Cyclists interacting with passenger cars; a study of real world crashes

M Lindman, S Jonsson, L Jakobsson, T Karlsson, D Gustafson, A Fredriksson

Abstract A growth in the number of cyclists was observed over the past decades. At the same time, cyclists account for a large share of injured road users. Crash data analysis for safety priorities, design of safety systems and development of effectiveness assessment methods for cyclist safety should be based on relevant and representative datasets of real world crashes. This study presents descriptive statistics and cyclist injury risk estimations from Volvo Cars Cyclist Accident Database that provides up-to-date distributions of conflict situations, crash configurations as well as cyclist characteristics and driver information. The most dominant conflict situations with MAIS2+ injured cyclists were 'Straight Crossing Path' scenarios, 'Car Turning when Cyclist approaching from Opposite Direction' and 'Cyclist hit an opening car door when passing by' (dooring). The most common crash configurations were 'car front to cyclist side', 'cyclist front to car side', 'car front to cyclist front' and 'dooring' in that order. The body parts with the highest risk for serious injuries were the torso and the lower extremities followed by the head. When adding moderate injuries, the highest risk for injuries was found in the upper extremities. The results of the analysis aim at prioritize and develop active, integrated and passive safety countermeasures in car to cyclist crashes.

Keywords car to cyclist crashes, conflict situations, precrash factors, cyclist injuries

I. INTRODUCTION

Cycling is a transport mode on the rise [1-2] due to health and environmental benefits, time and cost savings, improved cycling infrastructure and innovative cycle sharing programs to mention a few reasons. At the same time, vulnerable road users make up a substantial share of traffic fatalities in the EU countries [3], and in Sweden cyclists account for a higher proportion of causalities than any other road user type [4]. As was reported in the Netherlands, US and Sweden, most cyclist crashes are single cycle crashes [5-7]. About 17% of cyclist crashes involved motor vehicles [7]. From a car manufacturer's perspective to set priorities and develop countermeasures addressing reduction of injuries and crashes, it is essential to have knowledge about the character of real world crashes with cars relevant for the manufacturer. Ultimately, this includes full coverage of all crashes. For car to cyclist crashes, such knowledge is not readily available. First, the databases on hand usually contain a heterogeneous vehicle population, representing a variety of properties relevant for the consequences of a crash situation. Second, crash database inclusion criteria are often set to a certain injury level or limit the data collection to police- or hospital reported crashes. For example, only 50% of the crashes included in the insurance claim data, including cyclists with moderate to serious injuries, were also reported to the national crash databases in Sweden [8-9]. Earlier studies also showed that police reported cyclist crash data is under represented [10-11]. Further, many publications of car to cyclist crashes focus on car frontal collisions, while in fact side impacts are just as important. Other common limitations of such studies are cyclist injury severity level, age group, or crash location. For a car manufacturer, who ideally prefers to work with a relevant, modern and homogenous car-make sample when setting safety targets, it is a challenge to find a database that meets these requirements. In the present study, such a database was established, addressing the need for knowledge on full coverage of crashes. A database was designed to provide a comprehensive view of the safety challenge of car to cyclist interaction, addressing both driver support and crash compatibility aspects. The aim of this study was to establish priorities based on knowledge of the character of real world car to cyclist crashes to enable development of safety systems. Specifically, distribution of conflict situations, precrash factors, crash configurations and cyclist injuries will be studied using the Volvo Cars Cyclist Accident Database (V_CAD).

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II. METHODS

In this study, cyclist crashes with passenger cars in the Volvo Cars Cyclist Accident Database, V_CAD, were analyzed to identify frequent injuries and car impact points as well as the underlying crash mechanisms in terms of accident configurations.

Data

V_CAD contains extensive information on car to cyclist crashes in Sweden including information about the pre-crash scenario, the crash, the car, the driver and the cyclist. Cyclists are defined as conventional mechanical bikes, excluding e-bikes, mopeds etc. Basic information on car to cyclist crashes, from the database analyzed in [8-9], was provided by Volvia (IF P&C Insurances) to Volvo's Traffic Crash Research Team and stored in the V_CAD database. Since drivers in Sweden are obligated to report cyclist crashes according to the terms of insurance, a comprehensive coverage was assured. Cyclist crashes were identified using motor insurance claims reported by the third party liability insurance and sampled for all Volvo cars during their first three years in traffic, as well as for a portion of the older vehicles. Each case was anonymized before being stored in the database. The information provided by the insurance company came from several sources; the vehicle claim report, the cyclist claim report, the police report and from interviews with the drivers, cyclists and other eyewitnesses. A vehicle crash claim report was available for every case and in most cases a crash report was filed by the cyclist as well. The vehicle report contains information about the course of events from the driver's perspective. Also, estimated speed at impact, traffic environment (often described in a sketch), cyclist impact points, car damage, driver distraction elements and a description of injuries sustained were described. For fatal crashes, no information regarding injuries was collected by the insurance company. For cases where the police were present at the accident scene, a police report including a sketch of the crash scene and witness statements from the driver, the cyclist and any additional observers were available as well. Additionally, further information such as notes from conversations with the cyclist and the driver were collected by the insurance company during the insurance claim handling process. When relevant, this information was included in the database as well. Vehicle specification data were used to add additional car information, such as equipment and optional safety systems. Map data provided further information of the crash scene, such as road geometry and roadside objects. Conflict Situations were coded as described in 'Definitions and analyses' below. Based on the crash investigator's compilation of all information of the precrash phase, each case was digitalized in order to provide vehicle paths in relation to vehicle velocities and to the surroundings. For this purpose, the ordinal variable cyclist speed with the levels 'was cycling slow', 'was cycling', 'was cycling fast', 'was cycling fast downhill' was converted to numerical speed values: 7,5 km/h, 12.5 km/h, 15 km/h and 20km/h respectively. Medical records and/or autopsy reports for cyclists involved were collected using an informed consent procedure, and injuries were coded by a physician within Volvo Cars Traffic Accident Research Team, according to the Abbreviated Injury Scale (AIS) [12-13]. No attempt was made to assign a cyclist injury to a specific impact area; all injuries were regarded as sustained in the car to cyclist crash 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 crash research team coded the car deformation following SAE recommended practice [14], along with cyclist impact point x-, y- and z-coordinates. At the time of the analysis, 311 cyclist cases occurring between 2005-2013 were stored in the database.

