INTEGRATED BICYCLIST PROTECTION SYSTEMS - POTENTIAL OF HEAD INJURY REDUCTION COMBINING PASSIVE AND ACTIVE PROTECTION SYSTEMS

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ABSTRACT

In recent years both pedestrian passive and active safety systems, such as pedestrian bonnets/airbags and autonomous braking, have emerged on the market and are estimated to be effective to reduce injury of vulnerable road users in car crashes. A natural next step is to develop similar protection systems for bicyclists. The aim of this study was to investigate the potential bicyclist head injury reduction from passive and active protection systems compared to an integrated system.

The German In-Depth Accident Study (GIDAS) database was queried from 1999 to 2014 for severely (AIS3+) head injured bicyclists when struck by passenger car fronts. This resulted in 34 cases where information was sufficient for both the pre-crash and the in-crash part of the event. The default passive protection system was designed to mitigate head injuries caused by the bonnet area, A-pillars, and the lower windscreen (instrument panel) area (deployable hood and windshield airbag). To estimate the hood and airbag performance risk reduction functions were used based on experimental tests with and without the systems. The active protection system was an autonomous braking system, which was activated one second prior to impact if the bicyclist was visible to a forward-looking sensor. Maximum speed reduction was estimated using road condition information in each case. The integrated system was a direct combination of the passive and active protection systems. Case by case the effect from each of the active, passive and integrated systems was estimated. For the integrated system, the influence of the active system on the passive system performance was explicitly modelled in each case. A sensitivity analysis was performed varying the coverage area of the passive protection system and the activation criteria of the active system.

The integrated system resulted in 29%-62% higher effectiveness than the best single system of active respectively passive protection system in reducing the number of bicyclists sustaining severe (AIS3+) head injuries. These values were statistically tested and found to be significant. The study is based on representative data from Germany, but may not be representative to countries with a different car fleet or infrastructure. This study indicates that integrated systems of passive and active vulnerable road user countermeasures offer a significantly increased potential for head injury reduction compared to either of the two systems alone.

INTRODUCTION

World-wide it is estimated that over 500 000 pedestrians and bicyclists are killed annually in road traffic (Naci, Chisholm et al. 2009). Virtually all road pedestrian fatalities and a majority of the cyclist road fatalities are caused by crashes with vehicles (SIKA 2009). In larger European cities, bicycle transportation is increasing (Thiemann-Linden 2010), likely due to congestion, fuel prices and an increasing awareness of its health benefits. Pedestrians and bicyclists already make up roughly half the traffic fatalities in urban areas in the EU (ERSO 2012), risking fatalities to increase with increased bicycle use.

In research studies pedestrians have been the dominant subject group. Legal regulations as well as consumer rating tests for pedestrians have influenced car design during the last decade in Europe and Japan. Cars on these markets are now often equipped with energy absorbing bumpers and hoods, as well as deployable hoods. Furthermore,

airbags for the windshield area, attempting to mitigate head injury have been introduced (Volvo 2012; Jaguar-LandRover 2014). Pedestrian passive countermeasures have proven effective in reducing pedestrian injury. Strandroth et al. (2014) showed, in a study on Swedish accidents, that cars with higher pedestrian ratings in EuroNCAP consumer tests resulted in less severe injuries. A natural next step is to design the airbag to protect also for bicyclists. The major difference between pedestrians and bicyclists is the higher head impact point of bicyclists on the car (Fredriksson, Bylund et al. 2012; Fredriksson and Rosén 2012). Fredriksson et al (2014) showed a potential protection system with a higher protection area designed to protect both pedestrians and bicyclists. Another way to reduce injury is to reduce impact speed, where even moderate speed reductions can significantly decrease risk for the vulnerable road user in an impact. For example, Rosén and Sander showed that reducing the impact speed from 50 km/h to 40 km/h reduced the pedestrian fatality risk by 50% while a reduction (from 50 km/h) to 30 km/h reduced the risk by as much as 80% (2009). Currently, active systems such as autonomous braking are being rapidly introduced on the market. These systems consist of a pre-crash sensor that detects a dangerous situation where a pedestrian is about to be hit. If unnoticed by the driver the system will automatically brake the car and prevent impact at low speeds and mitigate pedestrian injury at higher speeds by decreasing the impact speed. These systems are potentially very effective in reducing impact severity of pedestrian and bicyclist crashes (Rosén, Källhammer et al. 2010; Rosén 2013). In 2016 EuroNCAP begins assessing autonomous emergency braking (AEB) or warning for pedestrians (EuroNCAP 2014), and in 2018 it is planned to begin testing active systems also for bicyclists.

It has been argued by some that autonomous braking systems could even replace passive protection systems. It is then interesting to estimate how effective these systems are, and in particular, answer the question: if one of these systems, such as an active system, is implemented, would there be any additional benefit in adding a passive system, or vice versa? In an earlier study it was shown beneficial for pedestrians to combine active and passive systems regarding injury reduction potential.

The aim of this study was, therefore, to investigate the potential reduction of bicyclists sustaining severe head injury from either a passive (in-crash) or active (pre-crash) countermeasure compared to an integrated system that is a combination of both. Since these countermeasures do not yet exist in cars, or have just been introduced, no accident data, with these systems involved, is available to aid in estimating effectiveness. The alternative solution would then be to use crash tests and head injury criteria with accompanying risk curves along with incidence data to estimate effectiveness. Although legal and NCAP tests may be effective in leading the development towards safer car fronts for pedestrians, they have limitations in estimating real-life benefits, and the connection between selected injury criteria and pedestrian head injury risk has not been thoroughly investigated. Therefore, ideal passive and active countermeasures were considered in this study. The focus was not on estimating and comparing the exact effectiveness of the individual systems, but rather on the improved benefit of combining the two.

METHOD

In this study three systems to reduce head injury of bicyclists in car crashes were considered, i.e. a passive deployable system, an active auto-brake system and finally a combined system of the active and passive system. The passive protection system consisted of a deployable hood and a windshield airbag and was designed to mitigate head injuries caused by the bonnet area, windshield frame and the lower windshield area where the instrument panel was in close proximity to the windshield glass. The active system was a so-called autonomous emergency braking (AEB) system that, if a bicyclist can be detected and is estimated to be impacted by the car, applies full braking to avoid or mitigate the crash. The combined system was a direct combination of the two systems with autonomous braking of the car first, followed by an activation of the passive system, in case the accident was not avoided and the remaining impact speed was sufficient to be estimated to cause severe head injury. This method was developed in an earlier study estimating effectiveness of pedestrian protection systems (Fredriksson and Rosén 2014).

We estimated the potential of these systems to reduce severe (AIS3+) head injury. Note that a bicyclist may sustain multiple severe head injuries from different impacts to the car, ground and other external objects in the same crash. In this study, bicyclists that sustained at least one of the severe head injuries from an impact to the ground, external objects or unprotected areas of the car were not considered helped by the passive

countermeasure. Only bicyclists that sustained all severe head injuries from impacts to the protected areas of the car were considered protected by the passive countermeasure.

To estimate the injury saving potential of the different systems we searched the GIDAS database for all cases where a bicyclist was severely (AIS3+) head injured when impacted by the car front. The database consisted of 4789 cases with bicyclists injured when struck by passenger cars between 1999-2014. When excluding the non-relevant cases (lower injury level, side/rear impacts to the car and cases when no severe head injury was sustained) it resulted in 34 cases where information was sufficient to estimate both passive and active protection potential. We then estimated the potential of the passive, active and the integrated system in reducing the risk of severe head injury case by case for the 34 cases.

Passive protection system

Head impact speed The head impact speed was, just like in the previous pedestrian study, assumed to be equal to the car impact speed. For pedestrians studies have shown head impact speeds both higher and lower than the car impact speed, ranging from 68%-146% in car-to-pedestrian post mortem human subject (PMHS) 40 km/h tests (Masson, Serre et al. 2007; Kerrigan, Crandall et al. 2008; Kerrigan, Arregui et al. 2009). For bicyclists no PMHS tests have been performed. Limited full-scale crash tests with the Polar II dummy showed head/car impact speed ratios of 87%-147% (van Schijndel, de Hair et al. 2012). Therefore the assumption that head impact speed was equal to car impact speed was made also in this study.

Deployable hood system The deployable hood performance was estimated in a previous study (Fredriksson and Rosén 2014) based on a study with headform tests at 40 km/h (Fredriksson, Håland et al. 2001) using a method by Searson et al (2012) to estimate performance at other impact speeds. Five different impact points were chosen distributed on the hood surface. The estimated HIC values for the reference hood and version 1 deployable hood was based on these tests. Since the active hood tested was designed to meet earlier Euro NCAP requirements on HIC1000 for full score with a 20% margin, it is likely that a system designed today would aim at keeping 20% below the current target of HIC650. Version 2 of the active hood was therefore estimated as a deployable hood designed to keep HIC 20% below the Euro NCAP level for full score in the hood area (HIC=0.8x650=520). The HIC values were used to calculate risk of AIS3+ head injury for the reference configuration and the active hood systems (Fredriksson and Rosén 2014).

Windshield airbag The airbag performance was also estimated in the previous study using the headform test method of Euro NCAP but varying the headform impact speed from 20-60 km/h for two different impact points (Fredriksson and Rosén 2014). One impact was chosen as the most severe, i.e. an impact directly to the A-pillar. The other impact was considered less severe, but still a frequent cause of severe head injuries, i.e. impact to the lower windshield glass with, in this case, 25 mm distance to the instrument panel. The tests were performed on a small family car in the standard condition as well as equipped with the windshield airbags as in Figure 1. Version 1 is a standard airbag design with a thickness of approximately 200 mm. Version 2 is a new design that increases the energy-absorbing distance achievable without increasing the airbag volume (Fredriksson and Rosén 2014).

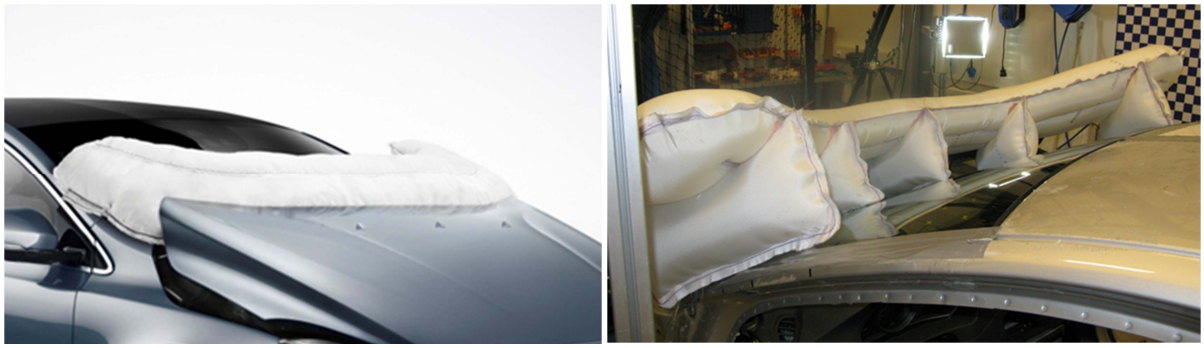

Figure 1. Pedestrian airbags used in the headform tests in the previous study to estimate airbag performance, left: version 1 airbag, right: version 2 airbag (Fredriksson and Rosén 2014)

For the effectiveness estimation it was assumed that the airbag was designed to cover the lower windshield, where the instrument panel is within the head line of motion, and the complete A-pillars for System 1 and 2. In System 3, version 2 airbag was extended to protect also in the area of the roof front edge. See Table 1. If the head injury or injuries resulted from what was judged as an A-pillar impact, fully or partially, or a direct hit to the lower windshield frame, we used the data from the A-pillar tests for estimation of the risk. If the impact was to lower windshield glass and instrument panel, we used the data from the lower windshield tests to estimate the risk.

Table 1. Deployable system parameters for the three versions used in the study

Deployable system parameters	***System 1***	***System 2***	***System 3***
Hood lifter	Version 1	**Version 2**	Version 2
Airbag design	Version 1	**Version 2**	Version 2
Coverage area	Hood	Hood	Hood
	Low WS	Low WS	Low WS
	A-pillars	A-pillars	A-pillars
			Roof front edge

When these data were collected, the severe head injury risk, for each impact speed and protection system, could be estimated for each case (i) using the risk function from NHTSA (1995). The risk reduction was then calculated (Fredriksson and Rosén 2014).

Note that if the impact location of any of the AIS3+ head injuries in a case is other than that protected by the protection system, i.e. other areas of the car or the surrounding/ground, then risk reduction potential in that case was set to 0. Also, for both systems, activation was limited to a minimum speed of 20 km/h.

Risk reduction functions In the earlier study (Fredriksson and Rosén 2014) risk reduction functions were developed for the two protection systems, deployable hood and windshield airbag (Figure 2). Linear interpolation between the data points was used for the airbag risk reduction functions. The risk reduction was 0 above 70 km/h for the active hood and above 60 km/h for the airbag in the A-pillar impact location. For the airbag lower windshield impact location the risk reduction was still 31% at 60 km/h. Since we did not have any test data above 60 km/h, we estimated the risk reduction function to continue linearly down to 0 at 70 km/h. Also the lower windshield reference test at 20 km/h was unsuccessful so the risk reductions from 20-29 km/h for lower windshield were estimated to be horizontal from the values at 29 km/h.

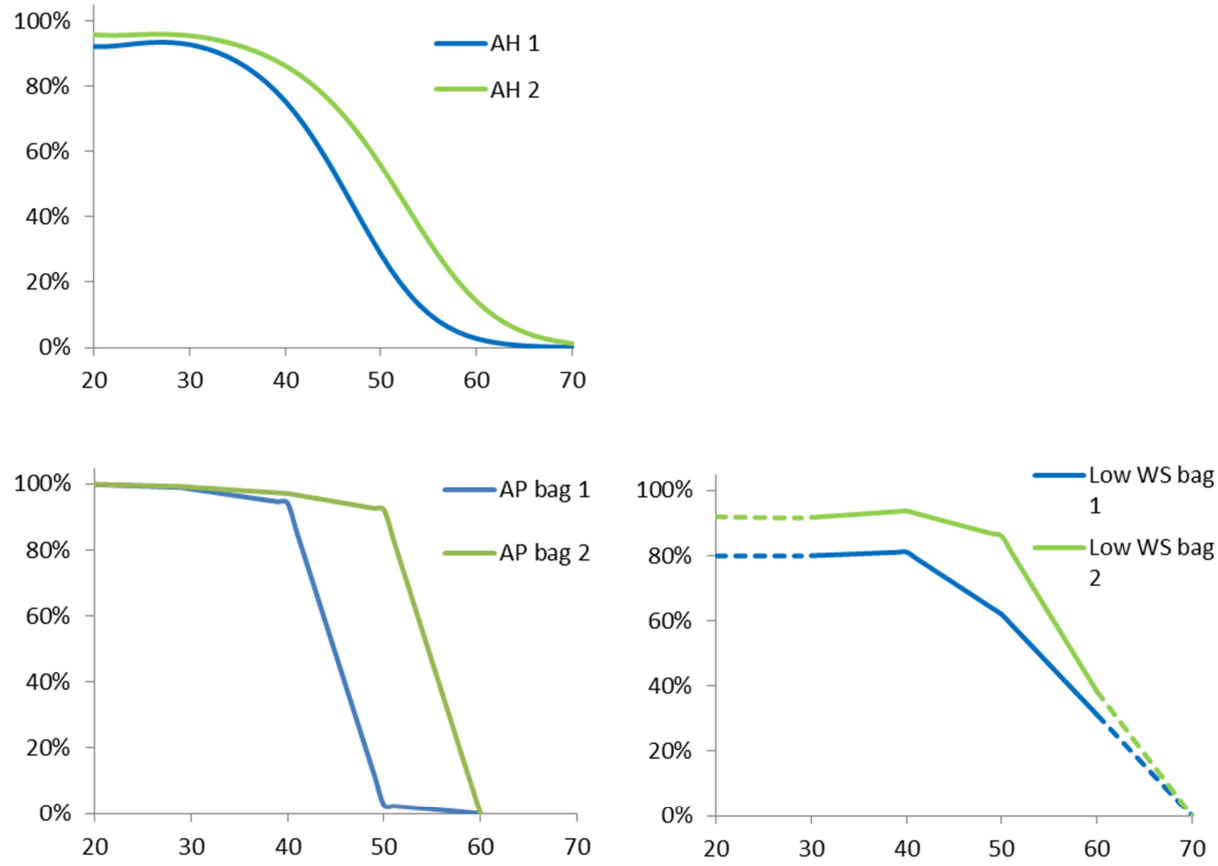

Figure 2. Head AIS3+ injury risk reduction for active hood average (top) and windshield airbag (below) for two impact locations; A-pillar (left) and lower windshield (right)

Using the risk reduction functions the possible effectiveness of the protection system could be estimated for each case. Note that if any of the AIS3+ head injuries was caused by a source outside the protected area, on the car or in the surrounding, the effectiveness of the protection system in that case was set to 0.

Finally, the total effectiveness of the passive protection system could be calculated as:

$$E_{passive}^{total} = \frac{1}{N}\sum_{i=1}^{N} \mathrm{e}_{passive}(v_i) \tag{1}$$

The rationale behind this effectiveness calculation method is described in more detail in a previous study (Fredriksson and Rosén 2012).

Active protection system

The active (AEB) system was estimated to detect all visible bicyclists within the field of view independent of weather and light conditions, and activate automatically the brakes up to 1.0 s before predicted impact. The braking system was estimated to have a ramp-up time of 300 ms and maximum braking level was set to 0.7 g, but reduced if road friction conditions were limited. Finally, three system parameters were varied: sensor field of view, trig width and cut-off speed for activation; the system was activated for bicyclists within the vehicle path or up to 1.0 or 3.0 m beside it (trig width), either up to 60 km/h or at all impact speeds, and during all light conditions (see Table 2). For further details on the AEB system, see earlier study by Rosén (2013).

Table 2. AEB parameters for the three versions used in the study (in bold parameters that are varied)

AEB parameters	*System 1*	*System 2*	*System 3*
Field of view	40°	40°	**60°**
TTC max	1.0 s	1.0 s	1.0 s
Trig width	1 m	1 m	**3 m**
Braking level max	0.7 g	0.7 g	0.7 g
Ramp-up time	300 ms	300 ms	300 ms
Cut-off speed	60 km/h	**No limitation**	No limitation
Light conditions	All	All	All

In order to derive injury risk functions for AIS3+ head injury, logistic regression analysis was conducted following Rosén and Sander (2009). The risk as a function of impact speed, p(v), was assumed to have the following form (logistic regression) $p(v) = 1/(1 + \exp(-a - bv))$, where v is the impact speed and a, b two parameters to be estimated by the method of maximum likelihood.

A bicyclist detected by the active system, so that autonomous braking could be activated, would be struck at an impact speed $v' \leq v$ (where v is the impact speed without activation). Hence, the relative risk becomes $p(v')/p(v)$ and so

$$E_{active}^{total} = \frac{1}{N}\sum_{i=1}^{N} 1 - \frac{1 + \exp(-a - bv_i)}{1 + \exp(-a - bv'_i)} \quad (2)$$

Integrated protection system

The integrated countermeasure combined both the passive and active countermeasures. To derive its effect, we first estimated new impact speeds from the active system and then estimated the risk reduction from the passive system with the same method previously used but using the new impact speeds.

Furthermore, the head WAD could change due to the autonomous braking. We know that the sliding effect of the bicyclist on the hood is speed dependent, leading to higher wrap around distance for higher impact speeds. On the other hand, pre-impact braking leads to pitching (lowering) of the car front which results in increased sliding. This was considered in a previous study for pedestrians and these two effects more or less cancelled

each other out and resulted in no total effect for pedestrians. We do not have this information for bicyclists so for simplicity we decided not to adjust the impact point for braking in this study.

A bicyclist that would have been helped only by the passive countermeasure has a relative risk of $1 - e(v)$. A bicyclist that would have been helped only by the active countermeasure has a relative risk of $(1 + \exp(-a - bv))/(1 + \exp(-a - bv'))$. Finally, a bicyclist that would have been helped by both countermeasures has a relative risk of $(1 - e(v'))(1 + \exp(-a - bv))/(1 + \exp(-a - bv'))$. Putting the pieces together, we get

$$E_{integrated}^{total} = \frac{1}{N}\sum_{i=1}^{N}(1 - (1 - e(v_i'))\frac{1+\exp(-a-bv_i)}{1+\exp(-a-bv'_i)}) \quad (3)$$

where $v_i' = v_i$ if the active countermeasure is not used and $e(v_i') = 0$ if the passive countermeasure is not helping. See also earlier study by Fredriksson & Rosén (2012) for more details and derivation of the effectiveness functions.

Statistical methods

To derive confidence intervals for the estimated effectiveness, we applied the bootstrap method (Efron and Tibshirani 1993). In this procedure, the original sample of 34 cases was used to generate another 1000 samples, each containing 34 cases, by random re-sampling with replacement from the 34 original cases. The effectiveness was then re-derived for each of the 1000 samples. Finally, the lower and upper 95% confidence bounds were chosen as the 2.5th percentile and 97.5th percentile of the 1000 estimates of effectiveness respectively (i.e. the value of the 975th largest and 25th largest estimates of effectiveness). The bootstrap samples were further used to compare the difference between the integrated system and the passive and active countermeasures respectively. For each bootstrap sample, the ratio of the integrated effectiveness and the passive and active effectiveness, respectively, were calculated. 95% confidence intervals for these ratios were formed as the 2.5th and 97.5th percentiles of the 1000 bootstrap estimates.

RESULTS

In total we had 34 cases with sufficient information to estimate both passive and active protection potential. The bicyclists, who had no limitation on age, were on average 48 years old with a body height of 169 cm, and the car mean model year was 1996. Note that information on stature and model year was not available for all cases. The impact speed for the 34 cases, which were all AIS3+ head injured when impacted by a passenger car front, ranged from 12-91 km/h, with a mean value of 43 km/h (Table 3). 8 of the 34 bicyclists were fatally injured. GIDAS does not conclude what injury was fatal.

Table 3. Descriptive statistics for the bicyclists in the sample (N = 34)

	mean	*median*	*min*	*max*	*n*
age (years)	48	55	13	81	34
stature (cm)	169	171	107	191	28
car model year	1996	1996	1986	2011	33
car impact speed (km/h)	43	38	12	91	34

In 1 of the 34 cases (3%) the bicyclist was severely head injured by the hood area alone, 6% from the lower windshield / I-panel area alone, 21% from the A-pillars alone, 24% from the roof edge alone, 9% from the remaining glass area alone, while 3% had at least one severe head injury from other parts of the car and 35% from the ground/surrounding. See Figure 3. This means that the passive system can potentially address all AIS3+ head injuries for 29% of the bicyclists for the system 1&2 protection systems and 53% for the more advanced system covering also the roof edge (system 3).

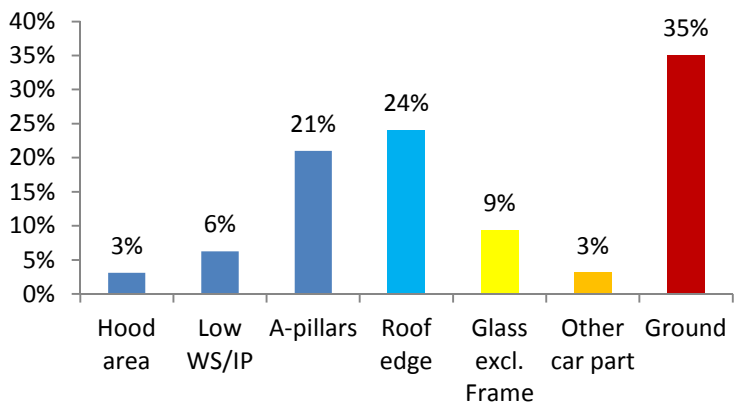

Figure 3. Distribution of injury sources (all AIS3+ head injuries for an injured bicyclist caused by the given area, except for "other" where only one injury from this area is sufficient to classify as "other")

The risk curve for AIS3+ bicyclist head injury was developed, see Figure 4. It shows the observed rates of AIS3+ head injured bicyclists at different intervals of impact speed and the best-fit logistic regression curves. The risk of severe (AIS3+) head injury is given in the function, $p(v) = 1/(1+\exp(6.1-0.080v))$.

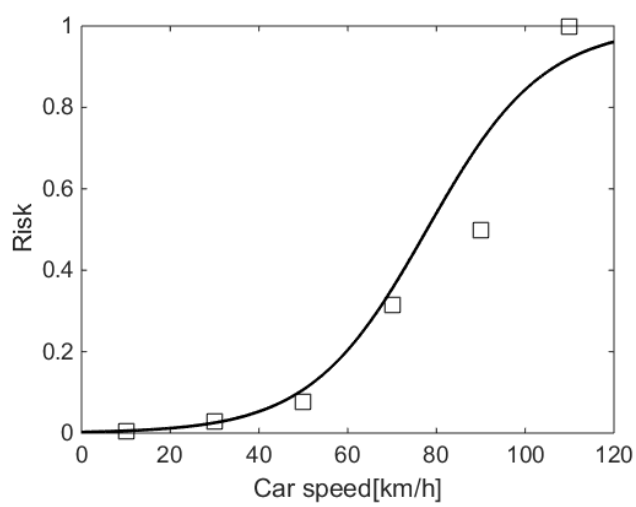

Figure 4. AIS3+ head injury risk for bicyclists impacted by passenger cars, and the corresponding empirical injury rates

Hence, the total effectiveness for active systems becomes:

$$E_{active}^{total} = \frac{1}{N}\sum_{i=1}^{N} 1 - \frac{1+\exp(6.1-0.080v_i)}{1+\exp(6.1-0.080v'_i)} \quad (4)$$

and for integrated systems:

$$E_{integrated}^{total} = \frac{1}{N}\sum_{i=1}^{N}(1-(1-e(v_i'))\frac{1+\exp(6.1-0.080v_i)}{1+\exp(6.1-0.080v'_i)}) \quad (5)$$

Estimated effectiveness

Using the risk reduction functions the possible effectiveness of the protection system could be estimated for each case. Note that if any of the AIS3+ head injuries was caused by a source outside the protected area, on the car or in the surrounding, the effectiveness of the protection system in that case was set to 0. Finally, the total effectiveness of the passive protection system for the 34 cases was summarized. The passive protection system, based on a deployable hood and a windshield airbag, was estimated in the baseline version to protect 21% of the severely head injured bicyclists from their AIS3+ head injury (system 1); that is, the AIS3+ head injury effectiveness was estimated to be 21% (CI: 10-34%). For system 2, with a different airbag design protecting better at higher speeds, but with the same coverage area, the effectiveness increased to 28% (CI: 14-45%). Finally if the passive system coverage area was increased to also protect the roof edge (system 3), the effectiveness increased to 38% (CI: 24-54%).

The effectiveness of the active AEB system was estimated in a similar manner, estimating in each case the reduction in risk achievable by applying the AEB system, by estimating the maximum time the brakes could be applied (depending on bicyclist visibility) and maximum braking level allowed depending on the road friction condition.

The AEB system was estimated to protect 26% (CI: 14-38%) with the baseline version (system 1), activated up to 60 km/h with the 40 degree field of view sensor and narrow trig width. When the active system was enhanced to activate for bicyclists in all impact speeds (system 2), the effectiveness increased to 30% (CI: 15-43%). Finally, if the system was enhanced further to activate also at a higher field of view and trig width (system 3), it could potentially save 48% (CI: 32-63%) of the bicyclists from their severe head injury.

By combining the passive and active protection systems a system is created that first brakes the car autonomously when a bicyclist is detected and if the impact cannot be avoided the passive system is activated to mitigate the head injury.

For the baseline system, with version 1 passive and active systems, the integrated system effectiveness was 38% (CI: 24-52%). The more advanced system, with version 2 passive and active systems, increased the effectiveness to 48% (CI: 32-64%), while the most advanced system, with version 3 passive and version systems, resulted in an integrated effectiveness of 62% (CI: 47-76%) (see Figure 5). The integrated systems had 29%-62% higher effectiveness than the best individual systems.

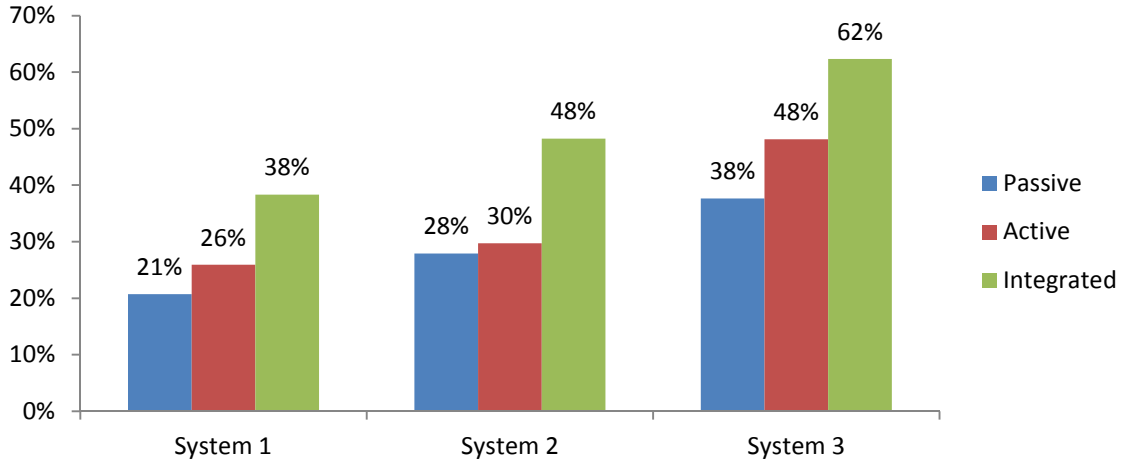

Figure 5. Estimated effectiveness of the active, passive and integrated systems for three different combinations

Significance estimation The ratios of the integrated and passive respectively active countermeasures were calculated, see Table 4. In all cases, the confidence intervals contained values constantly larger than 1. Thus, the effectiveness of the integrated countermeasures was significantly higher than either of the passive and active countermeasures alone.

Table 4. Significance calculations of integrated effectiveness relative to active and passive effectiveness

	$E_{integrated}/E_{passive}$ *(95% CI)*	$E_{integrated}/E_{active}$ *(95% CI)*
Version 1	1.9 (1.2-3.2)	1.6 (1.2-2.3)
Version 2	1.8 (1.2-2.9)	1.7 (1.2-2.7)
Version 3	1.7 (1.2-2.5)	1.3 (1.1-1.7)

DISCUSSION

Just like in the earlier study on pedestrians we made the assumption that head impact speed was equal to the car impact speed. Earlier studies on pedestrians and bicyclists have shown both higher and lower head impact speeds compared to the car impact speed. We also used the same passive risk curves for severe (AIS3+) head injury as in the previous study on pedestrians, since this is a risk curve based on HIC value, i.e. the loading that the head experiences, so it should not differ for different road users. However, the most important difference between pedestrians and bicyclists is the head impact point, the injury source on the car, and that was considered in this study.

For the active system we used a new risk curve since this is developed for the respective road user type and includes e.g. the difference in injury location. Here we assumed that the head impact point did not change however when an active protection system was introduced. This is a simplification, but as discussed in the method section, also this parameter could change in both directions. The decrease in impact speed by an auto-brake system is known to result in less sliding of the vulnerable road user on the car (less wrap around distance

to head impact) but in the same time the pitch of the car front leads to more sliding (larger wrap around distance). Therefore the assumption was made that the head impact point was unchanged. In a future study this could potentially be studied in full-body simulations with a human body model, but then very precise information about the accident, pedestrian direction, exact gait position, arm position, body angle etc is necessary which is often not known.

This study was performed using the same analysis method and data source as a previous study for pedestrians (Fredriksson and Rosén 2014). Bicyclist accidents are in one sense more challenging to the active sensor since bicyclists have a higher speed than pedestrians, but also to the passive system to some extent since bicyclists impact higher on the car. The current study on bicyclists accounted for this by increasing the field of view of the active sensor, and the coverage area of the passive systems for the most advanced system. But in the same time bicyclist accidents occur more frequently in day-light and dry conditions (Fredriksson, Bylund et al. 2012; Fredriksson and Rosén 2012) which increases the ability of especially the active sensor. These studies show that there is a benefit to combine active and passive protection for bicyclists as well as for pedestrians, which shows that that active and passive systems if designed right have the potential to protect both pedestrians and bicyclists in car crashes.

We performed this study using the probably most representative and extensive traffic injury database available. By doing so, and selecting the severely head injured bicyclists, we can estimate the effectiveness of reducing severe head injury of bicyclists with different countermeasures. (Note, that we make the assumption then that we do not raise the injury level for any person.) Although our estimations of the individual systems' effectiveness could be argued to be somewhat ideal (we estimate that the passive sensor activates for all crashes and that the active sensor has no other limitations than the parameters we chose), we made the same assumptions/simplifications for the integrated as for the individual systems so the conclusions of the benefit of the integrated system compared to the individual systems should therefore be sound.

Limitations

The data which this study is based on is from Germany, and the conclusions are therefore not valid for countries where the car fleet or infrastructure is different.

CONCLUSIONS

This study analyzed the benefit of combining car-mounted passive and active protection systems for bicyclists. If more and more cars in Europe are equipped with auto-brake functions is there still a need for passive protection, or can the active systems replace the passive systems?
The analysis was performed using the most representative and extensive traffic injury database in Europe, GIDAS, where all severely head injured bicyclists in car crashes were selected to study how many of those could be protected with the different protection systems. The passive system consisted of deployable hood lifters and windshield airbag, while the active system used autonomous braking. To analyze the sensitivity of the analysis three different, but according to the authors reasonable, versions of passive respectively active protection systems were included in the study. The performance of the systems was estimated based on experimental tests at different impact speeds for the passive system, and by using computer reconstructions where the sensor system was modeled for the active system.
The study shows that there is a significant benefit in combining car-mounted active and passive protection systems for bicyclists. For the different versions of the systems, the integrated system was 29%-62% more effective in protecting from injury than the best individual system.

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A NEW STRATEGY to ENHANCE TRAFFIC SAFETY in DEVELOPING COUNTRIES

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ABSTRACT

The rapid expansion of motor vehicle use in developing countries resulted in a sharp rise in road traffic–related deaths and injuries. The UN General Assembly recognized road deaths and injuries as a global epidemic since 2003. More than 90% of the 1.2 million people who die each year in traffic related crashes are from the developing countries in which more than 51% are vulnerable road users.

The Kurdistan region in Iraq has been chosen for this study where the number of registered vehicles has increased exponentially in the last decade, and the official number of fatalities in 2013 was 1,114. This number, however, is highly underreported; the actual figure of fatalities is estimated to be 100% more than the reported number according to World Health Organization. Pedestrians in the region are not separated from vehicles even on high speed roads, in front of schools, bus stops, parks and commercial areas. In addition, driving education and risk assessment is poor among drivers. A pre-study showed that only 5% of the current drivers in the largest city in Kurdistan, Erbil, know how to use a roundabout. Moreover, 0%, 1% and 12% could read and were knowledgeable about the signs of "One-way", "Give-Away" and" No-Entrance" respectively. The driving test and training systems are inadequate and inconsistent in the cities of Kurdistan. The test are performed in an isolated and controlled environment separate and far away from the everyday traffic. Moreover, the road network is non-standard and is lacking alignment and signs.

This study evaluates current traffic safety conditions in Kurdistan, and then proposes a new strategy to change the current driving license test system to a more realistic and educational test that is fair and promotes safe traffic flow. The new approach, in this study, is based on a new standard driving test and training system based on the 4 E's model which stands for: Engineering, Education, Enforcement, and Encouragement. The new proposed tests will be conducted on a limited, predefined, standardized and heavily monitored route within existing traffic environment.

This new testing system will focus on educating large groups of university students how to operate their vehicles more efficiently and safely. Moreover, the route within the existing road infrastructure that will be upgraded to standard and heavily monitored also allows licensed drivers, optionally or through an enforcement program, to retrain and experience driving on standard routes gradually leading to an improvement in drivers' awareness. The standard route can also be used as a model and starting point to successively standardize the current road network and when constructing new roads.

Keyword: Traffic Safety, Driving License, Developing Countries, Traffic System

INTRODUCTION

The rapid expansion of motor vehicle use in developing countries resulted in a sharp rise in road traffic–related deaths and injuries [1]. The UN General Assembly recognized road deaths and injuries as a global epidemic since 2003 [2]. Nevertheless, resources devoted to assist effected countries to address the problem is still inadequate. Although more than 90% of the 1.2 million people who die each year in traffic related crashes are from the developing countries in which more than 51% are vulnerable road users [2]. Even efforts by the developing countries in the high income group, with a fully funded national road safety strategy, were unsuccessful at improving traffic safety and to implement advanced workable safety programs. In Saud Arabia, for instance, despite a fully funded program, traffic death almost doubled from 3500 in 2000 to 6500 fatalities in 2009, while the target was an annual reduction by 3%. Meanwhile, a similar national road safety strategy in France halved fatalities on the roads from 2001 to 2010 [3]. This attests that providing resources and replicating interventions of good practices that are implemented in countries with effective safety programs, will fail to yield sustainable results. Apart from political will to commit resources, a sustainable solution must consider institutional capacity weaknesses, social obstacles and best intervention practices based on scientific evidences [1]. Moreover, research is required to determine optimum standards before adopting elements of good practice observed in the developed countries.

In the Kurdistan region of Iraq, which is the scope of this study, registered vehicles increased exponentially over the past decade. The increase is still going on and is leading to more fatalities on the roads annually; in 2014, the number of registered vehicles was 1 250 000, an increase by 10%, compared to 2013. The official number of fatalities in 2013 were 1,114 [4]. This number, however, is highly underreported, the actual figure is estimated to be 100% more than the reported [3], especially when the country has no eligible death registration data.

An institutional framework together with a strong political will are the main factors that affect traffic safety conditions on the national level [5]. The framework is to, among others, organize national policy, set manageable goals and sub-goals, coordinate activities, and cooperation with international organizations.

The mechanism of road accidents is related to a number of explanatory factors which are deeply rooted and interrelated [6]. The most common being human errors, where deficient road design and planning will often have contributed to or compounded these errors [7]. Inadequate training and testing programs together with insufficient enforcement of traffic and transport regulations greatly affect road users' attitude and behavior [8]. In Kurdistan, the driving tests and trainings, which have direct influence on human errors, are applied differently in the cities of the region. The inconsistent driving tests are partially based on different modules used in developed countries. In addition, the tests, in practice, are not performed in the existing traffic environment, but rather in an isolated and controlled environment separate from other drivers. This limitation is due to several obstacles such as inadequate driving test systems, a nonstandard road network and the great danger of operating by the driving regulations on an uncontrolled road where the other drivers ignore many of the regulations. Thus, to improve traffic safety in Kurdistan, a comprehensive traffic safety system is essential. In particular, a new driving test model to gradually improve road users' behavior is required. Moreover, exploiting the model to successively upgrade the safety aspects of the road networks' standards in the region.

AIM OF THE STUDY

The aim of this study is to evaluate current traffic safety conditions in the Kurdistan Region of Iraq, and then propose action plans to change the current system to a more fair and safe traffic flow. The action plan includes causal explanations of the persistence of poor traffic safety conditions in Kurdistan as well as long and short term strategies and approaches of improvement.

CURRENT TRAFFIC SAFETY SITUATION

A comprehensive evaluation of the current traffic safety situations in Kurdistan is based on main factors that influence the safety level including data collection, political will, institutional framework and development goal, driving test system, human behavior, infrastructure, and vehicle factors.

Data Collection: Providing reliable data is important to review the mobility and traffic safety status which is to be used in development of any strategic plan. Kurdistan does not have an adequate system for data collection. The lack of reliable data is one of the most serious obstacles to conducting proper analysis. The limited available data is either incomplete or skewed, which creates great problems in the analyses. Hence, analyses of the factors, mentioned above, that affect traffic safety will be based on available data, visual evaluation and/or experiences. The available limited data will be used as a rough approximation of the real figures. Accident data as the most important indicator of traffic safety is unreliable, and only absolute numbers of fatalities exist. The official number of fatalities in 2013 was 1,114[4]. This number, however, is highly underreported, the actual figure is estimated to be 100% more than the reported [3], especially when the country has no eligible death registration data. An important measure to improve analyses is to adopt accident and/or fatality rate, instead of an absolute number independent of rate of change, which is the number of fatalities/ accidents per vehicle or person per kilometer. However, the data for distance travelled by people is unavailable. Hence, only absolute number of fatalities in relation to population and vehicles can be used. Thus, considering only registered deaths, Kurdistan has more than 22 fatalities per 100 000 population, while this figure is less than 3 fatalities in the safest countries. Fatality rate per 10 000 vehicles is 20 times more than in the safest developed countries, that's despite longer travelled distance and more vehicle trips in the developed countries.

Political Will: Decision makers in all countries agree and there seems to be a political will to decrease traffic road deaths [2]. Kurdistan is no exception as the highest authorities in Kurdistan, including the Regional President and the Prime Minster, announced and decided implementation of the necessary measures to reduce traffic accidents. However, no further nor concrete steps have been taken on the ground as a matter of fact. That is because accidents have not been considered by the society as public health problems similar to contemporary illnesses such as mad cow disease and bird flu. Hence, the society does not require special attention from the state to solve the problem.
Additionally, public policy makers point towards shortcomings in electricity and housing as major problems that need to be acknowledged by the state. Thus the state took great and expensive actions to solve the electricity and housing problems. Therefore, improving traffic safety is not among the region's developmental priorities. The main focus of traffic policy is to optimize mobility and flow of vehicles without proper plans to include traffic safety.

Institutional Framework and Development Goal: Kurdistan has not any institutional framework for coordinating activities and setting a practical goal to reduce fatalities and injuries on the roads. There is no fund from the national budget to improve road safety. Moreover, the region lacks a national research center to improve traffic and road safety. The roads and traffic are responsibilities of several departments without any department for traffic safety as in many other developing countries. The Interior Ministry has the main responsibility for the traffic safety in Kurdistan. Hence, traffic police stands for the poor traffic safety performance and its legal consequences. However, several other ministries are directly involved in the traffic safety performance without being responsible legally for the safety outcomes on the national level. The involved ministries are: The Ministry of Municipality that is responsible for planning and organizing urban roads and streets; Housing and Reconstruction Ministry deals with constructing, operation and maintenance of the main roads between the cities; Ministry of Transport and Communications is responsible for the administration and management of all areas of communications, including public transportation; other concerned Ministries are Education, Health and Planning.

Driving Test System: The driving test and training systems are inadequate and non-consistent in the cities of Kurdistan. The test are performed in an isolated and controlled environment separate and far away from the everyday traffic. The obstacles to perform the tests in the existing environment consist of a lack of experience by the traffic police and a non-standard road network in terms of alignment and signs. Moreover, the difficulty to perform driving tests according to the standards of uncontrolled roads where many regulations are ignored by licensed drivers and where the traffic environment is chaotic. The drivers learn the practiced driving by their own, friends or parents before or after acquiring driving license. In addition, the driving license is used for formalities and legal issues only. The common question to find out whether somebody drives is: "Do you drive?" and not "Do you have a driving license?" Which indicates the big gap between the driving test and the actual driving environment.There is a large number of unauthorized drivers using the roads before having a driving license. In addition to that, it is possible to obtain a driving license

through private connections without doing the test. Another serious deficiency is that there is only a slight difference, in practice, between tests for private vehicles and trucks. Truck accidents are more serious and cause greater damage which means that operating trucks demands different knowledge and experience.

Human Behavior: Individuals, in their nature, do not expect that they will be involved in accidents. They overestimate their ability and consider accidents as human errors made by road users without direct effect on them [9]. Human performance in terms of traffic safety is very weak in many aspects and includes a high number of road users. Driving education and risk assessment is poor among drivers. A pre-study showed that only 5% of the current drivers in the largest city in Kurdistan, Erbil, know how to use a roundabout. Moreover, 0%, 1% and 12% could read and were knowledgeable about the signs of "One-way", "Give-Away" and" No-Entrance" respectively. This indicates a serious lack in the driving test system and current road design and signposting. Even the traffic police do not seem to have enough knowledge in regard to organizing the traffic and investigating accidents. A traffic police officer with the lowest rank only goes through 40 days of training while an officer has completed 6 months of training. This short education, however, is mostly about disciplines and the use of weapons. Serious human errors are noticed in many cases, but there is no research or data collection to figure out the size of the problem. The main human errors are mentioned below and include:

- One of the main human errors in traffic is the fact that pedestrians are not separated from vehicles even on high speed roads, in front of schools, bus stops, parks and commercial areas. Moreover, the pedestrians very often choose to walk on and along the high speed streets in the direction of driving. Furthermore, roadwork is carried out without signposting on high speed roads. Opposite to what is stated in the traffic law, drivers do not stop at stop signs to allow pedestrians to cross the streets. The drivers and pedestrians have developed informal ways to divide space between them. The drivers have the priority of spatial appropriation where pedestrians by many drivers are considered as second class citizens. The reason behind this attitude is that most pedestrians are perceived as poor, while people from the middle and upper class are believed to be able to travel by car.
- Speeding is another major problems which also occurs in residential areas. The speed cameras are often not placed on the accident-prone roads to make driving safer on these roads. They are usually placed where the layout of the roads encourage speeding. Dangerous overtaking is very frequent on two lane rural roads even in the presence of oncoming traffic.
- A third common human error concerns the use of seatbelts. A few years ago, drivers and passengers were asked to show their identification card at the security checkpoints if they had fastened their seatbelt. Wearing the seatbelt was a clear indication that the traveler was not from the region. Enforcement of seatbelt use has changed the picture now, and a great improvement has been noticed in this area. However, wearing a seatbelt is still not common among passengers and child restraints are equally quite uncommon. To avoid using a seatbelt, there is even a cheap separated seatbelt buckle device in the market to turn off the acoustic signal of the seat belt reminder in case the driver or passenger do not wear the seatbelt. Other dangerous practices, which do not lead to action taken by traffic police, are riding passengers in moving truck beds, hanging out of sunroofs and vehicle windows.
- Unfortunately, drinking and driving is common, and an uncountable number of drivers drink and picnic along the roads outside the large cities.
- Helmet wearing is rare for both motorcyclists, moped drivers as well as cyclists.
- Parking and stopping on the roadway and in other dangerous places are frequent.
- Wrong side driving to shorten trips occur frequently.
- Driving despite red lights is not uncommon.
- Chaotic driving in roundabouts is also a common human error.

Infrastructure: The way residential areas and the connecting roads are built have a direct effect on the nature of traffic conflicts and traffic accidents. The environment is dangerous for all road users, in particular vulnerable road users like pedestrians and cyclists. The roads are built to allow maximum mobility and traffic flow. The streets lack proper sidewalks for pedestrians or they are occupied by the neighboring residential or commercial buildings which compels pedestrians to share the roads with vehicles. Moreover, uncontrolled urban growth and irregular land use have promoted dangerous sidewalks, or absence of sidewalks at all, adjacent to main and high speed roads. This increases the number of conflicts between vulnerable road users and vehicles. Moreover, street

widening is often made at the expense of sidewalks. The vulnerable road users have to face heavy vehicle traffic due to urban social networks being disturbed. A biographic survey showed that in the1960s and 1970s non-motorized transport modes such as walking and bicycle usage were competitive to motorized vehicles in the largest city Erbil in Kurdistan. The rate of bicycle commuters in the city, however, diminished dramatically starting from the early 1980s along with the increasing motorized travel modes. Though, the number of private vehicles increased by more than 1000% in the 1980s compared to the 1970s. While the increase, the last two decades, was 40000% compared to 1970s, from approximately 1000 private vehicles to more than 400,000 in 2014 [10]. The results of the survey showed that the rate of bicycle use has declined to 0.05% although the city has an excellent flat topography for cycling and a generous climate most days of the year. More specific deficiencies in regard to infrastructure are:

- Pedestrian cross/walks on high speed roads with heavy traffic roads. Moreover, the drivers hardly ever stop for pedestrians who want to cross the street using the crosswalks. Moreover, using the pedestrian crosswalks are dangerous due to broad roads, heavy traffic on the roads and the high speed of the vehicles. There are pedestrian crosses on 10 lane roads where the speed limit is 80 km/h with even higher actual operation speeds, so the pedestrians face a hard task to wait for all 10 lanes to be safe to cross. 10 experiments were conducted where a pedestrian waited 15 minutes at 3 pedestrian crosswalks during the rush hour without any success to cross the street. The few walkers who take the risk, usually cross the streets by crossing one lane at a time while vehicles at high speed pass the pedestrians on both sides.

- Building U-turns on roads where the speed limit is 80 but where the actual speed is greater than 100 km/h. The U-turns lead to blocking overtaking lanes in both driving directions followed by frequent incidents and serious accidents. That is because U-turns lead to a mix of high and low speed vehicles on heavily trafficked roads. On smaller roads, with 4 or 6 lanes, vehicles block half of the lanes, or the whole street while they are waiting to make a U-turn.
- Road lighting and alignment is another problematic aspect. Newly built roads are usually opened and used without completing lightning and alignments. Moreover, most of the two-lane rural roads are without edge and midline alignments to limit and separate opposite driving direction lanes. The roads lack roadside reflector posts which is very important when driving at night. Operation and maintenance of the existing lighting and alignments are additionally inadequate.
- Speed bumps, as a cost effective injury prevention measure, have widely been installed on the roads. However, poor signing prior to the high speed bumps becomes a serious hazard if it is not discovered well in advance by the driver. Moreover, the speed bumps are sometimes installed for one direction of the traffic which encourages drivers to drive on the wrong side of the road to avoid the speed bump.
- Most of the accident-prone existing roads lack roadside crash barriers. The newly built roads, however, include crash barriers but the appropriate operation and maintenance actions of the roads are not followed.
- Operation and maintenance of the roads are not followed by proper actions leading to quick physical failure and dangerous traffic states.
- Construction materials on the roads, coinciding with the new constructions of buildings and roads, are serious physical hazards on the roads. Moreover, poor temporary diversion of the roads and lack of information prior and during the diversion result in serious accidents and bad traffic flow.
- Many illegal markets, restaurants, houses and peddlers on the roads also lead to conflicts between high and low speed traffic including vulnerable road users.

Vehicle Factor: There are more than 1,250,000 registered vehicles in Kurdistan with an increase of 10% annually. The increase in developed countries, for instance Sweden, is 2% only. Vehicle conditions are good in general as they are equipped with relatively new passive and active safety devices. There are annual advanced vehicle controls. The problem, however, is the lack of qualified technicians to maintain the advanced systems. Another serious problem is, similar to deactivating the seatbelt warning system, that quite a few drivers deactivate the airbag system in order to keep their car from damage associated with the deployment of airbags.

METHODOLOGY OF THE NEW STRATEGY

Many efforts by individuals and organizations have been conducted to create the political will to improve traffic safety on the national level. These efforts consisted of traditional approaches such as the political will to commit resources, establishing an institutional framework to coordinate activities concerning traffic safety, developing goals and sub-goals, gathering scientific evidence of the magnitude of the threat, identifying deficiencies in the current traffic safety system, and developing a social strategy for organizing effective interventions. However, the efforts were unsuccessful in affecting the decision-making process and the existing policy to prioritize traffic safety and to consider the problem as a public health issue. This lack of success is partly because public acknowledgment for the reasons of the problem range between seeing accidents as fatalistic, unavoidable outcomes of development, or simply placing the blame on the drivers. While it is clear that the current strategy for improving road safety in the Kurdistan Region is largely ineffective, certain aspects of the above mentioned interventions could still contribute in part to the long term goal and strategies to improve road safety in the region.

The new approach, in this study, is to develop a new driving test and training system based on the 4 E's model which are: Engineering, Education, Enforcement, and Encouragement. The current road network in the region lacks important features of safe driving and does not meet standards and regulations. Thus, a standardized route on a section of public roadway which includes the required road safety features, is required to conduct a safe driving test. This is the core of the methodology in this study. This study proposes that a limited route within the existing road network, no less than 10 kilometers and with moderate traffic density, be defined and upgraded according to the standards. The route should include important features of traffic flow and safety such as traffic signs, U-Turn, round about, lane-keeping, traffic light, give-away, primary-road, pedestrian crosswalks, alignments, residential area, etc. Further, the controlled route should be heavily monitored to limit traffic violations and enforce legal driving on this portion of the roadway.

The next step is to adapt the driver test and training, including a theory test, at a university as a part of the education program for a limited number of final year students. Further, it is important to publicize in the media the new strategy and goals of the controlled portion of the roadway prior to conducting the driving test. The aim of the test is to carefully evaluate the effectiveness of the new method and improve the model based on feedback from the test, which is important for untested assumptions. After an initial implementation, evaluation must be carried out on the effectiveness of conducting driving test on the controlled portion of roadway. From this evaluation, the new strategy can be adapted and generalized into a new method for driver education which can be applied in other cities as a part of the education program for final year student at all universities. The number of graduated students in Kurdistan in 2014 was 27,275 students. Therefore, the implementation of the university education portion of the project is a very large scale program. Many professional examiners and driving schools need to be prepared for both the training and driving tests to be conducted.

In this way, the new proposed system will teach a large group of the most educated class how to properly operate their vehicles more efficiently and safely. Moreover, the route allows licensed drivers, optionally or through an enforcement program, to retrain and experience driving on standard routes which may lead to a gradual improvement in drivers' awareness. The standard route can also be used as a model and starting point to successively standardize the current road network as new roads are constructed.

