Pedestrians interacting with a passenger car; a study of real world accidents

Magdalena Lindman, Lotta Jakobsson, Sofia Jonsson

Abstract Pedestrian safety priorities for passenger cars are usually based on data with varying car makes and models. This study presents a new database, V_PAD (Volvo Cars Pedestrian Accident Database), with a homogeneous car sample providing a relevant, up-to-date distribution of accident situations as well as pedestrian characteristics and driver information.

A total of 330 pedestrian car accidents are analyzed with the aim to present a first summary of the V_PAD data in terms of accident, injury and impact aspects. The database with cars of the same types gives unique possibilities to design and evaluate effective safety measures for pedestrian safety. The results in this study will form the basis for further improvements, both considering driver support and crash compatibility.

Keywords accident scenarios, AIS2+ injury, pedestrian, real world traffic accident data

I. INTRODUCTION

From a car manufacturer's perspective, in order to contribute to the reduction of injuries or accidents and set the right priorities, it is important to have knowledge about the character of real world accidents with cars relevant for the manufacturer. Also, as results from legal and consumer testing show significant differentiation between different car models, it is important to have a sufficiently large and homogenous data set in terms of the cars involved from which to work.

For car-to-pedestrian accidents, such knowledge is not readily available. First, the databases on hand usually contain a heterogeneous vehicle population. GIDAS, On-The Spot (OTS) and Pedestrian Crash Data Study (PCDS) are all comprising regularly referenced pedestrian accident datasets. GIDAS is a set of traffic accidents in Germany that are thoroughly investigated and analyzed in an extensive and well-defined process [1]. The large subset with pedestrian-car accidents are described in a number of publications [2]-[5]. The OTS project investigates pedestrian-car accidents collected in the UK [6]. In US, the PCDS provides information regarding pedestrian-car impacts [7]. Also, car-pedestrian accidents in urban areas of Spain [8], China [9] and Berlin, Germany were studied [10]. Second, most publications of car-pedestrian collisions focus on frontal collisions, while in fact impacts caused when the car is reversing are just as important (usually in a parking context). Further, in many studies the analysis is limited to a specific pedestrian injury severity level, age group, or excludes certain types of driving locations.

For a car manufacturer, who ideally would prefer to work with a modern and homogenous car-make sample that includes all types of pedestrian accidents, these limitations pose a difficult challenge. The aim of this study is to present a first summary analysis of a new database, the Volvo Cars Pedestrian Accident Database, which is designed to overcome this challenge. The database is intended to provide a basis for further developments within the pedestrian-car accident research area, aiming at priorities for active, integrated and passive safety measures, as well as comparative analyses with other pedestrian car accident databases.

Magdalena Lindman is Senior Research Engineer at Volvo Cars Safety Centre
(phone: +46 31 3256257, fax: +46 31 595922, e-mail: mlindman@volvocars.com)
Lotta Jakobsson is Safety Technical Leader at Volvo Cars Safety Centre and Adjunct Professor at Chalmers University of Technology in Sweden.
Sofia Jonsson is Data Management Specialist at Volvo Cars Safety Centre, employed by Volvia (IF P&C Insurance).

II. METHODS

In this study, pedestrian accidents with passenger cars in the Volvo Cars Pedestrian Accident Database, V_PAD, were analysed to identify frequent injuries and car impact points as well as the underlying mechanisms in terms of the accident situation.

Database

V_PAD contains extensive information on pedestrian accidents with a homogeneous and modern car fleet. The information about pedestrian accidents in Sweden involving Volvo Cars was provided by Volvia (IF P&C Insurances) to Volvo's Traffic Accident Research Team and stored in the V_PAD database. All new Volvo passenger cars in Sweden are insured with Volvia for at least three years. Thus all pedestrian accidents were identified and sampled both for the newest vehicles as well as for a large portion of the older vehicles. The database contained information about the pre-crash scenario, the crash, the car, the driver and the pedestrian, in a total of 126 variables. Each case was anonymised before being stored in the database.