Sample

All cyclists in collision with passenger cars were included in the database. For the analysis only one cyclist per crash was selected. Also, overall injury data for the cyclist should be available. With these inclusion criteria, no case was excluded. The distribution of car model years in the dataset is shown in Figure 1.

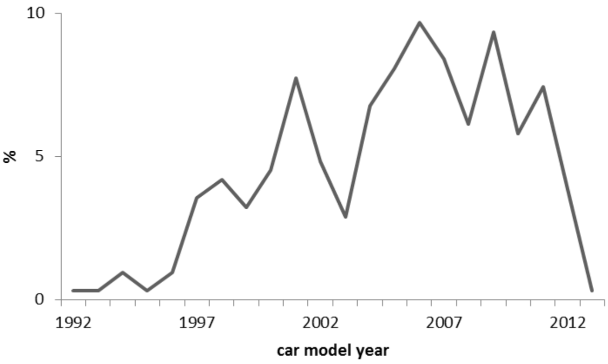


Fig. 1. Distribution of car model years (Q_1=2001, Median=2006. Q_3=2009).

Three datasets from the database, as illustrated in Figure 2, were used for the different purposes of the analysis. The main sample consists of 311 car-to-cyclist-crashes and was used for the study of accident characteristics. For the injury analysis, detailed injury information was available for 308 cyclists with a total of 786 injuries. In two (n=2) cases, cycle passengers were present, but not included in the analysis. One cyclist was uninjured and the two (n=2) cyclists who sustained fatal injuries were excluded in the injury analysis due to lack of detailed injury information. The two fatal cyclists were both involved in front to front crashes in Oncoming situations. In all cases where the car was damaged at cyclist contact, exact impact points were coded. 242 observed car impacts in 129 cases were available for analysis of cyclist to car impact area.

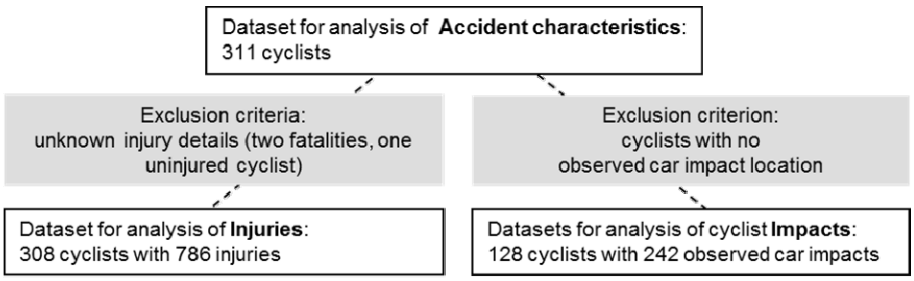
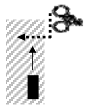
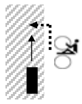
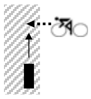
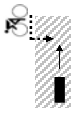
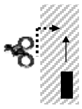
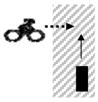
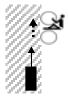


Fig. 2. Overview of datasets.

Definitions and analysis

Accident characteristics are described by *conflict situations, precrash-factors* and *crash configurations*. For all cases, the *conflict situation* was classified, describing the way the car and the cyclist were moving in relation to each other before the crash, see Figure 3. One example is Straight Crossing Paths (SCP), where the car was moving forward and the cyclist was crossing the path either from left or right. In a sublevel of SCP, the initial path of the cyclist is described, noting the direction of the cyclist during the time the car was approaching the crash location. An important distinction was made between the SCP situations and the car turning conflict situations; if the cyclist was crossing the path before the car had started to turn, the case was classified as a SCP. Otherwise, as in the example in Figure 4, it was noted as a car turning situation. The conflict situation does not depend on whether the cyclist was on the road or on a cycle path before the collision.

