DEVELOPMENTS IN CAR CRASH SAFETY AND COMPARISONS BETWEEN RESULTS FROM EURO NCAP TESTS AND REAL-WORLD CRASHES

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ABSTRACT

Developments in car crash safety is preferably demonstrated by analyzing results from real-world crashes. Also results from crash tests can be used to show improvements in crash performance. Previous research has shown a positive development regarding safety performance. Studies from the early 2000 have shown that the European New Car Assessment Programme (Euro NCAP) consumer tests seem to predict the outcome in real-world crashes, although they consider only a part of all accident scenarios. In 2009 Euro NCAP added rear-end crash tests to the test protocol and since 2012 Euro NCAP has gradually further revised the rating protocol. It is therefore important to study developments in crash safety, and to evaluate how Euro NCAP test results correlate with real-world performance.

This study aimed to show developments in car crash safety in cars launched since the 1980s based on real-world data, and to present how Euro NCAP crash test results predict the outcome in real-world crashes.

Two-car crashes reported by the police (n=202 360) and occupant injuries reported by emergency care centers (n=57 863) to the Swedish Traffic Accident Data Acquisition database (STRADA) were analyzed. The cars were categorized in 5-year periods, according to the year of introduction. Developments were studied in terms of risk of any injury, risk of serious injury, risk of fatality, and risk of permanent medical impairment (PMI). Correlations with Euro NCAP test results were evaluated based on star levels for all categories of injury severity.

It was found that vehicle crashworthiness has improved steadily over the years studied. The proportion of serious injuries was found to be reduced, as well as the injury risk for all injury severities studied. In a comparison of car models launched 1980-1984 with those launched 2015-2018 the proportion of AIS 3+ injuries was 67% lower. Furthermore, the risk for serious and fatal injury was 58% (+/-17%) lower, the risk for fatal injury was 88% (+/-57%) lower, and the risk for PMI was 73% (+/-14%) lower. It was also shown that Euro NCAP crash test ratings mirror real world injury outcomes for all injury severities studied. Comparing 5-star with 2-star rated cars, the proportion of AIS 3+ injuries was 34% lower. Furthermore, the risk for serious and fatal injury was 22% (+/-4%) lower, the risk for fatal injury was 40% (+/-16%) lower, and the risk for PMI was 42% (+/-4%) lower.

Large improvement in crash safety was found, especially regarding the risk for fatal injuries and injuries leading to PMI. Euro NCAP star ratings were found to well mirror the risk for fatal injuries and injuries leading to PMI.

Consumer crash tests play an important role for the development in car safety. It is however important to continuously study how well these consumer tests predict the outcome in real-world crashes. Especially considering rating systems that reward the overall safety of a vehicle, such as the Euro NCAP.

INTRODUCTION

Studies have shown improvements in vehicle crashworthiness over time [1,2,3,4,5]. The improvements have been shown with crash test results and real-world crash data analyses. There are several crash test programs like European New Car Assessment Programme (Euro NCAP) that evaluate the safety level of new cars using laboratory crash tests (e.g.,: USNCAP, ANCAP, JNCAP, IIHS Tests). By the end of 2018, Euro NCAP had tested approximately 600 of the most popular car models in Europe since 1994. Details of the tests and the results are available at Euro NCAP's web site http://www.euroncap.com.

The Euro NCAP star rating is based on point scores from front and side impacts, as well as rear sled tests that evaluate the car seats (added 2009 to evaluate the risk of whiplash injury). Since 2012 the protocol has been revised regarding, e.g., point score and weighting. The intention of these scores is not necessarily to predict the real-world outcome (although this is inferred from the test results), but to indicate what is the best practice (benchmarking) for an individual car model and the fleet generally. However, it is clearly of interest to continuously evaluate how the crash test results correlate with real-world outcome.

