EVALUATION OF SEAT PERFORMANCE CRITERIA FOR REAR-END IMPACT TESTING

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ABSTRACT

The BioRID II has been recommended to be used in future legislative dynamic rear-end impact seat performance tests. Recommended injury criteria and assessment reference values to be used with the dummy is however still pending. This is mainly due to the incomplete understanding of the injury site and mechanisms responsible for the symptoms presented after such impacts. This lack of biomechanical data limits the possibility to evaluate any proposed injury criteria and associated reference values.

The aim with this study is to address these limitations by comparing crash test dummy parameter values from performed sled tests with real-life accident data. The results are expected to indicate the injury predictability of the complete sled test method, which includes performance criteria, the use of generic sled acceleration pulse, the use of the BioRID II and its current positioning procedure, etc.

Real-life injury risk was calculated for groups with similar seat designs from data provided by Folksam. By introducing grouped data, i.e. by dividing applicable data into groups with similar characteristics, the reliability of the insurance data increased while the dummy measurements remained constant. Two different injury risks were used in this study; those that had documented symptoms for more than 1 month and those that were classified as a permanent impairment as the consequence of a rear-end impact. The injury risks for the groups were compared to single crash test dummy parameter values from sled tests performed with a BioRID II in 16 kph *medium* Euro-NCAP pulse. In the comparison, 12 seat groups were compared with 6665 insurance cases (range from 94 to 1575 cases/group). Regression coefficients (R^2) were calculated.

The analysis of groups with similar seat design provided the most reliable results. The analysis showed that NIC, upper neck shear force, vertical head acceleration and lower neck bending moment were the parameters that best predicted the risk of developing permanent impairment given that the occupant had initial symptoms following a rear-end impact. Similarly, NIC, vertical head acceleration and lower neck moment were parameters that best predicted the risk of short term (> 1 month) symptoms. These results are supported by recent studies.

INTRODUCTION

A number of studies have compared rear-end crash test results with real life performance in the past with the main target to either recommend new or evaluate existing test methods used to assess risk of symptoms following a rear-end impact. The main focus in many of these studies has been on the preferred choice of criteria. The choice of dummy, handling and instrumentation of the dummy, crash pulse used and so forth has a large effect of the outcome of such study and needs to be taken into account.

One of the first studies to combine dummy and real life data was that by Heitplatz et al. (2003). The study found that lower neck moment recorded in crash test with dummies with rigid or semi flexible spines such as the Hybrid III and RID 2, respectively, in OEM seats correlated with insurance claims data for these seats (data from Gesamtverband der Deutschen Versicherungswirtshaft, also referred to as GDV). The study approach adopted introduces some limitations on the generalization of their results, only three seat models, although these were seats with good, average and poor performance, were included for which the number of crashes per seat model were 79, 152 and 96 respectively. This reduces the generalization of the results to be valid for other types of seats than those tested. In case a normal distributed is adopted the statistical significance of the results can be estimated. It then appears that there was no significant difference (on 95% level) in injury risk, for any duration, between the seats included in the study.

Using whiplash insurance injury claims data from two cars only, the *Saab 900* and *Saab 9-3,* along with corresponding rear-end impact sled tests Kuppa (2004) developed an injury risk curve based on head-to-torso-rotation of the Hybrid III dummy. The author conducted a logistic regression, using only the two data sets of head-to-torso rotation and insurance injury claims, to establish the injury risk curve. Kuppa also suggested, based on data by Voo et al. (2003) that for the Hybrid III the peak head-to-torso rotations highly correlate to peak lower neck moments, which earlier have been suggested to correlate to injury risk in rear end impacts (Prasad et al. 1997). Despite incomplete control for vehicle acceleration, and the fact that only data for two seat models were included in the study by Kuppa in 2004, Kuppa et al. (2005) used the results to suggest a whiplash injury criterion along with dynamic test with the Hybrid III dummy. The Hybrid III dummy head rotation angle criterion later became the main criterion for the dynamic test option in the current GTR-7.

The injury reducing effect of the *WHIPS s*eat, which are seats installed in *Volvo* cars from 1998, on real-life performance have been shown to be significant for both initial and long term symptoms (Farmer et al. 2003, Jakobsson and Norin 2005, Kullgren and Krafft 2010). The former study showed that the short and long term symptoms were reduced in the *WHIPS* seat by 33% and 53%, respectively, compared to a traditional *Volvo* seat. Andersson and Boström (2006) presented results from rear-end impact tests using these two versions of the *Volvo* seats and a Hybrid III dummy. They found very small difference in peak head-to-torso rotation and that none of the seats had acceptable performance according to the dynamic injury criteria suggested by Kuppa et al. (2005). Those findings were in contradiction to the studies on injury reduction and suggest that the dynamic test procedure suggested by Kuppa et al. 2005 may not adequately assess risk of symptoms in rear end impacts.

