Injury Observations in High-exposure, Low-severity Frontal Car Crashes - a GIDAS Investigation

Martin Östling, Hanna Jeppsson, Jason Forman

Abstract In this study, we identify the most common crash configurations, injured body regions, and injuries in low-severity crashes (here defined as crashes with EES below 35 km/h). In addition, we investigate how sex, age, anthropometry (weight, height, and BMI), car size, and registration year influence the risk of sustaining an AIS2+ injury.

Injured belted occupants are predominantly of relatively average size and age, closely following the distribution of all belted occupants exposed to crashes. Likewise, the crash configuration distribution of low severity crashes resulting in AIS2+ injury closely matched the distribution of all low-severity crashes, where a full-frontal crash was the most frequent crash configuration. Females in general, are at a higher injury risk compared to males. Thereto, injured occupants were on average 5 years older compared to all occupants exposed to low-severity crashes. Head, thorax, and upper extremities are the most commonly injured body regions for middle-aged occupants while younger occupants are more frequently injured to head, and elderly more frequently injured to thorax. The majority of the injuries was of AIS2 level.

Occupants in low-severity crashes were in general at a relative low injury risk (5.6%). To further reduce the relative low injury risk presents a substantial challenge since current injury risk functions, evaluation tools, and assessment methods are developed for substantially higher injury risks and crash severities and might therefore not be applicable for these high-exposure low-severity crashes.

Keywords AIS2+ injuries, high-exposure low-severity frontal crashes, injury distribution.

I. INTRODUCTION

In the EU more than one million road users were injured in crashes involving cars during 2018, with car occupants accounting for the largest group (approximately 650,000) [1-2]. Frontal crashes are the most frequent crash mode where car occupants are seriously injured or killed in both the US [3-4] and EU [5-6]. The majority of frontal crashes where car occupants are injured occur at relatively low crash severity, i.e. crashes with equivalent delta velocity below 35 km/h [7-11]. Such crashes normally result in relatively low injury risk on a per-crash basis, but due to the very high number they result in a large proportion of the injury cases that occur [8-9]. Furthermore, focusing on belted occupants and not unbelted helps to investigate injury trends that remain when making use of modern restraint systems. Consequently, it was decided to further investigate low-severity frontal crashes with belted occupants in this study.

When evaluating crashworthiness and occupant protection, the conventional approach is to (1) define a test condition representing the crash, (2) run a laboratory test at this single crash condition (crash object, crash severity, impacted area, occupant seated position, occupant anthropometry, etc), and (3) use a human surrogate such as an anthropomorphic test device (ATD) and a set of pass/fail injury criteria based on validated injury risk functions. However, ATD measures below the specified thresholds are considered to still carry some acute risk of injury, due to natural injury tolerance variation. This way of evaluating occupant protection performance has served us well, as evidenced by the dramatic improvements in occupant protection performance since the 1970s [12-14]. However, there are indications that occupant protection performance improvement of newer cars has plateaued in the last 10 years [15-16] suggesting that additional work is needed to continue to improve car safety. Considering that high-exposure, low-to-moderate speed crashes, i.e. crashes below 35 km/h delta velocity, continue to comprise a substantial portion of the injury cases in the field, it is likely that additional safety gains may be made through expanding our typical evaluation approach to include those crashes (to complement safety evaluations at higher severities, i.e. crashes above current legal and rating test speeds [9][17]).

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The overall injury probability in a car crash can, in a simplified way, be described as the integral of a function representing the product of the injury risk and the exposure over the whole range of crash severities [18-19]. The vast majority of exposures are of relatively low crash severity. As a result, despite the relatively low per-crash injury risk, a majority of crashes resulting in injury are of relatively low crash severity. Therefore, an implementation of a low-severity crash test, such as proposed by European New Car Assessment Programme (Euro NCAP) for 2026 [20], is an encouraging step on the way to address crash severity variability with consideration of high-exposure crashes. However, crash severity is just one parameter that varies in crashes. Occupant variations in terms of height, weight, age, and sex, also vary widely, and likely affect the injury outcome in crashes [21-22]. To further improve real-world occupant protection performance, we need to identify priority populations [23] indicating who is most frequently injured and who is at higher injury risk. With this information, future cars may be able to utilise the increasing availability of data streams sensing crash severity and occupant characteristics to modify the restraint performance to fit the scenario. This may include advanced triggering algorithms working with current restraint technologies, or novel systems with expanded capability for adaptivity.

The goals of this study were to investigate the demographic distributions, crash configurations, car sizes, and injury patterns present in cases of high-exposure frontal low-severity crashes with belted occupants. Prevention priorities were further elucidated by examining the injury distributions present in crashes of various severities, occupant age groups, and seat belt pretensioner activation status.

II. METHODS

This study examined field data with the purpose to increase knowledge about how injuries occur, who are injured, and why belted front row occupants are injured in low-severity frontal crashes. In addition we compared occupants exposed to crashes and occupants experiencing various degrees of injury in terms of crash severity, anthropometry, age, car size, and seatbelt pretensioner activation status.

Generation of the Dataset

The crash data used in this investigation were extracted from the German In-Depth Accident Study (GIDAS) database, released January 2023. GIDAS is an extensive crash database containing detailed information about the environment, the vehicles involved, their occupants and sustained injuries. All information is collected from on-scene accident investigation [24]. The GIDAS inclusion criteria requires at least one suspected injured crash participant. The data used were extracted in a 3-stage process: (1) Vehicle level, (2) Occupant level, and (3) Injury level. All variables used in the inclusion criteria for the preselection of the GIDAS subset are described in Table AI-AIII, Appendix A.

Vehicle level Selected vehicles were registered as a passenger car (defined by UN-ECE class M1, i.e. vehicles used for carriage of passengers, comprising not more than eight seats in addition to the driver's) with registration year, i.e. when the car was first put into use, 2000 or later involved in a single event crash with another M1 vehicle or an object. Further, only cars impacted to the front, and cars impacted to the side, but in front of the A-pillar, were included. The purpose with this selection was to include all crashes where the frontal restraint system potentially protects the front row occupants. We excluded cars with fire, rollover, and unknown delta velocity and Energy Equivalent Speed (EES). This resulted in 5,950 cars involved in crashes, consisting of 5,362 car-to-car crashes, and 588 car-to-object crashes.

Occupant level In these 5,950 cars, only belted occupants in the front seat, 13 years or older were selected. Further, we excluded ejected occupants and occupants with unknown Maximum Abbreviated Injury Scale (MAIS) level according to the AIS codebook of 2015 [25]. The above criteria resulted in 6,284 occupants whereof 3,585 were males and 2,699 females. The majority of the occupants was uninjured (MAIS0) or did only sustain minor injuries (MAIS1), 90.5% and 92.9% of the females and males, respectively, Table I

Injury level 513 occupants (257 females and 256 males) sustained one or more moderate or more severe injury (AIS2+) according to the AIS scale [25]. The 513 occupants sustained in total 717 AIS2+ injuries, when considering only the highest injury per body region.

The total count (6,284) is our exposed occupants and the AIS2+ count (513) is our injured occupants. Since we only conducted descriptive analysis, comparing exposed and injured occupants, it is difficult to find a match in the German national statistics and therefore we did not weight the data. However, we checked that the uninjured and minorly injured occupants were evenly distributed between all groups.

TABLE I
PROPORTIONS AND COUNTS PER MAIS INJURY LEVEL FOR MALE, FEMALE, AND ALL OCCUPANTS.

MAIS	Male		Female		All	
	Percent	Count	Percent	Count	Percent	Count
0	60.2	2,158	39.4	1,064	51.2	3,222
1	32.7	1,171	51.1	1,378	40.5	2,549
2	5.6	201	7.9	213	6.6	414
3	1.0	37	1.2	33	1.1	70
4	0.3	10	0.2	6	0.3	16
5	0.2	7	0.2	5	0.2	12
6	0	1	0	0	0	1
	∑ 100	∑ 3,585	∑ 100	∑ 2,699	∑ 100	∑ 6,284

Description of the Dataset

All 6,284 occupants, i.e. both uninjured and injured, were stratified into weight, height, and body mass index (BMI) groups excluding occupants with unknown weight and height. For the female data there were 853 and 777 occupants with unknown weight and height, respectively. For the male data there were 1,082 and 1,013 occupants with unknown weight and height, respectively. From the weight, height, and BMI groups, 10th and 90th percentiles were calculated for both sexes, Table II. The percentiles in terms of weight and height correspond well to earlier published data of Caucasian populations [26] indicating that the dataset is representative in terms of population variation. The weight, height, and BMI percentile groups were later used to calculate the injury frequency and AIS2+ injury risks.

TABLE II
ALL 6,284 OCCUPANTS STRATIFIED BY WEIGHT, HEIGHT, AND BMI

	Weight (kg)			Height (cm)			BMI		
Percentile	10th	11-89th	90th	10th	11-89th	90th	10th	11-89th	90th
Female	< 54	54-84	>84	<158	158-175	>175	< 16.2	16.2-25.0	>25.0
Male	< 70	70-104	>104	<170	170-188	>188	< 19.4	19.4-28-7	>28.7

The 6,284 occupants were involved in crashes with varied crash severity. Crash severity was investigated using both delta velocity and EES, see Appendix B. Although delta velocity and EES gave similar result we decided to use EES to describe the crash severity. The EES distribution for all exposed occupants were similar for females and males, both having a median EES of 18 km/h Fig.1 left. For AIS2+ injured occupants the EES distribution was slightly different between the sexes with females and males having a median EES of 28 km/h and 31 km/h respectively (Fig.1 right). Fig. 1 left and right shows both the histogram and the cumulative distribution of the EES for both sexes.

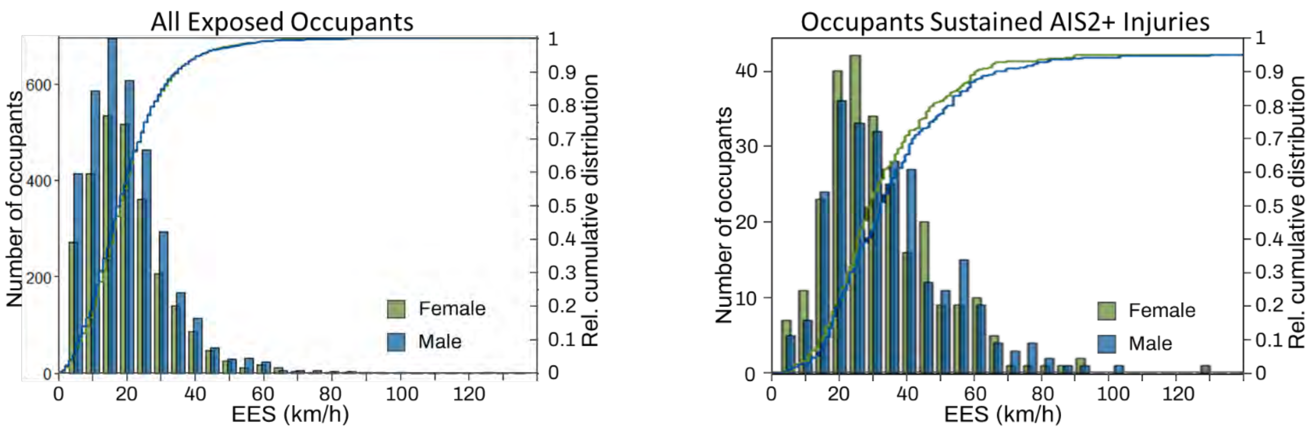

Fig. 1. Left: EES distribution of all exposed occupants. Right: EES distribution of all AIS2+ injured occupants.

The crash configuration frequency for all exposed and for all occupant sustained at least one AIS2+ injury was described according to the Collision Deformation Classification (CDC) code of the specific horizontal location of the damage and the principal direction of force (PDOF) [27] in Fig 2. The most frequent crash configuration was a full-frontal (CDC code 10) or close to full-frontal (CDC code 80 or 90) with a 12 o'clock PDOF. Note that the distribution of crash configurations resulting in AIS2+ injury very closely matched with the distribution of all low-severity crashes.

