

Cyclist kinematics in car impacts reconstructed in simulations and full scale testing with Polar dummy

Margriet van Schijndel¹, Stefanie de Hair², Carmen Rodarius³, Rikard Fredriksson⁴

Abstract

For the development of effective vehicle-related safety solutions to improve cyclist and pedestrian protection, essential information on impact locations, impact situations and cyclist and pedestrian kinematics in impacts with passenger cars is fundamental.

Accidentology research showed that cyclists typically have a higher impact location, with a larger share of injuries from the windscreen area. Majority of accidents happened at crossroads (72% of the Dutch cases). The average car speed was 36 kph, the median bicycle speed 14 kph.

A cyclist simulation study captured kinematics and injuries to head, torso, pelvis and legs for several human body sizes, bicycle types and generic car models. Six full-scale crash tests (passenger car versus cyclist or pedestrian (Polar II dummy) had as main parameters: head impact location (top of bonnet, windscreen, A-pillar), vehicle speed (40 kph) and dummy speed (15 kph).

Accidentology, simulation and crash test data showed that the windscreen is a frequent head and torso impact location. Accidentology and crash testing showed that cyclist protection should address higher, more rearward locations in the windscreen area than pedestrian countermeasures. Head impact speeds for cyclists in testing were generally higher than for pedestrians.

Keywords

Accidentology, Cyclist and pedestrian kinematics, Cyclist impact simulations, Polar II crash testing, Vulnerable road user protection

I. INTRODUCTION

Europe-wide, the total number of cyclists is increasing. Despite (inter)national road safety policies, aiming at decreasing the number of road fatalities and severe injuries, accident statistics show that the actual number of severely or fatally injured cyclists remains constant or is even increasing. The Dutch accident statistics show for example from 2010 to 2011 an increase from 162 to 200 fatalities among cyclists [1]. The combination of these trends urges for dedicated work to improve cyclist safety, combining infrastructure, behaviour and “cyclist-friendliness” of cars.

A thorough understanding of the circumstances of accidents between passenger cars and cyclists or pedestrians is essential in order to be able to develop vehicle-related safety solutions to improve protection for these vulnerable road users. In parallel to technology-focused developments on new systems like automatic braking and exterior airbags for cars, major work is being performed on impact locations, impact situations and cyclist and pedestrian kinematics.

Over the recent years, developments worldwide have had a large focus on increasing pedestrian safety by requiring protection capability of cars through both regulations and consumer tests; however, none of this has actively involved the safety of bicyclists in car crashes. The increasing use of bicycles in many major cities leads to the expectation that the number of cyclist fatalities will increase in the coming years unless proper actions are taken. The share of cyclist fatalities cannot be ignored as, for example, Dutch figures show. In the Netherlands, a country with many cyclists, there were 661 road fatalities in 2011; 74 were pedestrians and 200 were cyclists [1]. About half of the cyclist fatalities were directly related to an impact with a passenger car.

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Therefore, the work presented here focusses on cyclists. Accident statistics show that children below 18 years comprise 5% of the total number of road traffic fatalities [2]. Only part of them were pedestrian or cyclist. To start this relatively new field of work on the largest group, it was decided to focus on adults.

II. METHODS

This study contains three major parts: 1) accidentology 2) simulations and 3) crash tests. The methodologies for these three fields of work are described in detail separately but comprise a single research project.

Accidentology

A literature study and accidentology study were executed to gain more insight into the bicycle-to-car accidents. The focus of this study was on investigating the most common impact scenarios and injuries.

The literature study formed the basis for the simulation work and crash testing. For the literature study Dutch [3] and Swedish data sources [4] were used. This combination gave a lot of useful information, but had one major drawback; the various databases use different methods of data collection as well as level of detail of accident data. Thus, a comparison between the several sources of information is hard to make, especially for the less severe injuries such as MAIS 1. The study was limited to MAIS2+ injuries and specially focused on severe injuries MAIS3+. Specific searches were performed on cyclist-passenger car accidents, with MAIS2+ injuries for the cyclist. Impact speeds of the passenger car and cyclist, as well as driving directions and impact angles were searched, together with impact locations of the main body parts combined with information on the severest injured body region. In literature, information on these accident parameters was only limited. Therefore, in addition to the literature study an accidentology study was executed to retrieve more specific in-depth information such as injured body regions, impact sources and head impact locations on the vehicle windscreen. For this study the German in-depth database GIDAS was used.

Simulations

An extensive numerical parameter study was executed to identify the most important parameters influencing injuries (body region and severity), impact speeds and main impact locations. The main goal of the parameter study was to derive indicative relations between the input parameters as bicyclist size, seating position, bicycle orientation, vehicle geometry and impact speed and the requested outputs such as the cyclist's kinematics and injuries.

The parameter study was performed using numerical simulations in MADYMO (MATHematical DYnamic

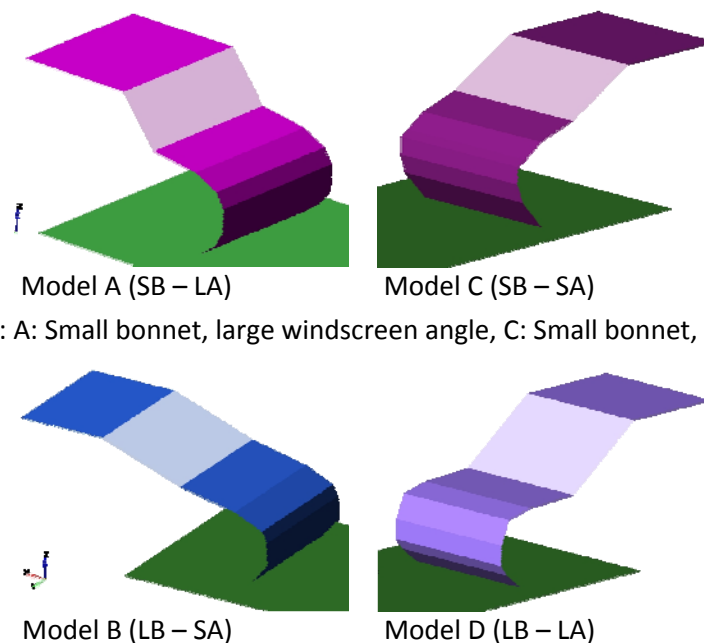


Figure 1 - Vehicle models: A: Small bonnet, large windscreen angle, C: Small bonnet, small windscreen angle

Figure 2 - Vehicle models: B: Long bonnet, small windscreen angle, D: Long bonnet, large windscreen angle

Model simulation software), focusing on lateral impacts (seen from the cyclist's perspective), based on the most frequently found accident scenarios [5]. For the simulation set up four types of generic car models were modelled: the basis of the models is an easily scalable car built up through eight planes representing the most important surfaces of a vehicle (Figure 1 and Figure 2).