The information provided by the insurance company came from several sources, including the vehicle accident report, the pedestrian accident report, the police report, vehicle specification/information system, personal contacts with the victims taken by the insurance company and internet map data sites. A vehicle accident report was available for every case, since drivers in Sweden are obligated to report pedestrian accidents to the insurance company. In most cases an accident report was filed by the pedestrian as well. The vehicle report contained information about course of events from the vehicle perspective, such as estimated speed at impact, traffic environment (often described by a sketch), pedestrian impact points, car damage, driver distraction elements and a description of injuries sustained. For cases where police were at the scene there was also a police report which included a sketch of the accident scene and witness statements from the driver, the pedestrian and any additional witnesses. During the process where the insurance company handled the insurance claim, further information was collected such as notes from conversations with the pedestrian and the driver. Vehicle specification/information systems were used to add additional vehicle information, such as color, specific equipment and optional safety systems. Internet map data sites provided further valuable information on the accident scene. Medical records and/or autopsy reports for those involved were collected through an informed consent procedure, and coded by a physician within Volvo's Traffic Accident Research Team, according to the Abbreviated Injury Scale (AIS) [11]-[12]. No attempt was made to assign a pedestrian injury to a specific impact area; all injuries are regarded as sustained in the car-pedestrian accident from either impact against a part of the car, the ground or the surroundings. In cases where photos of the car damage were available, experts within the Volvo accident research team coded the car deformation following SAE recommended practice [13], along with pedestrian impact point x-, y- and z-coordinates. At time of the analysis, 359 pedestrian cases occurring 2000-2010 were stored in the database.

Sample

For this study, all accidents which contained information on the pedestrian overall injury were selected. For accidents involving more than one pedestrian (n=12), only the first impacted pedestrian was included in the sample. This resulted in a main sample of 330 car-to-pedestrian-accidents to be further analyzed. The distribution of car model years in the dataset is shown in Figure 1.

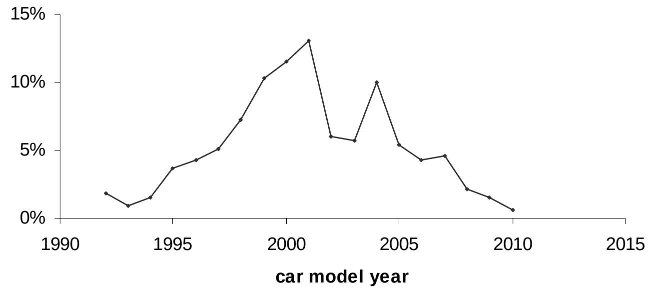

Fig. 1: Distribution of car model years (Q_1=1999, Q_3=2004).

Three datasets from the database, as illustrated in Figure 2, was used for the different purposes of the analysis. The main sample of 330 car-to-pedestrian-accidents was used for the study of accident characteristics.

For the injury analysis, detailed injury information was available for 326 pedestrians, including a total of 1007 injuries. Two pedestrians were uninjured and in two cases, the pedestrians were first hit by the car included in the dataset and thereafter run over by another car. The injuries associated with the specific car-pedestrian accident were thus difficult to specify. AIS1985 was used for this analysis. In terms of where the pedestrian impacted the car, a total of 239 vehicle contact areas from 156 cases were coded in the main dataset. In all cases where the car was damaged at the pedestrian contact, exact impact points based on observations of damage to the car (i.e. from pictures rather than witness statements) were available for 61 of the cases.

