COMPARISON OF EURO NCAP TEST RESULTS WITH FOLKSAM CAR MODEL SAFETY RATINGS

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ABSTRACT

The European crash test program, Euro NCAP, has since it's launch presented results of some 80 individual car models. The improvements in the general level of protection have been substantial. While the intention of the test program is to stimulate the use of best practice, and not to predict real life outcome, it is nevertheless important to validate the positive development, and to pinpoint potential areas not included in the laboratory safety ratings.

In this study, Euro NCAP rating results were compared with a comprehensive car model safety rating method based on real-life crashes, developed by Folksam. In addition, correlation with relative injury risks was also studied. In the Folksam method, the ratings are based on the risk of fatalities and long-term consequences due to injury. The car models were grouped together according to the Euro NCAP star ratings.

A correlation was found between Euro NCAP scoring and relative risk of serious and fatal injury as well as for the Folksam rating score (relative risk of fatality or permanent disability). No correlation between Euro NCAP scoring and relative risk of any injury was found. A stronger correlation between risks for serious consequences was found when AIS1 neck injuries were excluded compared to when they were included. This indicates correctly that these injuries are not reflected in the Euro NCAP ratings. The risk to sustain a police reported severe or fatal injury was found to diminish with 12 % per star. The risk to be fatally injured or sustaining a long-term disability was found to diminish with 7 % per star.

INTRODUCTION

The safety level differs between car models. It has also improved over time (Lie et al 1996). This safety development can be shown both in the laboratory and in real-life crash situations. There are several test programs to evaluate the safety level of new cars. Euro NCAP has become an important factor for vehicle design since the introduction in 1996. The program has tested some 80 of the best selling car models. Details of the tests used and the results are available on Euro NCAP's web site http://www.euroncap.com. The Euro NCAP star scoring is based on point scores for the front and side. Maximum 34 points can be achieved by adding 16 front and 18 side points (Hobbs and Gloyns 1999). The intention of the scores is to give an indication to what extent best practice or benchmarking has been applied to an individual car model, and not to predict the real-life outcome.

Laboratory crash testing only gives a limited possibility to establish the overall safety level of a specific car model. The real-life outcome is an important complement to the laboratory tests. There are several institutions doing real life rating of cars. Folksam has since mid 1980's published ratings. Folksam ratings indicate the relative risk for fatal or disabling injuries.

In 2000 the Swedish National Road Administration published a study on the correlation between Euro NCAP results and the real life risk for injury (Lie and Tingvall 2000). Police records were used for the injury descriptions. That is a relatively blunt method but give the possibility to use mass data. The correlation study indicated a strong and consistent correlation when the risks for fatal and serious injuries were studied. For minor injuries no correlation was seen.

The aim of this study was to further investigate the correlation between the Euro NCAP test results and the real-life injury outcome. This was done by the Folksam method using both police data and the more detailed injury data available in the insurance claim database.

The study is limited to the drivers of the vehicles.

METHODS

The calculations of real life risk values are based on two sources, police material and insurance data. From the police data the relative injury risk is calculated. The insurance data, containing more detailed injury descriptions, is used to calculate the fatality and disability risk. The calculation methods are further described in Hägg et al. (1992) and Hägg et al. (2000). Below is a short description how this has been done.

Calculation of Relative Injury Risk From Police Data

The relative injury risk was calculated using paired comparison technique with two-car crashes. The method was initially developed by Evans, but has been developed further for car-to-car collisions by Folksam (Evans 1986, Hägg et al. 1992, Hägg et al. 2000). By only studying two-car crashes where both cars experience the same impact severity, the paired comparison method controls for impact severity. The relative injury risk for the case car model is calculated by comparing the injury outcome in the case vehicle with the injury outcome in the vehicles it collides with. In two-car crashes mass relations influence the relative injury risk, as they will alter the impact severity distribution. This can be taken into account in the model and the influence of mass on the relative injury risk can be adjusted. Another factor influencing the results is aggressivity. Aggressivity is here defined as the properties of the case vehicle that influences the risk to injure the occupants of the opponent vehicle. The influence of aggressivity on injury risk using paired comparisons has been shown to be smaller than the influence of mass (Hägg et al. 2000, Kullgren et al 2001). Aggressivity has not been adjusted for in this study. This study includes all car-to-car crashes independent of crash type. The risk figures may be influenced by systematic differences in seatbelt use and accident type. However, these factors seem not to be likely sources of error in this study. The method assumes that injuries in one car are independent from the injuries in the other car, given a certain impact severity.