The stiffness of the vehicle front and bonnet has been based on the average force -deflection profiles as developed within the APROSYS project [6]. The windscreen stiffness has been adapted based on windscreen impact tests performed at TNO. The x and z coordinates of each of the planes were varied to obtain car models that would not only cover the current standard car models, but also possible future car shapes. The variation of the main parameters (BLE, bonnet length and windscreen angle) are presented in Table 1. The study uses 4 bicycle-bicyclist configurations, consisting of 2 different cyclist models and 2 different bicycle models.

Table 1- variation of the most important parameters for all 4 vehicle models

Vehicle model	BLE height [mm] ^{*)}		Bonnet length [mm]		Windscreen angle [°] ^{**))}	
	min	max	min	max	min	max
A	500	850	500	900	20	50
B	500	850	900	1300	0	20
C	500	1000	500	900	0	20
D	500	850	900	1300	20	50

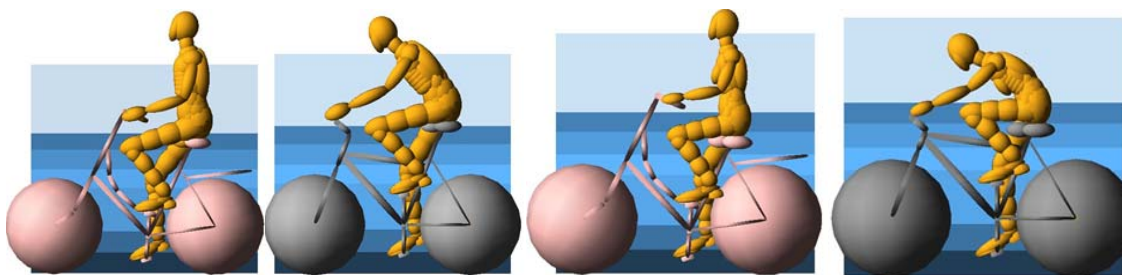


Figure 3 –The four bicycle-cyclist-configurations. 1-2: Average Dutch male on a granny bike and on a hybrid bike, 3-4: small female riding the granny bike and the hybrid bike

Representing different types of cyclists, two cyclist models were used: a Dutch 50th percentile male (the MADYMO scalable pedestrian model [7] was scaled to fit the average Dutch male whose anthropometry was based on the Dined 2004 anthropometric database [8]) and the standard 5th percentile female, both on a hybrid bike (sportive seating) and on a granny bike (upright seating), as shown in Figure 3. For the bicycle models, the Multibody modelling technique was used. A rigid bicycle frame is modelled and stiffness is added to the wheels and the front fork. The mass of the granny bicycle was 19.7 kg and the mass of the hybrid bicycle was 16.3 kg, based on the information of various bicycle manufacturers. The saddle and steer heights are adapted according to the cyclist anthropometry, shown in Table 2. Table 3 shows the saddle and steer heights for the different cyclist models.

Table 2 – Main anthropometry of the cyclist models [8]

Parameter	Female	Male
Standing height [m]	1.53	1.82
Sitting height [m]	0.81	0.95
Body mass [kg]	50.2	83.7

Table 3 - Saddle and steer heights for the different bicycle-cyclist combinations [9]

Parameter	Granny bicycle small female	Granny bicycle average male	Hybrid bicycle small female	Hybrid bicycle average male
Saddle height	0.87 m	0.98 m	0.89 m	1.05 m
Steer height	1.12 m	1.17 m	0.93 m	1.05 m

Crash testing

For crash testing the main accident scenarios for car-cyclist and car-pedestrian accidents were selected. For cyclists the following scenarios were chosen: bicyclist crossing with three different car impact locations and bicyclist longitudinal with one impact location. For pedestrians a side impact scenario was selected with two different car impact locations.

The tests were performed using a Volvo V70 model year 2011 at 40 kph crash speed, marked with Patrick markers (film tracking markers that enable automated film analysis) to enable film analysis. High speed 1000 fps digital cameras were used in five different camera views: full side view, close-up side view, top view, on-board car view and angled side/front large view. The Tema version 3.0 high speed film analysis software was used to evaluate the dummy kinematics. The car was in normal riding condition, but excluding the passenger weight, and was automatically braked 250 ms after the first impact, a time point when the event was considered to be over.

The Polar II pedestrian dummy was used [10][11], a dummy which has shown to represent a pedestrian well in car-to-PMHS tests [12][13]. The dummy was equipped with Patrick markers to enable film analysis.

A bicyclist dummy test method was developed. The Polar II dummy was positioned on a standard men's 28" (711 mm wheel diameter) bicycle. The saddle height was set to 100 cm and the steering height to 110 cm based on the average heights in a Dutch study [9]. The dummy was positioned with right pedal in lowest position, except for the rear impact test where the pedals were set at equal heights with right pedal forward.

A guide structure was designed to guide the dummy and bicycle up to release before impact. The hands and feet of the Polar dummy were attached to the steering handle and the pedals with fragile paper tape. The bicycle speed selected was 15 kph, the median bicycle speed in severe (MAIS3+) bicyclist accidents [15], controlled by the car control system using a direct mechanical steel wire coupling with a gear box in between. After the release the bike and dummy were moving autonomously, with the steering locked.

In the pedestrian tests the dummy was positioned in a walking stance with the impacted leg rearward. It was estimated that the low speed of a walking pedestrian was not influencing the results and impact location significantly. This is also in line with earlier studies on pedestrian dummy and post mortem human subject testing [10-13]. The dummy was positioned stationary in the pedestrian tests. The hands were tied in front of the dummy following normal procedures with Polar II (Figure 4).