Due to test limitations, laboratory crash tests can only provide a relatively limited evaluation of the overall safety level of a specific car model. Real-world performance gives a more comprehensive picture of the overall safety level, as it covers a variety of real-world crash configurations. Over the years, a number of international institutions have conducted retrospective statistical vehicle safety ratings using real-world crash databases, such as Transport Road Research Laboratories in the United Kingdom, Highway Loss Data Institute in the USA, Used Car Safety Ratings in Australia, VALT in Finland, and the Folksam Insurance Group (Folksam) in Sweden. Folksam has regularly published car safety ratings since the 1983. The Folksam system rates the relative risk that a driver sustains an injury that leads to fatality or permanent medical impairment (PMI), across all impact directions and locations [3].

Previous studies have presented the correlation between Euro NCAP results and injury risk based on real-world crashes [6,7,8]. In these studies, police assessments of injury outcome (killed, seriously injured, minor injuries or uninjured) were used as the injury descriptors. In Kullgren at al. [8] the risk for injuries leading to permanent medical impairment (PMI) was additionally shown. The study by Lie and Tingvall [7] showed a strong and consistent correlation when the risk for a fatal or serious injury was the dependent variable, although no correlation was found for minor injuries. A significant correlation between Euro NCAP scores and Folksam car model safety ratings was shown in 2001 [6], where 4-star rated Euro NCAP cars had a lower risk of serious injury than 2- and 3-star rated cars. The study by Kullgren et al. [8] showed that 5-star rated cars had a 27% lower risk of injuries leading to PMI compared to 2-star rated cars. The corresponding figure for fatal injury was 68%.

In Swedish road safety strategies fatal injuries and injuries leading to PMI are in focus. In 1997, the Swedish parliament decided on the Vision Zero strategy with the long-term vision of no fatal or serious injuries within the road transport system [9]. The definition of a serious injury is an injury leading to PMI. It is, therefore, important to follow the improvements in the passenger car fleet with respect to injury outcome in terms of both fatality and injuries leading to PMI.

The aim of this study was to evaluate developments in crash safety in cars launched since the 1980s based on real-world injury outcomes, and to evaluate how Euro NCAP crash test results predict the outcome in real-world crashes. Various severities of injury outcome were analyzed; the risk of any injury, serious and fatal injury, fatal injury, and the risk for injuries leading to PMI, as used in the Folksam car model safety ratings.

MATERIAL AND METHODS

The Swedish Traffic Accident Data Acquisition database (STRADA) was used that covers two data sets: car crashes reported by the police, and occupant injury data from emergency care centers [10]. Relative injury risk was calculated using paired comparisons from 202 360 two-car crashes with at least one injured front-seat occupant reported by the police. In these collisions the police classified the injuries as minor, serious or fatal. The accident years were 1994 to 2018. The risk for PMI was calculated from 57 863 injured front-seat occupants in car crashes between 2000 and 2018.

Two sets of analyses were made using the same method, one covering developments in crash safety since the early 80s, and the other evaluating the correlation between Euro NCAP star ratings and outcomes in real-world crashes. To mirror the developments in crash safety, the car models were categorized in 5-year periods according to year of introduction, beginning in 1980-84 and ending in 2014-2018. The year of introduction was chosen as a way to describe the year of design. The correlation between Euro NCAP crash test scores and real-world injury outcomes was made based on the star level. For both analyses four different injury levels were studied: any injury, serious and fatal injury, fatal injury and injury leading to PMI. The following sections describe how the relative risk using paired comparisons and the risk for PMI were calculated.

Calculating the Relative Injury Risk using Police Data

Relative injury risks were calculated using the paired comparison technique for two-car crashes. The method was initially developed by Evans [11], but has been further refined by Folksam for car-to-car collisions [12,13,8]. By studying two-car crashes in which both cars were involved in the same impact, the paired comparison method controls for variation in impact severity apart from the influence of car mass. The relative injury risk for a specific group of vehicles was calculated by comparing the injury outcome for that group with the injury outcome for the vehicles they collide with. In two-car crashes, mass differences can influence the relative injury risk, as they alter the impact severity distribution between the groups. This can be taken into account in the model and the influence of mass on the relative injury risk can be controlled for.