$SCPcr_{OD}$	Straight Crossing Path, cyclist from right, initially from Opposite Direction	
$SCPcr_{SD}$	Straight Crossing Path, cyclist from right, initially from Same Direction	
SCPcr	Straight Crossing Path, cyclist from right	
$SCPcl_{OD}$	Straight Crossing Path, cyclist from left, initially from Opposite Direction	
$SCPcl_{SD}$	Straight Crossing Path, cyclist from left, initially from Same Direction	
SCPcl	Straight Crossing Path, cyclist from left	
Oncoming	Straight, cyclist Oncoming	
SD	Straight, cyclist Same Direction	
Reversing	Car reversing accident	
Dooring	Car occupant is about to leave the car and the cyclist crashes into the door being opened	
Car standing still	Parked car, or car standing still in traffic	
Other	Other	

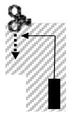
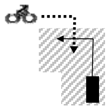
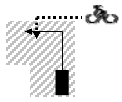
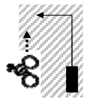
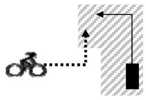
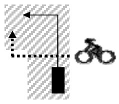
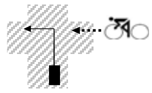
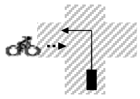
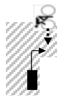
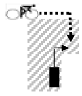
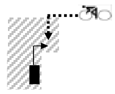
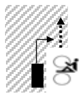
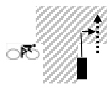
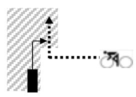
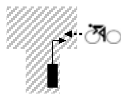
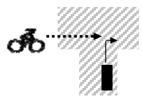
LT/OD	Left Turn, cyclist from Opposite Direction	
LT/OD_{LD}	Left Turn, cyclist from Opposite Direction, initially from left direction	
LT/OD_{RD}	Left Turn, cyclist from Opposite Direction, initially from right direction	
LT/SD	Left Turn, cyclist from Same Direction	
LT/SD_{LD}	Left Turn, cyclist from Same Direction, initially from left direction	
LT/SD_{RD}	Left Turn, cyclist from Same Direction, initially from right direction	
LT/RD	Left Turn, cyclist from Right Direction	
LT/LD	Left Turn, cyclist from Left Direction	
RT/OD	Right Turn, cyclist from Opposite Direction	
RT/OD_{LD}	Right Turn, cyclist from Opposite Direction, initially from left direction	
RT/OD_{RD}	Right Turn, cyclist from Opposite Direction, initially from right direction	
RT/SD	Right Turn, cyclist from Same Direction	
RT/SD_{LD}	Right Turn, cyclist from Same Direction, initially from left direction	
RT/SD_{RD}	Right Turn, cyclist from Same Direction, initially from right direction	
RT/RD	Right Turn, cyclist from Right Direction	
RT/LD	Right Turn, cyclist from Left Direction	

Fig. 3. Conflict situation classification scheme in V_CAD.

Fig. 4. Example of a RT/LD situation.

Precrash-factors are parameters that can influence the course of events before the crash. Examples are speed related measures and traffic environment related factors such as light condition and road status. Initial lateral offset was calculated for the opposite direction conflict situations LT/OD and RT/OD. In these conflicts both road users are initially travelling along the same road. The lateral offset was defined as the distance between the two road user's geometrical centres in the direction perpendicular to the road just prior to any turning manoeuvre, Figure 5a and 5b. In cases with obscured sight, the time to collision (TTC) was calculated. A line was drawn between the geometrical centers of the cyclist and the car for every time step, in the precrash sequence. The last time step where this line was broken by the obstruction was identified, see Figure 5c. TTC was then defined as the time from this point to the first contact between the two road users. The crash configuration describes the collision between the two road users in cases where the car was moving forward, i.e. car front to cyclist front or car front to cyclist side.

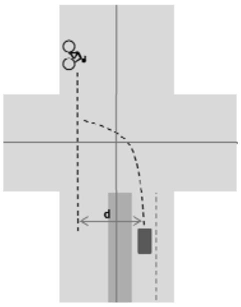


Figure 5a. Illustration of lateral offset in LT/OD.

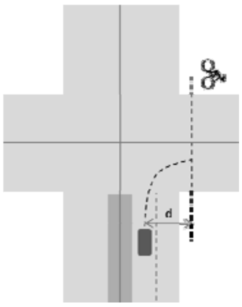


Figure 5b. Illustration of lateral offset in RT/OD.

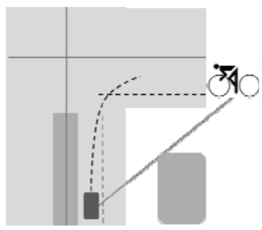


Fig. 5c. Illustration of the initial moment in the TTC calculation in cases with view obstruction.

For the *cyclist injury* analysis, each injury was classified according to the AIS body regions. Head and face were grouped in a category called head. Thorax, abdomen and spine (excluding cervical spine) were clustered in a category called torso. The risk of sustaining an injury was calculated using the most severe injury per cyclist, or the most severe injury per cyclist and body region. Risk was defined as the number of injured cyclists divided by the total number of cyclists involved (injured as well as uninjured) and binomial proportion confidence intervals were applied. The cyclists were grouped by age; juniors (up to 14 years old), adults (15-64 years old) and seniors (65 years or older). *Cyclist to car impact areas* were analyzed and compared for observed impacts to D-segment large family cars (Volvo S80, V70, XC70, S60 and 800 models), C-segment small family cars (Volvo S40, V40, V50 and C30 models) and SUVs; (Volvo XC90 and XC60 models).

