EFFECTIVENESS OF PEDESTRIAN SAFETY MEASURES AT THE VEHICLE FRONT WITH REGARD TO CYCLISTS

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ABSTRACT

Although the focus in the field of vulnerable road user safety has been on pedestrian safety so far, accident data shows a high relevance for cyclist-passenger car collisions as well. On the basis of an extensive simulation study the accident kinematics of cyclists is investigated for different vehicle classes in order to assess the effectiveness of existing passive safety measures, such as an active bonnet, a pedestrian or an extended cyclist windscreen airbag. Furthermore, the benefit of a reduced impact speed is analyzed in order to also consider the potential of autonomous emergency brake systems.

The assessment is done with the help of a specially developed procedure, which allows a vehicle-specific effectiveness measurement of passive and active safety measures for both pedestrians and cyclists. Six representative vehicle front geometries and four cyclist heights are considered within the kinematics analysis, reaching from a 6-year-old child to a 95%-male. Each cyclist model consists of a size-specific bicycle model and the corresponding MADYMO Ellipsoid Pedestrian Model placed on top. The simulation models and parameters are validated by reconstruction of a real accident taken from the GIDAS database. Two representative lateral accident constellations are defined together with four pedal positions. The speed of the cyclist always amounts to 15 km/h. The pedestrian kinematics analysis is based on simulations with comparable impact constellations as well as equal vehicle speeds.

An in-depth analysis shows that further rearwards located head impact positions constitute a fundamental characteristic of cyclist-passenger car frontal collisions compared to pedestrian frontal collisions. This is confirmed by the simulation results, where the cyclist head impact positions can reach up to the roof leading edge and in case of sports cars even beyond. Furthermore, the simulations show high values for head impact velocity as well as angle. The cyclist head impact velocities usually lie above the collision speed, which limits the benefit of purely design-related measures.

In order to study the cyclist accident kinematics in a lateral impact under real test conditions, full scale tests with a Polar-II dummy positioned on a moving bicycle (15 km/h) are conducted with different vehicle speeds (40, 30 & 20 km/h). Overall, the tests show a good correlation with the simulations and illustrate the safety potential of a collision speed reduction. Conspicuous are the loads measured for the secondary head impact, which are much higher compared to the primary impact, even for low vehicle speeds.

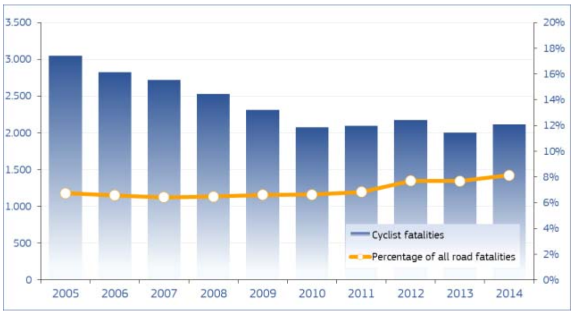
The results obtained from the assessment procedure reveal that cyclists are often not addressed by an active bonnet, whereas an additional airbag is able to reduce the head injury risk significantly. But it has to cover the whole A-pillar in order to be really effective. A reduction of impact speed is most beneficial - this is equally valid for all vehicle front categories, both for cyclists and for pedestrians as well as for adults and children. Additionally, there is a positive effect on the secondary impact.

INTRODUCTION

Although the focus in the field of vulnerable road user (VRU) safety has been on pedestrian safety so far, accident data shows a high relevance for cyclist-passenger car collisions as well.

Accident Analysis

Cyclist fatalities make up 8.1% of the total number of road accident fatalities in 2014 in the EU countries. In these countries, 2112 people riding bicycles were killed in road accidents in 2014 [1]. Figure 1 shows the number of cyclist fatalities and the percentage of all road fatalities in the EU between 2005 and 2014. In this period there was a decrease of 30% in the number of cyclist fatalities (pedestrians: -35%). However, since 2010 the number of cyclist fatalities is stagnating and the percentage of cyclist fatalities of all road fatalities increased from 7% in 2005 to 8% in 2014.



Source: CARE database, data available in May 2016

Figure 1. Number of cyclist fatalities & percentage of all road fatalities, EU, 2005-2014 or latest available year [1].

The percentage of cyclist fatalities in the total number of road accident fatalities is very country-specific. The EU countries with the highest percentage of cyclist fatalities in 2014 were the Netherlands (25%), Denmark (16%) and Hungary (16%). In contrast, e.g. in Greece, Spain and France cyclists constitute only a small part of the road accident fatalities [1].

Cyclists lie clearly ahead of pedestrians regarding the number of slightly as well as seriously injured road users within the official accident statistics in Germany. Although accidents involving cars are particularly severe here, cyclists are neither considered sufficiently in the legislative nor in the consumer ratings tests [2]. On the basis of German in-depth data regarding cyclist-passenger car accidents (German In-Depth Accident Study (GIDAS), German Insurers Accident Research) three representative accident constellations have been defined (Figure 2). These are two perpendicular constellations, i.e. with a collision angle of 90°, as well as another constellation with a cyclist orientated obliquely towards the straight driving vehicle, which represents two relevant turning situations within the analyzed data. This becomes apparent by rotation of the whole constellation in both directions (Figure 2, lower half).