CONCLUSIONS AND RECOMMENDATIONS

The political power is making motor vehicles the dominant mode of transport followed by extensive road building program. Moreover, the main focus in building the roads is to optimize mobility and flow of vehicles without proper plans to include traffic safety. Worsening traffic safety year after year is an indication that the practiced methods are not affective. Nonetheless, traditional views and approaches are still dominating. While the traditional strategy to improving road safety is ineffective, it is difficult to change from the top due to economic and political challenges. The rapid increase in the use of private car transport, upgrading old roads and constructing new roads that do not meet safety standards, and the lack of driver education led to increasing traffic accidents. Clearly, the traffic safety knowledge of drivers and the social environment were not prepared for the rapid changes leading to an increase in traffic accidents. Road safety in general, and the problems with vulnerable road users in particular, are not prioritized in updating the old road nor in constructing the new ones. Therefore, as new roads are built or old roads updated that

do not meet safety standards, they are building mistakes into their rapid growing road network which will require large amounts of money in the future to correct them. The blame of the poor safety performance, however, is mainly placed on the drivers. Based on the traffic safety research performed on developed countries, the main cause of accidents is human factors or automobile operator error. However, it is taken for granted that the developed countries already have a good road infrastructure, signing, and good vehicle condition.

Improving traffic safety in Kurdistan requires a strong political will, institutional framework to coordinate activities, feasible goals, funding from the national budget and interventions based on scientific evidences. The decision makers haven't prioritized traffic safety, despite more than 1,114 road deaths in 2013 and increasing fatalities annually. Thus, Kurdistan is 45 years behind developed countries when considering that road fatalities in the developed countries started to decline in the beginning of 1970's.

The suggested strategy in this study is based on the results of the survey which showed that licensed drivers do not know how to properly operate their vehicle according to driving regulations and were unable to correctly read road signs. The core of this method is to include an evaluated driving license tests in the universities final year program. This may gradually lead to an increased knowledge about the seriousness of the traffic safety problem among the public and politicians enabling them to rightly consider road deaths as a public health problem.

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CAR OR GROUND: WHICH CAUSES MORE PEDESTRIAN INJURIES?

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ABSTRACT

The aim was to study the cause of the injuries of pedestrians when hit in frontal impacts by a vehicle. Depending on the impact speed, the type and severity of the injuries may be due partly to the vehicle and partly to the road/ infrastructure, when falling down. The study took into account the projection distance and the age of pedestrians.
The work has been supported by FSR (Fondation Sécurité Routière)
All the accident cases were reviewed by an expert committee composed by physicians and accident analysis experts. For each wounded pedestrian, the injuries were reviewed in order to determine their causing mechanism taking into account the accident occurrence circonstances, the vehicle deformations and the clues on the road or infrastructure.
The data base was a sample of 100 in-depth investigations and reconstructions of accidents from years 2009 to 2011 involving at least one injured pedestrian hit by a vehicle and continuously collected in a 20 km diameter area in the south of Paris (France). The accident analysis team was called with the emergency team on field where the data were collected.
In the sample, 89 pedestrians were injured in a frontal impact. For 83 of them, it was possible to evaluate the vehicle speed during the impact. In 12% of the cases the speed exceeded 50 km/h and all the pedestrians were severely injured (MAIS3+: pedestrian with at least one injury scored above AIS3) with a high projection distance. Therefore, we focused on frontal impact with vehicle speed below 50 km/h. In this configuration , considering injuries AIS2+, the head was the most often injured (53%) and then the lower limbs (21%). Among the wounding elements, the ground was incriminated in 27.5% of the cases, then the bonnet (22%), the windshield (17%) and the bumper (15.5%).When the vehicle speed was below 30 km/h, more than half of the injuries AIS2+ observed were caused by an impact with the ground. There was a compounding effect of age.

Though the sample is not representative of all French pedestrian accidents, it allows categorizing these accidents depending on the impact speed. For each speed range, the main causal factor of the injuries was determined.

The vehicle speed was the major factor in the determinism of the injury severity of pedestrians involved in frontal impact, firstly by direct impact secondly by increasing the projection distance and thus the severity of injuries due to ground impact. Primary safety systems should reduce the severity of pedestrian injuries by decreasing the impact speed.

INTRODUCTION

The last WHO report relates that among the 1.24 milion deaths on the world's roads, 22% were pedestrians [1]. When focusing on European countries, they are representing 21% of the fatalities [2]. In France, the percent is lower but still high with 15% of the fatalities in 2014 [3]. In this context, a better understanding of the pedestrian injury mechanisms will help to orient the preventive actions. LAB and CEESAR carried out a specific study about this topic using in-depth accident analysis that was part of a larger project called CACIAUP supported by Fondation Sécurité Routière and the French car manufacturers. The aim of CACIAUP was to study three main topics: 1) to improve the in-depth accident analysis in order to specifically adapt them to pedestrian accidents. It means to optimize the alert, the way how data are collected and accident reconstruction techniques. 2) to follow the injured pedestrians until recovery or stabilization of injury sequelae in order to evaluate the efficiency of the Injury Impairment Scale (IIS) for this population of wounded people. 3) to identify main scenarios of accident involving a pedestrian in order to better specify the primary or secondary safety systems.
The paper focus on the evaluation of the type and severity of injuries depending on the impact speed in frontal impacts of pedestrians hit by a vehicle and of the determination of the cause of the injuries (part of the vehicle or road/ infrastructure).

METHOD

Even a large part of the road fatalities are pedestrians, there is a lack of knowledge about the mechanisms of injuries. In fact in accidents involving pedestrians, numerous clues and parameters rapidly disapear from the scene and render difficult the analysis of the accident. That explains the necessity to adapt the current methodology of in-depth accident investigation.
The in-depth accident investigation is a method to collect detailed road accident data. The latter are useful to describe the circumstances leading up to the occurrence of road accidents. Experts collect transient clues concerning many aspects of road environment (infrastructure, trafic, weather, …), vehicles and road users that may have contributed to the accident. This detailed knowledge allows to understand the determinism of the accident and to reconstruct the accident with the pre and post crash periods by a PC crash simulation. Two ways to collect data are available:
- on-the-spot in real time
- in delayed time: several days after the accidents

In-depth accident investigation is limited to a study zone where the accident analysis team has obtained all the authorizations from different organizations: national commission for computing and liberties, the prosecutor of the district: judicial authority, the police, the emergency services, the medical services, etc.

In-depth accident investigation in real time

A key point for the accident analysis experts is to be alerted at the same time as the emergency teams in order to arrive with them on the scene to note and figure out the meaning of the transient clues. Among the latter, were the locations of the involved vehicle and of the pedestrian in CACIAUP study. This point was specifically critical because in these accidents involving a pedestrian the damaged vehicle was often moved and the emergency and medical teams had to move the injured people in order to intervene as quickly as possible.
On the scene, experts collected transient data:

- Collection of the debriefings of the involved people and the potential witnesses,
- Collection of contextual information about infrastructrure, weather etc…
- Measures of the deformations of the involved vehicles and transcription of the clues

Though most of the information was collected on the scene, experts tried to keep in contact with the involved people in hospital or at home in order to complete the interview. They were also in contact with the police and hospital services.
This valuable method allows to collect very specific and useful data but has also drawbacks. It needs to be located in a limited geographical zone so that experts have time enough to join the accident location in a minimum time before transient clues disappear. Furthermore it is expensive and time consuming.

In-depth accident investigation in delayed time

In-depth accident investigation was sometimes carried out in delayed time. Experts were kept informed of the accidents involving a pedestrian on the investigation area. They had to collect all the information from the police and the road safety district squadron in order to get the accident location and time, accident configuration, vehicle type, name and address of the involved people. Then the investigation went further by looking for additional data. Experts went to analyze car deformations, infrastructure on the accident location. They also met the pedestrian and the driver involved in the accident in order to determine the accident conditions and the performed maneuvers before and during the accident.
This method was less efficient that the previous one on-the-spot due to the fact that transient clues were sometimes lost. It was still informative and allows to incease the number of observations.

In both cases, a physician was in charge of collecting the medical data and to anonymize them.

CACIAUP sample

The main interest of CACIAUP sample was to have numerous parameters and the reconstruction of the accidents in most of the cases. Though very useful, in-depth accident investigations addressed rather severe accidents and did not allow to gather a representative sample. Nevertheless, when possible, it will be compared to the French national road accident data base (BAAC: Bulletin d'Analyse des Accidents Corporels) collected in 2010.

The data base was a sample of 100 in-depth investigations and reconstructions of accidents from years 2009 to 2011 involving at least one injured pedestrian hit by a vehicle. They were collected in a 20 km diameter area in the south of Paris (France) in the timeframe ranging between 6 a.m. and 9 p.m.. A pedestrian was defined as one person who was on a roadway, a sidewalk, a path contiguous with a trafic way, or on a private property [4]. The road users in roller or in scooter were not considered as pedestrians in the study. Among 100 in-depth investigations, 67 were collected on-the-spot and in real time and 33 were collected a few days after the accidents.
Every accident was described in details using general variables in three areas (vehicle, occupant, and infrastructure). Up to 800 variables usable for future studies were coded for each accident. Medical data of every injured road users has been coded using AIS code revision 98 [5]. The score MAIS (Maximum AIS) was also used. It defined the overall level of severity of the injuries and was obtained by considering the highest level of AIS of a casualty having undergone multiple lesions. All the accident cases were reviewed by an expert committee composed by physicians and accident analysis experts. For each wounded pedestrian, the injuries were reviewed in order to determine their causing mechanism taking into account the accident occurrence circonstances, the vehicle deformations and the clues on the road or infrastructure. The categorization of the wounding elements was facilitated by the accident reconstructions.

GENERAL RESULTS:

General information on CACIAUP sample

Location

Among the 100 accidents, 95 of them were located in an urban area, 4 were on roads outside towns and 1 was on an highway. It is comparable to what was observed in the BAAC: 94% of the accidents involving a pedestrian against a car or a light truck were in urban areas.

Weather and light conditions

81% of the accidents occurred during the day, 4% at dawn or dusk and 15% during night. This differed from the accidents observed in the BAAC with 20% of the accidents during the night. It must be reminded that the timeframe of observation did not include a part of the night (from 9 p.m. to 6 a.m.).
81% of the accidents occurred under normal atmospheric conditions, 10% during rain, 6% under overcast and 3% in bright weather. This was approximatly the same in the BAAC.

General information on the injured pedestrians

Description of the population of injured pedestrians

The 100 accidents involved 110 pedestrians including 50 males and 60 females. This corresponded to the percent observed in the BAAC.
The sample was different from the BAAC with regard to age (Figure 1). 17% were children under 11 years (12% in the BAAC) and 13% of the people older than 70 years (19% in the BAAC).

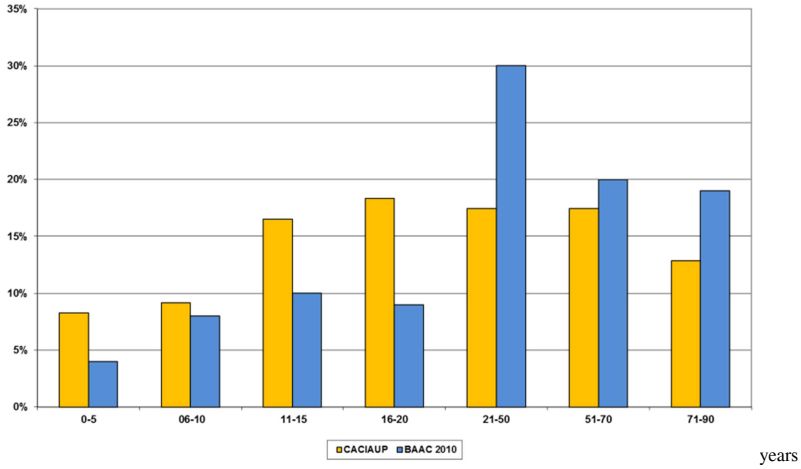

Figure1. Distribution of age (in years) among injured pedestrians in CACIAUP compared to the BAAC

Injury severity

The percent of pedestrians severely injured was similar in CACIAUP and in the BAAC (around 41%). Among them, the part of fatalities was higher in CACIAUP (14,5%) than in the BAAC (3,5%). Thus the CACIAUP sample included cases with a higher level of severity.

Distribution by impact type

The distribution was almost similar in CACIAUP sample and in the BAAC. In the sample, 82% of the vehicles hit the pedestrian by the frontal part, 10% by the rear part and 6% by the side part. Due to the limited size of the sample, further analysis was performed on the frontal impacts only.

RESULTS FOR FRONTAL IMPACT:

Currently, the study focuses on the pedestrians injured in a frontal impact. In the sample, 89 pedestrians were hit by the frontal part of the vehicle. For 83 of them, it was possible to evaluate the vehicle speed during the impact.

Distribution by accidental situations

In-depth accident investigations have shown that the main maneuvers of the pedestrians while hit by the vehicle were the following:

- Road crossing: 56%
- Road crossing at an intersection: 27%
- Walk along the road: 7%
- Other maneuvers: 10%

To sum up, 83% of the accidents occurred while the pedestrian was crossing a road.

Vehicle characteristics

Vehicle front shape

The vehicle front shape is considered as an important factor in the determinism of the pedestrian injuries [6]. It was taken into account. Four vehicle front shapes were observed:

- the wedge shape (2%),
- the box shape (8%),
- the pontoon shape (10%)
- the trapezoidal shape (80%) that was largely the most frequent.

Vehicle speed and projection of the pedestrian

The speed at impact and the projection distance of the pedestrian were two main parameters that were obtained thanks to the in-depth investigations. The projection distance of the pedestrian was correlated to the speed as is shown on figure 2. The higher the speed the longer the projection distance. A few accidents occurred at a speed above 50km/h with a projection distance so high that the severe injuries could be the result of the direct impact of the vehicle and/or of the falling down. So it was decided to focus on the accidents with a speed below 50 km/h.
The mean speed at impact was 32 km/h ± 21.3.

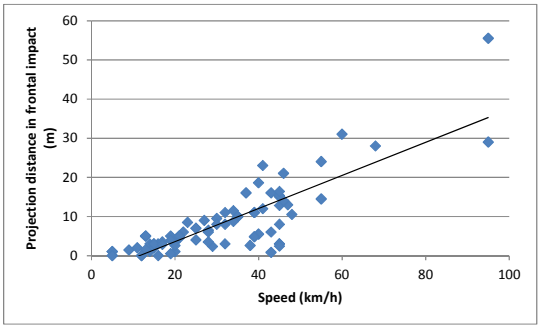

Figure 2. Distribution of the pedestrians according to the speed and the projection distance in frontal impact.

Injuries of the wounded pedestrians

87% of all the injuries , 97% of AIS2+ and 97% of AIS3+ were observed in frontal impacts.

Injuries of the pedestrians for a speed lower than 50 km/h

The sample of pedestrians hit by a vehicle at a speed lower than 50 km/h and for whom all the injuries were known included 71 persons. Thanks to the in-depth investigations, the wounding element was identified for 88% of the injuries. Table 1 describes the wounding elements incriminated to explain the injury AIS2+ of the different body areas.

	Head	Upper limbs	Lower limbs	Thorax	Abdomen	Spine	Total
Ground	19(15%)	8 (6%)	6 (4.5%)	0 (0%)	1 (1%)	1 (1%)	**35(27.5%)**
Bonnet	11 (9%)	1 (1%)	6(4.5%)	7(6%)	2 (1.5%)	0 (0%)	**27(22%)**
Bumper	2 (2%)	0 (0%)	12 (10%)	1(1%)	2 (1.5%)	1 (1%)	**18 (15.5%)**
Windshield	17(14%)	0 (0%)	0 (0%)	1(1%)	1 (1%)	1 (1%)	**20(17%)**
Lower windscreen frame	9(7%)	0 (0%)	0 (0%)	0 (0%)	0 (0%)	0 (0%)	**9 (7%)**
Pilar	5 (4%)	0 (0%)	0 (0%)	0 (0%)	0 (0%)	0 (0%)	**5 (4%)**
Upper windscreen frame	0 (0%)	0 (0%)	0 (0%)	0 (0%)	0 (0%)	0 (0%)	**0 (0%)**
Front light	0 (0%)	1 (1%)	1 (1%)	3(2%)	0 (0%)	0 (0%)	**5 (4%)**
Rear view mirror	3 (2%)	0 (0%)	0 (0%)	0 (0%)	0 (0%)	0 (0%)	**3 (2%)**
Others	0 (0%)	0 (0%)	1 (1%)	0 (0%)	0 (0%)	0 (0%)	**1(1%)**
Total	**66(53%)**	**10 (8%)**	**26 (21%)**	**12(10%)**	**6 (5%)**	**3 (3%)**	**123(100%)**

Table 1- Distribution of the injuries AIS2+ per body area and vehicle impact part or ground – Speed ≤ 50 km/h

The head was the most often injured (53%) and then the lower limbs (21%). Among the wounding element, the ground was incriminated in 27.5% of the cases, then the bonnet (22%), the windshield (17%) and the bumper (15.5%).

The severity of the injuries increased with the speed of impact (figure 3). 18% of the injuries were AIS3+.

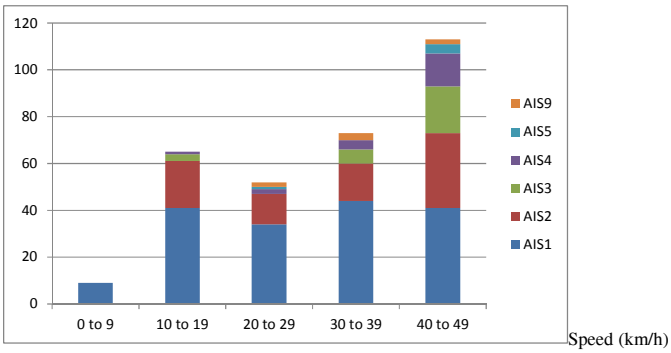

Figure 3. Distribution of AIS according to the speed(km/h) in frontal impact (n=316 injuries).

33% of the pedestrians were severely injured (MAIS3+). Among them, 59% had head injuries AIS3+. In about half the cases, the latter were the consequence of an impact with the windshield probably aggravated by the impact on the ground. 64% of the pedestrians were MAIS2+.
Considering the factor "age of the pedestrian", 63% of the wounded pedestrians with injuries AIS3+ were older than 51 years. Among them, 54% were older than 71 years.

Injuries of the pedestrians for a speed lower than 30 km/h

When the vehicle speed was below 30 km/h, still 11% of the pedestrians were severely injured (MAIS3+). In most of the cases, these severe injuries were related to the falling down. Considering now the injuries AIS2+ observed when the vehicle speed was below 30 km/h, thanks to the in-depth investigations, the wounding element was identified for 70% of the injuries. More than half of them were caused by an impact with the ground (table 2).

	Head	Upper limbs	Lower limbs	Thorax	Abdomen	Spine	Total
Ground	7(25%)	3 (11%)	4 (14%)	0 (0%)	1 (3.5%)	1 (3.5%)	**16(57%)**
Bonnet	1 (4%)	0 (0%)	1(3.5%)	0(0%)	0 (0%)	0 (%)	**2(7.5%)**
Bumper	0 (0%)	0 (0%)	3 (11%)	0(0%)	0 (0%)	1 (3%)	**4 (14.5%)**
Windshield	4(14%)	0 (0%)	0 (0%)	0(0%)	0 (0%)	0 (0%)	**4 (14%)**
Lower windscreen frame	0 (0%)	0 (0%)	0 (0%)	0 (0%)	0 (0%)	0 (0%)	**0 (0%)**
Pilar	0 (0%)	0 (0%)	0 (0%)	0 (0%)	0 (0%)	0 (0%)	**0 (0%)**
Upper windscreen frame	0 (0%)	0 (0%)	0 (0%)	0 (0%)	0 (0%)	0 (0%)	**0 (0%)**
Front light	0 (0%)	1 (3.5%)	0 (0%)	0(0%)	0 (0%)	0 (0%)	**1 (3.5%)**
Rear view mirror	0 (0%)	0 (0%)	0 (0%)	0 (0%)	0 (0%)	0 (0%)	**0 (0%)**
Others	0 (0%)	0 (0%)	1 (3.5%)	0 (0%)	0 (0%)	0 (0%)	**1(3.5%)**
Total	**12(43%)**	**4 (14.5%)**	**9 (32%)**	**0(0%)**	**1 (3.5%)**	**2 (7%)**	**28(100%)**

Table 2- Distribution of the injuries AIS2+ per body area and vehicle impact part or ground – Speed ≤ 30 km/h

The head was the most often injured (43%), then the lower limbs (32%) and the upper limbs (14.5%). Among the wounding element, the ground was incriminated in 57% of the cases, then the bumper (14.5%), the windshield (14%) and the bonnet(7.5%). 64% of the pedestrians were MAIS2+.
Considering the factor "age of the pedestrian", 30% of the wounded pedestrians with injuries AIS2+ were older than 51 years. Among them, 75% were older than 71 years.

DISCUSSION

Though CACIAUP sample was not representative of the population of pedestrians injured on the French roads, the in-depth investigations were useful to study the determinism of the injuries. For each injury, the causing mechanisms were discussed among the accident experts and the physicians in order to take into account the entire course of the accident and not only the direct impact by the vehicle. The share of all the information about the accidents and their reconstructions enabled to perform this complex task. The final positions of both the vehicle and the pedestrian were so important for an accurate analysis, that the project had asked to the police to mark these positions when they arrived on the spot. Thus, it was possible to obtain the projection distance for the in-depth investigations either in real time or in delayed time. The results showed that the impact speed and the projection distance were correlated although there was a high variation among the different cases. Sometimes, pedestrians hit different obstacles in the infrastructure which reduced the projection distance but often led to severe injuries. The regression curve shows that the higher the speed the longer the projection distance. For speed close to 50 km/h, it could reach more that 20 m. Such distances imply a high risk of injuries during the falling down or at least a risk to worsen the initial injuries due to the direct car impacts.

Most of the CACIAUP results were in accordance with previous studies. The role of the vehicle speed has already been described. Rosen and Sander (2009) have shown a strong relation between the fatality risk and the car impact speed [7]. The circumstances of the accident have been described with a large majority of pedestrians crossing roadway [8] as was found in CACIAUP. However, previous studies found that pedestrians were coded to be not as frequently and severely injured by the ground during vehicle-to-pedestrian crashes [4].
Looking at the two tables describing the distribution of the injuries AIS2+ per body areas and per wounding impact elements, more than a quarter of the injuries were due to ground/infrastructure impacts for speeds below 50 km/h, and more than half of the injuries were due to ground/infrastruture impacts for speeds below 30 km/h. In many studies, these injuries were often underestimated or all injuries were often related by excess to the direct car impacts. The high percent of injuries aggravated or due to the falling down imply that they have to be taken into account. Secondary safety systems have no efficiency on these injuries. They have a limited efficiency on the occurrence of lesions: 1) concerning those related to the direct vehicle impact, secondary safety systems could not impede the abnormal movements of body segments with each other, 2) during the impact, the kinematic energy related to the velocity is transmitted to the pedestrian that is projected to a more or less longer distance. The projection distance increases rapidly with the speed and these systems have no protective effects on the lesions provoked by the falling out. Given the important role of the speed on both direct injuries and secondary injuries due to the falling down or the impact against infrastructure, the priority is to reduce the impact speed. Several solutions could be proposed. First of all, as it is a problem of interaction among the different road users, each of them have rules to respect in order to avoid dangerous conflicts. Especially in urban areas, speed limits help the drivers to adapt their speed to the context of the road and the presence of pedestrians. Primary safety systems could also help the drivers when there is a failure of perception or attention. The advanced emergency braking systems (AEBS) could be very relevant because they avoid contact with the pedestrian or reduce the impact speed if they can not prevent contact. In the latter cases, the resulting reduction of the impact speed decreases the severity of the injuries due to direct vehicle contact and also decreases those due to the falling down because the projection distance is reduced. At low speed, it could be vital for elderly people to avoid the contact as they can be seriously injured only by falling from their height without any injuries due to the vehicle. In CACIAUP, this point especially affects the population of pedestrians over 71.

CONCLUSION

The vehicle speed was the major factor in the determinism of the injury severity of pedestrians involved in frontal impact, firstly by direct impact secondly by increasing the projection distance and thus the severity of injuries due to secondary impacts. CACIAUP results have showed a high number of the injuries due to the ground impact or aggravated by the falling down. Secondary safety has limited effects to protect the pedestrians due to the fact that it does not limit or impede the projection of the pedestrian when hit. Primary safety systems should more efficiently reduce the severity of pedestrian injuries by decreasing the impact speed. In that way, they decrease the energy of the direct impact and the projection distance and thus the severity of the injuries due to all the wounding elements in secondary impacts.

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BENEFITS ASSESSMENT OF AUTONOMOUS EMERGENCY BRAKING PEDESTRIAN SYSTEMS BASED ON REAL WORLD ACCIDENTS RECONSTRUCTION

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ABSTRACT

Despite the success in reducing Spanish traffic fatalities by 65 percent in the past decade (2004 - 2013), pedestrian fatalities only have diminished by 45% (decreased by 35% in urban areas).

This paper describes the main findings of a coordinated study performed by INSIA-UPM aimed to assess the potential influence of two active safety systems, a brake assist system (BAS) and an autonomous emergency braking system (AEB), in vehicle-pedestrian collisions through reconstruction of real-world accidents occurred in the city of Madrid (Spain).

A total number of 50 vehicle-pedestrian collisions have been in-depth investigated following a common methodology, including on the spot data collection, analysis and reconstruction to estimate the collision speed and the pedestrian kinematics. Every single case has been virtual simulated twice using PC-Crash® software: the first is a reconstruction of the real accident and the second is a simulation in which the operation of active safety systems is emulated.

The performance of the BAS system acts together with the antilock braking system (ABS). The AEB system emulated in this paper through computer simulations is based on the DaimlerChrysler's PROTECTOR system.

The benefit is assessed in terms of both collision speed and Injury Severity Probability (ISP) by comparing the reduction of their values from the real conditions to the virtual simulations. The pedestrian ISP was estimated, depending on the collision speed and the pedestrian head impact point, using a specific application to calculate its value based on the results of head form impact laboratory tests.

The findings show that in several cases the collision could be avoided by implementing the active safety systems (12% if the vehicle was fitted with BAS+ABS system; 42% with PROTECTOR system); and it would reduce their consequences in terms of the estimated ISP. It was also found that in few cases a low reduction of the collision speed would increase the head injury severity (10%).

Further research should include injury information and/or estimation (HIC). Other limitations are the sample size (only one city and frontal collisions) and no unhurt accidents have been included.

The injury severity assessment within this study only considers head impacts to the front surface of the vehicle, injuries provoked by subsequent impacts were not taken into account. Hence it can be an interesting subject for further research.

This is new because: it is a prospective assessment of active safety systems and autonomous emergency braking systems; it is based on accurate reconstructions, highly detailed parameters; the behavior of the system is simulated according to design parameters.

Multi-disciplinary approaches such as this study make the identification of critical parameters easier and simplify the development of practical solutions by quantifying their potential impact on future actions to improve pedestrian safety. The active safety braking pedestrian systems have a potential benefit in real conditions. It also has limitations so we cannot rely just on it. It has to act together with other passive features and the driver has to keep aware. This methodology can serve to test the benefit of forthcoming active safety technologies.

INTRODUCTION

Pedestrians are the most vulnerable road users and when involved in traffic accidents often suffer severe and fatal injuries. In year 2013 a total of 378 pedestrians were killed in the Spanish roads (22.5% of the overall traffic fatalities), 224 fatalities ocurred in urban areas (49.8% of the urban traffic fatalities). Compared with the year 2004 figures, the pedestrian fatalities percentage of total fatalities has increased (in 2004, 14.4% of national traffic fatalities, 38.1% of urban traffic fatalities).

This high vulnerability has its response in the manufacturers and the Public Administrations, which adopt different measures to protect these road users, e.g. driver and pedestrian education, urban planning, vehicles design and equipment...

The technological advances for vehicles adopted to enhance road users' protection have been primarily focused on secondary safety; however there are a number of recent developments aimed to avoid the collisions. Many accidents are caused by late braking and/or braking with insufficient force. In this way, the European Parliament and the Council have enacted Regulation (EC) 78/2009 (The European Parliament and the Council of the European Union, 2009 [11]) "on the type-approval of motor vehicles with regard to the protection of pedestrians and other vulnerable road users..." binding the manufacturers to equip the new vehicles placed on the European market with a type-approved brake assist system (BAS). According to the text of the Regulation, a brake assist system is a function of the braking system that deduces an emergency braking event from a characteristic of the driver's brake demand and, under such conditions assists the driver to deliver the maximum achievable braking rate; or is sufficient to cause full cycling of the Anti-lock Braking System (ABS).

The brake assist system was originally introduced to compensate the insufficient brake rates due to unexpected driver reactions discovered in rear-end collisions. It was found that despite the antilock braking system, the braking distance in critical situations was not significantly reduced. The reason was that drivers were not pushing the brake pedal strong and quick enough to its full stroke. The advantages of BAS as an active safety system were soon evidenced to avoid collisions and reduce the impact speed when the collision was inevitable. Thus the European Commission decided to make mandatory the fitting of BAS in new vehicles, representing one of the first active safety requirements for type-approval of motor vehicles with regard of the pedestrian protection (Badea-Romero et al, 2013 [1]).

Additionally primary safety systems have been developed for vehicles in order to autonomously detect a pedestrian and to avoid or mitigate the impact. The global functioning of these systems is based on analyzing the forward path of the vehicle in real time in order to try to identify a pedestrian on the road. If it is determined that the pedestrian trajectory is across the forward path of the vehicle, as a countermeasure to avoid an imminent crash, these systems employ emergency braking and some may potentially employ emergency steering (Hamdane et al, 2014 [4]). The systems they have developed can be grouped under the title AEB: Autonomous (the system acts independently of the driver to avoid or mitigate the accident); Emergency (the system will intervene only in a critical situation); and Braking (the system tries to avoid the accident by applying the brakes). AEB systems improve safety in two ways: firstly, they help to avoid accidents by identifying critical situations early and warning the driver; and secondly they reduce the severity of crashes which cannot be avoided by lowering the speed of collision ([14]).

The evaluation of the benefit of two active safety systems, a brake assist system (BAS) and an autonomous emergency braking system (the DaimlerChrysler's PROTECTOR system), for pedestrians involved in accidents is tackled in this paper which describes an in-depth accident investigation performed by INSIA-UPM. Data of 50 frontal vehicle-pedestrian collisions occurred in the city of Madrid between 2002 and 2006 were collected. Every single case has been virtual simulated twice using PC-Crash® software: the first is a reconstruction of the real accident and the second is a simulation in which the operation of the two active safety systems, BAS and PROTECTOR systems, is emulated modifying the collision parameters and its potential consequences.

To harmonise the process, a simulation procedure with simplified hypotheses about the driver's reactions, the brake assist system and the autonomous emergency braking pedestrian system operation was previously adopted. Collision speeds and pedestrian kinematics have been obtained from the reconstructions, which

allowed estimating the Injury Severity Probability (ISP) as the parameter considered for assessing the benefit of the active safety systems in terms of injury mitigation.

METHODOLOGY

The methods presented in this section were developed within the framework of a research project (INSIA et al., 2008 [5]). The methodology was established to encompass into one optimal procedure to investigate on the spot every single accident, perform reconstructions and simulations, and analyse the obtained data and the results.

Accident investigation and reconstruction

To investigate and reconstruct accidents occurred in Madrid, a multidisciplinary team was created with the support of local police forces, emergency services and hospitals.

The sampling was based in three main criteria: first, according to the road characteristics, the selected accidents should occur in urban areas; the second criterion is about the vehicle type, considering only accidents in which the striking vehicle was a passenger car (86%), a SUV (2%) or a people carrier (12%); the third is related to the accident configuration, only where the pedestrian was struck by the front of a passenger car. No restrictions about pedestrian characteristics such us gender, age, height or weight were imposed.

On the spot accident investigation and data collection was the first step of the process. The investigation teams in collaboration with the police forces attended the scene to collect all the available information about the scenario, geometry of the roads, visibility, visual evidence such as skid marks and traces, and also vehicle damages, dents and marks. Information about the injuries was obtained from paramedics and hospital data and used in the analysis phase for determining the injury mechanisms.

Once the investigation and data compilation phases were finished, the available information was analyzed, revised and prepared to be used in the reconstruction. Fully detailed scene plans were drown to be used in the reconstruction process.

Next the corresponding vehicle was selected in each case and loaded from the vehicle database available in the computer program; its characteristics were set up according to the real vehicle. The frontal shapes of real vehicles were accurately measured for this purpose.

Based on anthropometric studies (Spanish Ministry of Health, 2008 [10] and Benjumea, 2001 [2]), multi-body pedestrian models have been defined, representative of the up-to-date Spanish population for both male and female, and for a wide range of ages.

Finally, the virtual simulations of the accidents were performed using a reconstruction software. As it has been recently shown (Untaroiu et al., 2010 [12]) the initial conditions have a strong influence on the reconstruction kinematics. Many parameters such as approaching speed, path, position, pedestrian motion, driver maneuvers and sequences are slightly modified and tested in different combinations in an iterative process that leads to a reliable reconstruction, matching both the impact points with the visual evidence such as dents or marks and with the injury locations and mechanisms, and the vehicle and pedestrian rest positions.

Some simplifying hypotheses were established so all the simulations were performed from a common approach. These basic simplifications were: 1) the reaction time of the driver was considered to be one second for all cases; 2) the lag for a conventional brake system was 0.25 s; 3) the Possible Perception Point (PPP) of the driver was the instant in which the pedestrian stepped onto the pavement and no obstacle covered the driver's field of vision; 4) three intensity levels were established for the pre-collision brake force: no brakes when the evidence show that the driver had no time to react or was completely unaware of the pedestrian presence on the vehicle path, a default medium intensity brake for most accidents and a full brake when evidence such as skid marks leaded to it.

Simulation of BAS+ABS operation

The BAS operation can be described in three steps: a) detection of the pedal signal; b) interpretation and decision; and c) actuation.

At the first step a sensor detects a signal from the brake pedal. At the second phase the input signal is processed by the electronic central unit which decides if it corresponds to an emergency braking situation, triggering the system or keeping it in standby when normal braking. Next, if the control unit estimates that the signal corresponds to an emergency braking, an electric valve is opened and the pressure of the system increases to its maximum operating level activating the antilock system that prevents the vehicle from skidding.

The BAS operation features specified for its approval were taken into account when performing the virtual simulations. The parameters used to emulate the BAS in the virtual simulations are presented in table 1.

Table1. BAS and PROTECTOR systems variables used in the virtual simulations.

Variable Name	Notation	Unit	Source
Pre-collision braking distance	S_k	m	Reconstruction
Approaching speed	V_0	km/h	Reconstruction
Braking deceleration with BAS+ABS	a_{BAS}	m/s^2	BAS-simulation
Braking deceleration with PROTECTOR	a_{PROT}	m/s^2	PROT-simulation
Braking deceleration	a_k	m/s^2	Reconstruction
Reaction time	t_0	s	Average values
Pre-collision braking time	t_k	s	Reconstruction
Lag of the brake system with BAS+ABS	t_{BAS}	s	SAVE-U ([6])
Collision speed	V_k	km/h	Reconstruction
Collision speed with BAS+ABS	V_{kBAS}	km/h	Reconstruction
Collision speed with PROTECTOR	V_{kPROT}	km/h	Reconstruction
Brake distance with BAS	S_{BAS}	m	BAS-simulation
Collision speed with BAS	V_{BAS}	m	BAS-simulation
Brake distance with PROTECTOR	S_{PROT}	m	PROT-simulation
Collision speed with PROTECTOR	V_{PROT}	m	PROT-simulation

Starting from the initial driving speed (V_0) obtained from the real accident reconstruction; a second virtual simulation was performed considering the BAS. The hypotheses adopted for the pre-impact phase were: when the BAS starts to operate, the ABS has to be activated and its operation frequency set up at the correct value to prevent from skidding, regardless if the original vehicle was fitted or not with such system. The PPP remains the same as also does the reaction time of the driver (t_0) but the lag of the brake system is reduced from 0.25s in normal conditions to 0.1s when the BAS is activated according to the results presented by Meinecke et al. (2003 [6]) within the SAVE-U project.

After the reaction and the lag sequences, the braking phase was established at the maximum deceleration (a_{BAS}) allowed by the computer program according to the friction conditions, which was considered equal to the deceleration that can be achieved with full cycling of the ABS (a_{ABS}). Then new values of the braking distance and the impact velocity were obtained and the difference was evaluated. If the braking distance to the collision point with the BAS (S_{BAS}) was less than the pre-collision braking distance (S_k) obtained from the reconstruction, then the collision could have been avoided due to the BAS; otherwise new simulations of the collision and post-collision phases had to be performed modifying the values of both the impact velocity and brake deceleration (V_{BAS} and a_{BAS} respectively). The modifications of the relative position between the vehicle and the pedestrian and the pitch angle of the vehicle at the collision point were also considered.

Simulation of the DaimlerChrysler's PROTECTOR system

The DaimlerChrysler's PROTECTOR system (SAVE-U consortium, 2005 [9]) has been tested in the EC-Project "SAVE-U. Sensors and system Architecture for VulnerablE road Users protection (Project IST - 2001 - 34040)".

Two strategies for the protection of vulnerable road users (VRU) have been implemented in the DaimlerChrysler vehicle: acoustical driver warning and automatic braking. In case of a high risk of a collision, automatic braking tries to either avert the crash at all or to mitigate the impact if the collision is unavoidable.

The deployment strategy of these protection measures consists of three phases:

- Phase 1: Early Detection. The sensor platform detects and tracks all VRUs in front of the vehicle (within the sensor coverage area), but none of protection measures are activated yet.
- Phase 2: Acoustical Driver Warning. A VRU is detected to enter the vehicle's path, but there is no risk of an immediate collision yet. The driver is alerted by an acoustical signal about this potentially dangerous situation.
- Phase 3: Automatic Braking. A high risk of a collision has been identified. The vehicle is decelerated in order to avert the collision or, in case a collision is unavoidable, mitigate the impact.

The decision about the activation of a protection measure is made from the position and heading direction of the pedestrian, and the current vehicle path. For that purpose, the detection area is divided into three zones, see figure 1:

- The red zone, 1.5m to each side, approximately represents the vehicle path. VRUs within this area are considered of being in risk of collision.
- VRUs in the yellow zone, from 1.5m to 3m to each side, are considered only if they are heading towards the vehicle path.
- VRUs in the green zone are not considered for the activation of one of the protection measures.

The automatic brake system operation features specified for the DaimlerChrysler's PROTECTOR system were taken into account when performing the virtual simulations. The parameters used to emulate this system in the virtual simulations are presented in table 1.

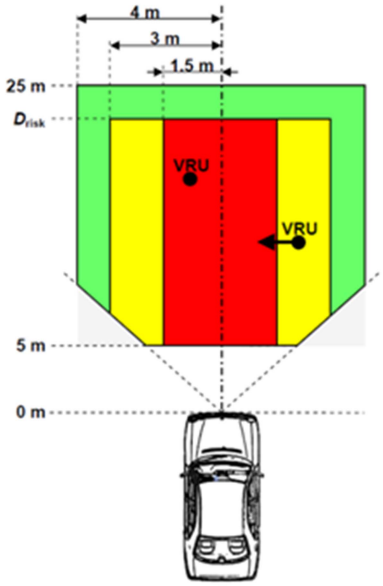

Figure1. DaimlerChrysler's PROTECTOR system. Subdivision of the detection area into 3 risk zones.

Starting from the approaching speed (V_0) obtained from the real accident reconstruction; a second virtual simulation was performed considering the PROTECTOR system. The hypotheses adopted for the pre-impact phase were: when the pedestrian goes into the red zone an automatic brake system starts to operate, the ABS has to be activated and its operation frequency set up at the correct value to prevent from skidding, regardless if the original vehicle was fitted or not with such system. The PPP (Possible Perception Point) remains the same as also does the reaction time of the driver (t_0).

After the reaction and lag sequences, the braking phase was established at the maximum deceleration (a_{PROT}) allowed by the computer program according to the friction conditions, which was considered equal to the deceleration that can be achieved with full cycling of the ABS. Then new values of the braking distance and the impact velocity were obtained and the difference was evaluated. If the braking distance to the collision point with the PROTECTOR system was less than the pre-collision braking distance (S_k) obtained from the reconstruction, then the collision could have been avoided due to the PROTECTOR system; otherwise new simulations of the collision and post-collision phases had to be performed modifying the values of both the impact velocity and brake deceleration (V_{PROT} and a_{PROT} respectively). The modifications of the relative position between the vehicle and the pedestrian and the pitch angle of the vehicle at the collision point were also considered.

Estimation of the Injury Severity Probability (ISP)

Head injuries are the most severe and with threat to life that pedestrians suffer when struck by a vehicle (Yao et al., 2008 [13]). The severity of the injuries depend on many parameters such as the collision speed, head impact point, collision configuration, vehicle shape, anthropometric measures of the pedestrian and rigidity of the component hit by the head.

The intensity of head impact is often assessed by the head injury criterion (HIC) (Mizuno and Ishikawa, 2001 [7]). The HIC can be correlated to the risk of severe injury, which gives a much clear idea of the how serious the head impact might be.

The methodology used in this research to estimate the head injury severity is described in figure 2 (Badea-Romero et al., 2013 [1]). First, the location of the head impact point is obtained from the computer simulation and represented by a row and a column corresponding to the wrap around distance (WAD) and the distance across the frontal respectively.

Then data from several laboratory tests performed at Applus+ IDIADA are used to estimate the correspondent HIC.

To estimate the injury severity, the value of the HIC obtained from the test is then derived into the probability of suffering a severe (AIS3+) head injury (ISPHIC,H,3). Thus the intensity of the head impact given by the HIC is translated into the injury severity that it can potentially cause. This is not a novel procedure, it has been previously presented by Fröming et al. (2006) [3].

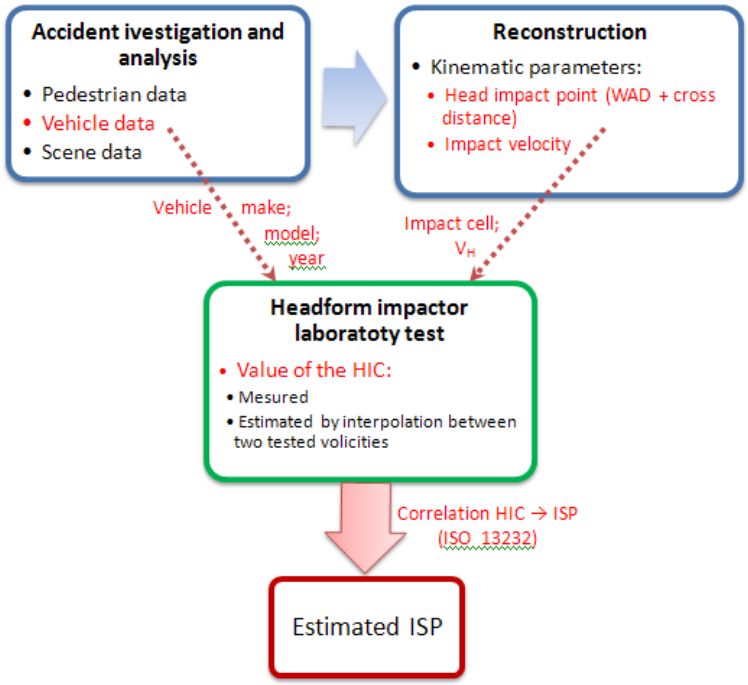

Figure2. Methodology to estimate the Injury Severity Probability (ISP) [1].

RESULTS AND DISCUSSION

All the 50 reconstructions of the real accidents have been obtained with reliable results matching the impact points and rest positions for both vehicle and pedestrian with the visual evidence collected on the spot.

By modifying the parameters that affect the braking sequences according to the active safety systems characteristics, a second set of virtual simulations for all the cases has been obtained. Both BAS+ABS and PROTECTOR system simulation outputs were compared by pairs.

It was found that in the 88% of the accidents, the vehicle started to brake during the pre-collision phase. No evidence of braking maneuvers was found for the other 12% of the cases, this hypothesis was confirmed by the reconstructions. I was proved that the driver was probably unaware of the pedestrian on his path, or the pedestrian was detected too late leaving no time to react.

Related to the ISP estimation, the pedestrian head impact point was located out of the car frontal in the 20% of the accidents so the ISP value could not be calculated. The Injury Severity Probability (ISP) estimated versus collision speed (Vk) is shown in figure 3.

Figure 4 shows the distribution of the cases according to the reduction in percentage between real and the BAS+ABS/PROTECTOR systems simulated collision speeds (V_{kBAS}/V_{kPROT} reduction in %); and figure 5 the distribution of the cases according to the reduction in percentage between real and the BAS+ABS/PROTECTOR systems simulated ISP (ISP_{kBAS}/ISP_{kPROT} reduction in %).

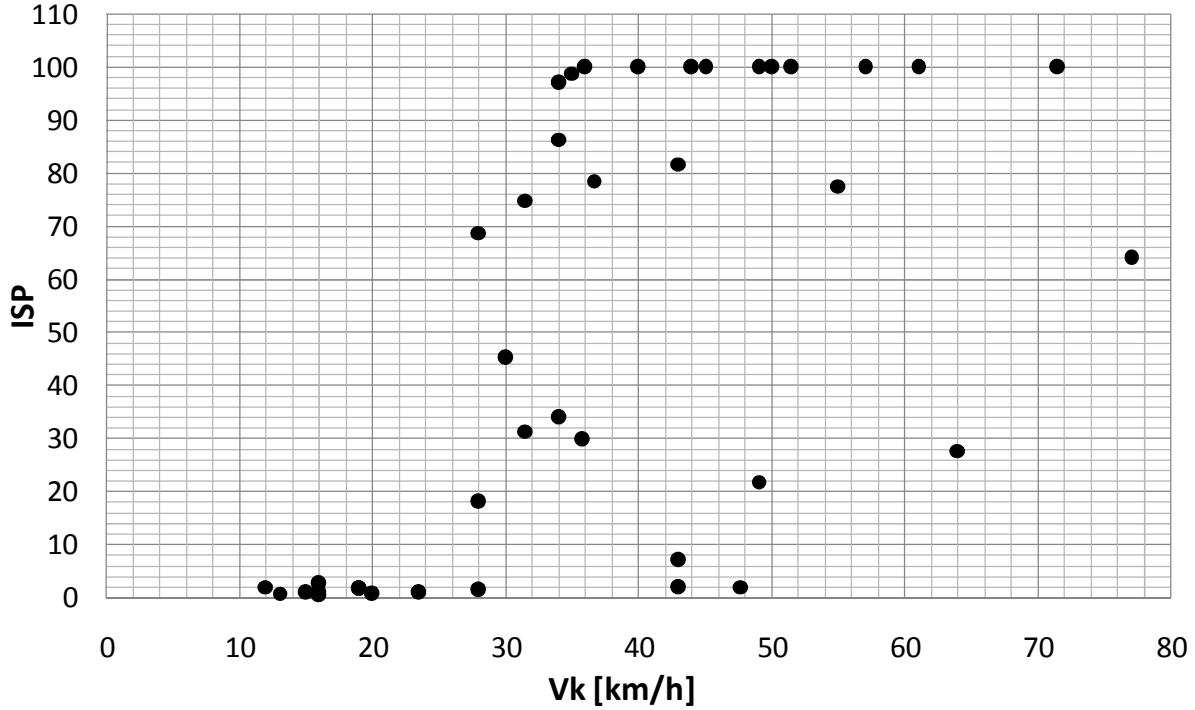

Figure3. Injury Severity Probability (ISP) versus collision speed (V_k).

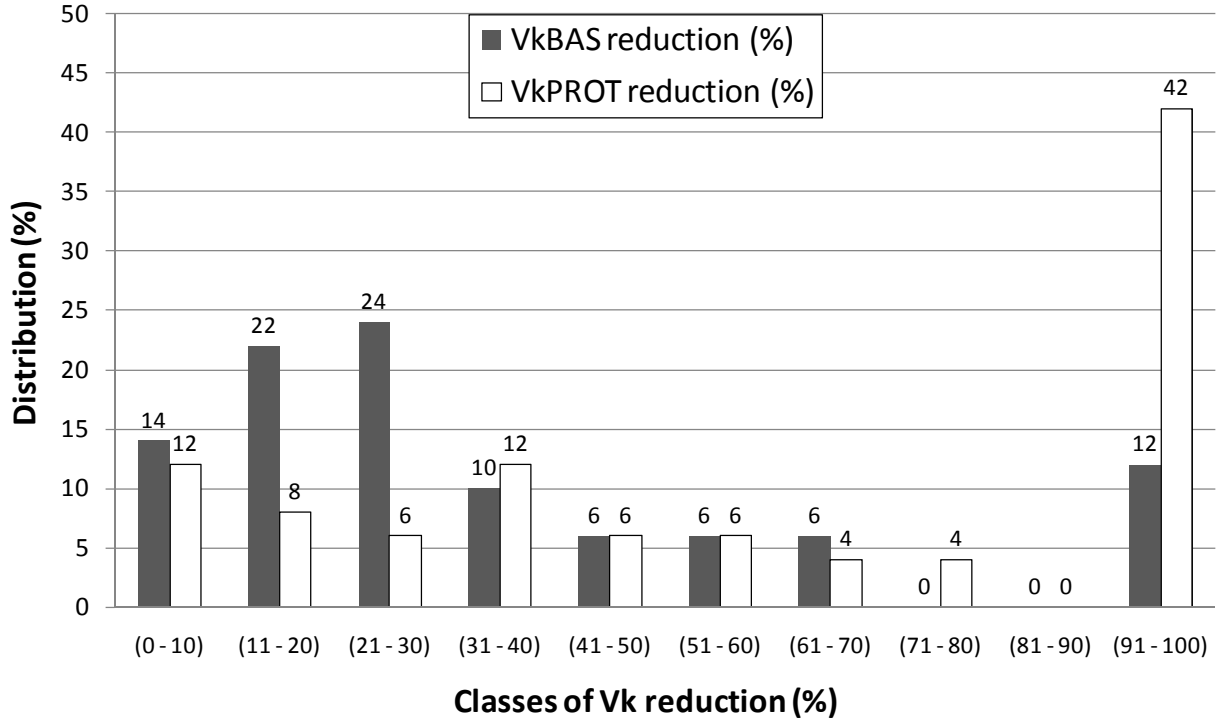

Figure4. Distribution of the cases by the percentage of collision speed (V_k) reduction.

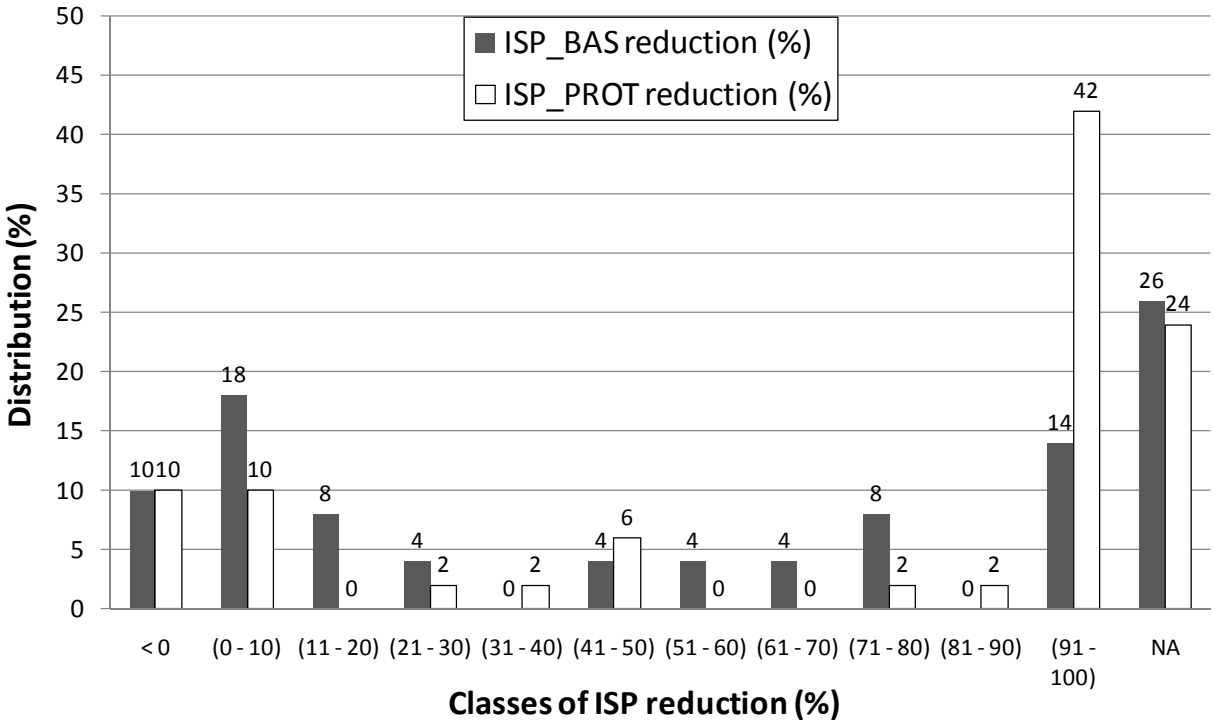

Figure5. Distribution of the cases by the percentage of Injury Severity Probability (ISP) reduction.