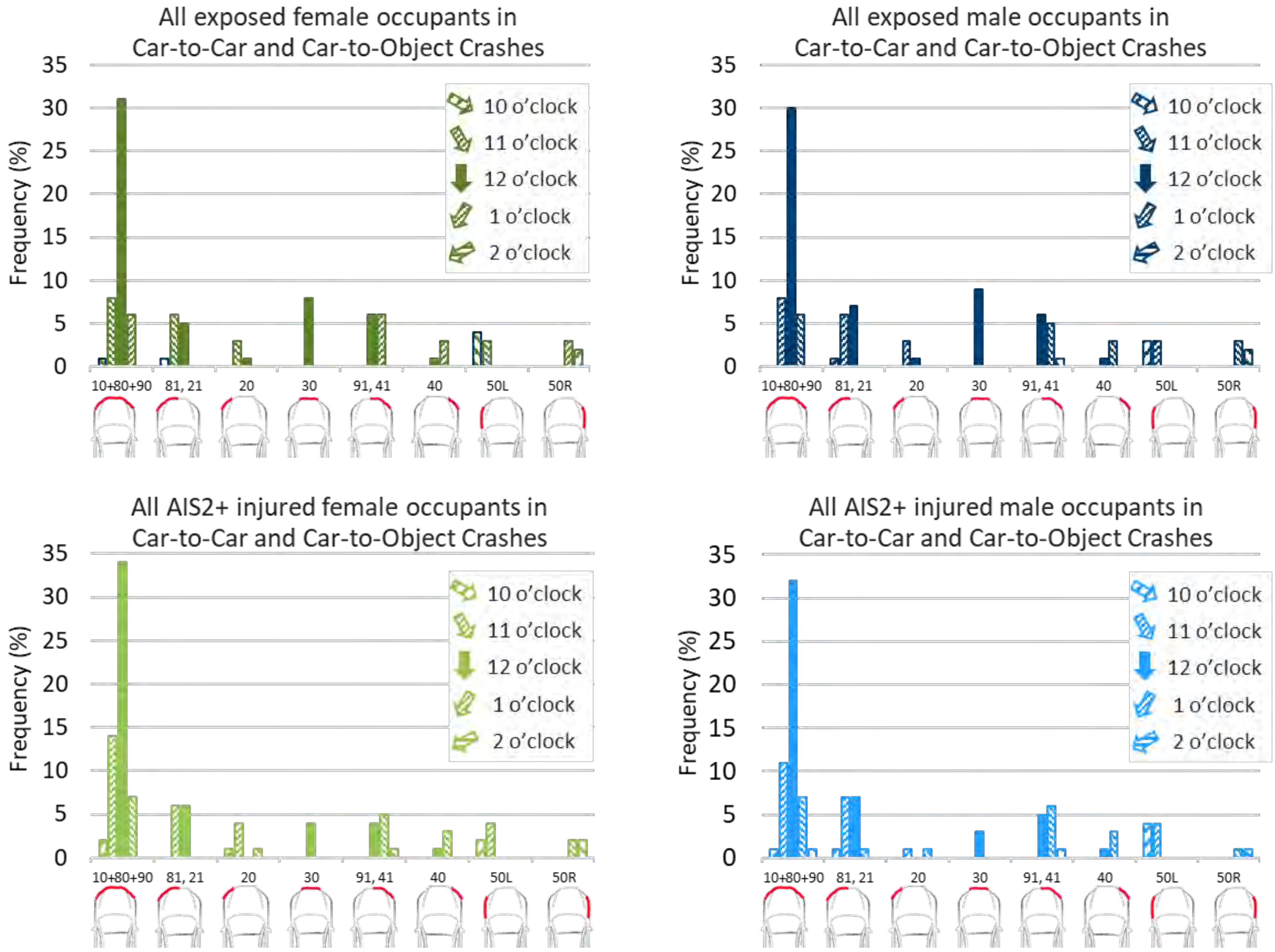

Fig. 2. Top row: Crash configuration distributions for all low-severity crashes. Left Female. Right Males. Bottom row: Crash configuration distributions for all low-severity crashes that result in an AIS2+ injury. Left Female. Right Males.

Analysis of the dataset

Injury frequency and injury risk for low-, mid-, and high-severity crashes.

The dataset was divided into three crash severity categories based on the EES, here named low- (0-34 km/h), mid- (35-59 km/h), and high- (≥ 60 km/h) severity crashes. Note that these labels are an arbitrary choice. There are many ways to label crash severities, and the 0-34 km/h category may be better labelled as *low-to-moderate* severity crashes. For simplicity in this study we use the three categories low, mid, and high. For each crash severity category, we calculated the injury frequency (sub-group proportion as percentage of all injured occupants in that group), and injury incidence rates (sub-group proportion as percentage of all exposed occupants in that group) for all crash exposed occupants, and occupants sustaining AIS2+ and AIS3+ injuries. For the sake of simplicity we refer to this as the injury risk.

Injury distributions for low-, mid-, and high-severity crashes for females and males.

The injuries were organised by AIS body region (head, face, neck, thorax, abdomen, spine, upper extremity (UE), and lower extremity (LE)), extracting the injuries for females and males for each of the three crash severity categories. To avoid multi-counting cases that exhibited multiple injuries in a body region, we focused the highest AIS injury per body region.

Who is injured and who is at higher risk in low-severity crashes?

Several analyses were performed for the low-severity crashes with the purpose to understand who is most frequently injured (sub-group proportion as percentage of all injured occupants in that group for females and males) and who is at higher injury incidence rates (sub-group proportion as percentage of all exposed occupants in that group for females and males). For the sake of simplicity we refer to this as the injury risk.

The AIS2+ injury frequency and injury risk, were calculated for three age groups (young, middle-age, and elderly) [21], three anthropometry groups (via weight, height, and BMI), four car sizes (small, mid, large, and SUV/Van), and three car registration year groups (2000-2006, 2007-2013, 2014 and newer). The four car sizes and the car registration year distribution are described in Appendix C. Additional analyses were made to increase understanding of injury distribution of the three age groups, and if the anthropometry (weight and height) and age differs between all exposed occupants and occupants that sustained an AIS2+ injury, Appendix D.

Seatbelt pretensioner activation.

In low-severity crashes, there is a chance that activating a seatbelt pretensioner may cause loading of the thorax that may exceed the belt loading caused by the crash. To investigate if there is an increased risk of AIS2+ thorax injuries when the seatbelt pretensioner is activated, the low-severity crashes were divided into two sub-groups, 0-15 km/h and 16-34 km/h. This investigation was done using two assumptions: (1) The 0-15 km/h crashes should have a low activation rate of the seatbelt pretensioners, (insurance testing requires *no fire* in a 40% overlap car-to-rigid bumper barrier test at 15 km/h [28-29]) and the 16-34 km/h crashes a high activation rate, (praxis of a *fire* threshold in a 40% overlap deformable barrier crash test at 40 km/h and a full-frontal rigid barrier crash test at approximately 20 km/h depending on OEM strategy). If the seatbelt pretensioner activation is correctly coded it should therefore be a substantially lower activation rate in the crashes with EES of 0-15 km/h compared to crashes with EES of 16-34 km/h, and assumption (2) – the risk of sustaining an AIS2+ thorax injury should be low in the crashes with 0-15 km/h. This makes it possible to investigate if crashes with activated seatbelt pretensioner in 0-15 km/h carry a higher AIS2+ thoracic injury risk than similar cases that do not have a seatbelt pretensioner activated. GIDAS variables used in this investigation are described in Table AII, Appendix A.

III. RESULTS

The results section is divided into analysis of the full data set (the two first sections) and a more extensive analysis of the low-severity crashes (the final two sections) with focus on who is injured and who is at higher injury risk.

Injury frequency and injury risk for low-, mid-, and high-severity crashes.

Table III shows the crash severity distribution for all crash exposed occupants, and for crashes that resulted in occupants sustaining an AIS2+ and AIS3+ injury. Table III also shows the AIS2+ and AIS3+ injury risk for each crash severity category. Low-severity crashes are most frequent, comprising 90% of all occupants, 62% of all AIS2+ injured occupants, and 28% of all AIS3+ injured occupants. However, the risk of sustaining an AIS2+ or AIS3+ injury is rather low: 5.6% and 0.5% risk, respectively. The injury risk increases to 27.4% and 8.6% for mid-severity crashes for AIS2+ and AIS3+ injuries, respectively, and to 52.2% and 32.3% for high-severity crashes for AIS2+ and AIS3+ injuries, respectively. Those injury risks values per crash severity level are very similar to those presented by [9] who investigated US crash statistics from the National Automotive Sampling System (NASS) Crashworthiness Data System (CDS). However, that study found a somewhat greater prevalence of AIS3+ injury cases in the 0-34 km/h category (46% of the AIS3+ injury cases).

TABLE III
EXPOSED FREQUENCY, AIS2+ AND AIS3+ INJURY FREQUENCY AND AIS2+ AND AIS3+ INJURY RISK FOR EACH CRASH SEVERITY CATEGORY

Crash severity level	Exposed frequency	AIS2+ frequency	AIS2+ injury risk	AIS3+ frequency	AIS3+ injury risk
Low (0-34 km/h)	89.6%	62.0%	5.6%	28.3%	0.5%
Mid (35-59 km/h)	9.4%	31.6%	27.4%	51.5%	8.6%
High (≥ 60 km/h)	1.0%	6.4%	53.2%	20.2%	32.3%
Total number	6284	513		99	

The average age of the occupants in low-severity crashes is 44.1 years old (all occupants) and 49.2 years old (AIS2+ injured occupants). In mid-severity crashes the average age is 45.8 years old (all occupants) and 51.0 years old (AIS2+ injured occupants) and in high-severity crashes the average age is 40.6 years old (all occupants) and 40.2 years old (AIS2+ injured occupants).

Injury distributions for low-, mid-, and high-severity crashes for females and males

Fig. 3 describes the injury distributions for the three crash severity categories for females and males, counting the highest AIS injury per body region (head, face, neck, thorax, abdomen, spine, upper extremity (UE), and lower extremity (LE)).

In the low-severity category, there were in total 167 females with 194 AIS2+ injured body regions and 151 males with 165 AIS2+ injured body regions. Most of the injuries were of an AIS severity level of 2 - 92.3% of the injured body regions for females and 92.7% for males. The head was the most frequently injured body region for both females 36.6% of AIS2+ injured body regions and males 37.6%. This was followed by injuries to the thorax 26.8% and 27.9%, and upper extremity injuries 17.0% and 20.0%. AIS3+ injured body regions comprised approximately 7% of the injured body regions for females and 5% for males. The most common MAIS3+ injuries were to thorax, 5.7% of injured body regions for females and 1.8% for males. A detailed list of all MAIS2+ injuries to the head, thorax, spine, lower and the upper extremities are presented in Appendix E.

In the mid-severity category, there were in total 77 females with 134 AIS2+ injured body regions and 85 males with 145 AIS2+ injured body regions. Also in this crash severity category, most of the injuries were AIS2 - 76.1% of the AIS2+ injured body regions for females and 73.8% for males. The most injured body region shifted from head to thorax for both sexes. For females, thorax injuries 28.4% of injured body regions, were followed by almost equal frequency of lower extremity injuries 19.4%, head 17.2%, and upper extremities 16.4%. For males, thorax injuries 33.1%, were followed by injuries to the head 22.8%, upper extremities 14.5%, and lower extremities 13.8%. The prevalence of AIS3+ injuries increased to 19.4% of injured body regions for females and 19.3% for males. The most common thorax AIS3+ injuries were lung contusions or rib fractures for both females and males.