Linder et al. (2004) reconstructed 25 rear-end impacts with known 1 month duration of neck injury symptoms. In the reconstructions the BioRID II was placed in the same type of seat as in the impacted vehicle and the vehicle accelerations were reproduced. The results from the study provided a link between real-world neck injury symptoms and average dummy readings and provided indications of thresholds for a 10% risk of neck injury symptoms persisting for more than 1 month. The parameters suggested to be studied further were:

- The Neck injury Criterion (NIC, Boström et al., 1996) that takes the horizontal relative acceleration and velocity between the head and the neck into account.
- Neck Injury Criteria (N_{km}, Schmitt et al., 2002) that takes the combination of shear forces and flexion/extension moments at the upper region of the neck into consideration.
- Maximum upper neck forces.
- Maximum horizontal T1 acceleration.

Cappon et al. (2005) correlated crash test parameters using the RID3D and the BioRID II dummies with German accident statistics. Only squared correlation coefficients of the linear relation between dummy measurements and acute injury risk was used. In one of the two parts of this study, injury risk for each vehicle model was estimated using insurance data in combination with the number of vehicles in the region for the particular model. The approach used gave a crude estimate of real life risk. The dummy parameters included in the study were NIC, N_{km}, Neck injury Criteria (N_{ij}), Lower Neck Load Criteria (LNL), upper neck shear and compression/tension forces, lower neck shear forces and bending moment, and average x-acceleration of the lower neck-thorax junction and the sled. The study found an acceptable correlation of the lower neck shear force measured in a RID^{3D} with their accident data. The study also found a reasonable correlation between NIC as measured in the BioRID and real life risk.

Kullgren et al. (2003) compared symptom duration of 110 occupants that had been involved in rear-end impacts with parameter values obtained in reconstructions of the impacts using a mathematical model of the BioRID and seats. The study showed that NIC and N_{km} clearly predicted a neck injury with high accuracy; both initial as well as symptoms duration of more than 1 month. The study also presented data that show that, when using a mathematical model of the BioRID, head-to-torso rotation does not correlate with neck injury symptoms. A general concern and weakness of the study was the use of mathematical models of seats and a prototype of BioRID II.

Boström and Kullgren (2007) compared real-life performance of car seats with BioRID II test results for Saab, Volvo and Toyota seats before and after the anti-whiplash systems were introduced. The authors included NIC, N_{km}, upper neck shear and compression loads, rebound and T1accelaration/head-to-contact time in the analysis. They found a positive correlation between good real-life performance and performance in dynamic tests, but did not suggest criteria to be used in future seat evaluations. Nevertheless, in their comparisons of dummy results in tests with seats with and without anti-whiplash systems, NIC and upper neck shear loads were found to have been reduced more than the other parameters. The reduction of these two parameters could have contributed to a large degree to the reduced injury risk as observed in the seats with anti-whiplash systems.

Farmer et al. (2008) studied the relationship between seat ratings schemes used by Insurance Institute of Highway Safety (IIHS) and their partner International Insurance Whiplash Protection Group (IIWPG) and the rating schemes used by Swedish Road Administration (SRA) to real-world neck injury rates due to rear-end impacts. The main finding was that seat systems that perform better in dynamic sled tests have lower risk of neck injury than seats that rate poor. This was especially clear for long term injuries (>3 months injury claim). However, the study also concluded that further research is needed in the field of injury criteria, injury threshold and test design to improve the predictability of real-world neck injuries by mechanical tests of seat systems.

Zuby and Farmer (2008) studied the correlation between 26 BioRID II test parameters and seat design injury rates. In total 55 different seat designs were included in the analysis for which more than 30 claims had been filed. The study found that none of the 26 studied parameters was highly correlated with neck injury rates. For some parameters, a higher parameter value even correlated with a lower injury risk. It was identified that variables other than sled test variables, such as state group, crash damage, vehicle price etc, could have reduced the expected correlations.

Ono et al. 2009 used mathematical modelling to reconstructed volunteer and cadaver experiments and rear-end impact accidents with known initial, short and long term risk of neck injury symptoms and known crash pulse and seat characteristics. In total 20 cases were reconstructed for which the velocity change during the rear-end impact ranged from 9 km/h to 28 km/h. The results reveal that displacements between the cervical vertebrae may be responsible for the persistent neck symptoms following rear-end impacts. The study suggested adopting the NIC and neck forces to assess the risk of these injuries. WAD2+ injury risk curves were suggested for NIC values and neck forces (upper M_y, lower F_x and F_z).