The collision could have been potentially avoided in 12% of the cases if the vehicle was fitted with BAS+ABS system ($V_{kBAS} = 0$) and in these accidents the ISP_{BAS} reduction is 100%. In 55% of the cases of the studied sample, the speed reduction achieved is less than 5 km/h. In 26% of the cases the ISP_{BAS} reduction value could not be calculated (NA) due to the pedestrian head impact point was located out of the car frontal (in the real accident and/or in the BAS+ABS system simulated). The data show that 18% of the cases in the sample present a percentage ISP_{BAS} reduction less than 10%, and in a 10% that reduction is negative (there is an increase in the value of ISP; these cases commented below).

In 42% of the cases with the PROTECTOR system simulated the percentage of the speed reduction achieved is more than 90% ($V_{kPROT} = 0$, the collision has been avoided due to the PROTECTOR system) and in these accidents the ISP_{PROT} reduction is 100%. In 70% of the cases of the studied sample, the speed reduction achieved with the PROTECTOR system is greater than 10 km/h, and in 44% of the cases the percentage of the ISP_{PROT} reduction achieved is greater than 80%. In 24% of the cases the ISP_{PROT} reduction value could not be calculated (NA) due to the pedestrian head impact point was located out of the car frontal (in the real accident and/or in the PROTECTOR system simulated). The data show that only 10% of the cases in the sample present a percentage ISP_{PROT} reduction less than 10%, and in a 10% that reduction is negative (there is an increase in the value of ISP; these cases commented below).

Reductions of ISP up to 50% correspond to low levels of collision speed reduction. This fact evidences that improvements of pedestrian protection in frontal collisions depend not only on speed but on other parameters (in our study, these parameters are those from which the ISP is calculated: characteristics of the vehicle and head impact point).

In 10% of the cases (both BAS+ABS system and PROTECTOR system simulated) the percentage of the ISP reduction is negative; it was found that the head impact location changed to a stiffer area of the vehicle causing a more severe head impact

Since vehicle-pedestrian collisions are complex phenomena in which many parameters are involved, some simplification hypotheses were made in order to make the reconstruction process easier and quicker. These simplifications are related to parameters that can hardly be estimated such as the driver behavior.

The injury severity assessment within this study only considers head impacts to the front surface of the vehicle, injuries provoked by subsequent impacts were not taken into account. Hence it can be an interesting subject for further research.

The accident sampling is specific for this study and their characteristics are limited by the criteria that the Local Police Forces use for attending within their coverage area. So the 50 cases cannot be considered a representative sample for the whole pedestrian accidents that occur in the Spanish cities and the findings of this investigation might be different for other samples.

CONCLUSIONS

Multi-disciplinary approaches such as this study make the identification of critical parameters easier and simplify the development of practical solutions by quantifying their potential impact on future actions to improve pedestrian safety.

Using this methodology, a database containing 50 pedestrian accidents was created, including in detail information of the vehicle, person (anthropomorphic variables, injury codification); scene and pedestrian kinematics. Reconstructions of these accidents were performed using advanced techniques to accurately estimate multiple parameters from the collision, the pre- and post-impact phases.

The gathered information has been used for the evaluation of the effectiveness of two active safety systems, a brake assist system (BAS+ABS) and an autonomous emergency braking system (AEB). The performance of these systems has been simulated in the reconstructions, so it was possible to analyze their capacity for severity reduction in pedestrian accidents or even its avoidance.

Both analyzed systems (BAS + ABS and PROTECTOR) proved to be efficient for reducing severity of pedestrian accidents in most of the studied cases. In the case of the BAS+ABS system the findings show that even though most of the collisions could not have been avoided by implementing these systems, their consequences would have been reduced in terms of the estimated ISP. The PROTECTOR system proved to be efficient for reducing collision speed of pedestrian accidents in most of the studied cases so the effect in terms of the estimated ISP reduction is greater than the case of the BAS+ABS system simulated.

In some cases a low reduction of the collision speed due to the simulated systems would increase the estimated ISP. The interaction between collision speed, vehicle frontal design and pedestrian parameters –height, weight, speed – is more relevant for the severity of the pedestrian head impact than the speed by itself, because it determines the head trajectory, acceleration and impact point. Thus, these primary safety systems should be combined with other secondary safety devices, such as the pop-up bonnet or the windscreen airbag.

ACKNOWLEDGEMENTS

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Eficiente y Seguro", P2013/MIT2713). The authors would like to thank the Local Authority of Madrid for their support in the investigations. The research work was also supported by the Madrid Regional Ministry of Education and the European Social Fund (ESF) through the Research Personnel Support Program of Madrid Autonomous Community

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FATAL URBAN CYCLIST COLLISIONS WITH LORRIES: AN IN-DEPTH STUDY OF CAUSATION FACTORS AND COUNTERMEASURES USING A SYSTEM-BASED APPROACH

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ABSTRACT

In the UK and other countries cyclists are the only group of road users with increasing fatalities and cyclist protection has become a high priority both to reduce the risks of cycling and the perception of risks amongst cyclists. The objective of this study is to apply a systems approach to a causation analysis of fatal crashes in order to identify key risk factors and countermeasures associated with all vehicles involved, the infrastructure, road users and road safety management.

The paper presents an analysis of fatal cyclist collisions that took place in London in the years 2007 to 2011. Case materials included police reports, witness statements, vehicle inspections, scene plans and photographs, collision reconstructions, post-mortem and other medical reports. The sample comprised a total of 53 fatal cyclist collisions that occurred during the five year period.

The most common collision type resulting in a fatal cyclist was an impact with a large vehicle >3.5T including 27 lorries and 3 buses. The most common manoeuvre involved the large vehicle turning left resulting in a low speed interaction with the cyclist. Generally impacts occurred to the front left side or left front side of the truck (24 cases, 89%). Insufficient direct vision of the cyclist was a factor in all of these cases with additional risks associated with driver attention and mirror limitations. The availability of Class V side and Class VI front mirrors did not prevent all fatalities.

12 (45%) of the lorries were equipped with side guards while 11 were exempt, however all of the fatally injured cyclists were on the ground before any side-guard interaction could have occurred and side guards were not seen to be effective in this sample.

INTRODUCTION

Although there has been a longer term reduction in fatalities of all road users in Great Britain, between 2009 and 2013, the number of pedal cycle fatalities fluctuated between 100 and 120 with some evidence of a slight upwards trend (DfT 2013). This has led to an increased focus on cycle safety in the UK – especially in areas such as London where there has also been an increase in the number of pedal cyclists on the road as a result of healthy mobility initiatives.

Cyclists, along with pedestrians and motor-cyclists are considered to comprise the group of "Vulnerable Road Users". Compared with the occupants of motorised vehicles they have very few opportunities for protection and injury mitigation and casualty reduction measures focus predominantly on collision avoidance measures. Unlike

other vulnerable road users however cyclists frequently do not have the segregation from traffic experienced by pedestrians but they do have increased conflicts with motorised vehicles due to the frequent speed differentials.

This paper describes the results of a study conducted on behalf of Transport for London that examined fatal along with a small number of very serious injury pedal cyclist crashes that occurred in London between 2007 and 2011 (Talbot et. al. 2014).

SYSTEMS APPROACH

The first step in developing countermeasures to road traffic crashes is to identify what factors contributed to their occurrence in the first place. Accident causation models have been developed to improve the safety of industrial processes for many years. An early model of accident causation was developed in the context of industrial accidents by Heinrich (1931). The model explained an accident as a step in a sequential chain of events or circumstances, each of which was dependent on the previous event. By removing one of the events the consequent circumstance would be avoided and the accident prevented. More recent models of accident causation developed for industrial processes have come to consider the development of risks within a closely coupled, integrated system of which humans are a part. All components of all systems have a variation in performance whether they are human, mechanical or algorithmic. Systems that are increasingly tightly coupled are less resilient to the effects of adverse circumstances. Humans in the control loop have the opportunity to adapt behaviour to enable the system to accommodate adverse conditions but in a tightly coupled system a minor human error can result in a major outcome.

In considering the behaviour of systems Reason (2000) identified two types of error that may occur. Active failures are unsafe acts that are committed by people who are components in the system. He states that they may take a variety of forms including slips, lapses, fumbles, mistakes, and procedural violations. Secondly he identifies latent conditions, which represent attributes of the system – design, functionality, operation. Normally these deficiencies have no consequence and there are no adverse outcomes. However when the trigger of an active failure aligns with the latent conditions of the system it may result in an adverse outcome.

The principles of the accident causation models discussed above have guided the approach used in the collection of data, the analysis of that data, as well as the identification of potential countermeasures. To this end, it can be said the crashes are failures in a road traffic system made up of four components:

- Environment: This includes aspects such as infrastructure and weather conditions.
- Vehicle: All vehicles (including bicycles), their design and safety systems.
- Road user: The human behaviour element in the system - drivers, pedestrians, pedal cyclists, motorcycle riders etc.
- Management: These are the indirect influences of the system including legislation, policy and procedures e.g. licensing, congestion charging, fleet management, which in turn influences factors such as who is on the road and when.

These components are not considered in isolation as they are all interlinked and each component can affect another in the system. For example a driver may drive differently (road user) in different weather conditions (environment) or misinterpret unfamiliar infrastructure.

METHODOLOGY

In the UK, specialist police officers, who are trained in road traffic crash investigation methodologies, attend crashes that are fatal or considered to be life threatening. They conduct detailed investigations and where possible reconstructions to gain as thorough as possible understanding about the crash and how it occurred. Data was collected from the resulting police files that were accessed in paper form at a London police station under conditions of a confidentiality agreement. A set of key documents from which the most data could be extracted were identified:

- the police collision investigation report;
- scene and vehicle photographs;
- scene plan and reconstruction;
- CCTV images;
- driver interview transcripts;
- witness statements;
- Post-mortem reports.

A simple database was created to allow quantitative data to be recorded such as time and date of crash, vehicle type, age, gender, impairment, as well as more detailed qualitative descriptions such as crash description, vehicle defects, information about road narrowing and route information. Other supplementary information such as mirror positions and vehicle damage was recorded on paper and copies of scene plans and photos were also obtained. Injury data collected from post-mortems and hospital consultant witness statements were recorded separately including Abbreviated Injury Scale (AIS, 2005) codes, injury descriptions, toxicology and date of death. Transport for London also provided context data such as the number and type of crashes that had occurred at each crash location during the previous three years.

A case review approach was adopted to analyse the crashes whereby the complete dataset (including the database variables, scene plan, photos, injury and context data) for each crash was reviewed by two or more researchers to identify factors that contributed to the crash. Contributory factors were not assigned according to a pre-defined list but the system approach as previously discussed was used to ensure factors relating to the environment, road user, vehicle and management were identified as appropriate.

RESULTS

Seventy-nine fatal and very serious crashes occurring in London were investigated by specialist police offices between 2007 and 2011. Of these, 53 were available for data collection. Forty-six were fatal pedal cyclist crashes, using the internationally accepted definition of death within 30 days. A further 7 involved a seriously injured pedal cyclist whose injuries were considered to be life threatening at the time of the crash. In the following results and analysis, the fatal and serious crashes have been grouped together the characteristics of the serious crashes, in terms of crash causation, were very similar to those of the fatal crashes.

Some differences were observed between the sample of 53 crashes occurring in London and the fatal pedal cyclist crashes occurring in Great Britain as a whole (See Figure 1). In London there were

- Fewer cyclist crashes in the summer months, more in winter (73% London, 42% GB)
- Fewer weekend crashes (7% London, 31% GB)
- A larger early morning peak (8:00 – 10:00) in collisions (25% London,12% GB)
- More cyclist crashes on A-roads (76% London, 53% GB)
- More cyclist crashes in 30 mph speed limits (89% London, 48% GB)
- More cyclist crashes on or on the approach to junctions (74% London,48% GB)

Collision partner

Table 1 shows the primary collision partner for the 53 fatal and serious crashes examined and the manoeuvres conducted by the two vehicles. The primary collision partner is defined as the vehicle that was involved in the initial interaction with the pedal cyclist. The most common collision partner was a goods vehicle corresponding to 29 (55%) of the total collisions while 15 (28%) of the collisions were with a car. In 17 crashes a motorised vehicle turned left across the path of the cyclist and 15 of these were goods vehicles. A further four collisions occurred when the cyclist and motorised vehicle were both turning left and three of these again involved a goods vehicle. In nine collisions the bicycle was struck in the rear by another vehicle and three of these involved goods vehicles.

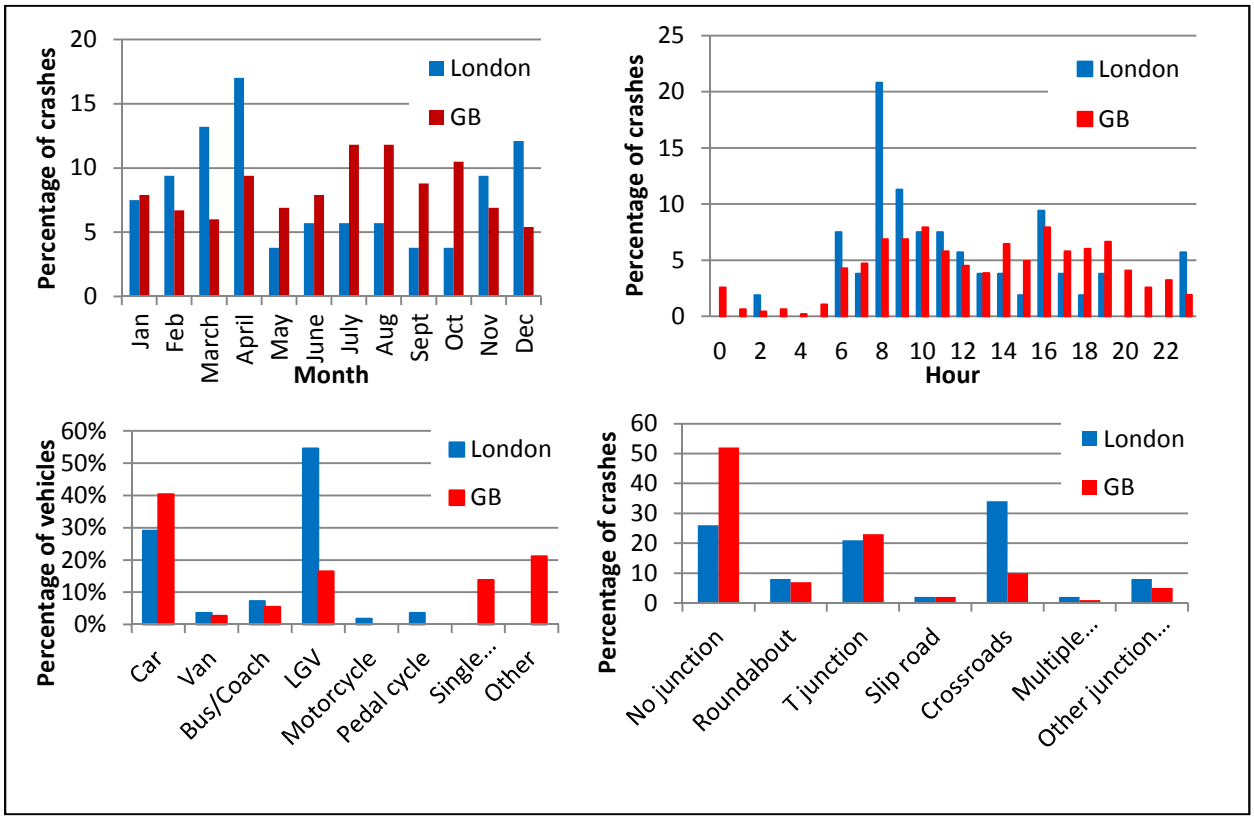

Figure 1. Comparison of London and GB accident circumstances

Table 2 shows the distribution of the relative movement between the cyclist and the large vehicles within the sample. There were 32 large vehicles, lorries and buses, of which the motion was identified in 30 cases. Most commonly the cyclist was undertaking – moving forward relative to the large vehicle – on the vehicles left-side, closest to the kerb. Out of the 32 cases there were 20 in which the cyclist undertook the large vehicle and a further three cases where the large vehicle overtook the cyclist. There were only two cases where the cyclist passed the large vehicle on its right side.

Direct and indirect vision of the cyclist

Each case file was examined in order to identify evidence relating to the location of the first contact between the large vehicle and the cyclist. Figure 2 shows the location of the first contact between the large vehicle and the bicycle for the 29 cases where there was information available within the case material. In the UK vehicles drive on the left side of the road and the most locations of the contact with the fatally injured cyclists were clustered around the front left corner either on the front or the side face of the large vehicle.

At the time of the analysis it was compulsory for large vehicles to be fitted with Class IV wide angle side mirrors and Class V close proximity side mirrors with very few exemptions and Table 3 shows that only one large vehicle was identified without one fitted. Fitting in a further three cases was unknown. Large vehicles manufactured after January 2007 were also required to be equipped with a front mounted Class VI mirror to identify close situated road users. Table 3 shows the numbers of contacts between cyclist and vehicle distributed to the relevant zone for each combination of mirrors. There were 26 large vehicles were the type of mirrors fitted was known and only one was not equipped with a class V mirror while only 14 were equipped with Class VI mirrors.

Eight of the 14 cyclists with first contacts on the side of the vehicle were in zones S1, S2 which were judged to lie within the vision zone of Class V mirrors according to the specification (European Commission regulation 2003/97/EC) and all of these vehicles were equipped with Class V mirrors. 13 of the 15 cyclists struck by the front of the vehicle were in zones F2 and F3, the area covered by Class VI mirrors and in eight of the 13 cases Class VI mirrors were available.

Table 1

Crash manoeuvre by collision partner

Manoeuvre	Diagram	Car	Van	Bus/ Coach	Goods vehicle >=3.5 T	Other	Total
Other vehicle turns left across the path of P/C		1			15	1	17 (32%)
Other vehicle runs into rear of P/C		2	1	1	5		9 (17%)
P/C and other vehicle travelling alongside each other		1			3	1	5 (9%)
P/C fails to give way or disobeys junction control & collides with other vehicle		4					4 (8%)
P/C and other vehicle collide when both turning left				1	3		4 (8%)
Head on collision between P/C and other vehicle		2					2 (2%)
Other vehicle fails to give way or disobeys junction control & collides with P/C		1			1		2 (2%)
No other vehicle hit by P/C. Various manoeuvres or loss of control only						2	2 (2%)
Other		4	1	1	2		8 (15%)
Total		15 (28%)	2 (4%)	3 (6%)	29 (55%)	4 (8%)	53 (100%)

Table 2
Relative movement of cyclists and large vehicles at point of collision

Relative motion	Number of crashes
Cyclist overtaking stationary large vehicle	2
Cyclist overtaking moving large vehicle	0
Cyclist undertaking stationary large vehicle	11
Cyclist undertaking moving large vehicle (not turning)	1
Cyclist undertaking moving large vehicle which was turning right	0
Cyclist undertaking moving large vehicle which was turning left	8
Both moving together (similar speed)	2
Large vehicle overtaking stationary cyclist	0
Large vehicle overtaking moving cyclist	3
Other crash configuration	3
Unknown	2
Total	32

Table 3
Mirror fitting and contact zone

Zone	Mirrors Fitted				Total
	No Class V or VI	Class IV or V only	Class IV, V & VI fitted	Not known	
F1	0	0	0	1	1
F2	1	0	3	1	5
F3	0	4	3	1	8
F4	0	1	0	0	1
S1	0	1	1	0	2
S2	0	2	4	0	6
S3	0	1	1	0	2
S4	0	2	2	0	4
Total	1	11	14	3	29

Table 4
HGV and 3.5-7.5 tonne truck types included in sample

HGV/3.5-7.5 tonne type	Image	Number of HGV/3.5-7.5 tonne	Side guard		
			Fitted	Not fitted	Unknown
Tipper		11 (37%)	0	9	2
Flat or drop side		5 (17%)	4		1
Box		4 (13%)	3		1
Skip carrier		3 (10%)		3	
Curtain sided articulated vehicle		3 (10%)	3		
Refuse Lorry		2 (7%)		2	
Tractor Unit only		1 (3%)		1	
Cement mixer		1 (3%)		1	
Total		30	10	16	4

SIDE UNDERRUN GUARDS

Table 4 shows the body style of the 30 goods vehicles involved in the collisions. 11 (37%) of the vehicles were tipper lorries and overall 19 of the vehicles – tipper, flat/drop side and skip carriers – were related to the construction industry and 12 were not fitted with side guards.

The trajectory of the interaction of the cyclist in the interaction with the lorry was established by reviewing the locations of contact marks and the final rest position of the cyclist. In 29 of the 30 cases the cyclist was run over by the wheels of the lorry sustaining the fatal injuries. Only four cyclists collided with the lorry in a zone that was a candidate and all of these were run over by a rear wheel.

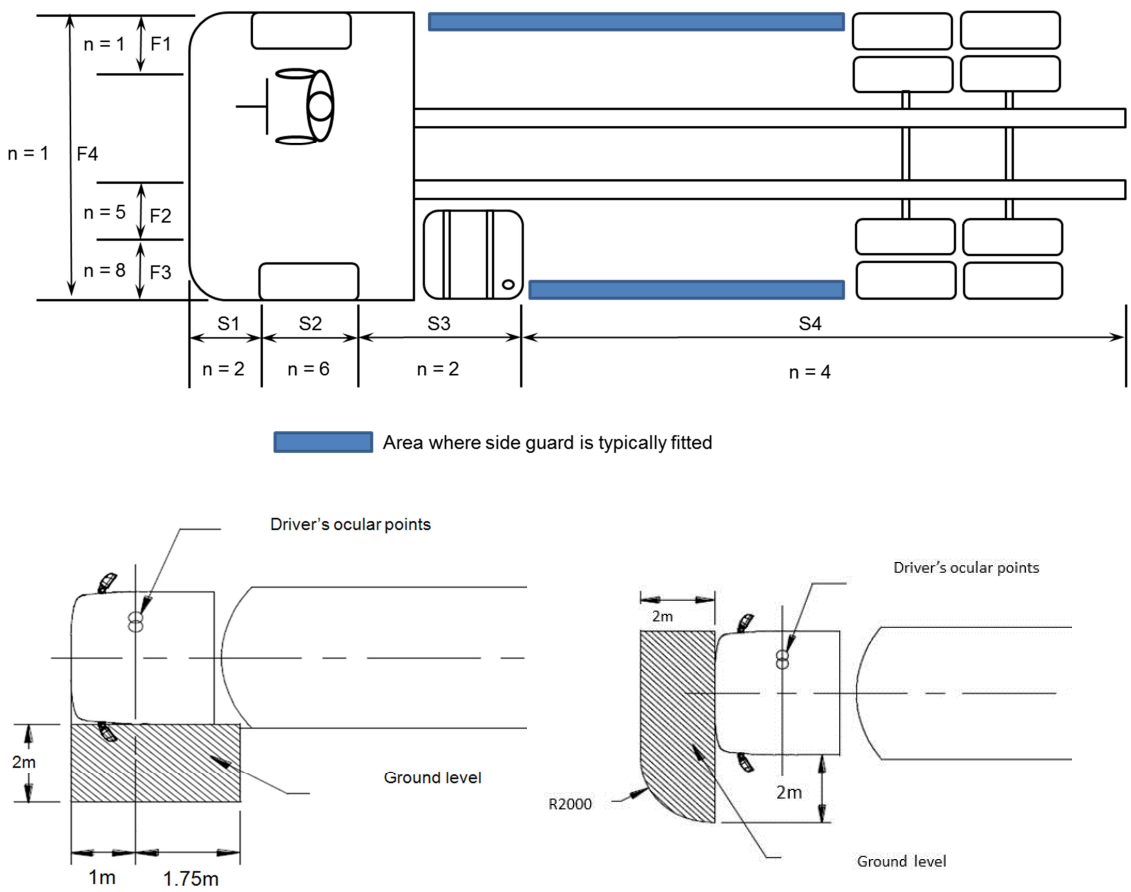

Figure 2: location of first contact point between large vehicle and bicycle and field of view of Class V mirror (left) and Class VI mirror (right) (European Commission regulation 2003/97/EC)

DISCUSSION

This analysis has been part of a wider research programme intended to form the evidence base for a range of actions that will improve the safety of cyclists in London and is reported by Talbot et al. 2014. The main objective was to identify beneficial interventions that could be applied within the context of the Metropolitan region. The approach, based on a systems analysis of all related factors, has enabled the principal road, vehicle and user factors to be fully established and their interactions to be identified. Using the systems analysis Talbot et al identify several risk factors related to the causation of lorry collisions with cyclists including

- conflicts between cyclists and lorries due to an overlap in peak lorry and cyclist traffic at specific times of the day and week
- installation of cycle lanes on roads with high lorry traffic
- road infrastructure design that increases the conflicts between cyclists and left-turning lorries
- lorry driver workload at busy junctions
- the entry points and design dimensions of Advanced Stop Lines
- late or no left turn signalling by lorry

This analysis has focussed on the interactions between cyclists and lorries to provide a more detailed description of the precise nature of the safety problem and support the development of new countermeasures.

The analysis is based on the data contained within the police accident records. In the UK fatal crashes are investigated by specialist police officers and the nature of the examination and reconstructions results in a detailed, reliable source of information. The 53 fatally injured cyclists in the sample form one of the largest groups of in-depth studies of cyclists available and the detailed nature of the data has been used to examine specific accident and injury risk factors.

The comparison between fatal cyclist collisions in London and elsewhere in Great Britain has identified that there are differences, mostly related to the characteristics of London. In particular a greater proportion of collisions occurred during weekdays, during the winter months, near junctions and on A-class roads. Therefore the overall distributions of the key accident risk factors may not be generalizable to the UK, however the present analysis focusses on the nature of the interaction between cyclists and large vehicles and therefore is highly relevant when considering the revision of the EU lorry dimensions (see EU Directive 96/53/EC). The data analysed only concerns fatally injured cyclists and therefore all crashes in the sample can be considered system failures, this means that the results cannot be taken to provide estimates of the effectiveness of safety systems.

The in-depth analysis of the fatal collisions indicates the typical sequence of events prior to the collision (see Figure 3). In Figure 3a the cyclist moves towards a lorry that is moving slowly or stopped at a junction and decides to pass on the left side, dedicated cycle paths or the availability of an advanced stop line may encourage the cyclist. The lorry driver intends to turn left but is either not indicating or the indicators are not visible to the cyclist. The cyclist moves to a zone around the front left corner of the lorry, either to the left side front or the front left, as illustrated in Figure 3b. The cyclist intends to continue ahead or to turn left but is not observed by the lorry driver who steers the lorry around the corner, being a long vehicle the front end takes a wider curve than the rear which moves close to the curb. The bicycle is struck at slow speed as the lorry moves away, the cyclist falls to the ground and passes underneath any side underrun guards to be run over by the following wheel either on a second front or a rear axle as in Figure 3c.

The conflict that leads to the collision typically occurs when the lorry driver is unable to perceive the presence of the cyclist and the cyclist does not recognise that the lorry is about to turn left. Schoon et al (2007) examined the Dutch national accident data to identify the frequency with which right-turning (in the case of the Netherlands) lorries collided with cyclists. They surmised that poor direct vision of the cyclist and insufficient field of view of side mirror systems was a relevant risk factor. Cook et al (2011) used human modelling methods and identified the presence of significant blind spots to the side of the lorry, even when equipped with both Class IV and Class V

mirrors. Niewohner and Berg (2005) similarly identified blind spots associated with side mirrors and proposed a range of countermeasures. Nevertheless there has been little research on the real-world performance of class VI mirrors.

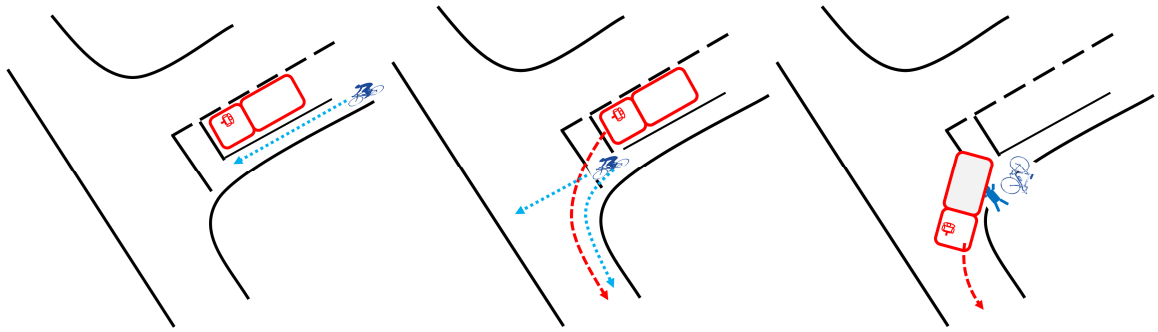

Figure 3a *Figure 3b* *Figure 3c*

Cyclist – lorry collision sequence

This analysis has shown that fatal collisions with cyclists occur despite the presence of Class V and Class VI mirrors and where contact zones are expected to be in view. 14 cyclists had their initial contact with the side of the lorry and eight of these were in zones expected to be covered by Class V mirrors. There was no definitive evidence available in the case reports of the reasons why the cyclists were not detected by the lorry drivers however some drivers reported the demands on attention of a busy traffic environment, others reported they did look at the mirrors but did not see the cyclist. It was observed that the frequent relative movement between the cyclist and the lorry meant that the cyclist would only be visible in a Class V mirror for a short period of time if moving at a normal speed due to the convex profile. The lorry driver would then have to be looking at the mirror during this time in order to detect the cyclist. Further anecdotal problems of the lorry driver identified in the case reports included incorrect mirror adjustment and incorrect understanding of the purpose of the mirrors.

The current EU requirements (2007/38/EC) for Class V mirrors were introduced in 2007 and the Directive included the requirement to retrofit older vehicles. Class VI mirrors were introduced in 2003 but there was no requirement for retrofit. This analysis has shown that Class VI mirrors were only fitted to 14 of the 29 lorries in the sample and 15 cyclists died after being struck by the front of the lorry. 13 of these were located in the zone covered by Class VI mirrors which were fitted to eight of these vehicles. This indicates that Class VI mirrors do not completely prevent fatal cyclist collisions with the front left of the lorry, cyclists can be located in this position yet still not be observed by the driver. There were six cases where no mirror was available however it cannot be concluded these would have been prevented the fatality.

Side underrun

Side underrun guards have been primarily developed to reduce the risks of injury to car occupants when in collision with the side of a lorry or its trailer. Pedestrians and cyclists are assumed to have protection by being diverted away from the rear wheels when colliding with the vertical face of the guard. This protection is determined on the basis that the cyclist or pedestrian will be vertical at the time of impact. The performance is specified in Council Directive 89/297/EEC which defines the dimensions of the underrun guard and requires the height above ground to be no more than 550mm. The present analysis has shown that 14 of the 29 fatally injured cyclists were in collision with the side of the lorry however only 4 of these contacts were in a zone covered by a side underrun guard and only one of these case files showed clear evidence of cyclist contact on the underrun guard. Overall the case reviews indicated that the cyclists struck by the side of the lorry, together with many of those struck by the front, were already on the ground before the approach of the following axle. Only 10 of the lorries were known to be equipped with side underrun guards, the remainder being considered exempt as a result of their purpose. It cannot be concluded that

side underrun guards do not offer any protection for cyclists since this data sample does not include collisions involving non-fatal cyclists. However the protection is considered to be limited and further investigation is recommended of the protection offered by a side guard to a cyclist lying on the ground.

CONCLUSIONS

This paper has examined the case reports of 53 fatally injured cyclists died in London between 2007 and 2011. The main conclusions are

1. Lorries are the most frequnt collision partner and further actions are necessary to reduce crsh risks
2. There is no single countermeasure that is available that will prevent all fatal cyclist collisions with lorries, a systems approach is required including veicle design measures
3. The most common crash scenario involves a slow-moving lorry turning across the path of an unidentified cyclist, the cyclist having a contact around the are of the front left corner of the lorry, falling off the bicycle and then being run over by the lorry wheels.
4. Even when Class V and Class VI mirrors are available on trucks the cyclist may not be observed by the driver
5. Many lorries are not equipped with side underrun guards
6. Side underrun guards do not prevent cyclists being run over by the rear wheels of lorries

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Development of a Test Procedure for Driver Assist Systems Addressing Accidents Between Right Turning Trucks and Straight Driving Cyclists

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ABSTRACT

Accidents between right turning trucks and straight riding cyclists often show massive consequences. Accident severity is much higher than in other accidents. The situation is critical especially due to the fact that, in spite of the six mirrors that are mandatory for ensuring a minimum field of sight for the truck drivers, cyclists in some situations cannot be seen or are not seen by the driver. Either the cyclist is overlooked or is in a blind spot area that results from the turning manoeuvre of the truck and its articulation if it is a truck trailer or truck semitrailer combination.
At present driver assistance systems are discussed that can support the driver in the turning situation by giving a warning when cyclists are riding parallel to the truck just before or in the turning manoeuvre. Such systems would generally bear a high potential to avoid accidents of right turning trucks and cyclists no matter if they ride on the road or on a parallel bicycle path. However, performance requirements for such turning assist systems or even test procedures do not exist yet. This paper describes the development of a testing method and requirements for turning assist systems for trucks.
The starting point of each development of test procedures is an analysis of accident data. A general study of accident figures determines the size of the problem. In-depth accident data is evaluated case by case in order to find out which are representative critical situations. These findings serve to determine characteristic parameters (e.g. boundary conditions, trajectories of truck and cyclist, speeds during the critical situation, impact points). Based on these parameters and technical feasibility by current sensor and actuator technology, representative test scenarios and pass/fail-criteria are defined.
The outcome of the study is an overview of the accident situation between right turning trucks and straight driving cyclists in Germany as well as a corresponding test procedure for driver assistance systems that at this first stage will be informing or warning the driver. This test procedure is meant to be the basis for an international discussion on introducing turning assist systems in vehicle regulations.

INTRODUCTION

The share of accidents at crossings and intersections between right turning trucks and cyclists that move straight is rather low with regard to other accident types. However these accidents are particularly severe if the cyclist is hit and as a consequence overrun. Such cases always cause high public awareness due to the appalling implications for the victim as well as for the involved truck driver so that countermeasures are searched for a long time.
Already in the year 2004 the German Federal Highway Research Institute (BASt) published a study on the risk for pedestrians and cyclists at crossings due to right turning trucks [DEKRA (2004)] which was carried out by DEKRA accident research on behalf of BASt. This report especially depicted the lacking fields of vision for the truck driver to the front and to the right side (for left hand traffic).
In the meantime improvements for the direct field of vision and for the indirect vision via mirrors have been implemented with the aim to reduce blind spots to a minimum. With the European directive 2003/97/EC a larger field of vision became mandatory so that a truck normally has to be equipped with six mirrors in order to cover the required areas of the field of view. In addition the European directive 2007/38/EC was entered into force. Trucks above 3.5 t with their first registration in the year 2000 or later had to be retrofitted with corresponding mirrors on the right side until end of March 2009.
The mirrors however are only able to serve as useful remedy in eliminating blind spots if they are adjusted correctly if the driver looks into the mirror and if he, depending on what he has detected, takes the appropriate action with regard to the following driving manoeuvre.
Another project on behalf of BASt [TU BERLIN (2014)] ("Blind spot – conflict between right turning truck and straight driving cyclist") considered, which issues in terms of the construction and operation of a junction are relevant if we look at blind spot accidents or road traffic safety. In addition it was examined in a simulator study if driver assistance systems could possibly contribute to alleviate the conflict in question. As main results, the regarded accidents were widely spread over built-up areas and both traffic participants (truck and cyclist) were mostly moving previous to the collision. Thus there was no standstill at the junction before the accident happened.
At present there is an ongoing discussion on turning assist systems, which warn the truck driver in the turning situation if a cyclist might be overlooked. Accident research of German insurers [HUMMEL et al. (2011)]

estimated ex-ante that a generic and best performing turning assist system (if the whole truck fleet is equipped) which scans the areas in front of and at the right side of the truck and which warns the driver or hinders the truck to move on would avoid about 40 % of the truck-pedestrian and truck-cyclist accidents.
However, there are no performance requirements for turning assist systems and on how they are supposed to operate yet. But the presence of such requirements would be a prerequisite for a possible promotion of systems and the basis for a possible mandatory installation by legislation.

Starting Point

Since there is no turning assist system on the market up to now it is on the one hand difficult to assess to which extent a system would be able to mitigate a certain critical turning situation and on the other hand to develop performance requirements which a system would have to fulfil. At least truck manufacturers revealed that systems are at stage of development.
The aim to avoid and mitigate the accidents with severe consequences between right turning trucks and cyclists is also pursued by the German Ministry of Transport and Digital Infrastructure (BMVI). How to tackle the problem of those blind spot accidents and if turning assist systems might help was also discussed with relevant stakeholders at round tables in April 2012 and May 2014 initiated by BMVI. It is planned to make a proposal for regulating a test procedure for turning assist systems on international level to introduce requirements in vehicle type approval regulations. For that purpose BASt was assigned by BMVI to develop a corresponding test procedure based on existing knowledge and taking in to account the state of the art technology, accident figures and circumstances of the accidents in question.
Thus BASt is actively developing a test method for turning assist systems for trucks since mid of the year 2014 addressing the following tasks:
At the beginning a thorough analysis of recorded accidents has to be carried out in order to identify the essential situations and accident constellations from which parameters for the test method have to be derived:

- Are vulnerable road users who become injured or killed by right turning trucks mostly cyclists or do pedestrians also have to be paid attention to?
- Is it allowed to restrict a testing procedure to daytime lighting conditions or do also accidents during night-time have to be taken into account?
- Initial speeds and collision speeds of cyclist and truck are of interest.
- How do cyclist and truck behave relatively with regard to their trajectory?
- Which typical turning radii are taken by trucks?
- What are typical lateral distances between truck and cyclist?
- Do obstructions for the view of the truck driver play any role?
- Should a testing procedure focus on trucks above 7.5 t or should lighter trucks be included as well?

The answers to these questions will deliver findings that allow to establish a few representative test cases for which boundary conditions, test parameters and criteria for pass/fail can be fixed.

ACCIDENT ANALYSIS

In 2010, 1,994 cyclists were killed in road accidents in the EU-24 countries, this represented 6.8 % of all road fatalities. For comparison: 381 cyclists were killed in road accidents in Germany in 2010 and 406 in 2012, which corresponds to 10.4 % (2010) and 11.3 % (2012) of all road fatalities, respectively [CANDAPPA N. et al. (2012)].

Road traffic accidents between heavy goods vehicles (HGVs over 3.5 tons maximum permissible gross vehicle weight) and cyclists resulted in 296 fatalities for 2010, as shown in Figure 1.

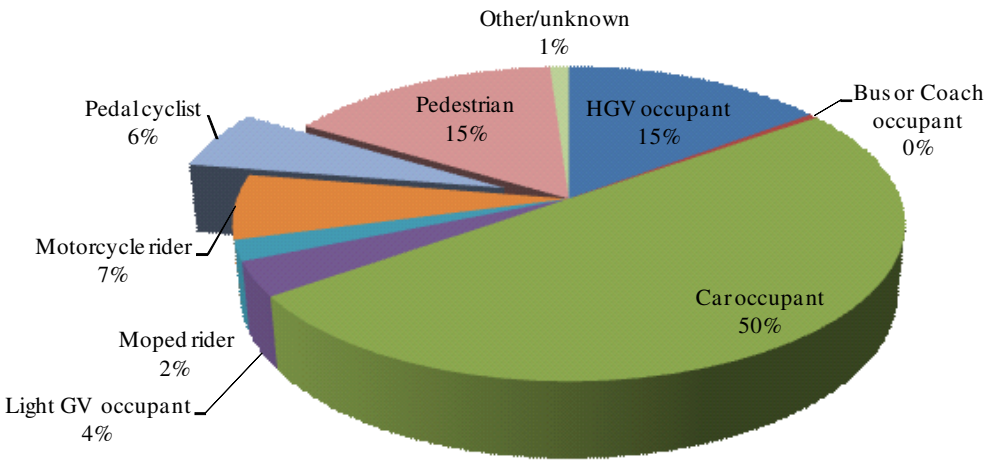


Figure 1: **Fatalities in accidents involving HGVs and in accidents involving buses or coaches, by road user type (Data: EU-24; 2010 (for EE, NI, NL and SE from 2009); Source: CARE Database/EC)**

It is not possible to identify the exact number and severity of this accident situation in the German national road accident statistics because the conflict situation "blind spot" is not explicitly quantified. Therefore, an extrapolation [SCHRECK & PÖPPEL-DECKER (2014)] for the year 2012 was carried out to regarding the relevance of the conflict situation. The extrapolation shows that around 640 injury accidents resulting in 23 fatalities and another 118 seriously injured cyclists are due to the accident situation between right-turning trucks and driving straight cyclists. In the same configuration, the number of injured, severely injured and killed pedestrians is a magnitude lower (55 injured, 16 sesiously injured, 4 fatalities), so pedestrians will be neglected for the following considerations.

Thus, accidents involving right turning trucks represent 1 % of all bicycle accidents, and about 6 % of cyclists killed. It became clear that the "light" trucks, as defined as vehicles weighing less than 7.5 tones permissible gross weight, only slightly contribute to the serious accidents. In 549 collisions with "light" trucks, one cyclist was killed. 90 % of the accidents with killed cyclists in "blind spot" situations are accidents with "heavy" trucks (more than 7.5 tones permissible gross weight). So, in every 10 injury accidents between a “heavy” truck and a cyclist in a "blind spot" situation on average about one cyclist is killed. That shows the accident severity in terms of seriously or fatally injured cyclists that are involved are much higher than in accidents of other traffic participants in other accident situations.

Within the research project this paper is based on ([SCHRECK & SEINIGER (2014)]), accidents are analyzed in detail. The study uses police-reported accident data from the German Federal Statistical Office. Furthermore the German In-Depth Accident Study (GIDAS) and the German Insurers accident database (database UDV) was used. For the detailed analysis of accidents in GIDAS and in the database UDV, 120 accidents were available.

Accident databases GIDAS and UDV allowed for the detailed analysis of the speeds of the truck and bicycle, the driving behavior of the truck before and during the collision, the driving characteristics of the truck before the collision with respect to the infrastructure and the type of junction. The point of collision of the cyclist hitting the truck and potential visual obstructions in the infrastructure were available as well. Figure 2 shows as an example for the evaluation of accident data the difference in speed between trucks and cyclists, absolute speeds as well as relative speeds.

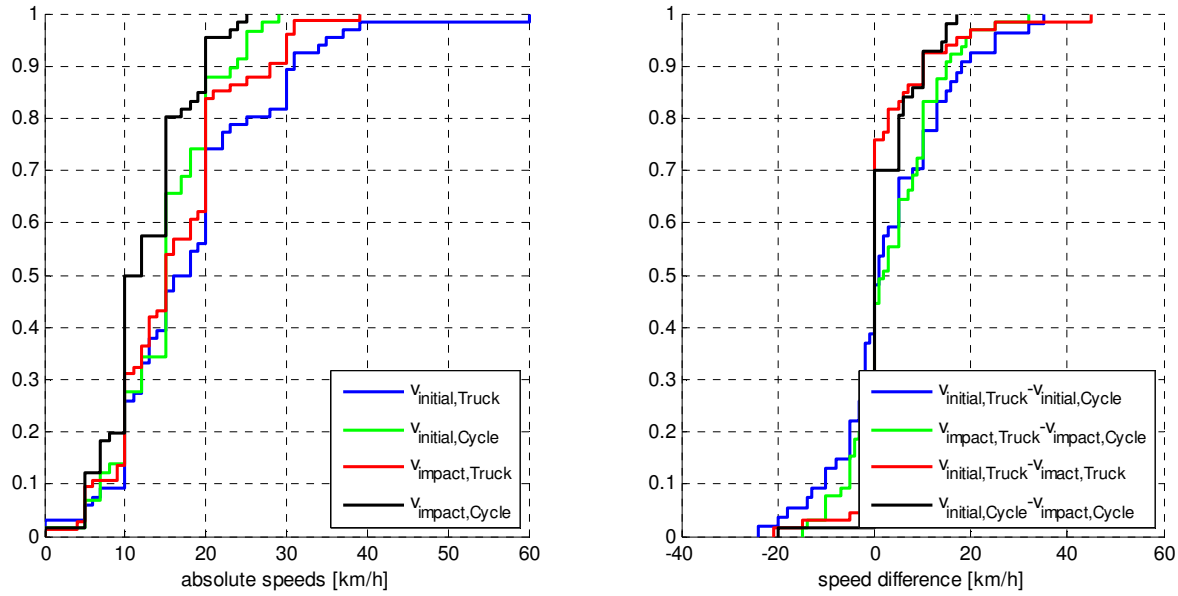


Figure 2: **Speeds and speed difference [km/h] between trucks and cyclists [SCHRECK & SEINIGER (2014)]**

Main findings from the accident analysis are:

- Truck speeds are below 30 km/h in more than 90% of all cases (as shown in Figure 2)
- Bicycle speeds are below 20 km/h in more than 80% of all cases (as shown in Figure 2)
- Bicycle and truck did not change their speeds during the accident in about two thirds of all cases.
- Visual obstruction and / or bad visibility due to weather (night, rain etc.) was not found to be an important factor.

With these results, it was possible to classify the accidents roughly into four scenarios. Figure 3 shows a sketch of this classification of the information collected, with the speed and track behavior of the truck and the lateral distance between truck and cyclist.

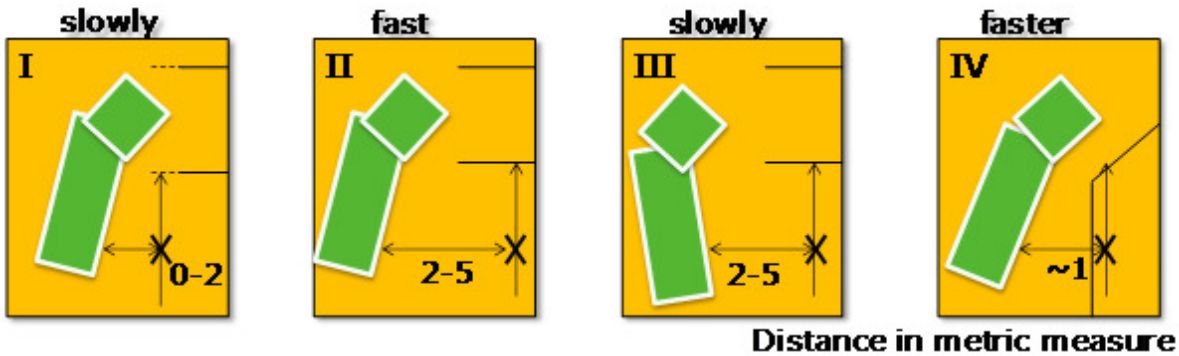


Figure 3: **Accident scenarios [SCHRECK & SEINIGER (2014)]**

DEDUCTION OF TEST CASES

The benefits of a turning assistance system for trucks based on the accident increases with increasing overlap between the standards set by the requirements of the test method for the system and the conditions in the accident situations.

Once a parameter space for typical accidents between trucks and cyclists is outlined, the greatest possible coverage of this parameter space by as few as possible test cases needs to be achieved.

Due to the missing experience with a turning assistance, the use of emergency braking for safety reasons (possible false activations) is initially not advisable. High-intensity information (warnings) are in the course of a driving situation only justified if the probability for an accident is high - otherwise vehicle drivers tend to ignore or disable the system alerts.

In general, driver reactions to any information (high or low threshold / warning or information) can be expected only after a reaction time. This response time is much longer than the time required to avoid the accident in many situations - the accident cannot be avoided despite the warning.
A (low threshold) informational assistance system, however, can be activated sufficiently early, as it helps the driver rather than annoys him. Such an approach provides a useful solution if the information is made available to the driver in an appropriate manner. The identification of an appropriate transfer of information in terms of human machine interaction is not part of this work.
Since the information given by turning assistance systems needs to be reliable, effective recognition of the objects is required. Specifications for sensors, viewing angles, and detection times can be derived from this detection requirement.
The definition of relevant detection areas is done via a parametric kinematics model of the truck and bicycle trajectories during an accident, and taking into account the needed reaction times (of the driver) and stopping distances (of the truck). Test cases then are defined in such a manner that the whole detection area around the truck is covered by as little as possible test cases.
An accident between truck and bicycle happens when the collision partners are at a time in the same place, so the trajectories of bicycle and any give point of the truck intersect in space and time. In first approximation, the bicycle motion can be described by a straight line. The movement of the truck is divided into two basic movements: first, it is a straight line as well, parallel to bicycle movement line, which at a certain time changes towards a turn. The turn is considered to have a constant radius for reasons of simplicity. Both trajectories intersect at the theoretical collision. Accident analyses show that obstructions of sight, night and bad weather are not an essential factor for these accidents.
The following parameters have been derived from accidentology:

- Driving speed truck: v_{Truck} = 10, 20, 30 km / h
- Driving speed bike: v_{Cycle} ranges from 10 to 20 km / h
- Lateral distance of the initial trajectories (with respect to the right edge of the truck): A = 1.5 to 4.5 m
- Truck turning radius R = 5, 10, 25 m
- Maximum lateral acceleration of the truck: $a_y < 3{,}2$ m/s²
- Impact location of the bike onto the truck: L = 0 to 6 m
- Required reaction time after driver information: 1,4 s
- Braking performance of driver after reaction time: 6 m/s²

A sketch of the situation is shown in *Figure 4*.

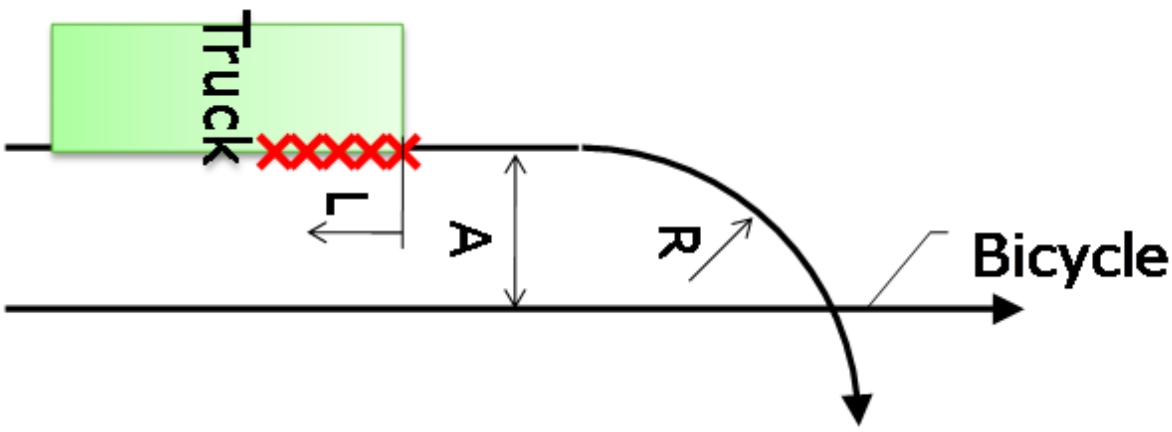
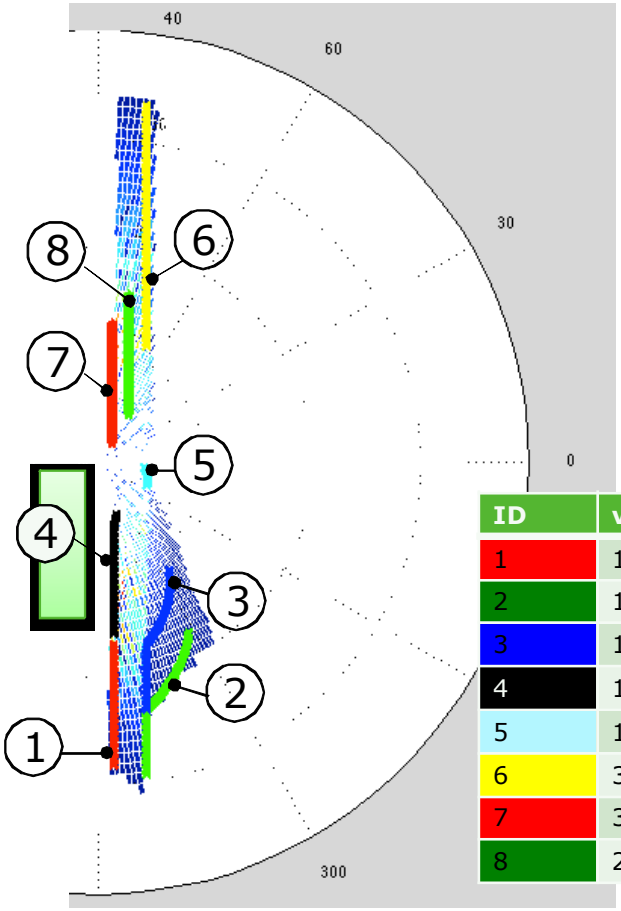


Figure 4. **Sketch summarizing the relevant parameters describing the accident situation.**

The necessary viewing area of a sensor is the hull around all bicycle trajectories relative to the front inner corner of the truck. All bicycle trajectories are determined assuming a full combination of all parameters, until the time when warning or information is still feasible, and starting with for instance 4 s time to go for both vehicles up to the theoretical collision.