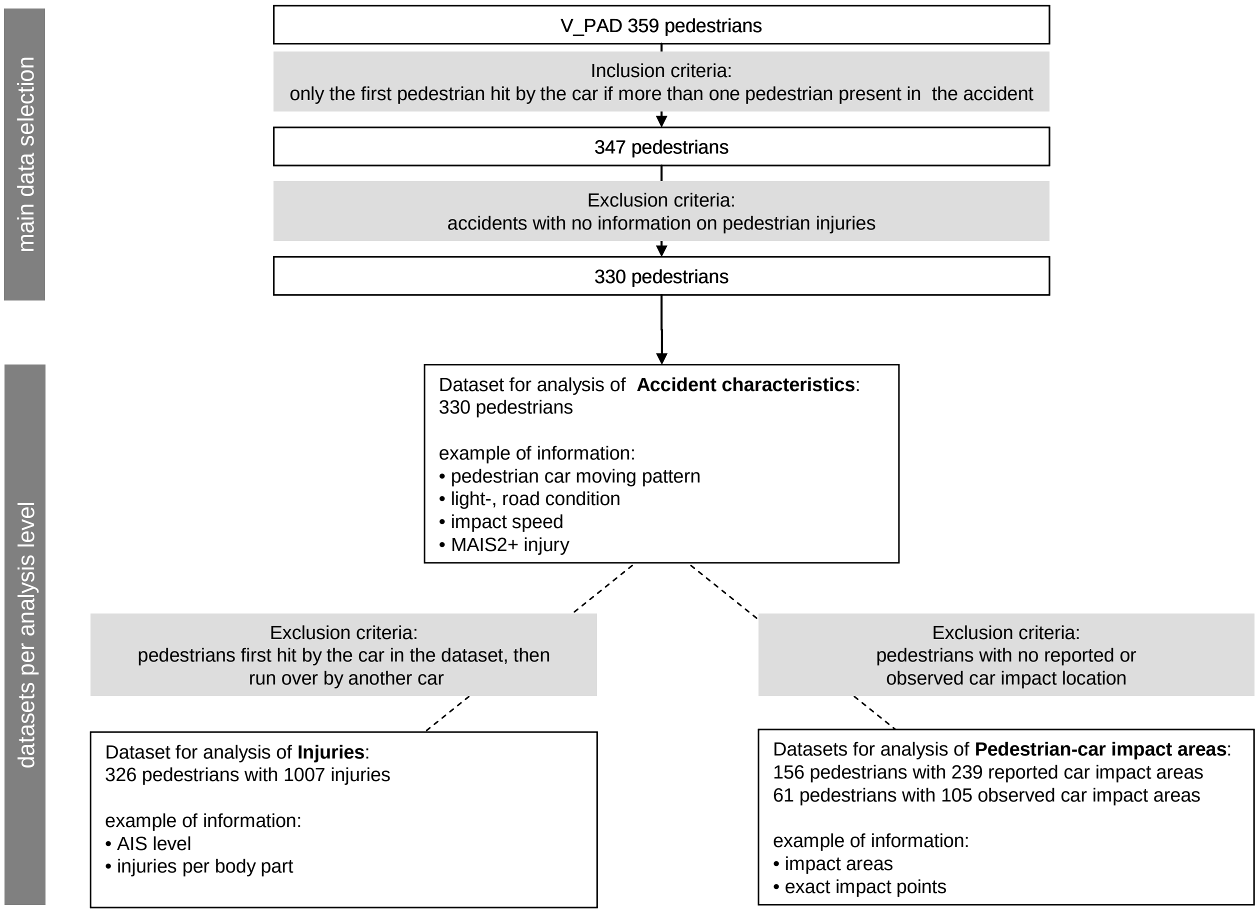

Fig. 2: Overview of data selection and datasets.

Definitions and analysis

The cases were separated into two main groups based on moving direction (forwards or backwards). Forward-moving cases were further subdivided into moving pattern clusters as described in Figure 3. Car reversing were not sub grouped, since information on pedestrian movements and position prior to impact usually is lacking for this accident type. The cars were classified as large cars (Volvo S80, V70, XC70, S60 and 800 models), small cars (Volvo S40, V40, V50 and C30 models) and SUVs; (Volvo XC90 model). The pedestrians were grouped by age; juniors (up to 14 years old), adults (15-64 years old) and seniors (65 years or older). The risk of sustaining a MAIS2+ injury was calculated using the most severe injury per pedestrian and case. Risk was defined as the number of MAIS2+ injured pedestrians divided by the total number of pedestrians involved (injured as well as uninjured); binomial proportion confidence intervals were used.