Another factor potentially influencing the results is aggressivity. Aggressivity is defined as the properties of a vehicle other than the mass that can influence the risk of injuries to the occupants of other vehicles (its structure and stiffness for instance can have such an effect). However, the influence of aggressivity on injury risk in paired comparisons has been shown to be much smaller than the influence of mass [12,14], thus aggressivity was not adjusted for in this analysis. All car-to-car crashes were included irrespective of crash type. It was assumed that the injuries among occupants in one car are independent from the injuries among occupants in the other car, given a particular impact severity.

Using the paired comparison method, crash outcomes in two-car crashes were grouped in four groups (see Table 1), where x_1 is the number of crashes causing injuries among occupants in both cars, x_2 is the number of crashes causing injuries in the case car only (but not in the other vehicle), x_3 is the number of injuries among occupants in the colliding vehicle only (but not in the case vehicle), x_4 reflects the situation that no one is injured in the crash (often little data are available here). In calculating the relative risk, x_4 is not used, as it does not add any important information.

Table 1.
Number of impacts with different combinations of injured drivers in Car 1 and Car 2

		Driver of Car 2		Total
		driver injured	driver not injured	
Driver of Car 1	driver injured	x_1	x_2	$x_1+ x_2$
	driver not injured	x_3	x_4	
Total		$x_1+ x_3$		

The unadjusted relative risk between the studied car or group of cars and its collision partners is calculated as the ratio between injuries in the studied car compared with the injuries in its collision partners (Equation 1). The collision partners are considered to be a sample of the whole car population, and therefore they provide the exposure basis that allows for comparisons across all case vehicles.

$$R=(x_1+x_2)/(x_1+x_3) \quad \text{(Equation 1)}$$

Compensation for Mass Differences

The influence of mass on injury outcome described by power model functions has been described extensively by Elvik et al. [15] and Krafft et al. [16]. If there are mass differences between the case vehicles and the vehicles that they collide with, both groups will be exposed to an impact severity different to that from when the two groups of vehicles have the same mass. If the case vehicle group is lighter than the other vehicle group, it will experience a higher impact severity compared to its collision partners (Impact Energy = mass * velocity^2). At the same time, the other heavier vehicles will experience a lower impact severity. The mass differential will therefore result in a benefit for one vehicle and a disadvantage for the other vehicle in a two-car crash. In order to allow for accurate comparisons and take into account the importance of mass for the case vehicles, the altered impact severity distribution for the cars they collide with must be compensated for. The adjusted relative injury risk is therefore expressed as in Equation 2. The power '*y*' in Equation 2 varies depending on the severity of the injury studied. Three mass adjustments were used depending on the injury severity; all injuries *y*=0.5, fatal and serious injury *y*=1.8, fatal injury *y*=3.5. The more severe the injury, the higher power '*y*', resulting in a steeper slope of the risk curve.

$$R_{mass\ adjusted} = (x_1+x_2)/(x_1+x_3) * M^y \qquad \text{(Equation 2)}$$

where M = (average case vehicle mass)/(average other vehicle mass)

Crash testing into a fixed barrier is equivalent to a crash into a car of the same mass, while the real-world outcome integrates mass as a factor that influences impact severity. In order to have a relevant comparison between crash test results and real-world performance, the influence of mass has to be fully adjusted for, considering both the case vehicle group and the group of cars that it collides with. The effect in the calculations will be that the power '*y*' in Equation 2 has to be doubled in the evaluation of Euro NCAP star ratings so that the pure safety design benefit can be isolated.

Compensation for the Year of the Crash

It has previously been found that the average safety level of vehicles in the fleet increases every year [13]. When using the paired comparison method with an accident sample including accidents that occurred several years back in time, the comparison between car models launched in different years will be influenced by this difference. By using the paired comparison method, it is possible to calculate the average decrease in injury risk of the whole car fleet. In [13,8] the average decrease in risk was found to be 1,5% per accident year as a linear relationship. For example, a car model involved in collisions 10 years back experienced an average collision partner that was 15% less safe than the average 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. Therefore, based on these results, compensations have been made to adjust for the year of impact according to Equation 3.

