to these vehicle components is shown by body region in Figure 8 and Figure 9. In both datasets, disabling injuries were primarily associated with the lower extremity, head & face, pelvis & hip, and upper extremity. If lower extremity injuries were eliminated, 31% of disability in the PCDS dataset and 46% of disability in the GIDAS dataset would be prevented. In contrast to analysis of serious injuries, the thorax is not a major contributor to disability and
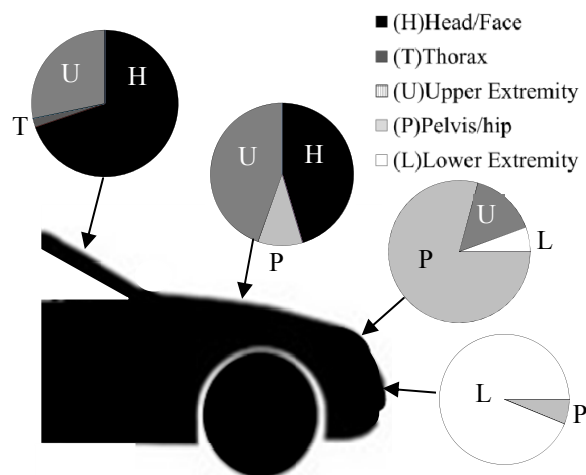

Figure 8 - Percentage of attributable disability by body region in PCDS for the Windshield, Hood Surface, Hood Leading Edge, and Bumper/Valence.
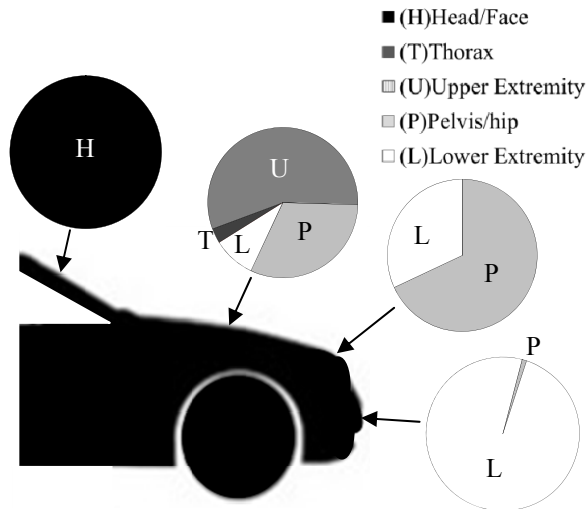
Figure 9 - Percentage of attributable disability by body region for GIDAS for the Windshield, Hood Surface, Hood Leading Edge, and Bumper/Valence.

accounts for less than 1% of disability in either dataset. Injuries to the upper extremity and pelvis & hip gain importance when the focus is on disabling injuries rather than serious injuries.Full numerical results for disability by injury region and by injury source included in Appendix Table A4.

All combinations that can be attributed with at least three percent of all disability in either database are compared in Figure 10.Overall, the combination that accounts for more than 20% of disability in both datasets is lower extremity injuries from bumper contact.
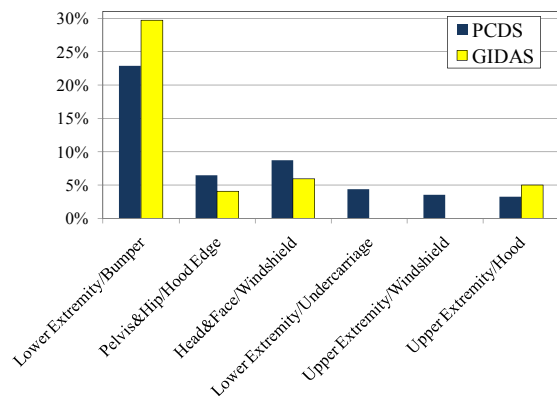

Figure 10 - Percentage of attributable disability associated with most frequent combinations of vehicle component and injury region.