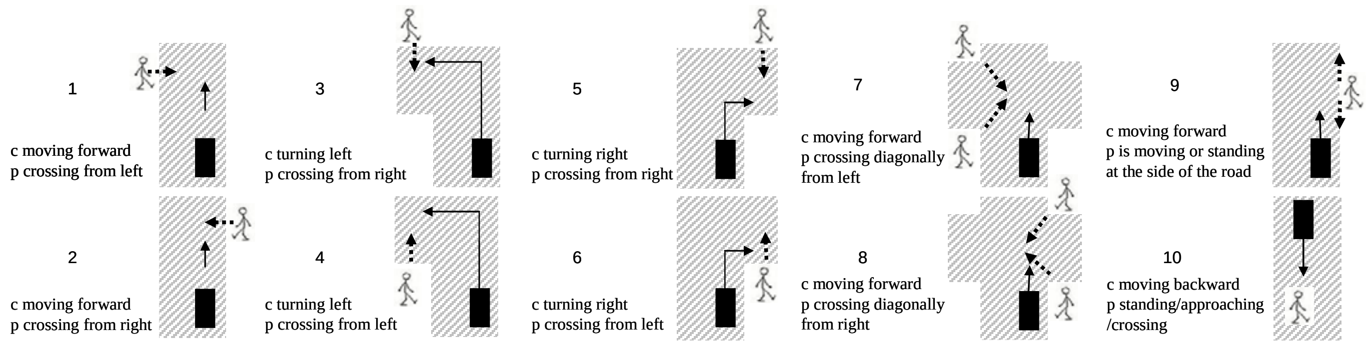

Fig. 3: Definitions of vehicle-pedestrian moving patterns.

III. RESULTS

In the following, characteristics of how pedestrians interact with a passenger vehicle during a crash are presented in terms of accident characteristics, injuries and pedestrian-car impact area aspects.

Accident characteristics

Among the 314 cases with known moving direction and pattern, 75% of the accidents occurred when the car was moving forward (moving patterns 1-9 in Figure 3) and 25% when the car was reversing (moving pattern 10 in Figure 3). As can be seen in Table 1, the most frequent moving patterns are "2, Car moving forward and pedestrian crossing from the right" (mp2), followed by "10, Car moving rearward" (mp10) and "1, Car moving forward and pedestrian crossing from the left" (mp1). These three moving patterns include 82% of all the cases with known moving direction and pattern in this dataset.

Accidents involving forward-moving vehicles mostly involved adult pedestrians (in total 149 cases for the 15-64 years age group), while 59 seniors and 29 children were impacted by a forward-moving car. In the 77 cases of reversing cars, only four children were involved, while the senior and adult group were approximately the same size (37 and 36, respectively). The involvement of adult pedestrians follows the overall frequency of the moving patterns, while junior pedestrian accidents are overrepresented in mp2 and underrepresented in mp10. Senior pedestrians on the other hand are overrepresented in reversing situations but less common in mp2, though this still is the second most common moving pattern for that age group.

Table 1. Distributions of cases per pedestrian accident moving patterns, separated per pedestrian age group.

moving pattern (mp) (c=car, p=pedestrian)	No. of cases	% of cases	% of Junior n=34	% of Adult n=196	% of Senior n=100
1. c moving forward , p crossing from left	65	19.7	20.6	21.4	16.0
2. c moving forward, p crossing from right	114	34.5	58.8	34.7	26.0
3. c turning left, p crossing from right	13	3.9	0	4.6	4.0
4. c turning left, p crossing from left	11	3.3	0	3.1	5.0
5. c turning right, p crossing from right	0	0	0	0	0
6. c turning right, p crossing from left	6	1.8	0	2.6	1.0
7. c moving forward, p crossing diagonally from left	3	0.9	0	1.5	0
8. c moving forward, p crossing diagonally from right	1	0.3	0	0	1.0
9. c moving forward, p moving /standing at the side of the road	24	7.3	5.9	8.2	6.0
10. c moving backward, p standing /approaching /crossing	77	23.3	11.8	18.4	37.0
not classified	16	4.8	5.6	5.6	4.0

Next, the three most common vehicle-pedestrian moving patterns (mp1, mp2 and mp10) were compared to all moving-forward accidents, as well as to the full dataset (all moving forwards and reversing), on a set of scenario variables and MAIS2+ injury prevalence.

For vehicles moving forward, 36% of crashes took place in darkness and 45% when the road was wet, snowy or icy (Table 2). 9% occurred in a parking area. In almost half of the cases, the driver was not aware of the pedestrian before impact. The most common moving pattern (mp2) generally follows these distributions. Both mp1 and mp10 however differ from the full dataset. For mp1, significantly more accidents occur in darkness. Also, the pedestrian was running more often compared to the total sample. For mp10, there are fewer accidents in darkness and on wet, snowy or icy roads.