In the paired comparison method, crash outcomes in two-car crashes are grouped in four groups (see Table 1) x_1 (injuries in both cars), x_2 (injuries in the case car but not in the opponent) and x_3 (injuries in the opponent vehicle but not in the case vehicle). If no one is injured in the crash, x_4, usually no data is available. To calculate relative risks, x_4 is not used and will not add any important extra information.

Table 1.
Grouping of Crashes into x_1, x_2 and x_3 Sums

		Opponent Vehicle	
		Injured	Not injured
Case car	Injured	x_1	x_2
	Not injured	x_3	x_4 *(unknown)*

The uncompensated risk relation between the two cars is calculated as the ratio between injuries in the case car compared with the opponent cars (Eq. 1). The opponent car is considered to be a sample of the whole car population and is therefore the exposure basis allowing comparisons across all case vehicles.

$$R=(x_1+x_2)/(x_1+x_3) \qquad \text{(Eq. 1.)}$$

Compensation for Mass Differences

If there is a mass difference between case vehicle and opponent vehicle, both vehicle types will be exposed to impact severity that differs from when the two groups of vehicles have the same weight (Fig. 1). If the case vehicle is lighter than the average vehicle it will have a higher change of velocity compared to the average vehicle. At the same time the opponent vehicle will have a lower change of velocity. The mass has therefore a double effect on the relative risk; it will be a benefit for one vehicle and a disadvantage for the other vehicle. While it might be desired to take into account the importance of mass for the case vehicle, the altered impact severity distribution must be compensated for relating to the opponent vehicle in order to allow comparisons with other case vehicles. The mass compensation coefficients were derived from another study (Kullgren et al. 2001). By analysing how a defined set of vehicles was affected by varying mass relations, the mass/change of velocity adjustment factor could be derived. It was found that mass relations influenced the risk of any injury as well as severe and fatal injury according to Equation 2. The calculation methods and assumptions are further described by Kullgren et al (2001).

$$R_{\text{mass adjusted}} =(x_1+x_2)/(x_1+x_3)* (1+0.62*M_{diff}-0.00122*M_{diff}^2) \qquad \text{(Eq. 2.)}$$

where M_{diff} = (case vehicle mass - average vehicle mass)/average vehicle mass

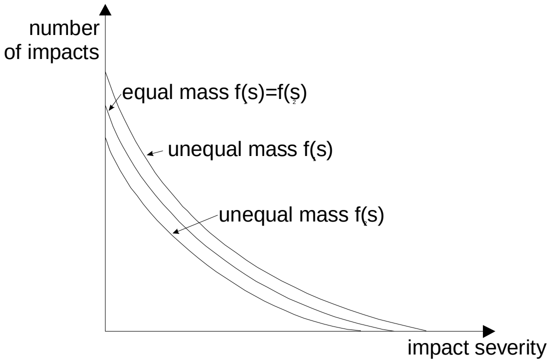

Figure 1. Change of velocity distribution depending on mass.

Mass Compensation to Crash Test Conditions

Crash testing into a fixed barrier is equivalent to a crash into a car of the same mass, while the real life outcome integrates weight as a factor influencing impact severity. To completely remove mass effects from the analysis, thereby allowing direct comparisons with barrier crash tests, it is possible to compensate for mass for the case vehicles as well. The same mass adjustment technique and factor as described in Eq. 2 was used.

Compensation for the Year of the Crash

The average safety level of vehicles increases every year. When using the paired comparison method with an accident sample including accidents that occurred several years back in time, the results will be influenced by this increase, particularly for older car models. By using the paired comparison method it is possible to calculate this average increase. In the Folksam Car Model Safety Ratings 1999 (Hägg et al. 2000) the average increase in risk was found to be 1,5% per year as a linear relationship. For example, a car model involved in collisions 10 years ago, at that time experienced an average opposite vehicle that was 15% less safe than the level today. This means that the rating result for that model will be 15% better than the ”true” result if compared with the average safety level of models existing today.

