THE CORRELATION BETWEEN PEDESTRIAN INJURY SEVERITY IN REAL-LIFE CRASHES AND EURO NCAP PEDESTRIAN TEST RESULTS

Johan Strandroth (1, 2)
Matteo Rizzi (3, 5)
Simon Sternlund (1)
Anders Lie (1, 4)
Claes Tingvall (1, 2)

1) Swedish Transport Administration
2) Chalmers University of Technology
3) Vectura Consulting
4) Karolinska Institutet, Department for Public Health Science
Sweden
5) Monash University Accident Research Centre
Australia
Paper Number 11-0188

ABSTRACT

The protection of pedestrians in crashes has been addressed by friendlier car fronts. This is a process driven by both regulation and consumer test programs. Since 1997, Euro NCAP has been testing and assessing the level of protection for most car models available in Europe.

In the current study, the Euro NCAP pedestrian scoring was compared with the real-life outcome in pedestrian crashes that occurred in Sweden 2003-2010. The real-life crash data was obtained from the data acquisition system STRADA, which combines police records and hospital admission data. The medical data consisted of ICD diagnoses and AIS scoring. In all approximately 500 pedestrians were included in the study. Each car model was coded according to Euro NCAP pedestrian scores. In addition, the presence or absence of Brake Assist (BA) was coded for each car involved. The injury scores for each individual were translated to Risk of Serious Consequences (RSC) at 1, 5 and 10% risk of disability level. This will indicate the total risk of a medical disability given the severity and location of injury.

The results showed a significant reduction of injury severity for cars with better pedestrian scoring, although cars with a high score could not be studied, due to lack of cases. The reduction of RSC for medium performing cars in comparison with low performing cars was 17, 26 and 38% for 1, 5 and 10% of medical impairment, respectively. These results applied to urban areas with speed limits up to 50 km/h, although no significant reduction was found in higher speed zones.

While Brake Assist (BA) was found to contribute to a small injury reduction of about 5%, the results were non-significant. It was also found that the combined effect of BA and higher pedestrian scoring was greater than the two effects separately.

INTRODUCTION

Every year 400 000 pedestrians are killed worldwide according to Naci et al (2009). In the European Union only, more than 5 000 pedestrians are killed (CARE database, 2009). In Sweden approximately 40 pedestrians are killed each year, which is 12% of all road fatalities, and 250-300 are severely injured according to police records. Out of the injured pedestrians 260 were calculated to have got injuries with long term disability in 2009 (Swedish Transport Administration, 2010). The number of killed pedestrians per 100 000 population is 0.4, compared to approximately 6.4 globally (Swedish Transport Administration, 2010; Statistics Sweden, 2011; Naci et al., 2009).

Several studies have reported that lower extremities are the most commonly injured body region among pedestrian to car crashes (Roudsari et al., 2005, EEVC WG 17, 1998). With regard to more severe injuries (AIS 3+), head injuries are more frequent in US data (Longhitano et al., 2005), followed by leg and thorax injuries. However, Fredriksson et al (2007) reported in a study with German GIDAS data that, even among AIS 3+ injuries, leg is still the most commonly injured body part, followed by head and thorax. Fredriksson et al (2007) also concluded that 30% of all surviving pedestrians suffer from permanent medical impairment and that the head is the dominating body region regarding more severe impairment.

As recognized by the working group of Pedestrian Safety in European Enhanced Vehicle safety Committee (EEVC WG 17), many studies have shown that a large proportion of pedestrians are hit by the front of the car (EEVC WG 17, 1998).

In a typical car to pedestrian crash, the bumper first strikes the leg. The thigh, pelvis or chest then most likely is hit by the bonnet leading edge. Next, the upper body moves to the bonnet area with the shoulder or thorax hitting the bonnet. Finally, the head hits the bonnet or windshield area or/and sometimes even the roof, depending on the impact speed. Based on this impact scenario, various recommendations for the crash testing of front design have been developed (EEVC WG 17, 1998; Fredriksson et al., 2007). EEVC WG 17 recommends that main concern should be given to the leg-to-front end impacts, chest impacts to the bonnet and windscreen areas and head-to-windscreen area impacts.

The process of making the car front more pedestrian friendly has been encouraged by both regulation and consumer test programs. In 1987, EEVC Working Group 10 Pedestrian Protection was set-up in order to determine test methods for assessing pedestrian protection by the front of cars. In 1998 EEVC Working Group 17 Pedestrian Safety was formed and asked to review the test method suggested by WG 10 in 1994 which resulted in the report "EEVC Working Group 17 Report – Improved test methods to evaluate pedestrian protection afforded by passenger cars", which was also updated in 2002 (EEVC WG 17, 1998). The assessment was based on dummy response data recorded in three test configurations; head to bonnet, upper leg to bonnet leading edge and leg to bumper impact. In the report WG 17 specifically pointed out the importance of not considering only life threatening injuries (high AIS levels) but also the risk for long term disability (EEVC WG 17, 1998).