In the past, EEVC WG12 (Biomechanics) has evaluated a number of low severity rear impact dummies and associated injury criteria and injury assessment reference values to be used in the WG20 (Whiplash) test procedure (Hynd et al. 2007 and Hynd and Carrol 2008). During the preparation of that report, it was concluded that a thorough understanding of the injury site and mechanisms responsible for the symptoms presented after rear-end collisions and injury threshold were unavailable. The reports concluded that this lack of biomechanical data presents challenges for the possibility to evaluate the proposed injury criteria and suggested reference values. The EEVC working groups have thereafter suggested comparing real-life data with crash test dummy parameter values and injury criteria values from sled tests to evaluate the applicability of crash test methods targeted at assessing the risk of whiplash injury in rear-end impacts.

Objective

The objective of this study is to assess the applicability of seat performance criteria, i.e. crash test dummy parameter values and injury criteria values, for rear-end impact seat-system testing. This will be done by finding a correlation between whiplash injury risks, as calculated from real real-life insurance data, and crash test dummy values. Parameters and injury criteria that correlate with injury risk will be recommended for additional studies in which injury risk functions and reference values are developed.

To serve this objective crash test results with injury claims rates for groups of seats in which the seat design was the same will be compared. An example of such a group would be all cars from Volvo in which only WHIPS seats of the same version were installed.

Such comparisons would be similar to the approach adopted by Heitplatz et al. (2003), Linder et al. (2004), Cappon et al. (2005) and Zuby and Farmer (2008) but the comparison will be carried using grouped data based on seat design and the real-life accident data will be more robust. Further, permanent impairment data have been suggested to be more robust than data on acute symptoms and the use of permanent impairment data, as in the current study, may lead to more reliable results. In addition, Folksam is using insurance data where a uniform compensation policy was used throughout the collection region and collection period, and possible compensation is limited to reimbursement of medical cost and loss of income. This policy will reduce the influence of variables other than collision and car related variables.

MATERIAL AND METHODS

Insurance data

Whiplash injury claims from crashes that occurred between 1995 and 2008 at +/-30 degree from straight rear-end and reported to the insurance company Folksam were used in this study. In total 13 958 reported injuries were included. Insurance claims were used to verify if the reported whiplash injuries led to long-term symptoms. Occupants that had a medical record of injury and claimed compensation for injury symptoms for more than 1 month were defined as *symptoms >1 month* (Equation 4). These claims entitle the occupant to a payment of 2000 SEK (about 210 €). The *symptoms >1 month* category includes those that possibly recovered after 1 month or later and those that later were classified as sustaining a permanent impairment. In total 2 665 occupants that reported whiplash injury sustained symptoms for more than one month.

$$> 1\ month = \frac{\#\ occupants\ with\ symptoms\ for > 1\ month}{\#\ occupants\ with\ reported\ initial\ symptoms} \quad (1)$$

The second injury category is occupants with whiplash symptoms classified as *permanent* (Equation 5). This classification is primarily set after approximately 1 year but it usually takes longer time to set a final degree of impairment. In rare cases it can even take up to three years. Due to the three-year period only data from accidents that occurred between 1995 and 2008 could be used. In total 1543 occupants with permanent whiplash symptoms were included.

$$\begin{matrix} permanent \\ impairment \end{matrix} = \frac{\#\ occupants\ with\ permanent\ syptoms}{\#\ occupants\ with\ reported\ initial\ symptoms} \quad (2)$$

Accuracy of data

All the variables included in this model can be considered as random variables with some associated distribution. Because we do not know the real distribution of the variables, all variables are assumed to be normally distributed. The injury risk utilised in the study is calculated by computing the proportion p_j of recorded crashes leading to a whiplash injury for each seat model j. If N_j crashes are recorded, an estimation of the standard deviation for each calculated proportion is

$$SE_j = \sqrt{\frac{p_j(1-p_j)}{N_j}} \quad (3)$$

The standard error (the estimate of the standard deviation) can be utilised when calculating confidence intervals for the injury risks. If xj is the measured value for a given parameter, the confidence interval for a 68% confidence is ($x_j - SE_j$ and $x_j + SE_j$).

For the sled-test parameter values, we cannot compute a standard error because we do not have access to the required number of tests. However, there will still be an uncertainty in the measure of these parameters. In the following sections, we will only plot the confidence intervals for the injury risk and not for the measures parameters.