In the high-severity category, there were only 13 females with 25 AIS2+ injured body regions and 20 males with 54 AIS2+ injured body regions. In this crash category there were a higher share of more severe injuries. For females the most injured body regions were the head, thorax, and lower extremities. For males the most injured body regions were the lower extremities, thorax, and head. The most common AIS3+ injuries were femur fracture, rib fractures, and lung contusion for both females and males.

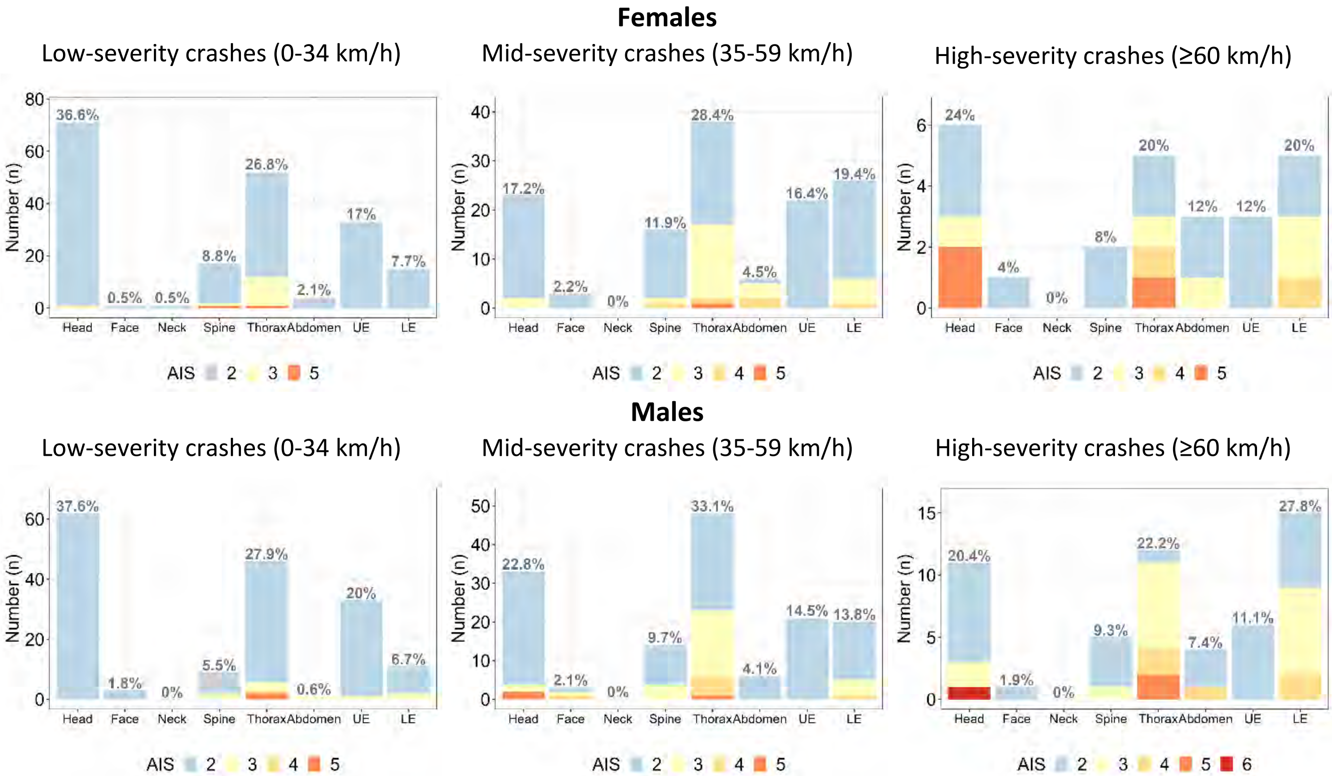

Fig. 3. Distribution of AIS2-6 injuries divided per body region for females and males in low-, mid-, and high severity crashes. (Note: For each occupant, only the most severe injury for each body region was counted.)

Who is injured and who is at higher risk in low-severity crashes?

The injury frequency and the risk of sustaining an AIS2+ injury were calculated for three age groups, young, middle-age, and elderly (Fig. 4). The average age (AIS2+ injured occupants) for the female age groups were 24.9, 51.7, and 77.0 years old and for the male age groups 25.7, 51.4, and 76 years old. The average age is similar between both sexes in all groups. Most injured occupants were in the middle-age group, 36-65 years old, 47.9% of the females and 40.4% of the males. In general, females exhibited a higher AIS2+ injury risk independent of age groups compared to the males. Elderly females had an AIS2+ injury risk of 10.7%, whereas younger females had a risk of 5.6%. Elderly males had an injury risk of 8.7%, compared to 4.1% for younger males.

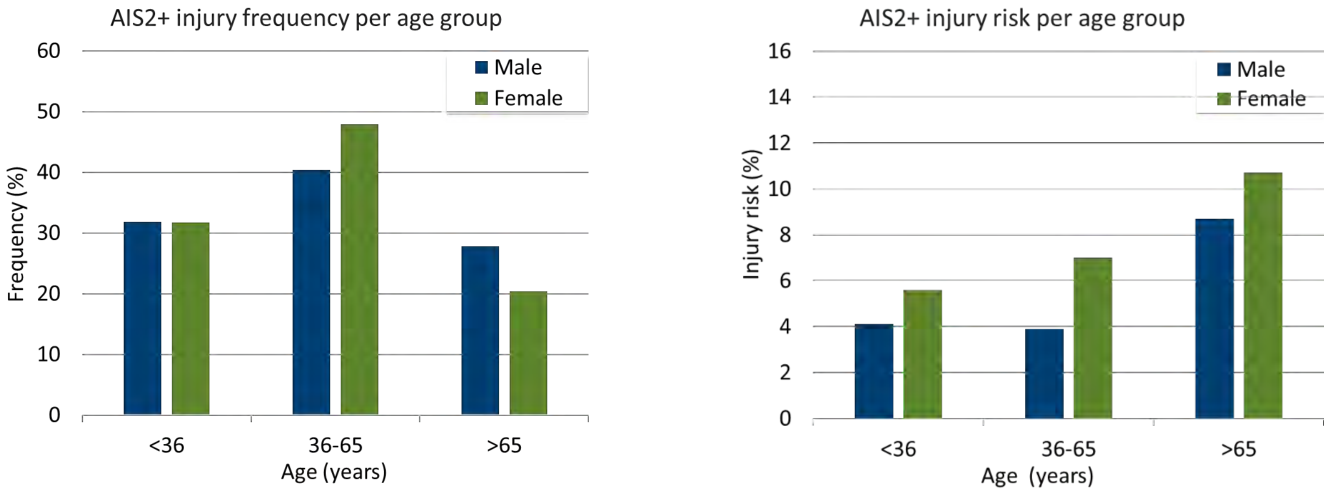

Fig. 4. Left: AIS2+ Injury frequency per age group and sex. Right: AIS2+ injury risk per age group and sex.

Fig. 5 describes the distribution of the highest AIS injury per body region for the three age groups for both sexes.

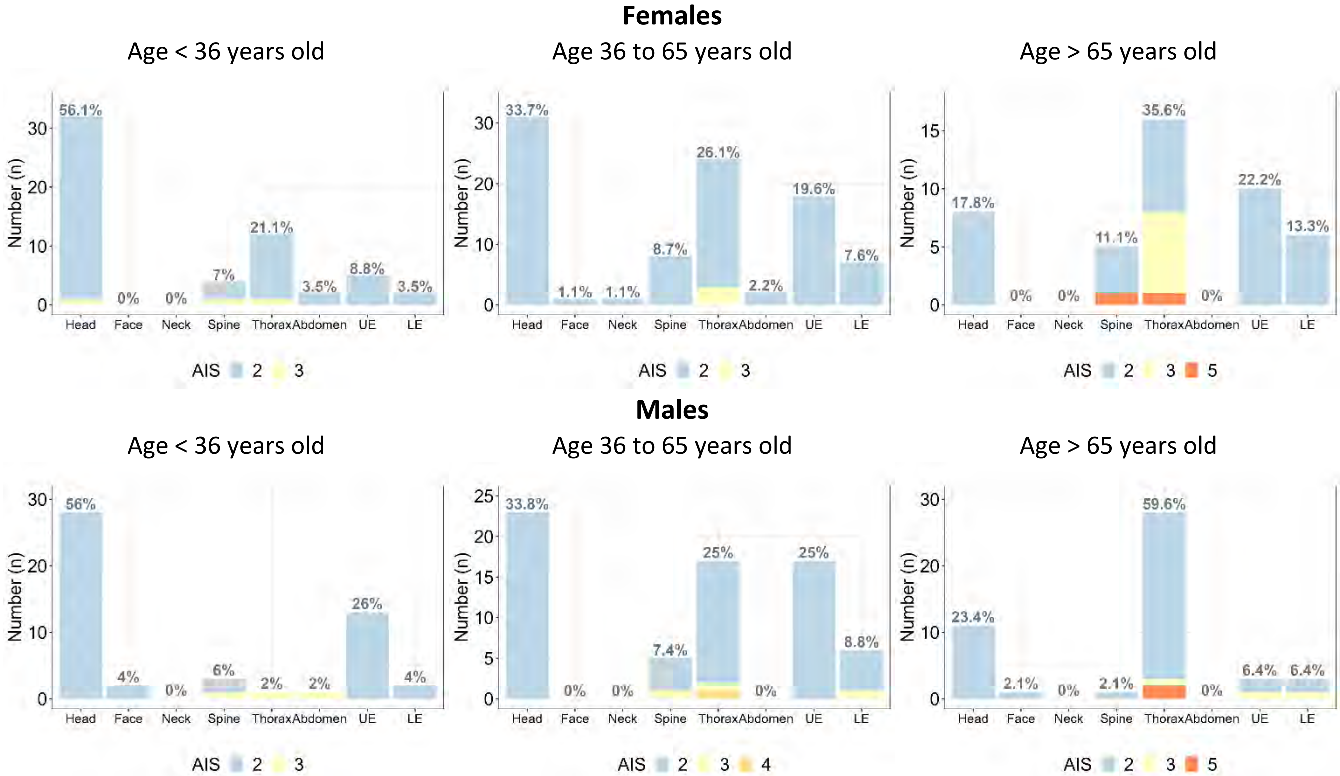

Fig. 5. Distribution of injured body regions for females and males per age group in low-severity crashes. (Note: For each occupant, only the most severe injury for each body region was counted.)

In the young group, there were in total 53 females with 57 AIS2+ injured body regions and 48 males with 50 AIS2+ injured body regions. Almost all of the injured body regions had a maximum AIS of 2 for both females 94.7% and males 94.0%. The head was the most frequently injured body region for both sexes. In the middle-age group, there were in total 80 females with 92 AIS2+ injured body regions and 61 males with 67 AIS2+ injured body regions. Almost all injured body regions had a maximum AIS of 2, for females 96.7% and for males 94.1%. The head was the most frequently injured body region, females 33.7% and males 33.8%, followed by the thorax, females 26.1% and males 25.0%, and upper extremities, females 19.6% and males 25%. In the elderly group, there were in total 34 females with 45 AIS2+ injured body regions and 42 males with 47 AIS2+ injured body regions. Most of the injured body regions had a maximum AIS of 2 for both females 80.0% and males 89.4%. The thorax was the most frequently injured body region, females 35.6% and males 59.6%. Approximately 16% of the injured body regions for the females has an AIS of 3, compared to 6% for males.

The AIS2+ injury frequency and injury risk were calculated by weight, height, and BMI, for the three groups: <10th percentile, 11-89th percentile, and >90th percentile; Fig 6. There is a chance that injury occurrence between these demographic percentiles may be confounded by difference in occupant age between these groups. To examine this, we also tabulated the average age for occupants with AIS2+ injury within those percentile groups.