In 2005 the test methods as proposed by EEVC were adopted by the European directive in the legal requirements on pedestrian protection (EC, 2003). Also in 2005 the Japan Ministry of Land, Infrastructure and Transport (MLIT) introduced a "Technical Standard for Protection of Heads of Pedestrians" (McLean, 2005). But already in 1997 the consumer organization European New Car Assessment Program (Euro NCAP) had started to assess pedestrian protection based on methods presented in the EEVC WG 17 report. Until 2008 the pedestrian rating was not included in the overall rating and a separate Euro NCAP star rating was given for pedestrian protection (1-9 points = one star, 10-18 points = two stars, 19-27 points = three stars and 28-36 points = four stars). In 2009 the pedestrian rating was included in the overall rating even though the test and the scoring system were still the same (Euro NCAP, 2009). During the first couple of years, the typical Euro NCAP pedestrian rating was one or two stars; in 1997 30% of the tested cars were given one star and 70% two stars. This suggested that the score was more a result of coincidence than focused engineering. However, in 2007 the distribution of stars was 13% one star, 65% two stars and 19% three stars (Euro NCAP, 2008). In 2009 the new overall rating system was introduced and the average score was 16.8 points and in 2010 19.1 points (Euro NCAP, 2011), suggesting that the recent improvements were an effect of more engineering efforts being put on pedestrian friendly car design. Looking into the future, 21 points in the pedestrian test will in 2012 be a minimum to qualify for five stars in the overall rating.

Now, consumer testing and regulation have encouraged the manufacturers to meet the requirements of the assessment protocols. However, it is still needed to understand whether the scoring in these assessments correlate with the injury outcome for pedestrians in real-life car to pedestrian crashes. In the SARAC2-project an analysis of police reported pedestrian crash data from Great Britain, France and Germany, Delaney and Cameron (2006) used logistic regression analysis to compare injury severity from pedestrians hit by one and two stars vehicles. No evidence of a relationship between Euro NCAP pedestrian star rating and pedestrian injury severity from police recorded data was found using that method. Another study published in 2009 used case-by-case analysis on 667 real-world crashes from the GIDAS in-depth database to estimate the benefit of Euro NCAP pedestrian rating (Liers and Hannawald, 2009). The Euro NCAP test results were used to estimate the benefit of vehicles already introduced into the market. Liers and Hannawald (2009) concluded that the number of severely injured pedestrians (MAIS2+) would be reduced by 6.5-9.7%, if the vehicle fleet would consist only of currently established models. Consequently, earlier studies give no clear picture about the real-world benefits of a high pedestrian ranking and, more importantly, no study has yet evaluated the effects on long term disability, or risk for permanent medical impairment (RPMI), which is in focus for the pedestrian assessment. RPMI is an estimation of the risk for a patient to suffer from a certain level of impairment based on the diagnosed injuries. The risk is derived from risk matrices for 1, 5 and 10% medical impairment (see Appendix II) developed by Malm et al (2008). As reference amputation of foot, knee or tibia is set to an impairment of 9, 12 or 19%, respectively. The risk matrices were developed for car passengers but are considered to be suitable even for pedestrians (Fredriksson et al., 2007).

The rating system for serious consequence (RSC) is a scale from 0 to 1 and is defined as the risk of being either killed or to suffer from a permanent medical impairment according to the criteria of the Swedish Insurance Companies (Försäkringsförbundet, 2004). The fatality risk is linked to ISS calculated from the maximum AIS (Gustafsson et al., 1985; Håland et al., 1993). RSC can be calculated if all injuries of a person are coded.

In a pedestrian to car impact the injury outcome is not only affected by on the front design but also on the impact speed and the contact with the ground. The ground is considered to have a limited influence on the injury severity, as Zhang et al (2008) estimated the ground to contribute to approximately 20% of injuries. However, impact speed is crucial and highly correlated with injury severity for head, chest and leg injuries (Fredriksson et al., 2007).

Since it has been shown that more than 90% of all drivers fail to apply the brakes enough in a panic situation, Brake Assist has been introduced in order to optimize braking. Brake Assist measures the speed with which the brake pedal is pressed down, and in some models how fast the accelerator pedal is released. If a panic situation is then detected, maximum brake pressure is applied (Wikipedia, 2011). Since this system enhance braking performance and thereby potentially decreases the impact speed, it could be argued to have a positive effect on pedestrian injury severity. Hannawald and Kauer (2004) estimated that braking occurred and would activate a Brake Assist system in 50% of the crashes and Lawrence et al (2006) estimated Brake Assist to have an effect to reduce fatal and serious injuries among pedestrians by 10%.