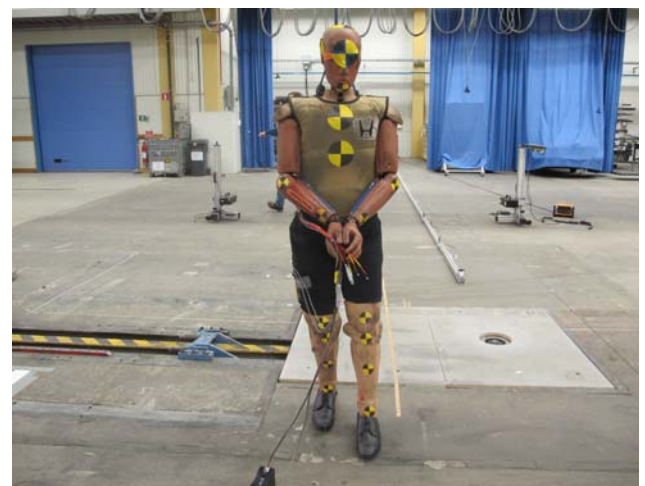


Figure 4 - Bicyclist and pedestrian dummy test condition

Table 4 shows an overview of the full test plan. Note that in the near-side bicyclist impact, the leg impact was more to the side than to the front of the vehicle. Comparison tests were also performed with a dummy representing a walking pedestrian in two impact locations (Figure 5 and Table 4).

Table 4 - Full-scale crash test plan

Test	VRU	VRU impacted	VRU speed	Head Impact location
1	Bicyclist	right side	15	near side AP
2	Bicyclist	right side	15	centre
3	Bicyclist	right side	15	far side AP
4	Bicyclist	rear	0	right AP
5	Pedestrian	right side	0	centre
6	Pedestrian	right side	0	far side



Figure 5 - VRU position at time of first impact (tests 1-6 left to right)

III. RESULTS

Accidentology

From the literature study on bicycle-to-car accidents the following results were obtained. The most common location [14] for a car-bicycle accident is an urban area (60-80%). In the Netherlands most of the accidents happened on roads with a speed limit around 50 kph (42%) while for zones with a speed limit of 30 kph it was 5%. However, the actual vehicle speed at time of impact might be higher. On one hand, it was shown that on roads with a speed limit of 30 kph, the actual speed was about 40-45kph. On the other hand, roads with 50 or 60kph are more often jammed and an actual speed might be below the speed limit. In other countries (UK, Sweden) ~85% of bicyclist accidents happened on roads with a speed limit of 50 kph. German accident reconstructions showed that 75.6% of bicyclist accidents happened with a collision velocity up to 50kph, with an average velocity of 35 kph.

The accident scenarios were studied for four countries: the Netherlands, the UK, Sweden and Germany [5]. The results indicate that in the Netherlands, most relevant accidents happened on a crossroad when:

- both partners were driving straight-on (40%)
- one partner turned left while the second went straight-on (12%)
- one partner crossed the road laterally while the other went straight-on (12%)
- one partner turned left while the other was going straight-on from the opposite direction (8%).

Dutch figures show that in 75% of accidents, the contact point of impact was located on the car front, 20% on the side of the car and 5% on the rear of the car. These numbers turned out to be representative also for Germany.

At the same time, the literature study showed that for the bicycle, in almost 60% the contact point was located on the bicycle's side (left or right), in 30% of cases it was located on the bicycle's front and in 4% it was the bicycle's rear part.

In the UK most accidents happened at or near some kind of junction-; the majority of cyclists were travelling straight ahead at the time of the accident (75%) and a small proportion were turning right (8%). The vehicle in 43.5% of all cases was moving straight ahead and in 30% it was turning. In Sweden the most common accident scenarios were when the bicycle was going straight ahead or turning left and was impacted by a vehicle which was going straight ahead or turning right. In Germany 60% of accidents happened when a vehicle was going straight ahead and the cyclist was crossing lateral to the vehicle which is close to one of the Dutch accident configurations [14].

Accident data from Sweden and Germany have shown that the most frequent scenario is the bicyclist impacted when crossing the road, followed by longitudinal bicyclist motion impacted from the rear. (The Swedish data was retrieved from the Swedish Transport Administration in-depth database on fatal accidents. The German data was retrieved from the German In-Depth Accident Study, GIDAS). Further, these accident data studies have shown that the most frequent injury source is the windscreen area, especially the frame and lower part of the windscreen [15][16], as shown in Figure 6. Fredriksson & Rosén [15] showed that median car impact crash speed in severe (MAIS3+) car-to-bicycle crashes was 36 kph with median bicycle speed 14 kph.

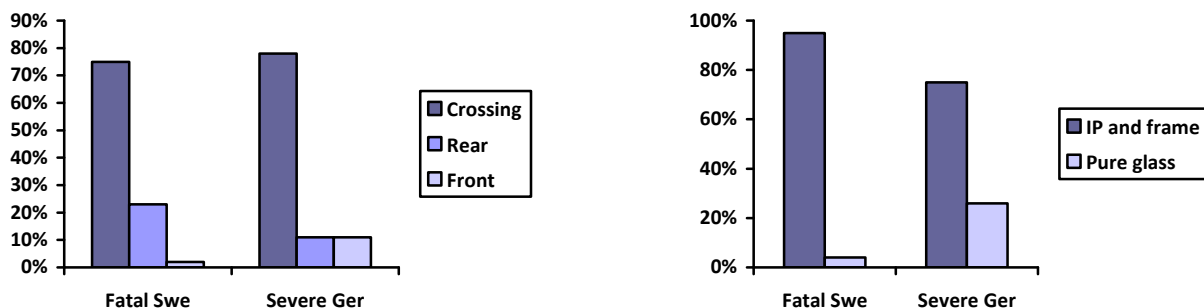


Figure 6 - Distribution of bicyclist orientation in crashes (left) and head impact location distribution (right)

Table 5 - Field data on bicycle sizes in the Netherlands [9]

	Average	n		Average	n
Saddle height (upper edge)			Steer height (upper edge)		
- All bikes	0,982 m	427	- All bikes	1,139 m	427
- City bikes	0,986 m	331	- City bikes	1,145 m	331

For setting up representative tests in the laboratory, field data were required of the saddle height and the steer height. Table 5 shows a summary of data from a Dutch investigation [9] on measurement of 400 bicycles parked in a bicycle parking area, used to set up the experimental testing. A more in-depth analysis on GIDAS data delivered more background information on the injured body regions and impact locations. Figure 7 shows the share of severe (MAIS3+) head injuries for fatal and severe car-to-pedestrian and car-to-cyclist accidents. For fatalities the share is 81% and for severe injuries, the share is only 31%. This indicates a strong relation between fatality risk and severe head injury, although the casualty number is statistically low.