For females, the average age of AIS2+ injured occupants in the three weight percentile groups was: 47.4, 48.8, and 50.5 years old. For the height percentile groups, the average age was: 59.5, 48.6, and 38.4 years old. For the BMI percentile groups, the average age was: 44.0, 49.0, and 50.0 years old. The average age is similar for the three groups except for height, where the 10th percentile has a higher average age and the 90th percentile has a lower average age. The females in the middle and 90th percentile groups are in general at higher risk compared to 10th percentile group, except for short females. It can be noticed that short females have a higher average age.

For males, the average age of AIS2+ injured occupants in the three weight percentile groups was: 54.5, 50.9, and 54.5 years old. The average age for the three height percentile groups was: 66.6, 50.6, and 39.2 years old. The average age for the three BMI groups was: 41.6, 53.4, and 54.3 years old. Similar to the females, the average age is similar for the three groups except for height, where 10th percentile has a higher average age and 90th percentile have lower average age. The males in the middle are in general at lower risk compared 10th and 90th percentile groups.

Most injured occupants were in the middle anthropometry groups (83.6% or higher for females and 74.0% or higher for males).

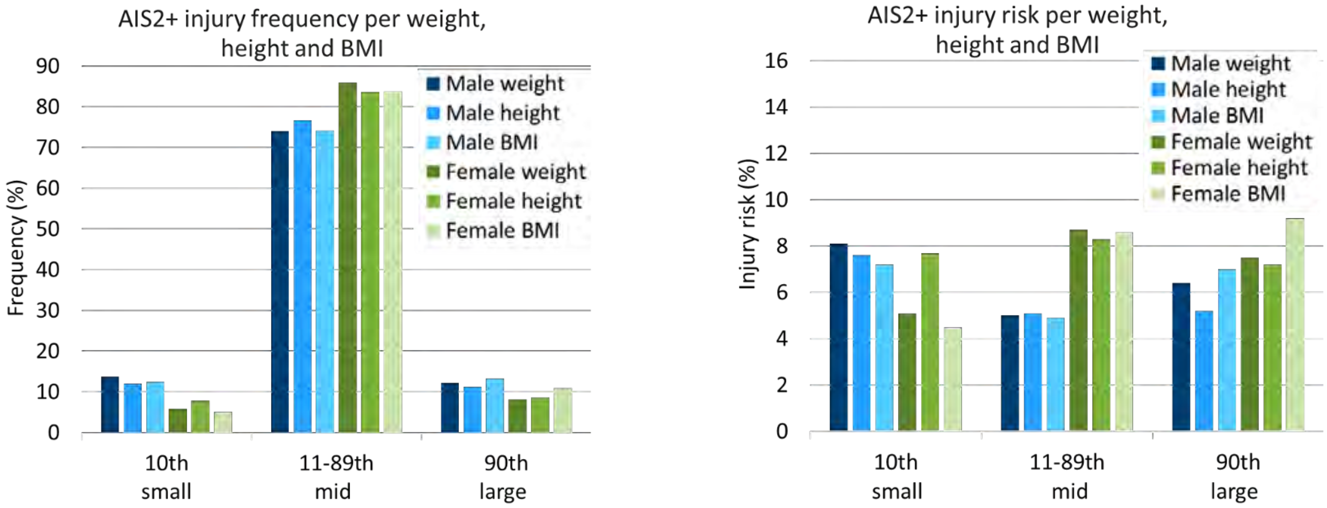

Fig. 6. Left: Distribution of AIS2+ injury frequency by height, weight, and BMI for females and males. Right: AIS2+ injury risk by height, weight, and BMI for females and males.

The AIS2+ injury frequency and injury risk were calculated for different car sizes, small, mid, large, and SUV/Van, Fig. 7. For females, the average occupant age of AIS2+ injured occupants in the different car sizes was: 46.6, 50.8, 50.0, and 45.9 years old. For males, the average occupants age of AIS2+ injured occupants was 48.9, 49.6, 51.3, and 54.3 years old. Females travelled in small cars in 46.1% of the cases compared to 31.1% of the males. Both females and males that travelled in small cars were at higher risk for AIS2+ injury (8.4% and 7.9% for females and males respectively). However, females were at higher risk whatever car size they travelled in.

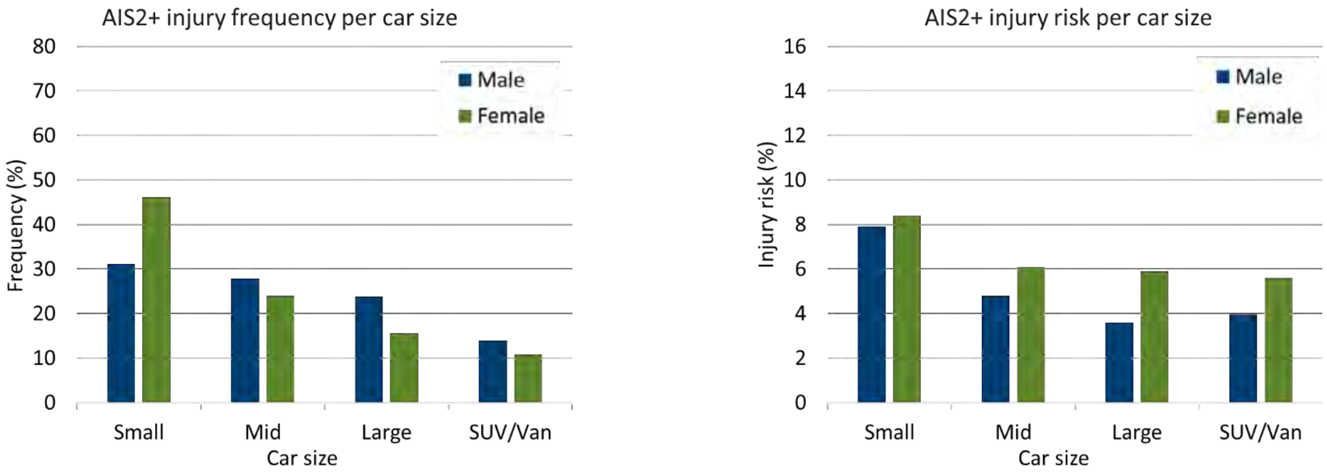

Fig. 7. Left: Distribution of AIS2+ injury cases by car size. Right: AIS2+ injury risk by car size.

The injury frequency and injury risk of sustaining an AIS2+ injury was calculated for cars with registration year 2000-2006, 2007-2013, and 2014 and newer, Fig. 8. For females, the average age of AIS2+ injured occupants for the different registration year categories was: 46.9, 50.9, and 48.2 years old. For males, the average age of AIS2+ injured occupants for the different registration year categories were: 49.0, 54.9, and 44.1 years old.

More than 50% of the occupants in the dataset that sustained an AIS2+injury travelled in cars with registration year 2000-2006, just above 30% in cars with registration year 2007-2013, and approximately 15% were in newer cars. Independent of the registration year, females exhibited greater injury risk than males.

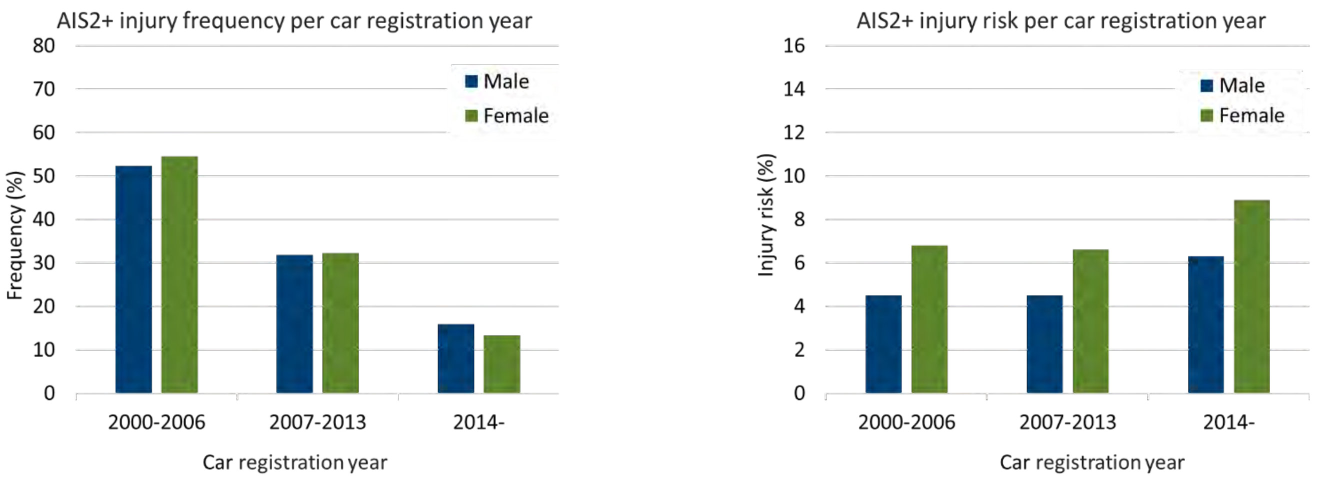

Fig. 8. Left: AIS2+ Injury frequency per car registration year for females and males. Right: AIS2+ injury risk per car registration year for females and males.

Seatbelt pretensioner activation.

Table IV shows that crashes with 0-15 km/h EES had a substantially lower seatbelt pretensioner activation rate, 17.8%, compared to crashes with 16-34 km/h EES, 58.6%. Thus, the seatbelt pretensioner activation coding is consistent with what would generally be expected based on differences in EES (supporting assumption (1)). The risk of sustaining an AIS2+ thorax injury in 0-15 km/h crashes with the seatbelt pretensioner not activated was 0.4% (7 AIS2+ thorax injuries in 1,830 occupants). The assumption (2) is thereby also fulfilled with a risk close to zero with non-activated seatbelt pretensioners. We can therefore assess whether or not there is an increased AIS2+ thorax injury risk with an activated seatbelt pretensioner. Pretensioner activation did not appear to increase thoracic injury risk - there was only one occupant with an AIS2+ thorax injury out of the 395 occupants with activated seat belt pretensioner. This gives an injury risk of 0.3%.

TABLE IV
FREQUENCY OF NON-ACTIVATED AND ACTIVATED SEATBELT PRETENSIONER IN LOW-SEVERITY CRASHES.

	0-15 km/h	16-34 km/h
Occupants in crashes with non-activated seatbelt pretensioner	1,830	1,119
Occupants in crashes with activated seatbelt pretensioner	395	1,583
Frequency of activated seat belt pretensioner	17.8%	58.6%
Occupant with thorax injury (AIS2+) with non-activated seatbelt pretensioner	7	N/A
Occupant with thorax injury (AIS2+) with activated seatbelt pretensioner	1	N/A

IV. DISCUSSION

With the purpose to give input to how real-world occupant protection can be improved, the goal of this study was to identify who is injured and who is at higher injury risk in high-exposure, low-severity crashes. It was shown that in general occupants that are most frequently exposed to crashes also are the ones that are most frequently injured. There are some shifts in injury frequency related to occupant risk factors such as age and sex, but the anthropometry of injured occupants tends to follow closely with the distribution of crash-exposed occupants (Appendix D). The average age for AIS2+ injured occupants in the low-severity crashes group were approximately five years older than the average age of those exposed (49.2 years old vs. 44.1 years old). In terms of anthropometry variations, females in the 10th percentile were at lower injury risk than females of the average and 90th percentile group. For males it was opposite with the 10th and 90th percentile being at higher risk. In low-severity crashes the most common AIS2+ injured body regions were the head, thorax, and upper extremities. Newer cars did not tend to show any decrease in injury risk. This can potentially be explained by newer cars being designed to avoid intrusion in high-severity frontal crashes but as a consequence they have become stiffer in low-severity crashes [30].