III. RESULTS

Characteristics of cyclists' interaction with a passenger vehicle before and during a crash are presented in terms of accident characteristics, cyclist injuries and cyclist-to-car impact area aspects.

Accident characteristics

The distribution of conflict situations provides an overview of the car to cyclist crash problem (Figure 6). The majority of crashes are SCP situations with 39% of all crashes and 34% of all MAIS2+ injured cyclists. LT/OD and RT/OD, the car turning and cyclist approaching from opposite direction situations, account for 14% and 17% of all and of MAIS2+ crashes respectively. In 6% of the crashes and 10% of the injured cyclists, the cyclist hit the car door that was being opened by the car driver or a passenger (hereafter called 'dooring'). Situations in longitudinal traffic, including the Oncoming and the SD situations, comprise 5% of all crashes and 9% of MAIS2+ injury crashes. In LT/LD, 8% of MAIS2+ cyclists were found. RT/RD held 6% of MAIS2+ causalities, but as much as 11% of all crashes. The same share of MAIS2+ cyclists was found when grouping LT/SD and RT/SD situations. There was 4% of the MAIS2+ injured cyclists in both crashes where the car was reversing and the car was standing still. The smallest portions of injured cyclists were found in merging path situations; RT/LD and LT/RD.

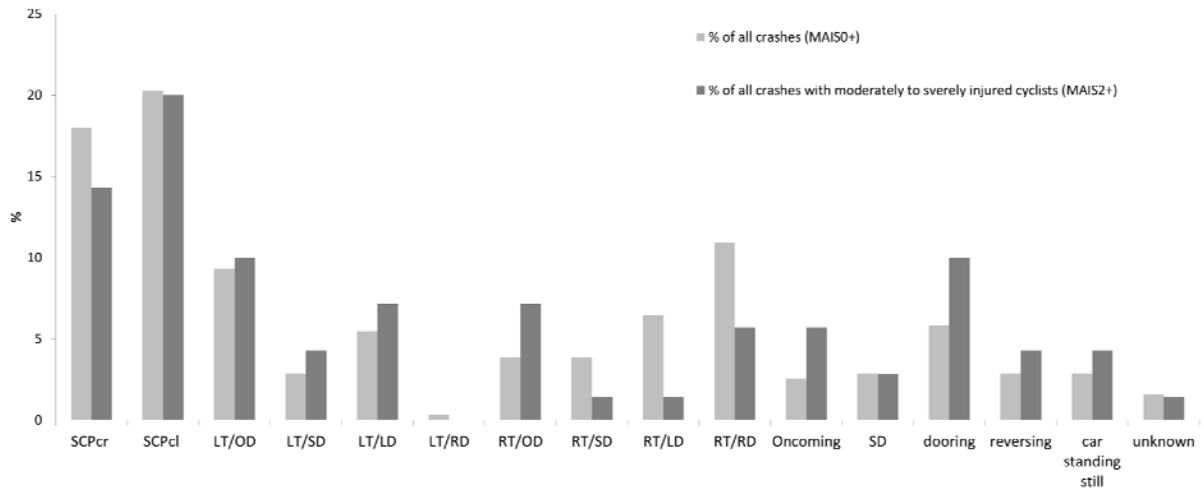


Fig. 6. Distribution of Conflict Situations for all crashes (MAIS0+), n=311 and for MAIS2+ injury crashes, n=70.

For the SCP, LT/OD and the RT/SD situations, distributions of cases classified as variants of the conflict situations in the distribution above are presented in Figure 7. In a substantial share of the SCPcr crashes, 20%, the cyclists initially came from the same direction as the car. In 4% the cyclists were approaching from the opposite direction. In SCPcl, the corresponding figure for both same and opposite direction was 6%. In LT/OD and RT/SD, a minor share of cyclists came from the right direction.

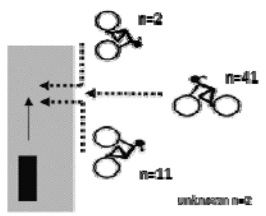


Fig. 7a. Distribution of SCPcr, $SCPcr_{OD}$ and $SCPcr_{SD}$.

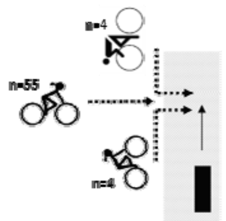


Fig. 7b. Distribution of SCPcl, $SCPcl_{OD}$ and $SCPcl_{SD}$.

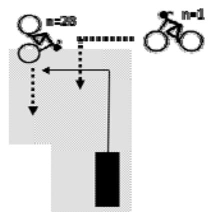


Fig. 7c. Distribution of LT/OD and LT/OD_{RD}.

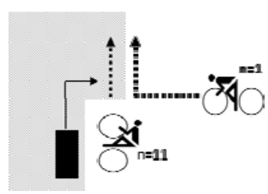


Fig. 7d. Distribution of RT/SD and RT/SD_{RD}.