Based on these results, compensations have been made to adjust for the year of impact according to the equation below.

$$x_{i,\ adjusted} = \sum_{j=1}^{m} (x_{i,j} * (1 + f*(Year_{actual} - Year_j))) \qquad \text{(Eq. 3.)}$$

f = factor 0.015 (1.5% per year)
$Year_{actual}$ = the latest accident year in the sample
$Year_j$ = the accident year

Compensation has been made in each accident with a factor linked to the accident year. The adjusted relative injury risk has been calculated based on the ratio between the adjusted x_1+x_2 in the nominator and the unadjusted x_1+x_3 in the denominator.

$$R_{year\ adjusted} = (x_{1,\ adjusted}+x_{2,\ adjusted})/(x_1+x_3) \qquad \text{(Eq. 4.)}$$

The total formula used to calculate the relative injury risk, from police data, would therefore be:

$$R_{adjusted}= (x_{1,\ adjusted}+x_{2,\ adjusted})/(x_1+x_3)* (1+0.62*M_{diff}-0.00122*M_{diff}^{2})^2 \qquad \text{(Eq. 5.)}$$

Calculation of Risk of Fatality or Permanent Disability from Insurance Data

All injuries in the insurance data were classified according to the 1985 revision of the Abbreviated Injury Scale, AIS (AAAM 1985). The severity of multiple injuries was expressed according to the ISS, where maximum AIS values (MAIS) for up to three out of six body regions are squared and summed. ISS thus has a range from 1 to 108, for those over 75, however, a fatal injury is always included (AIS 6). ISS was derived empirically and the formula used has no theoretical background.

In order to have a scale that fulfils some of the criteria for statistical analysis and also includes one other serious outcome of traumatic injuries, namely permanent disability, the RSC (Rating System for Serious Consequences) was used (Gustavsson et al. 1985). RSC is a scale from 0 to 1, which reflects the risk of either being killed or sustaining a permanent disability of at least 10% according to the procedures used by the Swedish insurance companies (Försäkringsförbundet 1996).

The RSC is based on the AIS coding of body regions and injury severities. ISS and AIS for up to 10 body regions are used as prior information for calculation of RSC. RSC is calculated from the formula:

$$RSC = r_f + ((1 - r_f) * (1-\Pi[1 - r_{id}])) \qquad \text{(Eq. 6.)}$$

r_f=fatality risk
r_{id}=disability risk

The fatality risk (r_f) is the fatality risk associated with an ISS value, and the disability risk (r_{id}) is the risk of being medically disabled as a result of an injury of a certain AIS level to a specific body region. The fatality risk values were derived from different studies of the relationship between ISS and mortality risk (Bull 1975, Baker et al. 1974, Baker and O'Neill 1976), see further descriptions in Hägg et al (1992) and Hägg et al (2000).

The disability risk values were derived from empirical materials on the relationship between AIS for different body regions and the proportion of permanently disabled (Gustavsson et al. 1985). The r_{id} values are treated as independent. The r_{id} values are presented in Table 2, and show the values for permanent medical disability for different body regions and AIS levels. In Sweden, the cases of all injured persons who sustain medical disability that is considered as permanent and of a level of at least 10%

Table 2.
Disability Risks (r_{id}) Used in the RSC Scale (from Gustavsson et al. (1985)).

Body region	AIS 1	AIS 2	AIS 3	AIS 4	AIS 5
Skull/Brain	0.01	0.02	0.15	0.30	0.55
Neck	0.05	0.10	0.40	0.50	1.00
Face	0.0002	0.01	0.10	0.10	-
Arm	0.005	0.05	0.20	0.60	-
Leg	0.005	0.15	0.30	0.60	-
Chest	0.001	0.003	0.01	0.03	0.05
Abdomen	0.0001	0.0001	0.02	0.04	0.04
Pelvis	0.001	0.05	0.10	0.10	-
Back	0.01	0.10	0.30	0.75	1.00
External	0.0001	0.05	0.05	0.05	n. a.

are evaluated regarding this disability by a partly governmental committee with representatives of all insurance companies (Försäkringsförbundet 1996). The evaluation of medical disability includes only loss of function and pain and should not include occupational or social handicap. 12,000 injured were followed during at least five years to produce the probabilities in Table 2 (Gustavsson et al 1985).