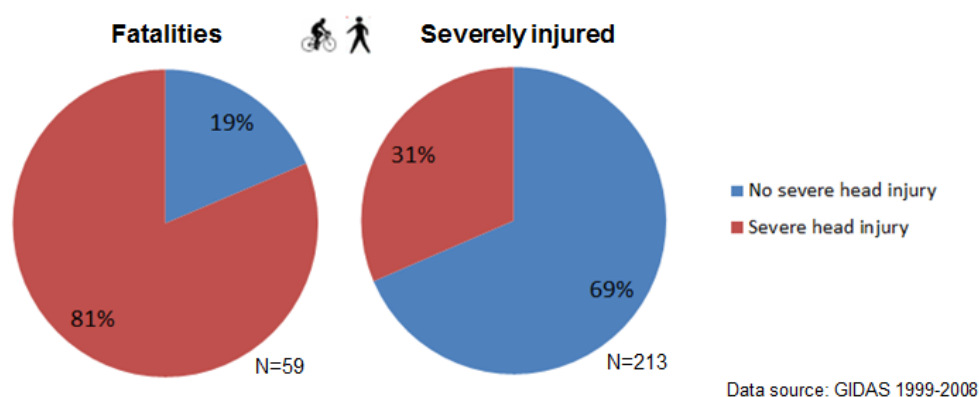


Figure 7 - Share of severe (MAIS3+) head injuries for fatal and severe car-to-pedestrian and car-to-cyclist accidents

Fredriksson [15] shows additional information showing the head impact locations for both car-to-pedestrian and car-to-cyclist accidents. This gives a good overview of the sources of the severe head injuries.

Beside head injury people can also die from other severely injured body regions or a combination of them. Therefore the combination of injured body regions was investigated. The results are shown in Figure 8. For fatalities the following conclusions can be drawn. The majority of vulnerable road users suffer from AIS3+ or AIS4+ injuries to more than 1 body region. 80% of the vulnerable road users suffer from both severe head and

chest injury. From all fatalities, 11% suffer from single severe head injury and 3% suffer from single severe chest injury (these numbers are low. The latter 3% represents actually only one case. The authors therefore only indicate these numbers, but don't conclude on it). For the severely injured people severe leg a single severe injury is dominant. Furthermore can be seen that 45% of pedestrians suffer from severe leg injury and 20% of the cyclists suffer from severe leg injury or head injury.

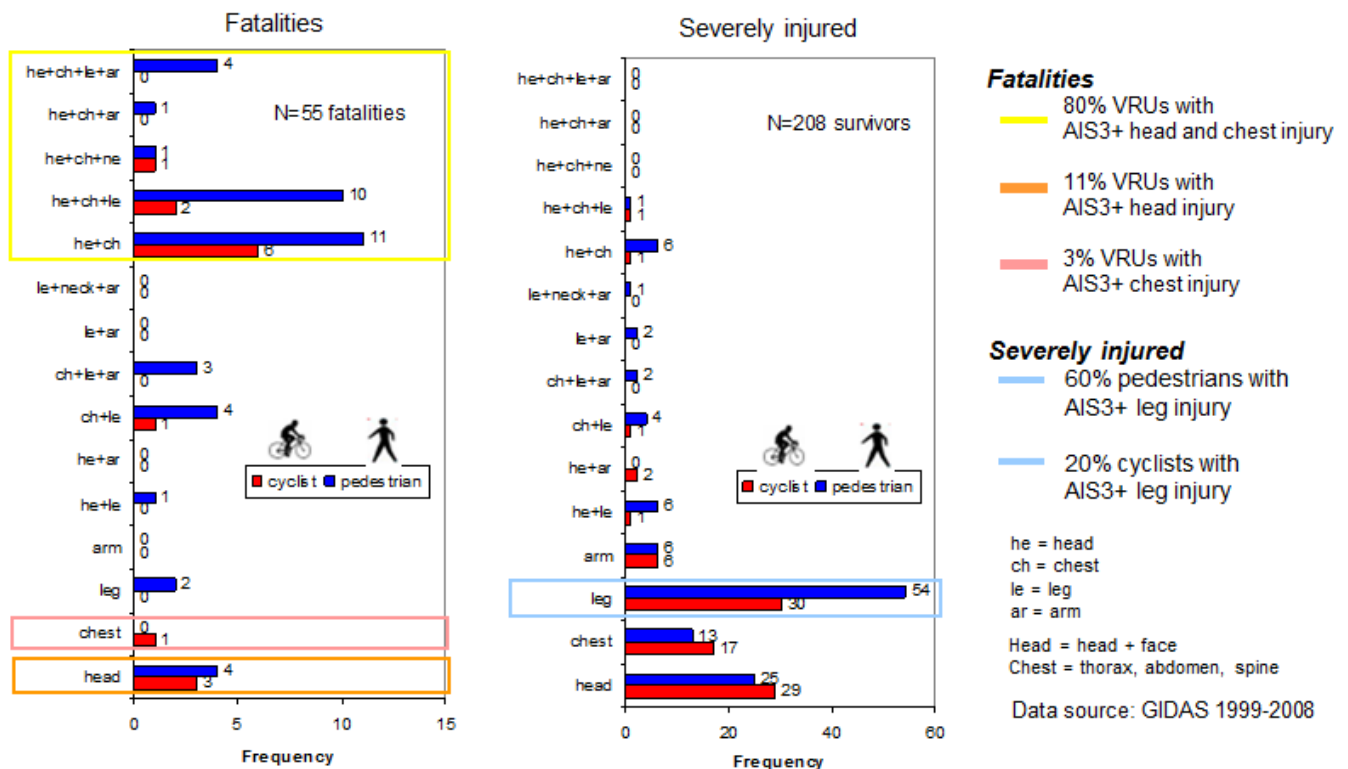
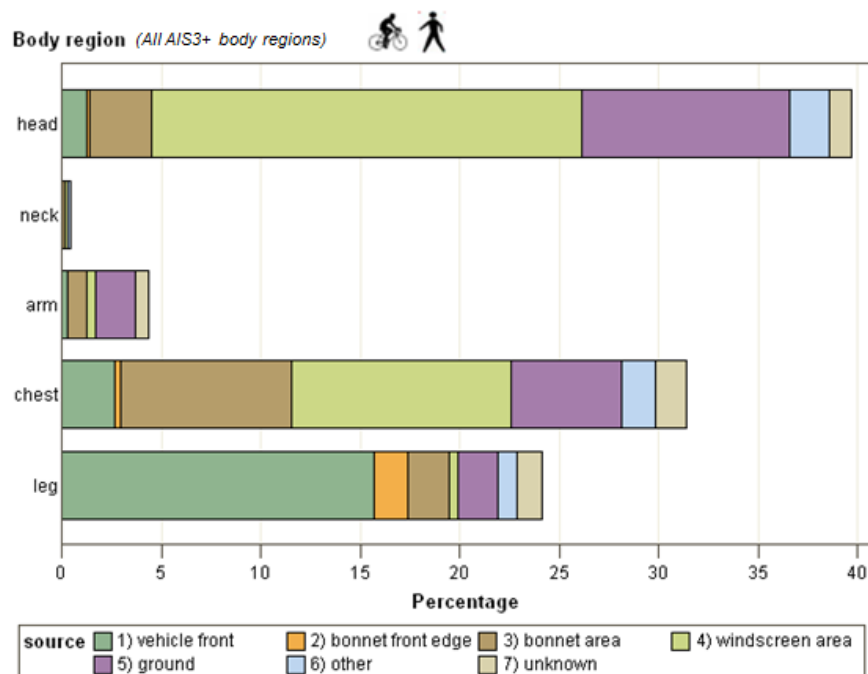