For conflict situations where the car was moving forward, precrash-factors are presented in Figure 8, providing basic information for crash avoidance functionality design. Impact speed estimations for the car were available in 245 cases. Highest mean impact speed was found in the SD situations, followed by the Oncoming crashes. The lowest impact speeds were found in RT/RD crashes. Cyclist speeds were roughly estimated and in Appendix A, percentages of car speed by cyclist speed are shown for conflict situations with more than 20 observations. In 20% of the car moving forward crashes, a sight obstruction was hindering the driver from detecting the cyclist prior to the crash. In 62% of these situations, TTC was 1s or longer at the time the crash opponent was visible. Initial lateral offset, another important piece of precrash information related to detection, varied between 3m and 13m in LT/OD and RT/OD situations. The majority of car to cyclist crashes occurred in daylight or in street light. Dry road conditions were present in more than 50% of the cases in most conflict situations. Cyclists of ages up to 14 years (juniors) were found in Oncoming, SCP, RT/RD, RT/SD and LT/OD. Seniors were most common in RT/RD and in SCPcl.

TABLE 1

DESCRIPTIVE STATISTICS FOR PRECRASH FACTORS AND CRASH CONFIGURATION FOR ALL CRASHES (MASI0+) IN CONFLICT SITUATIONS WHERE THE CAR WAS MOVING FORWARD.

	SCPcr n=56	SCPcl n=63	LT/OD n=29	LT/SD n=9	LT/LD n=17	LT/RD n=1	RT/OD n=12	RT/SD n=12	RT/LD n=20	RT/RD n=34	Oncoming n=8	SD n=9	total
CAR IMPACT SPPED													
mean (km/h)	21 ([illegible])	20 ([illegible])	14 ([illegible])	11 ([illegible])	11 ([illegible])		15 ([illegible])	12 ([illegible])	15 ([illegible])	7 ([illegible])	29 ([illegible])	44 ([illegible])	17
75th percentile (km/h)	30	25	18	15	15		19	16	19	10	36	70	20
50th percentile (km/h)	20	20	15	10	10	10	15	15	16	5	30	43	15
25th percentile (km/h)	10	10	10	5	6		10	8	11	5	19	23	10
unknown	4	7			2			4	7			1	25
SIGHT OBSTRUCTION													
yes	18	12	2		2				3	17	1		55
no	38	51	27	9	15	1	12	12	17	17	7	9	215
For cases with sight obstruction: TTC													
TTC<=0,5s	2	5								2	1		10
0,5s<TTC<=1s	6	2								3			11
1s<TTC<=1,5s	8	3								6			17
2s<TTC<=2,5s	1	1	1		2				3	4			12
TTC>3s	1	1	1							2			5
INITIAL LAT. OFFSET for LT/OD and RT/OD													
d<=5m			10				4						
5m<d<=10m			13				2						
10m<d<=15m			5				5						
unknown			1				1						
LIGHT CONDITION													
light	51	52	19	3	12	1	10	9	11	30	6	8	212
dark/dusk/dawn with street lights	3	3	4	6	1		2		5	2	1		27
dark/dusk/dawn		3	2		1				2	1			9
unknown	2	5	4		3			3	2	1	1	1	22
ROAD CONDITION													
dry	42	39	16	2	11	1	7	6	11	22	7	6	170
wet	1	12	3	5	2		2	1	2	4			32
snow/ice	1		1						1	2			5
unknown	12	12	9	2	4		3	5	6	6	1	3	63
CYCLIST AGE													
junior	13	10	2					1		5	3		34
adult	38	41	21	7	13	1	11	10	16	21	5	8	192
senior	4	10	3	1	2		1			6			27
unknown	1	2	3	1	2			1	4	2		1	17
CRASH TYPE													
car front to cyclist front	3	4	7		1		3	1	2	3	8		32
car front to cyclist side	22	38	10	4	6	1	6	1	9	25			122
car front to cyclist rear	1	1							2			3	7
cyclist front to car side	25	19	11	5	9		3	8	6	5			91
car side to cyclist side	1	1	1						1	1		5	10
unknown	4				1			2				1	8

The most common crash configuration was car front to cyclist side in 45% of crashes when the car was moving forward. Taking all crashes into account, this crash configuration represents 39% of car to cyclist crashes, followed by cyclist front to car side, front to front crashes and dooring situations with 29%, 10% and 6% respectively. Other crash configurations, i.e. for cases corresponding to the conflict situations dooring, reversing and car standing still, account for 2-3% of the crashes each.

Cyclist Injury Risks

The distribution of MAIS2+ injury risks is shown in Figure 8. Although the dooring situation was not the most frequent situation (Fig 6), it accounts for the highest MAIS2+ risk. Cyclists impacting a reversing or stationary car are also exposed to relatively high MAIS2+ injury risks as compared to conflict situations where the car was moving forward. However, no statistically significant differences were seen between the situations due to small sample sizes.