Combining Police and Insurance data

In order to get the risk of receiving a disabling or fatal injury in a crash, the relative injury risk from police data, $R_{adjusted}$, and injury severity, mrsc, is matched together. The estimation is given by the formula:

$$Z = R_{adjusted} * mrsc \qquad \text{(Eq. 7.)}$$

The two datasets, from the police and the insurance company, do not overlap to 100% on case-to-case basis. This is not considered to influence the outcome of this kind of studies.

The variance of the relative injury risk, R, was based on Gauss' approximation of variance for ratios.

MATERIAL

The relative injury risk was calculated based on police reports from crashes that occurred in Sweden between 1994-01-01 and 2000-12-31. Only car-two-car crashes with known car makes and models are included to calculate the relative injury risk. The police in the field have classified the injuries in correspondence with the ECE definitions. Four injury levels were used by the police; no injury; minor injury; severe injury; and fatal injury. The severe injuries should typically lead to hospital admittance. Only injured drivers are studied. The data was analysed in two groups: one containing only severe and fatal injuries; and one containing fatal, severe and minor injuries together.

The police data set contains information about vehicle make and model together with injury data for all crashes.

The risk of fatality or disability, mrsc, was calculated from crashes reported to Folksam between 1992-01-01 and 1999-05-31. In the calculation of fatality and disability risk both single vehicle and two-car crashes were used.

The cars are grouped by Euro NCAP star ratings. The Euro NCAP point score for the rated cars are available. The sum of points, from front and side tests is used. Euro NCAP uses 0 to 34 points to do the star rating. The star borders are at 8, 16, 24 and 32 points. Five stars can be achieved if the point score is 32 points or more. No car has achieved a five star result yet (February 2001).
Because of the limited material, all cars with the same star rating are grouped independently of their size group. The kerb weight for every individual car is collected from the vehicle register. All cars with Euro NCAP scores were used. Scores from Euro NCAP phases 1 to 7 were used, that is all tests published before February 2001.

Cars without Euro NCAP scores are used as reference. The reference cars were all of models introduced after 1992. As opponent cars in the pairs, all cars used had a kerb weight between 700kg and 2,500kg. In total 1,252 cases with severe or fatal outcome were studied along with 7,867 cases with at least minor injury outcome. In cars with known Euro NCAP score 422 were severely injured or killed and 3,128 sustained a minor injury.

Totally 2,607 injured occupants were used to calculate the injury severity, mrsc, where of 778 occupants in cars with known Euro NCAP score.

RESULTS

The distributions of the different combinations of crashes with injured drivers in both or either of the cars in two-car crashes are presented in Table 3. Both minor to fatal injuries and severe and fatal injuries are included. Table 4 shows the number of injured driver for the calculations of mean risk for serious consequences, mrsc.

Table 5 presents the relative risk to sustain a fatal or severe, the relative risk to sustain minor to fatal injuries and the risk of fatality or permanent disability, calculated from the values in Table 3 and 4 and with double mass compensation to represent crash test conditions. The Euro NCAP score for cars with Euro NCAP rating is summed and average values were calculated, see Table 5. Table 5 also shows the risk of fatality or permanent disability, mrsc, for all injuries and when whiplash injuries (AIS1 neck injuries) are excluded.

Table 3.
Distribution of Injuries in Case Vehicle and Other Vehicle.
Cars without Euro NCAP rating and launched since 1992

Severe and fatal injuries	All other vehicles		Minor, severe and fatal inj.	All other vehicles	
n=470	Injured	Not injured	n=2,542	Injured	Not injured
Injured	(x_1) 126	(x_2) 169	Injured	(x_1) 854	(x_2) 859
Not injured	(x_3) 175	(x_4) *unknown*	Not injured	(x_3) 829	(x_4) *unknown*

Euro NCAP 2 star cars

Severe and fatal injuries	All other vehicles		Minor, severe and fatal inj.	All other vehicles	
n=332	Injured	Not injured	n=2,969	Injured	Not injured
Injured	(x_1) 86	(x_2) 112	Injured	(x_1) 989	(x_2) 1,026
Not injured	(x_3) 134	(x_4) *unknown*	Not injured	(x_3) 954	(x_4) *unknown*