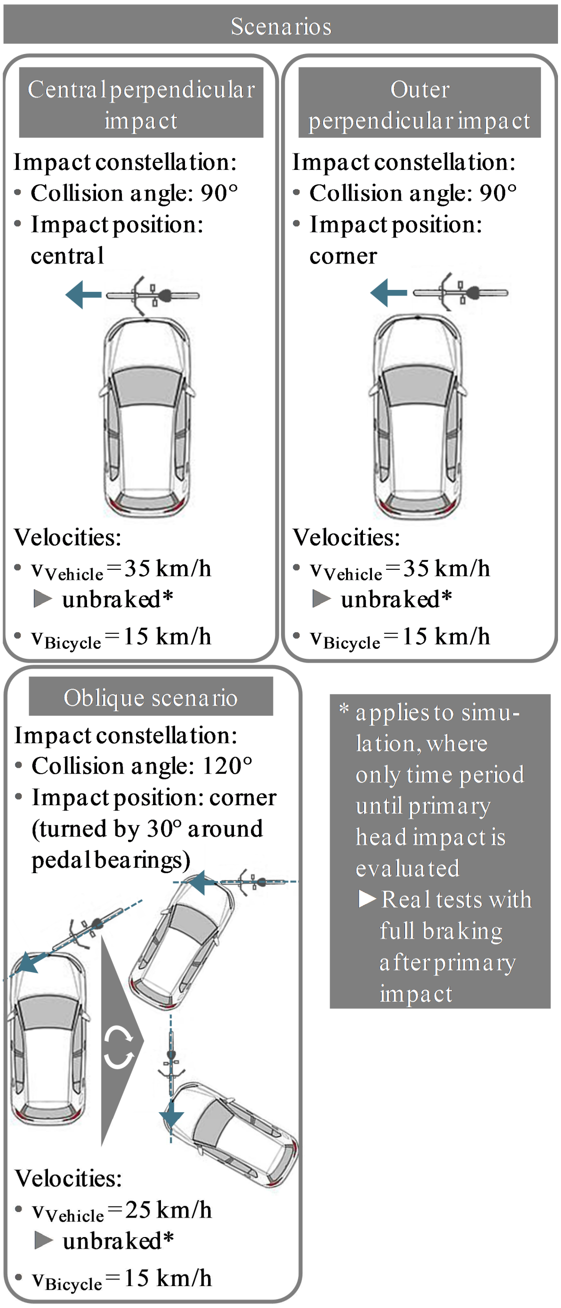


Figure 2. Cyclist test scenarios for simulation & testing as a result of the accident analysis [2].

Furthermore, a closer look is taken at the relevant head impact areas as well as the injury severity and frequency of individual body regions. But also aspects regarding the injury causing vehicle parts are regarded in the course of the accident analysis. With increasing injury severity the head turns out to be by far the most frequently injured body region, with the windscreen and here in particular the windscreen frame as the most relevant injury causing front area. Injuries of the lower extremities as well as the thorax are highly relevant, too. A fundamental characteristic of cyclist-passenger car frontal collisions compared to pedestrian frontal collisions constitute the oftentimes further rearwards located head impact positions. [2]

Research Question

On the basis of an extensive simulation study the accident kinematics of cyclists is investigated for different vehicle classes in order to assess the effectiveness of existing passive safety measures, such as an active bonnet, a pedestrian or an extended cyclist windscreen airbag. Furthermore, the benefit of a reduced impact speed is analyzed in order to also consider the potential of autonomous emergency brake systems.

The subsequent assessment is done with the help of a specially developed procedure, which allows a vehicle-specific effectiveness measurement of passive and active safety measures for both pedestrians and cyclists. An important characteristic of the assessment procedure is its modular design, combining structural characteristics of a vehicle front with accident kinematics and accident research data. The procedure uses the results of the Euro NCAP pedestrian protection tests of the car to be assessed and adapts the HIC values to the real accident kinematics of pedestrians and cyclists derived from numerical simulations.

SIMULATION OF VEHICLE-CYCLIST ACCIDENT CONSTELLATIONS

Impact Scenarios & Simulation Models

The implementation of the cyclist test scenarios illustrated in Figure 2 into the integrated assessment procedure requires some adaptations and restrictions. Only the two perpendicular constellations are considered, representing a lateral impact of the cyclist in the central and outboard area of the car front (Figure 3). The speed of the cyclist still amounts to 15 km/h while the initial vehicle speed is raised to 40 km/h. Thereby, the comparability to the pedestrian safety assessment is guaranteed, which is based on similar impact constellations describing a pedestrian crossing in front of a vehicle driving with a speed of 40 km/h. Starting from this base speed, also speed values of 35, 30 and 20 km/h are considered in order to analyze the benefit of a reduced vehicle speed. The according simulations are conducted with the MADYMO multi-body solver.

On the basis of investigations regarding common bicycle sizes, designs and seating positions representative bicycle models are built up, reaching from a 6-year-old child to a 95%-male (Figure 4).

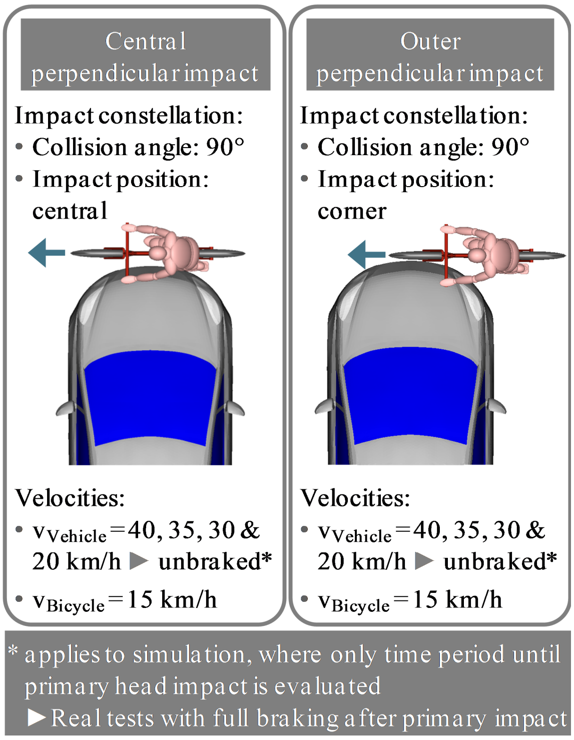


Figure 3. ***Cyclist impact constellations for the assessment procedure [2].***

Each cyclist model consists of a size-specific bicycle model and the corresponding MADYMO Ellipsoid Pedestrian Model placed on top. In order to sufficiently consider the influence of the cyclist's pedal position on the accident kinematics in total four pedal positions (leg facing the vehicle backward, forward, up & down) are defined and implemented into the simulations (Figure 4).

