Report

Title:	Study on Safer Motor Vehicles for Cyclists in the context of the EU Pedestrian Protection Regulations
Requested by:	European Cyclists‘ Federation
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1. Executive summary

The European directive EC 78/2009 which addresses pedestrian protection will be updated in view of the still high number of road casualties. Currently cyclist impact is not considered in this regulation. To increase safety of all vulnerable road users this shortcoming of the current regulation must be discussed. Although the impact scenarios for pedestrians and cyclists are generally similar, there is evidence that some relevant differences exist. Consequently these differences must be addressed in a revision of the test procedures to also consider safety of cyclists and thus increase the impact of this safety regulation. It is suggested to keep the methodology of the test procedures as described in regulation ECE R127, but to consider the larger wraparound distance of cyclists which results in a larger head impact area. Depending on the vehicle design this requires to extend the impact test zone to the upper windscreen area including A-pillars and the roof. Furthermore the impact conditions in terms of impact velocity and impact angle should be revisited, but it is suggested to use the same impactors as today. It is expected that such minor modification of the regulation will lead to improved safety of vulnerable road users in short term in which active safety measures will not yet be widely available in the European vehicle fleet.

2. Background

Vulnerable road users are of major concern in road traffic safety. High fatality rates call for improved measures to prevent or at least mitigate injury. In Europe several research projects, for instance funded by the EC under the FP7 and H2020 programme schemes, addressed the topic from different perspectives and with different foci. The project ASPECSS (Assessment methodologies for forward looking integrated pedestrian and further extension to cyclists safety systems) did, for example, look at head-on collisions involving pedestrians and cyclists while ASSESS (Assessment of integrated vehicle safety systems for improved vehicle safety) followed a more holistic approach. Follow-up projects are currently undertaken under the H2020 umbrella to consolidate the work of these previously mentioned research activities. Additionally technical innovation was stimulated by projects such as ARTRA (Advanced Radar Tracking). Latest vehicle technology has thus made significant advancements in detecting vulnerable road users and implementing systems to prevent collisions. However, such systems are not yet widely spread among the vehicle fleet. Consequently the impact is yet small. One option to further stimulate the development and implementation of such advanced protection systems is to update existing motor vehicle safety standards and include requirements for systems to protect vulnerable road users. While pedestrian protection is addressed by the current regulation EC 78/2009, cyclists are not explicitly focused on. Current thinking generally assumes that vehicles with improved pedestrian protection will also be of benefit for cyclists in collisions against the vehicle front.

The test procedures currently include impacts to the front of a passenger vehicle using free motion head forms (adult and child size) as well as upper and lower leg impactors. Impact tests are performed in different areas of the vehicle front that are thought to be relevant in case of a frontal impact against a pedestrian. However, the requirements do neither consider other pedestrian impact scenarios nor impacts against other vulnerable road users such as cyclists (incl. users of electric bicycles).

In addition to legal requirements for vehicle homologation, there are consumer organisations such as Euro-NCAP (European New Car Assessment Programme) that perform vehicle testing. The current Euro-NCAP test procedures also address pedestrian protection and in addition to the legal requirements assess active safety components (i.e. advanced driver assistance systems to detect potential conflicts, warn the driver if necessary and/or prevent a collision with a pedestrian). Specific test procedures with regard to cyclists, however, are not included in the current Euro-NCAP procedures.

3. Aim of the study

The overall aim of this study was to provide an overview on current pedestrian impact protection and point out opportunities how to improve them such that also cyclist protection is addressed. Therefore this study

- looked at the current testing requirements for passive safety systems within the pedestrian protection type approval regulations and reviewed possible weaknesses in the testing regime that could be improved particularly for cyclist crashes
- reviewed any new information on the impact areas of cyclist crashes with motor vehicles
- reviewed the current status of passive and active vehicle designs with regards to the pedestrian protection type approval regulations and state-of-the-art with regards to braking systems, windscreen, bonnet, A-pillar, and external airbags

After consulting ECF the study focussed on: passenger cars, passive safety, Europe, protection of cyclists riding without helmet (was assumed as standard case), all types of bicycles (i.e. incl. electric bikes, sports bikes, cargo bikes…).

4. Methodology

The focus of this study is set on gathering and reviewing existing information and summarising expert views on future trends. Thus possible gaps in current test regulations can be identified and recommendations how to improve consideration of cyclist safety can developed. In this study two methodologies were applied:

Firstly, existing regulations and current consumer testing procedures with regard to pedestrian protection were summarised. Additionally past and ongoing research activities were reviewed. Furthermore, publicly available information on trends in testing and vehicle design was screened. A literature review on latest studies with respect to cyclist impacts in Europe complemented this first step. The literature review focussed on publications of the last five years.

Secondly, different experts in the field were consulted and interviewed about their views and expectations regarding future test procedures, options to include cyclist protection testing and trends with regard to active safety systems to protect cyclists and pedestrians. An internal questionnaire was developed and used to structure the interview and to ensure all topics were addressed. The following experts participated:

Name	Organisation	Date of interview
Prof. Murray Mackay	ETSC (Belgium)	13.09.2016
Dr. Yukou Takahashi	Honda (Japan)	15.09.2016
Prof. Lotta Jakobsson	Volvo (Sweden)	13.09.2016
Prof. Ciaran Simms	Trinity College (Ireland)	14.09.2016
Dr. Michiel van Ratingen	Euro NCAP (Belgium)	14.09.2016
Christian Mayer	Daimler AG (Germany)	15.09.2016
Prof. Astrid Linder	VTI (Sweden)	29.09.2016 (by email)
Bernd Lorenz	BASt (Germany)	04.10.2016
Oliver Zander	BASt (Germany)	20.10.2016
Prof. Dietmar Otte	Medical Univ. Hannover / GIDAS (Germany)	14.10.2016
Klaus Bortenschlager	PDB (Germany)	20.10.2016 (by email)
Luana Bidasca	European Transport Safety Council (Belgium)	31.10.2016

5. Background knowledge and state-of-the-art

5.1. Cyclist impact studies / accident analysis

Accident statistics in Europe document a high injury risk for vulnerable road users. The need to reduce this injury risk is beyond controversy in the research community. Consequently the topic of cyclist safety has been subject of various research activities and it is addressed in ongoing projects, for instance, under the Horizon 2020 scheme.

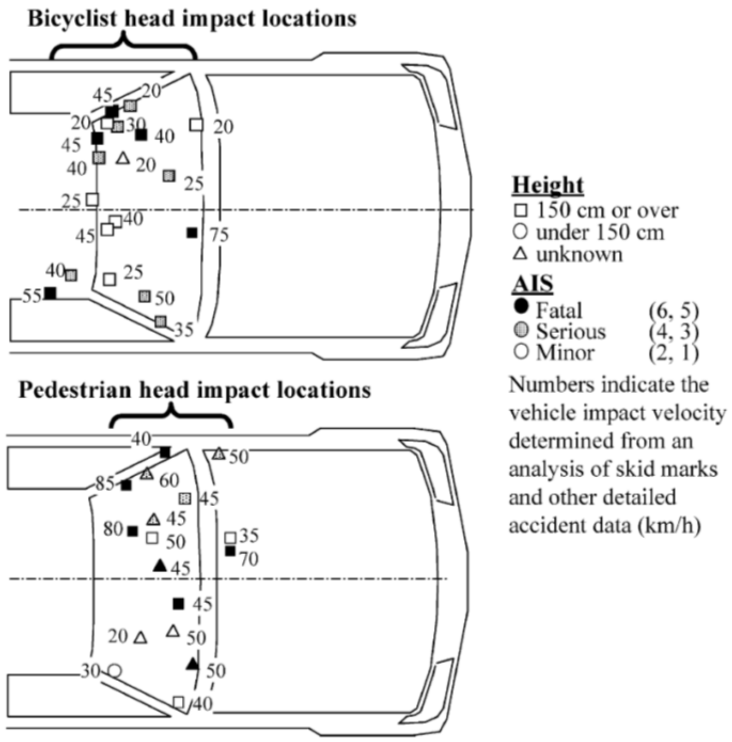
Accident data in Europe is generally recorded by the national police forces. Since 1993 the accident data of the EU member states as well as the EFTA countries is comprised in the Community database on Accidents on the Roads in Europe (CARE). Furthermore, the European Road Safety Observatory (ERSO) gathers harmonised specialist information on road safety practices and policy in European countries. The European Commission publishes the summarized accident statistics (cf. “Road safety in the European

Union", March 2015). With respect to pedestrian and cyclist accidents, also the PIN Flash Report 29 published by ETSC summarizes all relevant figures for the EU and EFTA member states.