Impact velocity estimations were available in 233 cases. The results are shown in Figure 4, comparing the full dataset with all cars moving forward as well as the three most common moving patterns, for all pedestrians and for those sustaining MAIS2+ injuries. Mean impact speed for car-moving-forward accidents was 30.3 kph (S.D. 20.7) for the whole group (n=186) and 33.3 kph (S.D. 20.0) for pedestrians sustaining a MAIS2+ injury (n=99). Overall, impact velocities were lower in reversing accidents and higher for MAIS2+ accidents. Comparing mp1 to all forward-moving accidents, 35% of mp1 cases are below 30 km/h impact velocity, as compared to 74% for car-moving-forward situations.

Considering the full data sample, the risk of a MAIS2+ injury is higher when the vehicle is travelling forward than when reversing (Figure 5). Senior pedestrians suffer a higher MAIS2+ injury risk (64%, CI 54%-73%) compared to adult pedestrians (43%, CI 36%-50%), and the highest MAIS2+ injury risk is seen when the car is moving forward and a pedestrian is crossing from the left (mp1) regardless of age group.

Table 2. Prevalence of a selection of pedestrian accident scenario relevant variables for the three most common moving patterns. *Significantly different from the full dataset, ° significantly different from all cases where the car is moving forward.

	moving pattern 1	moving pattern 2	moving pattern 10	ref: car moving forward	ref: full dataset
light condition=darkness	49.2*°	30.4	18.0*	35.6	31.3
road condition=wet, snowy or icy	52.3	47.0	18.0*	45.1	38.9
accident location=parking space	6.15*	8.7*	52.6*	8.7	19.0
driver did not see the pedestrian before the collision	52.3	49.5	84.6*	48.2	56.9
pedestrian velocity=running	21.5*	13.0	0*	12.7	9.6
pedestrian thrown up on the car during collision	16.9	15.6	0*	15.8	12.1

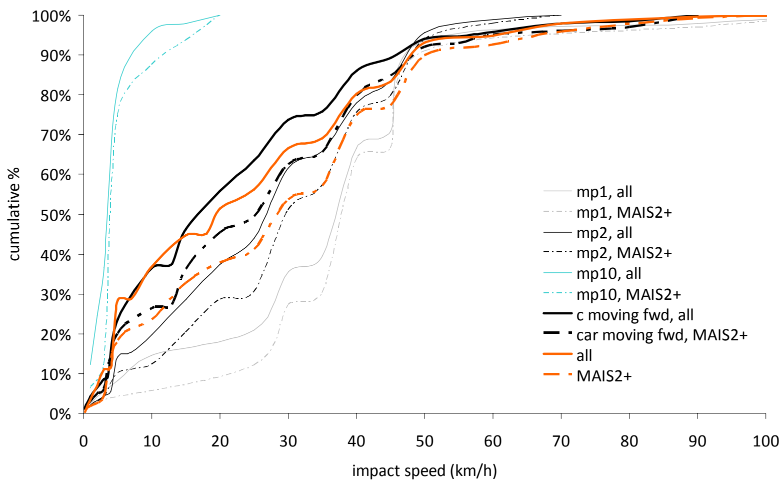

Fig. 4: Cumulative distribution of impact speeds, comparing the full dataset with cars moving forward and the three most common moving patterns for all pedestrians and those sustaining MAIS2+ injuries.

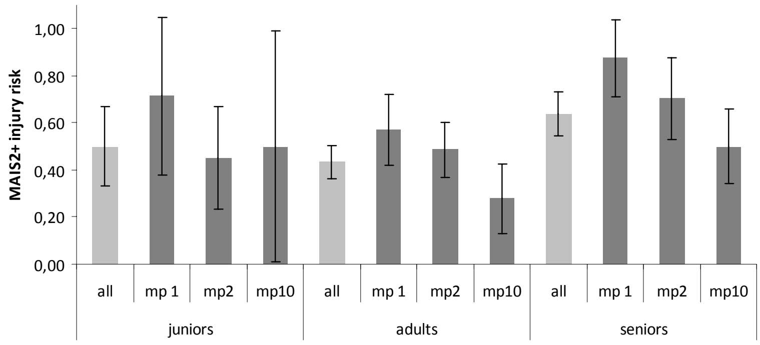

Fig. 5: MAIS2+ injury risks per pedestrian accident moving patterns and age groups.