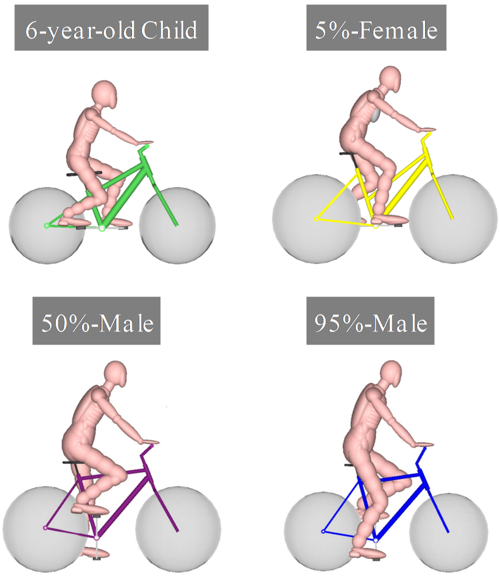


Figure 4. ***Cyclist models & pedal positions.***

The cyclist constellations considered within the simulations each result from the four cyclist heights, the four corresponding bicycle models as well as the four pedal positions defined for every cyclist.

The study comprises six real passenger car fronts, all representing different vehicle classes, named Compact, Sedan, Van, Sports Car, SUV and OneBox. Those classes are based upon a categorization, which has been developed to consider the different front designs of modern cars and their impact on pedestrian accident kinematics [3]. For each class a representative real passenger car front has been defined and converted into MADYMO, i.e. facet surfaces have been generated based on the corresponding finite elements. Figure 5 shows the front geometries of those class representatives.

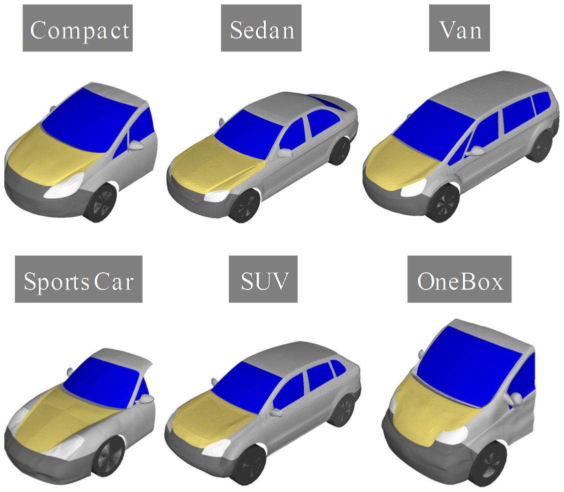


Figure 5. Vehicle models.

For the study no deceleration is applied to the vehicle models prior to the primary head impact, which on the one hand reflects the large percentage of cyclist-passenger car accidents without braking [2] and on the other hand guarantees uniform and reproducible boundary conditions for the analysis of the primary head impact. A brake dive of the vehicle is not considered in the simulations. Simulations are stopped right after the primary head impact. Passive safety measures primarily improve the structural properties within the protected area but they usually have an effect on the accident kinematics as well. In order to generally consider the kinematical influence of an active bonnet, additional simulations are conducted. Within these simulations, the bonnet of all vehicle models is raised by 100 mm at the rear.

The reconstruction of a real accident taken from the GIDAS database in order to validate the defined simulation parameters, such as contact stiffness values and friction coefficients, shows that the accident kinematics of a cyclist-passenger car collision can be reproduced realistically by the models used in the simulations. This includes the impact locations of hip and head as well as the final position of the cyclist. Both accident scenario as well as accident vehicle correspond well to the simulation boundary conditions described above. The vehicle is equivalent to the simulation model Compact (Figure 5). Regarding the cyclist, the 50th percentile male allows a sufficient representation within the simulation.

Simulation Results

Taking also into account the simulations with lifted bonnet, in total 960 simulations have been conducted within the scope of the cyclist accident kinematics analysis. As a result, the cyclist-relevant impact areas as well as the corresponding values for head impact velocity and head impact angle are obtained with regard to the defined vehicle velocities.

The simulations show for a large part of the constellations an increased head impact area compared to the already existing pedestrian results. The cyclist head impact positions can reach up to the roof leading edge and in case of sports cars even beyond. Furthermore, the simulations show high average values for head impact velocity and angle. In contrast to pedestrians, the cyclist head impact velocities usually lie above the collision speed, which inevitably limits the benefit of purely design-related measures.

Figure 6 illustrates the influence of the collision speed on the average head impact velocity for the different cyclist as well as vehicle models.

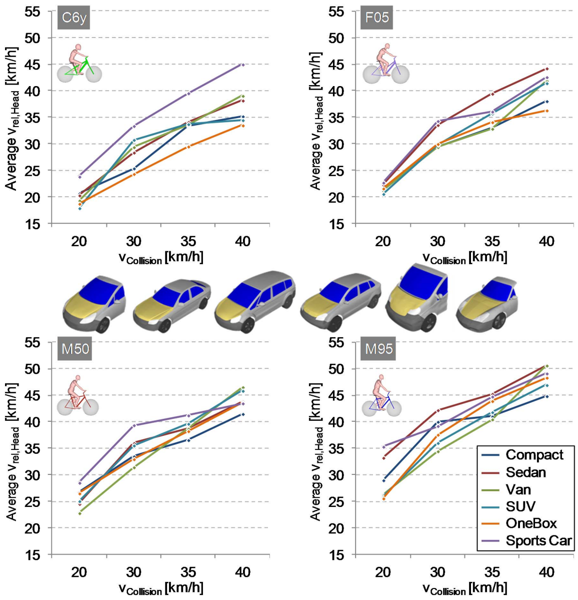


Figure 6. Average head impact velocity over collision speed for perpendicular impact scenarios.

A reduced collision speed leads for all vehicle models to a forward displacement of the head impact locations, i.e. the wrap around distances (WAD) of the head impact locations are getting shorter with decreasing collision speed. This effect is less pronounced for front geometries with a high bonnet leading edge, as is the case for the SUV and OneBox vehicle.