DISCUSSION

Overall, the two most frequent combinations of injury and vehicle source were lower extremity injury from bumper contact and head&face injury from windshield impact. This result was unchanged whether tracked by frequency among seriously-injured occupants or as a percentage of the total disability sustained by pedestrians.

Differences emerged in the ranking of other injuries when outcome was described by disability instead of serious injury. Considering disability rather than frequency of serious injury by AIS, thorax injuries decreased in importance and extremity and pelvis & hip injuries became more significant. The third-most frequent *serious* injury combination in both databases was thorax to hood injury, but the third-most *disabling* injury combinations in PCDS and GIDAS were pelvis and hip to hood edge, and upper extremity to hood injuries respectively. This shift is consistent with the immediate threat to life of thorax injuries compared to less life-threatening injuries that affect long-term function.

Differences between PCDS and GIDAS. Differences in the results between the two databases that can be explained by the larger percentage of light trucks and vans in the US PCDS cases include the higher frequency of hood-leading edge injuries and head & face to hood injuries in PCDS. Other differences between the datasets appear to occur even when only passenger cars are compared: head & face to windshield injuries, upper extremity and thorax to hood injuries, and lower extremity to bumper injuries are all more frequent in the US dataset, while head & face and thorax injuries from the environment are more common in the European dataset. Although vehicle shape and size certainly affect the frequency of injury from both vehicle contact sources and from the environment, it cannot be identified which differences between PCDS and GIDAS may be a result of variation in vehicle design between the US and Europe and which are related to other differences in the datasets. In particular, speed and age differences could lead to variation in both impact location on the vehicle and variation in injury tolerance and risk. Given that both impact speed and pedestrian age distribution vary between the two datasets, comparison of the effects of vehicle design between the US and European fleet cannot be made based on these results. Additional contributing factors in the differences between results for the two datasets include the somewhat newer vehicles in the GIDAS dataset, the slightly different case selection criteria for the two datasets, international differences in road design and infrastructure,and AIS version used for injury coding or differences in how injury source was coded. An example of coding differences is GIDAS's substantially higher number of cases

coded with injuries from unknown sources than PCDS, possibly reflecting that PCDS coders were more likely to document the best estimate of injury source while GIDAS injury sources are only listed if definitive. These potential dataset differences make it difficult to compare the US and European case data directly. Apart from differences that can be linked to the prevalence of light trucks and vans in the US, conclusions on design differences in the fleets should not be drawn. Instead, the two datasets should be considered in parallel to identify injury combinations most frequent in each.

Considering the results by vehicle component, the bumper/valence is responsible for the highest percentage of serious injuries and disability. When analyzed with respect to serious injuries, bumper injuries are primarily to the lower extremity only. If disabling injuries are considered, the bumper does contribute to pelvis and hip disability, but the majority of bumper disability results from lower extremity injury distal to the hip. For injury protection in bumper impacts, a focus on lower extremity injury is appropriate based on this analysis of both US and European data.

In contrast, the hood is responsible for serious and disabling injuries to a number of *different* body regions. Hood surface contact was responsible for serious injuries to body regions including the thorax, head&face, upper extremity, pelvis&hip and abdomen. Among disabling injuries, the hood was associated with head& face injuries in PCDS, lower extremity and thorax injuries in GIDAS, and upper extremity and pelvis & hip injuries in both datasets. It is unknown whether pedestrian headform testing is an effective method to evaluate injury risk to body regions other than the head. Given the high frequency of serious thorax injuries and disabling pelvis & hip and upper extremity injuries resulting from hood contact in both datasets, a better understanding of the effects of head protection countermeasures for the hood on injuries to *other* body regions is needed. It is likely that energy management strategies for head-to-hood impact will also improve injury outcome for other body regions, but this assumption should be confirmed so that designs optimized for head protection do not increase risk for other frequently injured body regions.