Grouping based on seat characteristics

To obtain a reliable statistical result regarding the injury risks, insurance claim data were grouped. Different types of groups can be used e.g. based on risk level and principle seat design. Here we have chosen to group seat and corresponding insurance data for seats that have the same design characteristics. By doing this we reduce the scatter in dummy readings that may appear if the groups were based according to risk level. This scatter may be due to the inclusion of seats with different injury reduction measures, which also influence the sled test parameters, and when included in the same group increases parameter value scatter.

The groups analyzed were *Volvo, Saab, Toyota, VW-group (Audi, Seat, WV and Skoda), Opel, Ford and Mercedes* (Table 1). For most of these groups both traditional seats and anti-whiplash seat designs from the same car producer were included. Heavy cars and light cars were excluded in this analysis to reduce the differences in average vehicle weight between the different groups (Table1). Gender distribution was not a reason for exclusion or inclusion in the different groups. The resulting proportion of females in each group is presented in Table 1. Table 2 lists the conditions in the particular sled test used to represent the different groups.

Table 1.
Groups defined in this study; n is the number of insurance cases included in each the group; f is the proportion of females in each group; m is the average vehicle weight of the cars included in the group. The range is the year the car model was produced.

Ford with STD, n=163, f=57%, m=1397 kg	
Focus	99-05
Galaxy	96-05
Mercedes with STD, n=227, f=44%, m=1469 kg	
A-class	98-04
C-class	93-01
E-class	96-01
Opel with STD, n=410, f=52%, m=1363 kg	
Astra	98-04
Meriva	03-
Vectra	96-98
Zafira	99-04
Opel with RHR, n=125, f=49%, m=1402 kg	
Signum	03-04
Tigra	04-
Vectra	99-01
Vectra	02-08
Saab with STD, n=968, f=49%, m=1462 kg	
Saab 900	94-98
Saab 9000	85-97
Saab with SAHR, n=279, f=51%, m=1597 kg	
Saab 9-3	98-02
Saab 9-5	98-09
Toyota with STD, n=735, f=61%, m=1335 kg	
Avensis	98-02
Camry	97-01
Corolla	98-02
Picnic	97-01
Previa	00-05
RAV4	95-99
Starlet	97-99
Toyota with WIL , n=976, f=64% m=1309 kg	
Auris	07-
Avensis	03-08
Avensis Verso	01-05
Camry	01-03
Corolla	02-07
Corolla Verso	02-03
Corolla Verso	04-10
Prius	00-03
Prius	04-09
Rav4	00-04
Rav4	05-
Yaris and Yaris Verso	99-05
Yaris	05-
Volvo with STD, n=921, f=50%, m=1496 kg	
S40/V40	96-99
850	91-97
V70	97-00
Volvo with WHIPS, n=192, f=50%, m=1524 kg	
S40/V40	00-04
S40/V50	04-
V70	00-06
S60	01-99
S80	98-06
VW group with STD, n=1575, f=51%, m=1414 kg	
Audi A3	96-03
Audi A4	95-00
Audi A6	95-97
Audi A6	98-05
Seat Toledo/Leon	99-04
Skoda Octavia	97-04
Skoda Fabia	00-
VW Bora	99-04
VW Golf	98-04
VW Passat	97-05
VW Polo	02-
VW group with RHR, n=94, f=59%, m=1475 kg	
Audi A3	03-04
Audi A3	05-06
Audi A4	01-06
Audi A6	05-06
Seat Ibiza	03-
Skoda Octavia	05-
VW Touran	03-
VW Golf/Jetta	04-
VW Passat	05-

All criteria/parameter values used in the analysis were taken from one single seat test from each seat group. In an additional analysis also a median criteria/parameter value for each seat group was also analysed. The former is referred to as representative values and the latter median values.

For the representative values, the seat test that provided the largest number of parameter values that were close to the median values for the studied parameter and appeared to provide reasonable values, including head-to-head restraint distance, was selected and used. In case the most representative test did not provide data for all parameters, e.g. a test that was selected and used in the analysis did not provide proper film data, the most representative parameter value among the available test for a particular parameter was used in the analysis.

The analysis using median values were included to evaluate if the selection of representative values could have introduced the results, i.e. the linear regression r^2-values. Such r^2-values were also calculated for all criteria/parameters using the median parameter value of the included test in each seat group (Table 5).