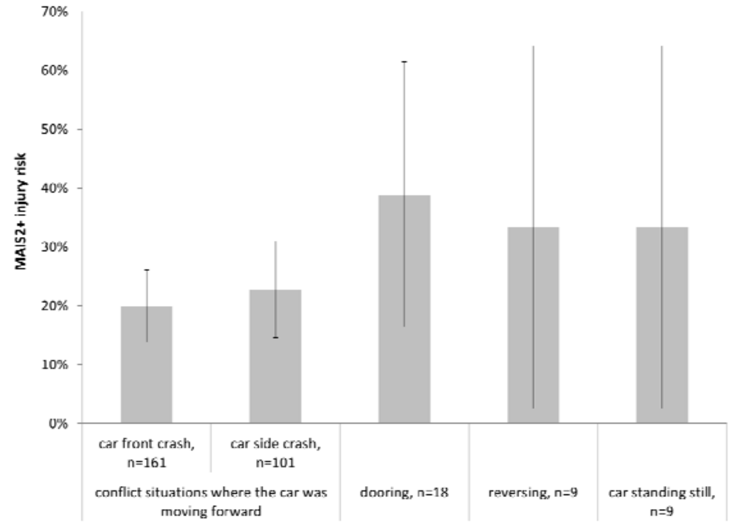


Fig. 8. MAIS2+ injury risk per conflict situation and crash configuration.

The MAIS3+ and MAIS2+ injury risks per body region are shown in Figure 9. The highest MAIS3+ injury risk was seen for the torso and the lower extremities (both 1.6%), followed by the head (0.9%). When adding moderate injuries the results were different, highlighting the upper extremities as the body region with highest MAIS2+ injury risk (8.5%). Beside the addition of the substantial proportion of AIS2 upper extremity injuries, the risk for the different body regions follow the same trend as for MAIS3+ injury risks with MAIS2+ injury risks of 6.6%, 6.0% and 4.1%, for the torso, the lower extremities and the head in turn.

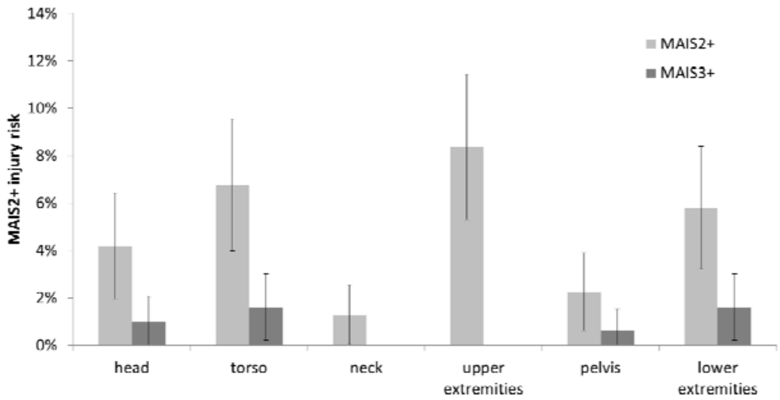


Fig. 9. MAIS2+ and MAIS3+ injury risk per body region

Cyclist Injuries

The 308 cyclists with known injury details sustained in total 667 AIS1 injuries and 119 AIS2+ injuries. AIS2+ injuries accounted for 15% of all injuries. Of all AIS2+ injuries, 76% were fractures, mainly in upper extremities (33%), torso (25%) and lower extremities (24%). Head, pelvis and neck fractures accounted for the rest of the fractures. Second to fractures, were brain injuries (mainly concussions) representing 10% of all AIS2+ injuries. Other AIS2+ injuries sustained were ruptures, luxation, laceration and contusions. The distribution of body parts for all the 117 AIS2+ injuries with known conflict situation is shown in Table 2. It can be seen that the lower extremities, upper extremities and thorax followed by the head were the dominating injured body parts. Especially notable was the relatively higher frequency of lower extremity injuries in conflict situations where the car was moving forward and the cyclist impacts the front of the car. The thorax and upper extremity injuries were more pronounced when the cyclist impacted the side of the car in conflict situations where the car was moving forward. Car moving forward situations are also the situations accounting for all of the head injuries, in this sample.

TABLE 2
NUMBERS OF AIS2+INJURIES PER BODY PART

	conflict situations where the car was moving forward				
	car front crash	car side crash	dooring	reversing	parked car
Head	9	7	0	0	0
Thorax	14	14	2	0	1
Neck	2	3	0	0	1
upper extremities	16	12	1	2	1
Pelvis	3	3	2	0	0
lower extremities	18	3	2	1	0
Total	62	42	7	3	3

Cyclist to car impact areas

In the 129 cases where the car was damaged by the cyclist (or bicycle) contact, the impact coordinates were documented for a total of 242 impact points. Estimated impact speeds in these accidents ranged from 0 km/h to 70 km/h. Although it was not possible to associate exact cyclist injury to a specific car impact point, it is interesting to note that all severity levels of overall cyclist injury were present in these 128 cases. 28 of the 128 cyclists sustained MAIS2+ injuries, while 100 cyclists sustained MAIS1 injuries only. 26% of all impacts were to the hood or the windscreen area. These 62 impact points are plotted for the different age groups and the two sizes, large and small, of generic Volvo car models (Fig. 10). For SUV's, only one impact in this area was found. A variety of impact points can be seen and no clear differences between the age groups are evident.