ID	v_{Truck}	v_{Cycle}	R	A	L
1	10	20	5	1,5	6
2	10	20	10	4,5	6
3	10	20	10	4,5	3
4	10	20	10	1,5	0
5	10	10	5	4,5	0
6	30	10	25	4,5	0
7	30	20	25	1,5	6
8	20	10	10	3	0

Figure 5. **Bicycle trajectories relative to the front inner corner of the truck (=center of polar diagram), and proposed test cases (ID = 1 to 8). Field size in the polar diagram is 1m and 1°.**

The required viewing area as well as appropriate test cases to check bicycle detection in the viewing area are shown in Figure 5. Note that in theory a bicycle detection at the end of the nearer end of the trajectory satisfies the necessary detection criterion; it is not required to inform the driver already at the point where the bicycle is at the far end of the trajectory (which corresponds to 4 seconds TTC before the last possible information).

TESTING

Concept

Purpose of testing is to verify whether the system informs the driver, at least at the latest time at which avoidance is still possible, defined by the braking performance, driver reaction time and kinematics as laid out in the preceeding section.
This means that an object which sufficiently appears to any sensor technology as a cycle needs to be moved and synchronized to the truck according to the proposed test cases.
Since an information must be given at a time when the accident is still comfortably avoidable, all tests can be conducted without impacts, thus allowing for the use of a real bicycle (and possibly human dummy) rather than a specific bicycle dummy.

Test Tools and Equipment

For tests of pedestrian emergency braking in cars using the Euro NCAP test procedure, a propulsion system for the pedestrian dummy is used. This system can determine the speed of a vehicle over several light barriers and thus synchronize the movement of the dummy very closely with the moving vehicle, so the development of test tools does not need to start from scratch. Measurement equipment in the truck is not required. For cost reasons, it may be useful to establish a simplified test tool and not to use the said motion system - but for feasibility studies and the identification of the tolerable error in testing it is a suitable tool.
While the propulsion system is commercially available, testing with parallel trajectories requires a few modifications, which have been prototypically established at BASt.

The bicycle is guided by the motion system, therefore a review of the trajectory is not required. For checking the trajectory of the truck itself, an alley from pylons or "Botts' Dots" can be used to visually determine whether the vehicle had maintained the required trajectory.
Video recording and time synchronizing equipment might be required to check whether the information was given at an appropriate time.

Necessary Modifications to the Propulsion System

In a first step, the use of a pedestrian propulsion system, for instance "4active systems surfboard" (see Figure 6) could be used. This system is state of the art and will be used by several test labs for Euro NCAP AEB pedestrian testing (starting in 2016).

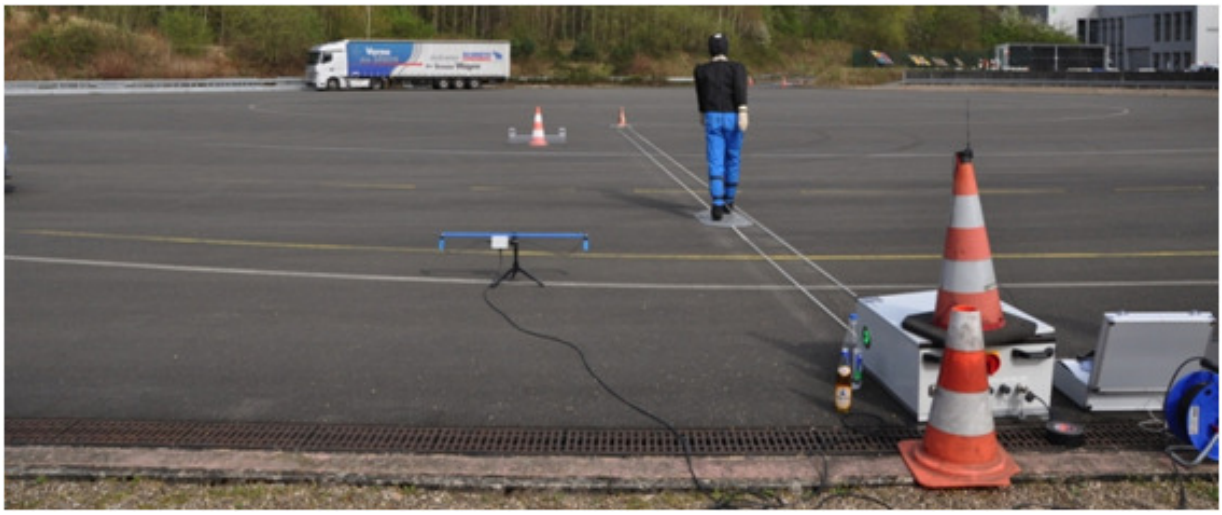


Figure 6. **4active systems "Surfboard" dummy propulsion system.**

This propulsion system has been designed to test with a crossing pedestrian. Magnets fit the pedestrian dummy to a platform. The platform is driven by a circular timing belt that of course requires bearings on both sides. When testing longitudinal scenarios (as is the case for the turning assistance systems), counter bearing or drive mechanism might disturb the vehicle's sensors, and since the belt is used in a circle, the available dummy displacement is not sufficient.
BASt therefore developed a method to use the propulsion system with a linear belt. This removes any bearing out of the sight of the vehicle sensors and doubles the effective belt length but also takes away lateral positional accuracy and requires manual transportation of the dummy to its' origin during testing.
A mechanism to fit a bicycle to the propulsion system also required and currently under development.

Test Track Requirements

As for all testing, a test track is required; it needs to be sufficiently large to fit all test cases. A typical test will consist of an acceleration phase for the truck (phase 1), a phase where the truck is moving alone at a stabilized speed (phase 2), and a phase where the bicycle movement is synchronized to the truck speed (phase 3). The space demand on the test track for phase 3 can be calculated from the kinematics of test cases as defined in *Figure 5*: the maximum space requirement is 44 m x 4.5 m excluding the size of the truck. The proposed tests therefore can be conducted even on small test tracks.

SUMMARY AND PERSPECTIVE

Turning maneuvers with collisions between trucks turning right and cyclists usually have serious consequences for the vulnerable road user. In the past the safety of vulnerable road users was raised by an improvement of the truck driver's vision by increasing the number of mirrors and by equipping trucks with side underrun protection. Since turning accidents still happen and driver assistance systems have been introduced in a lot of vehicle segments it seems to be obvious to use such assistance to address turning accidents between trucks and cyclists.
In order to stimulate system development, e. g. by means of incentives or legislation, performance requirements and corresponding test procedures are necessary. Aim of the work carried out by BASt therefore was to develop such requirements and a possible test method.
Starting from an in depth analysis of accidents, parameters and circumstances being characteristic in accidents with cyclists and right turning trucks were identified. Data at hand shows that the velocity is up to 30 km/h for the truck and up to 20 km/h for the bicycle. At the beginning of the critical situation the truck and the cyclist move parallel with a lateral distance of 1.5 m up to 4.5 m. Although there is no precise information about curve

radii it can be assumed that the inner side of the truck propagates predominantly on a radius between 5 m and 10 m since accidents occur in built-up areas. However, there can be junctions with triangular traffic islands where the radius is up to 25 m. Obstructions for the view of the truck driver were present only in a few cases. Also bad weather conditions or darkness hold only for a small fraction of accidents.
Considering driving dynamics in terms of reaction time and stopping distance for the given initial conditions leads to the conclusion that only an early and not annoying driver information can serve as effective function that assists the driver avoiding the accidents. For automatic braking being a massive intervention too less experience has been gained so far. Well known high priority warnings that are given at a late point in time would have no effect since the driver reaction time lasts that long that an emergency braking manoeuvre would start too late. So those variables and parameters that allow for comfortable braking can be used in a kinematic model to calculate the areas around the truck that have to be covered by a sensing system which has to detect cyclists in such a way that the driver is informed about the cyclist in time. Within the parameter range those special parameter combinations can be selected as test cases which cover the necessary sensing area with as less test cases as possible. A method to identify these test cases and the resulting test cases that are proposed for the test procedure were described in detail. A proposal how to effectively execute driving tests by using existing test tools coming from testing of automatic emergency braking systems to protect crossing pedestrians was described as well.
After having fixed the set of test cases and parameters a validation phase has to follow. For that purpose trucks equipped with turning assist system have to be used. It has to be examined if the system is able to inform the driver when necessary and how far it is still annoying due to possibly given false warnings.
It can be expected that a turning assist system that fulfils the requirements and tests elaborated in this study will have a very positive influence on accident figures concerning right turning trucks and cyclists.

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Sensitivity of Q10 and Q6 chest measurements to restraint and test parameters

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ABSTRACT

Upcoming test procedures and regulations consider the use of Q-dummies. Especially Q6 and Q10 will be introduced to assess the safety of child occupants in vehicle rear seats. Therefore detailed knowledge of these dummies is important to improve safety. As recent studies have shown, chest deflection measurements of both dummies are influenced by parameters like belt geometry. This could lead to a non optimized design of child restraint systems (CRS) and belt systems. The objective of this study is to obtain a more detailed understanding of the sensitivity of chest measurements to restraint parameters and to investigate the possibilities of chest acceleration as an alternative for the assessment of chest injury risks.
A study of frontal impact sled tests was performed with Q6 and Q10 in a generic rear seat environment on a bench. Belt parameters like modified belt attachment locations were varied. For the Q6 dummy, different positioning settings of the CRS (booster with backrest) and of the dummy itself were investigated. The Q10 dummy was seated on a booster cushion. Here the position of the upper belt anchorage point was varied. To simulate the influence of vehicle rotation in the ODB crash configuration, the bench was pre-rotated on the sled in additional tests with the Q10. This configuration was tested with and without pretensioner and load limiter.
Chest deflection in Q6 showed a high sensitivity to changes in positioning of the CRS and the dummy itself. A more slouched position of the CRS or dummy resulted in a reduction of measured chest deflection, whereas chest acceleration increased for a more slouched position of the CRS. Chest deflection in Q10 is sensitive to belt geometry as already shown in other studies. In a more outboard position of the shoulder belt anchorage the measured chest deflection is higher. Chest acceleration shows the opposite tendency, which is highest for the rearmost location of the upper belt anchorage. On a pre-rotated bench the highest chest deflection within this test series was observed without load limiter/pretensioner and an outboard belt position. By optimizing the belt location and the use of pretensioner/load limier the chest deflection was significantly reduced.
For the Q6 a criterion based on chest acceleration as well as deflection measured at two locations might be the most reliable approach, which requires further research with an additional upper deflection sensor. In the Q10 the measured chest deflection does not always correctly reflect the severity of chest loading. The deflection is depending on initial belt position and restraint parameters as well as test conditions, which result in different directions of belt migration. A3ms chest acceleration might be a better indicator for severity of chest loading independent of different conditions like belt geometries. However, in some cases the benefit of an optimized restraint system could only be shown by deflection. These findings suggest that further research is needed to identify a chest injury assessment method, which could be based on deflection as well as acceleration or other parameters related to belt to occupant interaction.

INTRODUCTION

To assess the safety of child occupants in the rear seat the dummies Q6 and Q10 are considered in upcoming test procedures (EEVC WG12 2015, EEVC WG12/18 2008). Recent studies with these dummies have shown sensitivity of chest deflection to parameters like belt path. Due to this, the design of protection systems for children based on chest deflection might be misguiding. An alternative to evaluate the chest injury risk could be the assessment of chest acceleration instead. Therefore, the objective of this study is to get a better and more detailed understanding of the sensitivity of chest measurements to test parameters.
Other studies with the Q10 have shown a high sensitivity of chest deflection to restraint parameters like belt geometry (Bohman et al. 2012, Croatto et al. 2013). However, chest acceleration was not discussed in these studies. The objective of this study was to investigate sensitivity of chest deflection and chest acceleration in dummies Q6 and Q10 to test conditions and restraint parameters. The main focus of the Q6 study was to investigate the influence of the position of the dummy in the CRS and position settings of the CRS itself. The focus of the Q10 study was the investigation of chest assessment parameters to belt geometry in a test configuration without backrest.

METHODOLOGY

For this purpose a series of sled tests was conducted with the dummies Q6 and Q10. A generic rear seat environment was created represented by a bench with deformable cushion based on ECE-R 129 specifications, mounted on a

deceleration sled with a hydraulic deceleration system (Figure 1). The test environment included a three-point-belt system with a 4 kN load limiter and a retractor pretensioner in the baseline configuration. The upper belt anchorage attachment point was variable to investigate different belt geometries. The pulse used for testing was based on the x-component of a 64 km/h ODB Euro NCAP deceleration pulse of a midsize vehicle with a peak of 30g and duration of 125 ms. The two dummies could be tested in parallel on the sled on separate benches. The Q10 dummy was positioned on a booster without backrest. The Q6 dummy was placed in a booster with backrest.

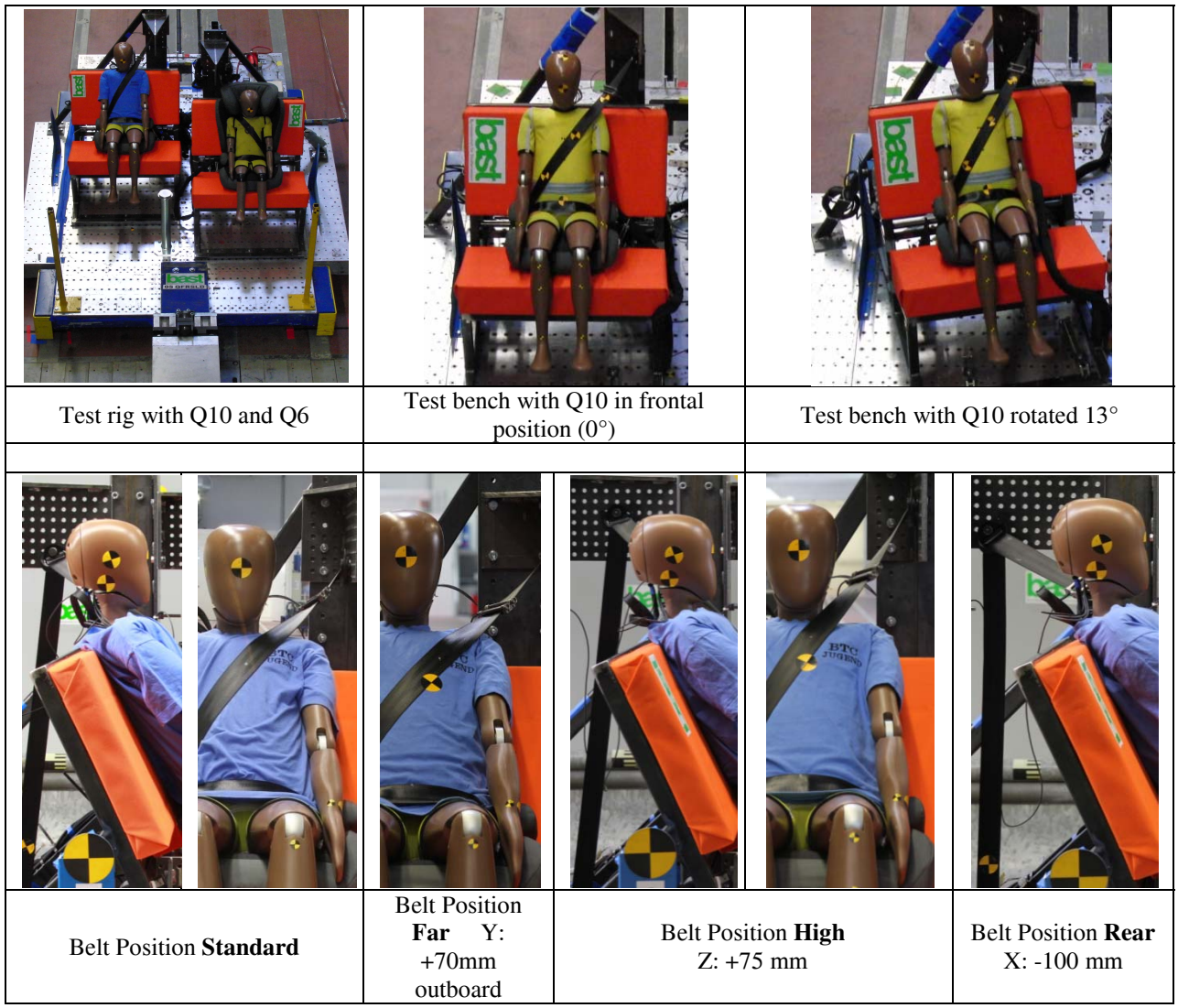
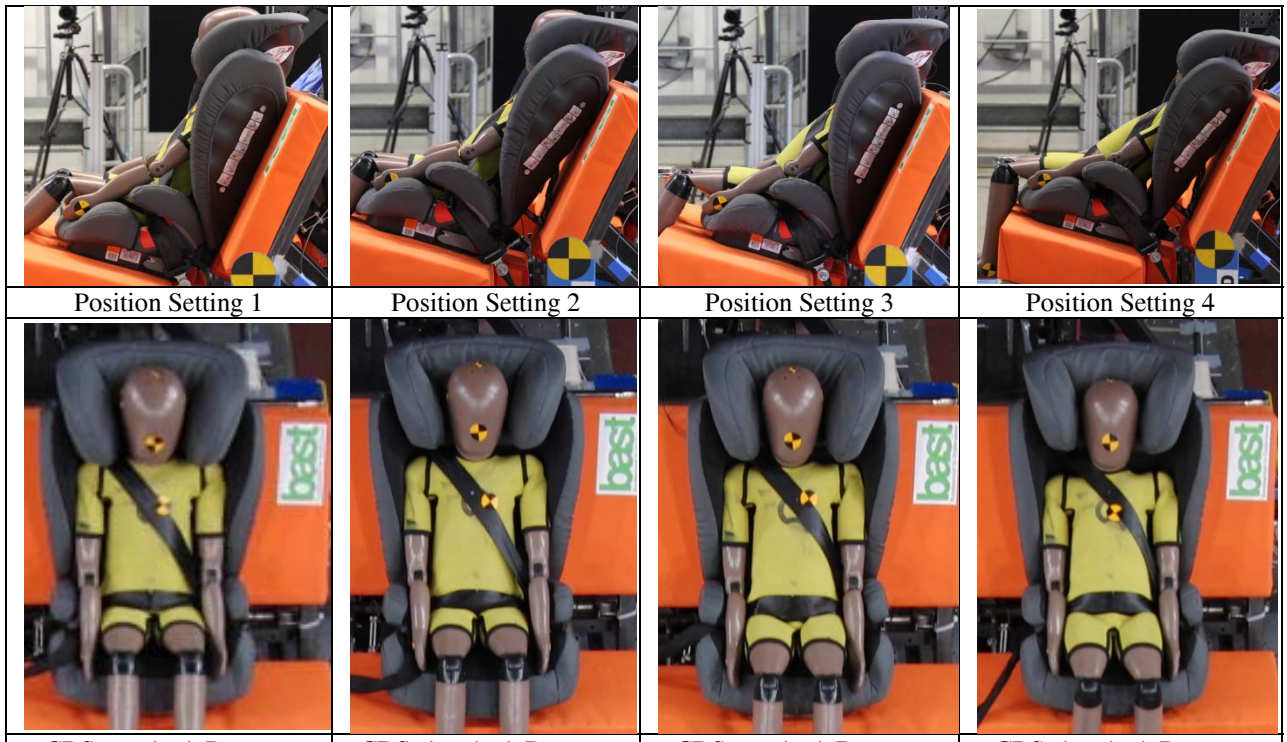


Figure 1. Test rig for sled tests with Q6 and Q10 dummies.

Test parameters

For the Q6 dummy a study of different positioning settings of the dummy and/or CRS was conducted, using a booster with backrest, a standard position of the upper belt anchorage point and a 4 kN load limiter with a pretensioner. Figure 2 shows the CRS and dummy in standard position (Setting 1). By placing a tube with a diameter of 70 mm behind the dummy in the CRS a slouched dummy position was defined (Position Setting 3). This led to a forward movement of the knees of 68 mm in x. The tube was removed before testing. When using the relax function of the CRS the backrest joint of the CRS was moved 72 mm in x direction, which was defined as slouched CRS position (Position Setting 2). The positioning of both, dummy in slouched position and CRS in slouched position resulted in a forward movement of the knees in comparison to the standard position of 134 mm in x-direction (see Figure 2 Setting 4). The parameters of all tests are shown in Table 1.



Position Setting 1	Position Setting 2	Position Setting 3	Position Setting 4
CRS standard, Dummy standard	CRS slouched, Dummy standard	CRS standard, Dummy slouched	CRS slouched, Dummy slouched
	Backrest joint: X: 72 mm forward	Knee joint: X: 68 mm forward	Backrest joint: X: 72 mm forward Knee joint: X: 134 mm forward

Figure 2. Different combinations of position setting of the Q6 dummy and CRS

Table 1: Test matrix

Test	Dummy	Load Limiter	Pretensioner	Orientation	CRS	ISOFix	Belt Position	CRS Setting	Dummy Setting
1	Q6	4 kN	Yes (20ms)	frontal (0°)	booster with backrest	no	standard	standard	standard
2	Q6	4 kN	Yes (20ms)	frontal (0°)	booster with backrest	no	standard	slouched	standard
3	Q6	4 kN	Yes (20ms)	frontal (0°)	booster with backrest	no	standard	standard	slouched
4	Q6	4 kN	Yes (20ms)	frontal (0°)	booster with backrest	no	standard	slouched	slouched
5	Q10	4 kN	Yes (20ms)	frontal (0°)	booster w/o backrest	no	high	standard	standard
6	Q10	4 kN	Yes (20ms)	frontal (0°)	booster w/o backrest	no	far	standard	standard
7	Q10	4 kN	Yes (20ms)	frontal (0°)	booster w/o backrest	no	rear	standard	standard
8	Q10	No	No	frontal (13°)	booster w/o backrest	yes	far	standard	standard
9	Q10	4 kN	Yes (20ms)	frontal (13°)	booster w/o backrest	yes	far	standard	standard
10	Q10	4 kN	Yes (20ms)	frontal (13°)	booster w/o backrest	yes	standard	standard	standard

In the tests with the Q10 dummy the effect of different belt geometry on dummy chest measurements were investigated by changing the upper belt anchorage point. Four different locations of the upper anchorage point were defined: “standard”, “far”, “high” and “rear” as indicated in Figure 1. The geometry of the belt, defined different attachment points of the upper anchorage and the location of buckle and lower belt anchorage, were based on average measurements taken from real vehicles confirmed by measurements of a study by Reed et al. (2008). From the standard position of the upper belt anchorage point position “far” is defined by moving the attachment plate 70 mm outboard. For position “high” the D-ring attachment screw was moved 75 mm upwards from the standard position and the “rear” position is defined as 100 mm behind the standard position keeping the same vertical height (see Figure 2)

To investigate the sensitivity of chest deflection measurement in oblique loading condition additional tests were conducted with the Q10 with a 13° pre-rotated bench to simulate the vehicle rotation in the ODB crash configuration. In these tests a backless booster with ISOFix attachment was used. Parameter variations in this test configuration include a modification of upper belt anchorage position. In addition the tests were conducted with and without load limiter and pretensioner. The test parameters are summarized in Table 1.

RESULTS

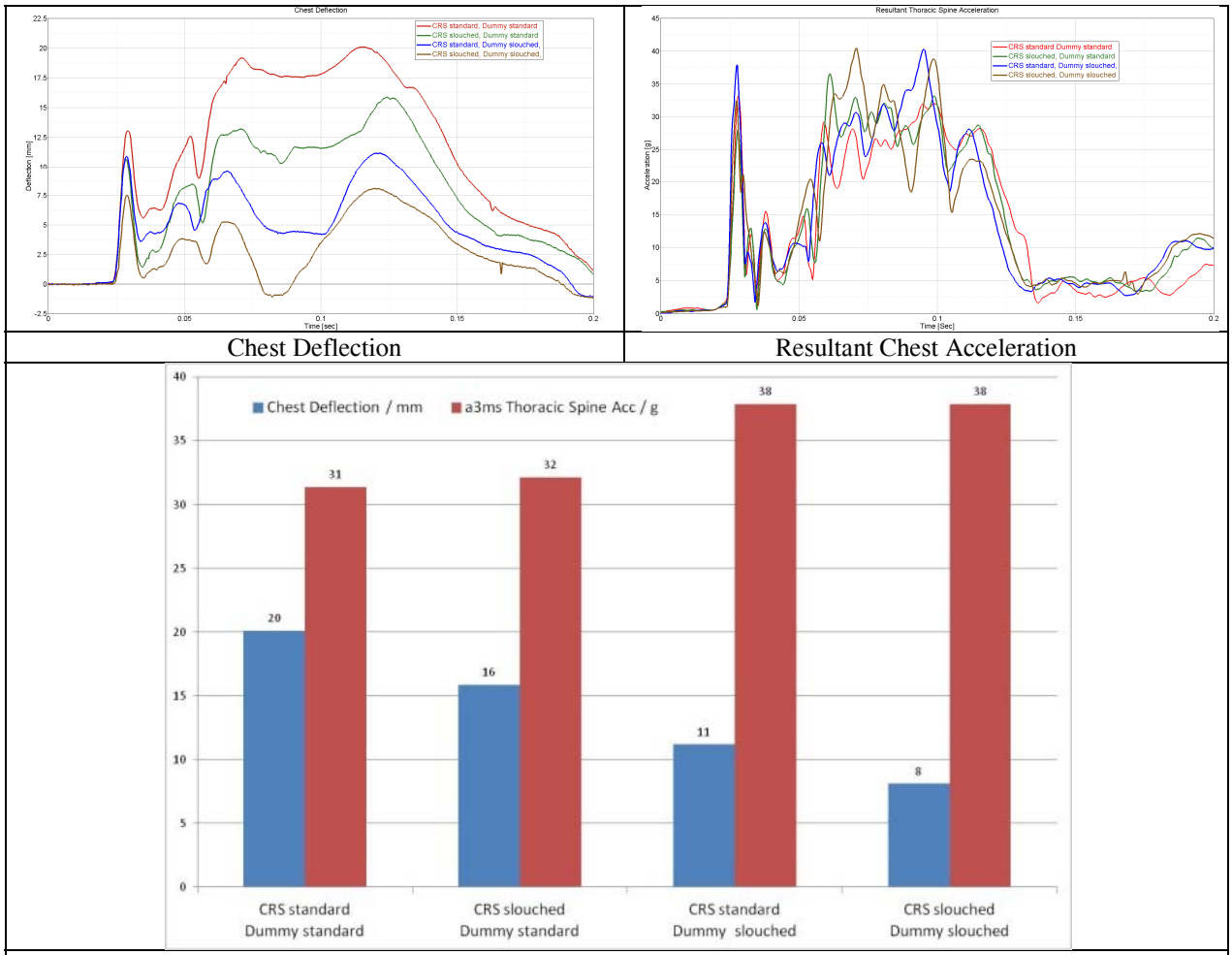
Q6 – position settings

The changes in the positioning settings of the Q6 led to different belt routings during the deceleration which are shown in Figure 3. Compared to the dummy and CRS in standard position the slouched position of the CRS supports an upward movement of the diagonal belt, in both cases the diagonal belt stays close to the IR-Tracc during impact. With the dummy in slouched position the diagonal belt shows a clear tendency to move toward the neck and away from the IR-Tracc. The slippage of the belt was also observed with the dummy and the CRS in slouched position. Here the diagonal belt moved up to the neck and under the arm of the dummy.

01	02	03	04
CRS standard, Dummy standard	CRS slouched, Dummy standard	CRS standard, Dummy slouched	CRS slouched, Dummy slouched

Figure 3. Comparison of kinematics of Q6 relative to shoulder belt during deceleration phase at 60 ms after impact

The chest deflection decreases when the diagonal belt moves away from the sensor towards the neck, especially with dummy and CRS in slouched position the deflection is low (Figure 4). The chest acceleration seems to be less sensitive for the belt position. Peak values for deflection and acceleration over the tests 1-4 showing the different positioning settings of the dummy and/or CRS are shown in (Figure 4). The chest deflection decreased with the distance of the belt from the IR-Tracc. Chest acceleration is only affected by the dummy position with an increase for the dummy in slouched position.



Chest Deflection | Resultant Chest Acceleration

Peak Values Chest Deflection Resultant Chest Acceleration (a3ms)

Figure 4. Q6 – Time History and Peak Values for Chest Deflection and Chest Acceleration

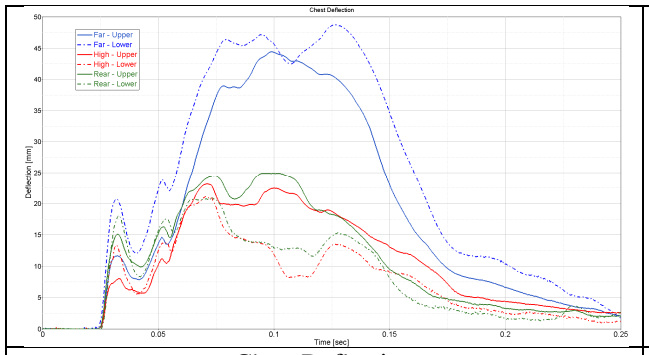
Q10 – belt position variation

For the Q10 in the tests 5-7 the upper belt anchorage was varied to “far”, “high” and “rear”. In the initial position the D-ring position “far” led to a belt routing close to the shoulder joint of the Q10 whereas the belt routings “high” and “rear” resulted in a belt position closer to the neck, especially for the position “high”. During impact (Figure 5), the belt in position “far” stays in the middle of the shoulder and on the chest close to the IR-Traccs. In both other positions the belt slides towards the neck during impact.

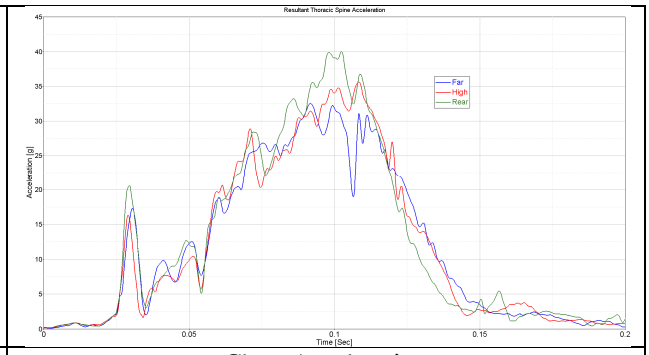
Looking at the chest deflection measured by the upper and the lower IR-Tracc, the deflection in the position “far” is nearly twice as high as in both other positions. For the chest acceleration differences are less, with the highest acceleration for the “rear” position (Figure 6). This tendency can also be seen in the peak values. Were the highest deflections are found for the D-ring position “far”, 44 mm (upper) and 49 mm (lower), the a3ms acceleration is the lowest in this test series (31 g). The peak values for both other belt position are only halve for deflection (23/ 25mm upper deflection; 21/ 21 lower deflection) while the resultant acceleration is slightly increasing (34 g for “high”; 39 g for “rear”).

06	05	07
Belt Position Far	Belt Position High	Belt Position Rear

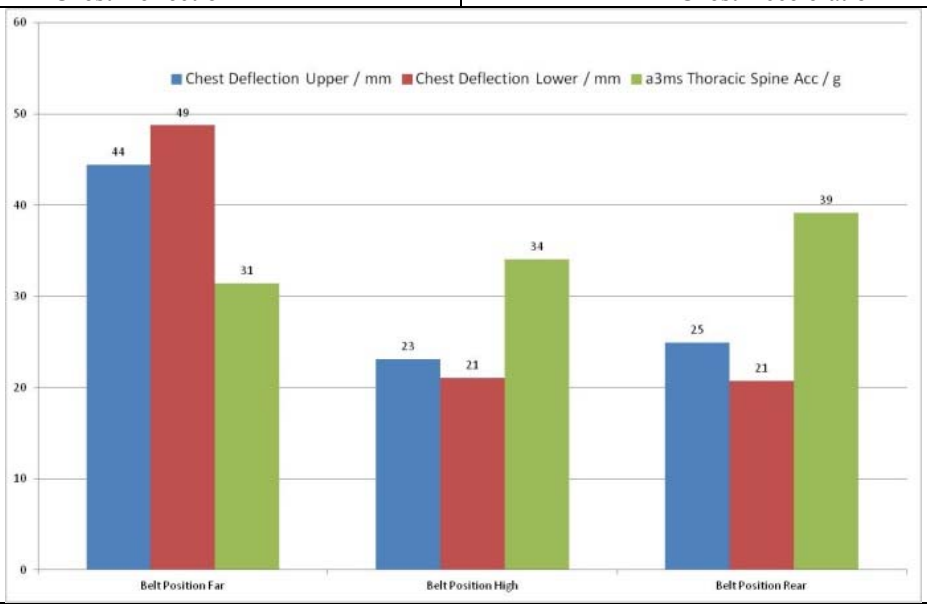
Figure 5. Kinematics of Q10 relative to shoulder belt at 90 ms start of deceleration



Chest Deflection



Chest Acceleration



Peak Values Chest Deflection Resultant Chest Acceleration (a3ms)

Figure 6. Q10 belt position variation – Time History and Peak Values for Chest Deflection and Chest Acceleration

Q10 – tests in 13° rotated bench

The kinematics of the Q10 on the 13° rotated bench at 80 ms after impact are shown in Figure 7. With the D-ring in "far" position the dummy rotates around the diagonal belt and slippage from the shoulder was observed. The belt gets trapped in the shoulder joint between shoulder and arm. Without load limiter and pretensioner the rotation is even more. Here also the lower part of the diagonal belt intrudes below the rib cage.

08	09	10
No Load Limiter, no Pretensioner, Belt Position Far (at 80 ms)	Load Limiter, Pretensioner, Belt Position Far (at 80 ms)	Load Limiter, Pretensioner, Belt Position Standard (at 80 ms)

Figure 7. Kinematics of Q10 relative to shoulder belt at 80 ms after beginning of deceleration

With load limiter and pretensioner and especially in combination with the standard D-ring position the Q10 stayed within the belt system.
For the cases tested with pretensioner and load limiter the load limiter level was reached (see upper plot in Figure 8). Without load limiter and pretensioner very high chest deflections were observed, especially at the lower IR-Tracc. Also the chest acceleration was higher. Load limiter and pretensioner reduced the chest deflection for both sensors and also the chest acceleration. Additional reduction for the chest deflection was achieved by the use of the "standard" D-ring position. These observations are supported by the peak values of chest deflection and resultant chest acceleration a3ms. The deflection at the lower IR-Tracc was more than halved by the use of load limiter, pretensioner and standard D-ring position. The chest acceleration slightly increased using the standard D-ring position compared to the use of pretensioner and load limiter in the far position.

DISCUSSION

Q6 – position settings

The deflection measured in the Q6 by the IR-Tracc is sensitive the position of the dummy within the CRS as well as the CRS position setting itself. The highest deflection is observed for the dummy and CRS in standard position, which would correspond to the position that would be used in regulatory or consumer test procedures. In the other test configurations with the dummy and/or CRS in a slouched position the chest deflection decreases. The lowest deflection is measured in the configuration with both dummy and CRS in a slouched position.
The chest deflection decreases even though a CRS with backrest including belt guidance for the upper shoulder belt is used. Thus the effect of belt migration towards the neck, which was provided as an explanation for reduced chest deflection in other studies without backrest is not the reason in this test series.

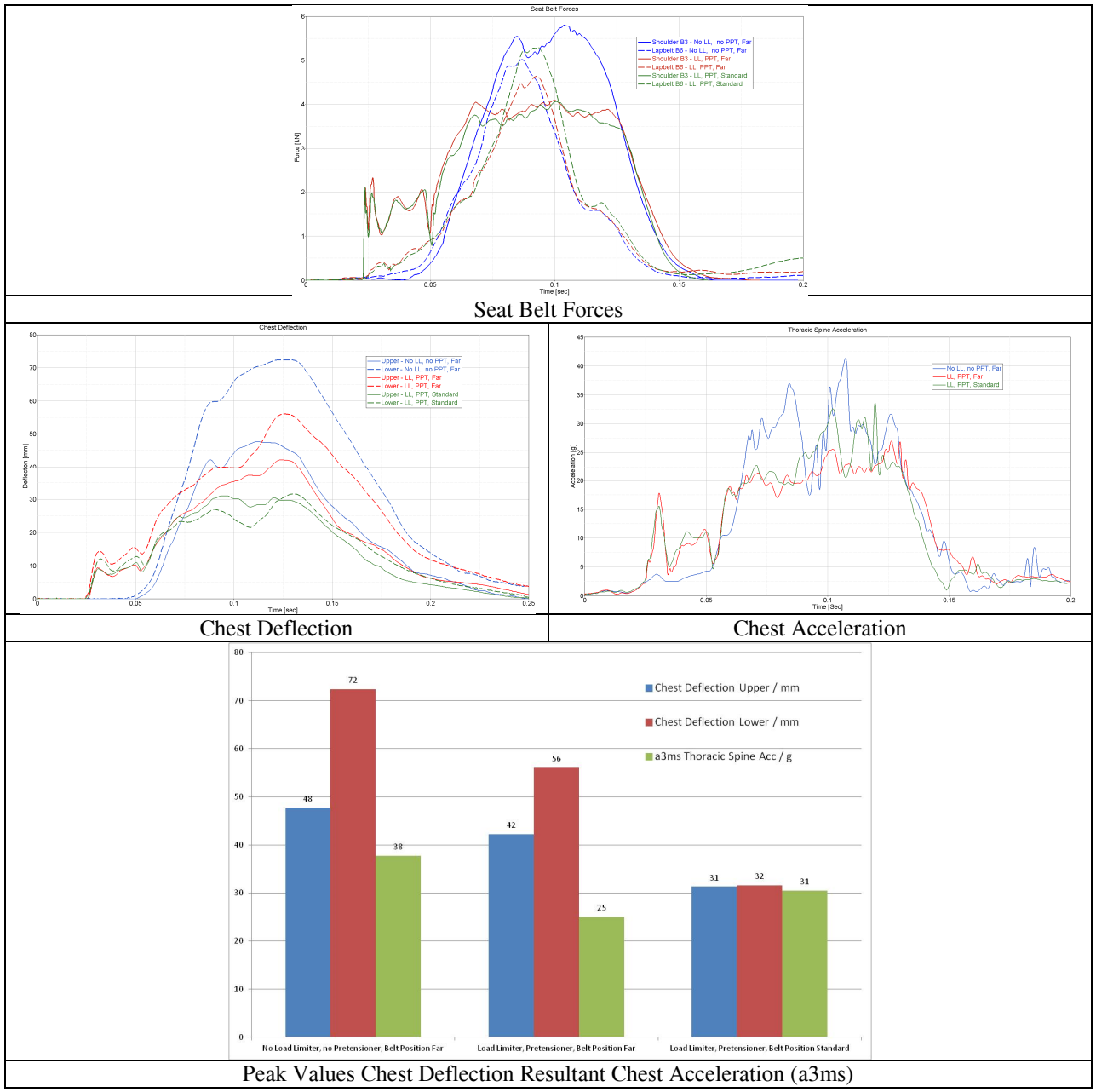


Figure 8. Q10 tests in 13° rotated bench – Time History Seat Belt Forces, Time History and Peak Values for Chest Deflection and Chest Acceleration

The decrease of measured chest deflection can be explained by the belt position relative to the IR-Tracc measurement location, which results from the dummy moving forward under the shoulder belt due to its inclined position. Due to this the belt moves up closer to the neck and does not apply direct load to the center of the chest where the IR-Tracc sensor is located. However, a slouched dummy position resulting in the observed belt kinematics could be realistic regarding the real world position of a real child in a CRS and should be considered for assessment of the CRS in a worst case scenario. On the other hand, the deflection sensor cannot assess the severity of this dummy to belt interaction, which seems to be worse compared to a standard position, correctly. A possible solution could be an additional upper deflection sensor in the Q6, which has already been proposed by other researchers. The a3ms value of chest resultant acceleration does not seem to be sensitive to dummy position in these tests. However, it increases with a more slouched CRS position setting. Based on this an acceleration based criterion seems to be more suitable than chest deflection measured only at the center of the chest.

Q10 – belt position variation

In the Q10 dummy the chest deflection shows a high sensitivity to changes in the position of the upper belt anchorage location. A more outboard location of the belt anchorage (position far) shows the highest chest deflection because the belt path is cloth to the location of the IR-Tracc sensors as shown in the photos during the deceleration event. Similar findings were also reported by (Bohman und Sunnevång 2012).
A higher belt anchorage location or a more rearward both lead to belt migration towards the dummy neck, which was also seen in the study by (Bohman und Sunnevång 2012). Belt migration towards the neck results in two effects. On the one hand part of the belt load will be transferred through the neck unloading the chest, which will lead to a reduction of actual chest compression. On the other hand a belt path close to the neck also leads to an increase of distance between the belt and the IR-Tracc measurement locations, which are in the centerline of the dummy. In this case the IR-Traccs will not measure the actual peak chest deflections and underestimate the maximum chest deflection. Due to this the observed sensitivity of deflection measurements to upper belt anchorage might not be biofidelic. Injury ratings based on chest deflection might underestimate the real injury risk.
Furthermore in studies with pediatric volunteers and child dummies by (Arbogast et al. 2013) an even higher magnitude of belt migration towards the neck was observed in volunteers compared to the Q10 dummy. If these finding would also be applicable to higher crash severities the possible above described underestimation of injury risk by chest deflection in the Q10 dummy might be even higher.
On the other hand a3ms values of peak chest acceleration shows the opposite trend for different upper belt anchorage locations. Chest a3ms is lowest for the “far” and the highest for the “rear” belt anchorage location. Based on this observation an acceleration based criterion might be more applicable to correctly rate the injury risk.

Q10 – tests in 13° rotated bench

In Q10 test with a test bench rotated by 13° without pretensioner and load limiter very high chest deflections were observed whereas the a3ms chest acceleration shows a comparable magnitude like in the 0° tests. The high deflections can be explained by the belt and dummy kinematics during the deceleration events. The shoulder belt completely slides of the shoulder and stays in the gap between arm and shoulder as can be observed in Figure 7. The lower part of the shoulder belt slides up the pelvis. As results the shoulder belt completely loads the thorax without any contact to the pelvis or shoulder structure.
Comparison to another test configurations shows that the dummy kinematics can be effectively controlled by introduction a pretensioner even this severe tests configuration with an oblique loading condition and a far position of the upper belt anchorage location. The belt still moves outboard during the deceleration event. However, the chest deflections are significantly reduced. A reduction of chest deflection by a belt load limiter was also found in a study by (Schnottale et al. 2013) with a Q10 in sled tests in a pre-rotated car body in white.
By an optimization of the location of the upper belt anchorage to an initial belt position in the middle of the shoulder the dummy kinematics can be further improved, which results in a further significant reduction of chest deflections at upper and lower IR-Tracc. The high importance of an optimized position of the upper belt anchorage in combination with a pretensioner and load limiter becomes clear by a comparison with the findings of a study by (Croatto und Masuda 2013). A sled test with the Q10 without backrest and a belt anchorage similar to the “rear” position was done as a base line test without pretensioner and load limiter. The shoulder belt was sliding towards the neck resulting in a low chest deflection. In another test with a pretensioner and load limiter the shoulder belt load was reduced. However, due to the pretensioner belt migration towards the neck was prevented, which resulted in increased chest deflection. Thus it highly depends on the belt geometry and the resulting direction of belt migration, whether a possible positive effect of a pretensioner to keep the belt in place and the positive effect of load limiter to reduce chest loading can be seen in a resulting reduction of chest deflection.
The a3ms value of the thorax acceleration shows a decrease by the introduction of pretensioner and load limiter in combination with the “far” belt location. However, an optimized belt anchorage location leads again to an increase of the a3ms value.
In summary in the tests with the rotated bench an optimization of the belt restraint system by introduction of a pretensioner/load limiter and adjustment of the belt anchorage location led to an improvement of dummy kinematics and dummy belt interaction. A chest deflection based assessment criterion would be able to show the benefit of this optimized restraint system. An assessment criterion only based on chest acceleration would not be able to show the benefit of an optimized restraint system in these test conditions.

CONCLUSIONS

For the Q6 it would be recommendable to implement an additional upper chest deflection sensor. An acceleration based assessment criterion seems to be more suitable than chest deflection measured only at the center of the chest, until further research has been done with this kind of sensor. Finally a chest injury assessment based on chest acceleration as well as chest deflection measured at two location in the chest might be the most reliable approach.
Chest deflection measured in the Q10 dummy is highly influenced by initial belt geometry. Belt migration towards the neck was observed in previous studies and also in this study for certain initial belt geometries and test conditions. This leads to a reduction of measured chest deflection, which does not correctly reflect the severity of chest loading. For initial belt positions far from the neck and restraint parameters as well as test conditions that result in a shoulder belt sliding outboard or staying in place on the shoulder the measured deflection might be correctly representing the severity of chest loading by the belt. Thus, only a deflection based criterion would not be able to correctly indicate the severity of thoracic loading under certain conditions and due to this has limitations.
A3ms chest acceleration seems to be a better indicator of severity of chest loading for different belt geometries. However, in the tests with the rotated bench an acceleration based criterion would not be able to show the benefit of a restraint system optimized with pretensioner, load limiter and adjusted D-ring position. Thus, a chest assessment only based on acceleration is also not recommendable.
Further research on a meaningful use of a deflection based criterion is recommended. A possible solution could be a criterion taking into account both deflection as well as acceleration and/or assessment of interaction between dummy and belt system during the deceleration.

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TEST PROCEDURES AND RESULTS FOR PEDESTRIAN AEB SYSTEMS

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ABSTRACT

Euro NCAP will start to test pedestrian Automatic Emergency Braking Systems (AEB) from 2016 on. Test procedures for these tests had been developed by and discussed between the AsPeCSS project and other initiatives (e.g. the AEB group with Thatcham Research from the UK). This paper gives an overview on the development process from the AsPeCSS side, summarizes the current test and assessment procedures as of March 2015 and shows test and assessment results of five cars that had been tested by BASt for AsPeCSS and the respective manufacturer.
The test and assessment methodology seems appropriate to rate the performance of different vehicles. The best test result - still one year ahead of the test implementation - is around 80%, while the worst rating result is around 10%. Other vehicles are between these boundaries.

INTRODUCTION

Automatic emergency braking systems for vehicle-to-rear-end-vehicle accidents are already in production since 2003 and have been considered in consumer testing by Euro NCAP since 2014. These look-ahead systems assess the risk of a collision with another vehicle and brake automatically if needed to mitigate or even avoid an accident.

Technology has made great progress in the last decade, and today also systems for avoiding or mitigating vehicle-to-pedestrian-accidents are within reach with first systems already on the market.

Systems that address pedestrian accidents are more challenging from a technology point of view due to three main reasons: pedestrians are able to change their heading almost immediately, making it difficult to correctly predict their movement; pedestrians are relatively small with only a little amount of metal, making it hard to detect and classify them with radar sensors, and last but not least, the majority of pedestrian accidents happen in cross-traffic situations. In longitudinal-traffic situations, directions of travel for both partners are parallel, while in cross-traffic they are perpendicular. Therefore, longitudinal accidents do happen as a function of velocity difference only. For cross-traffic accidents speed and starting position of the accident opponents have to match within small boundaries.

Pedestrian AEB[1] systems are being introduced into lower budget vehicle segments, but the technology is still relatively new. This poses the problem to define test and assessment criteria without knowing what the expected performance at the time of introduction will be. For a valid assessment methodology that also reflects real world accidentology it is of high importance to involve all stakeholders at an early state.

[1] Automatic Emergency Braking

Proposed requirements for pedestrian AEB systems (and corresponding test procedures) were developed mainly by three initiatives: the seventh-framework-program-founded research consortium AsPeCSS[2], the initiative vFSS[3] with German, Japanese and US-American manufacturers as well as independent research institutes) and the AEB-group (Thatcham Research, various manufacturers and suppliers, amongst others). The proposals then were considered by and discussed within Euro NCAP. A final set of test scenarios had been selected by the end of 2013, for extensive validation testing of the procedure (including repeatability and reproducibility considerations) in 2014. Pedestrian AEB systems will be rated from 2016 on.

This paper summarizes the proposals and concepts of the AsPeCSS-project and shows the scenarios that had been selected by Euro NCAP. An overview of the achieved rating according to Euro NCAP's preliminary rating scheme as of March 2015 will be given.

ACCIDENTOLOGY AND BOUNDARY CONDITIONS

Accidents involving passenger cars and pedestrians

Within the AsPeCSS project different European accident data sources (especially high level national data and in-depth accident data from Germany and Great Britain) were used to investigate the causations and backgrounds of road traffic accidents with pedestrians [Wisch 2013].

Results of the initiatives vFSS und AEB were reviewed and further extensive analysis was performed within AsPeCSS, focusing on the following topics:

- Aggregation of traffic accident data involving one passenger car and one pedestrian by accident type and impact configuration to Accident Scenarios
- Proportions of pedestrians by injury severity
- Darkness (i.e. frequency; accompanied visibility constraints due to weather conditions)
- Investigation of considerable accident parameters (i.e. pedestrian age; pedestrian impact points; crash reconstruction details such as driving and collision speeds of passenger cars, braking behaviour)
-

As result of the accident data analysis seven accident scenarios have been identified which are shown in Table 1. This data does show that most collisions between one pedestrian and one passenger car are crossing conflict situations. Smaller proportions could be assigned to crash situations with obstructed view as well as to collisions where the pedestrian went along the road. Crashes while reversing or parking have been excluded from the dataset due to their minor relevance regarding current ahead looking and thus front mounted pedestrian protection systems.

Table 1 shows the proportions of the AsPeCSS accident scenarios (crashes between one passenger car and one pedestrian) for killed pedestrians only again based on national accident data from Great Britain and Germany. For the killed or seriously injured the highest average shares were established for scenario 1 (25%; crossing straight road, **near side**, no obstruction), followed by scenario 2 (20%; crossing straight road, **far side**, no obstruction), other scenarios (16%) and scenario 7 (15%, along straight road, no obstruction). For the total fatalities the highest average shares were established for scenario 2 (30%; crossing straight road, offside, no obstruction), followed by scenario 1 (23%; crossing straight road, nearside, no obstruction), scenario 7 (19%, along straight road, no obstruction) and other scenarios (17%).

In summary, accident scenarios 1, 2 and 7 were found as the three most important scenarios for car-to-pedestrian crash configurations (sum of weights concerning KSI[4] is 60% and concerning fatalities is 72%) that may potentially be addressed by forward-looking integrated pedestrian safety systems. However, accident scenarios 3&4, 5 and 6 (KSI: 24%, Fatalities: 11%) also have a significant potential regarding future active pedestrian protection systems. Further, it was seen that more than half of the crashes which led to seriously injured pedestrians were assigned to darkness or low light conditions. This proportion increased to around three-quarters in case of killed pedestrians.

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[2] including partners such as BMW, Toyota, PSA, TRW, Bosch, Autoliv, IDIADA, TNO, BASt
[3] advanced forward-looking safety systems
[4] KSI = killed or seriously injured

Table 1. **AsPeCSS Accident Scenarios (A and B classify day (including twilight) and night times).**

ID	Accident Scenario	% KSI Total (Day/Night)	% Fatalities Total (Day/Night)
1	Crossing straight road, near side, no obstruction	25 (15/10)	23 (8/15)
2	Crossing straight road, offside, no obstruction	20 (8/12)	30 (7/23)
3	Crossing at junction, near- or offside, vehicle turning across traffic	8 (5/3)	4 (3/1)
4	Crossing at junction, near- or offside, vehicle not turning across traffic		
5	Crossing straight road, near side, obstruction	9 (7/2)	4 (1/3)
6	Crossing straight road, offside, obstruction	7 (5/2)	3 (1/2)
7	Along straight road, no obstruction	15 (8/7)	19 (5/14)
Total		84 (48/36)	83 (25/58)

In addition, the following conclusion could be drawn from the analysis of the accident data:

- Higher count of car-to-pedestrian crashes in urban areas, but higher injury severity on rural roads,
- Elderly (65+ years) record the highest percentage of casualties killed or seriously injured,
- Winter months November, December and January show higher number of car-to-pedestrian crashes compared to other months.

Impact point

The impact point of the pedestrian on the front of the hitting vehicle is a key factor for the expected AEB system performance.

An evaluation of in-depth data from GIDAS[5] shows that the impact point is actually distributed on the vehicle front, rather than being only in the vehicle center. In fact the occurrence of impacts at the outer regions of the vehicle front is higher than in the center. Impact point as function of vehicle velocity is shown in Figure 1 for running pedestrians that come from behind an obstruction. The lateral displacement of the impact point on the vehicle front is given in m, with 0 m corresponding to the vehicle centerline and with positive values towards the driverside. It can be seen that the impact is more likely to occur near the edge on that side where the pedestrian is coming from. Concluding from these observations, the impact point is a parameter that needs to be considered in the definition of test scenarios.