Injuries

Injury frequency and severity is summarized in Table 3, based on age groups and car moving direction. 326 pedestrians sustained in total 621 AIS1 injuries and 386 AIS2+ injuries. AIS2+ injuries account for 38% of all the injuries in these data, and the proportion of AIS2+ injuries is higher when the vehicle is moving forward (41%) than when it is reversing (27%).

The most frequent AIS2+ injured body parts were the lower extremities (34%) followed by the head (24%), upper extremities (15%), chest (8%), pelvis (7%), spine (5%), face and abdomen (3% each) (Table 4). The AIS2+ injured body part distribution in forward-moving cases follows the overall distribution, while more injuries to the upper extremities and the chest and less injuries to the lower extremities are noted when the cars is reversing.

Among the AIS2+ head injuries, concussions followed by hemorrhages and fractures are the most common type of injuries. AIS2+ upper extremity injuries are almost solely fractures, mostly to the arm (27%) followed by the forearm and at the elbow (15% each). The AIS2+ lower extremity injuries are more than 80% fractures, the majority to the leg (51%) for all age groups.

Table 3. Numbers of injuries per AIS level for the three age groups and car moving direction.

	Car moving forward				Car reversing			
	Juniors	Adults	Seniors	All	Juniors	Adults	Seniors	All
AIS 1	60	320	92	472	3	88	58	149
AIS 2	21	133	81	235	3	14	24	41
AIS 3	6	39	13	58	0	4	5	9
AIS 4	2	13	5	20	0	0	3	3
AIS 5	4	7	4	15	0	0	2	2
AIS 6	0	3	0	3	0	0	0	0
Total	93	515	195	803	6	106	92	204

Table 4. Numbers of AIS2+injuries per body part for the three age groups and car moving direction.

	Car moving forward				Car reversing			
	Juniors	Adults	Seniors	All	Juniors	Adults	Seniors	All
head	13	46	18	77	2	3	10	15
face	0	10	0	10	0	0	2	2
spine	1	11	6	18	0	0	2	2
up. ext	2	32	14	48	1	3	7	11
chest	2	18	3	23	0	2	5	7
abdomen	0	12	1	13	0	0	0	0
pelvis	3	12	8	23	0	1	3	4
lower ext	12	54	53	119	0	9	5	14
Total	33	195	103	331	3	18	34	55

Pedestrian- car impact areas

Addressing car impact aspects, the distribution of 239 vehicle contact areas in 156 cases are grouped and presented in Table 5 based on moving direction and age group. When the vehicle was reversing, the most frequent contact areas were the rear bumper area followed by the tires and the rear-view mirrors. When the car was moving forward, the most frequently impacted areas were front bumper area, windscreen area and the hood followed by the side including the rear-view mirrors. 40% of the car impacts by junior pedestrians were to the side of the vehicle; these numbers were lower for the older pedestrians. The windscreen area accounted for 20 and 23% of the contact areas for the adults and seniors, respectively, while only 15% for the juniors.

In the 61 cases where the car was damaged by the pedestrian contact, the impact coordinates were documented for a total of 105 impact points. Impact speeds in these accidents ranged from 2 km/h to 90 km/h. Although it is not possible to associate exact pedestrian injury to a specific car impact point, it is interesting to note that all levels of overall pedestrian injury are present in these 61 cases. 36 pedestrians sustained MAIS2+ injuries, while 25 pedestrians sustained MAIS1 injuries only. The distributions of 52 impacts to the hood and windscreen area are plotted for the different age groups on the two sizes of generic Volvo car models (Figure 6). A variety of spread of impact points can be seen and no clear differences between the age groups are evident.

Table 5. Numbers of vehicle parts contacted for the three age groups and car moving direction.