The hood leading edge is also responsible for serious and disabling injuries to a broad range of body regions, particularly in vehicles other than passenger cars in PCDS. Among serious injuries, thorax and pelvis & hip injuries were most common, but extremity injuries also emerge when disability is considered. Because of the smaller proportion of light trucks and vans in the European fleet, the hood leading edge is responsible for a much smaller proportion of serious injuries in GIDAS. However, evaluation of pedestrian performance of this vehicle component in either fleet should consider potential injury to multiple body regions.

The windshield is identified as the source of serious head injury in 27% of seriously-injured PCDS pedestriansand 15% of seriously-injured GIDAS pedestrians. This injury combination is attributed with causing 9% of total disability in the weighted PCDS dataset and 6% in GIDAS. In both datasets, head injuries from windshield contact are second only to lower extremity-bumper injury among serious and disabling injuries from vehicle contact. Although the windshield is also associated with injuries to body regions other than the head, none are as frequent as head injuries. The frequency of this injury combination is higher in PCDS than in GIDAS, and is highest when only PCDS passenger cars are included. Although the increased frequency with passenger cars is explained by the increased likelihood of head contact in the plane of the windshield with smaller vehicles, the reason for the higher frequency of this injury in PCDS than in GIDAS could be related to differences in the case characteristics of the two datasets or to design differences.

Injuries attributed to the A-pillars and header surrounding the windshield also affect the head/face more often than other body regions. In contrast to head injuries from windshield impact, serious head injuries from A-pillar/header contact occur with similar frequency in PCDS and GIDAS.

Among injuries from contact with the environment, rather than from vehicle sources, head & face injuries were most frequent in both datasets, followed by thorax injuries in GIDAS.

*Inclusion of disability data.*Given the different injury patterns that emerge when considering disabling versus serious injuries, it is valuable to include disability in injury analyses. While disability results cannot be compared directly to serious injury results because of the exclusion of children from the disability dataset, they offer additional insight into the outcome of injuries from different vehicle sources. The inclusion of disability in pedestrian crashes may be particularly important because of the high frequency of lower extremity injury in pedestrian impacts.

Although FCI as a measure of disability is limited in that the codes may be incomplete for AIS 90 and are unavailable for the AIS 90/update 98 version, FCI offers a method to compare the relative proportions of estimated disability resulting from impact with different vehicle structures. Updated FCI codes for the current version of AIS, as well as versions applicable to children or older adults will be useful for evaluation of pedestrian injury in the future. Case data on actual disability sustained by pedestrians, rather than FCI-estimated disability based on AIS-coded injuries, would also be valuable for the evaluation of outcome by age group.

*Limitations.*In the current study, injury regions and vehicle injury sources were grouped to allow only a broad look at which vehicle sources are associated with which injury types. This systematic, high-level view of the data precluded detailed analysis of individual injuries or injury sources, or estimation of the effects of pedestrian characteristics such as age or height or crash characteristics such as impact speed. Further analysis to understand how pedestrian injuries vary for children or older adults or the effect of impact speed will require a larger number of cases than those available for the current study. Additional work to understand the mechanisms and potential improvements for these individual combinations of injuries will involvea more detailed analysis of individual injuries and injury sources in the datasets.

The PCDS and GIDAS cases used in this analysis included relatively early-model vehicles, with median vehicle model years of 1993 and 1995 respectively. These datasets are the most recent large-scale, detailed pedestrian case studies available for the US and Germany. Collection and review of more current pedestrian cases involving late-model vehicles will be necessary to evaluate any recent or future improvements in pedestrian protection.

CONCLUSIONS

In evaluating the relative importance and frequency of injuries in pedestrian crashes, it is valuable to consider the frequency of *disabling* injury as well as *serious* injuries, particularly for consideration of the extremities and the pelvis & hip.