Figure 8 - Combination of AIS3+ injured body regions for fatal and severely injured cyclists and pedestrians



Data source: GIDAS 1999-2008

Figure 9 - Relation between severely injured body region and car impact location

Figure 9 shows the relation between the injured body regions and the involved car impact location. The windscreen area is the main injury source for both accident types (car-to-pedestrian and car-to-bicyclist). The bonnet and the full windscreen area account for 60% of all severe head and chest injuries. Further impact to the ground constitutes 20% of all severe injuries.

Simulations

Based on the accidentology information, it was chosen to focus simulations on car-to-bicycle impacts in side impacts. The impact angle was varied between -45° (bicyclist traveling towards the car), 0 and 45° (bicyclist traveling away from the car). Impact speeds were 30-80 kph for the car and 15 kph for the bicycle.

In total, 20.000 simulations were performed. The analysis of these simulations started with a feasibility check related to unrealistic HIC values or model corruptions. Model corruptions that were disregarded include the cases with issues with the human body model penetrating the edges of the car. In total, 16.000 simulations were feasible and of these 12.600 had a HIC value below 3000.

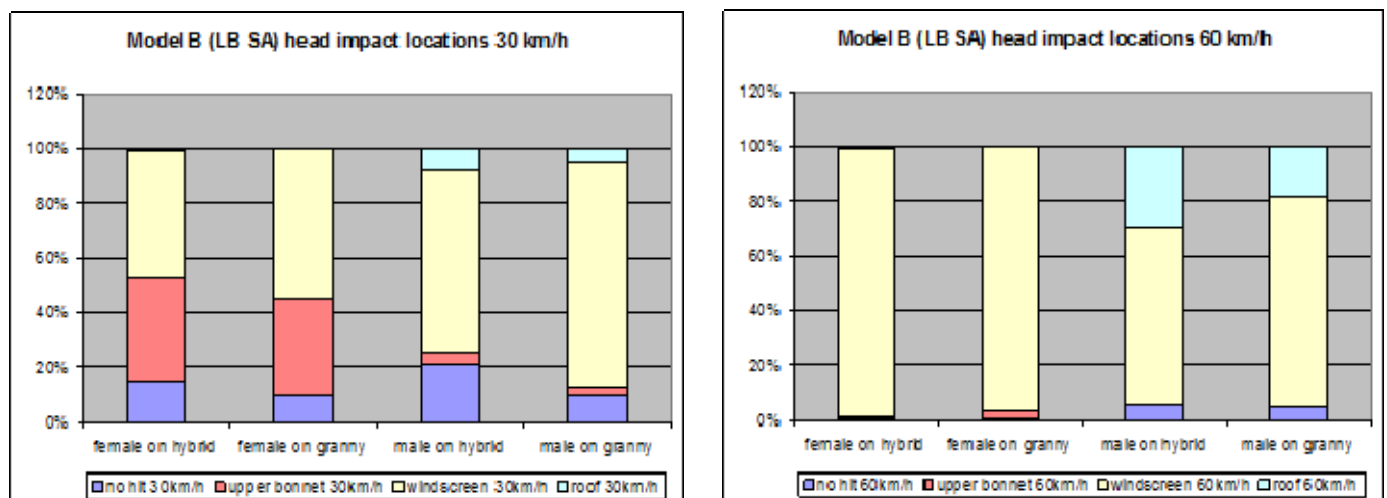


Figure 10 - Impact location of the head on the car structure for different cyclist – bicycle for Model B (LB SA). Left: car speed 30 kph, right: 60 kph.

Figure 10 shows head impact locations at 30 kph and 60 kph. In general it was found that contact with the car is significantly different for a cyclist compared to a pedestrian. Not only do cyclists impact the car structure at different angles, but they also impact higher up the car than pedestrians.