Autonomous braking, independent of the driver, would increase the potential of injury reduction. Rosén et al (2010) estimated autonomous braking to have positive effects of 40% for fatalities and 27% for severely injured. Bearing two injury mechanisms in mind (front design and impact speed), it would also be of interest to investigate whether they could be combined to find integrated safety solutions. While few studies have been made in this area, Fredriksson and Rosén (2010) concluded that a combined system would protect 64% of the pedestrian by analyzing pedestrian to car crashes with a severe head injury (AIS3+). The potential system would consist of an active autonomous braking system and a passive system with a deployable hood and a lower windshield/A-pillar airbag, which would separately give a reduction of 34 and 44% reduction, respectively.

AIM

The aim of the present study was to:

- estimate the correlation between Euro NCAP pedestrian rating scores and injury outcome in real-life car to pedestrian crashes, with special focus on long-term disability and permanent medical impairment;
- determine whether Brake Assist systems affect the injury outcome in real-life car to pedestrian crashes;
- estimate the combined effects in injury reduction of a medium Euro NCAP ranking score and Brake Assist, compared to a low Euro NCAP ranking score without Brake Assist.

MATERIAL

Swedish real-life crash data was obtained from the data acquisition system STRADA, which combines police records and hospital admission data. Police data contained information from the national vehicle register and it was thereby possible to identify every specific car model involved in a car to pedestrian crash. The hospital data consisted of ICD diagnoses and AIS coded injuries. AIS values from the three most severely injured body regions on a pedestrian were applied on the risk matrices for RPMI calculations. All pedestrian crashes from STRADA during the period 2003-2010 were selected. The material contained 1644 pedestrians with 4105 injuries. Only pedestrians hit by the front of cars tested by Euro NCAP were then selected which limited the numbers of pedestrians to 709 and the number of injuries to 1741. In the analysis, only crashes on roads with speed limit up to 50 km/h were included (except for the analysis in figure 3). In the end, 488 patients with 1156 injuries were included in the study.

Age distribution is shown in Table 1 and confirms that the ages of the pedestrians included in the study are comparable to the national crash statistics.

Table 1.
Age distribution of pedestrians in the study compared to national crash statistics on roads with speed limit 50 km/h

Age	Study material	National crash statistics
0-9	5%	6%
10-17	18%	18%
18-24	13%	15%
25-64	36%	39%
65+	27%	22%

Table 2 shows the number of tested cars in the material and their Euro NCAP rating. As it may be seen, the number of cars with high scores is limited.

Table 2.
Number of cars with different pedestrian rating and score groups, n = 488

Stars	Score	No. of cars
1	1-3	15
1	4-6	58
1	7-9	76
2	10-12	99
2	13-15	147
2	16-18	80
3	19-21	11
3	22-24	1
3	25-27	1

Injury distribution

The injury distribution in the material can be seen in Figure 1. In both AIS1+ (n = 1156), AIS2+ (n = 464) and AIS3+ (n = 130) lower extremities are the most frequent injured body region. However, as injury severity increases the proportion of head and thorax injuries increases too, while injuries on upper extremities decrease. This is well in line with the observations made by Fredriksson et al (2007).

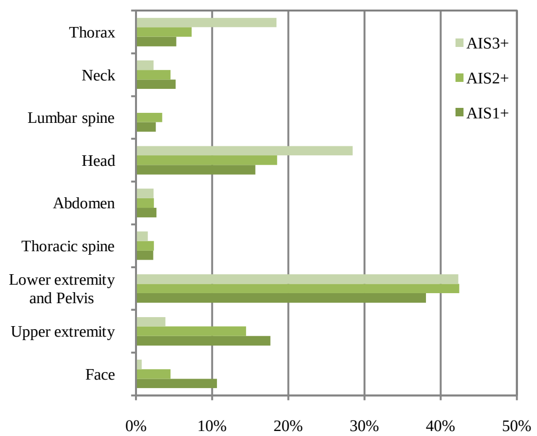

Figure 1. Injury distribution on body regions of pedestrians per AIS level, n = 1156.

Information about Brake Assist fitment was difficult to find. Hence, the assumption was made that a car fitted with Electronic Stability Control (ESC) would be also equipped with Brake Assist. In all, 129 pedestrians were hit by cars with Brake Assist and 357 pedestrians were hit by cars without. Two pedestrians were impacted by cars with unknown Brake Assist fitment. The share of one star cars in the material with Brake Assist was 23% whereas the share in two star cars was 25% (see Appendix I).

METHOD

Each car model in the crash data was linked to the corresponding Euro NCAP pedestrian scores found via the Euro NCAP web site. In addition, the presence or absence of Brake Assist was coded for each car involved, given the assumption that an ESC-equipped car would also be fitted with Brake Assist. Pedestrian injuries were then linked to each individual car model. The cars were divided into groups depending on their rating score and Brake Assist fitment. Since the pedestrian scoring is likely to have less effect in higher speed zones, pedestrians hit on roads with speed limit above 50 km/h were excluded in the analysis, except for results shown in Figure 3.
Cars with Brake Assist were compared to cars without Brake Assist regarding injury severity measured by AIS level and Rating system for Serious Consequences (RSC), which is explained in the next section. A p value < 0.05 was used as indicative of statistical significance.