In addition to the official accident statistics, specialised databases exit. These databases can include in-depth data and/or only include accidents with vehicles of a specific manufacturer. The German In-Depth Accident Study (GIDAS, www.gidas.org) or the Volvo Cars Cyclist Accident Database are examples of such databases.

A good overview on pedestrian and cyclist impact kinematics in different impact scenarios is provided by Simms and Wood (2009). While the height of the head from the ground is approximately the same for pedestrians and cyclists, the cyclist head impact locations on the front of bonnet type passenger cars are recorded more at the upper area of the windscreen (incl. roof edge) compared to pedestrians (Figure 1). A higher initial pelvis height in cyclists compared to pedestrians is thought to result in increased sliding of the cyclists' body on the bonnet and thus account for a larger wraparound distance. Generally it should be noted that a primary impact to the vehicle front might be followed by a secondary impact to the ground. Depending on the collision circumstances the secondary impact can also be associated with a significant injury risk. However, this study – as related to vehicle testing – focusses on primary impact.

Figure 1: Comparison of the head impact zones for pedestrians and cyclists (Maki et al, 2003).



In terms of injury biomechanics, the head injury risk, especially the brain injury risk, is determined by the acceleration the head sustains due to an impact (see, for example, Schmitt et al., 2014). Injury criteria such as the HIC (head injury criteria) use the acceleration as physical parameter to assess the injury risk. Impact testing using head forms, for instance, allows to record acceleration and thus to calculate the HIC value and compare the result with defined injury threshold values. However, HIC takes into account translational acceleration only whereas the rotation of the head is not directly considered. While translational acceleration is related to certain injuries that can be caused by a direct hit to the head, rotational acceleration is a relevant parameter for diffuse brain injury such as concussion. The relevance of the rotational component of head loading is currently intensively discussed as it is not included in existing standards. To date there are initiatives to consider rotation in the standard for sports/ bicycle helmets as well as in regulations related to vehicle occupant safety. A specific injury criteria, BrIC, was presented by the US authorities; this criterion takes into account the head rotational velocity. Besides head injury, cyclists are also prone to thorax injury as well as injury to the extremities. To assess the risk of thorax injury, acceleration is a relevant parameter, but also force and deformation (e.g. related to rib fracture) as well as impact velocity (linked to internal injury). Injury to the extremities is mainly related to impact force and bending moment resulting in fractures of bony structures, ruptures of ligaments and contusions.

With respect to injury, several studies have identified traumatic brain injury (TBI) as the main cause of death and serious injury in bicycle accidents (e.g. Scholten et al., 2015, Malczyk et al., 2014). Analysing in-depth accident data, Fredriksson and Rosen (2012) found that the most common severe (AIS3+ and fatal) injury for bicyclists was the head-to-windshield area (27%) followed by leg-to-vehicle front, while for pedestrians the same combinations occurred most frequently but leg-to-vehicle front (41%) was most common. For both bicyclists and pedestrians most head injuries from the windshield area were caused by the structural parts, but the bicyclists’ head impact locations were more commonly from higher impact locations. The authors concluded that car-mounted countermeasures designed to mitigate pedestrian injury have the potential to be effective even for bicyclists if redesigned to also protect higher frame parts of the windshield. Also van Schijndel et al. (2012) state that cyclists typically have a higher impact location, with a larger share of injuries from the windscreen area. Scholten et al. (2015) analysed patients who were treated in Dutch hospitals between 1998 and 2012 due to bicycle related traumatic brain injury. The sample included all kinds of bicycle accidents (i.e. including falls or single bicycle crashes). 26% of all TBI cases resulted from a collision with a 4-wheeled vehicle. 59.2% of all TBIs were classified as concussion. Older cyclists aged 55+ were identified as main risk group for TBI to be targeted in preventive strategies, due to their high risk for (serious) injuries and ever-increasing share of visits to the hospital emergency department and hospital admissions. The study revealed a high incidence rate of 456 emergency treatments per 100,000 persons. This rate is higher than rates reported from other countries. The difference was attributed to the more frequent use of bicycles in the Netherlands.

Evaluating the Volvo Cars Cyclist Accident Database, Lindman et al. (2015) found that 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. Somewhat in contrast to other work, 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.

Kröyer (2015) evaluated accident data from Sweden for the years 2004–2008 to identify accident locations and to analyse the relations between speed environment, age and injury outcome. Seventy-seven accident sites were used for field measurements and further analysis. The results show that both speed environment and age have considerable correlation with injury severity. There was a statistically significant relation between injury severity and the speed environment, and large proportion of the serious bicycle accidents occur at locations with vehicle speeds below 30 km/h. Also, the risk of serious injuries or fatalities seems to increase after the age of 45. The results were compared to analyses of pedestrian accidents. Generally bicyclists show a lower injury severity (reasons can include – among others – a different centre of gravity, different kinematics (sliding phase of a cyclist), different impact speeds). Despite some general similarities, the relation between injury severity and mean travel speed, age and vehicle type differs between struck pedestrians and struck bicyclists, where a large proportion of the seriously injured bicyclists are struck in low speed locations (20 km/h).

Fredriksson et al. (2014) – following-up on van Schijndel et al.(2012) – highlighted that there is currently no standardised test procedure for deployable vulnerable road user protection systems. In their study they have utilised a Polar II pedestrian dummy to assess the safety benefit of a system consisting of a pop-up bonnet and an external airbag. The dummy was used in a standing configuration to mimic pedestrian impact and, in addition, it was seated on a bicycle and used to simulate bicycle impact (Figure 2). Three different impact positions of the bicycle were used: the bicycle was hit laterally by the vehicle front on the far left (corner), the cyclist was hit laterally with large overlap and the bicycle was hit from behind (i.e. a situation in which the cyclist travels in the same direction as the vehicle). The study demonstrates the feasibility of dummy tests to evaluate the injury risk of vulnerable road users. Using a dummy allows measuring more biomechanical parameters (e.g. related to the neck or thorax) compared to todays' regulations for pedestrian impact which use head and leg impactors. In this study it was shown that the protection system significantly reduces the loading of the pedestrian/ cyclist at impact (particularly with respect to head loading). Consequently the authors conclude: "Being real-life based, including full-body loading, it is suggested as a complementary test method to the more simplified legal and rating component tests. Together these test methods will provide a more thorough evaluation of a protection system. The evaluated protection system performed well regarding both positioning and protection, indicating a capability to obtain the intended position in time with the potential to prevent the most common severe upper-body injuries of a pedestrian or cyclist in typical real-life accidents, without introducing negative side effects.".

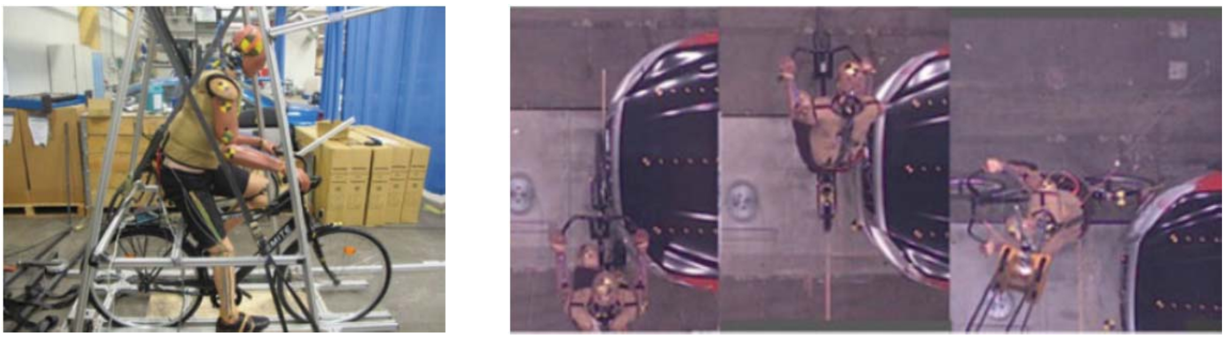


Figure 2: Cyclist impact testing using a Polar II crash test dummy (left). Three different impact scenarios (right) were evaluated in a study Fredriksson et al. (2014).