Although results from the US and European crash data differ as a result of the higher percentage of light trucks and vans in the US cases and other differences in the datasets, the most frequent injury combinations are the same in both datasets. When crash data was evaluated with respect to either serious or disabling injuries, the most frequent combinations of injuries are lower extremity injuries from bumper contact and

head injuries from windshield contact. Thorax injuries from hood contact are also frequent among serious injuries.

Although bumper injuries are primarily to the lower extremity and injuries from the windshield and surrounding area are most often to the head &face, other vehicle sources present injury risk to a broader number of body regions. Accordingly, it is appropriate to focus on lower extremity injury when evaluating injury risk from bumper impact and on head injury risk when evaluating windshield area injury risk. In contrast, injury risk from hood and hood leading edge impacts should be considered for multiple body regions in addition to the head. In particular, a better understanding of the effects of head protection countermeasures for the hood on injuries to the thorax, upper extremity, and pelvis & hip is needed. Additionally, pelvis & hip, thorax, and extremityinjury risk from hood leading edge impacts should be considered.

ACKNOWLEDGMENTS

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APPENDIX

Table A1 - Classification of vehicle injury sources by vehicle components

Injury Source Category	GIDAS Injury Source Values	PCDS Injury Source Values
A-pillar/Header	174 – Bottom section of A-pillar 552 – A pillar from front 553 – Front edge of roof 572 – A pillar, lateral	722 – A1 pillar (left) 742 – A1 pillar (right) 776 – Front header
Bumper/valence	521 – Front spoiler below bumper 522 – Front bumper 523 – Number plate	700 – Front bumper 701 – Front lower valance/spoiler 718 – Other front or add-on object* (*if specified as bumper-mounted license plate/frame only)
Grille/Lights	525 – Front grille, flat radiator 526 – Headlamp (integral)	702 – Front grille 706 - Headlight 708 – Turn signal/parking lights
Hood edge/trim	530 – Front edge of bonnet	703 – Hood edge and/or trim
Hood surface	540 – Bonnet surface	770 – Hood surface 771 – Hood surface reinforced by under hood component
Side/rear hood surround	543 – Rear edge of bonnet, air intake grille	772 – Front fender top surface 773 – Cowl area
Undercarriage/wheels/tires	500 – Run over 571 – Front wheel	790-819 – Wheel and undercarriage components
Windshield	544 – Windscreen wiper 550 – Windscreen, laminated safety glass 551 – Windscreen, single-layer glass	775 – Windshield glazing
Unknown	9 – Unknown	
Non contact	4 – Body motion e.g. whiplash	997 – Non-contact injury source
Other	5 – Rescue measures 8 – Other 337 – Collision partner 714 – Footrests, pedals 555 – Roof, front one third 580 – B pillar 590 – C pillar 529 – Front mudguard 541 – Outside mirror mounted on mudguard 554 – Roof aerial, front 577 – Exterior mirror 570 – Front mudguard, lateral 616 – Mudguard from rear 663 – Mudguard, front wheel	718 – Other front or add-on object* (*If specified as tow-hook or anchor only) 720/740 – Front fender side surface 724-739 – Left side components 744-759 – Right side components 777-789 – Roof and rear components
Environment	501 – Level road surface 502 – Potholed road surface 503 – Road surface with layers or add'l material 504 – Field, pasture 505 – Edge of kerbstone 510 – Fence 514 – Ditch	947 – Ground 948 – Other object in environment
Vehicle front, not further spec	520 Vehicle front	

Table A2 - FCI values assigned for AIS codes not included in FCI calculated for NASS CDS

AIS code	FCI	Basis
851614.3 Bi- or tri-malleolar fracture, open displaced or comminuted	14.53	Closed bi-malleolar or tri-malleolar fracture FCI = 14.53%
851800.3 Femur fracture, not further specified	14.53	All femur fractures to any site have FCI of at least 14.53%
852606.4, 852608.4, 852610.5 Pelvis fracture substantial deformation and displacement	63.4	Pelvis fracture (open, displaced, or comminuted) FCI = 63.4%
853404.2, 853405.3 Tibia fracture, not further specified	14.53	All tibia fractures to any site except medial malleolus have FCI of at least 14.53%[*].
752800.2 Radius fracture	43.39	All radius fractures any site have FCI of at least 43.39%.