[5] German In-Depth Accident Study, see www.gidas.org

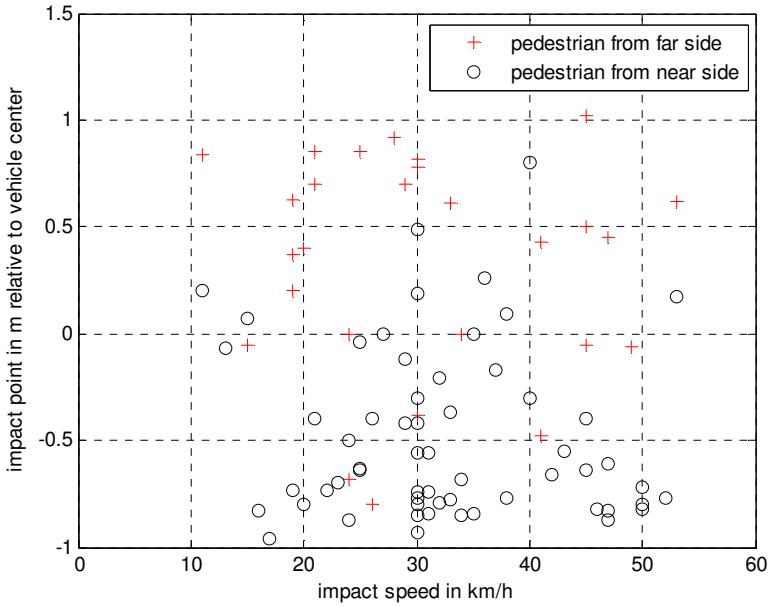

Figure 1: **Impact point as function of vehicle travelling speed for running pedestrians appearing from behind an obstruction.**

DEFINITION OF TEST SCENARIOS

Accident scenarios

Accident scenarios need to reflect real accident situations as good as possible. Since the accurate simulation of real accident situations in lab-testing is difficult and complex, characteristic parameters that have a significant impact on system performance have to be identified. Test scenarios then are defined using these characteristics.

For scenario definition, an accident kinematics model is developed using physical parameters like velocities, positions and starting times. In a first step, velocities are assumed to be constant, and in a second step, pedestrian detection timing and a brake logic were integrated. Using this model, the following parameters have been identified as most important for scenario definition:

- initial velocity of pedestrian and passenger car,
- impact point of pedestrian on the car front,
- start of pedestrian movement (timing) and total travel distance to impact point
- distance of obscuration (if applicable) to the passenger car path.

In addition, the following aspects need to be taken into account:

- test scenarios should reflect realistic accident situations as good as possible,
- test scenarios should be able to simulate various accident scenarios and not only those occurring most frequently,
- test scenarios should take estimated abilities of current and near-future AEB systems as well as current test tools (e.g. repeatability, contrast, light conditions) into account.

Test scenarios

Theoretical considerations and first test results showed that initial scenario definitions, especially a running child from behind an obstruction, are far too difficult for current and expected AEB systems.

In collaboration with other European initiatives, AsPeCSS developed the idea of distributing these difficulties (small child dummy, obstruction and running dummy) into more than one scenario in order to be able to better assess and compare system performances.

The test scenarios have been improved based on the AsPeCSS test results shown in this paper and on the test results generated within the AEB group and together with Euro NCAP for better comparability of vehicles, see Table 2. The dummy speed in the child scenario has been decreased to 5 km/h, and the different impact points (a fact that is quite important according to accident figures) are tested with a walking, unobscured adult dummy. Higher pedestrian walking speeds are transferred to a scenario with an adult dummy coming from the far side - the dummy will be easily visible long before the impact in this case. Low dummy speeds might be difficult for certain sensor systems and will be tested in the form of an entrance test; the same goes for low vehicle speeds (10; 15 km/h) since the required sensor viewing angle becomes rather large for high ratios of dummy speed to vehicle speed.

Table 2. **Current scenario definitions for Euro NCAP pedestrian tests.**

Scenario / Parameter	Running adult	Walking adult	Walking adult	Walking child
Denomination	CPAF	CPAN25	CPAN75	CPCN
Pedestrian speed	8 km/h	5 km/h	5 km/h	5 km/h
Dummy type	Adult	Adult	Adult	Child
Dummy initial position	Far side	Near side	Near side	Near side
Vehicle speeds	20-60 km/h	20-60 km/h	20-60 km/h	20-60 km/h
Obscuration	No	No	No	Yes
Impact point	50 % (Center)	25% (Nearside)	75% (Nearside)	50 % (Center)
Weighting	1	1	1	1

ASSESSMENT METHODOLOGY

Boundary conditions

Pedestrian travel speeds are generally much lower than car speeds [Tiemann, 2010]. But pedestrians can still comfortably avoid passenger car accidents just fractions of a second prior the collision. This is particularly true for accidents with impact on the near-side edge of the vehicle front and is less critical for impact points near the far-side edge. Determining for the achieved speed reductions is the time when full braking commences (which corresponds to a lateral distance of the pedestrian to the vehicle path). This brake timing limits the achievable speed reduction (which is a function of initial speed and deceleration). The ability of the brake system to increase the brake pressure and deceleration (maximum brake jerk) is another factor, as well as is the delay time between brake command and brake actuation.

If the pedestrian is hidden behind an obscuration and therefore is at first not freely visible for the vehicle's sensor system, the detection and classification time has a major impact on the entire system performance.

The derivation of performance boundaries in this paper is done based on an ideal braking system and a point-shaped pedestrian. A full investigation of the effects of real brake systems (e.g. increase of brake force) and finite size of pedestrians is published in [Seiniger, 2013].

The selected scenario configuration reflects the frequent case of a pedestrian crossing perpendicular to the vehicle. For full avoidance, the stopping distance s_{Stop} of an ideal vehicle is a function of initial velocity v_{Vehicle} and deceleration a_{x}

$$s_{\text{Stop}} = \frac{v_{\text{Vehicle}}^2}{2 \cdot a_x} . \qquad (1)$$

The quantity "Time-To-Collision" [Winner, 2011] is more reasonable for describing these situations than the stopping distance since it depends on the brake timing rather than a fixed distance. For the crossing pedestrian, is can be simplified to:

$$TTC = \frac{x_{\text{Vehicle}}}{v_{\text{Vehicle}}} . \qquad (2)$$

The unit of TTC is the second. TTC is the time until the collision occurs if all speeds were held constant and in this case it is used to describe discrete points in time.

The TTC (when braking needs to start) for full avoidance is the combination of (1) and (2):

$$TTC_{\text{Stop}} = \frac{v_{\text{Vehicle}}}{2 \cdot a_{\text{x,Vehicle}}} \qquad (3)$$

The essential quantity for speed reduction in pedestrian AEB systems is the time available for braking - which is in general the TTC at which the pedestrian is considered "critical". Real AEB systems will consider a pedestrian critical when it is near to the vehicle path (e.g. within a second) and on collision course.

The pedestrian's impact point on the vehicle front is the second essential quantity determining possible speed reduction. Pedestrians with a high probability for an impact on the near-side of the vehicle will become critical much later than those with an impact on the far-side of the vehicle, because those latter ones do travel within the path of the vehicle for a significant amount of time.

Balancing these criteria with the acceptable rate of false-positives then is the task of the vehicle manufacturer's philosophy, considering also product liability, customer acceptance and the likes, see for instance [Lübbe, 2013].

A real challenge for any AEB system are pedestrians coming from behind an obscuration near the side of the road. In this case, the total time available for detection, classification, decision and braking is limited by the time the pedestrian is visible.

Relevance of test speed for traffic safety

The assessment methodology for pedestrian AEBs needs to be in line with that established already for vehicle-vehicle AEB systems [Euro NCAP 2013]. For each scenario, tests with increasing test speeds are proposed.

In principle a linear assessment of speed reductions as measured in the individual test cases seems to be reasonable: 0% of "assessment units" for no speed reduction, 100% assessment units for full avoidance. The unified result of a test suite then depends on the weighting of the individual test speeds (within a test scenario) and the weighting in-between the scenarios.

The dose-response-model [Wisch 2013] is an established methodology for the weighting of speed reduction within a test scenario (= for different tested speeds). This methodology defines weighting factors by multiplying injury probability and accident occurrence frequency for all speeds. The factors then correspond to the "risk" and measure the relevance of a given test speed. Due to practicality reasons, the risk curve is approximated with 1 to 3 points, see Figure 2.

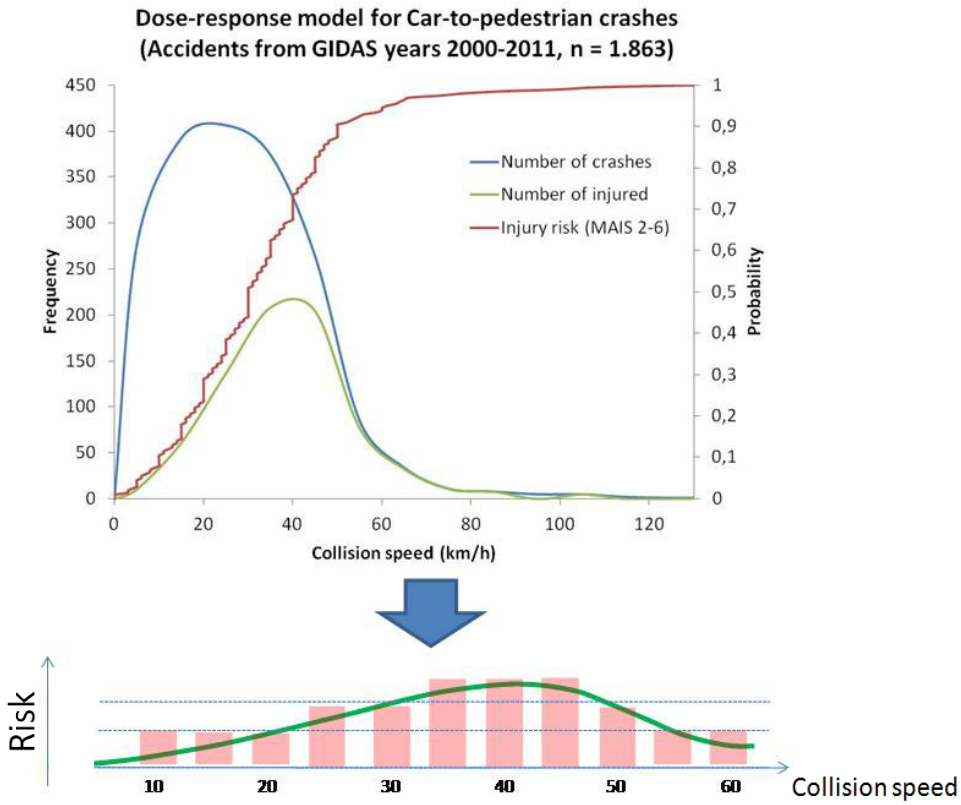

Figure 2: **Derivation of in-scenario weighting from accident velocity and injury risk.**

While the vehicle speed scale as defined from the AsPeCSS consortium runs from 10 to 60 km/h, tests and theoretical considerations have shown that an AEB intervention for low vehicle speeds is difficult to achieve due to the required high sensor viewing angle. Since additionally the risk level up to 20 km/h is still relatively low, Euro NCAP selected to exclude 10 and 15 km/h vehicle speed from performance testing; however it is necessary that the vehicle does at least show an AEB activation in these test speeds, in the form of an entrance test that needs to be passed for further assessment. The same goes for slower dummy speeds of less than 5 km/h.

In the previous section it has been laid out that full avoidance for high vehicle speeds is not possible: the pedestrian becomes a critical target so late that the time available for braking is not sufficient for the vehicle to come to a complete stop. Due to this, Euro NCAP has selected to award full score for high speeds (>45 km/h) if the speed reduction at the individual test is more than 20 km/h, and the test is conducted only if the preceding test was passed. The scoring is shown Table 3.

Table 3. **Rating parameters.**

Index "k"	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**
Test speed	20	25	30	35	40	45	50	55	60
Points	1	2	2	3	3	3	2	1	1
Sliding Scale	1	1	1	1	1	0	0	0	0
PassFail	0	0	0	0	0	1	1	1	1
Method	• Sliding scale: ratio of speed reduction and initial speed					• Pass for speed reduction > 20 km/h • Test only executed if previous test speed is passed			

In a mathematical formulation, the rating result per scenario will become:

$$Rating = \sum_{k=1}^{k=n} \mathrm{SC}(k) \cdot \mathrm{Points}(k) \cdot \frac{v_{\mathrm{x,red,k}}}{v_{\mathrm{x,0,k}}} + \mathrm{PF}(k) \cdot \mathrm{Points}(k) \cdot < v_{\mathrm{x,red,k}} - v_{\mathrm{x,red,min}} >^{0} ,$$

with the vectors “Sliding scale SC”, “PassFail PF”, “Points” and “$v_{x,red,min}$ = minimum speed reduction = 20 km/h” as defined in *Table 3*, and using the Föppl-parenthesis "$< \ >^{0}$" which becomes 0 for results less than zero and 1 elsewise.

TEST TOOLS

Testing pedestrian AEB systems requires a pedestrian dummy as well as an apparatus that is able to move the dummy with a necessary accuracy.

Requirements for the dummy are as follows:

- appears like a human for the vehicle sensor system,
- impactable without significant damage to the vehicle under test (especially damage to the AEB system's sensors),
- durability: the possibility to conduct a high number of tests with impacts without significant change in the physical properties.

AsPeCSS uses a dummy as specified by the vFSS group. A detailed description of the dummy characteristics can be found in [Lemmen, 2013]. This dummy proved to appear close to a human in extensive verification testing with various test vehicles, and the current version is able to take over 100 impacts and does not damage the vehicle under test. This dummy has also been selected by Euro NCAP as an appropriate static dummy. A dummy with animated legs is currently developed by industry and might be selected as the official test dummy; this decision was not taken as of March 2015.

Dummy movement is achieved using a transportable platform system which has sufficient position accuracy due to its tooth belt drive (Figure 3) and that carries the dummy by means of magnets. Driving robots for accurate longitudinal and lateral vehicle control were used in all experiments in this paper. The specifications of the dummy propulsion system meet the requirements set by Euro NCAP in their preliminary test protocol at the time of writing.

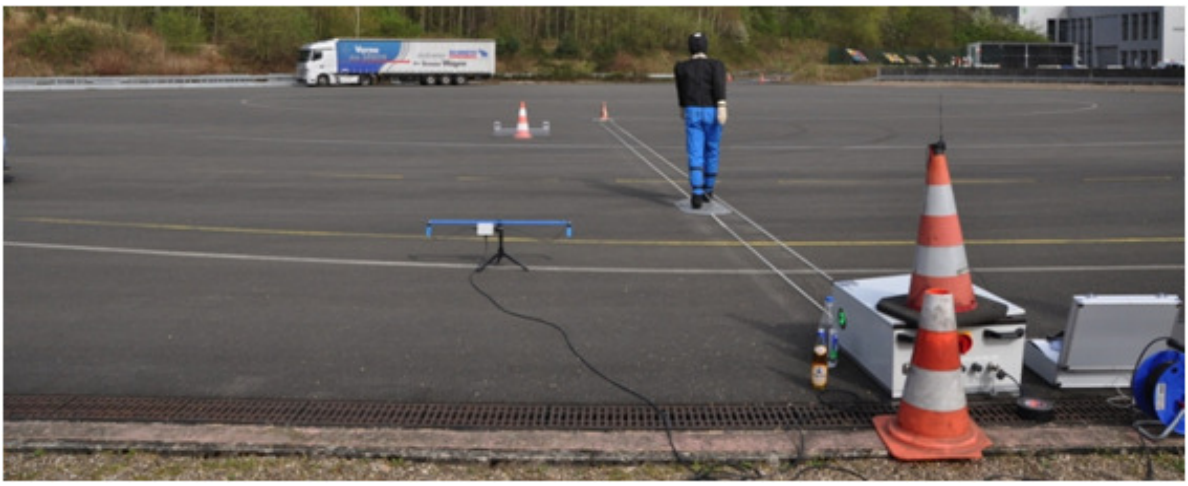

Figure 3: **Test setup with adult dummy, platform, belt drive and light switch system.**

DRIVING EXPERIMENTS AND RESULTS

Figure 4 shows speed reductions for vehicles A to D, distinguished between dummy type (child/adult), dummy speed, obstruction, propulsion system and desired impact point. All tests were conducted by BASt. Vehicles A, B and C were tested for the AsPeCSS project; vehicles D and E were tested in cooperation with the respective manufacturer.

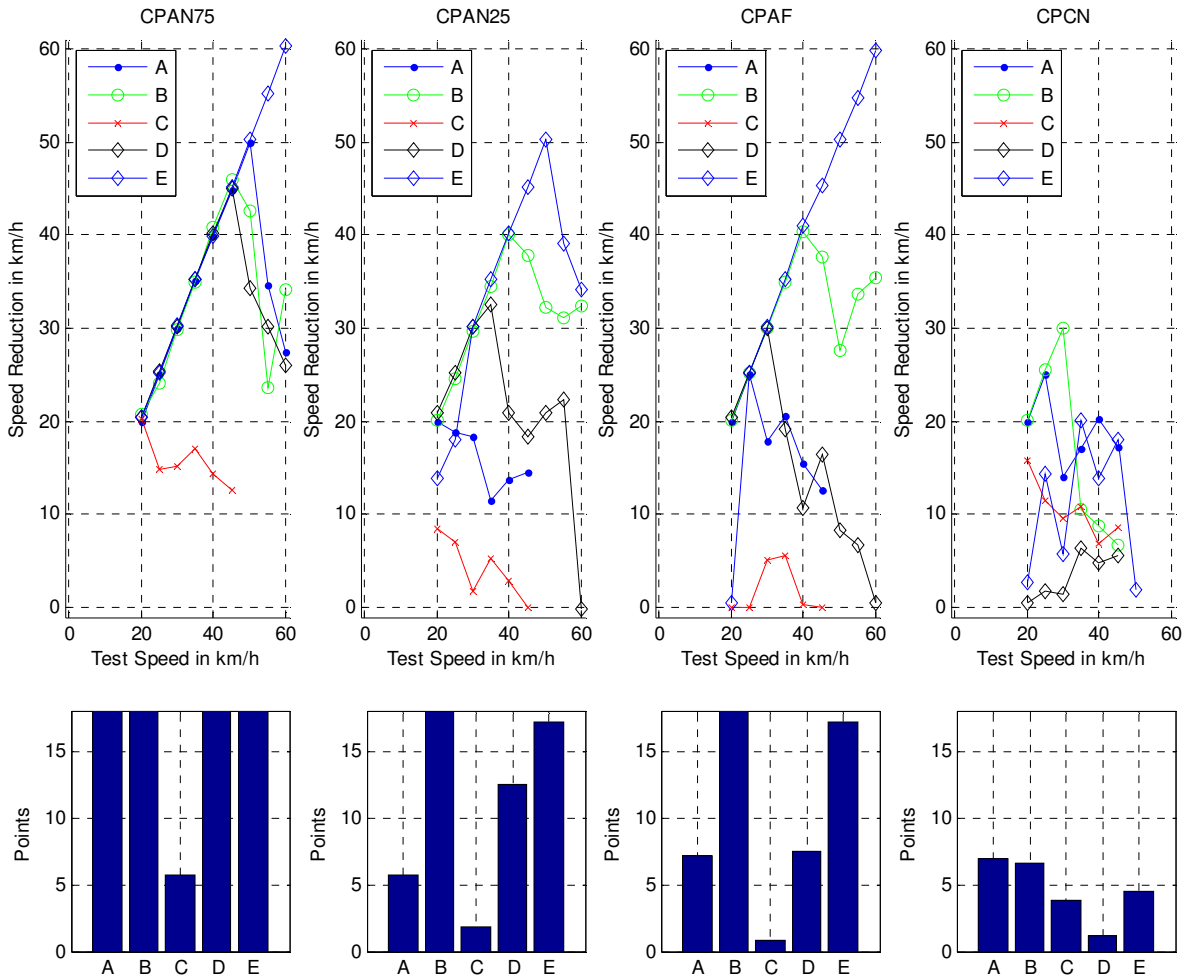

Figure 4: **Speed reduction (upper diagrams) and points awarded (lower diagrams) per vehicle and scenario. CPAN75/25= Car-to-Pedestrian Adult Near side, impact point 25% or 75%, CPAF= Car-to-Pedestrian Adult Far side, CPCN= Car-to-Pedestrian Child Near side.**

Note that the vehicles A to D were tested more than once per test speed. For this analysis, the highest speed reduction per test speed has been picked. Vehicle E was a prototype vehicle, all others are production vehicles.

This overview gives an impression on the range of results to be expected for the first tests in 2016. All but one vehicle do achieve maximum rating in the Adult near-side 75%-scenario, which is from a technical perspective considered to be the easiest. The same setup with a 25% impact point is more difficult: since the dummy is located more to the right[6] throughout the whole experiment, the required sensor viewing angle is higher. The

[6] For right hand traffic

dummy will also enter the zone where a braking intervention is justified at a later time. Two of the vehicles still achieve almost full score in this scenario.

An adult approaching from the far side at running speed is difficult as well: for lower speeds, the required viewing angle becomes relatively large, and the dummy enters the zone where braking is justified at a late time as well. Results for this scenario are comparable: vehicles B and E again achieve almost full score.

The most critical scenario from a technical perspective is the obstructed child: the dummy appears relatively late, so there is little time available for detection, classification and braking. The results show that none of the tested vehicles is able to achieve a rating of more than 7 points. This might change when vehicles will be equipped with quicker brake systems.

SUMMARY

The AsPeCSS project did define accident scenarios for pedestrian AEB systems. These scenario proposals then were discussed with other initiatives, the outcome of these discussions was the basis for Euro NCAP pedestrian test scenarios and assessment method.

Several vehicles have been tested and rated according to the Euro NCAP test and assessment method, within the AsPeCSS project and by BASt in cooperation with the respective vehicle manufacturer. While the 75% near-side adult scenario does not pose much difficulty to most of the systems, the near-side 25% and far-side running adult scenarios are far more difficult. Only two out of the five vehicles achieve almost full score.

None of the tested vehicles is able to achieve more than 7 points (=40% of the available points) in the running child scenario - a major technology innovation might be required before vehicles are able to perform equally well in this scenario.

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GUIDELINES FOR PEDESTRIAN FRIENDLY WINDSCREEN DESIGNS CONSIDERING PROBABILISTIC FRACTURE BEHAVIOR

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ABSTRACT

If adult pedestrians are being struck by passenger cars with short bonnets, head contact usually occurs in the windscreen area. In test procedures for regulation and consumer protection, this impact type is being assessed using so-called pedestrian head impactors. The head injury risk is being evaluated based on the acceleration signal using the so-called Head Injury Criterion (HIC). Corresponding experimental impactor tests in the windscreen center show large scatter. Main reason for the observed scatter is the fracture initiation of glass as already published in several studies [5]. Thus, for a head impact in the windscreen center an early fracture initiation results in a small head injury risk, while a late fracture initiation increases the injury risk significantly [14]. In the design of measures for the enhancement of vehicle sided pedestrian safety, this scatter is currently neglected.
Based on a theoretical description of the probabilistic fracture mechanics of glass, a methodology for designing pedestrian friendly windscreens considering the probabilistic fracture mechanics of glass will be described in the present paper. This methodology consists of two steps. First, the probability for certain fracture initiation times are assessed, considering probabilistic fracture mechanics and the tensile stress distribution on the glass surfaces during head impact. In a second step, the head injury risks for the different fracture initiation times are evaluated.
In order to show the potential impact of the described methodology, a windscreen of a vehicle model is being assessed and optimized. The findings of this optimization process are being used to derive guidelines for pedestrian friendly windscreens.

INTRODUCTION

In case of a vehicle-pedestrian collision the impact location of the head of the pedestrian is being mainly influenced by the vehicle speed, by the pedestrian size and the vehicle shape. For a combination of an adult pedestrian and a passenger car with a short bonnet, head contact usually occurs in the windscreen area (e.g. [8, 9]). If a pedestrian head impactor is being shot against the windscreen center, large scatter can be observed for the acceleration signal of the head impactor as shown by [5] and [14] (see Figure 1).

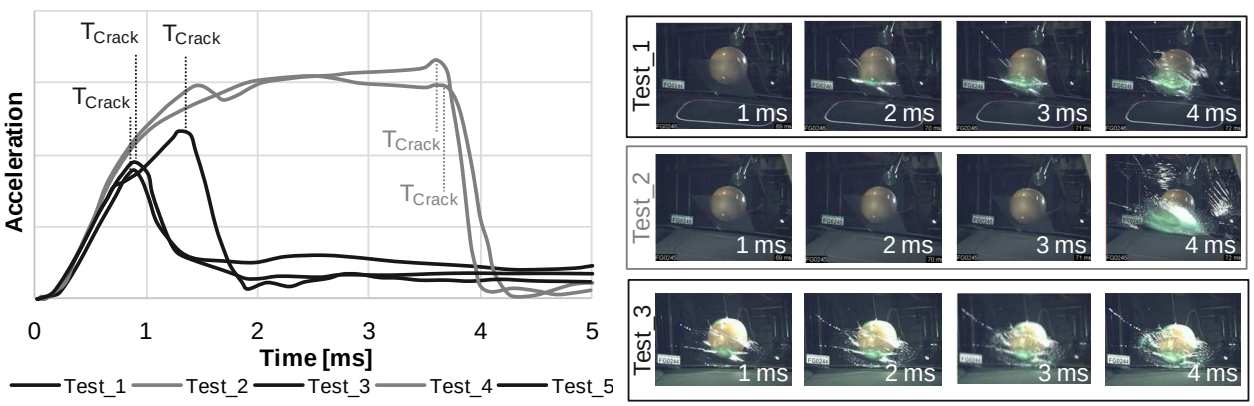


Figure 1. Acceleration signal and crack initiation times for head impact in windscreen center [14].

Since the boundary conditions are not changed and the windscreens are from the same batch, main reason for the scatter is the stochastic fracture behavior of the windscreen glass [14]. As can be seen in Figure 1, an early fracture initiation as in test 1, 3 and 5 results in lower accelerations and thus in lower head injury risks [14].
The stochastic fracture behavior of glass is a material dependent property, which cannot be changed easily. Due to the high viscosity of molten glass, the silicon dioxide molecules of glass cannot take the ordered structure of a crystal lattice during the cooling process, but solidify in a metastable order [4, 17]. Since the tensile stresses cannot be homogenized by plastic flow as within the elastic-plastic behavior of most metals [15], all glass components show a brittle fracture behavior.
Stochastically distributed material or surface defects influence the fracture behavior of glass [2]. In order to describe this stochastic behavior, the so-called Weibull-Distribution shown in Eq.1 is often used [10]. According to Eq.1 the fracture probability FP can be described by the current stress load σ, the characteristic strength σ_c and the so-called Weibull-Module m. σ_c and m can be assessed using quasi-static experiments like the double-ring (also called ring-on-ring) bending test.

$$FP(\sigma) = 1 - \exp\left(-\left(\frac{\sigma}{\sigma_c}\right)^m\right) \qquad \text{Eq.1 [10]}$$

In an approach with the title GLASPROB, the Weibull-Distribution has already been used for the design of windscreens focusing on endurance strength loads [1]. In [1] the stress state of the windscreen for different load cases is assessed based on Finite-Element (FE) simulations. Since the size of the loaded area strongly influences the fracture probability [19], [1] extended Eq.1 to Eq.2 in order to assess the fracture probability based on the stress loads for a certain area A for different endurance strength loads.

$$FP = 1 - \exp\left(-\int_A \left(\left(\frac{\sigma}{\sigma_c}\right)^m\right) dA\right) \qquad \text{Eq.2 [1]}$$

By considering the increase of the tensile strength in case of dynamic loadings [7], [3] has further extended Eq.2 for dynamic load cases as well. As shown in Eq.3 the fracture probability depends now on a Dynamic Factor DF, a reference area A_{ref} as well as the tensile stress and the size of the N FE-elements of the windscreen glass.

$$FP = 1 - \exp\left(-\frac{1}{A_{ref}} \sum_i \left(\frac{\sigma_i \cdot A_i}{\sigma_c \cdot DF}\right)^m\right) \quad \text{for i} = 1 \text{ to N} \qquad \text{Eq.3 [3]}$$

Scope of this study is to use the findings from [3] for the assessment of the probabilistic fracture mechanics of glass in order to design a pedestrian friendly windscreen geometry for a head impact against the windscreen center.

METHODS

For the evaluation of the head injury risk for an impact against the vehicle windscreen, a method considering the probabilistic fracture mechanics is proposed (see Figure 2). This procedure consists of two steps.
In the first step, which in part is already be published in [3] and [11], the probability for certain fracture initiation times is assessed. Within this step, a FE simulation of a head impactor being shot against the center of a vehicle windscreen is calculated. The windscreen center is being chosen in order to minimize the influence of the windscreen adhesive and of the glass edges. For these impact simulations an adult head impactor with a mass of 4.5 kg is used. The impact conditions are chosen based on the latest Euro NCAP test procedure. Since vehicle windscreens are made of laminated safety glass, consisting of two 2.1 mm thick float glass plies being attached by a 0.76 mm thick intermediate layer of polyvinyl butyrale (PVB), a three layered approach is being chosen. For the windscreen model a so-called Shell-Solid-Shell-approach is being used. The material data for glass is chosen based on literature values for not-pre-stressed glass, which is usually the case for the windscreen center. During this first step, the glass is modeled without fracture. More detailed information about the validation of the glass model is given in [11]. The windscreen is modeled to be attached to an adhesive layer, while the degrees of freedom of the adhesive surface being usually attached to the vehicle body is being blocked in the global coordinate system.

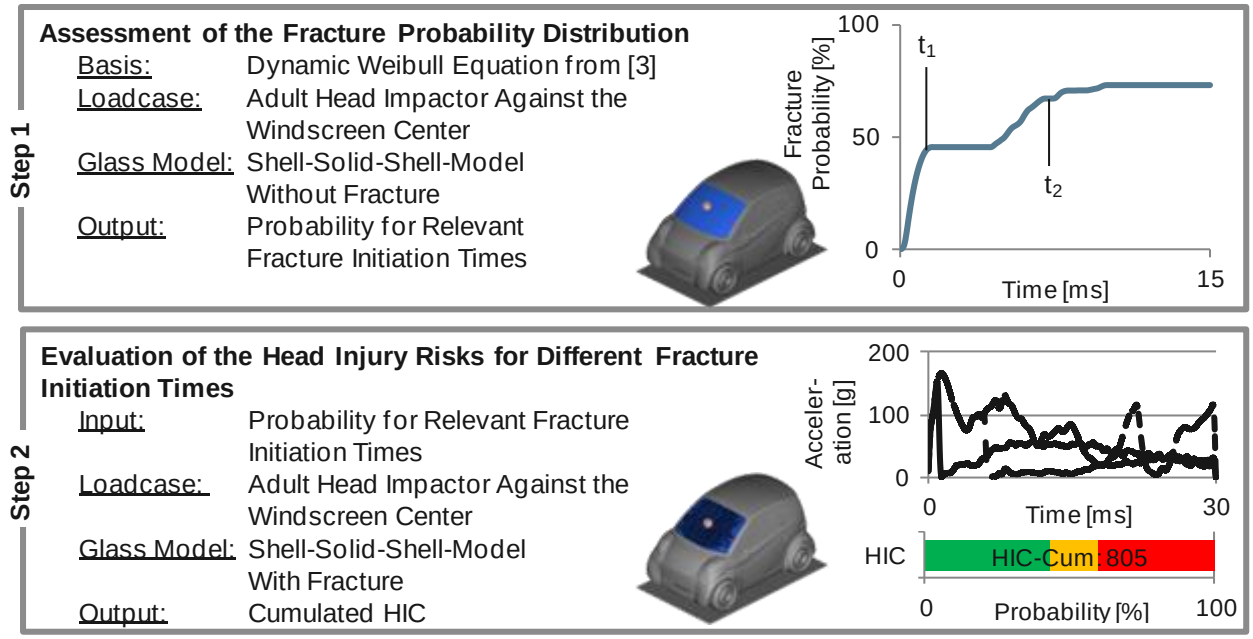


Figure 2. Methodology for Evaluation of Head Injury Risk Considering Probabilistic Fracture Mechanics.

As a result of the simulation the tensile stress over time distribution of each element on the glass surface is stored in a separate file. Due to the layered set-up of laminated safety glass, four glass surfaces have to be differentiated. The tensile stresses are combined with the test results from specimen tests using the Weibull-Distribution. Similar to windscreens of series vehicles, the windscreen is assumed to be in FTTF-design. This refers to the production process of float glass, in which the glass melt floats on a tin bath. The glass side floating on the tin bath is called tin side (T), while the other surfaces pointing to the atmosphere is called fire side (F). In an FTTF-design, for the outer and inner surface of the windscreen the fire (F) side of the float glass is chosen, while the surfaces attached to the PVB-foil are the tin (T) side of the float glass. In general, the fire side has a higher tensile strength than the tin side, since in the tin side some tin molecules are diffused in the glass structure. More specific information on the chosen material parameters as well as the dynamic factor is given in [3]. Result is a graph showing the fracture probability over time. In this graph, the probability for certain fracture initiation times can be assessed.
These fracture initiation times are used as input for the second step, which is not been published before. By integrating a failure criteria, the so-called 'non-local failure criterion' developed by [13], in the glass model, the head acceleration curve as well as the so-called Head Injury Criterion (HIC) can be determined. One simulation has to be conducted for each combination of fracture initiation time and fracture probability. Thus, the failure criterion parameters have to be adapted for each fracture initiation time. Further information on the validation of this failure criterion is given in [11]. Finally a cumulated HIC can be determined using Eq.4.

$$HIC_{cum} = \sum_{i} FP_i \cdot HIC_i \quad \text{for i = 1 to N} \qquad \text{Eq.4}$$

A sequence of the further work being described in the present paper is shown in Figure 3. The methodology and results of this work is also not been published before. The work is being conducted within a European research project named 'SafeEV', which is co-funded by the European Commission within the Seventh Framework Programme (2007-2013) (see http://www.project-safeev.eu/).
In order to show the potential impact of the described methodology, the head injury risk during an impact on a windscreen of a vehicle model is being assessed using the methodology described above. For the vehicle model the so-called REVM1 is being used. A description of the vehicle model is included in [12]. The resulting cumulated HIC is being used as reference.

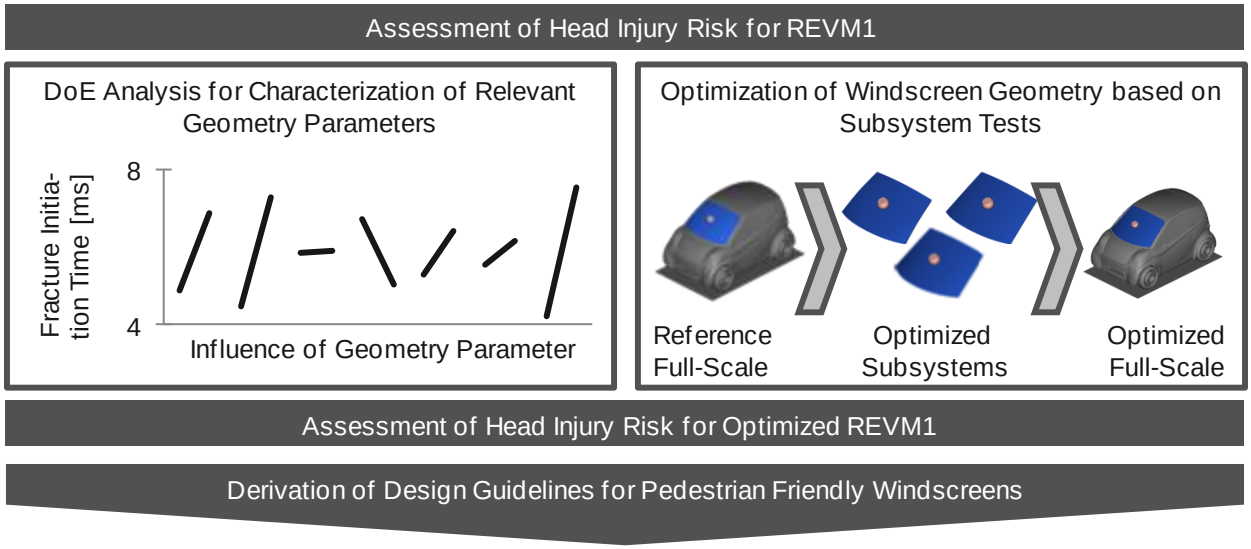


Figure 3. Work Sequence of Present Investigation.

Afterwards a "Design of Experiment" (DoE) analysis is conducted, in order to analyze the influence of the windscreen geometry on the fracture probability respectively the fracture initiation time. Seven of the eight geometry parameters shown in Figure 4 are included in the DoE analysis. Only the so-called end tangent angle is not included, since the windscreen side is assumed to have only a minor effect during an impact in the windscreen center. As a consequence a test plan including 64 windscreen designs is developed (see Figure 10). The according maximum and minimum values for the seven parameters are chosen based on series production vehicles (see Figure 11). In order to determine the fracture probability for certain fracture initiation times, the first step of the methodology shown in Figure 2 is being conducted for each of the 64 windscreens.

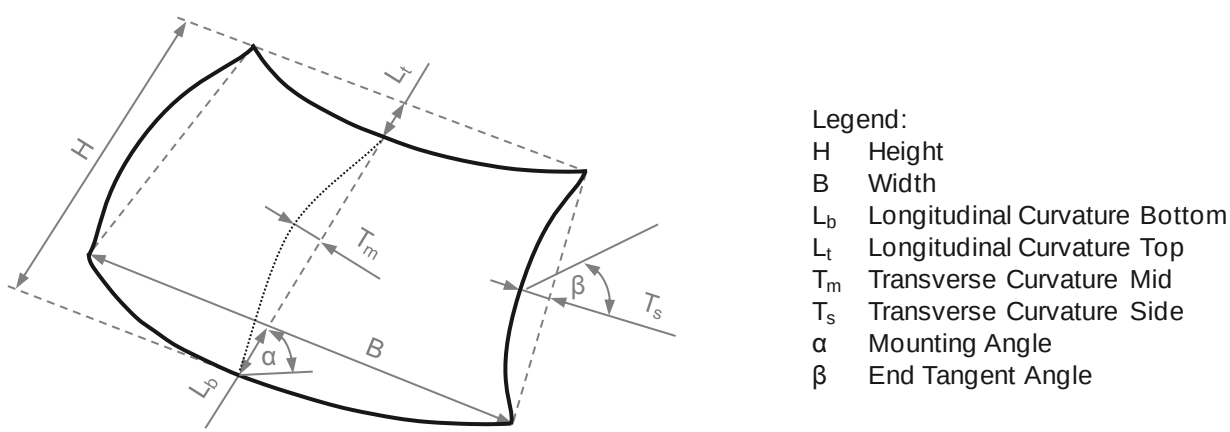


Figure4. Geometrical Characterization of Vehicle Windscreens.

Assuming that during a head impact in the windscreen center an early fracture initiation time results in low injury risk, the windscreen geometry of REVM1 can be optimized using the results of the DoE analysis. Since the integration of a redesigned windscreen in an existing vehicle geometry is very time-consuming, the effect of the redesigned windscreen is first investigated in a subsystem environment. Thus, the redesigned windscreens are only attached to a constrained windscreen. Since this new constraint is stiffer, the original windscreen is also being investigated as a subsystem. After the optimization process results in a satisfactory change of the fracture probability distribution, the windscreen flanges of the vehicle model are being updated for the new windscreen geometry, so that a full-scale model is available.

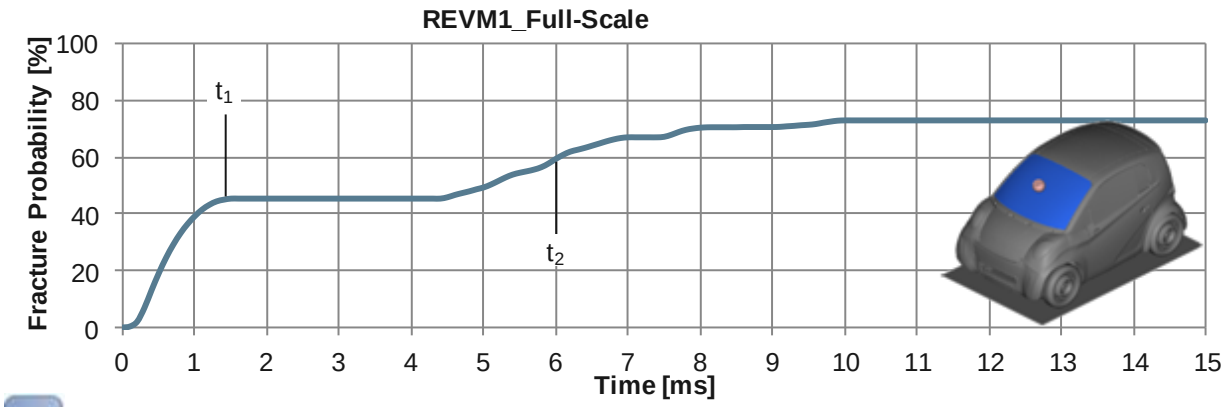
This full-scale model is being assessed using the methodology described in Figure 2. By comparing the cumulated HIC of the reference and the optimized vehicle, the benefit can be shown.

Finally, design guidelines for pedestrian friendly windscreens considering the probabilistic fracture mechanics of glass are being derived.

RESULTS

Assessment of Head Injury Risk for REVM1

Figure 5 shows the fracture probability over time curve for REVM1. Using the graph shown in Figure 5 a probability for three fracture initiation time periods are determined. The number of different periods is set to three periods in order to limit further necessary calculations to a reasonable number. For a first period from first impact to 1.5 ms after first impact, the windscreen will fracture with a probability of 43%. In a second time period between 1.5 ms and 6 ms after first impact, the windscreen will fracture with a probability of 17% (relative probability being calculated by subtracting 43% from 60%). Considering a worst case approach and assuming the head injury risk will decrease with an earlier fracture, the third period is being defined from 6 ms until the end of the impact. During this period the windscreen will not fracture with a probability of 40%.



43% fracture probability for $t < t_1$; 17% fracture probability for $t_1 < t < t_2$; 40% probability of no fracture

Figure 5. Fracture Probability over Time Curve for Head Impact in the Windscreen Center of REVM1.

By integrating a fracture criterion in the windscreen model, the head injury risk can be determined. The failure criterion is chosen in order to initiate the fracture at the end of the time period for the first two periods, while the windscreen should not fracture for the third period. Figure 6 shows the corresponding acceleration curves and the HIC-values. The cumulated HIC, which can be calculated using Eq.4, is 805.

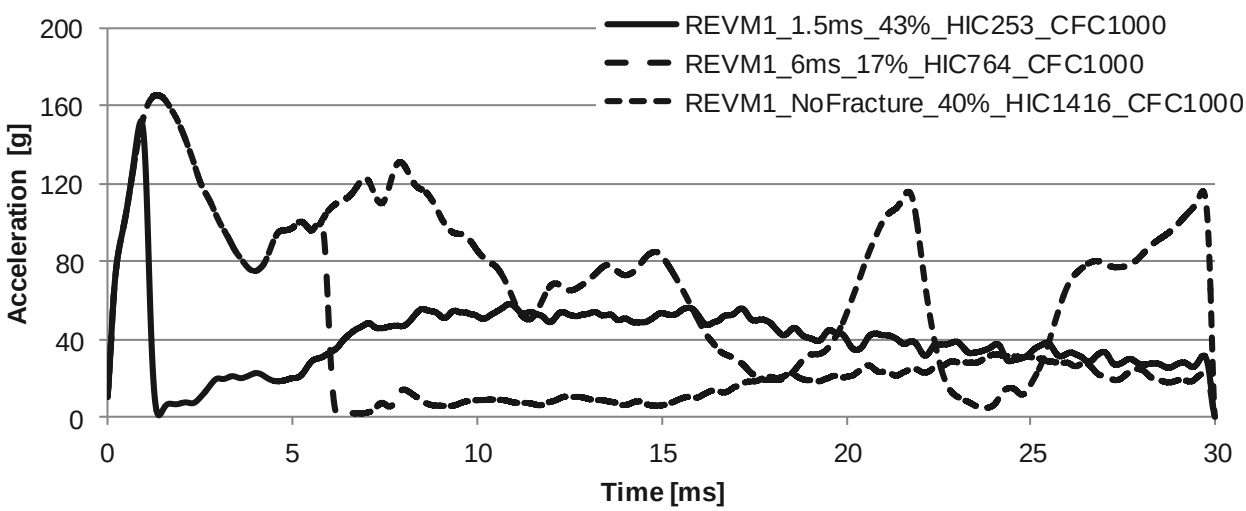
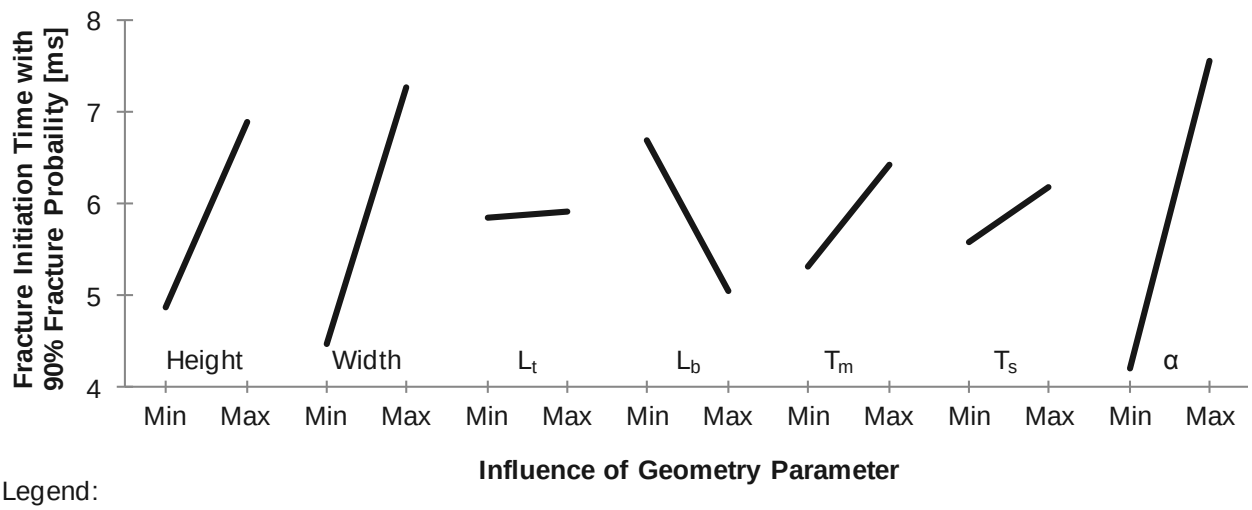


Figure 6. Head Impactor Acceleration for REVM1 for Three Different Fracture Times.

Similar to the results from [14], the head injury risk increases with later fracture times (see Figure 6). Since the stiffness of the windscreen strongly decreases after the fracture is being initiated, the acceleration signal rapidly decreases as well. After glass fracture, the head impactor is being further decelerated by the PVB-foil and attached glass fragments.

DoE Analysis for Characterization of Relevant Geometry Parameters

In Figure 7 the result of the DoE analysis is shown. The lines displayed in Figure 7 represent the influence of each windscreen parameter. A positive slope implies a small fracture initiation time for the corresponding minimum value of the parameter, while a negative slope implies a small fracture initiation time for a maximum value respectively. The absolute value of the slope gradient can be used to describe the impact of this parameter. According to this, the mounting angle, the windscreen width as well as the windscreen height have the largest influence on the fracture initiation time.

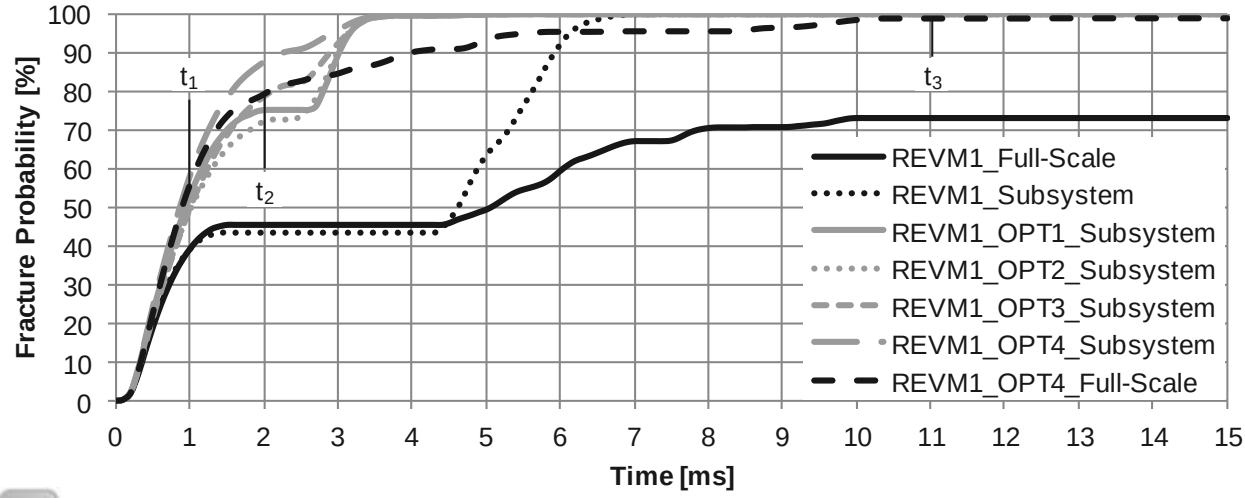


Legend:
L_b Longitudinal Curvature Bottom L_t Longitudinal Curvature Top T_m Transverse Curvature Mid
T_s Transverse Curvature Side α Mounting Angle

Figure 7. Effect of Windscreen Characteristics on Fracture Initiation Time.

Optimization of Windscreen Geometry based on Subsystem Tests

Assuming that during a head impact in the windscreen center an early fracture initiation time results in low injury risk, the windscreen geometry can be optimized using the results from the DoE analysis. According to the DoE analysis especially the windscreen mounting angle, height and width influence the fracture probability (see Figure 7). But since these parameters are usually defined by the vehicle designers, they were excluded from the optimization process in order to minimize the change of the vehicle design.
Other parameters influencing the fracture probability are the transverse curvature at the middle of the windscreen, the transverse curvature at the windscreen side as well as the longitudinal curvature at the bottom. In order to show the influence of these parameters, the windscreen geometry is changed. The fracture probability over time curves for the full-scale and subsystem tests are shown in Figure 8. As expected, the stiffer constraint influences the subsystem test of the original windscreen, so that the fracture probability for the subsystem test is being increased from 4 ms after first impact onwards. In the first optimization step (OPT1) only the transverse curvature at the middle of the windscreen is being reduced. In the second optimization step (OPT2) the transverse curvature at the middle of the windscreen as well as the transverse curvature at the windscreen side are reduced. In the third optimization step (OPT3) both transverse curvatures are reduced and the longitudinal curvature at the bottom is increased.



55% fracture prob. for $t < t_1$; 25% fracture prob. for $t_1 < t < t_2$; 20% fracture prob. for $t_2 < t < t_3$

Figure 8. Fracture Probability over Time Curve for Optimized Windscreen Designs of REVM1.

As can be seen in Figure 8, the fracture probability increases for OPT1, OPT2 and OPT3. Especially for the first 2 ms the fracture probability is larger compared to the original windscreen geometry. It seems that the influence of the transverse curvature at the side shows the largest effect, since either OPT2 as well as OPT3 show only a minor increase compared to OPT1.

In the fourth optimization step (OPT4), the effect of the positioning of the float glass within the laminated safety glass is considered. Thus, the windscreen geometry OPT3 is assessed in the so-called TFFT-design. Here, the inner and outer surface of the windscreen glass are chosen to be the tin side (T) of float glass, while the intermediate surfaces are made of the fire side (F). OPT4 shows a further increase of the fracture probability. By analyzing the corresponding tensile stress distribution, it seems that the combination of large tensile stresses and the corresponding area loaded by these stresses is especially for the glass surface directing to the vehicle compartment. The largest fracture probability results, if the tin-side is chosen for this surface. Thus, it is expected that a FTFT-design could lead to similar results. But this assumption is not further specified.

Since OPT4 shows the largest fracture probability, OPT4 is chosen to be integrated in the vehicle model. As can be seen in Figure 8, the fracture probability of OPT4 assessed in the Full-Scale model decreases due to the softer constraints as expected. But still, the improvement in comparison to the original windscreen is significant.

In order to calculate the head injury risk in the next step, three time periods have to be chosen based on the fracture probability curve for the Full-Scale model of the optimized windscreen geometry OPT4. Since the fracture probability curve changes due to the redesign, this step is necessary. The first period is defined to be between first impact and 1 ms after first impact with a probability of 55%. The second period with a probability of 25% is defined between 1 ms and 2 ms and the third period between 2 ms and 11 ms with a probability of 20% respectively.

Assessment of Head Injury Risk for Optimized REVM1

Figure 9 shows the resulting acceleration curves and the HIC-values for the optimized windscreen geometry. Similar to the results shown in Figure 6, the head injury risk increases with later fracture times due to the significant reduction of the windscreen stiffness after fracture initiation. Comparing Figure 6 and Figure 9 shows that the HIC values for the three periods of the original and the optimized windscreen are in a similar range. Due to the changes of the geometry design, the probability for the first two periods are increased for the optimized windscreen, which results in the reduction of the cumulated HIC from 805 to 577.

But Figure 9 reveals as well that a higher fracture probability for short fracture initiation times results in a higher acceleration peak. So, it seems that the windscreen stiffness has to be increased for a higher fracture probability.