Differences in injury risk were seen between different sub-groups evaluated in this study. However, cautions should be taken when interoperating these differences as not all injury risks differences is caused by biomechanical factors. For example, females were in general at higher risk of injury. One reason that females were at higher injury risk in this study can be explained by females more frequently travelling in smaller cars compared to males [31]. The reason for the higher risk seen in small cars can potentially be explained by that small cars tend to have less deformation space than large cars and a smaller mass. Thus a smaller car would expire a more severe crash for a similar crash configuration. In addition, smaller cars potentially have lower occupant protection equipment due to cost reasons. The injury risk was almost the same for females and males who travelled in smaller cars, but approximately double (8% vs 4%) compared to other car sizes for males and about 30% higher (8% vs 6%) for females.

Recent discussions on low-to-mid severity crashes have tended to focus on very fragile individuals, such as the elderly. Particular emphasis has been placed on rib fracture injury. The findings of this study suggest that injuries in low-to-mid severity crashes are not niche to the elderly. Though the average age of those injured was higher than the general exposure, it was not so high as to suggest that only the elderly are injured in low-severity crashes. Moreover, the injury distributions suggest that rib fractures are not the sole source of concern. Even within the thorax, rib fractures only comprised a portion of the injuries observed. A substantial number of the AIS2 thorax injury cases experienced sternum fractures, and of the AIS3 thorax injuries lung contusion was as common as rib fractures. While it is possible that the mechanism (and injury criteria) for lung contusion and sternum fracture may be similar as that for rib fracture, focusing solely on rib fracture may obscuring the potential injury-reduction benefit that may be achieved through reduced loading on the thorax (especially for younger occupants, who tend to exhibit a greater proportion of lung contusions vs. rib fractures compared to older occupants [10]). Outside of the thorax, AIS2 brain injuries, upper extremity injuries, lower extremity injuries, and spine injuries were quite common in the low- and mid-severity crashes. This suggests that assessment and countermeasure efforts targeting low-to-mid severity crashes cannot simply focus on reducing loading to the thorax, but also must continue to evaluate the balance of loading to other body regions to drive down injury risk throughout the body.

There will likely be some debate on the prevalence of AIS2 brain injuries in the low-severity crash group, based on concern for the accuracy of diagnosing and reporting concussion. We would encourage such debate, especially if it leads to critical review of diagnosis and reporting practices and the potential implications on prioritisation for safety advancement. For the time being though, instead of making assumptions on the accuracy of the brain injury numbers based on anecdote or speculation, the best that we can do is go by the data that is available. In this case, the data suggests that AIS2 brain injuries are the most common injuries observed in the low-severity crash group, followed by thoracic injury. This is consistent with the U.S. field-data analyses of [21][9], who also found that AIS2 brain injuries were the most common injuries in relatively low speed frontal impacts with belted occupants. The consistency of this observation across both European and U.S. datasets lends credence to the observation, suggesting that it is less likely that it is due to simple overdiagnosis (unless that overdiagnosis is so pervasive that it permeates different countries with different health care systems). The consistent prevalence of AIS2 brain injury suggests that these injuries should be considered in one form or another in future work – be it investigating the accuracy of diagnosis/reporting, the potential clinical implications of those injuries, or investigating the mechanisms that may be addressable by intervention.

The prevalence of injury cases in low-severity crashes is consistent with the very high-exposure to those types of crashes. Even though the per-crash injury risk is quite low, the very high exposure results in a substantial portion of the injury cases occurring at low-severity crashes. This suggests that benefit may be gained from safety assessments seeking to drive down risk even further in low-severity crashes. Note that several current safety assessment programmes nominally seek to evaluate risk over a range of crash severities up to a particular top-end severity. For example, the frontal impact safety performance standards of Federal Motor Vehicle Safety Standards (FMVSS) 208 specify that vehicles meet certain specified performance criteria in crashes up to a particular target speed, i.e., up to 56 km/h for the belted full-frontal rigid barrier test, [32]. While this does succeed on its face in providing performance criteria targets over a range of crashes from relatively low speed to relatively high speed, it is still limited in that it specifies the same target criteria (in the form of injury assessment reference values) across the entire range of speeds that it seeks to evaluate. As a result, the assessment is driven primarily by a vehicle’s performance at the top-end of the test severity range, as that will naturally be the test speed where meeting the performance criteria would be the most challenging (when the same target values are used across the entire range). Instead, to effectively drive down risk in low-severity crashes we need assessment tests at those speeds, and performance targets specifically designed for those seeking to decrease risk even lower than it already is [33]. This, in itself, may be challenging as it relies on having occupant modelling tools, e.g., ATDs, that are reasonably biofidelic in test speeds substantially lower than where the current tools are typically used, as well as injury risk functions that are able to detect relatively subtle changes in injury risk in scenarios where the injury risk is already quite low [33]. For example, the low-severity category studied here (0-34 km) comprised 62% of the AIS2+ injury cases (due to the very high-exposure), but only exhibited a per-crash AIS2+ injury risk of 5.6%. This presents a substantial challenge, as our goal should be to reduce this risk even further. It is unclear whether current occupant model tools and injury risk functions possess the accuracy, sensitivity, and precision necessary to discern changes in risk at this low a level.

As a result of the lack of validated tools and assessment criteria, novel means may be needed to refine injury prediction methods in these scenarios of already low risk. We cannot feasibly rely on traditional methods to improve the precision of prediction in these scenarios. Traditional methods would involve performing a number of postmortem human subject (PMHS) tests in an exemplar target scenario with a range of loading severities to increase the amount of data available for an injury risk function. In this case, however, if we are trying to increase the precision of prediction in scenarios that already carry a roughly 5% risk, we would need an intractable number of PMHS tests to achieve a useful mix of injurious and non-injurious tests, i.e., in this severity range we may need to perform 50 PMHS tests to result in one test that produces injury. Instead, we may need to augment traditional PMHS-based data with other data sources to improve precision in these low-risk ranges. One such approach may be a Bayesian approach. A Bayesian approach can sometimes be used to provide increased precision of risk estimates by combining effects estimates from multiple data sources (by informing prior distributions of the effects estimates [34]. In the case of injury risk function development, it may be possible to inform prior effect estimates by either field data (for occupant factors such as age) or simulation (with the effect estimates then refined via the available test data). Such methods, however, will undoubtedly take substantial time and developmental effort to execute in a manner that gains confidence in the field. An interim step may be a more practical approach, setting a lower bound for injury tolerance based on loading scenarios that are almost certainly non-injurious. For example, in our dataset the cases of very low-severity crashes (EES 0-15 km/h) in which a pretensioner was activated resulted in extremely low risk of AIS2+ thoracic injury (1 out of 395 crashes, or 0.3%).

This can provide valuable context for a lower-bound for a thoracic injury risk function. While several pretensioner designs are available on the market, these data suggest that loading by static deployment of pretensioners common to the market covered by GIDAS should result in near zero AIS2+ thoracic injury risk. Thus, a common-sense way to evaluate one aspect of thoracic injury risk functions in low-risk scenarios would be to subject an appropriate occupant model to static deployment tests with typical pretensioners. If the injury risk function predicts a noticeable risk of thoracic injury in such static deployment tests, then it is likely over-predictive (suggesting that refinement is needed to improve the injury risk function in scenarios of relatively low risk). This type of practical approach can also aid Bayesian methods noted above, using such lower-bound observations to guide the initial development of prior distributions for effect estimates to bound the risk estimates to a reasonable range. As data available for injury prediction in these low-risk scenarios will always be dwarfed by the very high number of these crashes present in the field, these types of practical, common sense approaches (potentially combined with novel data sources and analysis techniques) will likely be critical to the refinement of injury prediction and safety assessment strategies for low-risk, high-exposure crashes.

Overall, these findings support the need for attention to high-exposure, low-severity crashes, as they comprise a substantial portion of the injury cases that occur in the field. Development and implementation of assessment tests targeting low-severity crashes (with injury criteria designed to drive down risk further) are likely to prompt two types of changes – development of restraint systems that are more robust, naturally improving protection through the fundamental nature of their design; and development of restraint systems with expanded adaptive functionality, capable of adjusting their characteristics, e.g., the force applied by the seatbelt, based on sensing and classification of the crash and occupant characteristics. The former path – expanded robustness – may require novel restraint designs fundamentally changing how load is applied to the body, to make better use of the strong points on the body. One such example may be a 3+2 belt system, e.g., [35], adding a supplementary second shoulder belt with a relatively low force limit with the purpose to distribute the load from the seatbelt over a larger area of the thorax. Such novel concepts, however, may fall outside of what is currently permissible by some local regulations. The latter path – expanded adaptivity – also holds promise, especially since the sensor systems needed for crash severity and occupant classification are already seeing expanded deployment for other peripheral reasons, e.g., crash avoidance and occupant attention monitoring. However, caution must be taken with that approach though to ensure that the sensing and classification are robust enough to not drive an overall risk increase induced by occurrences of mis-classification. It will likely not be sufficient to rely solely on a single low-severity crash test. Instead, supplementary evaluation will also be needed to test the robustness of the sensing and classification systems to ensure that they result in protective control decisions across a range of crash configurations and occupant sizes (to mitigate the risk of adverse consequences from misclassification).

Finally, despite the several studies [7-11] that have examined the prevalence of injury in low-to-mid severity crashes, little is still known about what is actually causing injury in these crashes where the risk is quite low. The results of this study suggest that low-severity crash injury cases appear relatively *average* by all summary measures, tending to follow the fundamental distribution of exposures. These injury cases tend to have a full-frontal principal direction of force (PDOF), occupants that have relatively average height and weight, and occupant ages that are only slightly higher than the average ages of those exposed. There is nothing from these summary measures that stands out to suggest that these injury cases are substantially different to the 95% of similar crashes that do not result in injury. So the question is: what does make the difference in these crashes to tip the scales towards injury occurring? Are the occupants overly fragile, or do they exhibit some other fundamental difference that prompts them to be injured where others are not? Or is there something unique about the crashes that make them more severe than the EES-based delta velocity would suggest? Or is there something different about the occupant's posture or seatbelt fit that lead to less favourable loading conditions and make them more prone to injury? These questions are critical to address when developing new assessment methods and countermeasures seeking to drive down risk even further – if these cases cause injury because they are fundamentally different to the nominal conditions represented by typical laboratory crash tests, then it may take novel assessment methods to evaluate the robustness of protection outside of nominal conditions, e.g., through complementing physical testing with virtual assessment to expand the range of occupant and crash conditions that can be evaluated.

Further Work

Considering the uncertainty surrounding the root cause of injuries in these high-exposure, low-severity crashes, future work should include in-depth case review to discern the factors contributing to the injuries, and whether or not they could be reasonably captured through traditional crash tests. The low-severity category (0-34 km/h) contains crashes where the restraint system was activated and crashes where it was not activated. For example, it has been identified that the low-severity crashes include both non-activated and activated seatbelt pretensioners. In further work we propose to group the crashes differently: 0-15 km/h (no activation), 16-25 km/h (grey zone for activation) and 26-40 km/h (likely activation). Doing so would most likely give different injury risk per group – in the current dataset 0-15 km/h had a risk close to 0%, 16-25 km/h higher than current 5.6%, and 26-40 km/h above 10%. Such split would also reflect that in the 0-15 km/h group the injury risk is already close to 0% and then it does not matter if there is a huge underreporting of crashes in this range due to the inclusion criteria in GIDAS that requires at least one suspected injured crash participant. Therefore, future work should include evaluation of the ability of current injury prediction tools (ATDs and human body models) in discerning these gradations of risk affected by both crash severity and restraint characteristics. In addition, we recommend that the findings of this study should be checked against other complementary datasets to determine which findings are robust, and which are specific to GIDAS. Finally, we also recommend extending this analysis to examine rates and distributions of AIS1 injuries in low to moderate speed collisions, especially those AIS1 injuries that have been linked to negative long-term outcomes (e.g., AIS1 cervical spine injuries).

V. CONCLUSIONS

The overall injury risk in low-severity frontal crashes with belted occupants was low, but the high-exposure results in that many injuries occurring in relatively low-severity crashes. The majority of the injuries was at AIS2 level. The injured occupants were predominantly of our middle anthropometry band, closely following the distribution of all belted occupants exposed to low-severity crashes. Similarly, the distribution of crash configurations resulting in injured belted occupants matched the distribution of all low-severity crashes. In terms of injury pattern, head, thorax, and upper extremities were the most frequently injured body regions for middle aged occupants. Younger occupants were more frequently injured to head, and elderly were more frequently injured to the thorax.