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

f = 0.015 (1.5% per year)

$Year_{actual}$ = latest accident year in the sample

$Year_j$ = accident year for the particular crash

The accident year compensation was made for each crash with a factor linked to the accident year. The adjusted relative injury risk was 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, Equation 4.

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

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

$$R_{adjusted} = (x_{1,\ adjusted}+x_{2,\ adjusted})/(x_1+x_3) * M^y \qquad \text{(Equation 5)}$$

95% confidence intervals (CI) were calculated for each risk value. The variance of the relative injury risk, R, was based on Gauss' approximation of variance for ratios.

Calculation of risk of permanent medical impairment

The risk of permanent medical impairment (RPMI) was used to measure the risk of long-term consequences [17]. The risk of sustaining a PMI of at least 10% according to the procedures used by Swedish insurance companies [18] was chosen (see Table 2). All injuries were classified according to the 2005 revision of the Abbreviated Injury Scale, AIS [19]. RPMI was based on the AIS scale, where an impairment risk has been calculated for each AIS level and body region [17].

Table 2.
Risk of permanent medical impairment in percent (from Malm et al. 2005).

Body region	1	2	3	4	5
Head	2.5	8	35	75	100
Cervical Spine	2.5	10	30	100	100
Face	0.4	6	60	60	n.a.
Upper Extremity	0.3	3	15	100	n.a.
Lower Extremity and Pelvis	0.0	3	10	40	100
Thorax	0.0	0	0	15	15
Thoracic Spine	0.0	7	20	100	100
Abdomen	0.0	0.0	5	5	5
Lumbar Spine	0.1	6	6	100	100
External (Skin) and Thermal Injuries	0.03	0.03	50	50	100

Table 3 shows the probabilities for permanent medical impairment for different body regions and AIS levels.

The RPMI for an occupant is calculated by multiplying the individual risks for each injury diagnose with the highest AIS level in each body region according to Equation 6, where p_i is the risk of sustaining a permanent medical impairment as a result of an injury of a certain AIS level to body region *i*. The body regions can be seen in Table 2.

$$RPMI = (1-\prod[1 - p_i]))$$ (Equation 6)

Based on all reported injuries for a specific group of cars an average risk that an injury would lead to a permanent medical impairment was calculated.

Calculation of Relative Risk of Permanent Medical Impairment

The overall relative risk of receiving an injury leading to fatality or permanent medical impairment is then obtained by combining the relative injury risk and injury severity measures (Equation 7). The method has been used in Folksam's car model safety ratings since the 1990s. The latest description of the rating procedure was published by [13]. For the relative risk of PMI the 95% confidence intervals (CI) were calculated using monte carlo iterations.

$$\text{Relative RPMI} = R_{adjusted} * RPMI$$ (Equation 7)

RESULTS

The proportion of serious injuries was found be reduced in modern cars. Comparing car models launched 1980-1984 with those launched 2015-2018 the proportion of AIS2+ injuries (AIS2 and more severe) was 41% lower, the proportion of AIS3+ injuries (AIS3 and more severe) was 67% lower and the proportion of AIS4+ injuries (AIS4 and more severe) was 81% lower (see Table 3).

The higher number of stars in Euro NCAP, the lower proportion of serious injuries. Comparing 5-star rated cars with 2-star rated ones, the proportion of AIS2+ injuries was 24% lower, the proportion of AIS 3+ injuries was 34% lower and the proportion of AIS4+ injuries was 66% lower (see Table 3).

Table 3.
Proportions of injuries with different AIS levels at different years of introduction and for car models with various Euro NCAP stars.