[*]*In PCDS, only 3 of 147 tibia fractures were to medial malleolus*

Table A3 - Seriously-injured occupants in PCDS (n=193) and GIDAS (n=162) who sustained an AIS 3-6 injury in each body region/vehicle source category. Note that numbers do not total n because pedestrians can have serious injuries in multiple body region/vehicle source categories.

	Bumper/Valence		Hood surface		Hood edge or trim		Windshield/Wipers		APillar/Header		Other		Grille/Lights		Undercarriage, Wheels, Tires		Side/Rear Hood surround		Environment		Non contact, Unknown, Vehicle front NFS	
	PCDS	GIDAS	PCDS	GIDAS	PCDS	GIDAS	PCDS	GIDAS	PCDS	GIDAS	PCDS	GIDAS	PCDS	GIDAS	PCDS	GIDAS	PCDS	GIDAS	PCDS	GIDAS	PCDS	GIDAS
Head&Face	3	0	18	7	2	1	52	24	19	17	6	2	0	0	1	0	7	0	14	19	2	8
Neck	0	0	4	1	1	0	5	1	4	4	0	0	0	0	0	0	2	0	1	3	0	2
Thorax	2	1	33	20	15	1	7	9	5	8	5	3	3	0	3	0	3	0	0	12	0	10
Abdomen	1	1	5	6	8	1	1	4	0	0	1	0	2	0	2	0	0	0	0	1	0	3
Pelvis&Hip	1	1	10	6	19	5	1	0	1	1	1	0	6	0	2	0	2	0	2	4	0	0
Upper Extremity	1	1	16	5	6	0	2	1	5	0	2	1	3	0	0	0	2	0	0	7	0	4
Lower Extrrem.	83	56	1	1	4	4	0	2	3	0	8	5	6	2	7	1	0	0	1	3	0	15

Table A4 - Percentage of total disability in PCDS and GIDAS attributable to each body region/injury source combination, estimated by FCI based on AIS-coded injuries, with cases weighted by injury severity to be representative of national data.   Note that percentages do not add to 100% because a proportion of disability cannot be attributed to a single body region or injury source.

	Head&Face		Neck		Thorax		Abdomen		Pelvis & hip		Upper Extremity		Lower Extremity	
	PCDS	GIDAS	PCDS	GIDAS	PCDS	GIDAS	PCDS	GIDAS	PCDS	GIDAS	PCDS	GIDAS	PCDS	GIDAS
Bumper/Valence	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	1.7	0.3	0.0	0.0	22.9	29.7
Hood surface	3.3	0.0	0.0	0.0	0.0	0.3	0.0	0.0	0.7	2.8	3.3	5.0	0.0	0.8
Hood edge or trim	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	6.5	4.1	1.2	0.0	0.5	1.9
Windshield/Wipers	8.8	6.0	0.0	0.0	0.2	0.0	0.0	0.0	0.0	0.0	3.5	0.0	0.0	0.0
A-Pillar/Header	2.1	0.5	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.3	0.0	1.7	0.0	0.3
Other	2.9	0.0	0.0	0.0	0.0	0.3	0.0	0.0	0.0	1.7	0.7	0.0	1.2	1.4
Grille/Lights	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	1.7	0.0	0.5	0.5
Undercarriage/tires	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	4.4	0.0
Side/rear hood surround	1.4	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.7	0.0	0.0	0.0	0.0	0.0
Environment	4.9	2.6	0.8	0.0	0.0	0.0	0.0	0.0	0.6	6.6	2.8	8.6	0.9	2.8
Non-contact	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.6
Not attrib to single source	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0