It becomes apparent that for the bigger cyclist models, i.e. the 50th and 95th percentile male, the average head impact velocity always lies above the collision speed while for the smaller ones this depends on the vehicle front geometry. In case of the 6-year-old child the sports car is the only vehicle where the average head impact velocity exceeds the collision speed for all simulations conducted. A reason for this is the low front height of the sports car which causes a high rotational velocity component of the cyclist due to the low vehicle-sided contact point. This results in high impact velocities for all cyclist models. The 5th percentile female shows average head impact values equal or above collision speed for 20 and 30 km/h. Looking at collision speeds of 35 and 40 km/h, the compact and OneBox vehicle models achieve lower average head impact velocities while the sedan and sports car models lead for all simulations of the 5th percentile female to average head impact values above collision speed.

The simulations with vehicle speeds of 40 km/h, which is the speed level the Euro NCAP pedestrian head impact tests are based on, show very high average head impact velocities, especially for the 50th and 95th percentile male. A look at the maximum values stresses the difference in speed level compared to the boundary conditions for pedestrian protection. The maximum head impact velocities are achieved by the 95th percentile male. In a collision with the van a value of 66.8 km/h is reached, followed by a value of 65.9 km/h in a collision with the sedan. This demonstrates that the velocity level for a head impact of a cyclist can be considerably higher than the existing testing level for pedestrian protection.

POLAR-II DUMMY TESTS

In order to study the cyclist accident kinematics in a lateral impact under real test conditions, different full scale tests with a Honda Polar-II dummy positioned on a moving bicycle are carried out. For this purpose additional simulations with a corresponding model of the test vehicle are conducted at first. This allows the definition of suitable boundary conditions for the particular tests and a further validation of the simulation models. The full scale test program comprises in total three tests with a central perpendicular impact at different vehicle speeds. Thereby, vehicle speeds of 40, 30 & 20 km/h are considered, which have also been part of the simulation study. As in the simulations, the speed applied to the cyclist dummy by the test bench amounts to 15 km/h in all tests. The pedal position is consistent as well. In all tests the leg facing the vehicle is in down position.

Test with a Vehicle Speed of 40 km/h

Figure 7 shows the accident kinematics of the 40 km/h test until primary head impact from three different camera angles. The time t = 0 ms marks the initial contact between dummy and vehicle.

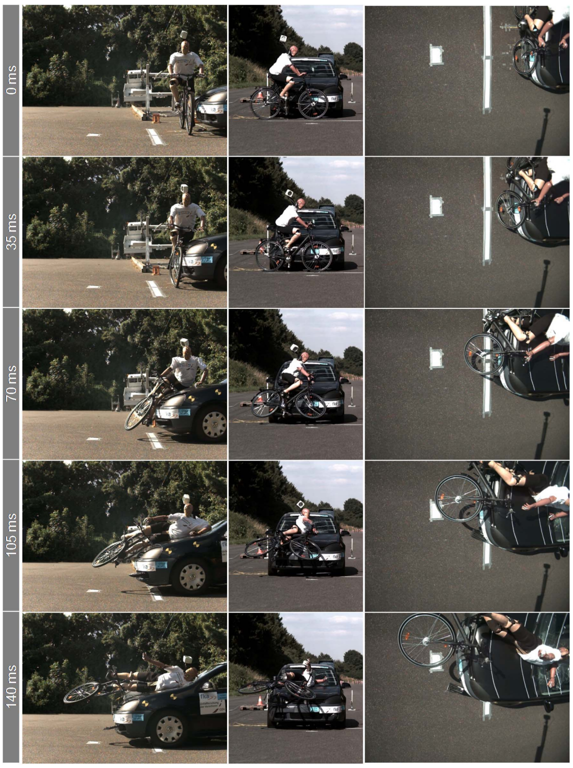


Figure 7. Central perpendicular impact with a vehicle speed of 40 km/h.

The head impact on the windscreen, which has already been damaged by the previous elbow impact, occurs after 140 ms at a wrap around distance of about 2200 mm. The calculated head impact speed is high and amounts to approximately 65 km/h. Due to the deceleration of the vehicle after the primary head impact, the dummy is thrown forwards along the vehicle front. The feet and legs hit the ground first, which happens directly in front of the decelerating vehicle, followed by the upper body and finally the head. After a short sliding phase the dummy reaches its end position. The longitudinal throw distance of the head, which is measured from the point of initial impact, is 16 m while the lateral throw distance is about 1.1 m.

The analysis of the dummy measurement data results in a HIC value of 598 for the primary impact, while the head loading due to the secondary impact is significantly higher and amounts to an extreme HIC value far exceeding all limits, which is caused by a maximum head deceleration of 1645 g. At primary head impact the maximum head deceleration is 125.6 g. Here, the pre-damage of the windscreen should have a significant effect.

Test with a Vehicle Speed of 30 km/h

For a reduction of the vehicle speed by 10 km/h the cyclist kinematics are illustrated in Figure 8.

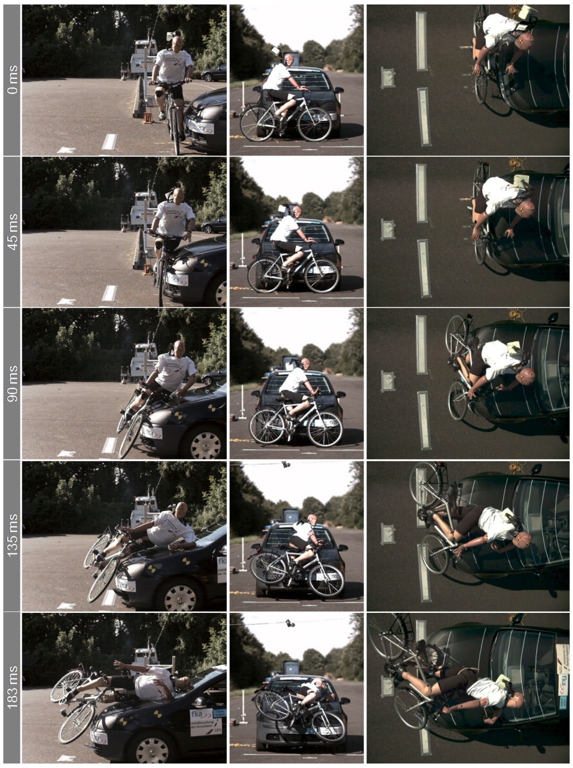


Figure 8. Central perpendicular impact with a vehicle speed of 30 km/h.