To be able to cover a wider range of impact scenarios as the ones mimicked by current test procedures, different studies have also facilitated computer simulations. Virtual testing would allow a much larger test matrix as is feasible with physical impact tests. Li et al. (2016), for example, presented a virtual test system based on accident data of the GIDAS database.

MacAlister and Zuby (2015) investigated US data to identify the most relevant cyclist crash scenarios which should be considered when designing cyclist detection systems. They found that the most common fatal crash modes involved the motor vehicle-cyclist movement combinations straight-in line, straight-crossing, and straight-against. The most common crash modes involved the movement combinations straight-crossing, turning-crossing, and turning-in line. Crashes that occurred in non-daylight conditions and on roads with speed limits of 40 mph and greater contributed to the greatest percentage of fatalities. Thus they concluded that cyclist detection systems that function at high speeds and in both daylight and non-daylight conditions offer the greatest potential benefit. They estimated that effective cyclist detection systems could help mitigate or prevent up to 47% of crashes, 48% of injuries, and 54% of fatalities, potentially saving up to 363 lives annually.

In addition to studies addressing cyclist impacts, more recently naturalistic driving studies emerge. Using instrumented bicycles (or e-bikes) various parameters are recorded to document the riding behaviour and any critical event that might occur during the ride. Dozza et al. (2014, 2016), for example, have performed such naturalistic driving studies which allow monitoring different parameters during cycling including critical incidents. Such work (also conducted with other vehicles) is expected to provide more information related to near-misses and even pre-crash conditions.

Also addressing a more recent topic, Xuechao et al. (2013) investigated collisions between cars and electric bicycles in Changsha (China). Although it must be noted that e-bikes in China are of a different design compared to Europe (the e-bikes are more like electric scooters rather than bicycles), the collision circumstances are interesting. 54% of all collisions were classified as frontal impact, i.e. the e-bike impacted the front of the vehicle. In 33% side impacts in which the e-bike collided against the side of a vehicle were recorded. Consequently, the authors recommend focusing future work on these two impact scenarios. Furthermore, the influence of the front geometry of the vehicle on the kinematics was analysed using computer simulations. The results indicate a tendency that head impact can be expected in the area of the upper windscreen in case of a sedan while SUVs and vehicles with an one-box design result in a head impact on the bonnet and the lower windscreen area, respectively. Further studies, for example by Katsuhara et al. (2014), basically showed similar results when performing computer simulations of cyclists involved in frontal impacts of vehicles with different shapes.

In summary, current research supports the following statements:

- Cyclist impact to the vehicle front is a relevant accident scenario. Cyclist and pedestrian impacts are similar, but there are also differences, for example, with regard to the impact area on the vehicle front.
- Brain injury is of major concern, but other injuries such as thorax injuries are also relevant.
- Passive safety measures are relevant as the head impact zone for cyclists includes the A-pillar, windscreen, and roof area.
- Cyclist detection systems as part of active safety measures will not eliminate all impacts, i.e. passive safety measures are also relevant in future.
- Alternative test methods are subject of research such as using dummy impact tests which also allow assessing other injuries but isolated head and leg impact. Computer simulations have the potential to investigate different cyclist impact scenarios.
- Trends such as electric bicycles and an ageing population demand monitoring cyclist impacts as priority in accident analysis.
- More research (for example using methods like naturalistic driving studies) is needed to establish a sound basis for the development of new safety measures and test procedures (e.g. to define relevant scenarios for cyclist detection systems).

5.2. Current regulations for pedestrian impact testing and related regulations

Overview regulations

Under the 1998 international agreement on vehicle construction so-called Global Technical Regulations (GTR) are developed. These GTR cover the approval of vehicles' safety and environmental aspects and are managed by the World Forum for Harmonization of Vehicle Regulations, a permanent working party of the UNECE. The EU is a contracting party whereas the Commission and Member States take part in the technical preparatory work of the Forum and the Commission exercises the right to vote in the Forum on behalf of the EU.

GTR9 addresses pedestrian safety. In fact the corresponding document states the safety need for pedestrians AND cyclists. However, it refers to pedestrians only in the text that follows saying “This global technical regulation (GTR) will significantly reduce the levels of injury sustained by pedestrians involved in frontal impacts with motor vehicles”. The activities of the International Harmonized Research Activities (IHRA) 1/ Pedestrian Safety working group (IHRA/PS) form the basis for the definition of this regulation.

Further specific pedestrian safety regulations are in place in Europe, Japan, China, India and South Korea (not in the US). For Europe, the directive EC78/2009 requires motor vehicles to be tested for pedestrian safety. The test procedures are laid out in regulation UN ECE R127. Figure 3 summarises current test procedures for impact testing according to GTR9, EC78/2009 and R127 as well as different consumer tests (see also section 5.3).

Test Procedures and Protection Criteria for Pedestrian Protection

Test method	Parameter	Europe Regulations 78/2009 and 631/2009		UN R127 01 series	Euro NCAP		JNCAP		KNCAP		Japan Article 18 Attachment 99	GTR No. 9
		Phase 1	Phase 2		max. score	zero score	max. score	zero score	max. score	zero score		
EEVC lower legform impactor to bumper	Velocity	40 km/h	40 km/h								40 km/h	40 km/h
	Impact angle	0°	0°								0°	0°
	Acceleration	200 g	170 g (250 g)								170 g (250 g)	170 g (250 g)
	Bending	21°	19°								19°	19°
	Shearing	6 mm	6 mm								6 mm	6 mm
Flex PLI to bumper	Velocity			40 km/h	40 km/h		40 (44)[5] km/h		40 km/h		40 km/h	40 km/h
	Impact angle			0°	0°		0°		0°		0°	0°
	Tibia Bending			340 Nm (380 Nm)	282 Nm	340 Nm	224 Nm	380 Nm	282 Nm	340 Nm	340 Nm (380 Nm)	340 Nm [2]
	MCL Elongation			22 mm	19 mm	22 mm	16.4 mm	22 mm	19 mm	22 mm	22 mm	22 mm [2]
	ACL/PCL Elong.			13 mm	10 mm	10 mm	0 mm	13 mm	10 mm	10 mm	13 mm	13 mm [2]
upper legform impactor to bumper	Velocity	40 km/h	40 km/h	40 km/h	40 km/h				40 km/h		40 km/h	40 km/h
	Impact angle	0°	0°	0°	0°				0°		0°	0°
	Sum force	7.5 kN	7.5 kN	7.5 kN	5 kN	6 kN			5 kN	7.5 kN	7.5 kN	7.5 kN
	Bending	510 Nm	510 Nm	510 Nm	285 Nm	350 Nm			300 Nm	510 Nm	510 Nm	510 Nm
upper legform impactor to bonnet leading edge	Velocity	20 - 40 km/h	20 - 40 km/h		20 - 33 km/h							
	Impact angle	10° - 47°	10° - 47°		90° w.r.t. IBRL - WAD 930							
	Sum force	5 kN [1]	5 kN [1]		5 kN	6 kN						
	Bending	300 Nm [1]	300 Nm [1]		285 Nm	350 Nm						
small adult headform impactor to bonnet	Velocity	35 km/h										
	Impact angle	50°										
	Diameter	165 mm										
	Mass	3.5 kg										
	HPC	1000 (2/3) 2000 (1/3)										
adult headform impactor, child headform impactor to windscreen	Velocity	35 km/h			40 km/h		35 km/h		40 km/h			
	Impact angle	35°			65° (AH) / 50° (CH)		40° / 40° / 45° (AH + CH)		65° (AH) / 50° (CH)			
	WAD (mm)	–			1500-2100 (AH) / 1000-1500 (CH)		1700-2100 (AH) / 1000-1700 (CH)		1700-2100 (AH) / 1000-1700 (CH)			
	Diameter	165 mm			165 mm		165 mm (AH + CH)		165 mm			
	Mass	4.8 kg			4.5 kg (AH) / 3.5 kg (CH)		4.5 kg (AH) / 3.5 kg (CH)		4.5 kg (AH) / 3.5 kg (CH)			
	HPC	1000 [1]			650	1700	650	2000	650	1700		
adult headform impactor to bonnet	Velocity		35 km/h	35 km/h	40 km/h		35 km/h		40 km/h		35 km/h	35 km/h
	Impact angle		65°	65°	65°		65° / 90° / 50°		65°		65°	65°
	WAD (mm)		1700 - 2100	1700 - 2100	1700 - 2100		1700 - 2100		1700 - 2100		1700 - 2100	1700 - 2100
	Diameter		165 mm	165 mm	165 mm		165 mm		165 mm		165 mm	165 mm
	Mass		4.5 kg	4.5 kg	4.5 kg		4.5 kg		4.5 kg		4.5 kg	4.5 kg
	HPC		1000 (2/3) [3] 1700 (1/3) [3]	1000 (2/3) [3] 1700 (1/3) [3]	650	1700	650	2000	650	1700	1000 (2/3) [3] 1700 (1/3) [3]	1000 (2/3) [3] 1700 (1/3) [3]
active interventions			BAS alternative Collision Avoidance Systems		AEB VRU		AEB Pedestrian as of 2016		AEB Pedestrian as of 2017			