The correlation between pedestrian score and real-life injuries was mainly estimated as the difference in injury severity (AIS level and RSC) between one and two star vehicles. Again, a p value < 0.05 was used as indicative of statistical significance. Linear regression was used to calculate the effect of injury reduction with increasing Euro NCAP pedestrian score.

Rating system for serious consequence

AIS values from the three most injured body regions on a pedestrian were applied on the risk matrices. RPMI was calculated according to Equation 1.

$$RPMI = 1 - (1 - risk_1) \times (1 - risk_2) \times (1 - risk_3) \quad (1).$$

RSC was calculated according to Equation 2.

$$RSC = 1 - ([1 - r_{fatality}] \times [1 - RPMI]) \quad (2).$$

To compare different groups, the mean RSC (mrsc) was calculated for each group.

RESULTS

Pedestrian score

In Table 3 injury severity for one and two stars cars are shown. For two stars cars the injury severity was significantly lower on all levels except for AIS3+ injuries. Also, the injury reduction between one and two stars cars increased with the level of mrsc from 17% in mrsc 1%+ to 38% in mrsc 10%+.

The average score in the one star and two stars groups were closer than the median value in the interval, indicating that the true difference between one and two star cars is probably larger. Further analysis of which body regions contributed to medical impairment showed no major difference between one and two stars cars.

Table 3.
Number of injuries and injured pedestrians as well as injury severity to one and two stars cars

	1 star	2 star	Rel. diff.
No. injuries	376	745	
No. pedestrian	149	326	
Average NCAP pedestrian score	6.24	13.84	
AIS2+	45.7% (172)	37.9% (282)	-17%
AIS3+	13.8% (52)	9.9% (74)	-28%
mrsc 1%+	48.6%	40.5%	-17%
mrsc 5%+	27.1%	20.0%	-26%
mrsc 10%+	14.8%	9.2%	-38%

Specific stars to illustrate the result of the pedestrian rating are not used after 2009. Consequently it is of special interest to investigate the correlation between mrsc on different levels and Euro NCAP pedestrian score. This is shown in Figure 2. Three groups of cars with similar point intervals and their corresponding mrsc values are plotted in the figure.

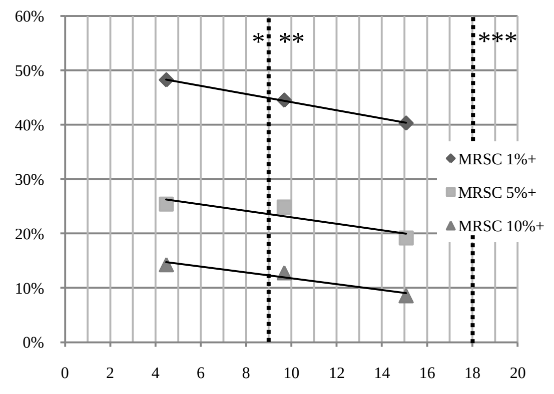

Figure 2. Correlation between Euro NCAP pedestrian score and mrsc.

The same figure is shown in Table 4. The reduction in the range 1-18 of mrsc 1, 5 and 10%+ is 1.6, 2.3 and 3.5% per points, respectively.

Table 4.
Pedestrian score divided in three groups compared to mrsc.

	Gr. I	Gr. II	Gr. III
NCAP ped. score	1-6	7-12	13-18
Average score	4.47	9.61	15.08
No. pedestrian	73	175	227
mrsc 1%+	48.2%	44.5%	40.3%
mrsc 5%+	25.4%	24.8%	19.2%
mrsc 10%+	14.3%	12.8%	8.6%

In Figure 3 pedestrian crashes on roads with speed limit 70 or 90 km/h (n = 73) are included in the analysis. A level of 5%+ medical impairment was chosen to illustrate the effect of pedestrian score on different speed limits. It was clear that the injury reduction due to a high pedestrian score was isolated only to speed limits up to50 km/h.

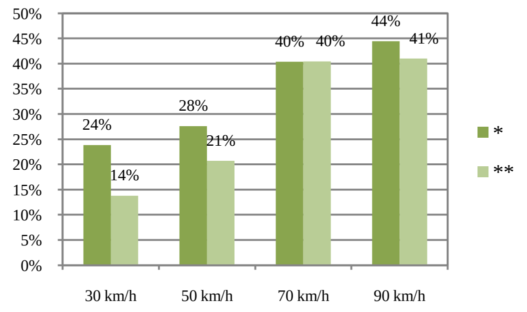

Figure 3. Comparison of mrsc in one and two star cars in different speed limits.

The effect of the Euro NCAP pedestrian score in different age groups was examined and is displayed in Figure 4. The findings showed that a two stars car gave a lower mrsc in all age groups except for small children (0-9). However, the number of pedestrians in this group is small and the estimation was considered uncertain.