After 181 ms the head hits the windscreen at a wrap around distance of 2035 mm with a calculated impact velocity of 47.5 km/h. After primary head impact the dummy falls along the left fender and head light to the ground in front of the decelerating vehicle. The lower extremities hit the ground first. Subsequently, the dummy lands on his buttocks, falls backwards and impacts after 1.42 s with the head on the ground. This occurs within the sliding phase, which ends at a longitudinal throw distance, measured from the head, of about 10.9 m and a lateral throw distance of about 2.3 m.

The HIC value at primary head impact amounts to 178 and turns out to be considerably lower than for the previous test. Again it has to be noted, that the windscreen is already damaged at the time of head impact. The maximum head deceleration is 85 g. The head loading due to the secondary impact is still high and results in a HIC value of 1906 (a_{max} = 465 g), which would furthermore receive a red rating in a Euro NCAP impactor test.

Test with a Vehicle Speed of 20 km/h

In the third test the vehicle does not remain in the track and moves to the right, so that the first contact occurs later than intended. As a result, there is no head impact on the vehicle but a direct impact on the ground next to the vehicle (Figure 9). However, this represents the most unfavorable constellation for the cyclist in the course of an accident with a low vehicle speed. Furthermore, the simulations show anyway a low head impact probability for the vehicle front due to the low difference in speed between the slow vehicle and the lateral moving cyclist.

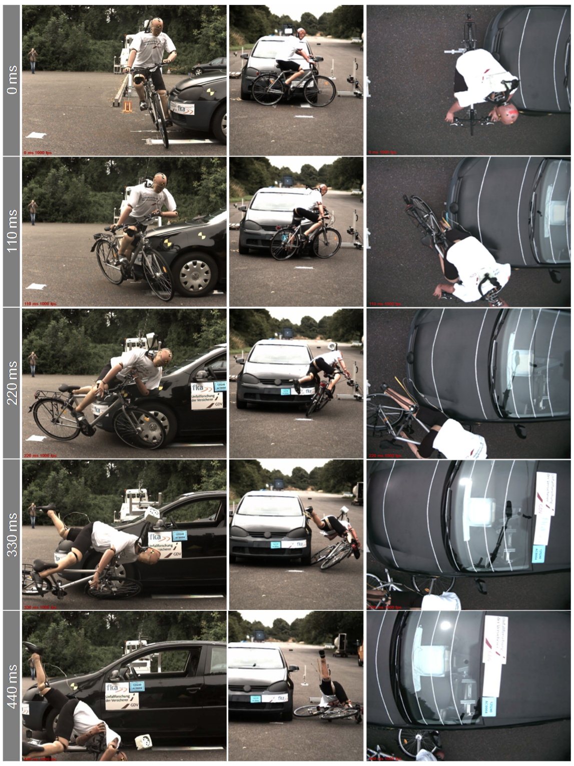


Figure 9. Central perpendicular impact with a vehicle speed of 20 km/h.

The dummy measurement data show a maximum head deceleration of 442 g, which is slightly below the value for the secondary impact in the 30 km/h test (465 g). Consequently, a high HIC value of 1787 is achieved, which still would get a red rating in a Euro NCAP impactor test.

Conclusions

Overall, the tests show a good correlation with the simulations carried out in advance and illustrate the safety potential of a collision speed reduction for the primary head impact. Furthermore, they confirm the high head impact velocities within the simulations. Figure 10 compares exemplarily the 30 km/h test with the corresponding simulation.

The measured values for head impact time and velocity are almost identical. The wrap around distance of the head impact position turns out to be a little shorter in the simulation. In y-direction the head impact locations are again very similar and thus the diagonal movement of the cyclist on the vehicle front.

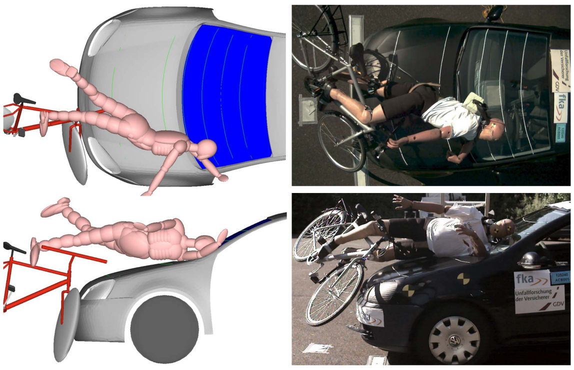


Figure 10. Comparison of simulation and full scale test for a central perpendicular impact with a vehicle speed of 30 km/h.

Conspicuous are the loads measured for the secondary head impact, which are much higher compared to the primary impact, even for low vehicle speeds. However, the low values for the primary impact are also a consequence of the windscreen damage prior to the head contact.

With regard to the assessment procedure described in the following, only the primary impact will be considered. Although the conducted tests reveal a high relevance for the secondary impact, there is no evaluation basis in terms of corresponding vehicle-specific test results, since the secondary impact is neither considered in the legislative nor in the consumer ratings tests. Furthermore, the simulation models are not designed or validated for the investigation of the secondary impact.

ASSESSMENT PROCEDURE

At the 23rd ESV conference a pedestrian safety assessment procedure has been presented [3], which allows the integrated assessment of active and passive safety measures on one scale for children and adults. Meanwhile, the integrated assessment procedure has been enhanced in order to address cyclists as well. Now the safety potential and the effectiveness of active and passive safety measures can be assessed and compared for both pedestrians and cyclists. The risk of a severe head injury serves as assessment criterion.