1 Monitoring only
2 injury criteria proposed by GRSP Flex-TEG
3 entire bonnet
4 child headform area
5 test velocity will be increased when leg impact is introduced in legal test (J-MLIT)

Table based on O. Zander, BASt, updated carhs Nov. 2015

Figure 3: Different test procedures for pedestrian impact testing (courtesy O. Zander, BASt / carhs).

UN ECE R127 (Pedestrian Safety)

The current directive EC78/2009 refers to the test procedures laid out in regulation R127 which is entitled “Uniform provisions concerning the approval of motor vehicles with regard to their pedestrian safety performance”. The regulation is based on prior work of working groups of the European Enhanced Vehicle Safety Committee (such as EEVC WG 17).

The standard defines impact tests to the front of motor vehicles of categories M1 and N1. The impact tests (see Figure 4) make use of different impactors mimicking the impact of a leg and the head to a defined area of the vehicle front. Headforms (adult size and child size) and a legform (tibia and femur) are used as impactors. Generally it can be noted that such a test procedure more easily allows testing various impact areas on the vehicle front. The limitation that, using dummies, only a few scenarios could be evaluated, was the main reason why impactor tests were adopted for the test procedure.

The *adult headform test area* is an area on the outer surfaces of the front structure. The area is bounded:

(a) In the front, by a wraparound distance (WAD) of 1700 or a line 82.5 mm rearward of the bonnet leading edge reference line, whichever is most rearward at a given lateral position;

(b) At the rear, by a WAD 2100 or a line 82.5 mm forward of the bonnet rear reference line, whichever is most forward at a given lateral position, and

(c) At each side, by a line 82.5 mm inside the side reference line. The distance of 82.5 mm is to be set with a flexible tape held tautly along the outer surface of the vehicle.

The *child headform test area* is an area on the outer surfaces of the front structure. The area is bounded:

(a) In the front, by a WAD 1000 or a line 82.5 mm rearward of the bonnet leading edge reference line, whichever is most rearward at a given lateral position,

(b) At the rear, by a WAD 1700 or a line 82.5 mm forward of the bonnet rear reference line, whichever is most forward at a given lateral position, and

(c) At each side, by a line 82.5 mm inside the side reference line. The distance of 82.5 mm is to be set with a flexible tape held tautly along the outer surface of the vehicle.

The *femur* of the lower legform impactor is defined as all components or parts of components (including flesh, skin covering, damper, instrumentation and brackets, pulleys, etc. attached to the impactor for the purpose of launching it) above the level of the centre of the knee. The *tibia* of the lower legform impactor is defined as all components below the level of the centre of the knee. Note that the tibia as defined includes allowances for the mass, etc., of the foot.

The vehicle front is impacted by the different forms at defined angles and impact speeds (Figure 4).

The head injury criterion (HIC) is used to evaluate the head injury risk. For the tests using the child and adult headform the HIC recorded shall not exceed 1000 over two thirds of the bonnet top test area. The HIC for the remaining areas shall not exceed 1700 for both headforms. In case there is only a child headform test area, the HIC recorded shall not exceed 1000 over two thirds of the test area. For the remaining area the HIC shall not exceed 1700.

Regarding the impact of the lower legform to the bumper (flexible lower legform impactor), the absolute value of the maximum dynamic medial collateral ligament elongation at the knee shall not exceed 22 mm, and the maximum dynamic anterior cruciate ligament and posterior cruciate ligament elongation shall not exceed 13 mm. The absolute value of dynamic bending moments at the tibia shall not exceed 340 Nm. In addition, the manufacturer may nominate bumper test widths up to a maximum of 264 mm in total where the absolute value of the tibia bending moment shall not exceed 380 Nm.

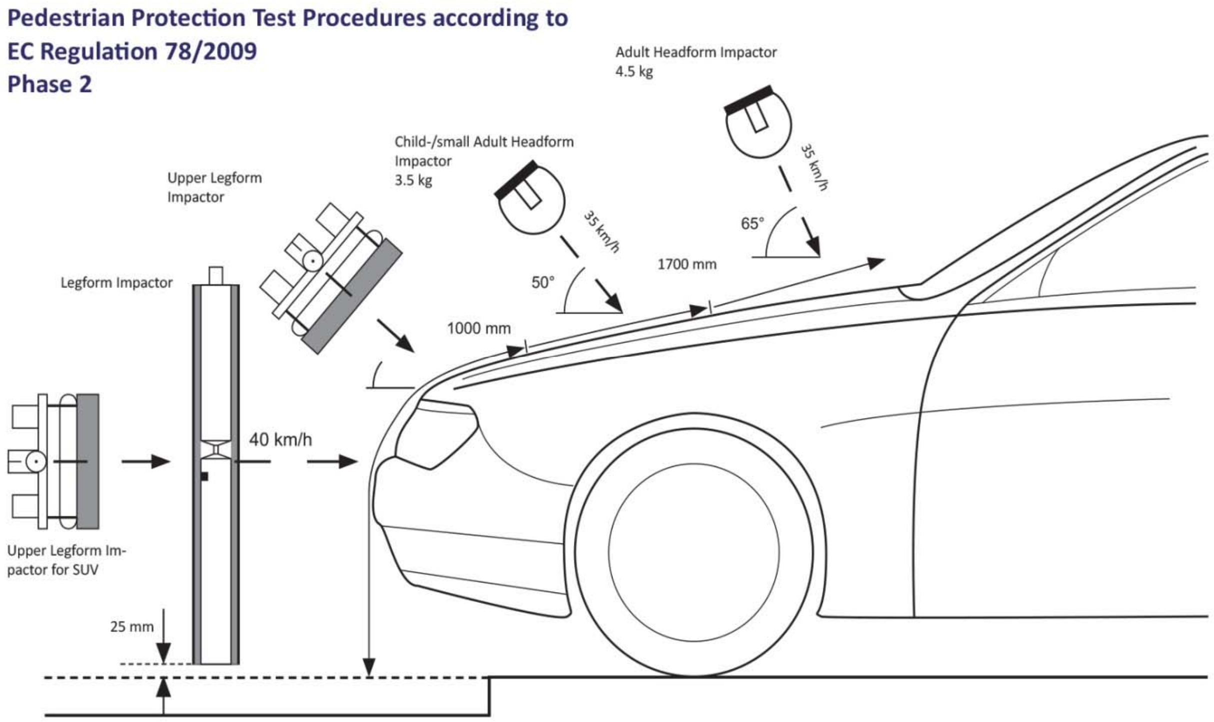


Figure 4: Pedestrian impact testing according to EC78/2009 (figure by carhs).