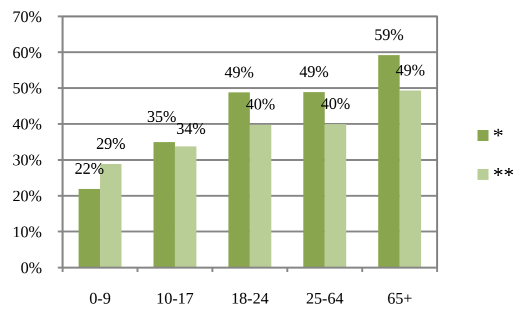

Figure 4. Comparison of mrsc 1%+ between one and two stars vehicle in different age groups.

Other factors that could affect injury severity for pedestrians and possibly confound the results (e.g. car year of manufacture, age and gender of pedestrians and car drivers, road type and road conditions as well as light conditions) were checked and no significant discrepancies were found. In all cases cars with a higher score in the pedestrian rating had a lower injury severity than poor performers.

Brake Assist

Comparisons between cars with and without Brake Assist (BA) are shown in Table 5. Pedestrians hit by BA-equipped cars had a lower proportion of AIS2+ and AIS3+ injuries, 4% and 16% respectively. However, the differences were not significant. Also, mrsc on all levels of medical impairment were lower with BA-cars. For mrsc 1, 5 and 10%+ the reduction with BA were 2, 5 and 4%, although non-significant.

Table 5.
Number of injuries and injured pedestrians as well as injury severity to cars with and without Brake Assist (BA)

	Without BA	With BA	Rel. diff.
No. injuries	839	313	
No. pedestrian	357	129	
AIS2+	40.6% (341)	39.0% (122)	-4%
AIS3+	11.8% (99)	9.9% (31)	-16%
mrsc 1%+	43.5%	42.5%	-2%
mrsc 5%+	22.6%	21.5%	-5%
mrsc 10%+	11.2%	10.8%	-4%

The combined effect of pedestrian score and Brake Assist

Finally, the combined effect of a high pedestrian scoring and Brake Assist (BA) was estimated. Two stars cars with Brake Assist were compared to one star cars without BA and a 20% significant reduction of mrsc 1%+ was found (see Figure 5). Consequently the combined effect of a higher pedestrian score and a lower impact speed (20%) is larger than the separate effects (17 and 2% respectively).

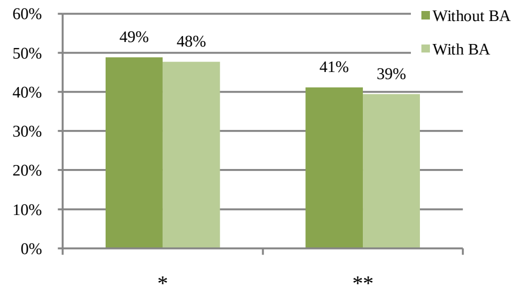

Figure 5. The combined effect of pedestrian score and Brake Assist.

DISCUSSION

This study showed a statistically significant correlation between Euro NCAP pedestrian results and real-life injury outcome for pedestrians. No correlations for specific car models are shown since the material is limited and models are grouped according to their test results. Instead this study showed that an average performing car in the pedestrian rating is in general better performing in real-life conditions too, compared to a poor performing car in the test.

In the groups of one and two stars cars the average Euro NCAP pedestrian score is 6.24 and 14.84, respectively. The reduction of fatal risk combined with risk for permanent medical impairment (mrsc) and also AIS2+ was significant, but not AIS3+ due to the limited material. Since the average score in the groups is closer than the median score, this indicates conservative results. A better correlation to the score is found with three intervals, estimating the injury reduction to between 1.5 and 3.5% per Euro NCAP point depending on injury severity. This way of evaluating the pedestrian rating will be more suitable in the future, with further good performers in the crash data and as the pedestrian stars disappear. The effect of injury reduction increases with increasing severity which is logical since the pedestrian test is design to simulate more severe crashes with focus on long term injuries.

As the number of real-life crashes was limited it was not possible to evaluate the separate tests for head, upper leg and lower leg. However, there was no difference between one and two stars cars regarding which body regions contributed to medical impairment. This can be interpreted as no specific test is more relevant than others and that the effect in real-life injuries is correlating to the total score. Further research with a larger dataset is needed to investigate this aspect.

However, it is clear that injury data with AIS coding for every injury (i.e. not only MAIS codes), is needed to find the actual correlations.

Also, the largest injury reductions are observed on mrsc. This is well in line with the ambitions of the regulation and test procedures to also focus on these impairing injuries. This could also explain why previous studies have not found any correlations. Another factor is that the front design seems to give large benefit only at lower speeds. If evaluations were to be based only on injuries with a high mortality risk one would need to include crashes in speed zones which are probably too high for the front design to be of any real significance. This study only showed an effect in crashes on roads with speed limit up to 50 km/h (and in crashes most likely with impact speeds much lower than 50 km/h). This could be a logical consequence of the fact that Euro NCAP pedestrian test is designed to simulate a crash at 40 km/h. Since about 80 % of all police reported fatal and severe crashes with pedestrians in Sweden are in speed zones up to 50 km/h (Kullgren et al., 2011) the limitation of the effect on front design to lower speeds should not be an issue.