Euro NCAP 3 star cars

Severe and fatal injuries	All other vehicles		Minor, severe and fatal inj.	All other vehicles	
n=267	Injured	Not injured	n=1,496	Injured	Not injured
Injured	(x_1) 64	(x_2) 66	Injured	(x_1) 504	(x_2) 442
Not injured	(x_3) 137	(x_4) *unknown*	Not injured	(x_3) 550	(x_4) *unknown*

Euro NCAP 4 star cars

Severe and fatal injuries	All other vehicles		Minor, severe and fatal inj.	All other vehicles	
n=183	Injured	Not injured	n=860	Injured	Not injured
Injured	(x_1) 44	(x_2) 50	Injured	(x_1) 310	(x_2) 279
Not injured	(x_3) 89	(x_4) *unknown*	Not injured	(x_3) 271	(x_4) *unknown*

Table 4.
RSC, Number of Injured Drivers and mrsc for the Different Euro NCAP Stars.

	Whiplash included			Whiplash excluded		
Stars	RSC	n	mrsc	RSC	n	mrsc
No class	103.5494	1,829	0.0566	34.2629	554	0.0618
2	18.9772	374	0.0507	4.8331	114	0.0424
3	13.8301	294	0.0470	2.0941	74	0.0283
4	4.9462	110	0.0450	0.5793	27	0.0215

Table 5.
Relative Risk Values, Average Mass and Average Euro NCAP Point Values.

Stars	R, severe and fatal injuries	R, all injuries	mrsc injury severity	mrsc, fatality or disability, without whiplash	Z, fatality or disability	Avg. mass (kg) severe (all)	Avg. Euro NCAP points
No class	0.99 ±0.07	1.05 ±0.03	0.057	0.062	0.059	1238 (1254)	
2	0.95 ±0.09	1.08 ±0.03	0.051	0.042	0.055	1261 (1258)	13
3	0.77 ±0.10	1.08 ±0.04	0.047	0.028	0.051	1427 (1427)	21
4	0.76 ±0.12	1.08 ±0.05	0.045	0.022	0.048	1329 (1310)	26
Total	0.880	1.035	0.054	0.054	0.056	1291 (1295)	

A correlation between relative risk of severe to fatal injuries and Euro NCAP score was found, see Figure 2. No correlation was found for relative risk of any (minor to fatal) injury. Correlations were found between Euro NCAP score and mrsc calculated both with and without AIS1 neck injuries included, see Figure 3. However, a stronger correlation was found without AIS1 neck injuries included, indicating that those injuries not are fully reflected in the Euro NCAP ratings. In Figure 4 a linear relationship can be seen for the relative risk of fatality or permanent disability, Z (R*mrsc), and the Euro NCAP scores. The estimated line fit in the figures indicates a difference in injury risk of 12% per star when looking at severe injures from police data. When looking at risk of fatal or disabling injuries as reflected by mrsc the difference is 7% per star. If the whiplash cases were excluded the risk of fatality or disability (mrsc) differs with 26% per star. The combined Folksam rating result shows a 7% difference in risk of fatality or disability per Euro NCAP star.

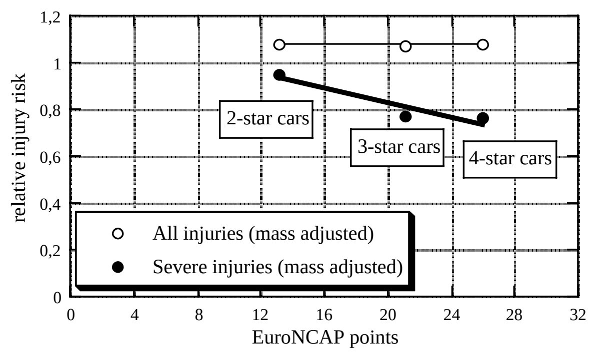

Figure 2. Relative injury risk after mass compensation to crash test conditions

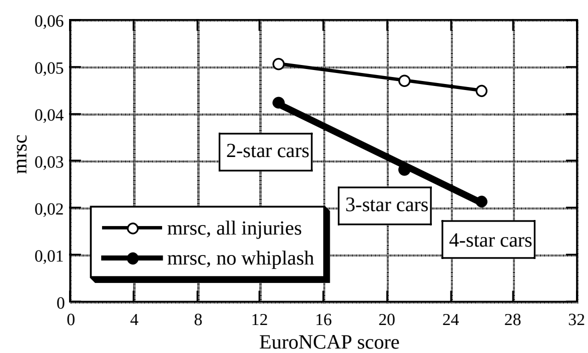

Figure 3. Risk of fatality or permanent disability, mrsc, versus Euro NCAP scores.