To reduce the overall number of injured belted occupants in low-severity frontal crashes, there is a need to further reduce the injury risk experienced by occupants of our middle anthropometry band in full-frontal crashes. That said, it was identified that females in general were at higher risk compared to males. All occupants in small cars tended to be at the same risk, and injured occupants were on average five years older compared to all occupants exposed to low-severity crashes. Reducing the overall number of injured occupants in low-severity crashes presents a substantial challenge since current injury risk functions, evaluation tools, and assessment methods are developed for higher crash severity and injury risk levels. Future work should include evaluating the efficacy of such tools (and revising where necessary) in low-to-moderate severe crashes.

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VII. APPENDIX A

Table AI describe what GIDAS variables that has been used in the study for inclusion or exclusion criteria on vehicle level. To extract frontal crashes we used a combination of principal direction of force (VDI1) and main deformation area (VDI2). To include vehicles impacted to the side in front of the A-pillar we also used the horizontal location of the damage (VDI3).

TABLE AI
GIDAS VARIABLES AND THEIR MEANING – VEHICLE LEVEL

Variable name	Description	Inclusion/exclusion criteria
KLASSECE	Official vehicle class	1 - M1
KONBETEI	Involved collision opponent	0 - collision with object
ANZKOLL	Number of collisions	1
TDEZJ	Registration year	>1999
VDI1	Principal direction of force	10,11,12,1,2
VDI2	Main deformation area	1-front 2-right side 4-left side
VDI3	Horizontal location of the damage	50-in front of A-pillar
ROLLWANN	Rollover event	2 - no rollover
BRANDURS	Fire after crash	2 - no fire
DV	Delta velocity	≠ 888 – not applicable ≠ 999 - unknown
EES	Energy Equivalent Speed	≠ 888 – not applicable ≠ 999 - unknown

Table AII describes the GIDAS variables used on occupant level. To extract the correct belted occupants a combination of the belt usage (RHSBEN) and seatbelt information (GURTE). For the seatbelt pretensioner investigation we used a combination of seatbelt used, seatbelt pretensioner present (GURTST) and the activation status (GURTSTA).

TABLE AII
GIDAS VARIABLES AND THEIR MEANING – OCCUPANT LEVEL

Variable name	Description	Inclusion/exclusion criteria
PSKZ	Personal reference number	1-passenger car – driver 2-passenger car – co-driver
RHSBEN	Seatbelt usage	1-yes
GURTE	Seatbelt information	4 – 3 point seat belt with automatic retraction
GURTST	Seatbelt pretensioner present	1 - present
GURTSTA	Seatbelt pretensioner activated	1 - activated
ALTER1	Age in years	≥13
MBAIS15	Maximum known AIS	Range from 0 to 6
GESCHL	Gender	3 - male 4 – female 5 - pregnant
GROESP	Height	≠ 999
GEWP	Body weight	≠ 999

Table AIII described what GIDAS variables we used to extract the information about the injury level.

TABLE AIII
GIDAS VARIABLES AND THEIR MEANING – INJURY LEVEL

Variable name	Description	Inclusion/exclusion criteria
AIS15	Injury severity	2 - moderate 3 - serious 4 - severe 5 - critical 6 - maximum
AISG15	Complete AIS15 code	

VIII. APPENDIX B

In GIDAS the crash severity is described with both delta velocity and EES. Delta velocity is defined as the vector difference between immediate post-crash and pre-crash velocity coded in km/h and EES (Energy Equivalent Speed) is defined as equivalent to the collision speed of the vehicle under consideration against a rigid barrier, in which all energy is converted into deformation work in the collision to achieve the same damage pattern.

We investigated how delta velocity and EES correlate in our dataset by plotting the cumulative frequency of all exposed occupants, Fig B1 upper, and of all AIS2+ injured occupants, Fig B1 lower. For velocities higher than 25 km/h, delta velocity report higher velocity in general compared to EES. We did in depth analysis of some of the cases where delta velocity reported a higher velocity and found that many of them have a small overlap and the photos of the cars indicated relatively small deformation. This made us decide to use the EES instead of delta velocity when describing the crash severity. However, to be sure we calculated all our result using both EES and delta velocity. Doing so we found almost no differences in the result. As an example the frequency in the three crash severity categories are almost the same see Table BI. However, when calculated as the relative frequencies, the two higher crash severities groups show a larger difference. As an example for occupant sustaining a MAIS2+ injury there where 49 occupants when using delta velocity and only 33 occupants when using EES, i.e. 50% differences. It is our understanding that when investigating the crashes between 0-34 km/h, delta velocity or EES will give almost the same result. However, if the purpose is to investigate higher crash severity the chose between delta velocity and EES is more important and should be carefully review with in dept analysis.

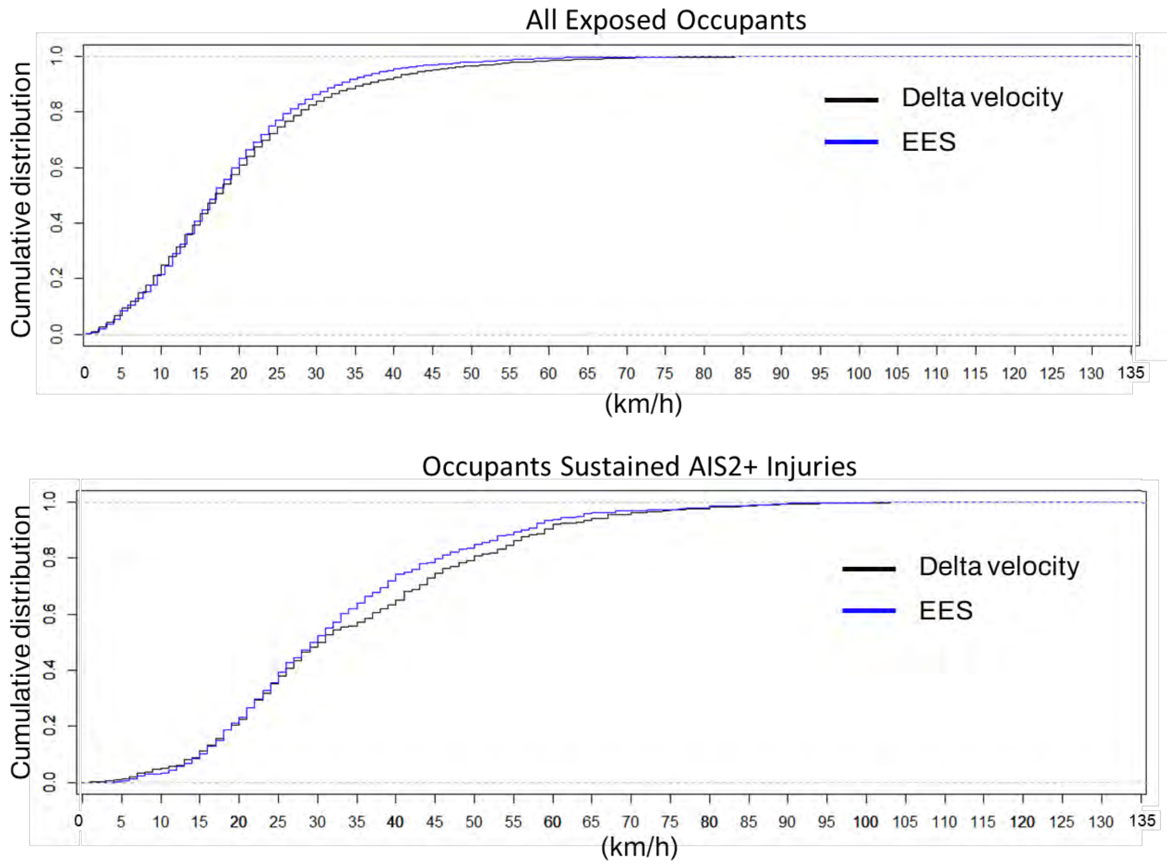


Fig. B1. Left: Distribution of AIS2+ injury frequency by height, weight, and BMI for females and males. Right: AIS2+ injury risk by height, weight, and BMI for females and males.

TABLE III
EXPOSED FREQUENCY FOR EES AND DELTA VELOCITY+
FOR EACH CRASH SEVERITY CATEGORY

Crash severity level	EES exposed frequency	Delta velocity frequency
Low (0-34 km/h)	89.6%	88.4%
Mid (35-59 km/h)	9.4%	10.0%
High (≥ 60 km/h)	1.0%	1.6%

IX. APPENDIX C

In GIDAS the passenger cars are categorized according to its type into several categories. Table CI shows how we used FZGKLASS to group the passenger cars into five different sizes: small, mid, large and SUV/Van and other. Table BI also shows the count for all low-severity crashes and all low-severity crashes where the occupant sustained an AIS2+ injury.

TABLE CI
PASSENGER CARS CLASSES AND FREQUENCIES IN LOW-SEVERITY CRASHES.

FZGKLASS + Description	Example	Car size	Count all	Count all per group	Count all AIS2+ per group
4 - mini	Fiat 500	Small	411	1505	124
5 - small car	VW Polo	Small	1094		
6 - lower mid class car	VW Golf	Mid	1542	1542	82
7 - mid class car	VW Passat	Large	1035		
8 - upper mid class car	Mercedes E	Large	303		
9 - top class	BMW 7	Large	46	1430	63
11 - sports vehicle	Mercedes SLK	Large	46		
10 - off-road vehicles (SUV)	Toyota RAV 4	SUV/Van	339		
12 - mini-van	Renault Scenic	SUV/Van	187	847	37
13 - large van	VW Touran	SUV/Van	321		
14 - utilities	VW T5	Other	290	Not included	Not included
15 - camper van	Fiat Ducato	Other	6	Not included	Not included
16 - light 4-wheeled vehicle		Other	0	Not included	Not included
21 - delivery van	Ford Transit	Other	0	Not included	Not included
88 - other		Other	7	Not included	Not included
99 - unknown		Other	4	Not included	Not included

Fig. C1 shows car registration year distribution for all low-severity crashes (left) and all low-severity crashes with AIS2+ injured occupants (right).

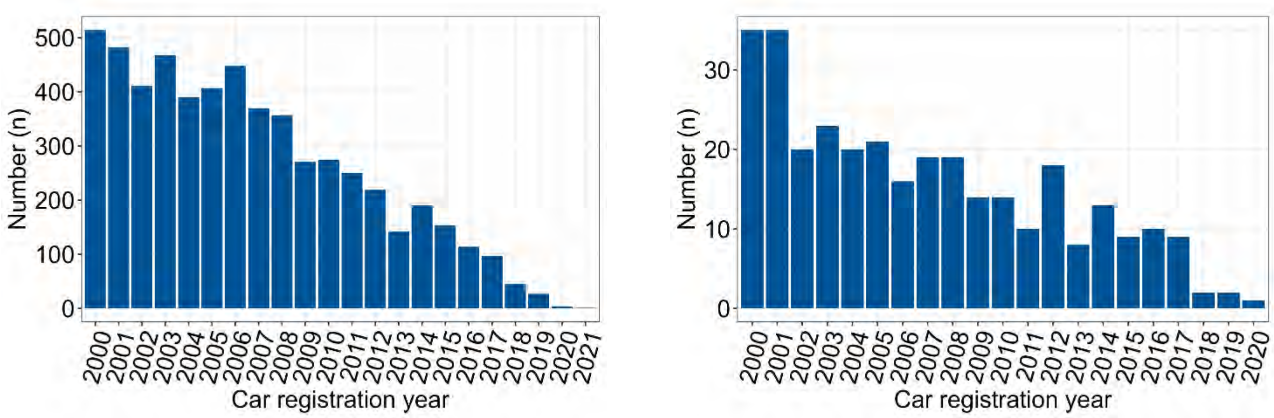


Fig.C1. Car registration year distribution for all low-severity crashes (left) and all low-severity crashes with AIS2+ injured occupants (right).