If a high pedestrian score had been found to have benefits also in higher speed zones, there could have been reasons to suspect confounding factors in the results. Now, a number of factors such as vehicle year of manufacture, vehicle weight, road type, speed limit, light and weather conditions as well as driver and pedestrian characteristics were checked. A possible confounder could still be the absence or presence of Brake Assist, if it had been associated to large injury reductions. In this study the difference between one and two stars cars with regard to Brake Assist fitment is only 2%. Giving that the effect is approximately 10%, as shown in this and previous studies, it is highly unlikely that Brake Assist could affect the results to such degree. The assumption that Brake Assist fitment corresponds to ESC fitment is a source of uncertainty. However, it is more likely that Brake Assist exist without ESC than the other way around. This scenario would make a slight underestimation of the injury reduction due to Brake Assist, suggesting that the results are conservative.

The combined effects of two stars cars with Brake Assist compared to one star cars without Brake Assist are larger than the separate effects. Even though it is hard to draw any real conclusion out of this, it can be used to illustrate the large potential in combining friendly car fronts and impact speed reduction with e.g. autonomous braking (the reduction of impact speed due to Brake Assist could in this study be estimated to be 2-3 km/h using the relationship in the power model).

In a combined system the autonomous braking would expose the pedestrian to crashes with impact speeds were a friendlier front design would be beneficial, creating additional effects.

It is fundamental for the development of safer vehicles that test procedures as basis for safety rating are evaluated in a real-life environment too. Previous studies have shown positive correlation between the Euro NCAP occupant protection score and better real-life crashworthiness (Lie et al., 2001; Kullgren et al., 2010). This has encouraged a broader implementation of cars with a high Euro NCAP occupant rating including it as a performance indicator in traffic safety management.

The inclusion of pedestrian scores in the overall NCAP star rating seems to be relevant. Pedestrian protection might also be relevant as well as occupant protection to include as a performance indicator in traffic safety management.

CONCLUSIONS

- A significant correlation between Euro NCAP pedestrian score and injury outcome in real-life car to pedestrian crashes was found.

- Injury reduction was found to be larger with increasing severity and level of permanent medical impairment.

- The difference between one and two star cars is 17% in AIS2+, 17% in mean risk of permanent medical impairment (mrsc) 1%+, 26% in mrsc 5%+ and 38% in mrsc 10%+, for crashes in speed zones up to 50 km/h.

- Brake Assist was found to give a small injury reduction. The effects of Brake Assist were non- significant.

REFERENCES

CARE database. 2009. "CARE - Road fatalities by Country." http://ec.europa.eu/transport/road_safety/specialist/statistics/care_reports_graphics/index_en.htm. (Accessed 2011-03-10).

Delaney, A. and Cameron M. 2006. "Analysis of Pedestrian Crash Data from Great Britain, France and Germany". Report of sub-task 3.4.

EC. 2003. "Directive 2003/102/EC of the European Parliament and of the Council of 17 November 2003 Relating to the Protection of Pedestrians and Other Vulnerable Road Users Before and in the Event of a Collision With a Motor Vehicle and Amending Council Directive 70/156/EEC." In: UNION, T.E.P.A.T.C.O.T.E. (ed.) 2003/102/EC. Brussels: Official Journal of the European Union.

EEVC, Working Group 17. 1998. "Improved Test Methods to Evaluate Pedestrian Protection Afforded by Passenger Cars".

European New Car Assessment Programme (Euro NCAP). 2009. Assessment Protocol Version 5.0

Fredriksson, R. and Rosén E. 2010. "Integrated Pedestrian Countermeasures - Potential of Head Injury Reduction Combining Passive and Active Countermeasures." IRCOBI Conference, Hannover, Germany.

Fredriksson, R., Zhang, L., Boström, O., Yang, K. 2007. "Influence of Impact Speed on Head and Brain Injury Outcome in Vulnerable Road User Impacts to the Car Hood". Stapp Car Crash Journal, 51, 155-67.

Försäkringsförbundet. 2004. "Medicinsk invaliditet – Gradering av medinsk invaliditet" (Swedish Insurance Federation: Medical impairment – Grading of medical impairment, in Swedish). Stockholm, Sweden, Sveriges Försäkringsförbund.

Hannawald, L. and Kauer, F. 2004. "Equal Effectiveness Study on Pedestrian Protection". Technische Universität, Dresden, Germany.

Kullgren, A., Lie, A., Tingvall, C. 2010. "Comparison between Euro NCAP Test Results and Real-World Crash Data". 2010 Traffic Injury Prevention, 11: 6, 587-593.