In contrast to pedestrians who mostly impacted the bonnet and the bumper of a car, the main impact location for cyclists was found to be the windscreen. It was not only impacted in a significant amount of cases by the cyclist's head, but also by the torso and, for large bonnet–windscreen angles, even by the average Dutch male's pelvis. Furthermore, the cyclist's anthropometry as well as seating posture were found to be of significant influence with respect to the contact locations between cyclist and car. Tall or upright sitting cyclists impacted the car structure in general higher than small cyclists or ones sitting bent. Also, higher impact locations were found for increasing car speeds as well as decreasing bicycle orientation.

Figure 11 shows the head impact locations for an average Dutch male as well as for the small female for the four generic car models. Figure 12 shows the torso impact locations for both these cyclists, again for the four generic car models.

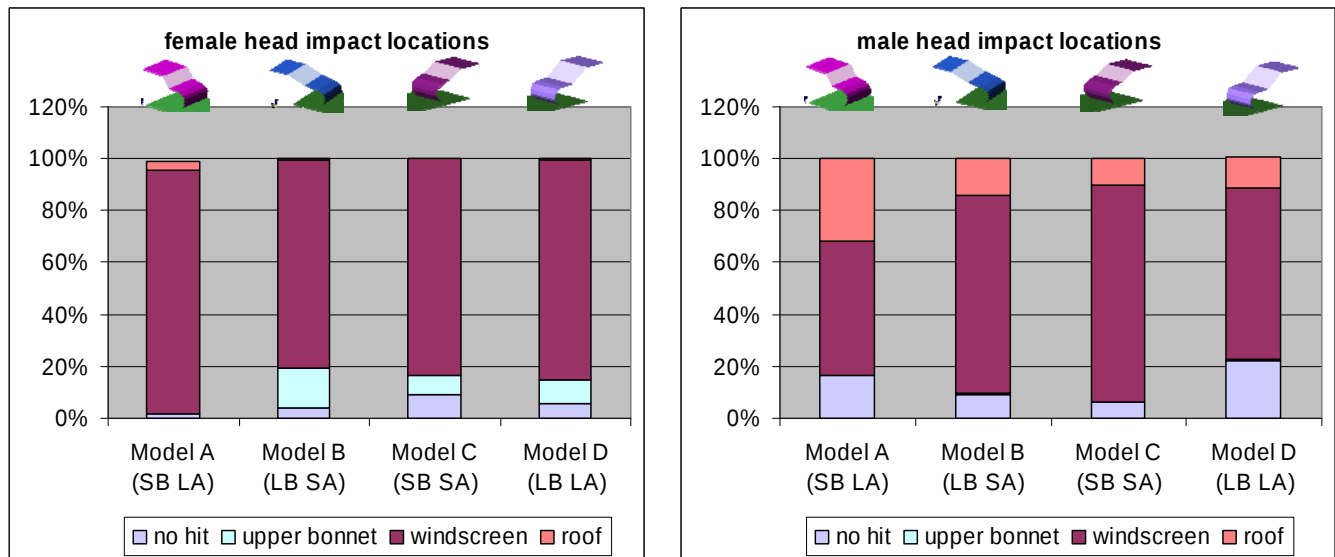


Figure 11 - Head impact locations for four models for average Dutch male (right) and small female (left)

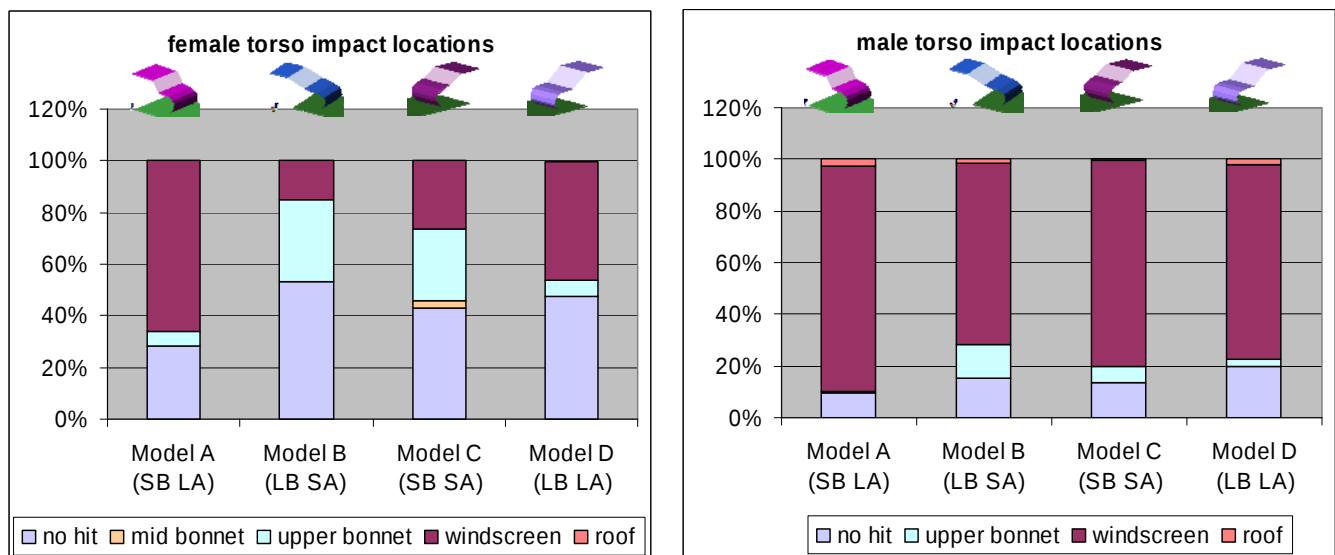


Figure 12 - Torso impact locations for four models for average Dutch male (right) and small female (left)

The following conclusions were drawn from the simulation study:

- Vehicle impact velocity and the impact location are the major factors influencing the level of injury.
- Injuries rose with increased car speed and generally decreased with increasing bicycle impact angle (a cyclist approaching a car at less than a 45° angle was at higher risk of obtaining injuries than a cyclist heading away at less than an angle of 45°).
- Influences of car speeds, bicycle orientations and bicycle-cyclist combination were found to be more significant than the influence of car geometry.
- A small female on a hybrid bicycle has higher accelerations than an average Dutch male on a granny bicycle.
- A lower bonnet leading edge in general resulted in lower pelvis and head accelerations.