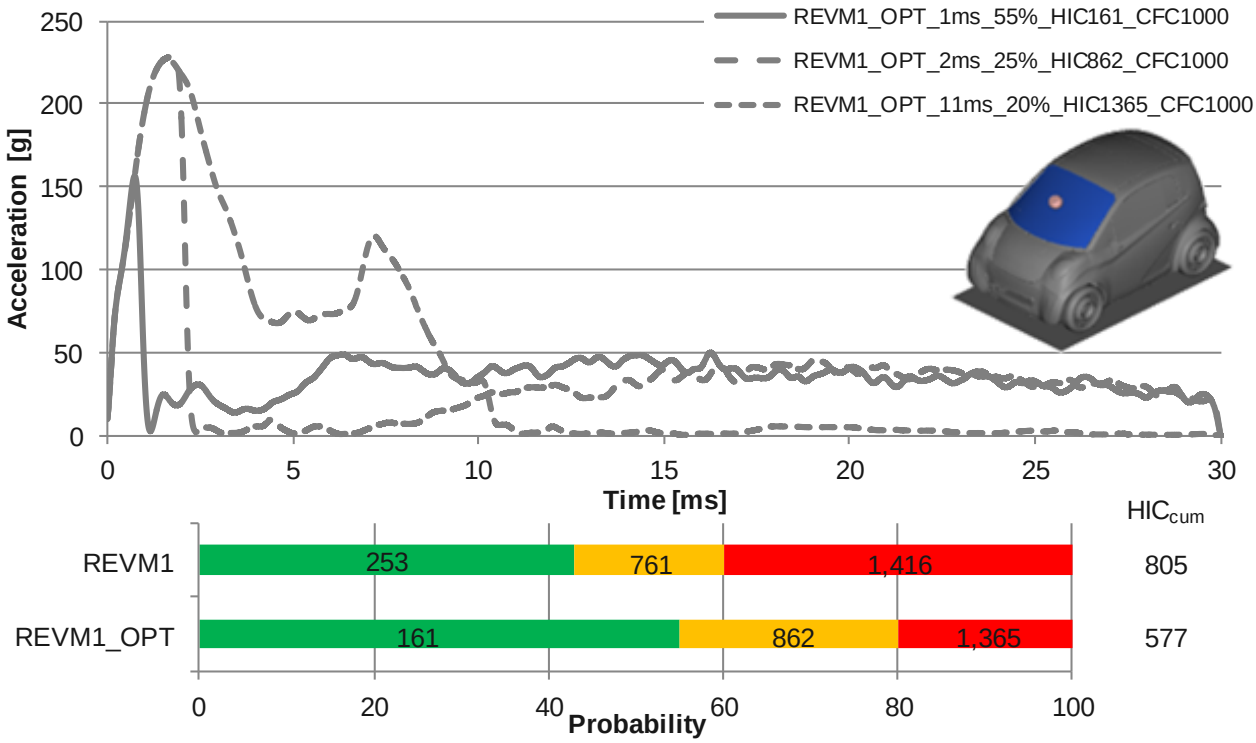


Figure 9. Head Impactor Acceleration for REVM1 and Optimized Windscreen.

Derivation of Design Guidelines for Pedestrian Friendly Windscreens

Based on the work described in the present paper some guidelines for a pedestrian friendly windscreen design can be derived. These guidelines are only valid for a head impact in the windscreen center and are based on an evaluation of the HIC using an adult head impactor.
First, probabilistic fracture mechanics shall be considered within the design process of the windscreen geometry and associated injury risks, since an early fracture initiation seems to result in low injury risks.
Second, in order to increase the fracture probability for an early fracture initiation time, the mounting angle, the windscreen width, the windscreen height, the transverse curvature at the middle of the windscreen as well as the transverse curvature at the windscreen side shall be reduced and the longitudinal curvature at the bottom increased.
Third, the positioning of the float glass influences the fracture probability as well. In the present case it seems that a TFFT- or a FTFT-design is more beneficial for pedestrian safety.

LIMITATIONS

The presented study can be separated in two main sections. First the limitations of the methodology for the assessment of the fracture probability over time curve are discussed. Afterwards the limitations of the optimization process will be given.
Input for the fracture mechanical analysis are mainly material data based on a literature study. If this approach is being considered in the design phase of series vehicles, the material data should be updated in cooperation with the windscreen manufacturer. Thus, the specification sheet for the windscreen manufacturer should be expanded e.g. by Weibull-Module, characteristic tensile strength and Dynamic Factor.
Especially, the Dynamic Factor should be investigated in more detail. At the moment, the Dynamic Factor is defined based on Split Hopkinson Pressure Bar tests for laminated safety glass from [18] and the resulting strain rate during head impactor simulations in the windscreen center. Unfortunately, the analyzed strain rates in [18] show a large gap in the relevant strain rate field during head impact. Thus, the chosen Dynamic Factor is a rough approximation. In order to specify the Dynamic Factor further tests in the relevant strain rate field should be conducted.

Main input for the calculation of the fracture probability over time curve is the tensile stresses on the glass surfaces. These tensile stresses are being determined using FE simulations. An experimental verification of the resulting tensile stresses is according to the opinion of the authors not possible. Using polarization filters results only in a qualitative stress state, while instruments using the scattered light method cannot be conducted without contact to the glass surface and thus would influence the test results.
Nevertheless, the combination of stress state during head impact in the windscreen center and probabilistic fracture mechanics are verified using internally available test results. Thus, the authors are confident, that the effects and tendency shown in the present paper are reasonable.
The optimization steps currently focus on head impacts in the windscreen centre. In case of a head impact being close to the scuttle area, an early fracture initiation might result in a more severe impact with the instrument panel. This effect has to be investigated in future studies.
Furthermore, the pedestrian friendly windscreen design is evaluated using the HIC value. According to [16] the larger acceleration peak shown in Figure 8 can also result in a higher skull fracture risk. This risk will be integrated in the further course of the SafeEV-project. If the results from [16] are confirmed, further optimization criteria should be included in the optimization process.
For the validation of the windscreen model including failure, experimental tests of a middle class vehicle are used. Since no test results for the REVM1 are available, the windscreen model for the original and for the optimized windscreens could not be validated. Nevertheless based on the expertise of the authors, the calculated acceleration signals and fracture behavior seem reasonable. Main scope of the present paper is to show that the probabilistic fracture behavior of glass could be considered during the design of a pedestrian friendly windscreen. Thus, using reasonable, but not fully validated windscreen models is assumed to be acceptable. If this approach will be further evaluated, a broad experimental testing verification should be done.
The windscreen is optimized in order to minimize the head injury risk for pedestrians. In this context an early fracture is beneficial. Nevertheless, the windscreen shall fulfill further requirements as well. Main tasks for windscreen are protection against external events, optically faultless vision, prevention of serious injuries and sufficiently long service life [6]. None of these main tasks are negatively influenced by an early fracture initiation. In addition, the windscreen shall support the correct unfolding process and position of airbags for occupants. For this task a late fracture initiation is required. According to the opinion of the authors, the presented methodology could also be used to assess the corresponding effects.

CONCLUSIONS

In the present paper a methodology for designing pedestrian friendly windscreens is described. Main advantage of this methodology is that the probabilistic fracture behavior of glass, which strongly influences the injury risk during head impact in the windscreen center, is considered within the design process. The methodology consists of two steps. In the first step, the probability for certain fracture initiation times is assessed. Therefore, a FE simulation of a head impactor being shot against a vehicle windscreen without fracture criteria is calculated. The resulting tensile stress over time distribution of each element on the glass surface is used to calculate the fracture probability. Result is a graph showing the fracture probability over time, in which the probability for certain fracture initiation times can be assessed. These fracture initiation times are used as input for the second step. By integrating a failure criteria, the so-called ‘non-local failure criterion’ developed by [13], in the glass model, the head acceleration curve as well as a so-called cumulated Head Injury Criterion (HIC) can be determined.
In order to show the potential impact of the described methodology, a windscreen of a vehicle model is being assessed and optimized assuming a short fracture initiation time results in a small injury risk. By changing the transverse curvature, the longitudinal curvature at the bottom of the windscreen and the set-up of the laminated safety glass of the windscreen, the cumulated HIC value could be significantly decreased from 805 to 577. This refers to a reduction by 28 %. Finally guidelines for pedestrian friendly windscreen designs are derived.

ACKNOWLEDGEMENTS

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APPENDIX

Windscreen Design	Height [mm]	Width [mm]	Longitudinal Curvature Bottom [mm]	Longitudinal Curvature Top [mm]	Transverse Curvature Mid [mm]	Transverse Curvature Side [mm]	Mounting Angle [°]
1	-	-	-	-	-	-	+
2	+	-	-	-	-	-	-
3	-	+	-	-	-	-	-
4	+	+	-	-	-	-	+
5	-	-	+	-	-	-	-
6	+	-	+	-	-	-	+
7	-	+	+	-	-	-	+
8	+	+	+	-	-	-	-
…….							
63	-	+	+	+	+	+	-
64	+	+	+	+	+	+	+

Figure 10. Parameter Set-Up for DoE Analysis based on 64 Windscreen Designs.

Parameter	Maximum Value (+)	Minimum Value (-)
Height [mm]	1,000	600
Width [mm]	1,600	1,100
Longitudinal Curvature Bottom [mm]	150	0
Longitudinal Curvature Top [mm]	75	0
Transverse Curvature Mid [mm]	100	0
Transverse Curvature Side [mm]	40	0
Mounting Angle [°]	70°	25°

Figure 11. Maximum and Minimum Value for DoE Analysis.

IS COMFORT IMPORTANT FOR OPTIMAL USE OF CHILD RESTRAINTS?

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Paper Number 15-0330

ABSTRACT

Suboptimal restraint use, particularly the incorrect use of restraints, is a significant and widespread problem among child vehicle occupants, and increases the risk of injury. Previous research has identified comfort as a potential factor influencing suboptimal restraint use.

Both the real comfort experienced by the child and the parent's perception of the child's comfort are reported to influence the optimal use of restraints. Problems with real comfort may lead the child to misuse the restraint in their attempt to achieve better comfort whilst parent-perceived discomfort has been reported as a driver for premature graduation and inappropriate restraint choice. However, this work has largely been qualitative. There has been no research that objectively studies either the association between real and parental perceived comfort, or any association between comfort and suboptimal restraint use. One barrier to such studies is the absence of validated tools for quantifying real comfort in children.

We aimed to develop methods to examine both real and parent-perceived comfort and examine their effects on suboptimal restraint use.

We conducted online parent surveys (n=470) to explore what drives parental perceptions of their child's comfort in restraint systems (study 1) and used data from field observation studies (n=497) to examine parent-perceived comfort and its relationship with observed restraint use (study 2). We developed methods to measure comfort in children in a laboratory setting (n=14) using video analysis to estimate a Discomfort Avoidance Behaviour (DAB) score, pressure mapping and adapted survey tools to differentiate between comfortable and induced discomfort conditions (study 3).

Preliminary analysis of our recent online survey of Australian parents (study 1) indicates that 23% of parents report comfort as a consideration when making a decision to change restraints. Logistic regression modelling of data collected during the field observation study (study 2) revealed that parent-perceived discomfort was not significantly associated with premature graduation. Contrary to expectation, children of parents who reported that their child was comfortable were almost twice as likely to have been incorrectly restrained ($p<0.01$, 95% CI 1.24 - 2.77).

In the laboratory study (study 3) we found our adapted survey tools did not provide a reliable measurement of real comfort among children. However our DAB score was able to differentiate between comfortable and induced discomfort conditions and correlated well with pressure mapping.

Our results suggest that while some parents report concern about their child's comfort, parent-reported comfort levels were not associated with restraint choice. If comfort is important for optimal restraint use, it is likely to be the real comfort of the child rather than that reported by the parent. The method we have developed for studying real comfort can be used in naturalistic studies involving child occupants to further understand this relationship.

This work will be of interest to vehicle and child restraint manufacturers interested in improving restraint design for young occupants as well as researchers and other stakeholders interested in reducing the incidence of restraint misuse among children.

INTRODUCTION

One of the leading causes of death among children in Australia is traffic crashes. On average 70 children are killed per year (10 year average, 2002-2011, (BITRE 2012)), and 3000 are seriously injured as vehicle passengers (Brown and Bilston 2012) despite greater than 99% child restraint system (CRS) use (Brown et al. 2010). These statistics have not changed greatly over the last two decades (Brown and Bilston 2012).

Incorrect and inappropriate CRS use or suboptimal CRS use is a widespread problem that reduces the protection offered by a child restraint and increases the risk of injury (Brown and Bilston 2007; Bull et al. 1988; Jakobsson et al. 2005). Incorrect restraint use includes both the errors in installation as well as incorrect adjustment and securing of the child into the restraint. Inappropriate restraint use is the use of a restraint that does not match the age and size of the child, this usually manifests in using a restraint designed for an older/larger child. Incorrect restraint use is as common as inappropriate restraint choice (Brown et al. 2010) and carries a higher risk of injury than inappropriate choice (Brown and Bilston 2007; Du et al. 2008).

There have been some indications that child comfort and/or the parental perception of child comfor plays a role in the choice of CRS and/or the correctness of use of a child restraint (Bilston et al. 2011; Pettersson and Osvalder 2005; Simpson et al. 2002). Studies have suggested that children prefer restraints that are comfortable for them (Bohman et al. 2007; Osvalder et al. 2013; Pettersson and Osvalder 2005). While Bingham et al. (2006) reported that parental perception of increased comfort motivated parents to use boosters for their children rather than adult seat belts, other studies report perceived discomfort in a booster seat as a reason for parents to prematurely move their child to an adult seat belt (Charlton et al. 2006; Simpson et al. 2002).

Discomfort has also been associated with incorrect child restraint use (Klinich et al. 1994; Osvalder et al. 2013). Bohman et al. (2007) suggested that poor restraint fit caused discomfort in children, and the avoidance of discomfort resulted in severe misuse of restraints.

The lack of validated methods for studying seating comfort in children is a barrier to the study of comfort among children in child restraints. While there are accepted methods such as the use of self-report survey tools (Chae et al. 2011; Donnelly et al. 2009; Gyi and Porter 1999; Smith et al. 2006) and pressure distribution mapping (Chae et al. 2011; Gyi and Porter 1999; Kyung and Nussbaum 2008; Kyung et al. 2008; Paul, Daniell, et al. 2012; Paul, Pendlebury, et al. 2012; Porter et al. 2003) for studying the comfort of adults in vehicles there has been almost no use of these methods for child occupants. The exception is a recent study by Osvalder et al. (2013) who used a self-report survey tool to capture comfort of children in a naturalistic study of children in booster seats. However, the validity of this self-report tool is untested. Earlier studies examined the comfort and usability of different CRS through the observation of parental handling and interaction with the CRS, parental surveys and observations of the child in the CRS during a drive (Pettersson and Osvalder 2005). This study did not interview the child, noting that incoherent answers are often provided by children under the age of 10. Nilsson and Wolstedt (2007) combined anthropometric data, ergonomic modelling and child opinions to develop an ergonomic booster seat however they did not describe the process in detail.

Over the last three years, we have undertaken a number of studies in an attempt to study comfort and its association with sub-optimal restraint use. This paper presents an overview of the work conducted to date.

METHODS

The work presented here relates to preliminary findings from three independent studies conducted as part of a large program of work aimed at providing a wider understanding of the factors underpinning optimal restraint use and the role that comfort might play. All studies have been approved by the UNSW Human Research Ethics Committee.

Online Parent Survey

This study used data collected during an online survey of a cohort of Australian parents and carers, designed to examine and evaluate barriers to appropriate and correct restraint use. Data was collected between May and

July, 2014. Participants had to be over the age of 18, own their own vehicle, have a child between the ages of 0 and 7 years who they transport at least once a week, and regularly use some sort of child restraint. Three questions related to comfort were extracted for this analysis.

One question asked parents to report which of the following factors they would take into account when making a decision to move their child into a different type of restraint: "My child is too big for the restraint; The new restraint is more convenient that than my current restraint; The restraint is easier to use than my current restraint; My child is not comfortable in the current restraint; My child is too old for the restraint; My child does not want to use the current restraint any longer; I need the restraint for a younger child". This data was used to examine how often parents take comfort into account when making transition decisions.

The second question asked whether parents thought that the child restraint their child was using looked comfortable using a five level Likert scale.

The third question asked parents directly if their child was comfortable in the restraint and if so they were asked to provide reasons why. This was an open ended question. The reasons provided by parents were qualitatively explored. This involved reading through the responses and identifying commonly reported reasons why parents thought the child was comfortable using content analysis techniques.

Field Observation Study

This analysis used data collected during a 2008 cross-sectional population representative observational study of child restraint practices among children aged 0-12 years across NSW (see Brown et al. (2010) for more details). Children aged 0-12 arriving in vehicles were observed at randomly selected early childhood health clinics, day care centres, pre-schools and primary schools within randomly selected local government areas across NSW. Trained researchers made in situ observations of the child within the restraint, conducted a detailed examination of the restraint installation, and conducted a structured interview with the driver. Only one child per vehicle was selected for observation.

Variables related to parent perceived comfort issues and other known risk factors of inappropriate and incorrect use, together with the observed appropriate and correct use of restraints was extracted for this analysis and this has been reported elsewhere (Fong et al, manuscript under review). In summary, logistic regression modelling was used to examine 1. the relationship between age appropriate restraint use and parent reported comfort issues while controlling for parent education levels, language spoken at home, parent income and the restraint type (seat belt vs child restraint), and 2. The relationship between correct restraint use and parent reported comfort issues while controlling for parent education levels, language spoken at home, parent income and the restraint type (convertible restraint, yes/no).

All analysis was performed using SAS Version 9.4 (SAS Institute, 2013). The SURVEYLOGISTIC procedure was used to account for the complex sample design.

Laboratory Comfort Measuring Study

This study compared anthropometrically comfortable seating positions to induced discomfort seating positions using a specially designed seating rig that allowed for the adjustment of cushion length and seat belt height. Children aged 4- 8yrs were recruited through social media and advertisements on public noticeboards. Prior to the sitting trial, stature, weight and buttock-to-popliteal length (BPL) were measured.

The comfortable (Fit) position of the seat was determined for each child using (i) a seat cushion length that corresponded to the BPL, and (ii) adjusting the seatbelt D-ring so that the sash belt was placed in the optimum position running midway across the shoulder, crossing the centre of the chest without contacting the neck. The seat back angle remained at a constant 10 degree recline.

Children were then asked to sit sequentially in the four conditions listed in Table 1. The order of these conditions was randomised. Each child was required to sit, correctly restrained, in each condition for 10

minutes. At the end of the 10 minutes, while the child was still restrained, the self-report survey tool was administered. There was a 10 minute break between each trial.

For the majority of the trials, the child watched children's TV shows throughout the 10 minute trial interval. In four participants, this was removed to provide the 'no stimulus' (NS) condition.

Each trial was video recorded for later analysis.

Table 1

Laboratory study experimental conditions, presented randomly

Condition	***n***	***Description***
Fit	14	Anthropometric fit based of stature and buttocks to popliteal length (comfortable)
Fit+Footrest	14	As above with the introduction of a footrest (comfortable)
Cushion Long	14	As above but with the cushion length 10cm too long (uncomfortable)
Seat Belt High	14	As Fit+Footrest but with the seatbelt height adjusted to create sash belt contact with neck (uncomfortable)
No Stimulus	4	As Fit but without video stimulus

Three different methods of measuring comfort were compared in order to find a method that can reliably differentiate between comfortable and uncomfortable seating positions among children. This is also presented in more detail elsewhere (Fong et al, manuscript in preparation). In summary, the methods used to measure comfort were (i) a self-report questionnaire, (ii) pressure distribution mapping, and (iii) a newly developed analysis method.

For the self-report survey tool, we looked at established and validated pain research protocols (Bieri et al. 1990; Hicks et al. 2001; Wong and Baker 1988) and guidelines for constructing surveys for children (Borgers et al. 2000, 2004) as well as some tools used to study comfort in adults (Gyi and Porter 1999). Taking all these into account we modified the body discomfort chart (Gyi and Porter 1999) and paired it with a modified form of the Wong-Baker FACES Pain (Wong and Baker 1988) in an effort to create a survey instrument that can be used with children.

Two different survey tools were used. Survey Tool 1 included the FACES Pain Scale with one mid-range face removed (7 point scale modified to 6 point scale) and the full 20 point Body Part Discomfort Chart, with the scale reduced from 1-7 to 0-5. The mid-range face was removed as it did not appear to provide much discrimination between the two adjacent faces, and the Body part Discomfort Chart scale was reduced in line with Borgers et al. (2000, 2004)'s guidelines. Survey Tool 2 used the same components of the FACES Pain Scale with the 20 Body Part Discomfort Chart summarised to six body regions. See Figure 1.

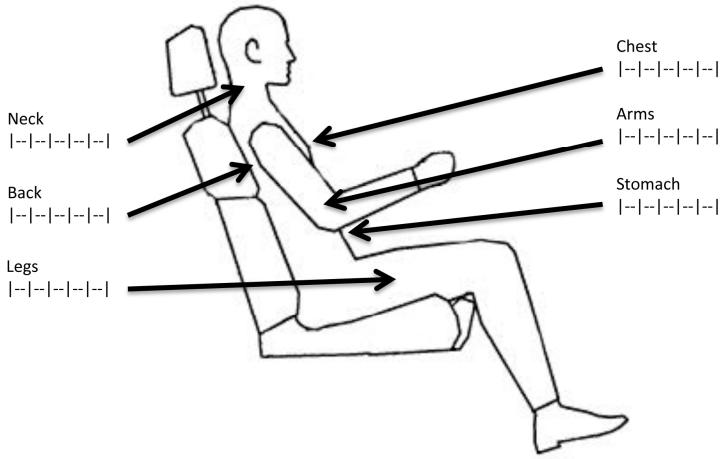

Figure 1: Six Point Scale

Pressure distribution data were collected using a CONFORMat (Tekscan, Inc South Boston MA, USA) which consists of two pressure mats, one for the seat base and one for the seat back. Recordings from the CONFORMat system was analysed in three ways; change in centre of force (ΔCOF - distance), contact area (CA - area) and peak pressure (PP - force).

Video footage was recorded using a 720p camcorder placed at a 45 degree angle to the left of the testing rig to record wide angle front left quarter view. Still images were also captured using a 12MP digital camera for reference. A video analysis protocol was developed to calculate the rate of Discomfort Avoidance Behaviours (DAB) observed. Video footage was analysed using Kinovea (Kinovea 0.8.15, Kinovea.org 2012) video analysis software. DAB was defined as any shift in seating position, playing with the seat belt, and child stretching. To score the footage, each clip was watched and any instance of these behaviours was marked with a reference frame in the software. These behaviours were then tallied for each condition before being divided by the video clip duration to calculate the average number of discomfort avoidance behaviours per minute (the DAB score or DAB rate).

The reliability of the DAB rate was measured by having a second researcher repeat the scoring. Differences between the two researcher scores were examined using the intraclass correlation coefficient (ICC).

The overall analysis involved paired samples T-tests to examine differences between seating conditions for the DAB, pressure and survey protocols. Correlation between the three measures of comfort was examined using Pearson's r. Normal distribution of data was also tested.

RESULTS

Online Survey

Data was collected from 470 parents or carers across Australia. Figure 2 provides the responses obtained to the question about what factors parents consider in making restraint transitions.

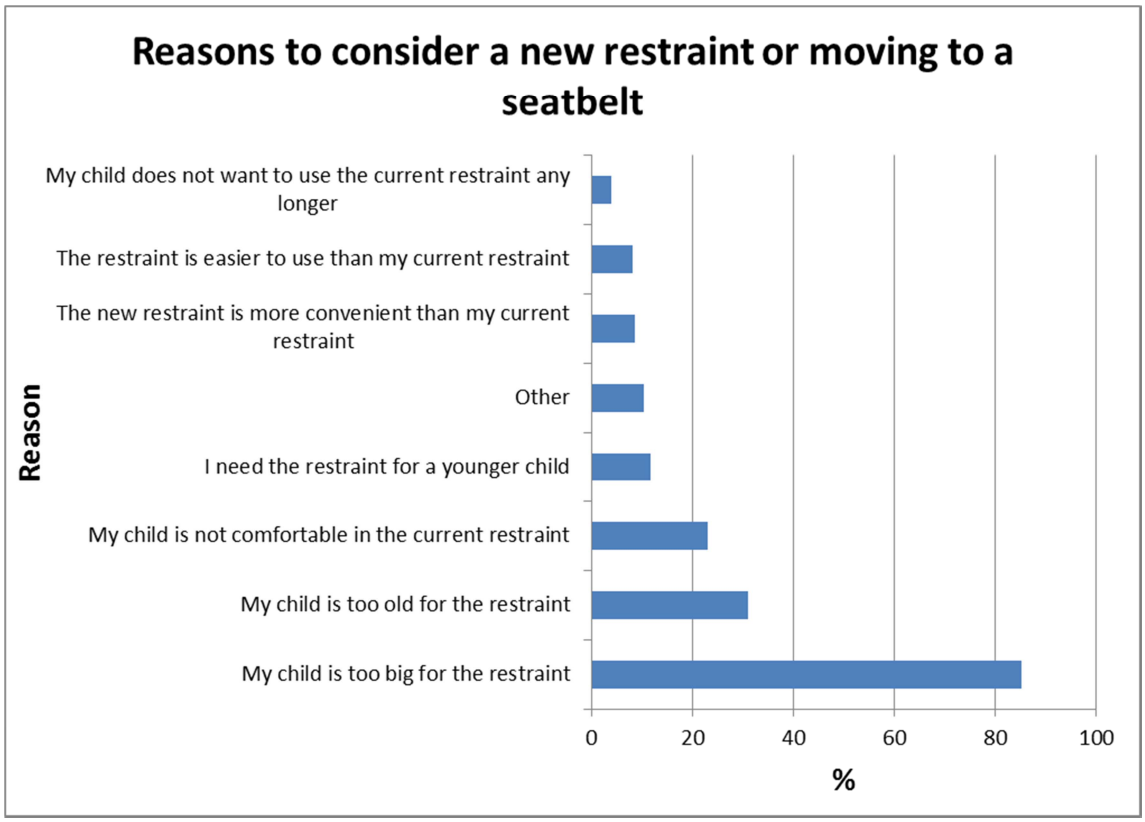

Figure 2: Relative importance of reasons provided by parents for considering a new restraint or moving their child into a seat belt (multiple responses were allowed)

Almost one quarter of parents (23%) reported that they would consider transitioning their child if they thought their child was not comfortable in their current restraint.

Most parents (86.4%) agreed that the restraint their child was using looked comfortable (39.4% strongly agree, and a further 47% agree).

Three quarters (75%) of parents also indicated they perceived their child was comfortable in the restraint. The most common reasons given related to a lack of complaint from the child (26% of those reporting the child was comfortable), the ability of the child to sleep in the restraint (22% of those reporting the child was comfortable) and the presence of padding and support in the restraints (22% of those reporting the child was comfortable).

Field Observation Study

Results from the logistic regression modelling are presented in Table 2 and Table 3.

As shown in Table 2 there was a significant increase in the odds of child restraint misuse when there were no comfort problems reported by the parent (OR 1.85, 95% CI 1.24-2.77). There was also an increased odds of restraint misuse when a convertible restraint (rearward facing/forward facing or forward facing/booster) was used, irrespective of a reported comfort problem (OR 13.47, 95% CI 5.66-32.03).

Table 2

Logistic regression results for incorrect use vs correct use (= significant)**

Misuse											
Variable	***Category***	***Unweighted Frequency***	***Weighted %***	***Unweighted***				***Weighted***			
				OR	***CI 95%***			***OR***	***CI 95%***		
*ComfortProblem***	Yes	60	61.7%	Reference				Reference			
	No	374	58.3%	0.87	0.57	-	1.32	1.85	1.24	-	2.77
Education	Tertiary Education	288	56.9%	Reference				Reference			
	Secondary or Lower	155	61.9%	1.24	0.81	-	1.91	0.98	0.46	-	2.10
LanguageAtHome	Other	20	60.0%	Reference				Reference			
	English	444	58.6%	1.24	0.35	-	4.36	2.15	0.69	-	6.67
Income	Over $100,000	112	60.7%	Reference				Reference			
	$50,000-$100,000	191	56.5%	0.91	0.52	-	1.60	0.99	0.36	-	2.71
	Less than $50,000	132	59.8%	1.13	0.71	-	1.78	1.45	0.42	-	4.99
Convertible**	No	350	46.0%	Reference				Reference			
	Yes	147	90.5%	11.88	6.73	-	20.97	13.47	5.66	-	32.03

As shown in Table 3 there was no significant association between parent reported comfort problems and the use of age appropriate child restraints. However, there was a significant decrease in the odds of using a non-age appropriate restraint when the parents education level was higher, irrespective of a parent reported comfort problem (OR 0.33, 95% CI 0.21-.53). Furthermore, the likelihood that an age appropriate restraint was used was increased when a child restraint was used as opposed to a seatbelt, irrespective of a parent reported comfort problem (OR 2.75, 95% CI 1.29-5.12).

Table 3

Logistic regression results showing age appropriate restraint use versus inappropriate use (= significant)**

Age Appropriate											
Variable	***Category***	***Unweighted Frequency***	***Weighted %***	***Unweighted***				***Weighted***			
				OR	***CI 95%***			***OR***	***CI 95%***		
ComfortProblem	Yes	60	73.3%	Reference				Reference			
	No	374	80.7%	1.42	0.80	-	2.54	1.11	0.34	-	3.59
Education**	Tertiary Education	288	80.2%	Reference				Reference			
	Secondary or Lower	155	76.1%	0.78	0.59	-	1.03	0.33	0.21	-	0.53
LanguageAtHome	Other	20	60.0%	Reference				Reference			
	English	444	80.2%	1.75	0.51	-	6.03	1.90	0.88	-	4.12
Income	Over $100,000	112	83.0%	Reference				Reference			
	$50,000-$100,000	191	78.0%	0.80	0.50	-	1.28	0.81	0.31	-	2.15
	Less than $50,000	132	78.8%	0.88	0.49	-	1.61	1.03	0.40	-	2.67
RestraintType**	Seatbelt	196	63.8%	Reference				Reference			
	Restraint	301	89.7%	3.99	2.40	-	6.64	2.57	1.29	-	5.12

Laboratory Comfort Study

Data was collected from 14 participants aged 4-8yrs (M=5.4yrs, SD=1.5yrs), 3 males and 11 females.

We found our adapted survey tools did not provide a reliable measurement of real comfort among the children within our sample. There were no significant differences in survey scores between seating conditions with the

children reporting comfort even in induced discomfort seating conditions. Survey Tool 1 was used with the first 10 participants but we found it was impractical with the young children that we were working with because they appeared to lose concentration due to the number of items in the tool. Survey Tool 2 was used with the remaining 4 participants but did not seem to be any more useful than Survey Tool 1 because the children did not provide answers that could be used to discriminate between seating conditions.

The seat base and the seat back pressure distributions were analysed separately. There was a significant increase in the ΔCOF between Fit and Fit+Footrest conditions for the seat base ($p=0.033$, $n=13$) and a non-significant trend towards an increase ΔCOF for the seat base between Fit and No Stimulus ($p=0.056$, $n=4$). For the seat back there was a non-significant trend toward an increase in ΔCOF between Fit and No Stimulus ($p=0.058$, $n=4$).

There was a significantly higher average seat base contact area for the Fit condition compared to the Fit+Footrest condition ($p=0.007$, $n=14$) and a significantly lower average seat base contact area for the Fit condition compared to the Cushion Long condition ($p=0.000$, $n=14$). For the seat back there was a significantly higher contact area for the F condition compared to the CL condition ($p=0.023$, $n=14$).

There were no significant differences for either the seat back or seat base for peak pressure.

Analysis of the video footage for discomfort avoidance behaviours allowed us to calculate a DAB rate. We observed a significant increase in the DAB rate for the Seat Belt High condition over the baseline F condition ($p<0.01$, $n=13$). No other significant differences were observed between any conditions (Figure 4). However the difference in the DAB rate between Fit and the No Stimulus condition could be significant if there was a larger sample ($p=0.087$, $n=4$).

Significant correlations between DAB rate and ΔCOF were observed for the seat base ($r(10)=0.763$, $p<0.01$) and seat back ($r(11)=0.584$, $p<0.05$) in the Cushion Long condition and in the seat base ($r(11)=0.679$, $p<0.05$) of the Fit condition.

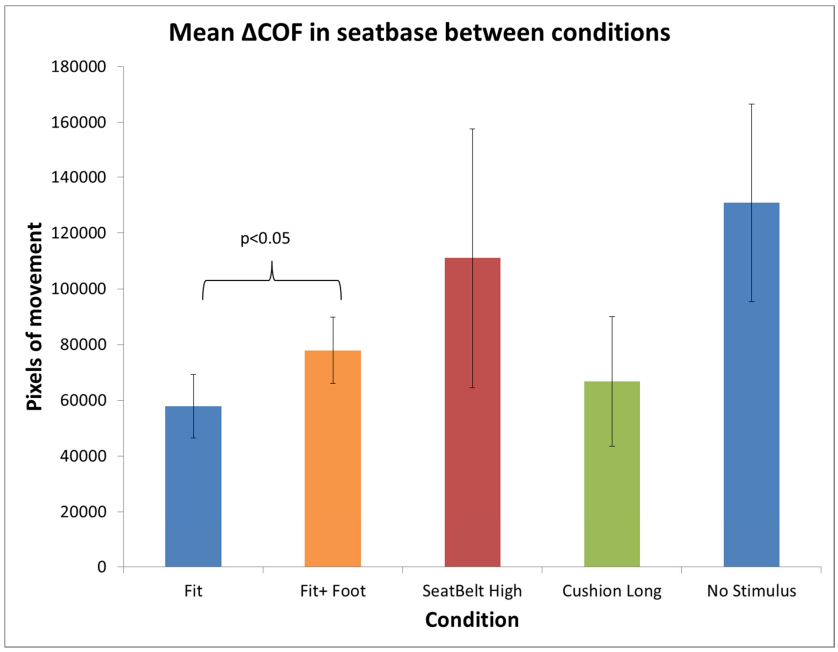

Figure 3: Comparison of ΔCOF for the seat base between conditions (No Stimulus, n=4, for all other conditions n=14). A statistically significant difference was observed between the Fit and Fit+Footrest conditions (p<0.05).

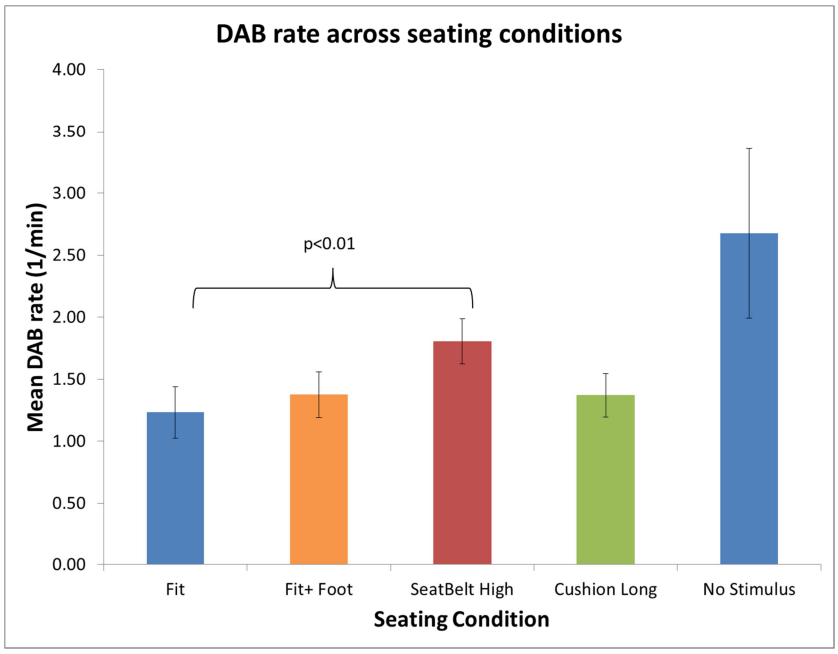

Figure 4: Comparison of DAB rate across tested seating conditions (No Stimulus, n=4, for all other conditions n=14)

The DAB scoring method also proved to be repeatable with average intra class correlation coefficient (ICC) was 0.98 (95% CI 0.954-0.991, $F(31,31)=61.425$, $p<0.001$) which indicates a high degree of agreement between the two raters used to assess the DAB rate, indicating the repeatability of this measurement

DISCUSSION

Our key results from the online survey were that parents continue to report comfort as a factor in their transition decisions but most parents feel that their child is comfortable in their current restraint. In the field observation study we saw that parent perceived comfort is not a predictor of age appropriate restraint use, but contrary to expectation the lack of reported comfort problems increased the odds of restraint misuse. The laboratory comfort study demonstrated that the most useful tool for studying comfort of children in child restraints is likely to be the DAB score.

Parent perception of child comfort in restraints

From the combined field observation study and parental survey we observed an overall low rate of parent reported comfort problems, suggesting that most parents do not believe that their child is experiencing issues with comfort in their CRS. Despite this, comfort was the third most common factor reported as a consideration when making decisions about restraint transitions. This suggests some disconnect in how parents perceive the comfort of their children 'now' i.e. the restraint they are using now looks comfortable, and they are comfortable in the restraint they are using now, compared to how parents think they might act in the future e.g. if the child becomes uncomfortable in the future they would change restraints. Yet in the logistic regression models, there was no significant association between parent reported comfort and appropriate/inappropriate restraint status of the child, indicating this 'future' concern is not actually driving inappropriate restraint choices. Future analysis could explore this in more detail to examine any possible difference in parent reported comfort for children at transition margins compared to other children.

In our open-ended questions asking why parents thought their child was comfortable; the most common reasons were a lack of complaint from the child, and the child's ability to sleep in the restraint. While these would appear to be indicators of the child's actual comfort in the restraint, there is no available data linking child behaviour to comfort. Therefore while this provides some understanding of how the parent perception of child comfort is built, it still does not tell us anything concrete about the actual comfort of the child.

Our finding that child restraint misuse is almost twice as more likely in children where parents do not report comfort problems is contrary to expectations. Considering the above discussion it suggests that when children are not complaining, or are sleeping, or are otherwise indicating to their parents that they are not uncomfortable there is an increased risk of misuse. This anomaly requires further study. It may be that children have incorrectly positioned themselves to achieve a level of comfort or that there is some problem with the factors parents use in making decisions about their child's level of comfort. Either way it highlights the need to educate parents to be alert for errors in use. Furthermore, this indicates that as suggested by other researchers (Bilston et al. 2011; Pettersson and Osvalder 2005; Simpson et al. 2002), there may be a relationship between the actual comfort of children and incorrect use. While there have been few studies examining comfort experienced by children in child restraint systems and the influence this might have on misuse this remains untested. One study which examined the subjective comfort experienced by a small sample of children using different types of boosters suggested a potential interaction between comfort and the seated posture adopted by a child (Osvalder et al. 2013). There may also be a link between the posture adopted by the child and incorrect use, and this also requires further study.

Measuring the actual comfort of the child

A major barrier to the study of the actual comfort of the child is the lack of available validated measures of comfort in children in child restraint systems. Comfort in general is difficult to study, and young children offer a particular challenge. While there have been a number of studies examining comfort in adults, including in vehicles (Chae et al. 2011; Kyung and Nussbaum 2008; Kyung et al. 2008; Paul, Pendlebury, et al. 2012), there are few validated methods for assessing comfort that could easily be adapted for use with young children. Self-report surveys, questionnaires and pressure distribution mapping (Chae et al. 2011; Gyi and Porter 1999; Porter et al. 2003; Smith et al. 2006) appear to be the most common methods employed. Notable examples of survey instruments include the Automotive Seating Discomfort Questionnaire (ASDQ) (Smith et al. 2006) and the body discomfort chart used by Gyi and Porter (1999). However as noted by other researchers (Pettersson and Osvalder 2005), survey and interview measures may not be reliable in children as unreliable answers are often provided by children under age 10. To counter this, we attempted to combine a method commonly used to capture self-reported pain data in young children, with survey and interview methods. However, as reported here, we found this to be an unsuccessful approach. Interestingly, Osvalder et al. (2013) reported the successful use of a survey tool developed using a combination of faces paired with questions in their battery of survey tools to collect information about comfort from children in vehicles. It may be that the difference in child age range between our study and their study might explain this discrepancy. In our study the majority of our participants were less than the age of 6, while in the (Osvalder et al. 2013) study they studied children aged 7-9 years. However it is important to note that our laboratory study aimed to validate the responses of the children with anthropometrically predicted comfortable and uncomfortable seating positions while no validation data for the survey used by other researchers has been presented.

In our laboratory comfort study we attempted to provide each participant with a personalised baseline anthropometric fit using our adjustable testing rig which was constructed from the rear seat of a car as a baseline "comfort" seating condition. This rig was constructed to allow the adjustment of cushion length and height of the D-ring for the seat belt. The angle of the seat back was fixed. For children it has been suggested that a seat base length of 80-95% of the buttocks to popliteal length is required for good fit (Parcells et al. 1999). Our rig allowed us to achieve this seat base length. We have assumed that this will equate to a comfortable seating situation as providing sufficient cushion length would avoid discomfort caused by uneven pressure distribution due to increased flexion of the hips and knees as seen by Le et al. (2014) in taller people; and discouraging a slouched posture since the knees can bend over the front edge of the seat (Parcells et al. 1999). We have also assumed that having an appropriate sash belt fit that does contact the neck and passes over the mid line of the shoulder would also equate to a comfortable condition. However, to date there is no data to support or refute this assumption. Our DAB results do however indicate that children were more likely to fidget in seating conditions where the seatbelt D-ring was high indicating that our assumption about sash belt fit comfort may be correct.

Pressure distribution mapping is another method commonly used to study comfort of adults in vehicle seats. Pressure data has been reported to be strongly associated with comfort (Kolich and Taboun 2004; Kyung and Nussbaum 2008) and static pressure distribution measurements have been shown to be repeatable and sensitive to different seating characteristics (Kolich and Taboun 2004). However, at least two studies have reported no clear relationship between interface pressure and comfort (Chae et al. 2011; Gyi and Porter 1999; Porter et al. 2003). Furthermore, Porter et al. (2003) reported pressure measurements lacked enough sensitivity to distinguish between four different seats. Despite the contentiousness of this issue, pressure mapping continues to be a reasonable objective measure of comfort/discomfort and pressure variables are still commonly used for this purpose in ergonomic seat design. Chae et al. (2011) and Kyung and Nussbaum (2008; 2008) argue that pressure data such as the total contact area, average pressure ratio and peak pressure still provide useful data for seat. In our laboratory study we did observe some significant variations between change in centre of force and average contact area between different seating conditions, indicating some sensitivity of this method to postural changes at least, when used with child occupants. However the relationship between changes in pressure distribution and the association between anthropometrically predicted fit and comfort remains unclear.

We also saw significant correlations between pressure distribution measurements and our newly developed DAB score. The DAB rate proved to be the most sensitive measure of discomfort between the three different methods that we tested. Furthermore, this is a relatively easy method to implement and may prove a useful tool in naturalistic studies.

Osvalder et al. (2013) used video analysis in their naturalistic study to monitor the child's behaviour and body language. Our work takes this further and employs video recordings and subsequent analysis to quantify the child behaviours in a repeatable form, the DAB rate. Forman et al. (2011) extracted frames from video recordings to evaluate seat belt fit and posture, whilst this is a good compromise for seat belt fit analysis we felt that we would lose too much data and we were using much shorter video recordings which made a full video analysis much more manageable.

Limitations

It should be noted that each of the three studies has its own limitations. Firstly, the online parental survey was distributed primarily through social media with the aid of a motoring services company, NRMA, and targeted parents who were currently using a child restraint. This delivery method leads to a sample bias towards those parents who are interested or concerned about child restraints and currently using a child restraint and consequently likely to be better informed about child restraints. It also targets parents with existing links to the motoring services organization. While the data extracted from the observation study came from a study that originally had a robust population referenced sample, the comfort variable used in this analysis had a lot of missing data (24.7%). Therefore weightings used may not accurately reflect the population, so results cannot be generalised to the wider population. Finally, the laboratory study was conducted as a pilot study to develop methods for later work. The sample size, particularly for some aspects of the analysis, was very small. Non-significant results may reflect low power, particularly those related to trials involving the 'NFS' condition. Further, the sample size was also biased towards younger children, and it may be fruitful to repeat this work with a larger sample and greater age range of children.

Conclusion

Our results suggest that whilst some parents report that child comfort is a contributor to their restraint transition decisions, in reality parent reported comfort is not associated with appropriate or inappropriate restraint use by their children. If comfort is important for optimal restraint, it is likely to be the real comfort of the child rather than that reported by the parent. The method we have developed for studying real comfort can be used to further understand this relationship.

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Mechanisms of head and neck injuries sustained by helmeted motorcyclists in NSW, Australia.

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ABSTRACT

The wearing of a standard-approved motorcycle helmet has been the most significant step in reducing fatal and serious injury among motorcyclists worldwide. Mandatory helmet use for motorcyclists is now in place in many parts of the world. Nevertheless, some researchers have observed a high percentage and duration of hospitalisations in helmet-protected motorcyclists with the long-term outcome considerably influenced by head injury severity. The objective of this study was to investigate head and neck injuries sustained by helmeted motorcyclists in real world crashes and define the circumstances which result in injury.

Data were collected by in-depth crash investigations of motorcyclist crashes in NSW, Australia. The crash investigations included inspections of the accident scene, the crash involved motorcycle and the helmet. Where possible, detailed helmet examination including helmet disassembly was performed to identify all crash related damage. The type of damage, damage location and damage severity on the helmets were recorded. The major head and neck injury types sustained by these helmeted riders were analysed for crash and helmet damage related factors which influenced the incidence of injury.

Due to the recruitment procedures used, participants in this study were biased towards lower severity head injuries. A head injury was sustained in 23.9% of cases but serious (AIS 3+) head injury was sustained in only 2.3%. There was neck injury in 9.1% of cases but no serious (AIS 3+) neck injuries. The main head and neck injury types by frequency were superficial injury (13.6%), “diffuse” type brain injury (13.6%), facial/dental fracture (4.5%) and cervical spine fracture (4.5%).

Helmet damage was observed in the majority of cases (86.4%) suggesting successful injury prevention in many instances. A high proportion of observed impact damage was to the front of the helmet (78.5% of cases), particularly the chin bar and visor of full-face helmets. Impact damage associated with a predominantly tangential force onto the head was more common than radially directed force damage.

Superficial head injury and facial/dental fractures was significantly more common ($p < 0.01$) in riders who were wearing open face helmets, where the face and chin are exposed to direct impact, compared to full face protected riders. There were significantly more cervical spine fractures in cases with damage indicative of a radially directed force ($p = 0.036$) than where damage indicated a tangentially applied force. The circumstances resulting in “diffuse” brain injuries could not be clearly defined by the data in this study due to the small number of riders with this injury.

The results highlight potential areas for improving the head and neck protection offered to motorcyclists including extending the required region of coverage, particularly to the face, and through mitigating the effect of tangential

impacts on the helmet. Given the high frequency of diffuse intracranial injury even in lower severity head injury cases, assessment of helmet effectiveness should use performance criteria reflecting the mechanisms of this type of injury.

INTRODUCTION

The effectiveness of motorcycle helmets in reducing fatal and serious injury among motorcyclists is well known [1–3]. Mandatory helmet use is now required by motorcyclists in many countries including Australia and throughout Europe. Nevertheless, a high percentage and duration of hospitalisations have been observed even in helmet protected motorcyclists [5] and injuries to the head are still the most common cause of death in fatally injured helmeted motorcyclists [6].

Current motorcycle helmet designs are largely shaped by helmet performance standards which are in force in most countries. Standards define how a helmet must perform in an impact consisting of dropping an instrumented rigid headform, fitted with the test helmet, onto a rigid anvil. The helmet is assessed based on the linear acceleration experienced by the headform centre of gravity. This test and helmet assessment criteria were originally developed in the late 1960's [7] using some of the earliest and most widely used biomechanical head injury tolerance data, the Wayne State University Concussion Tolerance Curve [8], which despite its name, was originally based on the level of linear acceleration producing a linear skull fracture in an adult. The simplified loading conditions of the impact attenuation tests were chosen to ensure the test results were repeatable and reproducible, both necessary and appropriate for ensuring the consistent performance of a mass produced product such as helmets. However the drop test may not reflect what occurs to the head of a motorcyclist in a real crash. Furthermore the response criteria measured during these tests cannot assess the potential for all types of head and neck injury.

The aim of the present study was to investigate the types of head and neck injury sustained by helmeted motorcyclists in real crashes and common loading conditions to the helmet that result in injury to the rider. Hence indicating areas of helmet protection where further research effort can be applied to reduce the frequency and severity of head and neck injuries to helmeted riders in crashes.

METHODS

The data used for this study were collected by Neuroscience Research Australia as part of an in-depth case-control study of motorcycle crashes. 91 cases of injured motorcyclists over the age of 14, admitted to a NSW hospital, were recruited by research nurses. The participant then completed a face-to-face interview, self-reporting various details regarding the crash. The crash related injuries were recorded from the medical records of the patient. The crash involved motorcycle and the crash scene were inspected noting all evidence of the incident. The clothing and helmet worn by the rider at the time of the crash were also inspected. Where authorised by the study participant the clothing and helmet were collected for subsequent analysis. A subset of these cases has been previously presented assessing the effectiveness of the motorcycle protective clothing worn by the rider [9].

To address the aims of the current study, three of the cases were excluded from the analysis because there was either no helmet worn in the crash or the helmet was ejected sometime during the crash sequence. Helmets that were retained from the study participants were disassembled and any internal or external evidence of crash related damage was also recorded.

The data were analysed using the Statistical Package for Social Sciences, version 21. Pearson's Chi-square tests and Fisher Exact tests were used to analyse any differences in the proportion of injured riders with respect to variables of crash characteristics, helmet characteristics, helmet damage and damage location. A p-value of < 0.05 was considered significant.

RESULTS

The 88 helmeted riders had an average age of 36.9 ± 15.6 years with a range of 16 to 80 years. 82 riders were male (93.2%) and six (6) were female (6.8%). The following sections outline the injuries sustained by these riders, the general crash characteristics and details regarding the helmets.

Incidence of Head and Neck Injury

Head injury was sustained in 21 of the 88 cases (23.9%), see Table1. but serious (AIS 3+) head injury was sustained in only 2 (2.3%). Based on the frequency and severity of the injuries, the major injury types sustained in this set of riders were superficial head injury, diffuse intracranial brain injury, facial/dental fractures and cervical spine fractures.

Superficial head injury was most common with the face sustaining the majority (80.8%) of these injuries. Of the 9 fractures to the head 1 (11.1%) involved the skull vault and the remaining 8 (88.9%) involved the facial bones or teeth. The intracranial injuries seen in this study were predominantly "diffuse" type brain injuries which included closed head injury/loss of consciousness, concussion or change in cranial pressure which was sustained by all 12 riders with intracranial injury. Neck injury was sustained in 8 cases (9.1%), see Table1., but there were no serious (AIS 3+) neck injuries. Cervical spine fractures occurred in 4 cases (5%) and minor injuries to the skin and soft tissues occurred in a further 4 cases (5%).

Table1.
Head and neck injury cases

Injury type		Number of cases (% of total cases)	Total no. of injuries	Frequency of injury severity (% of injuries)			
				AIS 1	AIS 2	AIS 3	AIS 4
Head injuries	Superficial	12 (14%)	26	26 (100%)	0	0	0
	Fracture	4 (5%)	9	2 (22%)	6 (67%)	1 (11%)	0
	Intracranial	12 (14%)	17	6 (35%)	7 (41%)	3 (18%)	1 (6%)
	All Head Injury	21 (24%)	52	38 (68%)	13 (23%)	4 (7%)	1 (2%)
Neck injuries	Superficial	2 (2%)	4	4 (100%)	0	0	0
	Fracture	4 (5%)	4	0	4 (100%)	0	0
	Soft Tissue	2 (2%)	2	2 (100%)	0	0	0
	All Neck Injury	8 (9%)	10	6 (60%)	4 (40%)	0	0

Crash Characteristics

The estimated speed prior to crashing was recorded for 91.2% of cases, with a median estimated pre-crash speed of 52.5 km/h and a mean of 52.3 ± 23.9 km/h.

In the majority of cases (75%), the crashed motorcyclist was involved in a collision with another vehicle. The predominant collision opponent was a passenger car (58%) followed by the roadway/kerb only (13.6%) and then poles/trees (6.8%).

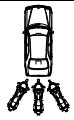
Table2. shows the distribution of crash configurations based on the classification used in the COST 327 study of European motorcycle in-depth crash investigations [1]. Type 7 crashes (at 29.5%) were most common, which included 22 cases of single vehicle loss of control crashes (25% of all cases). Circumstances where the front of the motorcycle collided with the rear (Type 5) or side (Types 3 and 4) of a passenger car were also common.

Helmet Type

The majority of riders (86.4%) wore a full face type motorcycle helmet which included a chin bar and the remainder wore an open face "jet" style helmet (13.6%).

There was a statistically higher proportion of open face helmeted riders who sustained superficial head injuries (p=0.009, FET) and facial/dental fractures (p=0.007, FET) compared to full face protected riders.