	AIS Level						
Year of launch	**1**	**2**	**3**	**4**	**5**	**6**	**Tot**
1980-1984	76,7%	13,6%	6,45%	1,71%	1,17%	0,45%	100%
1985-1989	75,9%	15,3%	5,84%	1,08%	1,32%	0,59%	100%
1990-1994	80,6%	12,8%	4,19%	1,25%	0,96%	0,14%	100%
1995-1999	82,2%	12,4%	3,66%	0,88%	0,61%	0,17%	100%
2000-2004	84,3%	11,1%	3,57%	0,58%	0,37%	0,10%	100%
2005-2009	85,9%	10,4%	3,00%	0,40%	0,25%	0,08%	100%
2010-2014	84,8%	11,3%	3,19%	0,22%	0,43%	0,14%	100%
2015-2018	86,1%	10,6%	2,58%	0,65%	0,00%	0,00%	100%
Euro NCAP stars	**1**	**2**	**3**	**4**	**5**	**6**	**Tot**
2	80,76%	13,24%	3,88%	1,05%	0,91%	0,17%	100%
3	82,31%	11,98%	4,10%	0,82%	0,69%	0,11%	100%
4	83,57%	11,74%	3,35%	0,72%	0,52%	0,11%	100%
5	85,36%	10,68%	3,22%	0,38%	0,27%	0,08%	100%
Total	83,74%	11,56%	3,45%	0,65%	0,49%	0,11%	100%

Comparing car models introduced in 1980-1984 with models introduced in 2015-2018, it was found that the risk of any injury was reduced by 40% (+/-4.5%), the risk of serious and fatal injury by 58% (+/-17%), the risk of fatal injury by 88% (+/-57%) and the risk of PMI was reduced by 73% (+/-14%) (see Table 4). Regarding the risk of fatality, the number of crashes was relatively low for the two later 5-year periods. When comparing cars introduced 1980-1984 with those introduced 2010-2014 the fatality risk was reduced by 69% (+/-15%).

Comparing 5-star with 2-star rated cars in Euro NCAP, it was found that the risk of any injury was reduced by 18% (+/-1%), the risk of serious and fatal injury by 22% (+/-4%), the risk of fatal injury by 40% (+/-16%) and the risk of PMI was reduced with 42% (+/-4%) (see Table 5).

Table 4.
Relative risk of any injury, fatal and serious injury, fatal injury and injury leading to PMI (grey column).

	Year of launch	n	mass case	mass other	x_1	x_2	x_3	R	R_{adj}	95% CI
All injuries	**1980-1984**	21018	1205	1326	8132	10274	5748	1,326	1,17	0,0108
	1985-1989	18209	1262	1341	6791	8503	5157	1,280	1,14	0,0119
	1990-1994	24980	1363	1383	8936	10294	7508	1,169	1,04	0,0108
	1995-1999	43318	1406	1424	14085	16217	13675	1,092	0,94	0,0087
	2000-2004	27290	1511	1464	7978	9278	9291	0,999	0,86	0,0115
	2005-2009	21271	1574	1498	5643	7004	7598	0,955	0,82	0,0133
	2010-2014	8340	1519	1524	2094	2732	2986	0,950	0,78	0,0216
	2015-2019	1297	1711	1557	323	367	525	0,814	0,70	0,0554
	Total	202360	1407	1409	64500	82204	64195	1,140	1,00	0,0039
Fatal and serious injuries	**1980-1984**	21018	1205	1326	998	1863	863	1,537	1,16	0,0293
	1985-1989	18209	1262	1341	812	1432	752	1,435	1,14	0,0322
	1990-1994	24980	1363	1383	890	1509	1161	1,169	0,98	0,0310
	1995-1999	43318	1406	1424	1214	2240	1969	1,085	0,89	0,0259
	2000-2004	27290	1511	1464	566	989	1236	0,863	0,75	0,0373
	2005-2009	21271	1574	1498	337	616	968	0,730	0,65	0,0462
	2010-2014	8340	1519	1524	151	264	347	0,833	0,66	0,0718
	2015-2019	1297	1711	1557	17	28	71	0,515	0,49	0,1941
	Total	202360	1407	1409	6207	11773	9100	1,175	1,00	0,0113
Fatal injuries	**1980-1984**	21018	1205	1326	24	295	96	2,655	1,56	0,0986
	1985-1989	18209	1262	1341	26	176	104	1,553	1,03	0,1169
	1990-1994	24980	1363	1383	24	170	136	1,211	0,93	0,1121
	1995-1999	43318	1406	1424	26	230	205	1,109	0,85	0,0966
	2000-2004	27290	1511	1464	11	81	134	0,635	0,56	0,1435
	2005-2009	21271	1574	1498	1	35	108	0,333	0,31	0,1858
	2010-2014	8340	1519	1524	4	25	44	0,614	0,48	0,2451
	2015-2019	1297	1711	1557	0	1	6	0,169	0,18	0,8879
	Total	202360	1407	1409	149	1361	1060	1,249	1,00	0,0396
	Year of launch	**n**	**mass case**	**mass other**	**R**	**R_{adj}**	**n RPMI**	**RPMI**	**Rel RPMI**	**95% CI**
Injuries leading to PMI	**1980-1984**	21018	1205	1326	1,326	1,17	3332	0,0489	0,054	0,0042
	1985-1989	18209	1262	1341	1,280	1,14	3701	0,0523	0,058	0,0040
	1990-1994	24980	1363	1383	1,169	1,04	8347	0,0401	0,041	0,0025
	1995-1999	43318	1406	1424	1,092	0,94	18229	0,0343	0,032	0,0016
	2000-2004	27290	1511	1464	0,999	0,86	11569	0,0299	0,026	0,0017
	2005-2009	21271	1574	1498	0,955	0,82	8524	0,0260	0,022	0,0020
	2010-2014	8340	1519	1524	0,950	0,78	2761	0,0275	0,021	0,0034
	2015-2019	1297	1711	1557	0,814	0,70	310	0,0221	0,016	0,0080
	Total	202360	1407	1409	1,140	1,00	57863	0,0378	0,038	0,0009