Crash testing

Simplified in-crash motion patterns of the dummy in respective tests are shown in Figure 13. In the bicyclist crossing tests, there is a clear diagonal motion of the dummy over the bonnet surface, with a head impact more forward than the leg impact. The highest head impacts were achieved in the bicyclist rear impact and near-side impact, and in the pedestrian right A-pillar impact. Both in the bicyclist near-side and the pedestrian right A-pillar impact, the leg impact was not directly to the front surface of the car but rather a glance-off impact resulting in the lower body of the dummy sliding along the side of the vehicle.

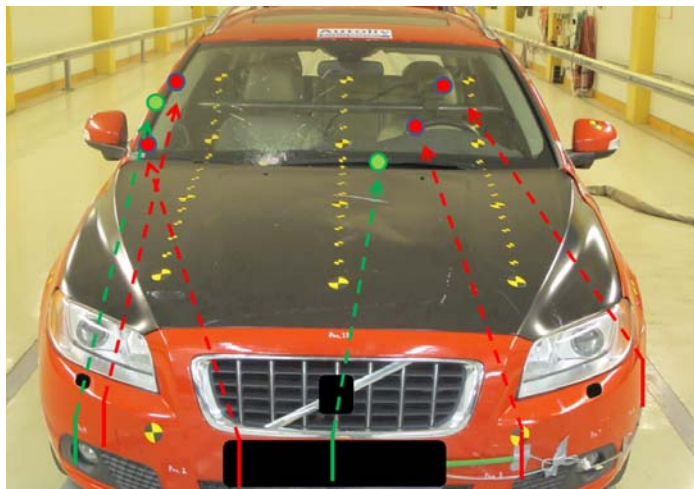


Figure 13 - VRU kinematic pattern, in full-scale crash tests, from leg (vertical line) to head impact (circle) location. Bicyclist marked red, pedestrian green

The kinematics of the dummy is shown in Figure 14.

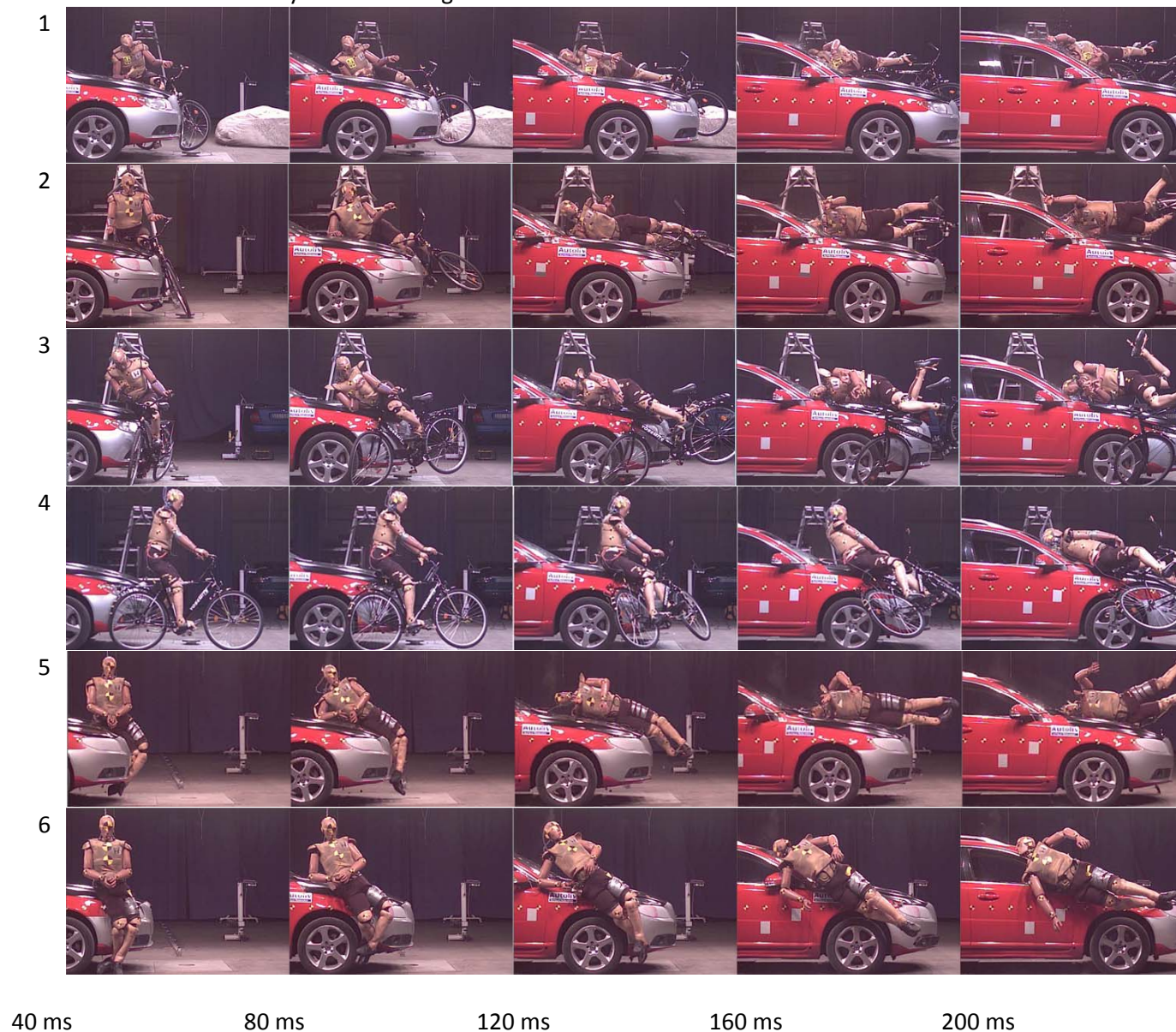


Figure 14 - Film sequences from crash tests (tests 1-6 from top to bottom)

In the cyclist lateral impact cases (1-3) there is first a translational motion of the upper body before the upper body starts to bend. The head then lags behind the upper body until shoulder impact when the neck pulls the head down. The rear impact (4) shows a different motion with a longer phase where the upper body translates and therefore stays vertical. When comparing cyclist and pedestrian motion, tests 2 and 5 showing lateral impacts at the centreline are most comparable. In the bicyclist case (2) the motion is similar to the pedestrian impact (5), although with a higher head impact location in the cyclist case. It should be noted that in tests 1 and 3 there were problems with the posture of the dummy; the dummy started to lean towards the car before impact.