Assessing the impact of the upper legform to the bumper, the instantaneous sum of the impact forces with respect to time shall not exceed 7.5 kN and the bending moment on the test impactor shall not exceed 510 Nm. Originally, the upper legform impactor was designed for an impact test against the bonnet leading edge; this procedure however caused criticism for the test as such and also for the biofidelity of the test device. In ECE R127, the upper legform is now used for impacts against the bumper. In GTR 9, the test requirements (usage of lower or upper legform) vary depending on bumper height. The impactor itself is subject to studies regarding its improvement and biofidelity, respectively.

Other standards

Note that other standards might have an influence on the design of a car front. ECE R42 and FMVSS 581 ensure that bumpers are not damaged in low speed impacts. This also influences the design (stiffness) of the bumpers. ECE R42 (front and rear protective devices (bumpers etc.)) addresses low speed collisions. Its purpose is to ensure that elements located at the front and rear ends of vehicles are designed in such a way as to allow contacts and small shocks to occur without causing any serious damage. The vehicle impacts a barrier at 4 km/h. Likewise FMVSS 581 (bumper standard) is used to assess low speed front and rear collisions. The purpose of this standard is to reduce physical damage. Impact speed is 2.5 mph.

Other test devices

There are other legforms available such as the Flex PLI which is used in regulations outside Europe and in consumer test procedures (incl. Euro NCAP). Additionally alternative leg impactors (e.g. TRL leg impactor (WG17 impactor)) were developed, but not prescribed in any standard.

5.3. Current pedestrian impact testing at consumer organisations

There are various consumer organizations that rate the safety performance of a vehicle. Best known are the so-called “new car assessment programmes” (NCAP) which are implemented in different world regions (e.g. Europe, Japan, South Korea, Latin America, Australia). These NCAP's include procedures to assess the injury risk generated by a vehicle front impacting a pedestrian.

Euro NCAP, the European NCAP, includes impact testing similar to the safety regulation R127 (Figure 5). However, in comparison to R127, a somewhat larger impact area towards the windscreen is used for head impact. Furthermore, a different leg impactor (Flex PLI) is used and the head forms impact the vehicle front at a slightly higher speed. The pedestrian protection score is determined from tests to vehicle front-end structures such as the bonnet and windshield, the bonnet leading edge and the bumper. In these tests, the potential risk of injuries to head, pelvis, upper and lower leg is assessed. Euro NCAP also uses the head injury criterion HIC to assess the results of the head impactors. HIC values below 650 obtain a “green” rating, values above 1700 receive a “red” rating and values between those thresholds are rated “yellow”, “orange” or “brown” based on the Euro NCAP scale. For the lower leg, the bending moment and the elongation of the knee ligaments are rated; for the upper leg, the force and the bending moment are evaluated. In contrast to ECE R127 and GTR9 where the upper legform impactor is used against the bumper, the upper legform impact test against the bonnet leading edge is still being performed by

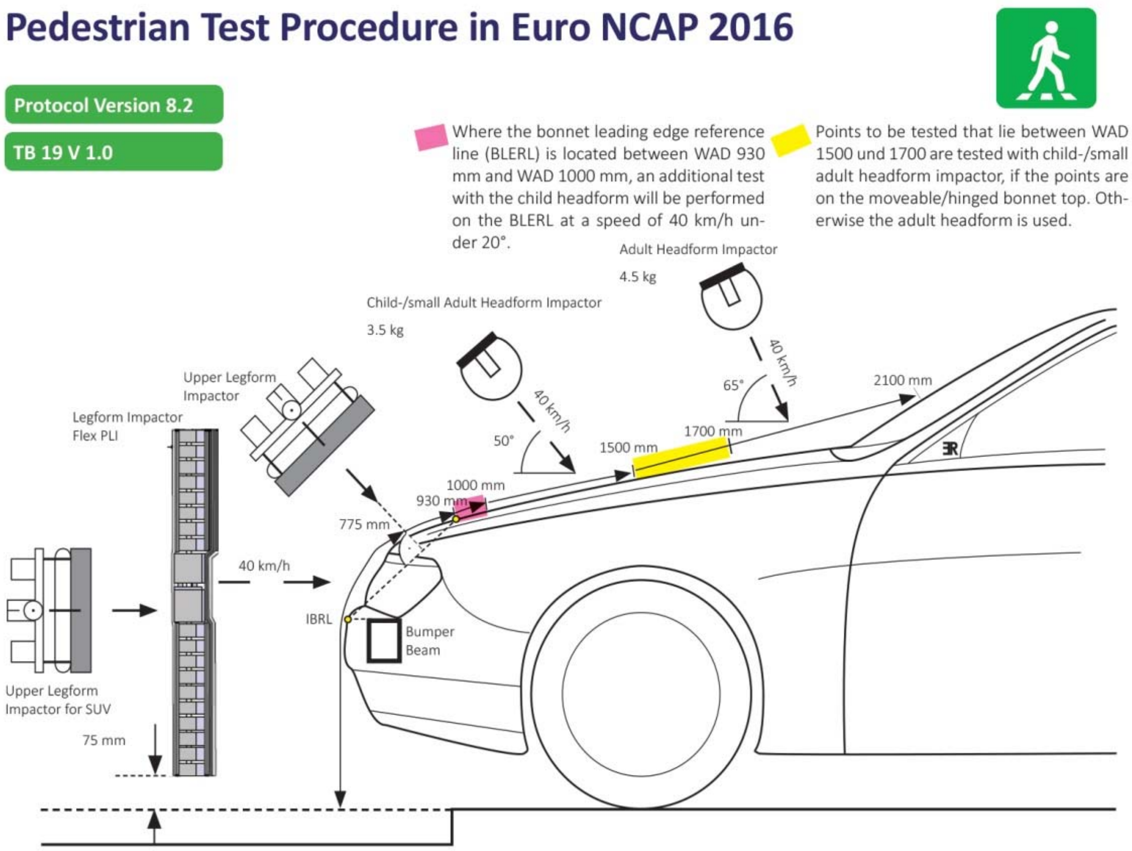


Figure 5: Pedestrian impact testing according to Euro NCAP protocol (figure by carhs).

EuroNCAP in its original EEVC WG 17 configuration.

Cars which perform well in the Euro NCAP test procedure can gain additional points if they have an autonomous emergency braking (AEB) system which detects pedestrians. For future AEB, systems that also detect cyclists (or more generally "vulnerable road users (VRU)") will be included. According to the Euro NCAP Road Map 2020, such AEB systems will be considered in ratings starting 2018.

5.4. Vehicle based approaches to reduced impact to the front

The front structures of a vehicle play an important role to reduce injury risk in case of a cyclist impact. Generally, measures related to the design of the vehicle front are referred to as measures of passive safety. The overall geometry (i.e. the shape) and stiffness of the front structure influences kinematics of an impact. The following structures are of particular interest:

- bumpers: often the initial contact structure in pedestrian impacts, but less relevant in cyclist impacts due to geometry. While the bumper standard (no-damage criterion) requires a certain stiffness, the shape of today's bumper structures aim at transferring impact loads across a larger surface. Modern bumpers include thus soft, easily replaced layers suited for the leg impact test, and stiffer structures underneath that handle the loads during the bumper standard tests.
- bonnet: a sufficient clearance between stiff component, e.g. shock absorber caps, engine parts and cover structures, must be ascertained. Furthermore, the bonnet and its underlying reinforcement structures need to be deformable at the load levels occurring at a head impact, while at the same time ensuring sufficient structural stiffness, in particular against aerodynamic loading. To overcome this dilemma, so-called pop-up bonnets (i.e. bonnets that are lifted in case of an pedestrian/cyclist impact and thus allow for more deformation space) have been proposed by AGU Zurich as early as in 1984. Such systems are on the market today. Another critical element is the bonnet latch and its mounting bracket.
- windscreen: the windshield itself usually breaks at impact and is generally regarded as one of the 'softer' structures of a vehicle front. However, an impact to the stiff windshield frame such as the A-pillars, the area of the wipers or the roof results in significant head loading. The A-pillars extend to an area under the bonnet connected to the front fender, usually near the aforementioned shock absorber caps, thereby creating another potentially problematic zone.
- A-pillars: the A-pillars, along with the windshield frame, represent very stiff structures as they need to carry high loads in the event of a rollover accident. Currently, A-pillars offer no pedestrian impact protection at all and can thus be the source of serious injuries.
- external airbags systems: such systems cover the lower area of the windscreen (i.e. lower frame) and the A-pillars and thus reduce head impact protection. These systems might be the only solution for a better head protection in impacts against the A-pillar.