Sled test data

All sled tests that were suitable and available for this study were conducted at Autoliv in Vårgårda, Sweden, during the period 2004 to 2006 and at Thatcham, UK, between 2003 and 2006. Table 2 provides information on the selected sled tests used in the analysis of grouped data. Additional information on the sled tests conditions and insurance data can be found in Davidsson and Kullgren (2011). The sled tests carried out at Autoliv were performed according to the Swedish Road Administration (SRA) and Folksam seat performance rating procedure which was harmonized with the International Insurance Whiplash Protection Group (IIWPG) rating procedure used by Thatcham. In brief, a H-point machine including a Head Restraint Measuring Device (HRMD) was used to adjust seatback angle and determine H-point position. Thereafter the H-point tool was removed and a BioRID II, build level e or g, was installed in the seat.

The main differences between the included test series were the make and build level of the Head Restraint Measuring Device (HRMD), H-point tool and the BioRID II (Table 2).

The sled acceleration used was the median risk - median frequency pulse (Krafft et al. 2005, Krafft et al. 2002), with a velocity change of 16 kph, an average acceleration of 5.5 g and with a triangular shape with 10 g peak. This pulse is the same as one of the pulses currently used in Euro-NCAP.

The injury parameters measured and calculated were those previously suggested by SRA/Folksam and IIWPG (Table 3). In addition, head relative T1 displacement data expressed in a coordinate system that was attached to the T1 unit were retrieved from film analysis.

The tested seats were mainly new except seats from Volvo V70 97-00, SAAB 900 94-97 and SAAB 9-3 98-02 which were used.

Linear regression

A linear regression model was adopted to provide ideas about how the parameters were correlated with the injury risk. To have a measure of how good the fit of the model a coefficient of determination, r^2-values, were calculated. The r^2-value represents the proportion of common variation in the two variables, i.e. the parameter value and the injury risk. In addition a significance level could be calculated for each correlation and will be a measure of the reliability of the correlation. However, the number samples in this study are small and for that reason significance level is not calculated.

The regression line is determined by minimizing the sum of squares of distances of data points from this line. Therefore single outliers have a profound influence on the slope of the regression line and on the value of the correlation coefficient r^2. For this reason data was plotted and outliers identified.

Table 2.
Car model, type of seat system, year the seat was tested, test facility, BioRID build level, H-point tool, initial horizontal head-to-head-restraint distance (back set).

Groups	Model	Prod. year	WAD mitigation system[1]	Year tested	Test facility	BioRID II version	H-point tool[2]	Backset (mm)
Ford	Focus I	99-06	None	2004	Autoliv	E	TS	55
Mercedes	C-class	93-01	None	2004	Thatcham	G	AA	55
Opel	Astra	98-04	None	2004	Thatcham	G	AA	72
	Vectra	02-08	RHR	2004	Thatcham	G	AA	75
SAAB	900	94-97	None	2006	Autoliv	G	AA	30
	9-5	98-09	SAHR	2004	Autoliv	E	AA	40
Toyota	Corolla	98-02	None	2005	Autoliv	E	AA	65
	Corolla Versio	04-10	WIL	2005	Autoliv	E	AA	95
Volvo	V70	97-00	None	2006	Autoliv	G	AA	74
	V/S70	00-06	WHIPS	2004	Thatcham	G	AA	32
VW	Seat Altea	04-	None	2004	Thatcham	G	AA	65
	Audi A6	05-06	RHR	2005	Autoliv	E	TS	55

Note 1	None	No system is activated before or during the impact
	RHR	Reactive Head Restraints
	SAHR	Saab Active Head Restraint, version 1 and 2
	WHIPS	Whiplash Protection System
	WIL	Whiplash Injury Lessening
Note 2	TS refers to TechnoSports, Inc., USA and AA refers to Automotive Accessories, Ltd., UK	

Table 3
Parameters included in the analysis in this study:

Maximum Neck Injury Criteria (NIC)
Maximum Neck Force Criteria (N_{km})
Maximum Lower Neck Loads Criteria (LNL)
Maximum Head x- and z-acceleration
Maximum C4 x- and z-acceleration
Maximum T1 x- and z-acceleration
Maximum T8 x- and z-acceleration
Maximum L1 x- and z-acceleration
Maximum Pelvis x- and z-acceleration
Maximum and minimum Upper Neck Loads (U. N. F_x, F_z and M_y, before head contact stop)
Maximum and minimum Lower Neck Loads (L. N. F_x, F_z and M_y, before head contact stop)
Maximum Occipital condyle rel. T1 x- and z-displacement in the T1 frame (OC-x and OC-z, respectively)
Maximum Head relative T1 angular displacement (Neck extension)
Head Contact Time (HCT)
Maximum Head Rebound Velocity (HRV)

RESULTS

Linear regression for neck injury criteria and other parameters measured in a representative dummy test were performed on the grouped data. The correlations between the parameters and the two categories of injury risks are presented in Table 4 and 5 and plots of the injury risks versus the various parameters are displayed in Figure 1-3. In addition, the correlations between the median parameter values for each group and the two categories of injury risks are listed in Table 5. Only parameters with correlation coefficients above 0.3 are listed Table 4 and 5 in addition to those included in the current Euro-NCAP protocol.