An important characteristic of the assessment procedure is its modular design, combining structural characteristics of a vehicle front with accident kinematics and accident research data (Figure 11). The actual assessment is carried out in the modules 4 and 5. The procedure uses the results of the Euro NCAP pedestrian protection tests of the car to be assessed (module 3) and automatically adapts the HIC values to the real accident kinematics of pedestrians and cyclists derived from numerical simulations (module 2). This also applies to kinematical changes caused by a reduced collision speed. Kinematics parameters are the head impact velocity, angle and probability.

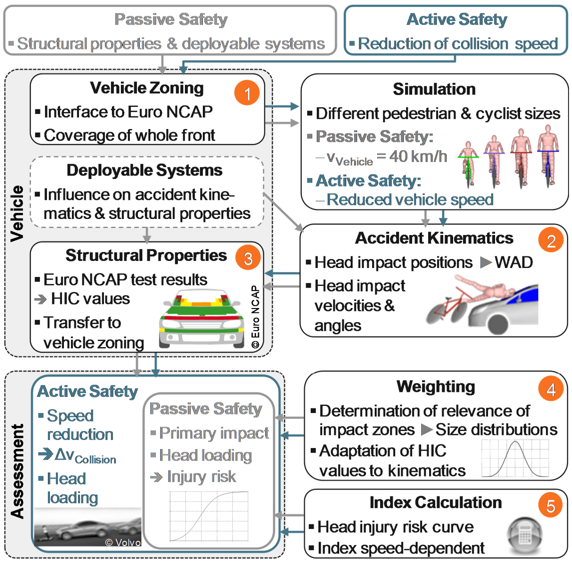


Figure 11. Assessment procedure.

The head impact probability defines the relevance of the particular wrap-around-distance zones of the vehicle front (module 1), which is in the end decisive for the effectiveness of a safety measure. The relevance of the respective front zones is dependent on both the geometrical boundary conditions, such as the height of the bonnet leading edge as well as the length and the angle of the bonnet, and the pedestrian or cyclist size and its distribution respectively. The pedestrian and cyclist size distributions for children and adults used in the course of the calculation of the head impact probabilities are based on the GIDAS database and therefore establish a direct link to the actual accident situation.

Besides the kinematics parameters of the vehicle front, its structural properties form another basis for the assessment. These are directly transferred, in the form of the results of the Euro NCAP pedestrian head impact tests, to the vehicle zoning. Within the assessment process the influence of possible deployable systems, such as an active bonnet or a windscreen airbag, on the structural properties as well as the accident kinematics is also considered. Head impactor tests with different impact angles and speeds have been conducted to further validate the adaption of the standardized Euro NCAP values to the kinematics parameters.

The assessment procedure finally provides index values for children and adults, which, depending on the collision speed and under consideration of relevance and stiffness of the particular vehicle fields, indicate the risk for an AIS3+ head injury due to the primary impact. For active safety systems the reduction in collision speed forms the main assessment criterion. Based on index values for different vehicle speeds lower than the base speed of 40 km/h, the safety potential of autonomous emergency brake (AEB) systems can be illustrated.

Assessment Results

In order to assess the effectiveness of pedestrian safety measures at the vehicle front with regard to cyclists, index values for cyclists are calculated using the simulation results presented above combined with present Euro NCAP test results per vehicle class. Beside the basic vehicle, an active bonnet, a pedestrian as well as an extended cyclist windscreen airbag and reductions in vehicle speed are each assessed

Compact The index results for the compact car are shown in Figure 12. For the basic vehicle as well as for each of the additional passive safety measures two bars are specified, indicating the AIS3+ head injury risk for children and adults. The two graphs next to the bars of the basic vehicle illustrate the reduction of the index value for children and adults due to a speed reduction of the basic vehicle of 5, 10, 15 and 20 km/h. This allows a direct transfer of the safety potential of additional passive measures into an equivalent speed reduction of the basic vehicle.

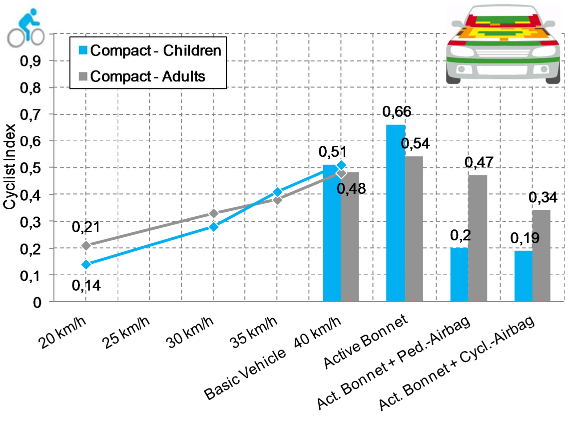


Figure 12. Cyclist index results for vehicle class Compact.

For the vehicle assessed in Figure 12 the injury risk for children and adults is almost identical and rises for both groups if an active bonnet is implemented. Especially for children there is a significant increase. One reason for this is the injury risk coming from the lifted bonnet rear edge, which is a relevant impact area for children but not for adults. Furthermore, the head impact velocities show higher values due to the lifted bonnet, with the strongest increases in the bonnet and cowl area.

Because of the short bonnet geometry of the compact car, mainly children benefit from a classic U-shaped pedestrian windscreen airbag, which covers a significant part of the relevant head impact area of children while adults are only protected in the area of the A-pillars. This protection can be extended until the roof leading edge in case of a cyclist airbag. Thereby, the adult index value can be further reduced but does not reach the level of the children value. A transfer of the safety potential calculated for the cyclist airbag into an equivalent collision speed results in a speed reduction of 10 km/h for adults, whereas for children the cyclist airbag safety potential is equivalent to a speed reduction of more than 15 km/h.

Sedan The vehicle representative of the class Sedan is equipped as standard with an active bonnet, resulting in very good structural properties in the bonnet area. For reasons of comparability with the other vehicle classes, a generic Euro NCAP test result representing typical structural properties of a car without an active bonnet is used for the assessment (Figure 13).