The design of bumpers and the bonnet has significantly improved in the past. The benefit of pop-up bonnets was shown in various studies and such systems are commercially available. Also the protective capability of an external airbag was demonstrated and such a system is currently implemented in one Volvo model. Technical advancements focussing on the A-pillar, however, were not made in recent years. Likewise the top of the windscreen frame represents an unprotected area with respect to cyclist impact.

In addition to passive safety measures, advanced driver assistance systems (ADAS) are available that aim at avoiding a collision instead of mitigating its consequences. Such systems fall into the group of active safety devices. In the context of this study, mainly autonomous emergency braking (AEB) systems are of interest. To date systems are available that stop a vehicle if it gets too close to another vehicle; currently AEB systems are mainly designed to function in urban traffic. A few systems already feature a combination with pedestrian/ cyclist detection, i.e. the system recognises an approaching pedestrian/ cyclist and brakes the vehicle if the trajectories of the two objects indicate a potential collision.

However, fleet penetration with ADAS is still very scarce. Analysing the German vehicle fleet, the Federal Highway Research Institute reported that emergency braking systems or collision warning systems are on the road in about 1% of the fleet (Bast, 2015).

From a technical point of view, it is obvious that a combination of passive and active safety measures would be most promising. However, vehicle manufacturers today clearly prioritise collision avoidance by active safety over passive safety (cf. ACEA position paper, section 7). The balance between active and passive safety is thus subject to discussion. Focussing on pedestrians Edwards et al. (2015) assessed the benefit of fitting an autonomous emergency braking (AEB) system to a vehicle. It was found that the decrease in casualty injury cost achieved by fitting an AEB system was approximately equivalent to that achieved by increasing the current Euro NCAP passive safety rating from poor to average. Because the assessment was influenced strongly by the level of head protection offered in the scuttle and windscreen area, a hypothetical A-pillar airbag showed high potential to reduce overall casualty cost. This finding indicates that passive safety measures still do have a potential to significantly reduce the injury risk. The continuous enhancement of passive safety must thus not be neglected.

In a study on behalf of the European Commission, different possible measures to improve safety were assessed also with respect to legislative aspects and cost-benefit. The study was conducted by TRL in preparation of the revision of EC661/2009 and EC78/2009 (TRL, 2015). The report presents an overview of the feasibility and a cost-benefit assessment of a wide range of candidate measures for inclusion in the General Safety Regulation. The outputs are indicative cost-benefits provided in order to differentiate those measures that are very likely, moderately likely or very unlikely to provide a benefit consistent with the cost of implementation. The report also provides advice on the necessity and feasibility of including the upper legform to bonnet leading edge and adult headform to windscreen tests in pedestrian safety legislation, until recently carried out by vehicle manufacturers only with a view to monitor the situation in the field. The authors conclude that the expansion and enhancement of autonomous emergency braking (AEB) will have a positive impact. In contrast, pedestrian/ cyclist detection systems themselves are regarded as feasible, but with unclear benefit-cost-ratio. This measure should be re-evaluated. Also, impact testing of an adult head to the windscreen received an unclear rating. It is also regarded feasible (as shown by Euro NCAP) and there are indications that the performance of the central area of the windscreen can be controlled better at negligible cost. Hence this should be investigated further. A negative rating, however, was given for testing the pedestrian upper leg and pelvis to bonnet leading edge. It was argued that only small numbers of pelvis and upper leg injuries are caused by the bonnet leading edge of modern cars. A potential benefit for head, thorax and abdomen protection for children is not yet quantified and should be further reviewed in depth, if considered. Adding other body regions and harmonisation with other tests could elevate the benefit-cost-ratio above 1.

5.5. Relevant on-going research projects

Numerous projects were conducted addressing different aspects of pedestrian and cyclist impacts (including work related to cycling helmets). More recently, the European Commission has funded several projects under the 7th frame work programme (FP7) and continues to fund such work under the Horizon 2020 programme. The following list highlights some major projects related to cyclist impacts. While the FP7 projects certainly contributed to current discussions, there is yet no clear impact that can specifically be attributed to individual projects. Projects under H2020 have only started recently.

FP7 (projects completed):

- ASSESS: Assessment of integrated vehicle safety systems for improved vehicle safety (http://cordis.europa.eu/project/rcn/91187_en.html). Specific project goals were to develop harmonized and standardized assessment procedures and related tools for selected integrated safety systems.
- ASPECSS: Assessment methodologies for forward looking integrated pedestrian and further extension to cyclists safety systems (http://cordis.europa.eu/project/rcn/99619_en.html). The project contributed towards improving the protection of vulnerable road users, in particular pedestrians and cyclists by developing harmonized test and assessment procedures for forward looking integrated pedestrian safety systems. The outcome of the project is a suite of tests and assessment methods as input to future regulatory procedures and consumer rating protocols.
- ARTRA: Advanced Radar Tracking and Classification for Enhanced Road Safety (http://cordis.europa.eu/project/rcn/100866_en.html), the aim of the project was to develop an active safety system to protect vulnerable road users (VRUs) from vehicles in motion.
- SMART RRS: Innovative concepts for smart road restraint systems to provide greater safety for vulnerable road users (http://cordis.europa.eu/project/rcn/90093_en.html). The project focussed on information processing and information systems to increase traffic safety, particularly for powered two-wheelers.
- VRUITS: Improving the safety and mobility of vulnerable road users through ITS applications (http://cordis.europa.eu/project/rcn/186986_en.html). The project recommended ITS that meet the needs of VRUs.

H2020 (recently started projects, ongoing research):

- SafetyCube: Safety CaUsation, Benefits and Efficiency (http://cordis.europa.eu/project/rcn/193237_en.html). Focus: accident analysis; linked to the European Road Safety Observatory.
- InDeV: In-Depth understanding of accident causation for vulnerable road users (http://cordis.europa.eu/project/rcn/193358_en.html). The objective of the project is to develop a tool-box for in-depth analysis of accident causation for Vulnerable Road Users (VRU).
- PROSPECT: PROactive Safety for PEdestrians and CyclisTs (http://cordis.europa.eu/project/rcn/193275_en.html). PROSPECT targets five key objectives: i. Better understanding of relevant VRU scenarios; ii. Improved VRU sensing and situational analysis; iii. Advanced HMI and vehicle control strategies; iv. Four vehicle demonstrators, a mobile driving simulator and a realistic bicycle dummy demonstrator; v. Testing in realistic traffic scenarios and user acceptance study.
- XCYCLE: Advanced measures to reduce cyclists' fatalities and increase comfort in the interaction with motorised vehicles (http://cordis.europa.eu/project/rcn/193364_en.html). XCYCLE will develop technologies aimed at improving active and passive detection of cyclists, systems informing both drivers and cyclists of a hazard at junctions, methods of presenting information in vehicles and on-site as well as cooperation systems aimed at reducing collisions with cyclists.

Further projects:

- CATS: Cyclist-AEB Testing System (http://www.TNO.nl/CATS). In this project (completed in June 2016) a test procedure for assessing AEB systems that detect cyclists was developed. The project delivered a test protocol which is appropriate for consumer testing (i.e. the proposed protocol is in Euro NCAP format).
- COST TU 1101: This European activity called HOPE – Helmet Optimization in Europe (http://www.bicycle-helmets.eu/) addressed different aspects of bicycle helmet design.