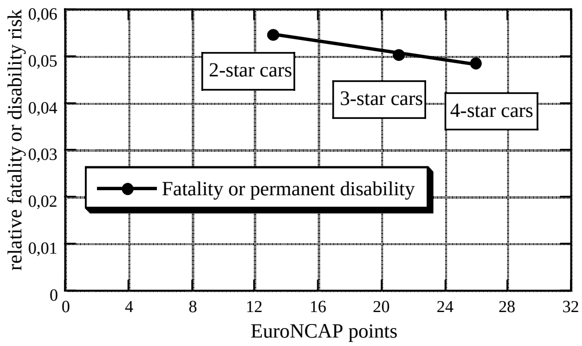

Figure 4. Relative risk of fatality or disability, Z, versus average Euro NCAP points.

DISCUSSION

This study shows a correlation between the real life injury outcome and the Euro NCAP results for cars. Similar results have been seen in other parts of the world (Newstead and Cameron 1998, Kahane et al 1994, O'Neill et al 1994).

Since the cars are grouped it does not show the potential correlation for an individual car model. It is instead mainly an evaluation of the Euro NCAP assessment principles. A car with generally good performance is found as a good car in real life rating. It is also probable that the good performance shows up in the laboratory during Euro NCAP testing. Euro NCAP is trying to replicate typical and frequent collision modes.

The Euro NCAP procedures do not try to predict the relative real life injury risks even if the test set-ups are typical. Instead the program is promoting best practice in a more general way.

A manufacturer can choose to build a car to perform well in the Euro NCAP tests without looking at the real life performance. This kind of sub-optimisation was not a risk in the beginning of the Euro NCAP test program. As time is passing and the importance of good test data is growing this can become a problem and must be monitored.

For this reason real life follow up is essential. Initiatives in a small country like Sweden will need very long exposure time before reliable data are available. A pan European co-operation around police accident records would be a very attractive companion to the Euro NCAP co-operation. By using data from a large proportion of Europe, analysis can be made after weeks instead of after years.

In theory a good score can be achieved in the paired comparison by being aggressive to the opponent vehicles. A study by Kullgren et al (2001) shows that the aggressivity is differing only to a minor degree when the aggressivity is analysed for cars with different Euro NCAP star scores.

Whiplash is a very important factor when risk of disability is analysed and the largest single reason for disabling injuries in Swedish traffic (Krafft 1998). Euro NCAP is today not addressing this injury in the testing. This is also obvious when studying the difference in correlation between mrsc and Euro NCAP points when AIS1 neck injuries were included and when they were not. However, by including some sort of testing attributing the capability to diminish the risk for whiplash, a major step towards safer cars can be taken.

This study shows a strong and consistent correlation between the Euro NCAP scores and the real life injury outcome. It is, however, based on a limited material and the research group will continue to monitor the vehicles under study to re-evaluate the findings.

This study is analysing the over-all risk levels. New methods have been developed to analyse the risk functions (Krafft et al 2000, Krafft et al 2001). Such studies on Euro NCAP scored cars would give more valuable information about how to further develop the crash test program.

CONCLUSIONS

- A correlation was found between Euro NCAP scoring and relative risk of serious and fatal injury (police data) as well as for the Folksam rating score (relative risk of fatality or permanent disability).
- No correlation between Euro NCAP scoring and relative risk of minor injuries was found.
- A stronger correlation between risks for serious consequences was found when AIS1 neck injuries were excluded (26 % difference in risk per Euro NCAP star) compared to when they were included (7 % difference in risk per star).
- The risk to sustain a police reported severe or fatal injury was found to diminish with 12 % per star.
- The risk to be fatally injured or sustaining a long-term disability was found to diminish with 7 % per star.

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