Lawrance, G. J. L., Hardy, B. J., Carroll, J. A., Donaldson, W. M. S., Visvikis, C. and Peel, D. A. 2006. "A Study on the Feasibility of Measures Relating to the Protection of Pedestrians and Other Vulnerable Road Users". EC report UPR/VE/045/06, contract ENTR/05/17.01. TRL Limited, UK.

Lie, A., Kullgren, A., Tingvall, C. 2001. Comparison of Euro NCAP Test Results with Folksam Car Model Safety Rating". In ESV proceedings 2001, paper number 277.

Liers, L. and Hannawald, L. 2009. "Benefit Estimation of the Euro NCAP Pedestrian Rating Concerning Real-World Pedestrian Safety". In ESV proceedings 2009, paper number 387.

Malm, S., Krafft, M., Kullgren, A., Ydenius, A., Tingvall, C., 2008. "Risk of Permanent Medical Impairment (RPMI) in Road Traffic Accidents." Annu. Proc. Assoc. Adv. Automot. Med. 52, 93–100.

McLean, AJ. 2005. "Vehicle Design for Pedestrian Protection." CASR report series report no. CASR037. ISBN 1 920947 39 6.

Naci, H., Chisholm, D. and Baker, T. D. 2009. "Distribution of Road Traffic Deaths by Road User Group: a Global Comparison." Traffic Injury Prevention, 15, 55-9.

Rosén, E., Källhammer, J.-E., Eriksson, D., Nentwich, M., Fredriksson, R. and Smith, K. 2010. "Pedestrian Injury Mitigation by Autonomous Braking". Accident Analysis and Prevention, 42, 1949-1957.

Roudsari, B. S., Mock, C. N. and Kaufman, R. 2005. "An Evaluation of the Association Between Vehicle Type and the Source and Severity of Pedestrian Injuries." Traffic Injury Prevention, 6, 185 - 192.

Kullgren, A., Lie, A., Strandroth, J., Rizzi, M., Tingvall, C. 2011. "The importance of age for injury severity among car drivers and pedestrians". In ESV proceedings 2011.

Wikipedia. (2010). Brake Assist, http://en.wikipedia.org/wiki/Brake_Assist. (Accessed 2011-03-09.)

Zhang, G., Cao, L., Hu, J. and Yang, K. H. 2008. "A Field Data Analysis of Risk Factors Affecting the Injury Risks in Vehicle-to-Pedestrian Crashes." Annu Proc Assoc Adv Automot Med, 52, 199-214.

APPENDIX I – CAR MODELS

1 star-cars, with BA	n
AUDI A2	2
AUDI A4 01-	4
AUDI A6 04-	1
BMW 1 SERIES 04-	1
BMW 3 SERIES 98-05	1
BMW 5 SERIES 03-	4
BMW 5 SERIES 96-02	3
BMW X3	1
MAZDA 6	1
MERCEDES-BENZ A CLASS W169	1
MERCEDES-BENZ E CLASS 02-09	4
OPEL ASTRA 04-	2
OPEL VECTRA 02-	5
SAAB 9-3 04-	4
VOLVO C30	1
SUM	**35**

1 star-cars, without BA	n
BMW 3 SERIES 98-05	1
BMW 5 SERIES 96-02	8
CHRYSLER PT CRUISER	1
CHRYSLER VOYAGER 2	4
CITROEN XANTIA	3
FIAT PUNTO 94-98	1
FORD FIESTA 96-02	3
FORD KA	1
MERCEDES-BENZ VITO 03-	1
MINI COOPER	2
MITSUBISHI COLT 04-	3
NISSAN ALMERA 98-00	1
OPEL ASTRA 04-	4
OPEL ASTRA 99-03	8
OPEL CORSA 00-	1
OPEL MERIVA	1
PEUGEOT 306	3
RENAULT CLIO 06-	1
RENAULT CLIO 91-98	3
RENAULT MEGANE 97-03	14
RENAULT MODUS	1
SAAB 9-3 04-	2
SAAB 9-3 98-03	7
TOYOTA AVENSIS 03-	3
VOLVO S40 96-04	26
VW POLO 02-05	4
VW POLO 95-00	7
SUM	**114**

2 stars-cars, with BA	n
AUDI A3 97-03	1
AUDI A4 94-00	1
AUDI A6 97-04	1
CITROEN C5	1
FORD FOCUS 05-	2
FORD MONDEO 01-06	1
FORD MONDEO 07-	1
HYUNDAI I30	1
LEXUS GS 450	1
MERCEDES-BENZ B CLASS	1
MERCEDES-BENZ C CLASS 01-07	1
MERCEDES-BENZ E CLASS 96-01	7
NISSAN QASHQAI	1
OPEL ZAFIRA 05-	1
PEUGEOT 206	6
PEUGEOT 307	5
PEUGEOT 406	1
PEUGEOT 407	2
SAAB 9-5 99-10	3
TOYOTA COROLLA 02-	2
TOYOTA YARIS 05-	1
VOLVO S40/V50 04-	6
VOLVO S60	2
VOLVO V70 N 00-06	17
VOLVO V70 N2 07-	3
VOLVO XC90	2
VW PASSAT 4 97-04	5
VW PASSAT 5 05-	5
VW SHARAN 95-10	1
SUM	**82**