6. Future trends and expectations

6.1. Expert opinions and expectations

Different expert opinions were gathered by interviews. Generally, all experts agreed that cyclist safety is a relevant topic which should be addressed. Various projects were conducted in the past (several unpublished, e.g. by vehicle manufacturers) and there are corresponding initiatives underway or planned to look into cyclist safety in more detail. This holds true for Europe, but also Japan where a new J-NCAP protocol was introduced and where it is intended to re-work the pedestrian impact safety regulations next year; cyclist safety will be a topic then.

It was highlighted that GTR9 and related work in the 1990s (e.g. in relevant working groups) did not really have cyclist safety in mind. The focus was clearly set on pedestrians although the initial idea was to have a much wider regulation (e.g. also including windscreen impact tests). However, the final document of GTR9 is related to pedestrians only (even if cyclists are still mentioned in the preface; the corresponding ideas discussed in the committee during the process of establishing the regulation were dropped in the final version). Nonetheless, it was always assumed that measures to increase pedestrian safety are also beneficial for cyclists. While this might generally be correct, there is a need to look into the topic of cyclist impacts in more detail as there are differences to pedestrian impacts.

The experts agreed that head injury is the most relevant topic in cyclist impacts. Lower extremity injury is less an issue with cyclists than it is for pedestrians. However, several experts highlighted that thorax injury should be considered as well. It was also suspected that – compared to pedestrians – cyclists might experience more oblique impacts in which they slide on the bonnet. This could explain why cyclists sustain less head injuries than pedestrians, but thorax injuries are a relevant topic in cyclists. More research might be needed, but the topic should be kept in mind particularly as there are no impactors used today that mimic impact of the thorax to the vehicle front.

With regard to head impact to the vehicle front most experts confirmed that the head impact zone for cyclists extends to a higher wraparound distance than for pedestrians. It extends further up the windscreen towards the roof, also covering the A-pillars. Research by BASt (Federal Highway Research Institute, Germany) has shown that a wraparound distance of 2100mm (as implemented in testing today) accounts for approximately 80% of all pedestrian head impacts, but for only 65% of all cyclist head impacts (for collision speeds below 40 km/h). To also cover 80% of all cyclist head impacts, a larger wrap-around distance (a first suggestion is 2300mm) should be considered. This finding is in line with an in-house study of a manufacturer (computer simulations) indicating that the head impact of cyclists can be expected to occur approx. 20-30 cm higher than pedestrian head impacts. In contrast it was expressed that in Japan no large difference (if any at all) between pedestrians and cyclists is expected, as apparently Japanese cyclists are smaller and sit lower on a bike. To learn more about such differences there are also approaches using in-depth accident analysis. Volvo has for example extended its accident database to cover accidents with cyclists (see publication by Lindman et al. 2015). The advantage of such a database is the fact that it covers 100% of accidents involving Volvo cars, i.e. cases with fatalities, but also (minor) injuries are recorded.

With regard to today's standards, it was pointed out that the EU regulation requires less than current Euro NCAP tests. Hence the current Euro NCAP procedures for pedestrian impact testing already account to some extent for cyclist impacts as a larger impact area is used. Consequently, a change of the regulations to meet at least the Euro NCAP requirements (e.g. larger impact area in impact tests) should not be a problem at all. Manufacturers will be able to manage the technical challenges. Thus also the expected safety benefit will be limited compared to the situation today (as most (European) manufacturers are already used to the Euro NCAP procedures). However, it remains unclear how Euro NCAP will react if the EU regulations were adjusted like this. Given that Euro NCAP procedures are supposed to be more challenging than the legal requirements which represent a basic minimum standard, some changes to the current Euro NCAP procedures could result.

The experts mostly considered the current pedestrian impact test procedure (using impactors) an appropriate methodology to assess the safety performance of a vehicle front. To consider cyclists, there is a need for adjustments, but the general approach seems practical and well established. Thus, it was recommended to build on this methodology which is accepted among the vehicle manufacturers. Adjustments for cyclist safety include refining the impact areas for the child and adult head form, verifying the impact angles and the impact velocity. To some extend (unpublished) research was already made to provide suggestions for such adjustments. BASt has, for example, also conducted impact tests using a 50%ile Hybrid III dummy (Figure 6). It was shown that the head impact occurs above the currently used impact area and adjusted areas can be developed taking such research into account. Furthermore, some experts highlighted that not only the head impact zone should be revised, but also impacts to other areas of the vehicle front such as the transition area between A-pillar and front fender which might be relevant for thorax impact. The introduction of a new thorax impactor was also suggested by some experts.

Figure 6: Impact tests using a Hybrid III dummy on a bicycle indicate that the head impact zone can be outside the wrap-around-distance of 2100mm as used today (presentation O Zander, crash.tech 2012).

Concerning passive safety measures to reduce the cyclist injury risk, experts indicated that the development of external airbags for pedestrians was driven by vehicle design (not enough space for other solutions), but that such airbags are not ideal and very complex; other design solutions are to be preferred. A major challenge for such systems is detecting a pedestrian impact, and cyclist impacts are even more challenging to detect in order to deploy the airbag in time. Nonetheless, some experts argued that passive safety technology such as airbags (for bonnet edge or A-pillar) is basically available and was shown to be feasible. However, such technology will solely be implemented if regulatory requirements are to be met only with this technology. As long as vehicles manage to fulfil the regulations without further technology, manufacturers have no motivation to implement it. Likewise it was commented that head impact to the windscreen should be addressed. Impact tests have shown that high HIC values (above 1000) may occur. Arguments by vehicle manufacturers that nothing can be done with regard to the windscreen design or glass properties should be challenged. This holds particularly true for smaller cars. While the head impact to the windscreen might be less of a problem in larger passenger cars (sedan type), the head impact in smaller cars (such as a MCC Smart) can be a problem if the cyclist hits the upper area of the windscreen and/or the roof.

While improving cyclist safety by means of passive safety seems possible (e.g. also with regard to the A-pillar design), the future trend is towards active safety. According to some experts, active safety is regarded key to eliminate pedestrian and cyclist impacts. Most experts assumed that active safety will be more widely introduced in future. Cycling detection systems as part of collision avoidance systems and automated braking systems are expected to be more widely available in future. Consequently some experts suggested that impact test procedures should account of such new technology, for example, by testing at reduced impact speeds if a vehicle is equipped with a pedestrian/ cyclist detection system. Along this line, Euro NCAP indicated that it will keep and maintain the passive safety requirements for pedestrian testing and regard active safety measures as an addition. The requirements for passive safety in pedestrian testing will be maintained (or elevated if necessary) and not be lowered if a vehicle is also equipped with active safety devices. Euro NCAP is currently not planning to introduce a specific test procedure related to cyclist safety, but Euro NCAP considers cyclist safety in their road map for 2020 (in terms of active safety systems detecting cyclists). Further passive safety measures (e.g. related to the A-pillar design) are apparently subject to debate regarding the Euro NCAP 2025 road map.

Furthermore, the expert mentioned related topics in the interviews such as:

- a need for research to analyse head impact area for pedestrians and cyclists of different age group, i.e. more in-depth accident analysis should be carried out across Europe.
- a need for improvement needed regarding the detection of bicycles by radar technology. Bicycles are difficult to detect by radar, i.e. some radar reflectors would be important. Radar technology is regarded more important than video technology for detecting bicycles.
- the fact that the US standard regarding front bumpers is disadvantageous or limits new, better vehicle designs, respectively (“no damage”- criterion).
- on-going research looking at the influence of anti-lock braking systems (ABS) on the stability of bicycles (inspired by the positive effects seen in motorcycling).
- concerns related to electric bicycles. While data from Germany does generally not indicate a difference between bicycles and electric bicycles when involved in a frontal vehicle crash, it seems that head injuries are somewhat more severe in electric bicyclists. However, this is not conclusive and might be an effect of a slightly higher age of e-bikers rather than an effect of kinematics or speeds involved.
- bicycle helmets and how they interact in case of an impact. Additional test scenarios (such as using bicycle helmets in impact tests), improved helmet performance and measure to increase helmet usage (e.g. for electric bicycles) were mentioned as relevant topics.