As can be seen in Table 4, the permanent impairment risk and symptoms longer than one month both showed correlations with both the maximum NIC and Upper Neck Shear Force. The Lower Neck Flexion Moment and L1 x-acceleration and N_{km} showed a limited correlation. Notably, HCT and HRV showed small or only limited correlation with the injury risk.

Table 4.
Correlation (r^2) between the peak value of the included parameters and the injury risks. Based on analysis of data from one representative sled test per seat group.

Parameter	Permanent Imp.	Symp. < 1 month
NIC	0,75	0,78
U. N. F_x (head r.w.)	0,53	0,64
L. N. M_y (flexion)	0,37	0,63
L1 x-acceleration	0,34	0,28
N_{km}	0,32	0,39
Neck extension	0,31	0,21
T8 z-acc.	0,31	0,19
L. N. M_y (extension)	0,26	0,29
HCT	0,20	0,37
Head z-acc.	0,20	0,22
LNL	0,16	0,44
T1 x-acc.	0,11	0,34
U. N. F_z (tension)	0,08	0,29
L. N. F_x (head r.w.)	0,08	0,33
OC x-disp.	0,03	0,03
Head x-acc.	0,03	0,21
HRV	0,09	0,19

A mathematical method to be used to select the most representative test, when there was more than one test available for each seat group, was not developed or used. The selection of the most representative test, as explained in the Materials and Methods section, could have introduced some bias. Therefore a complimentary analysis was carried out using the median value for each parameter of all available seat tests data for each seat group (Table 5). As can be seen in Table 5, a few additional parameters were found to correlate to injury risk. The additional parameters Head and T1 vertical accelerations and Lower Neck Flexion Moment appear to be more convincing than in the analysis of representative data. One other change, when using median values for each seat group, were that Head Contact Time appeared to correlate even less compared to when representative test were used.

Table 5.
Correlation (r^2) between the peak value of the included parameters and the injury risks. Based on an analysis in which the median values for each parameter from each seat group was used.

Parameter	Permanent Imp.	Symp. < 1 month
NIC	0,70	0,74
Head z-acc.	0,61	0,73
U. N. Fx (head r.w.)	0,57	0,68
T8 z-acc.	0,52	0,42
L. N. My (flexion)	0,47	0,69
Neck extension	0,46	0,33
L1 x-acceleration	0,44	0,45
OC x-disp.	0,44	0,44
N_{km}	0,37	0,47
L. N. My (extension)	0,31	0,26
LNL	0,23	0,53
U. N. Fz (tension)	0,17	0,41
L. N. Fx (head r.w.)	0,15	0,40
HRV	0,14	0,25
Head x-acc.	0,11	0,32
T1 x-acc.	0,09	0,32
HCT	0,00	0,04

In Figure 1-3, lines have been drawn between data points for groups for which grouped data were available for seats with and without ant-whiplash systems. These lines were included to enable a comparison between parameter values and injury risk with a reduce influence of factors such chassis design characteristics of the make, car owner characteristics specific for the make, and partly vehicle mass.