Table 5.
Relative risk of any injury, fatal and serious injury, fatal injury and injury leading to PMI (grey column).

	Euro NCAP stars	n	mass case	mass other	x_1	x_2	x_3	R	R adj	95% CI
All injuries	2	10450	1313	1381	3737	4464	3014	1,21	1,03	0,01659
	3	13437	1348	1425	4241	5337	4099	1,15	0,95	0,01558
	4	43160	1432	1445	13323	15464	13967	1,05	0,90	0,00894
	5	35419	1565	1492	9531	11801	12439	0,97	0,85	0,01029
	Total	102466	1455	1452	30832	37066	33519	1,00	0,91	0,00582
Fatal+serious	2	10450	1313	1381	393	691	441	1,30	0,96	0,04700
	3	13437	1348	1425	357	779	562	1,24	0,87	0,04653
	4	43160	1432	1445	991	1858	1921	0,98	0,80	0,02827
	5	35419	1565	1492	640	1074	1603	0,76	0,75	0,03476
	Total	102466	1455	1452	2381	4402	4527	1,00	0,84	0,01829
Fatal injuries	2	10450	1313	1381	14	79	52	1,41	0,84	0,16910
	3	13437	1348	1425	5	71	57	1,23	0,69	0,18366
	4	43160	1432	1445	24	182	203	0,91	0,70	0,10381
	5	35419	1565	1492	7	75	181	0,44	0,50	0,13640
	Total	102466	1455	1452	50	407	493	1,00	0,70	0,06857
Injuries with PMI	**Year of launch**	**n**	**mass case**	**mass other**	**R**	**R adj**	**n RPMI**	**rpmi**	**Rel RPMI**	**95% CI**
	2	10450	1313	1381	1,21	1,03	3534	0,0374	0,0386	0,00358
	3	13437	1348	1425	1,15	0,95	5392	0,0334	0,0316	0,00292
	4	43160	1432	1445	1,05	0,90	18590	0,0323	0,0290	0,00150
	5	35419	1565	1492	0,97	0,85	13152	0,0266	0,0226	0,00148
	Total	102466	1455	1452	1,00	0,91	40668	0,0310	0,0281	0,00101

DISCUSSION

These results clearly show that vehicle crashworthiness has improved since the early 80s. Such results have also been found in other studies [1,2,3,4,5]. They also show that the improvements are larger for more severe injuries. The largest improvement was found for fatal injuries, but a large improvement was also found for injuries leading to permanent medical impairment. In Sweden, which has adopted the Vision Zero approach, this is very positive, because the vision includes both fatal and serious injuries, and serious injury is in Sweden defined as an injury leading to any kind of permanent medical impairment.