X. APPENDIX D

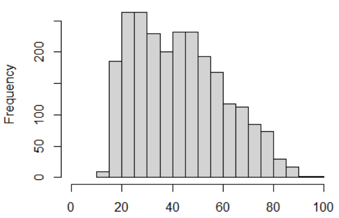
Table DI (female) and DII (male) show the age and anthropometry (weight and height) for all low-severity crashes for all exposed occupants and for occupants that sustain an AIS2+ injury.

TABLE DI

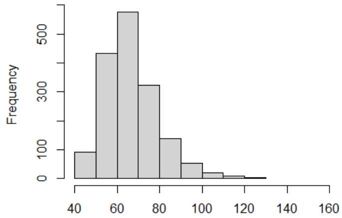
FEMALE OCCUPANT DISTRIBUTION OF AGE AND ANTHROPOMETRY (WEIGHT AND HEIGHT) IN LOW-SEVERITY CRASHES

MAIS0-6
Female n = 2,414
Average age 43.2 years
Average weight 68 kg
(768 unknown)
Average height 167 cm
(449 unknown)

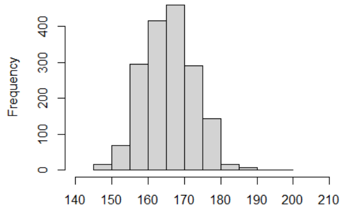
Age



Weight

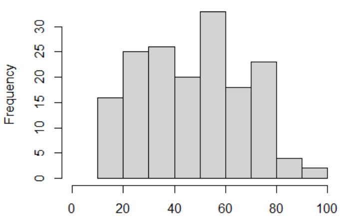


Height

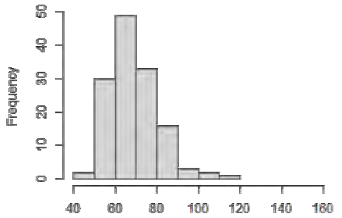


MAIS2-6
Female n = 167
Average age 48.3 years
Average weight 70 kg
(31 unknown)
Average height 167 cm
(27 unknown)

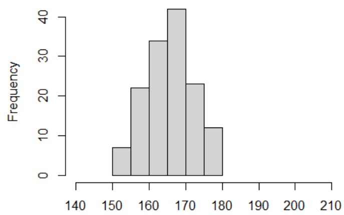
Age



Weight

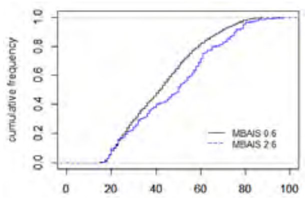


Height

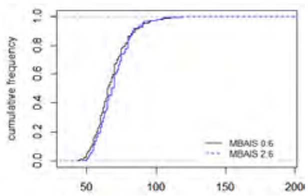


Cumulative distribution:
Black MAIS0-6
Blue MAIS2-

Age



Weight



Height

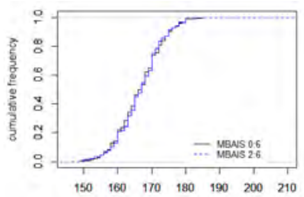
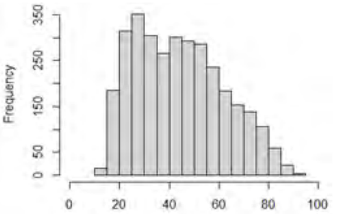


TABLE DII

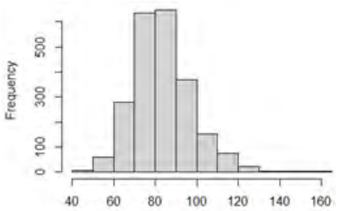
MALE OCCUPANT DISTRIBUTION OF AGE AND ANTHROPOMETRY (WEIGHT AND HEIGHT) IN LOW-SEVERITY CRASHES

MAIS0-6
Male n = 3217
Average age 44.8 years
Average weight 85 kg
(954 unknown)
Average height 179 cm
(893 unknown)

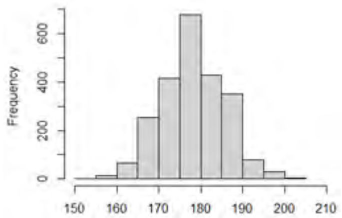
Age



Weight



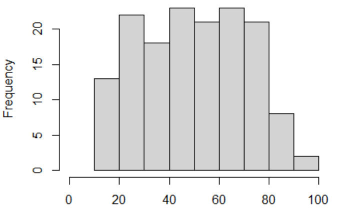
Height



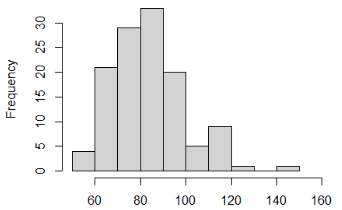
MAIS2-6
Male n = 151
Average age 50.1 years

Average weight 86 kg
(28 unknown)
Average height 179 cm
(27 unknown)

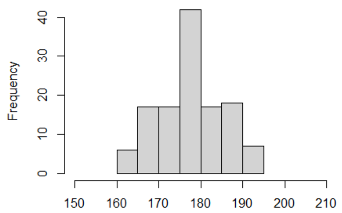
Age



Weight

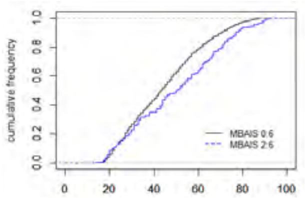


Height

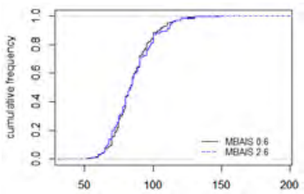


Cumulative distribution:
Black MAIS0-6
Blue MAIS2-6

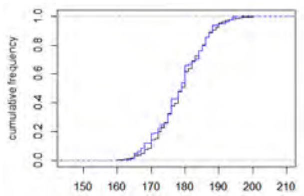
Age



Weight



Height



XI. APPENDIX E

Table EI (female) and Table EII (male) listed all AIS2+ injuries to head, thorax, spine, lower and upper extremities in low-severity crashes. For both sexes the most common AIS2+ injuries are concussion (head), sternum fractures (thorax).

TABLE EI

FEMALE AIS2+ CODE AND COUNT FOR HEAD, THORAX, SPINE, UPPER AND LOWER EXTREMITIES.

AIS code – Description	Count
Head AIS2+ = 73	
161001.2 - Head: Diffuse brain injury: Cerebral concussion: mild concussion, no loss of consciousness	52
161000.2 - Head: Diffuse brain injury: Cerebral concussion: NFS	9
161004.2 - Head: Diffuse brain injury: Cerebral concussion: loss of consciousness <1 hour: loss of consciousness ≤ 30 min	4
161003.2 - Head: Diffuse brain injury: Cerebral concussion: loss of consciousness <1 hour: NFS	3
110604.2 - Head: Whole Area: Scalp: laceration: major; >10cm long and into subcutaneous tissue	1
140602.3 - Head: Internal Organs: Cerebrum: contusion: NFS	1
140639.2 - Head: Internal Organs: Cerebrum: hematoma (hemorrhage): intracerebral: tiny; single or multiple <1 cm diameter	1
140651.3 - Head: Internal Organs: Cerebrum: hematoma (hemorrhage): subdural: tiny; <0.6cm thick [includes tentorial (subdural) blood one or both sides]	1
140693.2 - Head: Internal Organs: Cerebrum: subarachnoid hemorrhage: NFS	1
Thorax, AIS2+ = 59	
450804.2 - Thorax: Skeletal: Sternum: fracture [OIS II, III]	38
450202.2 - Thorax: Skeletal: Rib Cage: fracture(s) without flail, any location unilateral or bilateral: two ribs [OIS I]	5
450203.3 - Thorax: Skeletal: Rib Cage: fracture(s) without flail, any location unilateral or bilateral: ≥ 3 ribs [OIS II]	5
441402.3 - Thorax: Internal Organs: Lungs: contusion: NFS	3
419200.2 - Thorax: Internal Organs: Lungs: inhalation injury: NFS	2
441410.3 - Thorax: Internal Organs: Lungs: contusion: bilateral: NFS	2
441406.2 - Thorax: Internal Organs: Lungs: contusion: unilateral: NFS	1
441603.3 - Thorax: Internal Organs: Pericardium: hemopericardium: NFS	1
442200.3 - Thorax: Internal Organs: Thoracic cavity injury: Hemothorax	1
450214.5 - Thorax: Skeletal: Rib Cage: fractures with flail: bilateral flail chest [OIS V]	1
Spine, AIS2+ = 22	
650632.2 - Spine: Lumbar Spine: Vertebra: Vertebra(e) injury: fracture without neurological deficit: vertebral body: minor compression (≤ 20% loss of anterior height) [only one endplate]	5
650430.2 - Spine: Thoracic Spine: Vertebra: Vertebra(e) injury: fracture without neurological deficit: vertebral body: NFS	4
650432.2 - Spine: Thoracic Spine: Vertebra: Vertebra(e) injury: fracture without neurological deficit: vertebral body: minor compression (≤ 20% loss of anterior height) [only one end plate]	3
610201.2 - Spine: Cervical Spine: Cervical Cord: Spinal cord injury: with transient neurological signs: NFS	1
610228.5 - Spine: Cervical Spine: Cervical Cord: Spinal cord injury: complete spinal cord injury: C4 or below: with both fracture and dislocation (with or without disc involvement)	1
630212.2 - Spine: Cervical Spine: Nerves: Brachial Plexus: incomplete plexus injury: contusion; stretch injury	1
630262.2 - Spine: Cervical Spine: Nerves: Nerve root: avulsion: NFS	1
650216.2 - Spine: Cervical Spine: Vertebra: Vertebra(e) injury: fracture without neurological deficit: NFS	1
650217.2 - Spine: Cervical Spine: Vertebra: Vertebra(e) injury: fracture without neurological deficit: multiple fractures of same vertebra	1
650224.2 - Spine: Cervical Spine: Vertebra: Vertebra(e) injury: fracture without neurological deficit: lamina	1
650434.3 - Spine: Thoracic Spine: Vertebra: Vertebra(e) injury: fracture without neurological deficit: vertebral body: major compression (>20% loss of anterior height) [only one endplate]	1
650616.2 - Spine: Lumbar Spine: Vertebra: Vertebra(e) injury: fracture without neurological deficit: NFS	1
650630.2 - Spine: Lumbar Spine: Vertebra: Vertebra(e) injury: fracture without neurological deficit: vertebral body: NFS	1
Upper Extremity, AIS2+ = 39	
752351.2 - Upper Extremity: Skeletal: Radius fracture: Distal radius fracture: extra-articular [includes styloid]	5
752553.2 - Upper Extremity: Skeletal: Metacarpus fracture: One of lateral four fingers: extra-articular or shaft	5
752311.2 - Upper Extremity: Skeletal: Radius fracture: Distal radius fracture	4
750500.2 - Upper Extremity: Skeletal: Clavicle fracture: NFS	3
752500.2 - Upper Extremity: Skeletal: Metacarpus fracture: NFS	3
750651.2 - Upper Extremity: Skeletal: Clavicle fracture: Clavicle shaft fracture: simple	2
751900.2 - Upper Extremity: Skeletal: Forearm fracture	2
752253.2 - Upper Extremity: Skeletal: Ulna fracture: Ulna shaft fracture: simple; oblique; transverse	2
752353.2 - Upper Extremity: Skeletal: Ulna fracture: Distal ulna fracture: extra-articular [includes styloid]	2
752361.2 - Upper Extremity: Skeletal: Radius fracture: Distal radius fracture: partial articular; Colles	2
752363.2 - Upper Extremity: Skeletal: Ulna fracture: Distal ulna fracture: partial articular	2
752521.2 - Upper Extremity: Skeletal: Metacarpus fracture: One of lateral four fingers: NFS	2
752313.2 - Upper Extremity: Skeletal: Ulna fracture: Distal ulna fracture	1
752371.2 - Upper Extremity: Skeletal: Radius fracture: Distal radius fracture: complete articular; T-shaped; Y-shaped; T-condylar; Barton	1
752800.2 - Upper Extremity: Skeletal: Radius fracture: NFS	1
753200.2 - Upper Extremity: Skeletal: Ulna fracture: NFS	1
772330.2 - Upper Extremity: Joints: Carpal (wrist) joint: dislocation [radiocarpal]	1
Lower Extremity, Pelvis and Buttocks, AIS2+ = 22	
858163.2 - Lower Extremity, Pelvis and Buttocks: Skeletal: Metatarsal fracture: One of four lateral metatarsals: partial articular	3
854161.2 - Lower Extremity, Pelvis and Buttocks: Skeletal: Tibia fracture: Proximal tibia fracture: partial articular; Schatzker 1, 2, 3	2
857600.2 - Lower Extremity, Pelvis and Buttocks: Skeletal: Cuboid fracture: NFS	2
858153.2 - Lower Extremity, Pelvis and Buttocks: Skeletal: Metatarsal fracture: One of four lateral metatarsals: extra-articular or shaft	2
840402.2 - Lower Extremity, Pelvis and Buttocks: Muscles, Tendons, Ligaments: Collateral ligament tear; avulsion: ankle	1
840404.2 - Lower Extremity, Pelvis and Buttocks: Muscles, Tendons, Ligaments: Collateral ligament tear; avulsion: ankle: complete disruption	1
854351.2 - Lower Extremity, Pelvis and Buttocks: Skeletal: Tibia fracture: Distal tibia fracture: extra-articular; isolated medial or posterior malleolus	1
854361.2 - Lower Extremity, Pelvis and Buttocks: Skeletal: Tibia fracture: Distal tibia fracture: partial articular	1
854461.2 - Lower Extremity, Pelvis and Buttocks: Skeletal: Fibula [malleoli] fracture: through joint (transsyndesmotic); Weber B	1
854465.2 - Lower Extremity, Pelvis and Buttocks: Skeletal: Fibula [malleoli] fracture: through joint (transsyndesmotic); Weber B: trimalleolar	1
854561.2 - Lower Extremity, Pelvis and Buttocks: Skeletal: Patella fracture: partial articular or extensor mechanism intact	1
856100.2 - Lower Extremity, Pelvis and Buttocks: Skeletal: Pelvic ring fracture: NFS	1
856151.2 - Lower Extremity, Pelvis and Buttocks: Skeletal: Pelvic ring fracture: posterior arch intact; isolated fracture not destroying the integrity of the pelvic ring	1
857371.2 - Lower Extremity, Pelvis and Buttocks: Skeletal: Calcaneus fracture: fracture line into ≥ 2 joint surfaces	1
857400.2 - Lower Extremity, Pelvis and Buttocks: Skeletal: Navicular fracture: NFS	1
857500.2 - Lower Extremity, Pelvis and Buttocks: Skeletal: Cuneiform fracture: NFS	1
858111.2 - Lower Extremity, Pelvis and Buttocks: Skeletal: Metatarsal fracture: First metatarsal: NFS	1