Table2.
Distribution of crash configurations

Collision Types	Description	Diagram	Number of Cases (% of cases)
Type 1	Side collision against the front of a four wheel vehicle		4 (4.5%)
Type 2	Head-on collision against the front of a four wheel vehicle		7 (8.0%)
Type 3	Head-on against the side of a four wheel vehicle		12 (13.6%)
Type 4	Oblique collision against the side of a four wheel vehicle		13 (14.8%)
Type 5	Head-on collision against the rear-end of a four wheel vehicle		14 (15.9%)
Type 6	Rear-end collision against the front of a four wheel vehicle		12 (13.6%)
Type 7	Collision against pedestrians, bicycles, non-moving objects		26 (29.5%)
Total			88

Helmet Damage Type

There was observed or reported damage to the helmet in 76 cases (86.4%), 10 helmets (11.4%) were undamaged and the condition was not known for 2 (2.2%). Scratches were most common, observed in 72 cases, followed by cracks to the shell (16) and observable liner damage (10).

The type of helmet damage was assessed in 69 cases as either associated with a tangentially directed force or radially directed force to the head. Tangentially directed force damage was more common (62.5%) than radially directed force damage (44.9%) and 24.6% of cases had areas of both types of damage.
Cases with radially directed impacts had a significantly higher incidence of cervical spine fracture than cases without normal impacts ($p = 0.036$, FET).

Helmet Damage Location

The location of the damage on 65 inspected helmets was mapped on a schematic of the helmet divided into zones based on the crown, front, sides and rear of the helmet at varying levels of elevation from the helmet rim. Figure1. shows that the majority of helmet damage was to the face, despite 11 open face helmets without a chin bar and 5 of these without a face shield (visor) that could not sustain damage in these areas. The remainder of the damage was concentrated in a band around the sides and the rear of the mid-level of the helmet with relatively infrequent damage to the crown. The proportion of cases sustaining damage to each area of the helmet is shown in Table3.

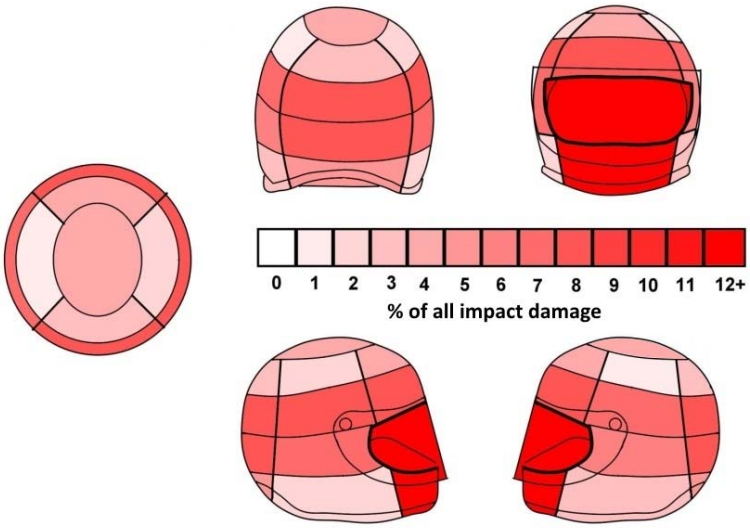


Figure1. Distribution of impact damage on the 65 inspected helmets.

Table3.
Location of helmet damage for 65 inspected helmets

Location on helmet	Frequency of cases	Percentage of cases
Chin bar	34	63.0 (of full-face type helmets)
Visor/Facial	39	65.0 (of visor equipped helmets)
Frontal	19	29.2
Any frontal impact damage	51	78.5
Left	30	46.2
Right	32	49.2
Rear	40	61.5
Crown	8	12.3
Total helmets with recorded damage location	65	100.0

Devices attached to the Helmet Shell

11 (12.5%) of the crashed riders in this study had a Bluetooth headset attached to the exterior of the outer shell of the helmet. The devices allow the motorcyclist to communicate with other riders, make phone calls and listen to audio while riding and typically consist of a set of speakers and a microphone placed inside the helmet, and a small box of electronics mounted on the outside of the helmet, as shown in Figure 2. In one of these 11 cases, the helmet also had an attachment for a video camera device.

When an attachment to the external shell was present, 27.3% of riders sustained a diffuse type intracranial injury compared to only 7.4% of riders sustaining intracranial injury when there was no attachment. However, this difference was not statistically significant ($p = 0.088$, FET).

Figure2. Bluetooth device (left) and attachment point indicated by spots of glue (right).

DISCUSSION

In-depth crash investigations of the 88 helmeted motorcyclists attending an emergency room were used to identify the injuries being sustained by helmeted riders and to define the common and injurious loading conditions being applied to the helmet in real crashes. The collected cases demonstrate the effectiveness of motorcycle helmets in preventing injury as damage was present in over 85% of helmets while less than 25% of riders sustained a head or neck injury. However, the collected cases appear to be biased towards low severity head and neck injury as the proportion of serious (AIS 3+) head injury sustained by helmeted riders in this study (2.3%) is lower than that reported in European data [5] (9.7%) and in the Hurt data of crashes in the US [3] (17.9%). Exclusion of helmet ejected cases, which were classified as helmeted riders by both Richter et al. and Hurt et al., was not the reason for the difference with the two excluded cases in this study sustaining only AIS 1 superficial head injury. Nevertheless, the major injuries sustained by helmeted riders in these crashes in terms of frequency and severity were identified as intracranial injury, facial/dental fractures, superficial head injury and cervical spine fractures.

Superficial head injury (mostly comprising superficial facial injury) and facial and dental fractures were significantly more common when an open face helmet was worn compared to full-face helmet protection in this study. This result confirms the almost identical findings reported by Cannell et al. [10], although the relationship was not significant in their study, and is not surprising given the face of the rider is exposed to direct impact while wearing an open face helmet. Furthermore, inspection of the location of helmet damage demonstrates that the face region is the most commonly impacted region of the rider's head. Data reflecting a more severe group of fatal crashes is currently being investigated and will be able to determine whether this trend is also true for more seriously head injured riders.

Cervical spine fractures were sustained in only 4.5% of cases in this study. The cases indicated that cervical spine fracture tended to result from radially direct impacts to the helmet. This outcome relates to the clinical cadaver experiments performed by Hodgson and Thomas [11]. These researchers found that excessive strain on the cervical spine was produced in flat (radial) impacts to the crown and impacts inducing hyperextension on the neck. Hodgson and Thomas found that the effect of the helmet in preventing this type of injury was limited however considerable research effort has shown that the motorcycle helmet at least does not contribute to producing additional neck injury [12,13].

Diffuse intracranial injury was the most common and most severe head or neck injury sustained by the helmeted riders collected in this study but there were no clear circumstances that produced a significantly higher proportion of cases with this injury. The majority of these diffuse injuries were concussions and losses of consciousness. Such injuries have received considerable attention in sports such as American football. It is now understood that rotation of the head is the primary contributor to diffuse brain injury based on the pioneering experiments of Gennarelli et al. [14–16]. As a result, football helmets have undergone significant design improvements by using rotational head injury criteria specifically related to concussion. Assessment of motorcycle helmets to these criteria is ongoing[17–19] but it is important to note the concern that the stiffness of some helmets is such that they are ineffective in reducing brain injury risk at low impact speeds [20]. Given the severity and frequency of the diffuse brain injuries observed in real motorcycle crashes, there is a demonstrated need for helmet design to be assessed in a manner relevant to the known mechanism of this type of injury.

Examination of the crashed helmets in this study was performed to obtain data on the likely loading conditions experienced by the head and neck of riders in real crashes. In the distribution of impacts shown in Figure1., a high frequency of impacts occurred to the front and facial area of the helmets of crashed riders. This is in agreement with previous major crash investigation studies in Europe [5], the US [3] and Australia [21,22]. Despite this, the chin and facial region is outside the require region of protective coverage required by many motorcycle helmet standards, including the Australian Standard AS 1698 and the US regulation FMVSS 218. Further the distribution of impacts around the circumference of the crash damaged helmets, shown in Figure1., coincides with the edge of the region of protective coverage in AS/NZS 1698 and FMVSS 218. Previous Australian motorcycle crash studies recommended extending the area of impact protection to these areas to improve the protection of helmets in frontal and lateral impacts [21,22].

The specification of performance requirements for a helmet able to protect the rider in a frontal impact to the head is a complex task. This is due to the multiple types of injuries that can result from an impact to the face which include local focal injuries (face and skull fractures), remote focal injuries (basilar skull fracture) and head and neck motion induced injuries (brain and cervical spine injuries) [23]. Helmet design for facial impacts remains a critical area where further research could improve protection from injury for a motorcyclist.

The helmets in this study also predominantly showed damage indicating a tangentially directed force, or a rotation of the head. This has also been observed in real crash investigation studies by Otte et al. [24] and Hurt et al. [12]. Oblique impacts to the head have been the subject of ongoing research for two main reasons: First, current knowledge of head injury biomechanics recognizes the importance of head rotation in the production of brain injury; and second, most motorcycle helmet standards do not attempt to measure or produce this type of impact or rotation. A number of laboratory test methods [25,26] have demonstrated a reduction in angular head acceleration from current and new helmet designs but the relevance of these in real crash circumstances remains unknown.

The attachment of Bluetooth and video camera devices to the outside of the helmet shell is a relatively new issue. This tends to go against what is prescribed in motorcycle performance standards, such as in AS 1698 which requires a smooth outer helmet shell to minimize friction or snagging that may promote helmet rotation [27]. This study found a higher proportion of cases sustaining diffuse type intracranial injury when these devices were attached than when they were absent, although the difference was not significant. The fitment of such devices is becoming increasingly popular and accessible as they become cheaper and more reliable. The effect on head injury risk requires further investigation. At present there are no regulations in Australia regarding attaching these devices to helmets.

DIRECTIONS OF FUTURE RESEARCH

This crash investigation study has highlighted a number of areas where further research has the potential to improve the head and neck protection for helmeted motorcyclists in real crashes.

1. Diffuse type intracranial injury was the predominant injury type in terms of frequency and severity sustained by the riders in these crashes indicating the need to be able to assess the capability of the helmet to ameliorate the risk of this type of injury.
2. Impacts to the front and face of the helmet were common and injurious, particularly to open face helmeted riders. Given the existing lack of impact protection required in this area of the helmet by many current motorcycle helmet standards, there is a need to examine the optimal design of full facial protection for the lowest risk of injury to the face, the skull, the brain and the neck.
3. Tangential impacts to the helmet were the predominant damage type to the crashed riders in this study. Further assessment of these types of impacts in the laboratory is required to match a test methodology to the loads and injuries experienced by riders in real crashes.

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COUNTERMEASURES TO ADDRESS MISUSE IN CHILD RESTRAINT INSTALLATIONS: FROM TECHNICAL SOLUTIONS TO REAL WORLD EVALUATION

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ABSTRACT

Misuse has been reported in various studies as an important issue in countries where local legislation requires a mandatory use of child restraint systems. It has been shown that the rate of incorrect fitting of the CRS to the car may vary between 60 to 80% (1 Bendjellal, 2006).
However research has not confirmed that all misuse scenarios result in critical occupant loading but a combination of several misuse situations may lead to an improper occupant restraint (2 Bilston, Brown, 2011). It is therefore important to develop technical solutions aiming at reducing the risk of misuse in real-world. Slack in vehicle seat belts when securing the CRS to the vehicle and improper occupant restraint within the CRS are among the top 5 misuse situations according to Bennett study (3 Bennett, 2011) and in NHTSA 2005 survey (4 NHTSA, 2006).
Two technical solutions are presented in this paper, these are:

- A system (called A) that enables improving the attachment of the CRS to the vehicle by assisting the user to tighten properly the vehicle seatbelt
- A system (called B) that was developed: to improve the attachment of the CRS to the vehicle by tightening the vehicle seat-belt (mechanical solution); and (for harness seats) to reduce slack in the harness in riding conditions (electronic solution).

Operating modes of both systems are described. User trials were conducted to assess further the functionality of the systems as well as getting consumer feedback when utilizing them in real world. Key findings from these are also provided in the paper. Both systems show promising results in terms of assisting the users in installing CRSs.

INTRODUCTION

In previous papers, mechanical and / or visual systems were presented and these enabled the tension of the harness of the CRS to be adjusted by the caregiver. The Safe Strap system was developed in 2006 with the aim to provide such indication. The system is mounted on one of the straps of the CRS harness and comprises 2 members which are pivotally coupled. The upper member as shown in Figure 1 is equipped with visual pictograms illustrating the status of the harness tension. When the desired tension is not achieved the member is in a raised position thereby indicating that the tension is not correct. Pulling the adjuster strap of the CRS will reduce the slack and increase the tension in the harness; the upper member is then deflected to a flat position that is parallel with the harness strap. Pictograms are provided as indicators of the correct or incorrect tension.

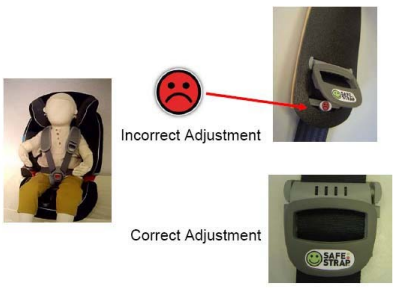


Figure 1: Safe Strap System

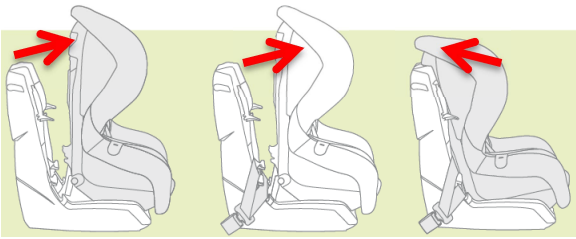
Figure 2: Audible system to help user adjusting correctly the harness

Another technical solution consists in providing the user an audible signal that indicates a correct level of harness adjustment was reached. Such a solution, called Click & Safe™ was introduced in 2008 on Group 1 seats. When pulling the adjuster strap forward and upwards audible clicks indicate that there is no slack or a minimum slack and, that an optimum tension in the harness was achieved. An illustration is provided in Figure 2. Based on lessons learned with these systems, new features were developed which are presented in the following. This paper focuses on CRS systems which use: the vehicle's 3-point seat belt to secure the CRS to the vehicle; and an integrated harness system to secure the child occupant within the CRS.

Installing car seats in vehicles requires 3 steps – First reading the user guide of both the vehicle and the CRS by the caregiver; second- installing the seat into the car and securing the CRS with the seat-belt with a properly routed belt, third-installing the child in the seat and placing the harness and tightening it. It is important that all these 3 steps are carried out properly. But in reality parents tend to speed up the first step, hence the risk to oversee important information. User manuals in general contain a lot of information, required by regulation but can be intimidating for parents. The second step is essential to ensure that the CRS is adequately secured to the car. That means a correct belt routing and getting the belt tight enough to retain the CRS. This part of the installation can be challenging as parents, once the belt is properly routed, often exert less or much effort to tighten the belt, only to find as they check their work that the child restraint still feels loose. Isofix system was introduced to address this potential problem and provide an effective solution for parents. However there are still many countries around the world where this attachment is not available in vehicles. For seats which use harness systems, the 3rd step involves tightening the harness with sufficient force to properly restrain the child.

ENHANCING THE CHILD ATTACHMENT WITH THE SEAT-BELT- SYSTEM A

Introduced in 2000 on a forward facing CRS, the system features a tensioning arrangement for the lap strap of a vehicle seat belt, consisting of side limbs and levers. When the seat shell is moved from the raised position illustrated in Figure 3 by the letter (a), to its position of normal use (c) , the levers are pushed downwards so that the side limbs (position b) deflect the lap strap from the direct path of the belt guides.



a b c

Figure 3: A tensioning system of the seat-belt introduced in 2000 on a Forward Facing CRS

Recently a system called Click-Tight (System A) was developed and introduced on a US convertible platform. It features a large tensioning arm that opens completely to allow for easy and clear routing of the belt from the front of the seat with easy access forward or rearward facing. With the system, there is only one installation method necessary regardless of the size of the child, or which orientation (FWF or RWF).

Once the belt is routed properly through the simple and accessible belt path, the tensioning arm can be easily closed over the vehicle belt. Once the tensioner clicks closed, the mechanism is locked and the belt is properly tensioned. Figure 4 illustrates the operating mode of the Click Tight.

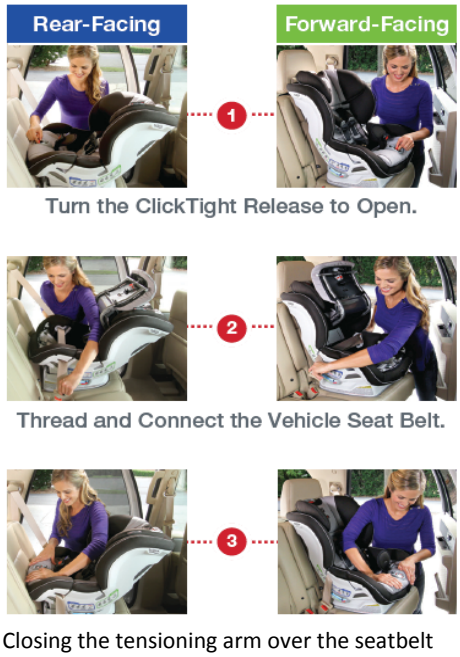


Figure 4: Click Tight Feature

ENHANCING THE CHILD TO CRS ATTACHMENT - SYSTEM B

The system was developed for child restraint systems with integrated harness and was introduced in EU in 2014 on a Group I platform (9-18 kg mass range). The CRS was equipped with seat-belt tightening system. The feature described here is included in the 'safety loop' of the integral harness and comprises harness straps, an adjuster, a buckle, energy absorbing chest pads and 4 key elements that are part of the innovation, called Automatic Tensioning System:

- A bezel as the communication interface to consumers showing the status of the child restraint system,
- An integrated retractor system that bridges the harness and the adjuster,
- Sensor that detects the occupant presence and controls automatically power supply,
- Software and electronic components.

The Automatic Tensioning System supports the installation of the child by a real time measured tension control on the integrated harness with respective feedback to the caregiver. The resulting tension on the safety loop of the child restraint system is kept over time by the Automatic Tensioning System in real time as well, independent from movements of the child or any other unintentional effect, which could cause loss of tension.
For extreme situations, e.g. unintended buckle release, the system is equipped with electromechanical alert devices, communicating with the caregiver. The key steps in utilizing the ATS are shown in Figure 5.
Once the user has placed the child into the seat, the system is automatically detecting that a child has been placed into the seat. The seat can detect this by the means of a sensor that is located underneath the seating surface. After a pre-defined time the bezel lights up red, as shown in Figure 6, which indicates to the user that the system is activated.

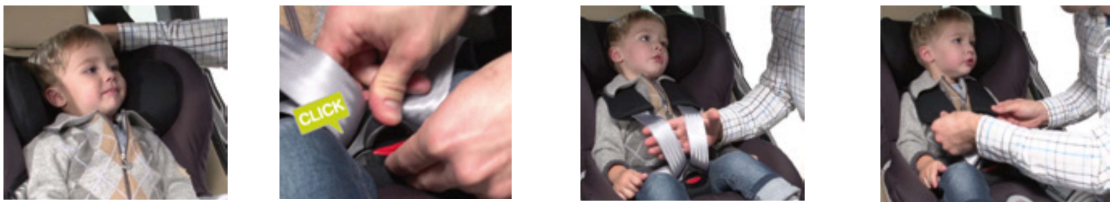


Figure 5: Key steps in utilizing the Automatic Tensioning System

Figure 6: The bezel lights up red and no audible signal indicates that the system is activated.

Figure 7: The bezel lights up green and audible signal can be heard.

Would the user leave the child un-buckled in the child seat or would not harness the child to the correct harness tension an audible alert will be activated after a pre-defined time. This is comparable to the seat belt reminder installed in vehicles that will deliver an audible alert if the driver forgets to buckle up.

In normal operating, a user would harness the child in a similar process as for comparable 5 point safety harnesses. The shoulder straps would be placed over the shoulders and the buckle tongs would be brought together and placed into the buckle. The tightening of the harness can be done by pulling the adjustor strap. The user needs to pull the adjustor strap till the bezel, as shown in figure 7, is lighting-up green and giving an audible signal.

Besides that the system is guiding the user to a proper harness fit the system has two additional functions. The mechanical part of the system has the capability to take slack out of the harness system. The system is able to remove this slack or looseness of the harness within a defined range. The system is designed to ensure that the harness fit remains at the same level of tension as at the moment of harnessing or increases in tension to the required level over time. In case the defined range of compensation has been reached the system will alert the user that the system will not compensate further. Where further tension is required (in normal usage, this should not be necessary as the fit should be equal or better than the original harness tension) or desired by the user, the system can be reloaded again by pulling again the adjustor strap, till the bezel lights-up green, as shown in Figure 7.

Another function that the system provides is that, once the system is fully loaded, it can alert the user in case the child is escaping or unbuckling itself. The bezel will light up red and an audible signal will alert the user. Allowing users to pull over and harness the child correctly.

CLICK TIGHT SYSTEM VALIDATION

The system A was evaluated in consumer trials that took place in different geographic locations. Consumers were asked to read the user guide, install the CRS in the vehicle and then use the Click Tight system. Both rear facing and forward facing installation were used. The key result: participants found the system easy to understand and operate, and felt satisfied with the resulting tension of the seat-belt once the tensioning arm was locked.

AUTOMATIC TENSIONING SYSTEM VALIDATION

The ATS system has been tested during the development multiple times in various conditions, ranging from mechanical tests to electronic tests. Besides all relevant component / seat testing related to the homologation of the seat has been tested as well with consumer at different development stages. Some of the main research questions were: would users be able to use the ATS system, would the comfort of the child be influenced by the continuous retracting of the ATS system, would the perceived fit of the harness be rated as sufficient?

The system has been tested with consumers in two different ways. Pre-homologation of the seat the test took place in a car clinic environment. Multiple groups with more than 30 users tested different models during the development in this controlled environment, as shown in Figure 8. The consumers were asked to perform pre-

defined tasks like placing the child into the seat while the car seat was installed into a car. During this test children wore different types of clothes. Children age ranged from 9 months to 4 years.

Figure 8: Car clinic of fitting test.

After the seat has been homologated it has been tested in a large scale combined qualitative and quantitative test. More than 100 consumers participated for a prolonged period of time. The main objective of the research was to gain a deep understanding of the user experience. The field investigation consisted of 3 different stages.

In the first stage the consumers have been trained similar to the training they would get in a retail environment. After this the same predefined tasks has been performed as in the car clinic tests. In the second stage the test persons tested the seat in their own car for more than 3 weeks. During this period a group of 40 users had an application installed on their smart-phones to give real-time feedback about the ATS. They have been asked to perform some predefined tasks of harnessing their child before and after their journey, to rate this and make pictures of these situations. As last stage of the field test all test persons have been interviewed to gain quantitative and qualitative feedback on the seat.

FINDINGS /RESULTS

The system A (Click Tight) shows very good results in terms of:

- Facilitation the task of seat-belt routing and seat-belt tensioning when installing a convertible CRS,
- Reducing the slack in the vehicle seat belt
- This holds true for both rear facing and forward facing installation as the same tensioning arm is utilized for both configurations.

For the system B (ATS) results of the research highlighted that all users understood the functions of the system and could perform the task to harness their child correctly. In summary:

- 96% of the users rated the harness fit as correct.
- 27% of the users responded even that they would harness their child now tighter than before after discovering and using the ATS system.
- 90% of the users rated that the ATS system fulfilled the comfort expectations for their children.

CONCLUSIONS/PERSPECTIVE

The objective of this study was to present 2 features that were developed respectively to enhance the CRS to vehicle attachment, and to improve both CRS to vehicle attachment and securing the child to the CRS. The first system, called Click-Tight, was developed to help the user to get the appropriate tension of the vehicle seat-belt. A key component of the feature, i.e. a large tensioning arm helps to reach the correct tension of the seat-belt. In addition, the system works for both rear facing and forward facing installation. Feedback from consumer trials allowed assessing the system at various stages of the program. The system was launched in 2014 on a convertible CRS.

The 2nd system called “Automatic Tensioning System” was developed to help the care giver to install the child into the seat by providing a real time feedback on the harness tension. The ATS includes electronic as well as mechanical components, and has been developed and introduced on a R44 Group I platform. That platform was already equipped with a seat-belt tensioning system. The ATS among others features a sensor that detects the occupant presence. Once the child is installed and attached with harness, the ATS assists the user, when the

later pulls the adjuster strap, with visual and sound indicators to reach the appropriate harness tension. The system has also the capability to remove the slack in the harness in real time. In addition an alert signal is initiated when a large slack is detected or when the seat buckle is released.

The ATS has been validated during various evaluation trials with consumers which were divided into 2 phases: a pre-homologation phase where the consumer trials took place in a car clinic environment. The second phase (post-homologation) involved more than 100 consumers. The key results from the whole consumer trial research shows that 96% of the participants rated the harness fit as correct and about one third responded that they would harness their child now tighter, and 90% of the users rated the ATS fulfilling the comfort expectations for their children.

Based on the consumer trials and experience gained in developing both systems; the next step will be to extend their application to other platforms.

ACKNOWLEDGEMENTS

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The views expressed here are those of the author and not necessarily those of BRITAX GROUP and its entities.

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PEDESTRIAN RESPONSE WITH DIFFERENT INITIAL POSITIONS DURING IMPACT WITH A MID-SIZED SEDAN

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ABSTRACT

Real-world pedestrian impacts occur with highly-variable or unknown initial conditions of the pedestrian. However, experimental pedestrian tests and computational pedestrian impact simulations mainly focus on the response of the subject using specific initial conditions. The objective of this study is to investigate computationally the influence of posture and impact direction angle on pedestrian response during an impact. The 50th male THUMS pedestrian model was integrated with a mid-sized sedan finite element model initially travelling at 40 km/h. The influence of the pedestrian position during impact was investigated by varying 9 orientations (relative to the vehicle) and 3 standing/gait postures, for a total of 27 impact configurations simulated. Pedestrian kinematics and injury were assessed and compared across all simulations. Substantial variations were observed on the pedestrian torso rotation (-68.9°~57.6°), and head impact conditions (head impact time 111~139 ms, and head impact velocity 10.7~15.3 m/s). The head impact velocity was found to correlate with the impact direction angle, where facing towards or away from the vehicle would result in greater head impact velocity than when struck in a purely-lateral impact.

INTRODUCTION

Although significant improvements have been achieved in mitigating pedestrian fatalities, there are still over 400,000 pedestrians killed each year worldwide [1]. Epidemiological reviews have highlighted that 66-82% of pedestrians were hit by passenger cars and 60-77% of pedestrians were struck by the vehicle front [2], and serious injuries occur frequently at speeds between 25 and 55 km/h [3]. More than 60 % of the pedestrian accidents occurred at a vehicle speed of 40 km/h or less, and impacts with the bumper, hood, and windshield were believed to be the leading sources of pedestrian injury [4]. This suggests that an indepth understanding of the complex interaction between the pedestrian and vehicle is essential to ensure effective countermeasures.

The response of the human body to vehicle impact has been extensively studied using post-mortem human specimens (PMHS) on component tests [5] and vehicle-impact tests [6- 9]. These tests are the primary source of data for the development of physical and computational surrogates (anthropomorphic test devices and human body models, respectively). Understandably, studies involving vehicle-pedestrian impact using PMHS have focused on well-defined situations such as pure-lateral vehicle impact direction and specific pedestrian posture.

The most common pedestrian-vehicle impacts occur when pedestrians are crossing the road, and the amount of pedestrians struck laterally varies between 65-89% of all impact cases [2,3,10]. However, an accurate pedestrian impact angle may not always be reported and it is reasonable to assume that the pedestrian impact direction is not purely lateral. In addition, prior to an accident, pedestrians often move in different ways: 71-79 % of pedestrians involved in accidents are standing upright and moving across the road [11], while 65% of pedestrians are walking and 20% are running [2]. Reaction to an oncoming vehicle will also influence the initial orientation and posture of a pedestrian [12]. Changes to pedestrian orientation and posture from the purely-lateral stance may greatly affect the ensuing kinematics, injury risk, and pattern during a vehicle-pedestrian impact.

Compared to experimental tests performed with PMHS which differ in age and anthropometry, simulations with human computational models have the potential to evaluate the impact response of a single individual while introducing extrinsic variability. Peng et al. [13] used the stances for different gait parameters developed in a previous pedestrian sensitivity study by Untaroiu et al. [14] to investigate the effects of gait on pedestrian head

kinematics. However, this study did not investigate the whole-body kinematics and injury mechanism because a simplified multibody ellipsoid model was used. Finite element (FE) models of a human body offer some promising advantages for studying injury biomechanics, including the prediction of injury mechanisms and injury criteria and a large potential for customization. One the existing human body models (HBMs) that have been developed is the Total Human Model for Safety (THUMS) pedestrian model, which has been used to investigate the biomechanics of vehicle-pedestrian impact [15- 21]. While these studies focused on the risk of injury to a specific body part (brain: [19], shoulder: [21]) or the influence of specific parameters such as car type, vehicle speed, and pedestrian size [17-20], there were no studies on the influence of posture and impact orientation.

The hypothesis of this study is that changes to the pedestrian posture and orientation at the time of impact will significantly affect the resulting responses and distribution of injury predicted for the pedestrian. Thus, the objective of this study is to computationally investigate the influence of posture and impact orientation on pedestrian kinematics and injury during an impact with a mid-sized sedan.

METHODS

Model Setup

The THUMS pedestrian model (50th male, version 4.01) was integrated with a FE model of the front-end structure of a mid-sized sedan (Figure 1). The vehicle model is the same vehicle used in a previous experimental PMHS pedestrian test series at UVA reported by Subit et al. [9] . All boundary conditions and mass distributions assigned to the FE vehicle model were consistent with those of the test series. An initial velocity of 40 km/h was applied on the vehicle and was allowed to impact the pedestrian. The friction coefficient between the HBM and the vehicle was 0.5, and was 0.6 between the feet and ground [13]. The simulation time was 200 ms, using the code LS-DYNA v971 7.1.1.

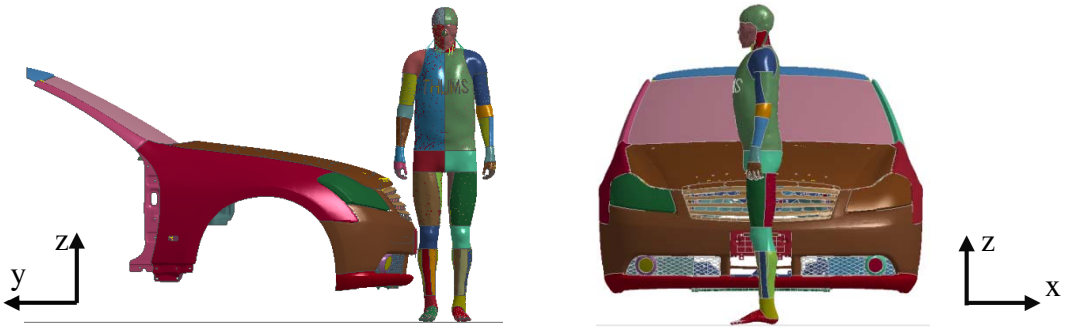

Figure1. Simulation set up (Baseline model S0).

Alteration of posture

Three human postures were created from the original HBM (Figure 2). A baseline model “S”, which is the default position of the THUMS pedestrian model, was defined as a standing posture with arms down and legs aligned. Two additional models were defined with walking postures, referred to as “RF” and “LF”, and were derived from a normal gait-cycle of 0% (right leg forward) and 50% (left leg forward) respectively [14]. Positioning of the THUMS pedestrian model for the RF and LF postures was done using pre-simulation to match the angles of the hips, knees, shoulders and elbows.

Standing (S) ***Right leg forward (RF)*** ***Left leg forward (LF)***

Figure 2. Pedestrian postures.

Impact direction

Nine pedestrian impact orientations were defined in the study, with the pedestrian center of gravity (CG) located along the centerline of the vehicle. The baseline impact orientation was the pure-lateral case (Figure 1) with an associated impact direction angle of 0 degrees. Eight additional impact directions were created from the baseline orientation by rotating the pedestrian relative to the vehicle by ±15° ("near lateral"), ±30° and ±60° ("non-lateral"), and ±90° ("facing toward" or "facing away") (Figure 3). Due to the nearly symmetric geometry of the vehicle and HBM, these cases represent a full 360° array of pedestrian impact orientation relative to the vehicle.

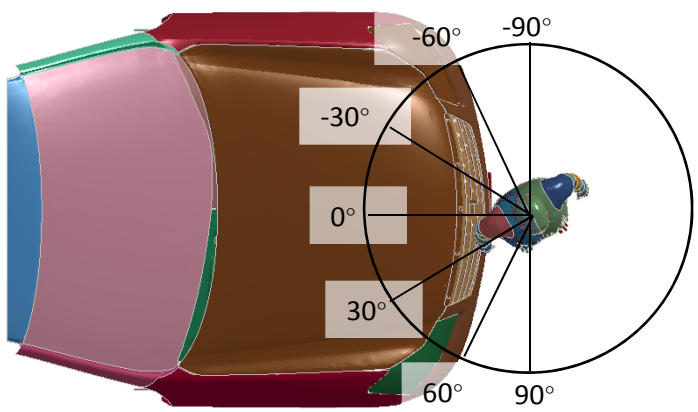

Figure3. Impact direction angles. The model shown is S30.

Simulation matrix

By varying the three pedestrian postures and nine impact directions, a matrix of 27 cases in total was created and simulated (Table 1).

Table 1. Simulation Matrix

	Simulation ID								
Impact direction angle	**0**	**15**	**30**	**60**	**90**	**-15**	**-30**	**-60**	**-90**
Standing posture	S0	S15	S30	S60	S90	SN15	SN30	SN60	SN90
Right leg forward posture	RF0	RF 15	RF 30	RF 60	RF90	RFN15	RFN30	RFN60	RFN90
Left leg forward posture	LF0	LF15	LF30	LF60	LF90	LFN15	LFN30	LFN60	LFN90

Pedestrian Kinematics

Head impact velocity V_h was defined as the relative velocity between the head center gravity and the vehicle CG after initiation of contact (Equation 1). The head impact location was categorized by 4 areas on the vehicle according to the wrap around distance (WAD) [23], which was measured as the sum of the distance from the ground to bumper, bumper to hood leading edge, and hood leading edge to head impact location. For the vehicle used in this study, the head impact location could be classified by the 4 areas illustrated on Figure 4.

$$V_{relative} = |\vec{V}_{head} - \vec{V}_{car}| \qquad \text{[Equation 1]}$$

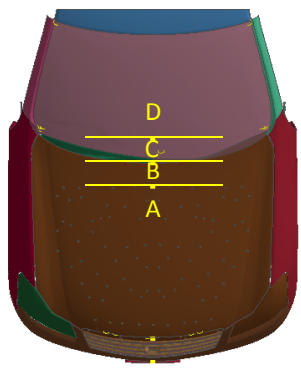

Figure4. Wrap around distance (WAD) categories. A: WAD < 1800 mm (hood), B: 1800 ⩽ WAD<1950 (cowl), C: 1950 ⩽ WAD< 2100 (windshield frame), D: WAD ⩾ 2100 mm (windshield).

Torso rotation was calculated by change in the line formed by the left and right acromion, from the initial and final (when torso impacts vehicle) pedestrian facing angle to the vehicle (Equation 2) and Figure 5.

$$\theta_{initial} = accsin(\frac{L_x}{L}) \qquad \theta_{final} = accos(\frac{L_z}{L}) \qquad \text{[Equation 2]}$$

Figure5. Initial torso angle and final torso angle (Configuration SN30).

Bony Fracture and Ligament rupture

The injuries predicted to occur in the simulations were bone fractures and ligament ruptures, and strain-based injury criteria were used for predicting these types of injuries. A 3% principal strain fracture criterion was used to predict all the cortical bone fracture (except for hands and feet), and 16% principal strain injury criterion was used for knee ligament rupture [20, 22]. These values are representative of a 40 year-old subject [20]. Tissue-level injury prediction was done in the post-processing stage of the simulation, since element deletion was not activated during the simulations to ensure stability of the models.

Statistical Analyses

The response variables in this study were the pedestrian kinematics obtained from the models: head impact time, head impact site, head velocity Vh, torso impact angle, torso rotation. Descriptive statistics were given for all variables as mean ± one standard deviation (SD). Posture and impact direction effects were explored using a general linear regression model with the pedestrian kinematics as the dependent variables. Student's t-tests were performed on the regressed coefficients and $p < 0.05$ was considered statistically significant.

RESULTS

Pedestrian Kinematics

Pedestrian kinematics for each simulation are listed in Table 2. Considerable variability was found with the observed head impact time of 111~139 ms, head impact velocity of 10.7~15.3 m/s, and torso rotation of -68.9°~57.6°. All head impact locations were between the cowl and windshield frame, with the WAD ranging from 1900 to 2100 mm. In all 27 configurations, 8 experienced shoulder impact, and 14 experienced elbow impact (4 experienced both), while only 9 did not experience either impact. In Figure 6, V_h is displayed crossed impact direction angle and absolute impact direction angle according to the respective posture. The head impact velocity V_h was higher in cases where the pedestrian was turned away from the purely-lateral orientation (Figure 6). No trend was observed for the amount of torso rotation experienced by the pedestrian as a factor of impact direction angle (Figure 7).

Linear regression coefficients of the pedestrian kinematics are shown in Table 3. Posture was a significant predictor for head impact site ($p=0.029$), torso impact angle ($p=0.049$) and torso rotation ($p=0.049$). Impact direction angle was a significant predictor for head impact site ($p<0.0001$) and torso impact angle ($p<0.0001$). There was a trend that impact direction may be predictor for head impact velocity V_h ($p=0.066$). The absolute impact direction angle was found to be a significant predictor ($p<0.0001$) for the head impact velocity Vh.

Table 2. Pedestrian kinematics

Cases	Head impact time (ms)	Head impact site	Head impact location	V_h (m/s)	Torso impact angle (°)	Torso rotation (°)	Upper extremity impact
S0	139	lateral	C	11.6	15	15	both
S15	139	occipital	C,D	10.8	72.6	57.6	elbow
SN15	135	frontal	C	10.8	-83.9	-68.9	elbow
S30	134	occipital	C	11.8	84.0	54.0	elbow
SN30	125	frontal	C	12	-89.0	-59.0	elbow
S60	123	occipital	C	14.6	77.6	17.6	-
SN60	117	frontal	B,C	13.4	-88.3	-28.3	-
S90	117	occipital	C	15.3	87.9	-2.1	-
SN90	111	frontal	B	14.0	-88.6	1.4	-
RF0	128	occipital	C	12.2	29.5	29.5	shoulder
RF15	124	occipital	C	12.7	47.6	32.6	shoulder
RFN15	129	lateral	B,C	13.6	8.5	23.5	shoulder
RF30	125	occipital	B,C	12.7	75.5	45.5	elbow
RFN30	129	lateral	B	14.9	-27.0	3.0	shoulder
RF60	123	occipital	B,C	13.5	77.5	17.5	elbow
RFN60	130	frontal	B,C	12.5	-86.5	-26.5	-
RF90	130	occipital	B	15	87.0	-3.0	-
RFN90	129	frontal	B,C	13.3	-75.0	15.0	-
LF0	132	frontal	C	11.7	-40.0	-40.0	both
LF15	132	lateral	C	12.5	11.8	-3.2	both
LFN15	131	frontal	C	11.2	-76.0	-61.0	elbow
LF30	130	lateral	B,C	13.9	23.9	-6.1	both
LFN30	118	frontal	B,C	10.7	-77.6	-47.6	elbow
LF60	134	occipital	B,C	13.3	90.0	30.0	-
LFN60	124	frontal	B	12.1	-52.2	7.8	elbow
LF90	132	occipital	B, C	15.4	88.2	-0.8	-
LFN90	129	frontal	B	13.2	-106.0	-16.0	elbow

*A: WAD < 1800 mm (hood), B: 1800 ⩽ WAD<1950 (cowl), C: 1950 ⩽ WAD< 2100 (windshield frame), D: WAD ⩾ 2100 mm (windshield).

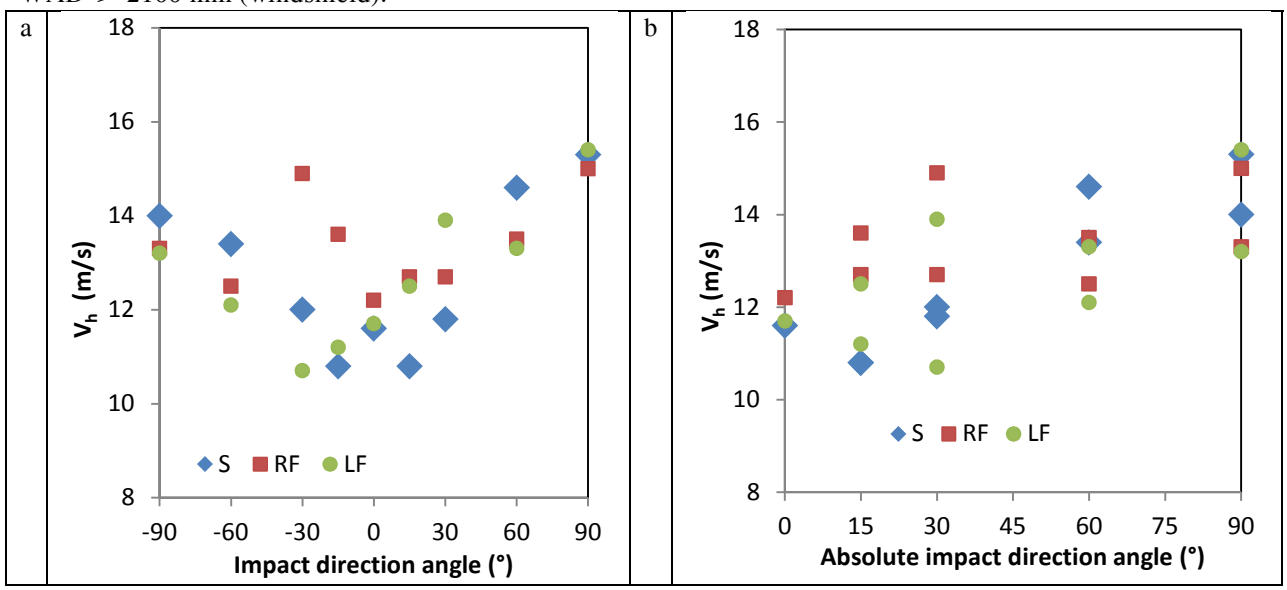

Figure 6. Correlation of head impact velocity with impact direction angle and posture

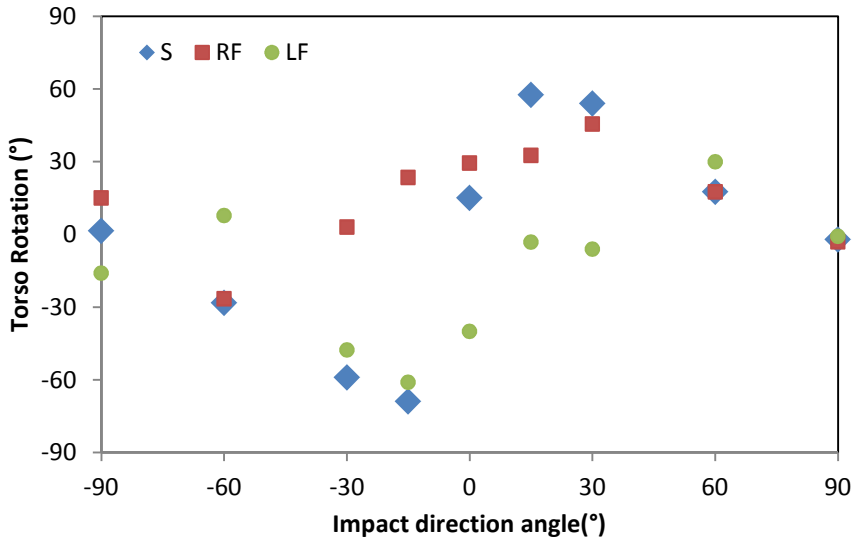

Figure7. Correlation of torso rotation with impact direction angle and posture

Table 3. Linear regression analysis of pedestrian kinematics

Variables	Coefficients	S.D.	t-Stat	P-value	Lower 95%	Upper 95.0%
Head impact time						
Posture	-0.83	1.60	-0.52	0.607	-4.13	2.46
Impact direction angle	0.03	0.02	1.04	0.310	-0.03	0.08
Head impact site						
Posture*	-0.33	0.14	-2.32	0.029	-0.63	-0.04
Impact direction angle*	-0.01	0.00	-6.39	0.0000	-0.02	-0.01
Head impact velocity V_h						
Posture	0.36	0.31	1.15	0.263	-0.28	1.00
Impact direction angle	0.01	0.00	1.92	0.066	0.00	0.02
Absolute impact direction angle*	0.03	0.01	4.94	0.000	0.02	0.04
Torso impact angle						
Posture*	15.28	7.36	2.08	0.049	0.09	30.46
Impact direction angle*	1.19	0.11	10.61	0.0001	0.96	1.43
Torso rotation angle						
Posture*	15.22	7.36	2.07	0.049	0.04	30.40
Impact direction angle	0.19	0.11	1.73	0.097	-0.04	0.43

*p< 0.05

Bony Fracture and Ligament Rupture

The observed cortical bone fractures and knee ligament ruptures are listed in Table 4. The skeletal fractures and ligament ruptures were mainly found in the skull and knee ligaments. Skull fractures were observed in every case except three cases (cases S15, R30, and RN30). Only two upper neck (C2) fractures were observed, and one of them (case RFN30) experienced a shoulder impact causing the neck to sustain a substantial bending moment. In three cases, there was a single rib (upper thorax) fracture and in one case a sternum fracture was observed. Only one upper extremity fracture (right ulna during an elbow impact in S30) and two thoracic spine fractures occurred. Shoulder injuries were found and included four cases of scapular fracture and one clavicle fracture. All cases with shoulder injury experienced oblique torso impact with the hood (facing down, with torso impact angle -40°~ -76°), but in the case RFN90 and LFN60, the scapula fractures did not happen on the impacted side.

Pelvis fractures occurred in four cases, all on the right acetabulum occur. Those cases were pure-lateral or near-lateral impacts. There were no thigh and leg fracture observed in these cases, and in all cases except S90 a knee ligament rupture occurred. There was a correlation between the number of knee ligament ruptures and the impact direction (Figure 8). Most knee ligament ruptures occurred when the pedestrian was facing towards the vehicle (creating a hyperextension of the knees) and least ruptures occurred when the pedestrian was facing away from the vehicle (creating a flexion of the knees).

Table 4. Bony fractures and ligament ruptures

Cases	Head/ Neck	Upper Extremity	Chest/spine /shoulder	Pelvis	Thigh /Leg	Knee ligaments rupture (R/L/Number)
S0	Skull/-	-	-	R Hipbone Acetabulum	-	(ACL, MCL)/ (ACL, PCL, LCL)/5
S15	-	-	Sternum, L 1st rib /-/-	-	-	(ACL, MCL)/(ACL, LCL)/4
SN15	Skull/-	-	-	-	-	(All)/(ACL, LCL, PCL)/7
S30	Skull/-	R ULNA	-	-	-	(MCL)/(LCL, ACL)/3
SN30	Skull/-	-	-	-	-	(MCL,ACL,PCL)/(ACL,LCL,PCL),6
S60	Skull/-	-	-	-	-	/(ACL, LCL)/2
SN60	Skull/-	-	-	-	-	(All)/(ACL, LCL, PCL)/7
S90	Skull/-	-	-	-	-	-/-/0
SN90	Skull/-	-	-	-	-	All/All/8
RF0	Skull/-	-	-	R Hipbone Acetabulum	-	(ACL, MCL)/ (ACL, LCL)/4
RF15	Skull/-	-	-	-	-	(MCL)/(ACL, LCL)/3
RFN15	Skull/-	-	-	-	-	(MCL,ACL,PCL)/(ACL,LCL)/5
RF30	-	-	R 2nd rib/-/-	-	-	(MCL)/(LCL, ACL)/3
RFN30	-/C2	-	-	-	-	(MCL, ACL, PCL)/ (ACL, PCL, LCL)/6
RF60	Skull/-	-	-	-	-	-/(ACL, LCL)/2
RFN60	Skull/-	-	-	-	-	(MCL, ACL, PCL)/(All)/7
RF90	Skull/-	-	-	-	-	(LCL)/-/1
RFN90	Skull/-	-	-/-/L scapula	-	-	All/All/8
LF0	Skull/-	-	-/-/R scapula	R Hipbone Acetabulum	-	(ACL, MCL)/ (ACL, LCL, PCL)/5
LF15	Skull/-	-	R 3rd rib/T3/-	-	-	(MCL)/(ACL, LCL, PCL)/4
LFN15	Skull/-	-	-/-/R clavicle, R scapula	R Hipbone Acetabulum	-	(ACL, MCL)/ (ACL, LCL, PCL)/5
LF30	Skull/-	-	-/T3/-	-	-	(ACL,MCL)/(ACL,LCL,PCL)/5
LFN30	Skull/-	-	-	-	-	(ACL,MCL,PCL)/(ACL,LCL,PCL)/6
LF60	Skull/-	-	-	-	-	(ACL, LCL)/(ACL, LCL)/4
LFN60	Skull/-	-	-/-/R scapula	-	-	(ACL,MCL,PCL)/(ACL,LCL,PCL)/6
LF90	Skull/C2	-	-	-	-	-/(LCL)/1
LFN90	Skull/-	-	-	-	-	(ACL, LCL, PCL)/(All)/7

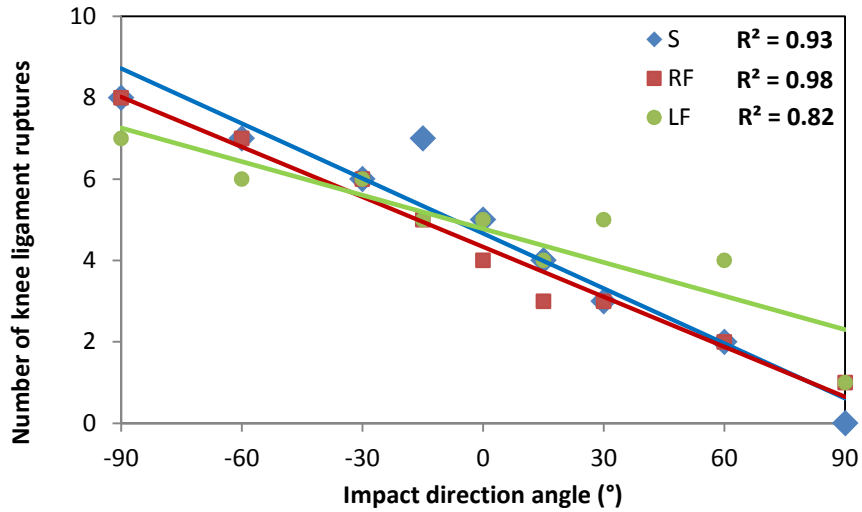

Figure 8. Correlation of the number of knee ligament ruptures with impact direction angle and posture.

DISCUSSION

Pedestrian Kinematics

Torso rotation Pedestrian torso rotation was caused by the impact of the vehicle initially striking the pedestrian leg at a location away from the body CG, which depended on the initial impact direction and human posture. Generally, a positive initial impact orientation caused positive torso rotation and vice versa. For the standing posture cases, the torso rotation entirely depended on the initial impact direction. However, for the right leg forward (RF) and left leg forward (LF) cases, the torso rotations were jointly determined by the initial impact direction and human posture. In RF cases, the initial contact point was anterior to the body CG even in pure-lateral impact, and as a result, case RF0 obtained 29.5° torso rotation; while in LF cases, the initial contact point was posterior to the body CG in pure-lateral impact, and case LF0 obtained -40° torso rotation. Consequently, only one negative torso rotation was observed in all 9 RF cases, and only two positive torso rotations were observed in all LF cases (Figure 7).

Shoulder impact and elbow impact In most of the pedestrian experimental tests [6-9], the PMHS hands were attached to each other prior to the pure-lateral impact. As a result, substantial elbow impact and shoulder impact were seen in the tests conducted [6-8]. In this study, the occurance of shoulder impact depended on the initial impact direction. All the cadaver tests were pure-lateral impact and all experienced shoulder impact. In the simulations, fewer shoulder impacts were observed and they were mainly from cases with a purely-lateral or near-lateral orientation. The occurance of elbow impact depended on both the initial impact direction and arm posture. Eleven of 14 cases with elbow impacts occurred with an initial impact direction from 0° ~ 30°. The cases with right leg forward (RF) posture (Figure 1-2) had less occurrence of elbow impact. All those cases without shoulder or elbow impact were with initial impact angles of ±60° and ±90°.

The experiments revealed that elbow and shoulder impacts had considerable influence on head kinematics [6-9]. Elbow impact influences torso rotation and changes the proceeding head kinematics. In the simulations, those configurations with elbow or shoulder impact had much lower head impact velocity (12.3±1.2 m/s, while 14.1±1.0 m/s for cases without elbow or shoulder impact) and later head impact time (average 129.2±5.5 ms, while average 124.8±8.1 ms for cases without elbow or shoulder impact).