2 stars-cars, without BA	n
AUDI A3 97-03	2
AUDI A4 94-00	7
AUDI A6 97-04	1
BMW 3 SERIES 91-97	9
CITROEN BERLINGO	1
CITROEN C3	2
CITROEN C5	1
CITROEN XSARA	1
FIAT PUNTO 99-	1
FORD ESCORT 91-	5
FORD FIESTA 03-	7
FORD FOCUS 05-	2
FORD FOCUS 98-04	6
FORD MONDEO 93-00	7
FORD MONDEO 01-06	2
HYUNDAI ACCENT	3
HYUNDAI ATOS	1

2 stars-cars, without BA, cont.	n
MERCEDES-BENZ C CLASS 93-00	1
MERCEDES-BENZ E CLASS 96-01	2
MITSUBISHI SPACESTAR/WAGON 99-	4
MITSUBISHI CARISMA	2
MITSUBISHI COLT 96-04	2
MITSUBISHI WAGON/GEAR 96-	1
NISSAN ALMERA 00-06	1
NISSAN MICRA 92-03	1
NISSAN PRIMERA 98-	4
OPEL CORSA 92-00	2
OPEL OMEGA 94-99	1
OPEL VECTRA 97-02	2
OPEL ZAFIRA 05-	2
OPEL ZAFIRA 99-05	2
PEUGEOT 206	9
PEUGEOT 406	8
RENAULT CLIO 99-06	2
RENAULT LAGUNA	3
RENAULT LAGUNA 2	3
RENAULT MEGANE SCENIC 04-	1
ROVER 75	1
SAAB 900	3
SAAB 9-5 99-10	15
SEAT IBIZA/CORDOBA 93-98	1
SEAT IBIZA/CORDOBA 99-	3
SKODA FABIA	3
SKODA OCTAVIA	4
SUZUKI BALENO	2
TOYOTA AVENSIS 98-02	2
TOYOTA COROLLA 02-	1
TOYOTA COROLLA 98-	9
TOYOTA COROLLA VERSO 04-	1
TOYOTA PICNIC	1
TOYOTA PRIUS 04-	5
TOYOTA YARIS 99-05	2
VOLVO 800/S70	21
VOLVO C70	2
VOLVO S60	9
VOLVO S80	2
VOLVO V70 N 00-06	18
VW GOLF 4 98-03	9
VW LUPO	1
VW NEW BEETLE	1
VW PASSAT 4 97-04	11
VW POLO 00-02	4
SUM	**163**

2 stars-cars, BA fitment unknown	n
SAAB 9-5 99-10	2

3 stars-cars with BA	n
CITROEN C4	1
TOYOTA AURIS	2
VW GOLF 5 04-	7
VW TOURAN	2
SUM	**12**

3 stars-cars without BA	n
HONDA CIVIC 02-	1

TOT 1 star	149
TOT 2 stars	326
TOT 3 stars	13
SUM	488
TOT with BA (including 3 stars)	129
TOT without BA (including 3 stars)	357
TOT BA unknown	2
SUM	488

APPENDIX II – RISC MATRICES FOR PERMANENT MEDICAL IMPAIRMENT

Risk for 1% or more permanent medical impairment

(%)	AIS 1	AIS 2	AIS 3	AIS 4	AIS 5
Face	5.8	28	80	80	n/a
Upper extremity	17.4	35	85	100	n/a
Lower extremity	17.6	50	60	60	100
Thoracic spine	4.9	45	90	100	100
Abdomen	0.0	2.4	10	20	20
Head	8.0	15	50	80	100
Lumbar spine	5.7	55	70	100	100
Neck	16.7	61	80	100	100
Thorax	2.6	4.0	4	30	30

Risk for 5% or more permanent medical impairment

(%)	AIS 1	AIS 2	AIS 3	AIS 4	AIS 5
Face	2.4	10	60	60	n/a
Upper extremity	4.2	10	65	100	n/a
Lower extremity	1.6	20	35	60	100
Thoracic spine	0.9	20	55	100	100
Abdomen	0.0	0.0	4.5	10	10
Head	5.0	12	45	80	100
Lumbar spine	1.6	25	45	100	100
Neck	9.7	40	55	100	100
Thorax	0.0	0.5	0.7	15	15

Risk for 10% or more permanent medical impairment

(%)	AIS 1	AIS 2	AIS 3	AIS 4	AIS 5
Face	0.4	6	60	60	n/a
Upper extremity	0.3	3	15	100	n/a
Lower extremity	0.0	3	10	40	100
Thoracic spine	0.0	7	20	100	100
Abdomen	0.0	0.0	5	5	5
Head	2.5	8	35	75	100
Lumbar spine	0.1	6	6	100	100
Neck	2.5	10	30	100	100
Thorax	0.0	0	0	15	15