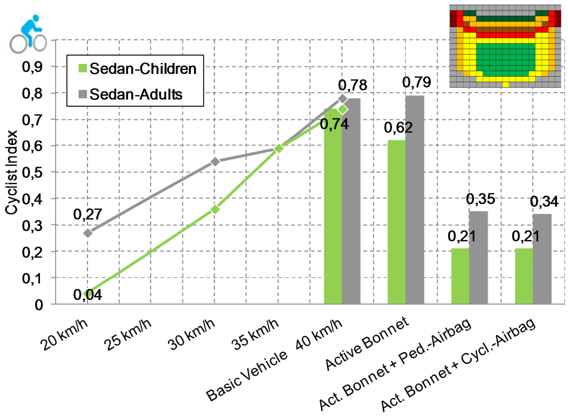


Figure 13. Cyclist index results for vehicle class Sedan.

In case of the sedan car the critical cowl and lower windscreen area have a relevance of almost 50% with regard to the head impact locations of children, while adults show high head impact velocities for the windscreen area. Both effects result in high index values for the particular groups. Also with an equipped active bonnet the relevance of the cowl and lower windscreen area stays high for children, so that no significant improvement can be achieved by this measure. Only in combination with an additional windscreen airbag the index values for both children and adults can be reduced considerably. An extension of the protected area due to a cyclist airbag is not very effective since only a few adults benefit from such a system.

Looking at the index results of the sedan car, the influence of the structural properties on the safety potential of AEB systems becomes apparent. While children achieve a very low index value (0.04) when the vehicle speed is halved (20 km/h), there is still a significant AIS3+ head injury risk of 27% for adults. This is a result of the forward displacement of the head impact locations due to the reduced collision speed. While for a collision speed of 40 km/h the relevance of the critical cowl and lower windscreen area amounts to 8% with regard to the head impact of adults, it increases to a share of more than 72% in case of a collision with 20 km/h. Thus, the injury risk reduction resulting from lower head impact velocities is partially compensated by a shift of the head impact locations towards areas with a high structural stiffness.

Van Figure 14 illustrates the assessment results for the vehicle class Van. The head impact velocities are very high. Especially for the windscreen area high average values up to 50 km/h are reached. But also for the relevant bonnet areas the averages lie above the collision speed. Accordingly, high index values are calculated for the basic vehicle.

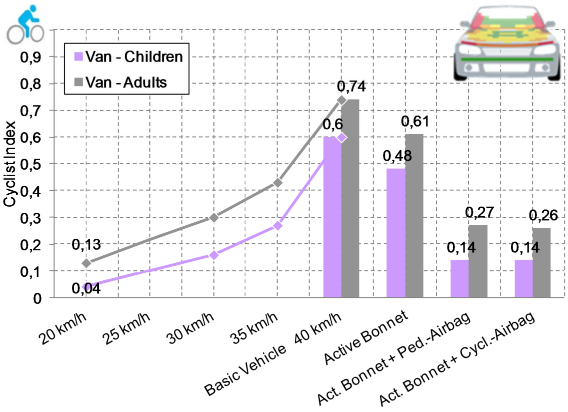


Figure 14. Cyclist index results for vehicle class Van.

The head impact velocities are reduced by an active bonnet for both children and adults, which is reflected by the corresponding index values. Due to the high relevance of the critical cowl and lower windscreen area for children, the pedestrian windscreen airbag offers a high safety potential here. Because of the steeper front geometry of the van, the wrap around distances of the head impact locations are generally shorter compared to the sedan car. Thus, the pedestrian windscreen airbag again covers the relevant A-pillar areas almost completely. The highest head injury risk reduction for children and adults can be achieved by halving the collision speed.

SUV In case of the SUV the end of the Euro NCAP test zone (WAD 2100 mm) lies in the lower windscreen area. Thus, the structural properties of large parts of the adult head impact area are quite critical, particularly as the area beyond the wrap around distance of 2100 mm is hardly relevant for the head impact of cyclists. Furthermore, the average head impact velocities in the cowl and lower windscreen area lie above 45 km/h, so that the resulting adult index value is very high (Figure 15). A significant reduction is possible through the implementation of an active bonnet, which reduces both the head impact velocities and the relevance of the cowl and lower windscreen area.

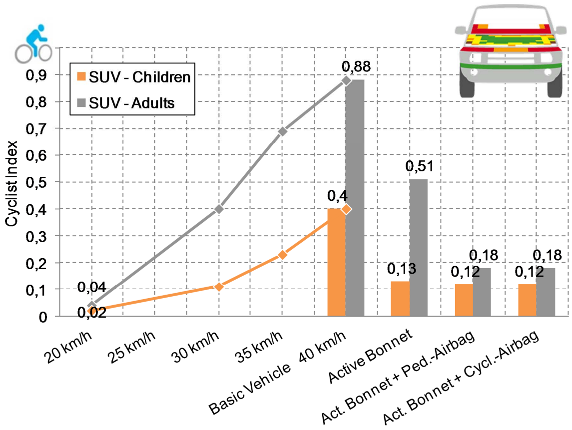


Figure 15. Cyclist index results for vehicle class SUV.

Conspicuous is the relatively low index value for children, who benefit from low head impact velocities as well as good structural properties in the bonnet area. Due to the high and long front geometry of the SUV, the cowl area is hardly relevant for children. Consequently, the safety potential of a windscreen airbag is low with regard to children. This does not apply to adults, where the pedestrian windscreen airbag addresses all relevant head impact areas beyond the bonnet rear edge, which leads to a considerable reduction of the index value achieved by the active bonnet. Due to the geometrical boundary conditions there is no additional benefit arising from a cyclist airbag.

In the course of a vehicle speed reduction the index values of children as well as adults can be lowered significantly. Especially for adults the reduction is noticeable. Halving the vehicle speed reduces the risk for a severe head injury from 88% to 4%. Here, the forward displacement of the head impact locations supports the injury risk reduction resulting from the lower head impact velocities since the relevance of the stiff cowl and lower windscreen area decreases from 66% to only 0.2%. This means that at a vehicle speed of 20 km/h the head impact of almost all adults occurs on the bonnet.