Head impact condition In 11 cases, the head impact sites are at the occipital portion of the head, and in the other 11 cases the head impacts are frontal portion of the head. Only 5 of 27 cases resulted in a lateral impact to the head. Different phenomenon can explain this finding. Firstly, facing toward or away from the vehicle resulted in the head impact direction in the frontal and occipital regions respectively. Secondly, the torso rotation, due to the initial impact direction and human posture, resulted in the oblique torso impact with the hood. The torso would continue to rotate around the shoulder during the impact which resulted in the head impact striking the vehicle either in the frontal portion of the head or the occipital portion, not an oblique

impact (posterior-lateral or anterio-lateral). In a typical example (case RF15), the pre-impact, shoulder-impact, and head impact shown in Figure 9, and illustrates the torso rotation and the following head impact. Consequently, the lateral head impacts only happen when the torso impact was lateral (S0, RFN15, RFN30, LF15 and LF30), which account for a very low proportion of the simulated cases (5/27). Interestingly, the head impact velocity of cases resulting in occipital head impacts was 13.4±1.5 m/s, while cases with frontal head impact was slightly lower at 12.3±1.1 m/s.

0 ms (torso yaw 15°) ***110 ms (torso yaw 47.6°)*** ***135 ms (torso yaw 63.1°)***

Figure 9. Torso rotation and head impact direction (case RF15).

The head impact velocity was sensitive to the initial impact direction, and increased as the initial impact angle increased (in magnitude). The head impact velocity was 11.8±0.3 m/s in pure-lateral impact, 11.9±1.2 m/s in near-lateral impact, 13.0±1.2 m/s in non-lateral impact, and 14.4±1.0 m/s in facing toward and facing away impacts. The head impact velocity was not sensitive to human posture, and was 12.7±1.67 m/s in standing postures, 13.4±1.0 m/s in RF postures, and 12.7±1.5 m/s in LF postures.

Directional dependence In standing and LF posture cases, the near-lateral cases had different torso rotation than pure-lateral cases. The head velocity was found to correlate with the impact direction angle ($p=0.029$). Since the head impact velocity was found to greatly influence the head injury risk [22], the head injury risk might be substantially influenced by the impact direction angle.

Posture dependence The directions of torso rotation were fundamentally different for various postures; torso rotation was found correlated to the posture ($p=0.049$). Therefore evaluating a pedestrian model in only one posture as in previous studies [18, 20] may not sufficiently encompass all likely head injury responses.

Bony Fracture and Ligament Rupture

Frequent skull fractures in these simulation could be attributed to the high stiffness of the impact locations (cowl and windshield frame) and the severity of the vehicle impact. In one of the three cases without skull fracture (S15), the head contacted the windshield, which is the softest area in all the head impact locations in this study. In the studies by Watanabe et al. [19, 20], skull fracture was not observed in centerline impact (at 40 km/h), but observed in corner impacts in which the head impact location was the A pillar. In the simulation study by Han et al., more than 70% AIS 4+ head injury risk (based on HIC value) was observed for a 50th percentile male impacted by a medium-sized sedan (centerline) at 40 km/h.

Very few rib fractures were observed in this study, but this is consistent with the pedestrian impact literature. In a simulation study by Han et al., the risk of chest injury was low [17, 18]. Likewise, no rib fractures were observed in the studies by Watanabe et al. [19, 20]. In the PMHS experiments, Subit et al. reported that subjects impacted by the small city car sustained more rib fractures than the subjects impacted by the mid-sized sedan [9].

In this study, the height of pedestrian knee was approximately at the center of the vehicle bumper causing a substantial bending effect at the knee joint and exposing the knee to severe impact. Knee ligament injury was very sensitive to impact direction. The most severe knee injuries were in the facing toward impacts where the knee was hyperextended, while the facing away impact rarely resulted in knee ligament ruptures because the knee flexed. In most of pure-lateral and near-lateral impacts, the valgus knee sustained MCL an ACL rupture,

and the varus knee sustained ACL and LCL rupture. As a result, ACL was the most frequently injured knee ligament in the pedestrian impacts because it happens on both knees, while MCL ruptures were mainly on valgus knee and LCL were mainly on varus knee.

Limitations

In this study, the influence of pre-crash posture was investigated using a standing posture and two walking postures representing the most distinct upper and lower extremity postures during the entire gait cycle [14]. An extension of this study, where intermediate gaits are added to the study will help to confirm the results presented in this paper.

The vehicle model was designed to reproduce the pedestrian impact buck used in Subit et al. [9] and did not contain an engine which might affect the pedestrian kinetics while in contact with the hood. However in another pedestrian impact study, Han et al. reported that the clearance between the hood and the engine in a mid-sized sedan was large enough to prevent the hood from impacting against the engine during a pedestrian impact [17, 18].

Finally, injury modeling using element deletion was not used to ensure numerical stability of the model. Thus, the results of this study would rely on the assumption that the influence of bone fracture on the ensuing pedestrian kinematics and kinetics would be negligible.

CONCLUSIONS

In the present study, a 50th pedestrian human body model was subjected to impact with the centerline of a mid-sized sedan at 40 km/h. Three postured models were created from the original HBM: one matching the standard posture and two matching extreme walking gait postures. Nine impact directions were also investigated. A substantial variety of responses was observed when the impact direction and human posture were varied, including the pedestrian torso rotation, head impact condition, and knee ligament rupture. The patterns observed in the responses of the postured HBM indicate that the shoulder and elbow impact occurred frequently and substantially influenced the head kinematics. The head impact velocity was found to correlate with the impact direction angle, where facing towards or away from the vehicle would result in greater head impact velocity than when struck in a purely-lateral impact.

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IMPLICATION OF CHILDREN IN ROAD ACCIDENTS IN FRANCE IN 2011

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ABSTRACT

This study intends to present the analysis of all road accidents that occurred in France during the year 2011 in which children (0-13y incl.) have been involved. Based on the data collected and coded in the French safety project (VOIESUR) accidents with children have been analysed by experts. Then, these data have been weighted to be representative of the French situation.

The paper proposes an analysis of the accident data for 5 categories of road users that are light vehicle occupants, pedestrians, cyclists, motorbike passengers and buses and coaches' occupants. A distribution of the different parameters of the accident and its outcomes such as the children's injury severity is available per different road user categories.

The repartition of children across the previously described user categories shows that the most common accident for children is being light vehicle occupants (64%), then cyclists (17%) and finally pedestrians (15%). Buses and PTW occupants are representing a very small proportion (approximately 2% each).

On the 101 fatally injured children, the repartition is different and as follow: 61% are light vehicle occupants, 11% are cyclists and 26% are pedestrians. No power two wheels (PTW) passengers or coach and bus occupants have been fatally injured in 2011 in France. The remaining 2% are not belonging to any of these categories of road users.
For each category, a comparison of accident data between fatal cases and the others is proposed ending in a list of some remarkable differences. Countermeasures for fatal accidents are also proposed in each respective category.
For light vehicle occupants, the analysis of usual data such as infrastructure and journeys have been completed by a sociological profile of children's drivers and specific psychological items such as alcohol and drug consumption, atmosphere in the vehicle. Concerning children involved in cars, the sample size for children in cars is 654 that once weighted to make it representative of reality correspond to 17748 children including 62 that were killed. Evidence of a restraint system used by children has been coded for 69% of children, but in only 44% of the cases, the restraint system was appropriate and correctly used.

For children in the other road user categories, the analysis is a little bit more limited but it includes the age distribution, infrastructure and journeys data, the responsibility of involved parts (including children). The presence of protection device such as helmets: it is about 8% for cyclists and about 82% for PTW passengers. For pedestrian children they sustained their accident while they were using a crosswalk in only 5% of the cases, and in 50% of the cases they were running across the road.

Conclusion: This paper opens the field of considering all children involved in a road traffic accident in a national safety study, not focusing only on fatal cases and not limited to the situation of children in cars. Even if some limitations due to the use of weighting factors exist, it gives a comprehensive picture of the situation in France.

INTRODUCTION

This paper is presenting two visions of the implication of children in road accidents in France. First, the global picture for all children and secondly it is focusing on the characteristics of accidents per types of road users. It is based on the one year collection data done in the VOIESUR project that have been weighted to be representative of the French situation. The official indication of the implication of children in road accidents that have occurred in France in 2011 is given in the publication of the National data results for the year 2011. The figures shows there are lower than the ones presented in this study. This is due to the fact that this kind of data when collected on police report is underestimating the proportion of slightly injured and uninjured occupants, especially children (generally not interviewed by the police). That's why the weighting factors have been adjusted to be representative of the observed situation based on observations in hospitals. More information about the context has already been detailed precisely in the publication [1] presented at the 11th International Conference of child safety in cars.

VOIESUR project

Despite a sharp reduction of the number of fatalities on French roads since 2000, road accidents are still one of the priorities of the French government. VOIESUR (Vehicle, Occupants, Infrastructure, Environment, and Safety of Users of the Road) is a National project of 40 months started in January 2012. This project, partly funded by the Agence Nationale de la Recherche (National Agency for Research) and the MAIF foundation fits with the EU declaration of the "Decade of Road Safety". Its consortium is composed of 4 partners: LAB - Laboratory of Accidentology, Biomechanics and Human behaviour, CEESAR - European Centre for Safety Studies and Risk Analysis, CEREMA - National Centre For Studies and Expertise on Risks, Environment, Mobility, and Urban and Country planning , IFSTTAR - French institute of science and technology for transport, development and networks. Among its multiple objectives, the VOIESUR project has a key-point: to keep moving forward in the field of road safety and thus place France among the safest countries in the world. To do so it is necessary to have complete and accurate information in line with current issues such as vulnerable road users. In the VOIESUR project, a new database of road accidents that occurred during the year 2011 in France has been built with the aim to be representative of the national situation. Based on in-depth police report studies, VOIESUR expands the fields of observation not only to fatal accidents but also to traffic accidents with injuries. The project is updating the comprehensive information system on road safety that dates from 2000. It is based on reports established by the police in France during the year 2011 related to road accidents in which at least one person was injured.
People concerned by the coding will be all French fatalities, all Rhône area accident injuries and 1/20 random of national accident injuries. The database includes the details of the accidents and when available the full medical records of the people involved. A match between the VOIESUR database and the Rhône register injury database provides the basis for a data recovery methodology to propose a correction of the underreporting in the French national data.
The analysis of this database, allows to improve the general knowledge in accidentology and to focus on specific road users such as pedestrians, two-wheelers, children, seniors or to look at the evolution of the road safety in France over the last thirty years by comparison with data previously coded and analysed. In addition, this database is used to evaluate the method of data recovery and to suggest a correction on national data. The realization of thematic studies supplies a better safety diagnosis on specific road users and in the end these studies is providing row material to elaborate new safety systems and to base statements to establish new road safety regulations.
The version of the database used for this study is v19, on which the version 2 of weighting factors has been applied.
One of the thematic studies of the VOIESUR project is dealing with the situation of children involved in road accidents. The motivations and the work organisation of that part of the project have been reported in the Child safety culture workshop held in 2012 prior to the Munich conference "children in cars", and are explained in the proceeding of the conference [2].

METHOD

Every accident is described in details using general variables in three areas (vehicle, occupant, and infrastructure) and specific safety variables are coded by experts in the domain to understand all aspects of the accident. Up to 450 variables usable for future studies are coded for each accident. The analysis of injured children in a road accident that occurred in 2011 has been conducted using the VOIESUR database. Victims have been classified according to 5

categories, light vehicle occupants, cyclists, powered two wheels passengers, buses and coaches' occupants and pedestrians. Over-accidents have been excluded from the sample has the same person can change of user category between two events and make the analysis too complex.

In the VOIESUR database, medical data of injured road users has been coded using AIS code revision 98 [3] when available. But in fact, there are not so many cases that contain such data as autopsy or complete medical report of people involved in road accident in France, because this is not mandatory but only performed if required by the justice. External post mortem inspections are sometimes performed but cannot be considered as a detailed medical report. They do not present a complete list of injuries, but can be useful for the determination of locations of impact across the children's bodies, and in a certain way the determination of restraint conditions for vehicle occupants. The present study focusses on all child injury levels including those fatality and such medical inspection reports are included in the sample. Children involved in a road accidents are split in four injury level categories: Uninjured, slightly injured, seriously injured, and killed, with clear definitions for each of them.

Weighting factors

The purpose of this study is to be as far as possible representative of French situation. As it has been already highlighted in previous National projects, a recording gap between the number of accidents recorded by the police and the number of accidents that actually occurred in 2011. Thus, weightings have been determined in the VOIESUR project to correct the record found error. The document [4] refers to the VOIESUR deliverable explaining the calculation of these weightings.

Sampling at 1/20th the personal road accidents led us to the creation of the first correction factor. It is therefore assigned to each injury accident a weight of 20 to return to a condition called exhaustive (All fatal accidents have been coded, no correction is applied to them). After that, a recording gap in the sharing between the different entities of the security forces was found, which led us again to the creation of another correction factor to restore the right proportions. Finally, an under recording of some accidents has been also found while comparing the exhaustive list of hospital recordings of admissions following a road accident and the list of people recorded by the police. This last factor is depending on the category of road users, the injury severity level and the unit of police in charge of reporting the event. Therefore, on all the following results, the three weightings were applied to correct the raw data. There are of course limitations to use such factors to make the data representative of the real road situation, and questions on the validity of these factors for the situation of children on the road are sometimes possible. For example, children cyclists in the original sample are not very numerous, but they are also rarely recorded by the police if none of the people implied in the accident is severely injured. Therefore, the weighting factors to scale these cases to the road reality are often high. Unlike fatalities, the information obtained for personal accidents are not exhaustive, this can have an influence on the quality of the analysis that is performed.

GENERAL RESULTS

The sample size for this chapter is 31636 children (0-13 years of age) involved in roads accidents in France in 2011. The material is coded data for 915 children on whom corrector factors were applied to obtain this sample representative of road situation reality. It is composed of all type of users and all injury severity levels.

Proportion of children involved in road accident in France -2011 per road user categories

The distribution between the categories of road users is shown on Figure1and can be read as follow: 64% are light vehicle occupants, 17% are cyclists and 15% are pedestrians. PTW passengers and bus and coach occupants represent a little less than 2% each. The remaining children (0,5%) are not belonging to any of these categories of road users.

Implication of children in accidents occurring in France in 2011

The situation of children needs to be compared with the one of adults involved in road accidents to underline differences. Children represent 6% of the total number of people involved in road accidents in France in 2011. Having a look on the proportions of children in the different user categories, it clearly appears that for the categories of PTW and "other vehicles", children are representing very low figures (less than 1%), but they represent 18% of the total number of the pedestrians having accidents, and 8% of cyclists. This underlines the fact that when they have to take decisions, such as crossing a street, being able to stop at crossroads, or riding

a bike in the traffic, they more often fail than adults. Children represent 7% of all people involved in road accident as occupant of a light vehicle.

The part of children considered in categories of vulnerable road users is 34% of the total number of children. The same figure for adults is 40%, but excluding PTW makes this proportion going down to 17% for adults while it remains to 32% for children. Therefore, accidents with children need to be treated with special cares.

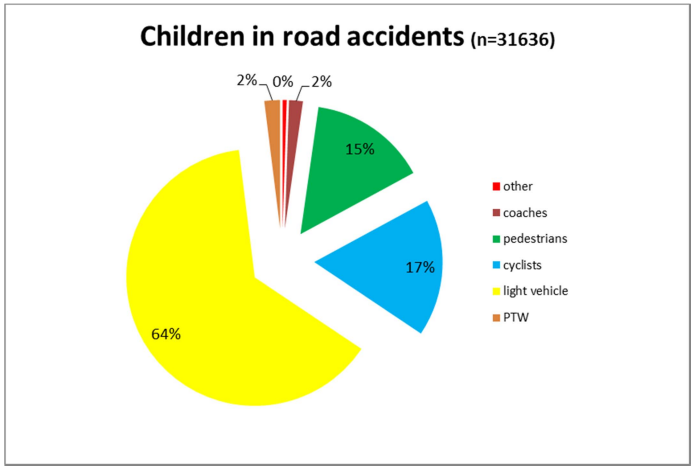

Figure1. Proportion of children involved in personal road accident in France -2011 per road user categories

Distribution of injury severity per different road user categories.

Once the implication of children across the different road users categories, it becomes important to analyse the severity of the injuries of children consecutively to their accidents. It is what is shown on Figure2. For that a relative simple way is to consider the duration of hospitalization of children, which is the official way to do it in France. Some children do not go to the hospital at all, they are considered as not injured, some others are conducted by rescue teams or parents to hospital but their stay there is shorter than 24 hours, these ones are considered as lightly injured. Children staying more than 24 hours are considered as severely injured, except for those who do not survive within the period of 30 days following the accident. In some cases, only the information that the child was transported to the hospital is available in the police report without any other indication of the injuries they sustained (from hospitals nor parents).These have been put in a separate category named injured NFS, but very often, not reported injuries are of a low level of severity.

The proportion of children fatally injured is 0,3% of the total number of children involved in road accidents. This proportion can be considered as relatively low as compared to the one of adults that is 0,8%, but it is important to remind the psychological impact of children's fatality in the society and the relative costs. For the category of severely injured road users, children are showing lower figures (4,3%) than the ones of adults (7,7%). If just looking at the proportion of road users involved in a road accident but not injured, the proportion for adults and children is similar with 30% in each category and the proportion of light injured population is also very close (50%). The proportion of children for who no information at all on injury severity are available is higher than for adults.

The previously described repartition is not uniform across all the road user categories. Details are on Figure2. The proportion of uninjured children is very high for bus and coach occupants with 77%, followed by light vehicle occupants for which the proportion is 44%. This proportion dramatically goes down when children are part of the most vulnerable road user categories such as pedestrians, PTW passengers, and cyclists. For these two last ones, the proportion of light injuries is very high, with respectively 80% and 90%. Pedestrians are showing the largest proportion of severely injured children with nearly 15%, and also have the higher rate of fatally injured children with 0,6%. They are followed by the light vehicle occupants with a fatality rate of 0,3% and finally by cyclists with 0,2%.

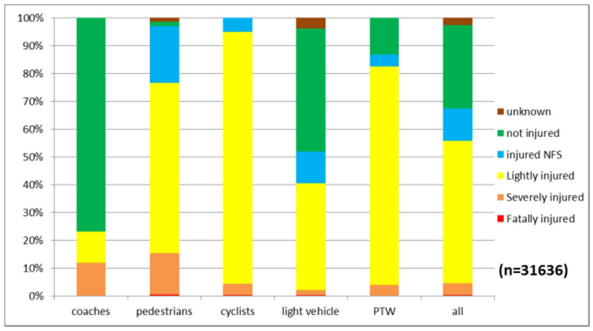

Figure2. Injury severity per different road user categories for children involved in a personal accident

As children passengers of light vehicles are representing nearly 2/3 of the total number of children involved in road accidents, even if showing a rate of fatality lower than pedestrians, their number is higher. On the 101 fatally injured children, 61% are light vehicle occupants, 26% are pedestrians and 11% are cyclists. No PTW passengers or coach and bus occupant has been fatally injured in 2011 in France. The remaining 2% of children fatally injured are not belonging to any of these categories of road users.

An important point in terms of protection of children as road users is to know the location and if possible the injury mechanisms that occurred during their accidents. To evaluate the injury severity, the AIS scale is used. In order to eliminate the lightest injuries, the present analysis is focussing on AIS3+ injuries that are defined on this scale as serious injuries. The number of AIS3+ injuries in the sample once weighted is 996. But having a look of their distribution makes no sense if they are not spread per user categories. Figure3 gives an overview for the categories of road users for which the number of severe injuries was sufficient to be dispatch across the different body segments. It is more detailed in the analysis for the different road user's categories, but what clearly appears is that limbs and more particularly lower limbs are the most often injured body segments at AIS3+ level, for all categories of road users and that this represents more than half of the total number of severe injuries for children pedestrians and cyclists. This has to be balanced with the fact that fatal cases of children are not often containing autopsy report, so fatal injuries or combination of injuries are missing in the database, but some external examinations can report injuries such as opened fractures. The head remains the first vital body segment in terms of frequency of severe injuries for cyclists and light vehicle occupants while this is the chest for pedestrians.

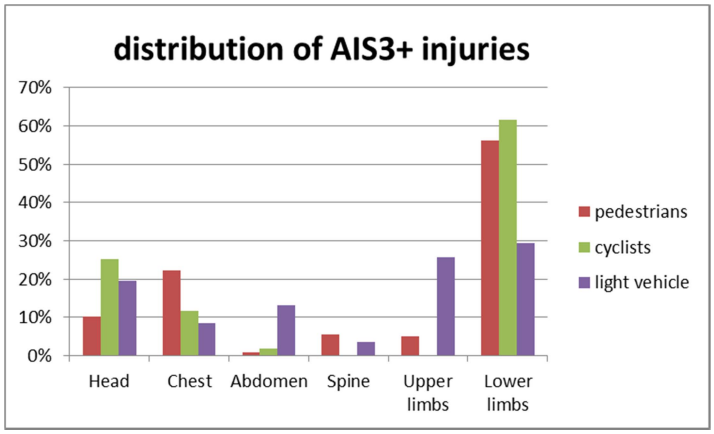

Figure3. Distribution of AIS3+ injuries per body segments for the different road user categories (n=996)

RESULTS PER USER CATEGORIES:

From this point, the analysis is only considering the children for who the age is known. Their number is 28851 for the 5 categories of road users considered in the following analysis. When distributed according to the age of children it clearly appears that globally implication of children in road accidents is slowly growing as children get older from birth to 10 years of age, and that the increase is much faster from 11 to 13 years. This

is mainly coming from a combination of the fact that if the number of light vehicle occupant and pedestrians is more or less stable up to 10 years old and then going up, the number of cyclists, PTW passengers and occupant of buses and coaches is concentrated around 10 year old children and more, which is re-enforcing this phenomena. This statement can be attributed to the appearance of the child's autonomy and need of mobility.

Light vehicle occupants

The number of children occupant of a light vehicle that has been involved in a road accident in 2011 in France is 17748. Children from birth to 10 years of age are more or less equally involved in road accidents as light vehicle occupants with an average value of 1200 for each year of age. As the sample is based on only one year of data collection, gaps and peaks are existing but could certainly be limited using a multi-annual sample. The extrapolation cannot be effective for the data that is missing in the sample. For children after 10 years of age, the number is rising up regularly to reach 2300 for children that are 13 year old.

Infrastructure and accident conditions About 50% of the accidents involving a child as light vehicle occupant occurred in built up areas. 75% happened during the day, 22% during the night and 3% at dawn or twilight. The most common obstacle is another light vehicle in 53% of the cases. Fixed obstacles represent 27% of the sample, 2 wheels 10% and 6% is heavy utility vehicles that are mainly trucks. Pedestrians have been coded as opposite obstacle for 2% of the cases. The 2% remaining of opposite obstacles belongs to the categories of "other vehicles".

52% of the accidents occurred on primary roads, one third on secondary roads, highways are "only" totalizing 16% of the total of accidents with children as car occupants. The typology of accidents is different according to the different road categories for children accidents. For highways, the most common accident type is roll-overs with 40% of the cases to which 10% of tip-overs could be added. Frontal impacts represent 32% and rear impacts 10%. Side impact is only scoring 4%, on this type of road. On primary roads, frontal impacts are the first accident type with 58%, rear impacts are following 19%, then side impacts with 11%. Roll-overs on such roads are only 5% of the sample and side swipe counts for 3%. On secondary roads, Frontal and side impacts are equivalent with 39% each, rear impacts are coming then with 14%. Very few roll-overs and tip-overs has been mentioned for this category of roads, but it has to be said that side swipe are showing their higher score with 6%. This can be explained partially by the fact that roads from this category are certainly narrower than the other ones, facilitating this kind of impacts.

30% of accidents occurred in or close to an intersection. From this particular configuration, 61% of the drivers intended to cross the intersection and 25% had the wish to turn left or right. It has to be noticed that 7% were stopped prior or in the intersection at the moment of the accident. For the 70% of accidents that did not happened at intersections it has to be noticed that in 71% of the cases, the vehicle was going strait, without any intension of changing direction, 8% are overtaking another vehicle, other 8% are slowing down, 5% are changing of lane and finally, 7% are stopped.

From that point, it is important to notice that for the analysis accident of light vehicles against pedestrians and two wheels (with and without engine) have been excluded as the loads are very often very low for the light vehicle occupants in this kind of road accidents. The number of children in the following analysis is 15236.

Type of impacts The distribution of the type of impacts for children light vehicle passengers is as follow: 51% of the children are involved in frontal impact, side impacts and rear impacts are very close one to the other with respectively 16 and 17%. Roll-overs count for 10% and tip-overs for 2%. Side swipe, falls and other accident configuration are representing approximately 1% all together.

Sociological profile of children's drivers: This point is not always considered in analysis of topics related to road safety and more particularly child safety in cars. The part of technical data is of course crucial to understand the situation and define axes of progress, but the knowledge of sociological and psychological data are also essential to be efficient in the communication campaigns and educational programs. [5] The number of variable that can be used for that and being present in the police reports are not so numerous. For example, the school level is not available, and information such as profession of the driver is not always reported, which makes more difficult the definition of a sociological profile. Nevertheless professional activity, the level of responsibility in the accident, the fact of having

an insurance for the vehicle, the relationship between child and the driver, the type journey, and the main reason of the accident have been coded in the VOIESUR database for accidents in which children were involved.
In 94% of the cases, vehicles in which children were transported were covered by an insurance policy. This is not totally surprising as this is mandatory in France to have one to use a vehicle.
Journeys for children are unknown for 31%, which is limiting a little bit the use of this data, but it's interesting to notice that leisure activities comes to the first range of known journeys with 21%, closely followed by the visit to family that scores 20%. Departures to holidays are not a negligible part of the accident with children in light vehicles with 10%. What can appear to be surprising in this list is that the activities conducted every day such as the travel to school, or nursery is only representing 4% of the total and that shopping activities is scoring 6%.

Drivers in a very large majority of cases are the parents or parents in law of the transported children mothers representing 49% of the cases and fathers 31%. The other members of the family such as grand-parents, sisters and brothers, uncles and aunts represent additional 8%. This means that information on child safety as to be focussed on the familial environment. Friends and neighbours are driving in 9% of the cases. They can also be good vectors for forwarding safety messages to parents of children but also need to receive information on the right way to transport children in cars.

Looking at the driving experience, the variable used to determine this parameter is the number of years of driving licence which is available for 78% of cases. The figures are showing that drivers with a shorter experience have tendency of being more involved in accidents with children and that the percentage of implication is going down as the number of years of driving license is increasing.: 33% for less than 10 year, 26% between 11 and 20 years, and 19% for more than drivers with more than 20 years of driving licence. This can be a bias due to the fact that people having children to transport are relatively young and therefore are relatively young in their driving experience.
59% of drivers have a professional activity, 20% are non-actives, and the professional situation is unknown for 21%.
The responsibility in the accident has been coded using different method in the VOIESUR project. For this analysis, it is proposed to use the judgement of the expert on this point as when coding, he knows the facts and the involvement of the different parts in the accident. As results, the driver of the vehicle in which the child is transported is responsible in 47% of the cases. In 50% the driver has not responsibility in the accident. For 2% the responsibility is shared between parts and in 1% it was not possible to determine this parameter.

Psychological items: The consumption of alcohol or drugs prior to driving have been considered in the psychological profile of drivers. Other parameters sometimes more difficult to evaluate, or subject to interpretation have been when possible coded by experts such as the atmosphere in the vehicle, the influence of the presence of the child on the driving performance, and the time pressure on the driver to make the journey. Personal data for drivers such as the stability of the professional situation and the recent change of family status have also been taken into account.

First of all, the data is showing that the driver behaviour in terms of restraint use has a huge influence on the fact that the child is restrained or not: when the driver is using the seatbelt only 5% of the children are not restrained that has to be compared with a rate of unrestrained children of 26% when the driver is not belted.

Going one step further, the proportion of children that seems to be correctly restrained with the limitations indicated in the section dedicated to this item, is only 1% when the driver is not restrained versus 46% for the cases in which the driver is wearing the vehicle seatbelt.
The measure of the level of alcohol for drivers compulsory in France after an accident occurred, so this data is available for 91% of the cases of our sample. The maximum authorized alcohol level is 0,5 g/l of blood, which correspond to a limit of 0,25g/l of expulsed air. For 20% of the accidents, alcohol has been found for one of the drivers, and at least 8% of the drivers with children on board were over the legal limit.
The consumption of drugs in France is not legalized and if no medical treatment is declared, no drug should be found for drivers. The control of presence is not mandatory in all accidents, but more on request of the legal department in severe cases. Up to now the cost of such control was high. This could change in the coming years with

the apparition of saliva tests that seems to give satisfying results. The data is missing for 27% of the drivers in our sample. For 72%, drivers have shown no evidence of drug consumption but the test was positive for 1% of them. About 5% of the drivers with children on board had a recent change in their family status, to be compared with 69% for which no evidence of change has been recorded. This data is missing for the remaining 26%. Figures are relatively similar for the stability of the professional situation, with 67% without any change, about 5% recorded with a recent change and with 28% unknown.

The atmosphere in the vehicle at the moment of the accident is determined by expert according to the statement of the drivers when available, and by other occupant's and witnesses reports if any. In 27% of the cases, the data was not possible to determinate. It was considered as neutral if no evidence of one of the category was reported, or if the statements report that nothing special was on-going in the vehicle. This comes in the first row with 59%. On-going conversations are the second configuration with 5%, and playing or laughing is reported in 3% of the cases. Another category is that all passengers in the car are sleeping, this happened in 1% of the case. Some cases of fights or violent discussions between adults have also been reported but they are isolated cases. The 5% remaining were coded as other situations and a more in-depth investigation of these cases could be interesting but is not available at this day.

Another point partially link with the previous one was the estimation of the influence of the presence of the child in the following of events ending by accident. Experts have stated that for 90% of cases, children had no influence in the accident story, but they also stated that in 4% of the cases the child is clearly involved in the chain of events ending into the accident and that in other 4% they had potentially influence the driving performance. In 2% of the cases, it was not possible to status due to a lack of information.

The last point that has been studied is the fact that the driver was under time pressure to make the journey, which was the case for only 6% of them.

Restraint conditions: The use of restraint systems and the quality of use of these systems while travelling in light vehicles is one of the key point in the definition of ways of progress in child safety studies [6]. Data collections since years are reporting that the number of correctly installed children is very low. Even recent studies stated that this figure is between one quarter and one third, depending on the studies and their relative methods of collection [7].

On the sample of 15536 children, the restraint conditions are unknown for 25% of them, because no indication in the police report can help experts to status on this point. About 6% of the children were not restrained at all; this is not far from the figures obtained in real life observations previously stated as references. For the 69% remaining, experts have coded that restraint systems were used by children, and for 44%, it seems that the restraint system was correctly used. Misuse of restraint systems have been identified for only 2% of children of the sample, which is not close to the real situation. This clearly shows the limitation of the analysis that can be conducted on such detailed points by only using police reports, even if coded by accidentologists. For the remaining 23%, no indication was available to make a decision on the quality of use of the restraint systems.

Injuries: Injuries or absence of injury have been coded using the AIS scale for more than 10000 children involved in accidents as light vehicle occupants. This can give a more precise picture than the length of hospitalization used in the official national statistics, as it is based most of the time on medical information reported by hospital or in the statement of parents. The level of protection seems to be already high and 49% of the children have not been injured. 43% other percent receive injuries of a minor level. 6% of the remaining children received moderate injuries. The 2 % remaining received severe, serious, critical or fatal injuries

It is important to focus and these particular children and have a look on the repartition of these injuries of having a high level of severity. Looking at Figure3, it is clear that limbs represent a high percentage of them, but the head that is scoring 20%, the abdomen with 13% and also the chest are vital body segments that need to be better protected.

Remarkable points between all accidents / fatal accidents: This paragraph is presenting the main differences between all accidents and the fatal ones in which children are involved as light vehicles occupants. All the following statements on these differences are statistically significant.

First of all, fatal accidents occur for 94% in non-built up area which as to be compared the fact that this proportion is 50% for all accidents. Fatal accidents occur more often than other during the night time (35% versus 22%). Their proportion representing highways is a little bit higher with 20% against 16%, but the main difference in terms of road categories comes from the secondary roads that are two times higher than for non-fatal cases.

Focusing now on the driver, in terms of responsibility in the accident, the ones in fatal accidents have a part of responsibility in 70% of the cases to be compared with the 47% in other accidents. The proportion of drivers with alcohol is twice higher in fatal accidents than for others, and the same observation is done concerning the consumption of drugs. Human factors and more particularly psychological points are different when comparing fatal and non-fatal accidents: the change in family status is 13% in the first case and 5% in the second one. A similar observation is done concerning the professional stability. Drivers involved in accidents being not fatal for children have had a recent change in their professional activity for 5% and for the ones driving a light vehicle in which a child is killed this rate is 16%, which is more than 3 times higher.

Finally when looking at children themselves, two remarkable points: the number of unrestrained children is also different with 6% in accidents versus 22% in fatal cases and the proportion of children that are sleeping is 2% in non-fatal accidents and reach 26% in fatal cases.

Main countermeasures for fatal accidents: This part is an extract from the deliverable of the VOIESUR project dedicated to the situation of children fatally injured in road accident as light vehicle occupants [8]. More details are available on the referenced document. Countermeasures can belong to different categories, such as infrastructure, primary or passive safety devices. For the first two, the counter-measures are not specific to child safety but may also apply to all road users. It is important also to mention that multiple proposals could have been made for each accident. For the infrastructure, being not expert in the domain, this value has only been chosen when the infrastructure could have clearly been safer. For example, the separation in the traffic between train, trucks and light vehicles is the best possible solution to avoid collisions between them as there are few chances for car occupants to survive in an accident against a train. More simply to apply, in some cases the mere presence of guardrail could have avoided the vehicle to fall in water or in ravines. For the primary safety, systems based on the communication between cars and infrastructures with the decision of action such as automatic stops in case of a stopped vehicle in front, or arriving at a stop line could be helpful, automatic speed adaptation systems to location or weather conditions could also be beneficial in a large number of cases, and so would be systems keeping a safe distance between vehicles. The other types of systems that could participate to the reduction of the number of children killed in light vehicles are the ones giving information to the driver that something wrong is happening. For example line departure warnings, trajectory control aids and “falling asleep” control systems could be applied in some cases of this study.

In terms of passive safety, looking at the number of unrestrained children in vehicles, it is clear that the use of a restraint system is in this area the first and necessary thing to be done. Then the choice of the appropriate CRS and its correct use are the following step. It seems that these two first points could improve the situation in more than 40% of the fatalities. Once correctly used, restraint systems both on the car and CRS could be improved. Of course some countermeasures for the drivers are also necessary such as reinforcing the law application with regard to alcohol consumption or speeding.

Globally there is a big need of safety information for drivers, to respect the rules in terms of speed, distance between vehicles, and to adapt their driving to conditions. Messages dealing with the use of restraint systems for all car occupants are needed in combination with the message of adapted correctly used restraint systems.

Pedestrians

4696 children have been involved as pedestrians in road accidents in 2011 in France. This represents 15% of the total number of children and 18% of the total number of pedestrians of all ages recorded. The number of children killed as pedestrians represent 26% of the total number of children killed on the road.

The distribution of ages of children pedestrians for all injury severities shows that as soon as they are able to walk, children are involved as pedestrians in road accidents. Their number is stable across the different ages but for the data of 2011 a peak is visible only for the 12 years old children without any evident reason for that.

Infrastructure

Nearly all accidents of children pedestrians have occurred in built up areas (98%), and mainly during the day time (86%). Night accidents are representing 9% to which 3% that have happened at the dawn or twilight as for the light vehicle occupants.

Concerning the moment to which the accident occurs, there is no big differences between the months of the year, the two first ones being June and April with 13% each and the month with the lower number of accident being July with only 2%. Children pedestrians' accidents mainly took place on the week working days. Week-ends are only counting for 11% of the total. A large part of children pedestrians accidents happened between 4 and 6 pm, a peak is also visible at 8 am. Nearly no accident between 8pm and 8 am.

2/3 of the accidents, took place on primary roads, 30% in smaller streets and 3% on highways. About 1% occurred on other road categories such as private or public parking places.

About 71% of children are impacted by the front of the vehicle and about 22% are in contact with the side of the vehicle. In about 5% children are overpassed by one of the wheel not necessarily with another impact with the vehicle. In 58% of the cases, the child pedestrian is impacted by a light vehicle. The second category of opposite vehicles is motorbikes that are surprisingly involved in 27% of the accidents of pedestrian children. Heavy vehicles come third with 10%, and bicycles are representing 2%. The 3% remaining belongs to the category "other vehicles".

Figure 4 shows the distribution of the children's actions when the accident happened. About ¾ of them were simply crossing the street perpendicularly. To this it is necessary to add another 11% that were crossing not necessary perpendicularly which make this action at the top place with 85%. For children crossing the road, in 44% of the cases, it was noted that the child was crossing on a crosswalk, but in 47% it was coded that the child was crossing outside of cross walk. The data is unknown for the remaining 9%. This underlines that there is still a need of education for children to cross in fit areas. 13% of the children were walking along the street or road and have been impacted by an incoming vehicle and 1% of the children were just standing.

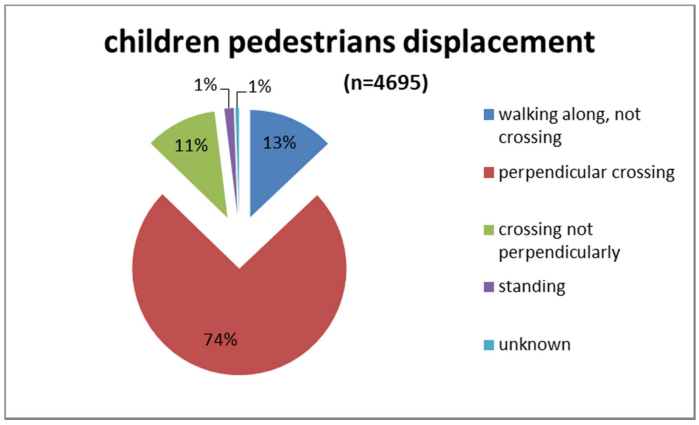

Figure4: distribution of the displacement of the children pedestrians at the moment of the accident

Human factors As for all accidents of the VOIESUR database, the responsibility of all parts involved in road accidents have been established by expert, based on the infrastructure configuration, the behaviour and actions of each part. As results it appears that children have been considered as the most responsible part in 49% of the cases, to which 6% have to be added for shared responsibility. It is important to look then at the children's activity when the accident occurred and on the journey they were doing. For that, one variable available in the database gives indication of the speed of the pedestrian at the moment of the impact. This data is unknown for 12% of the children but in 50% of the accidents, children were running while 31% were walking. In the 7% missing, the data has been coded as other, which can indicate that the child was not moving, or was trying to catch something under a car, or hidden in a game...

For 16% of them children have been coded as escaping from the vigilance of an adult. This shows the important not only to deliver safety messages to children but also to the accompanying people. It has to be underline that 90% of them are under 6 year old.
In terms of "journey", child pedestrian accidents happened for 38% in a leisure activity and for 32% on their way from home to school or back. In 11% the variable is coded as other, 6% were going shopping, 3% were on their way to visit their family and this data is unknown for 10% of the cases.

Injuries 9% of the children have been over passed by the vehicle that is involved in the accident, 5% without any other impact, the others having being first impacted and then overpassed. The recording of injury severity using the AIS98 code has allow to have an overview of the severity of all children pedestrians involved in road accidents. Very few children are reported as not injured (only 2%) but the level of injury severity is unknown for 40% of the children. In this category all fatal accidents without autopsy are counted but also all the cases for which no medical data was available in the police report, very often because the injury severity if any if very low. This is confirmed when looking at the Figure2 for which the rate of lightly injured is 61% to which a large number of cases from the category of "injured NFS" that is scoring 20% could be added. For moderate and severe injuries, that are globally more reported in the police documentation, injuries of AIS2 level represent 13%, the ones of AIS3, 7% and the ones of AIS4, 2%
A distribution of AIS 3+ injuries across the body segments has been done to determine priorities in terms of protection for children as pedestrians based on the road reality. The sample is composed of 597 AIS3+ injuries, among which the most commonly body segment is lower limbs with 56%. It is followed by the chest with 22% and then by the head with 10%. The spine is representing 6%, upper limbs 5% and the abdomen about 1%.

Remarkable points between all accidents / fatal accidents As for the light vehicle occupants, this paragraph intends to show the biggest difference between accidents of all severities with children and the fatal ones. For pedestrians, there are more similitudes than differences for the infrastructure, the light, the fact that half of the children are running.

The repartition between the accident locations is a little bit different between all children pedestrian accidents that happen for 98% in built-up areas to be compared with 88% "only" for fatal accidents.

The order in the distribution of the pedestrian displacements is totally different. For fatal accidents, crossing not perpendicularly reaches 68% instead of 11% while perpendicularly is representing 4%, instead of 75% for all accidents. A bigger proportion of static pedestrians is also visible in the fatality sample with 16% versus 1%.
The proportion of children that have been over passed is far higher in the fatality cases for which this injury mechanism represents 44% of the sample while it is only 9% when considering the totality of accidents.

Main countermeasures for fatal accidents: this part is an extract from the deliverable of the VOIESUR project dedicated to the situation of children fatally injured road accident in the section pedestrians [8]. Educational programs are needed: to change their general behaviour while being on the road is not a game place, and that you need to cross without running and after having check that no vehicle is coming. Some infrastructure could also be arranged: to slow down the speed of vehicles at crossing points would be effective; manage a clearer area so the vision of drivers could be better at pedestrian crossing points. This will be effective only if children are using these points to cross the street. To better arrange sidewalks in a way that it is only possible to cross the streets at given points. Solutions proposed on the infrastructure side can be combined for a better efficiency and would not only be profitable for children, but for all pedestrians. In addition, the detection of vulnerable road users is now becoming more common on vehicles but collision avoidance systems will only be effective if children (cyclists or pedestrians) are not hidden. The proportion of children being over passed by the vehicle in the sample of fatally injured children is 44%, and for them, no passive safety action is possible.

Cyclists

5472 children have been involved in a road accident as cyclists in France in 2011. This makes the cyclists being at the second user category with 17% of the total number of children the road accident. By cyclist it is understood than the children were riding the bicycle. The number of children fatally injured in the sample is 11 that are representing 11% of the total number of children killed.
The youngest child in the sample is 4 year old but the number of children cyclists becomes more consistent after 8 years of age and regularly increase with the age from that point.

Infrastructure
Nearly all (99%) of the children cyclist accidents happened in built up areas, and during the daylight period. Looking at road categories, most of the accidents occurred on primary roads (68%) and 31% on secondary roads, the last 1% occurred on roads of other types. It has to be noticed that the presence of intersection has been coded for 84% of the cases. In 91% of cases children were going straight even at intersections, in 7% of the cases they intend to turn, but not necessary at intersections! 77% of cyclists have been involved in a frontal impact, 22% impacted on their side.
The light vehicles represent the first kind of obstacle, followed by heavy vehicles and fixed obstacles.

Human factors
Children cyclist accidents are concentrated around April, May and June. They also happened more on Saturdays and Wednesdays which are days without school for children younger than 14 years of age. The proportion of accidents also recorded on Sundays is not negligible. All accidents happened between 11am and 9pm.
The journeys that children were doing are distributed as follow: visit to family comes at the first row with 93%, far behind come leisure activities with 3%, going or coming back from school only represent 1%, and shopping is at the same level with also 1%. The data is unknown for 2%.
Experts have coded the responsibility in the happening of the accident of the children as vulnerable road users and of the driver of the opposite vehicle for every accident case. 3 levels of responsibility have been defined: full, share, and none. Of course this is subject to interpretation bias but in the case of accidents of children on bicycles, the information is considered as reliable as accident scenarios were not too complex. Children on their bicycles have been found to be fully responsible in 96% of the cases, the responsibility was shared with another part in 1% of the cases and in only 3% the children were considered as not responsible at all.

Protection In France, the use of a helmet is only mandatory for riders of motorized two wheels. Cyclists are not included in this category and can therefore ride without any helmet. The only obligation for them is to wear reflecting jacket if they ride by night outside of urban areas. Bicycle helmet legislation appears to be effective in increasing helmet use and decreasing head injury rates in the populations for which it is implemented. However, there are very few high quality evaluative studies that measure these outcomes [9, 10]. Nevertheless, it is highly recommended by authorities to use a homologated helmet when cycling [11], especially for children as in half of their falls injuries to head occurred. Even if this seems to be an appropriate protection device, helmets approved for cycling are recognized to be efficient for falls up to 20 kph. Children are normally not riding very fast compared to adults but this could limit the number of cases for which helmets are useful. The proportion of children using a helmet in the sample is 8%, and the proportion not wearing any is 84%. The data is unknown for the remaining 9%. It is not possible to measure any efficiency of the system due to the low sample of children wearing protecting device.

Injuries: As for other road user categories, injuries have been coded using AIS98 code. None of the cyclists in the sample are uninjured, 85% only sustained light injuries, 10% received moderate injuries. Children cyclists seriously injured counts for 1%, the level of injury is unknown for 4% of the children.
As visible on Figure3, the repartition of the serious injuries (AIS3+ level) indicates that the lower limbs is the most often seriously injured body segment with 61%. Then comes the head with 25%, the chest with 12% and finally the abdomen with 2%.

Remarkable points between all accidents / fatal accidents: This paragraph is presenting the main differences between all accidents and the fatal ones in which children are involved as cyclists. All the following statements on these differences are statistically significant.
The main difference is the location of the accident that is occurring only for 44% at intersection for fatal accident while it happens 84% for all cases.
None of the children involved in the fatal cases was wearing a helmet. This has led to a case by case analysis of the cases concluding that a very limited benefit of helmet would be expected on the sample of fatal cases.

Main countermeasures for fatal accidents: this part is an extract from the deliverable of the VOIESUR project dedicated to the situation of children fatally injured road accident in the section cyclists [8].
Educational programs are needed: for children to better behave when riding bicycles and a need of awareness of for parents on the fact that their children are not necessary ready to be left alone in the road traffic.
To improve the visibility of the children on their bikes would allow a better prevention of their behaviours for other road users. It is known that separating road users ones from the others is one of the safest solution: it is necessary to encourage the development of dedicated infrastructures for riding bicycles with crossroads infrastructures specific for bicycle. In addition, as for pedestrians, the detection by vehicles of cyclists using Intelligent Technical Systems would also limit the number of fatalities of cyclists and by the way of children cyclists. Considering children killed on their bicycles it has to be remind that they are nearly all perpendicular to the opposite vehicle trajectory.

Powered Two Wheels passengers

The number of children present as PTW passengers in the database is equivalent to 624 children that have been involved in 2011 in France. No fatality of children has been recorded as PTW passenger in the year 2011. The youngest children are 6 years old and it seems that the tendency of implication is growing with the age of children. Looking at the type of the vehicles on which children are passengers, the sample is composed about a little bit more than 1/3 by mopeds, the others being motorcycles. 30% of the PTW are fitted with engine lower than 50cc, 46% have an engine that is between 50 and 125cc, 15% are on motorbikes with an engine bigger than 125cc. The size of the engine is unknown for 9% of the cases.

Infrastructure: 95% of the accidents in this category happened in build-up areas. 78% mostly during the daytime, dawn and twilight represent 15% of the cases and 6% happened during the night time.
Looking at the road categories, there is a good balance between primary and secondary roads. The majority of collisions with PTW took place at intersections. Finally, concerning the opposite obstacle, it is very often another vehicle, light vehicles coming at the first row. Impacts against fixed obstacles count for 10%.

Human factors: Experts have coded the responsibility in the happening of the accident of the drivers of the PTW riding with children. The same levels as for the other children road users categories are used in this section. Globally the balance between responsible or not clearly goes for not responsible in the case of accident with children passengers of PTW. The distribution of the type of journey, when known, shows that leisure and rides come first, and that visit to family or friends is at the second row. Shopping is very far behind and no accident riding to or from school was registered.

Protection use: 91% of the children of the sample are wearing a helmet when being transported on a PTW. It has to be noticed that for 9% of them the helmet is not attached to the head and the data is unknown for the last 9%. Due to the low number of children on PTW with injuries, it is not possible to compare the situation of children travelling with and without helmets.

Injuries: Injuries, when known have been coded using the AIS scale. Very few AIS3+ injuries have been noted, and only 13% of the children involved in such accidents are uninjured, but the number of children that have being staying in hospital less than 24 hours is 79%. The seriously and severely injured children represent 4% of the

sample and the injury severity is not known and cannot be estimated for the last 4%. Results have to be taken with a lot of caution as the original number of children is not very high.

Bus and coach occupants

General data on buses and coaches: The definition used in the analysis is the same as the one used in the French National data: buses are city buses in which you can either be seated or be standing. Coaches are vehicles in which only seated passengers can be transported and since 2009 have to use a restraint system if the vehicle is equipped. Transportation of children to school in France is done by bus inside the big city and their close suburbs but in rural areas, it is normally done using coaches. In the VOIESUR database, for buses and coaches, 6606 occupants of all ages are present. Frontal impact is first impact type with more than 40%, followed by side impact about 30%. Rear collision scores 15% of the total and surprisingly roll-overs only represent 2%. For frontal impact, most of the time, the accident severity, coded in EES (Equivalent Energy Speed) in the database is not known.

The projection at national level for children is 311. This represents 2% of the total number of children involved in road accident in a year. Of course, the number of accident with such vehicle can show fluctuation from one year to another one, so conclusions are only valid for the year 2011. What is remarkable in this year is that no fatality of children in buses and coaches has been observed in France. In addition, it can be noted that there is no child under the age of 4 in the sample. Children in the following analysis are all between 4 and 14 years of age.

Infrastructure:

A very large proportion (93%) of buses and coaches accidents with children on board happened in built-up areas, and for 97% during the day. They took place on primary roads for 85%.

The typology of accidents for the buses and coaches are globally at low severity. Some of them were against pedestrians that represent no real physical impact for the bus occupants. In other cases, some children standing in the vehicle felt down on the door and were ejected without any impact of the bus, but just during a steering manoeuvre. Some frontal cases are reported but most of them have a very low EES (Equivalent Energy Speed) which means that their occupants are submitted to relatively low loads. Very few cases with a EES over 15 kph, are part of the sample. That's the main reason why it has not been possible to study the efficiency for children of restraint systems in such vehicles. For that a sample big enough containing restrained and non-restrained children in different crash scenarios is needed. May be the VOIESUR database is one of the brick to build the scientific knowledge on this point, but the project itself cannot bring any conclusion on that point.

Injuries: Children from 4 to 11 are all uninjured or are slightly injured only, no severe injury was observed for this age group. For children from 12 to 14 years, the sample contains different levels of injuries and a part of non-injured children. The injury severity for all children involved in accidents as bus or coach occupants has been coded using the AIS code version 1998. This parameter is known for 91% of the children of the sample. 59% of them are uninjured, and 20% only sustained AIS1 level injuries (cuts, skin abrasions, contusions,…). Severe AIS3 injuries have been observed on lower limbs, but no cerebral injury, chest fracture, spine injury or abdominal injury has been reported.

CONCLUSIONS

It is difficult to consider a global road child safety message as children involved in road accidents belongs to different kind of roads users in which they do not have the same level of responsibility. Children are globally not able to take decision by themselves to properly behave in the road traffic. That's an additional reason for them to be treated as vulnerable road users. But when adults are deciding for children as for example in cars, it is clearly shown that the way children are protected is not satisfying mostly because the restraint systems are not adapted or not correctly used.

Globally, children involved in road accidents are for a large proportion not injured or slightly injured but the proportion of severely injured is sometimes over 10% as for pedestrians. The type of severe injuries that can be sustained by children is linked to the category of road user as reminded on Figure3. In the VOIESUR sample, a

large proportion of severe injuries has been attributed to the lower and upper limbs. This is somehow surprising as this is not necessary the conclusions issued from the CASPER accident database [12] that was orientated to biomechanical works research and for which the data collection was not representative of the road reality. Nevertheless, it appears that to improve the protection of children the head is always an important body segment whatever the type of road user, that for pedestrians it seems important to consider the chest while for car occupants, the abdomen seems also to be one of the priorities.
Works on the infrastructures are possible but it has to be reminded that children's road accidents do not occur in the same locations, especially the ones leading to severe injuries or fatalities. This would be helpful to focus on pedestrians and cyclists in cities and on the communication that is forwarded to both parents and children in order that they improve their behaviour while walking or riding in the streets. For children car occupants, the most urgent points to improve the situation are the improvement of the quality of use of the restraint systems and the protection of vital body segments such as the head and the abdomen.
This study has some limitations because of the use of weighting factors calculated for each child. This is helpful when considering the complete data set but it can become a bias when working on selection of data in which one of the children is representing a large proportion of the total. In addition, this study is limited in terms of the size of the sample because it contains only one year of data collection, which is representing a large amount of data but relatively few for each category of road users. In addition, a multi-annual data collection would allow to eliminate the bias of exceptional events that are may be in the sample, and some other rare configurations that are not there. One speaking example could be a coach accident with multi fatality of children. This would completely change the picture compared to the one of the VOIESUR data set.
This study has shown a picture that it representative of the situation of accidents with children in France compared them as different types of road users, and have brought data to construct ways of progress.

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