TABLE EII

MALE AIS2+ CODE AND COUNT FOR HEAD, THORAX, SPINE, UPPER AND LOWER EXTREMITIES.

AIS code – Description	Count
Head MAIS2+ = 62	
161001.2 - Head: Diffuse brain injury: Cerebral concussion: mild concussion, no loss of consciousness	49
161000.2 - Head: Diffuse brain injury: Cerebral concussion: NFS	9
161004.2 - Head: Diffuse brain injury: Cerebral concussion: loss of consciousness <1 hour: loss of consciousness ≤ 30 min	3
161002.2 - Head: Diffuse brain injury: Cerebral concussion: brief loss of consciousness	1
Thorax MAIS2+ = 55	
450804.2 - Thorax: Skeletal: Sternum: fracture [OIS II, III]	37
441402.3 - Thorax: Internal Organs: Lungs: contusion: NFS	3
450202.2 - Thorax: Skeletal: Rib Cage: fracture(s) without flail, any location unilateral or bilateral: two ribs [OIS I]	3
450210.2 - Thorax: Skeletal: Rib Cage: multiple rib fractures: NFS	2
450214.5 - Thorax: Skeletal: Rib Cage: fractures with flail: bilateral flail chest [OIS V]	2
441406.2 - Thorax: Internal Organs: Lungs: contusion: unilateral: NFS	1
441412.4 - Thorax: Internal Organs: Lungs: contusion: bilateral: major; large in at least one lung; extensive; massive	1
441414.3 - Thorax: Internal Organs: Lungs: laceration: NFS	1
442200.3 - Thorax: Internal Organs: Thoracic cavity injury: Hemothorax	1
442202.2 - Thorax: Internal Organs: Thoracic cavity injury: Pneumothorax	1
442208.2 - Thorax: Internal Organs: Thoracic cavity injury: Hemomediastinum	1
450203.3 - Thorax: Skeletal: Rib Cage: fracture(s) without flail, any location unilateral or bilateral: ≥ 3 ribs [OIS II]	1
450211.3 - Thorax: Skeletal: Rib Cage: fractures with flail: unilateral flail chest [OIS IV]: NFS	1
Spine MAIS2+ = 14	
650430.2 - Spine: Thoracic Spine: Vertebra: Vertebra(e) injury: fracture without neurological deficit: vertebral body: NFS	2
650432.2 - Spine: Thoracic Spine: Vertebra: Vertebra(e) injury: fracture without neurological deficit: vertebral body: minor compression (≤ 20% loss of anterior height) [only one end plate]	2
650602.2 - Spine: Lumbar Spine: Disc: Disc: herniation: no nerve root damage (radiculopathy)	2
650630.2 - Spine: Lumbar Spine: Vertebra: Vertebra(e) injury: fracture without neurological deficit: vertebral body: NFS	2
650217.2 - Spine: Cervical Spine: Vertebra: Vertebra(e) injury: fracture without neurological deficit: multiple fractures of same vertebra	1
650232.2 - Spine: Cervical Spine: Vertebra: Vertebra(e) injury: fracture without neurological deficit: vertebral body: minor compression (≤ 20% loss of anterior height) [only one endplate]	1
650400.2 - Spine: Thoracic Spine: Disc: Disc: herniation: NFS	1
650603.3 - Spine: Lumbar Spine: Disc: Disc: herniation: with nerve root damage (radiculopathy)	1
650632.2 - Spine: Lumbar Spine: Vertebra: Vertebra(e) injury: fracture without neurological deficit: vertebral body: minor compression (≤ 20% loss of anterior height) [only one endplate]	1
650634.3 - Spine: Lumbar Spine: Vertebra: Vertebra(e) injury: fracture without neurological deficit: vertebral body: major compression (>20% loss of anterior height) [only one endplate]	1
Upper Extremity MAIS2+ = 35	
752371.2 - Upper Extremity: Skeletal: Radius fracture: Distal radius fracture: complete articular; T-shaped; Y-shaped; T-condylar; Barton	4
750500.2 - Upper Extremity: Skeletal: Clavicle fracture: NFS	3
752553.2 - Upper Extremity: Skeletal: Metacarpus fracture: One of lateral four fingers: extra-articular or shaft	3
751900.2 - Upper Extremity: Skeletal: Forearm fracture	2
752251.2 - Upper Extremity: Skeletal: Radius fracture: Radius shaft fracture: simple; oblique; transverse	2
752361.2 - Upper Extremity: Skeletal: Radius fracture: Distal radius fracture: partial articular; Colles	2
752400.2 - Upper Extremity: Skeletal: Carpus fracture: NFS	2
752461.2 - Upper Extremity: Skeletal: Carpus fracture: bone other than scaphoid	2
752521.2 - Upper Extremity: Skeletal: Metacarpus fracture: One of lateral four fingers: NFS	2
714002.2 - Upper Extremity: Whole Area: Degloving: arm or forearm [includes elbow]	1
751161.2 - Upper Extremity: Skeletal: Humerus fracture: Proximal humerus fracture: extra-articular; bifocal [either one of the tuberosities and the metaphysis]; ≥ 2 fracture lines	1
752000.2 - Upper Extremity: Skeletal: Hand fracture	1
752001.2 - Upper Extremity: Skeletal: Hand fracture: open	1
752161.2 - Upper Extremity: Skeletal: Radius fracture: Proximal radius fracture: partial articular; radial head	1
752253.2 - Upper Extremity: Skeletal: Ulna fracture: Ulna shaft fracture: simple; oblique; transverse	1
752273.2 - Upper Extremity: Skeletal: Ulna fracture: Ulna shaft fracture: complex; comminuted; segmental	1
752311.2 - Upper Extremity: Skeletal: Radius fracture: Distal radius fracture	1
752451.2 - Upper Extremity: Skeletal: Carpus fracture: scaphoid only	1
752500.2 - Upper Extremity: Skeletal: Metacarpus fracture: NFS	1
752551.2 - Upper Extremity: Skeletal: Metacarpus fracture: Thumb: extra-articular or shaft	1
752800.2 - Upper Extremity: Skeletal: Radius fracture: NFS	1
752801.3 - Upper Extremity: Skeletal: Radius fracture: open	1
Lower Extremity, Pelvis and Buttocks, MAIS2+ = 17	
854500.2 - Lower Extremity, Pelvis and Buttocks: Skeletal: Patella fracture: NFS	2
840402.2 - Lower Extremity, Pelvis and Buttocks: Muscles, Tendons, Ligaments: Collateral ligament tear; avulsion: ankle	1
840406.2 - Lower Extremity, Pelvis and Buttocks: Muscles, Tendons, Ligaments: Collateral ligament tear; avulsion: knee: partial disruption	1
840501.2 - Lower Extremity, Pelvis and Buttocks: Muscles, Tendons, Ligaments: Cruciate ligament tear; avulsion: partial disruption	1
852004.2 - Lower Extremity, Pelvis and Buttocks: Skeletal: Foot fracture: NFS	1
853271.3 - Lower Extremity, Pelvis and Buttocks: Skeletal: Femur fracture: Femur shaft fracture: complex; comminuted; segmental; Winquist IV	1
853331.3 - Lower Extremity, Pelvis and Buttocks: Skeletal: Femur fracture: Distal femur fracture: NFS	1
853371.3 - Lower Extremity, Pelvis and Buttocks: Skeletal: Femur fracture: Distal femur fracture: complete articular; bicondylar; T-shaped; Y-shaped	1
854171.2 - Lower Extremity, Pelvis and Buttocks: Skeletal: Tibia fracture: Proximal tibia fracture: complete articular; plateau; bicondylar; Schatzker 4, 5, 6	1
854571.2 - Lower Extremity, Pelvis and Buttocks: Skeletal: Patella fracture: complete articular or extensor mechanism disrupted	1
857271.2 - Lower Extremity, Pelvis and Buttocks: Skeletal: Talus fracture: fracture line into ≥ 2 joint surfaces	1
857300.2 - Lower Extremity, Pelvis and Buttocks: Skeletal: Calcaneus fracture: NFS	1
857361.2 - Lower Extremity, Pelvis and Buttocks: Skeletal: Calcaneus fracture: fracture line into one joint surface	1
857400.2 - Lower Extremity, Pelvis and Buttocks: Skeletal: Navicular fracture: NFS	1
857461.2 - Lower Extremity, Pelvis and Buttocks: Skeletal: Navicular fracture: fracture line into one joint surface	1
857471.2 - Lower Extremity, Pelvis and Buttocks: Skeletal: Navicular fracture: fracture line into ≥ 2 joint surfaces	1