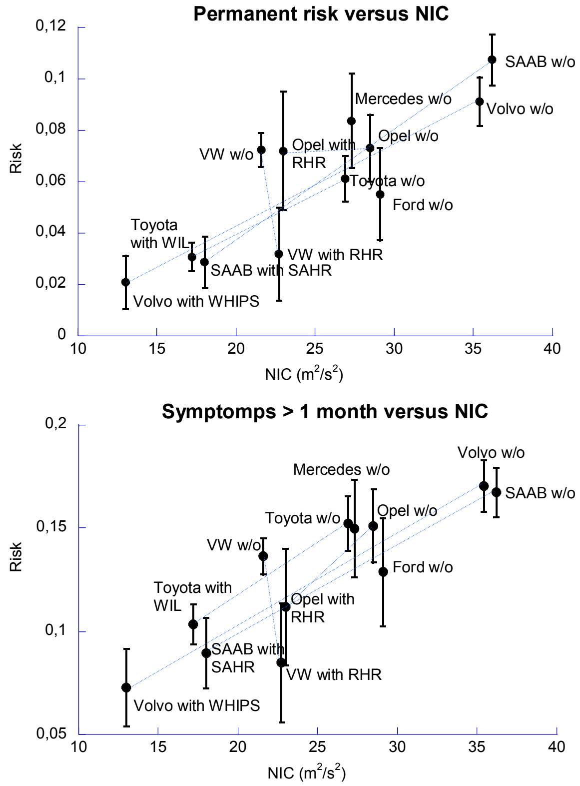


Figure 1. Permanent impairment group and > 1 month symptom limit risks versus the maximum of the parameter NIC for twelve different groups (average ±1 SE).

By studying Figure 1, it appears that all car producers have reduced the NIC values considerably when anti-whiplash systems were introduced with the exception of the VW group. For the VW group the reduction in injury risk, may have been achieved by a combination of the reduction of other parameters/criteria values. Despite these differences between the seat groups, it appears that seats designs that produces a NIC lower than 25 m^2/s^2 will result in a risk that is less than approximately 6% to develop permanent neck symptoms following a rear-end with initial symptoms (Figure 1).

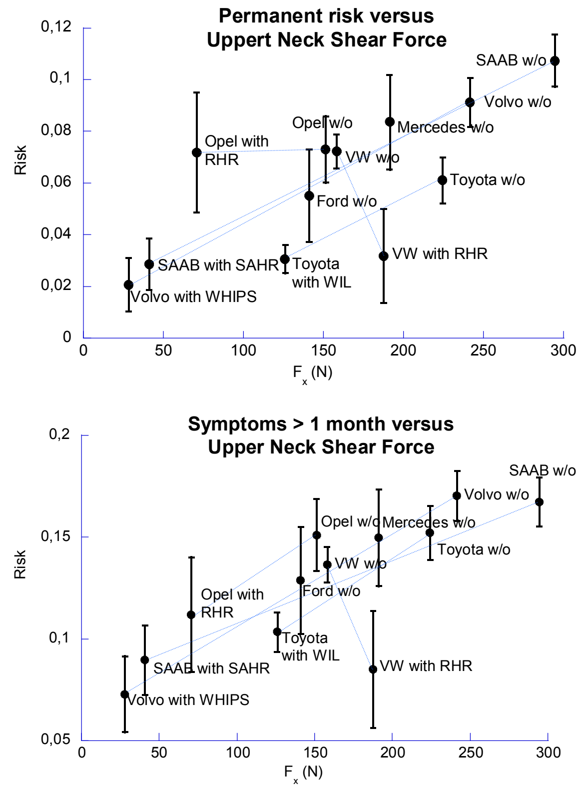
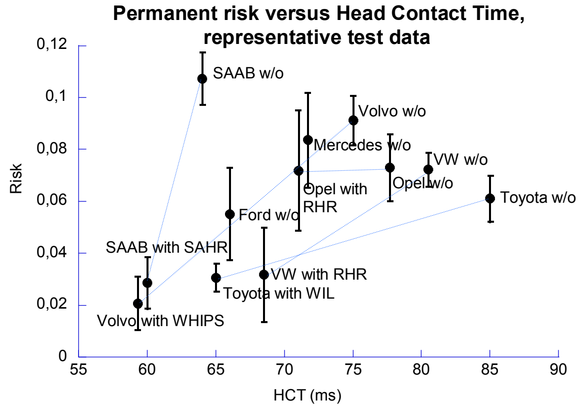


Figure 2. Permanent impairment group and > 1 month symptom limit risks versus the maximum of the parameter Upper Neck Shear Force (Fx) for twelve different groups (average ±1 SE).

The similar situation appears to be the case for the Upper Neck Shear Force produced when the head moves rearward relative to the upper neck (Figure 2). For this parameter it appears that a 125 N force or less will result in a risk of 6% or less.

There seem to be no relation between Head Contact Time and risk of permanent impairment or symptoms lasting more than one month (Figure 3) following an accident with acute symptoms. The



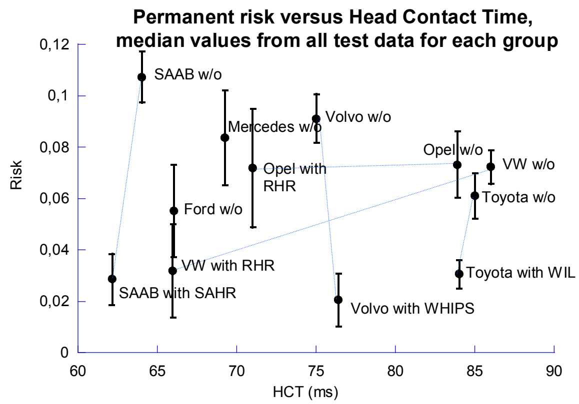


Figure 3. Risk of permanent impairment versus the Head Contact Time for twelve groups (average ±1 SE). HCT values as presented when a single representative test (top) and median (bottom) were used in the analysis.