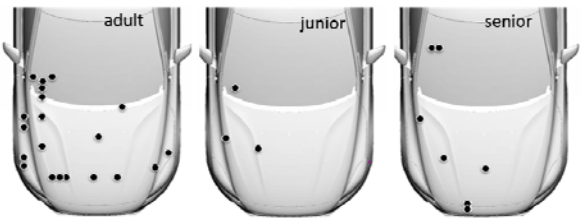


Fig. 10a. Small C-segment cars.

Fig. 10b. Large D-segment cars.

Distribution of impact points on small and large cars for all cyclist contacts resulting in car damage on the hood or in the windscreen area for adult, junior and senior cyclists respectively.

IV. DISCUSSION

In this study, car to cyclist crash occurrences and consequences were analyzed, giving valuable knowledge for improved vehicle design. A homogenous dataset in terms of car make and model year provides relevant information for cyclist safety priorities as the description of crash characteristics will not depend on an excessive variety of car design. Also, the crash data used was not restricted to police- or hospital reported crashes only since drivers in Sweden are obliged to report crashes involving cyclists to an insurance company [8-9]. Hence, using insurance claims as the sampling frame for the car to cyclist crash database, the analysis presented covers a representative view of all cyclist crashes with Volvo cars in Sweden.

A relevant classification scheme for Conflict Situations of car to cyclist crashes was defined and used for a structured presentation of Precrash factors. The majority of car to cyclist crashes were SCP and Car Turning when Cyclist approaching from the Opposite Direction situations. It is also important to recognize conflict situations where the car is not moving forward. Dooring (the cyclist hits an opening car door when passing by) accounted for 10% of crashes with MAIS2+ injured cyclists. The proportion of cyclist to car crashes involving other types stationary or reversing of cars was 9%. Thus, situations when the car was not moving forward accounted for 19% of the total share of car to cyclist crashes, representing a relevant share of the car to cyclist crash conflict situation distribution.

An interesting relocation of shares of conflict situations was found after revisiting the raw data for a review of the classification for the present study. Using a previous and less detailed version of the conflict classification scheme, the SCP share of conflicts was somewhat larger than in the current classification. This was due to not considering turning manoeuvres by drivers involved in crashes in intersections in the previous conflict situation coding. Figure 4 illustrates a typical crash that previously was classified as a SCP, but in the present study was defined as a RT/LD. Figure 11 shows one example of the transfer in the distribution of conflict situations when using the previous and the present, revised, classification scheme. A substantial share of SCP situations was moved to the LT/LD and RT/RD situations, indicating the importance of precise conflict situation interpretation and coding from the crash data collected.

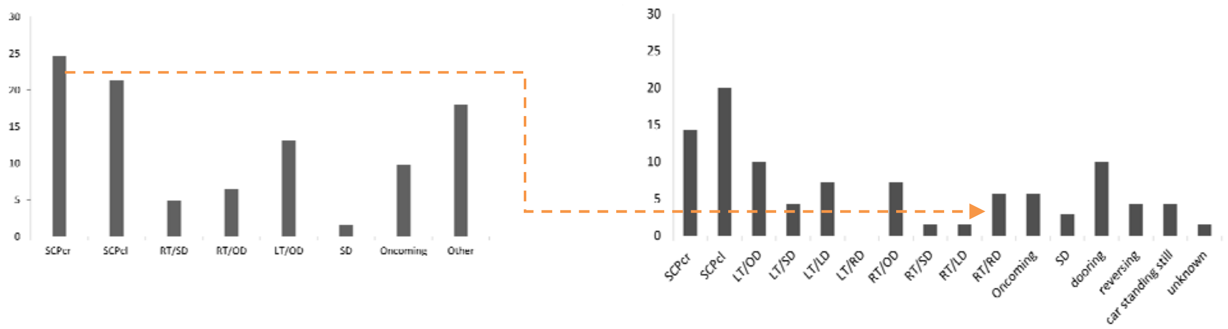


Fig. 11. One example (dotted line) of transfer in the distribution of conflict situations with cyclist MAIS2+ injuries when using a previous (to the left in the figure) and the present, revised, classification scheme (to the right) in V_CAD.

The analysis of precrash-factors provided a further description of the conflict situations. Among the 270 cases where the car was traveling forward before the crash, information of lateral offset between the car and the cyclist is important for detection purposes. A relatively large variation in lateral offset distance was found in LT/OD and RT/OD situations. Adverse road conditions and cyclist size are other parameters to consider, as well as the presence of sight obstructions in the traffic environment. Complementary information is still needed to more precisely describe the precrash phase of car to cyclist accidents than retrospectively collected crash data can provide. Cyclist crash speed is one of the parameters not investigated in detail, however some publications reveals some data on this topic. In [15], the main proportion of MAIS2+ injured cyclists in frontal car to cyclist crashes in GIDAS occurred in cyclist speeds up to 15 km/h, and in [16], about 90% of the cyclists' speed at impact was less than 10 km/h in a smaller dataset. Ultimately, car and cyclist paths as well as cyclist velocities and acceleration profiles could be retrieved from crash situations in naturalistic driving study (NDS) data, but so far research into this approach has been limited. Altogether, the accurate classification of conflict situations and the description of these provide an overview and details to crash avoidance functionality design.