In summary, the different experts

- seem to agree that cyclist safety is a relevant topic and that current pedestrian impact testing does not fully account for cyclist impact. Hence there is a gap in current regulations with regard to cyclists.
- regard the current pedestrian impact testing which uses different impactors to test the vehicle front as appropriate, but it might need adjustment to consider cyclist impacts.
- state that the head impact zone must be extended for cyclist head impact testing compared to pedestrian impact.
- acknowledge the importance of passive safety measures. Some experts highlight the A-pillars as a structure that needs further attention. Particularly representatives of vehicle manufacturers comment on the importance of developing cyclist detection systems in combination with active safety measures.

6.2. Proposed changes in pedestrian safety regulation

The EC aims at a revision of the General Safety Regulation (EC 661/2009) and the Pedestrian Safety Regulation (EC 78/2009). According to a presentation by the Commission (DG GROWTH / Internal Market, Industry, Entrepreneurship and SMEs, February 2016), it is proposed to update the regulation for pedestrian safety such that it refers directly to UN ECE R127 while taking into account recent technological advances. Pedestrian and cyclist detection coupled with autonomous emergency braking (AEB) should be introduced. For new vehicle types, pedestrian detection should be implemented until 2024, cyclist detection until 2026. Regarding impact testing the adult head impact zone shall be extended to the A-pillar and the windscreen. For windscreen and A-pillar testing the introduction of reduced impact speeds may be considered for vehicles equipped with AEB featuring pedestrian and cyclist detection.

While the changes proposed by the EC reflect developments with regard to active safety and corresponding test procedures (e.g. as also suggested by Euro NCAP), the basic concept of impact testing is not questioned. The EC seems to regard the current procedures as a sound basis and does not respond to remonstrance that the impact areas must be extended. Even with respect to pedestrian impact, there are voices that argue that current test zones are not representative. Mueller et al. (2012) analysed pedestrian impacts recorded in the US (CIREN data base). Injury patterns were compared to test zones defined in GTR9. Various discrepancies were found. 59 of the 67 pedestrians had injuries to body regions not addressed by GTR 9 test procedures, indicating that a significant pedestrian injury problem may persist even if GTR 9 completely eliminates the injuries it addresses.

7. Positions of other stakeholders

In view of the expected revision of the general safety regulation different stakeholders have published their opinion. ACEA, the European Automobile Manufacturers Association, recommends focusing on active safety measures. Highlighting the need to improve safety of vulnerable road users such as pedestrians and cyclists, ACEA promotes the introduction of advanced emergency braking (AEB) for pedestrians and in a longer perspective also for cyclists. ”Given the potential benefits achievable with AEB, ACEA does not see the need to mandate further passive safety measures requiring external protection against pedestrian head in collision with the A-pillar or windscreen” (ACEA Position Paper, 2016). However, it should be pointed out that the German Automobile Club ADAC has just recently (Sept. 2016) published a test series demonstrating that currently available AEB systems with cyclist detection are still highly limited, several not being able to reliably detect a cyclist.

In contrast ETSC argues that both passive and active in-vehicle safety systems play an important role in reducing the number of pedestrian and cyclist fatalities (ETSC Position Paper, 2016). With respect to cyclists ETSC recommends to update existing tests and extend the scope of regulation 78/2009 to include cyclist protection.

8. Conclusions and recommendations for cyclist safety

Reviewing various sources of information we summarize the current situation with regard to the revision of the current pedestrian impact testing regulation in the following statements:

- There is agreement that cyclist safety is an important topic, accident statistics highlight the need to improve cyclist safety.
- The introduction of a completely new and specific standard to account for cyclist impact testing is not needed, but cyclist safety should considered in the revision of EC78/2009.
- Impactor testing as currently done for pedestrians is basically a suitable methodology, but adjustments are needed to account for some differences between pedestrian and cyclist impact. First of all the head impact area needs to be adjusted, furthermore the impact conditions (angle / velocity) must be reviewed.
- Injuries to the thorax should to be considered as they are currently not considered in impact testing. More research is needed to provide a sound basis to develop, for example, a suitable thorax impactor.
- Upgrading EC78/2009 to meet the current EuroNCAP procedure is a first step and should be the minimum.
- Various research was performed on impact testing for cyclists. The research seems sufficient to prepare a draft of impact testing. The draft should be followed by a feasibility study including cost-benefit analysis.

- Active safety should be taken into account in the sense that it could have an influence on the impact conditions. However, current technology has not yet reached a level allowing passive safety measures to be neglected.
- More challenging standards result in more innovative safety solutions. Thus, stricter standards should be enforced. This holds particularly true as there is safety technology available (e.g. external airbags), but not implemented. Further development regarding the A-pillars, the roof region and windscreen should be motivated.

How to implement cyclist safety in short term?

- Use R127 as a basis and keep the methodology as used today.
- Increase the wraparound distance that must be considered, thereby obtaining a larger head impact testing area. Depending on the vehicle design this will extend the area to the upper windscreen area including A-pillars and the roof. This will require many vehicle manufacturers to significantly improve the passive safety features of the vehicle front.
- Revisit the impact conditions in terms of impact velocity and impact angle, but use the same impactors as today.
- The necessity of corresponding adjustments of the regulations is backed by existing research.

How to implement cyclist safety in mid to long term?

More elaborate test methods should be considered (particularly virtual testing by using computer models). This would allow taking into account more realistic cyclist impact scenarios (e.g. for different bicycle types, considering helmeted cyclists, the interaction with active safety measures that might change the impact conditions). The definition of such impact test procedures requires further research to be conducted. Some of the currently performed EU research projects address this topic and might thus contribute to the development of a more advanced test procedure. Collaboration with Euro NCAP seems crucial.

Good to know and things to consider

- The contents of the current regulation R127 is based on work by working group “EEVC WG 17” which is well known in our community.
- Improving safety for pedestrians and cyclists goes together (goal congruence). There are, of course, some differences (such a higher relevance of lower extremity injuries for pedestrians than for cyclists or a higher relevance of head impact to the upper windscreen, the A-pillar or the roof for cyclists), but generally these topics go very well together. Thus it seems to make sense to address pedestrian and cyclist impact testing in one regulation.
- Testing the vehicle front by different impactors is established and widely accepted today. This test method has its strength, but also some shortcomings (such as some body regions not being tested, being limited to certain biomechanical measures, not mimicking the entire kinematics). Alternative methods are impact tests using crash test dummies or computer simulations. There are pros and cons for each of the methods; ideally, a test procedure would therefore combine different methods to benefit from the different strengths. However, for practical reasons, it seems reasonable to focus in a first step on a test procedure similar to the impactor tests as implemented today. Using this test methodology improvement of cyclist safety can be achieved.
- Thorax injury is currently not considered in pedestrian test regulations. This is a shortcoming. However, it should be considered that the introduction of some sort of thorax testing is regarded as a very complex undertaking. The development a new impactor requires significant effort. It is, of course, feasible, but would require further research, engineering of the impactor and validation. This is not a short-term project even if it might sound very straightforward. Furthermore, most manufacturers and test labs are strongly opposed to new developments in this field.
- Design requirements should be avoided in any standard; a regulation should define performance requirements only.
- The current regulation addresses the primary impact of a pedestrian at the vehicle front. However, also so-called secondary impact, i.e. impact to the ground, is related to a significant injury risk. This is not covered by the current regulation. Consequently injuries due to secondary impact will continue to happen and the accident statistics do not reflect such details.
- Automotive industry currently favours active safety measures. Basically, this is fine and these measures certainly offer interesting possibilities to prevent collisions. However, improvements of passive safety measure must not be neglected as also the active systems will fail. Thus it can be argued that the biomechanical threshold values currently implemented in the regulation (such as HIC 1000) are kept unchanged and will not be made tougher with the argument that active safety measures will contribute to the overall reduction of the injury risk.

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