	Car moving forward				Car reversing			
	Juniors	Adults	Seniors	All	Juniors	Adults	Seniors	All
Front bumper area, incl. headlights	5	34	13	52	0	0	0	0
Hood	3	25	5	33	0	0	0	0
Windscreen, A-pillars, header, plenum	4	29	10	43	0	0	0	0
Roof	0	1	0	1	0	0	1	1
Side, rear view mirrors, fenders	12	45	11	68	0	0	2	2
Rear bumper area	0	0	0	0	2	8	6	16
Wheels	3	9	5	17	0	3	3	6
Total	27	143	44	214	2	11	12	25

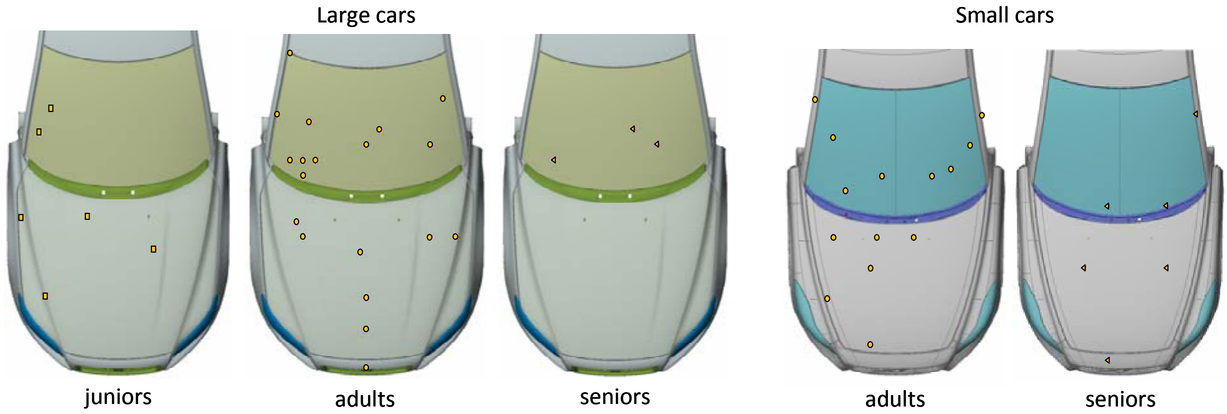

Fig.6: Distribution of impact points for all pedestrian contacts resulting in car damage on the hood or in the windscreen area, for pedestrian age groups and for large and small cars respectively.

IV. DISCUSSION

Setting priorities and developing effective measures for pedestrian passenger car accidents require a detailed understanding of accident occurrences and consequences. Results from legal and consumer testing show differentiation between different car models and further extensive car impact testing in order to evaluate the specific car compliance are suggested [14]. Also, field accident data studies [15] confirm that type of car influence the pedestrian injury risk. The need for a traffic accident database that is homogenous in terms of car models came up when the potential effectiveness of a technology designed to support the car driver in mitigating or avoiding pedestrian accidents was estimated [16]. Hence, a homogeneous database is a necessity for a devoted car manufacturer to address and contribute to pedestrian safety improvements.

This study presents the first car-make homogeneous database known to date, providing representative distributions of accident situations, pedestrian characteristics and driver information. The data used cover all pedestrian accidents which occurred between 2000-2010 with all Volvo cars in Sweden the first three years after production. For older cars the coverage is more limited, but still substantial. No missing cases due to lack of questionnaire responses are biasing the database. Hence, this data set covers a representative view of pedestrian impacts in Sweden on modern Volvo cars accidents, thus providing a basis for understanding accident occurrences and consequences giving valuable knowledge for improved vehicle design.