The analysis of injury risk showed that compared to conflict situations where the car was moving forward, the dooring situation accounted for the highest overall MAIS2+ risk, although no statistically significant differences were found. Separated by body regions, the highest MAIS2+ risk was found in the upper extremities. This body region would not be considered at all if only studying MAIS3+ injury risk. The highest MAIS3+ injury risk was seen for the torso and the lower extremities (both 1.6%), followed by the head (0.9%). Information of cyclist helmet use was available in 148 of all crashes. Only in 7 of cases with head injury, the cyclist was wearing a helmet. Hence no significant difference in head injury risk was found when comparing MAIS2+ head injury risk for cyclists with and without helmet. The importance of cyclist helmet use for prevention of head injuries was nevertheless established in a large number of previous studies, i.e. [17-22].

One challenge with respect to injury analysis in car to cyclist crashes is how to determine the specific injury mechanisms. The cyclist-to-car impact point is very difficult to reconstruct based on the information typically available in retrospectively collected data. Furthermore, during the post cyclist-to-car impact sequences, numerous possible injury sources appear. For example, previous research suggest that contact with the ground frequently leads to significant cyclist injuries [23]. Enhanced quality of input data is needed to fully understand cyclist-car impact events and to validate accident reconstruction results. Nevertheless, the overall and complete picture of cyclist injuries supplied by the dataset analyzed is important for setting priorities and developing effective measures. The cyclist-to-car impact information from cases where the impact caused a car deformation, as exemplified in Figure 9, provides an essential and valuable view on cyclist harm since this subset represents all cases where the car was damaged at the cyclist contact.

The majority of cyclist crashes are single-cyclist accidents [5-7], these were not included in this study. In a Norwegian study [24], some single cyclist crashes were due to an interaction with another vehicle, although no vehicle impact occurred. This situation poses a challenge to a data collection process aiming for a more comprehensive picture of cyclist crashes where passenger cars are involved. Further limitations of the present study were the low number of cases, which made it difficult to divide the data into more relevant subgroups. Also, the sampling frame focusing crashes occurring in one country limits the conclusions for other regions of the world. It is likely that the traffic situation and vehicle combination is different in other countries, which would probably result in a different distribution of both conflict situations and precrash factors.

To conclude, the great discrepancy in conflict situations, crash configurations, cyclist characteristics and possible injury mechanisms call for a combination of different countermeasures in order to provide sufficient protection for cyclists of all ages. Given the complexity of crash circumstances, the first hand choice for preventing cyclist causalities in crashes with cars should be crash avoidance measures that have the potential to address a large group of cyclist injury mechanisms.

V. CONCLUSIONS

In this study, a relevant and representative database of real world crashes that provides a comprehensive view of the safety challenge of car to cyclist interaction was used, addressing both driver support and crash compatibility aspects. The results aim to prioritize and design active-, integrated- and passive safety measures. The most frequent conflict situations in terms of MAIS2+ injured cyclists was Straight Crossing Path scenarios, Car Turning when Cyclist approaching from the opposite direction and the cyclist hitting one of the car doors that was being opened (dooring). The variation in initial lateral offset, crash configuration, car impact speed, cyclist size (age), and TTC in crashes with a sight obstruction prior to the crash was noticeable. The body regions with highest risk for serious injuries were the torso, the lower extremities and the head and when adding moderate injuries, the highest risk for injuries was found in the upper extremities. The great diversity in conflict situations, crash configurations, cyclist characteristics and possible injury mechanisms calls for a combination of different countermeasures in order to provide sufficient protection for cyclists of all ages.

VI. ACKNOWLEDGEMENT

The authors thank colleagues at Volvo Cars Safety Centre and Volvia and IF P&C Insurance for their support with preparation of the database as well as for feedback on the writing of the paper.

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VIII. APPENDIX

TABLE A

DISTRIBUTION OF ESTIMATED CAR- AND CYCLIST IMPACT SPEED IN THE CONFLICT SITUATION SCPCR

	was cycling slow	was cycling	was cycling fast	was cycling fast downhill	total
1-10 km/h	0	14	1	0	15
11-20 km/h	1	10	2	2	15
21-30 km/h	0	12	4	0	16
31-40 km/h	0	4	0	1	5
>40 km/h	0	1	0	0	1
Total	1	41	7	3	52

TABLE B

DISTRIBUTION OF ESTIMATED CAR- AND CYCLIST IMPACT SPEED IN THE CONFLICT SITUATION SCPCL

	was cycling slow	was cycling	was cycling fast	was cycling fast downhill	total
1-10 km/h	1	11	3	0	15
11-20 km/h	3	17	4	1	25
21-30 km/h	1	6	2	1	10
31-40 km/h	0	2	1	0	3
>40 km/h	0	2	1	0	3
Total	5	38	11	2	56

TABLE C

DISTRIBUTION OF ESTIMATED CAR- AND CYCLIST IMPACT SPEED IN THE CONFLICT SITUATION RT/RD

	was cycling slow	was cycling	was cycling fast	was cycling fast downhill	total
1-10 km/h	2	23	3	1	29
11-20 km/h	0	4	1	0	5
Total	2	27	4	1	34