The head impact speed varied from 9.7 to 16.3 m/s for the bicyclists and 7.5 to 8.1 m/s for the pedestrians (Table 5). The wrap around distance (WAD) ranged from 2.00 to 2.50 m for the bicyclists and 1.86 to 2.43 m for the pedestrians.

Head translational acceleration and lateral rib deflection in ribs 4 and 7 were recorded and HIC_{15} and max rib deflection could be compared between the different test setups. HIC values ranged from 301 up to 4429 depending on impact configuration and impact location, with the highest values recorded in impacts to the A-pillars. The highest chest deflection values were recorded in the near-side and far-side bicyclist tests. In the near-side test the chest impacted the lower A-pillar and in the far-side test the right side of the bonnet.

Table 5 - Dummy kinematics and injury values

Test	Test type	Head impact speed (m/s)	Head impact time (ms)	Chest impact speed (m/s)	WAD (mm)	HIC_{15}	Max chest deflection (mm)
1	Bicyclist Near side	n/a	121	n/a	2500	502	67
2	Bicyclist Centre	14.8	134	6.5	2300	753	24
3	Bicyclist Far side	9.7	130	7.5	2000	1433	61
4	Bicyclist Rear	16.3	200	7.8	2500	4429	8
5	Pedestrian Centre	7.5	134	n/a	1860	301	23
6	Pedestrian Far side	8.1	158	8	2430	2214	15

IV. DISCUSSION

The large spread in injury values supports the accident data indicating that certain parts of the windscreen area represent higher risk of injury when impacted. Earlier studies on pedestrians [17][18][19] showed that the structural parts of the windscreen area were over-represented for severe or fatal injuries, and unpublished studies for bicyclist accidents support this finding also [15][20]. In two of the tests (1 and 3) there were problems with the initial dummy where the dummy was leaning towards the car before impact. This could have influenced an earlier head impact time and a lower head impact speed. The head-to-car relative velocity prior to head impact is typically higher than the car impact speed, due to the head lagging behind and then pulled towards the car by the neck after shoulder impact. It is likely that in these two cases the head was not lagging behind to the same extent and therefore not reaching the same level of relative velocity at the time of impact.

The bicyclist tests resulted in high values in head impact speed, up to 145% of the car impact speed, while both pedestrian tests recorded head impact speeds lower than the car impact speed of 11.1 m/s (40 kph). In post mortem human subject (PMHS) tests with crash conditions representing a centerline pedestrian in 40 kph the head impact speed ranged from 68% to 146% [21][22][23], with a tendency for lower values for bonnet impacts compared to windscreen impacts. A hypothesis is that the higher angle of the windscreen results in a higher head impact speed, due to the fact that the neck cannot limit the head motion to the same extent as in a bonnet impact. (See also discussion in previous paragraph.) Kerrigan et al. [22] performed Polar II dummy tests in identical pedestrian conditions, all windscreen impacts, and measured head impact speeds of 120 to 135% windscreen. To summarize, the higher head impact speeds measured in the cyclist tests are therefore likely to result from a combination of different kinematics and a larger share of windscreen impacts due to higher impact locations.

The impact locations were generally higher in the bicyclist tests, which is indicated also by accident data [15][21][24]. Especially the rear impact and the glance-off near-side impact resulted in high head impact locations and high WAD values. In the rear impact the sitting position of the dummy resulted in the lower legs of the VRU impacting the car front late and therefore allowing a large sliding of the torso on the bonnet surface prior to bending of the torso towards the windscreen. In the glance-off bicyclist impact the lower body was not pushed forward by the car front, but rather allowed to slide along the side of the vehicle which explained the high impact location. This was also the case in the pedestrian case with high impact location. This could also explain high impact locations found in accident data, with head impacts to the roof edge even on larger passenger cars [20].

V. CONCLUSIONS

This paper shows a combination of accidentology, simulations and full scale testing. The overall outcomes of the study justify that in protection of vulnerable road users, cyclists and pedestrians have their own specific issues related to accident scenarios and kinematics. Accident scenarios for cyclist-car impacts have been established. The paper has shown successful full scale testing with a standing and with a cycling Polar II dummy with representative set of scenarios for vulnerable road user accidents. Both accidentology, simulation and crash test data show that the windscreen is a frequent head and torso impact location. Accidentology and crash testing also show that cyclist protection should address higher, more rearward locations in the windscreen area than pedestrian countermeasures. Head impact speeds for the cyclist were found to be up to 145% of the car speed in testing, while for pedestrians, the car speed was not exceeded. Information like this is essential in the effective future development and deployment of vehicle related protection measures for vulnerable road users. The authors jointly work on this next step.

VI. ACKNOWLEDGEMENT

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VIII. Appendix

Table A1 and A2 give the aimed dummy positioning measurements before tests in cyclist respectively pedestrian tests. See also Figure 5. In the pedestrian tests the dummy was positioned with right leg rearward and a foot position of 200 mm heel-to-heel distance in both X and Y direction. Thereafter the right foot rear edge of the sole was used as reference point.

Table A1. Dummy positioning measurements in cyclist tests

	X (mm)	Y (mm)	Z (mm)
Head COG	465	545	1530
Pelvis	890	495	1025
Upper tibia right front	510	610	515
Foot joint right front	550	655	150

Table A2. Dummy position in pedestrian tests. Tibia angle left: -10°, Tibia angle right: 18°

Knee Y rel. distance	190 mm	
	X (mm)	Z (mm)
Pelvis plate	+40	1040
Hand wrists		1010
Shoulder joint	195	1370
Head COG	290	1610