The analysis presented is based on a sample of 330 cases. Compared to other often referenced datasets, this is a substantial amount taking into account the homogeneous car-make sample and the representative accident collection procedure. Although differences are expected in distributions of accident scenario relevant parameters and injury occurrence, comparisons with the forward-moving vehicle subset show as much overall similarities to findings from other databases that could be anticipated, given that case selection criteria for the studies mentioned are not identical to that of V_PAD. For example, compared to GIDAS data in [5], V_PAD includes slightly more MAIS2+ injured pedestrians (54% as compared to 45%), but about the same share of MAIS3+ injured pedestrians (15% as compared to 16%) and fatally injured pedestrian (5% for both). Again in V_PAD, 85% of the pedestrians were impacted at speeds below 40 kph. This is somewhat higher but still in correspondence with GIDAS [2], [4] and OTS [6], which report a range from 77.5%-80%. According to the US-database PCDS, over 50% of the vehicles were traveling at speeds less than 20 miles per hour at impact [15]. Considering pedestrian injuries, this data set contains on average 3.1 injuries per pedestrian, which is quite similar to the GIDAS data [2]. However, in the US-data 7.5 injuries per pedestrian are seen [15]. All data sets contain 61-65% AIS1 injuries. Concerning AIS2+ injured body parts, the percentage of both injured upper and lower extremities are slightly greater in the V_PAD data analyzed than in GIDAS and PCDS and the share of head injuries is a bit lower. Thus, from an overall perspective, V_PAD seems to share the typical properties of other available pedestrian accident data sets, while offering the added advantage of a homogenous car-make sample and detailed vehicle information.

One area of future improvement concerns the estimation of impact speeds. These are known to highly influence the injury outcome in a pedestrian-car accident, and distributions and risk assessments in relation to speed are highly sensitive to errors in the assessment of impact speed. To date, the coded impact velocity in

V_PAD is based on an expert judgment by the Volvo accident research team, using the different available information sources (police report, witness statements etc). For the future, this could probably be improved by performing more complete reconstructions, since the amount of information available for most cases is sufficient for that purpose. This would enhance the usability of the database in future studies, such as when developing car-model relevant risk functions which is of use in both the target-setting processes and when estimating the benefit of an injury-preventing system.

Accident scenarios describe the traffic situation and driver actions that precede an accident event and are hence sensitive to the infrastructure, traffic elements and driving culture. The results presented in this study are representative for Sweden and countries of similar driving culture and infrastructure. Since injuries sustained in the car-pedestrian impact are more correlated to the characteristics of the impacting car than to details of the traffic environment, conclusions drawn from V_PAD on passenger-to-car interactions should be valid for Volvo cars in any traffic environment.

The main challenge with respect to injury analysis in pedestrian accidents is how to determine the specific injury mechanisms. The pedestrian-car impact is very difficult to reconstruct based on the data typically available in retrospectively collected data. Further, during the post pedestrian-car impact sequence, numerous possible injury sources appear. Enhanced quality of input data is needed to fully understand pedestrian-car impact events and to validate accident reconstruction results. Nevertheless, the overall and complete picture of pedestrian injuries supplied by the dataset analysed is important information in setting priorities and developing effective measures. Regarding the pedestrian-car impact information available in almost half of the cases analyzed, impacts reported by the police, driver or pedestrian is presented. It is probable that impacts are missed due to subjective reporting. On the other hand, information from cases where the impact lead to a car deformation, as shown in Figure 6, provides an essential and valuable view on pedestrian harm since this subset represents all cases where the car was damaged at the pedestrian contact.

In summary, this study provides an overview of a new data set, V_PAD, which has been collected to further investigate pedestrian and passenger car interactions based on a homogenous car-make sample taking injured as well as uninjured pedestrians and all driving directions into account. The homogeneity of the database gives unique possibilities to design and evaluate effective safety measures for total pedestrian safety. The results in this study will form the basis for further improvements, emphasizing the focus on both supporting the driver and further improvement on crash compatibility.

V. CONCLUSIONS

A homogenous car-make database providing relevant and up-to-date distributions of accident situations, pedestrian characteristics and driver information is a prerequisite for design of effective active, integrated and passive safety measures. In this study, an overview of the first known homogenous car-make pedestrian traffic accident database, the Volvo Pedestrian Accident Database (V_PAD), was presented and comparisions made with related data sets in order to assess V_PAD's potential as such data set. As the set covers all car moving directions, accident locations, injured as well as uninjured pedestrians for all age groups within a homogenous car-make sample it very likely can fulfil that role, i.e. provide the basis for a holistic analysis of how to further enhance pedestrian safety.

VI. ACKNOWLEDGEMENT

The authors thank colleagues at Volvo Cars Safety Centre, Volvia and IF P&C Insurance for their support with preparation of the database.

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