The study also demonstrated that 5-star rated cars offer superior safety performance over 2-star rated cars for all types of injury severity studied. A consistent and positive correlation was found between real-world injury outcomes and Euro NCAP test results. Similar results have been seen in other parts of the world and in other studies [20,6,7,21,8]. The findings reported here though controlled for differences in vehicle mass and the year of impact using the two-car paired comparison method. Furthermore, of the previous studies only Kullgren et al. [8] was able to contrast differences in injury outcome in terms of relative risk of permanent medical impairment.

It should be stressed that as the cars were grouped by their star level, and that these results say nothing about the potential correlation for an individual car model. It is instead an evaluation of the Euro NCAP assessment principles with statistical findings from real-world crash data. While not shown here, though, a car with generally good performance in Euro NCAP was found to perform well in real-world crashes, in coherence with what has been reported previously.

The estimates in this study are based on star bands. It is important to stress that the average point performance (basis for star rating) is not necessarily in the center of the star band [7]. Furthermore the Euro NCAP test protocol has been revised in 2009 to also mirror vehicle seat performance in rear-end crashes. Whiplash injuries are very important in terms of the risk of permanent medical impairment. Swedish evidence shows that they constitute the vast majority of injuries leading to permanent medical impairment [22]. Furthermore, since 2013 it has been revised every year to also include driver assistant technologies, for example. It is important to conduct further studies to evaluate how these revisions of the test protocol correlates with real-world outcome. The Euro NCAP procedure does not try to predict the relative real-world injury risks. Instead the program is aimed at promoting the best practice in a more general way. Despite this, it is reassuring that there is good correlation between the crash test results and real-world performance, confirming Euro NCAP's relevance to vehicle crashworthiness.

It is important, however, for other studies to confirm the correlation between consumer crash test results and performance in real-world crashes to ensure that the outcome and interpretation of consumer crash tests are relevant to vehicle safety. Sweden is a small country and these findings are only possible with long exposure times before reliable data are available. A pan European co-operation using police accident records from a number of different countries would allow faster comparisons in just a few years. Studies that examine ways of undertaking such analyses would be extremely useful.

While not central to this analysis, a good score of a particular car model can be achieved in the paired comparison by being aggressive to its collision partner. While an earlier study by Kullgren et al. [14] showed that aggressivity was less important than vehicle mass, it would nevertheless be beneficial if aggressivity could be controlled for in the way that mass and age were in the current study. This would further enhance similarities between real world crash ratings and Euro NCAP scores.

The risk figures may also 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, although high rated cars that normally have seat belt reminders might have a slightly higher seat belt use. This should, on the other hand, be included in modern cars to improve safety for the occupants.

It is important to stress that while the weight of new cars have gone up substantially in recent years, the results of this study confirm that improved crashworthiness has been the primary factor in enhanced vehicle safety, rather than the increase in mass. For an individual consumer though, the benefit of choosing a new car with greater mass might be larger than for the overall population, as would choosing a car with a higher Euro NCAP score or superior result in the Folksam car model safety rating.

CONCLUSIONS

It was found that vehicle crashworthiness has steadily improved over the vehicle years studied. The proportion of serious injuries was found to be reduced and also the injury risk for all injury severities studied. When comparing car models launched 1980-1984 with those launched 2015-2018, the proportion of AIS 3+ injuries was 67% lower. Furthermore, the risk of serious and fatal injury was found to be 58% (+/-17%) lower, the risk of fatal injury 88% (+/-57%) lower, and the risk of PMI was 73% (+/-14%) lower.

It was also shown that Euro NCAP crash test ratings mirror real-world injury outcomes for all injury severities studied. Comparing 5-star rated cars with 2-star rated ones, the proportion of AIS 3+ injuries was 34% lower. Furthermore, the risk of serious and fatal injury was 22% (+/-4%) lower, the risk of fatal injury was 40% (+/-16%) lower, and the risk of PMI was 42% (+/-4%) lower.

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