OneBox The example vehicle of the OneBox class shows the worst Euro NCAP test results of all vehicles regarded so far, which is reflected accordingly by the calculated cyclist index values in Figure 16.

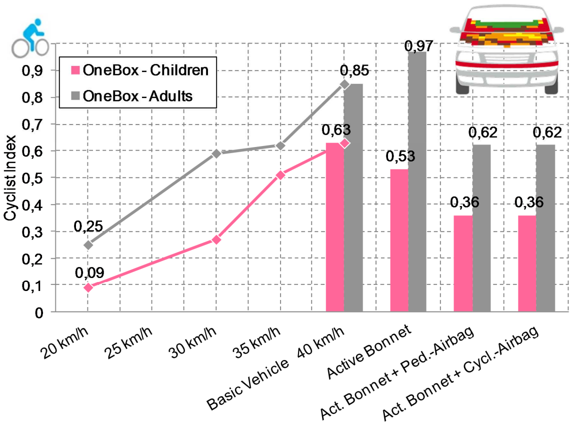


Figure 16. Cyclist index results for vehicle class OneBox.

The very high index value for adults results from a high relevance of the in large parts red rated cowl and lower windscreen area as well as high average head impact velocities above 45 km/h in the middle windscreen area. Even for a halved vehicle speed a severe head injury risk of 25% remains. With regard to children the inadequate structural properties in the bonnet area have a negative effect on the index value. Furthermore, one third of the head impact locations of children lie in the cowl and lower windscreen area.

The implementation of an active bonnet results in higher head impact velocities for both children and adults, which reduces the benefit due to the improved structural properties in the bonnet area and in case of the adults even increases the injury risk. As a consequence of the high head impact velocities caused by the active bonnet, the safety potential of an additional windscreen airbag is reduced as well. The achieved index values are significantly higher than the airbag results of the other vehicles.

Sports Car A vehicle fulfilling the geometrical boundary conditions of the class Sports Car has not been tested by Euro NCAP so far. Thus, there are no concrete test results available for the vehicle class Sports Car. Therefore, again a generic Euro NCAP test result has been defined for the index calculation, which is illustrated in Figure 17.

The assessment of the basic vehicle reveals a high index value for children, which even lies above the adult value. Due to the low front geometry of the sports car, the cyclist head impact locations are so far rearwards located that the cowl and lower windscreen area is hardly relevant for adults (1.6%) but comprises almost 50% of the children head impact locations. Nearly all adults impact in the middle and upper windscreen area, which offers, except for the A-pillars, adequate structural properties. Furthermore, the head impact velocities achieved within the windscreen area are lower compared to those in the bonnet area. This turns into the opposite in case of an active bonnet, i.e. the head impact velocities in the bonnet area decrease while the average head impact velocities in the cowl and windscreen area increase, which causes a corresponding higher adult index value. Children do not benefit from an active bonnet as well. The positive effects in the bonnet area are compensated by a further increased relevance of the cowl and lower windscreen area.

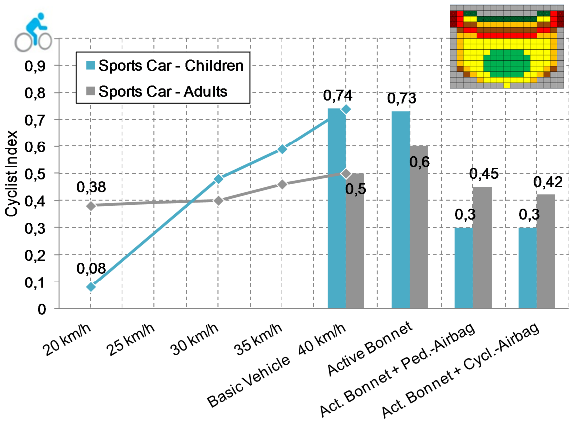


Figure 17. Cyclist index results for vehicle class Sports Car.

An additional windscreen airbag covers a large part of the head impact locations of children, while most of the adults are only addressed in the area of the A-pillars. The additional safety potential due to an extended cyclist airbag is rather small. The children index value can be significantly reduced by halving the vehicle speed, resulting in a risk for a severe head injury of only 8%. For adults the forward displacement of the head impact locations, which is very pronounced for vehicle speed reductions of more than 10 km/h, counteracts the decrease of the injury risk due to the lower head impact velocities. This results in almost identical index values for a vehicle speed of 30 and 20 km/h.

CONCLUSIONS

Overall, the cyclist index values and the related AIS3+ head injury risks respectively are relatively high. When comparing the presented cyclist index values with the corresponding pedestrian index values, it becomes apparent that for all vehicle classes the cyclist values are considerably higher than the values calculated for pedestrians. In this regard, the high average head impact velocities achieved by the cyclists are crucial, which often, especially in the relevant impact areas of the adults, lie above the vehicle speed. This is not the case for pedestrians and reduces the safety potential and effectiveness respectively of merely passive safety measures with respect to cyclists. Moreover, characteristically for cyclist-passenger car frontal collisions are the oftentimes further rearwards located head impact locations compared to pedestrian frontal collisions. As a consequence, the relevance of the stiff cowl and lower windscreen area is usually increased for children. At the same time, especially the head impact locations of tall adults often exceed the test area defined for the Euro NCAP pedestrian tests.

The results obtained from the assessment procedure reveal that cyclists are often not addressed by an active bonnet, even negative effects can be determined, whereas an additional windscreen airbag is able to reduce the head injury risk significantly. For shorter vehicle front geometries it has to cover the whole A-pillar in order to be really effective.

The VRU friendlier the structural properties of a vehicle front, the more pronounced is the positive effect of a vehicle speed reduction (as long as the accident is not completely avoided). Compared to the safety potential of passive measures at a vehicle speed of 40 km/h, a halving of the impact speed is more beneficial - this is equally valid for all vehicle front categories, both for cyclists and for pedestrians as well as for adults and children. Additionally, a reduction of vehicle speed is the only measure that also has a positive effect on the secondary impact, which turned out to be highly relevant in the full scale tests conducted.

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