DISCUSSION

By pooling seat models without anti-whiplash seat designs in one group, and seat models with anti-whiplash seat designs in another group (for each car manufacturer), it was expected that a better statistical analysis can be made. The injury risks estimate was found to be more reliable than using individual seat data and the vehicle related parameters less influential compared to the use of groups based on similar risk. The reason for the latter was partly due to the inclusion of vehicles with similar mass and vehicle body characteristics for each car manufacturer.

The car manufacturers included in the analysis claim that their systems were designed to reduce head-to-head restraint distance and/or yield/absorb energy in a force controlled manner. Using the insurance data, we can conclude that the anti-whiplash seat designs reduce the risk of sustaining whiplash injuries. *Saab* showed a reduction of approximately 73%, *Toyota* a reduction of approximately 50% and *Volvo* a reduction of approximately 77% of permanent impairment. Opel have managed to cut the risk of short term injury but it does not appear to have changed the risk of permanent impairment when introducing RHR. By analyzing the figures, one can note that:

- Saab has managed to lower the value for all available parameters by introducing SAHR except Head Contact Time (HCT).
- Toyota managed to lower the value for all available parameters except T1, Upper neck F_z and Head Rebound velocity (HRV).
- Volvo decreased all parameter, including OC-x, except HCT. The HCT remained almost constant when comparing before and after the introduction of WHIPS.
- VW group has managed to reduce some of the upper and lower neck forces, LNL and the HCT while many parameters have remained rather constant e.g. the NIC or HRV.
- Opel has managed to reduce NIC, N_{km}, LNL and some of the neck load parameters.

In summary the analysis of these five car makes showed that a reduction of NIC, Upper Neck Shear Force (F_x) and Lower Neck Compression (increasing the -F_z) appear to reduce the injury risk (Figure 1-2). Further, there is no apparent correlation between HCT and injury risks (Figure 3).

For evaluation of the robustness of the analysis, two other groups were included in the analysis. These were Ford and Mercedes and were not fitted with anti-whiplash systems. The regression analysis, including these seats (Table 4) provided that NIC, Upper Neck Shear Force (F_x), and Lower Neck Flexion Moment, predicted the risk of permanent as well as the risk of symptoms for more than one month following a rear-end impact. These findings are in line with other studies on this matter which suggested that NIC and Upper Neck Shear Forces are suitable for assessing seat performance in rear-end impacts (Kullgren and Boström 2007).

Ono et al. (2009) also came to similar conclusions as in this study, but using a different approach than in our study. Ono and co-authors reconstructed a number of rear-end impacts using a detailed mathematical model of the human and combining the results obtained with results obtained in previous studies in which volunteers were used. The study by Ono et al (2009) also suggested the NIC and neck loads, including upper neck M_y, lower F_x and lower F_z, should be used in the evaluation of seat performance in rear-end impacts.

The findings of this study are, however, not in line with the study by Zuby and Farmer (2008) who found no correlation between dummy measurements and claims rate. The differences between these two studies are difficult to identify and only tentative explanations have been identified. Firstly, in the study by Zuby and Farmer (2008) the number of insurance cases for most of the car models was high. But for some car models included in their analysis, only 30 cases of rear-end impacts were available in the insurance database. For these models the estimated injury risk was uncertain since the outcome of a single accident highly influence the numbers used in the correlation study. Secondly, there are probably differences in the insurance data between the study by Zuby and Farmer and the current study. These differences could be associated with differences in injury coding, differences in compensation for property damage, compensation for injury claims, social welfare system, etc. Thirdly, in the current study the most representative sled test data set was used in the analysis. This data set was selected from a number of available sled tests that had been conducted at either Autoliv or Thatcham (Davidsson and Kullgren 2011). The use of representative data sets in this study means that the analysis was carried out using more robust dummy data than in the study by Zuby and Framer. These three differences may be small but can in combination with the methods used to assess correlations, in these two studies, which both are known to be very sensitive to outliers, provide very different level of correlation and as such, explain the differences between the two studies.

As mentioned in the previous paragraph, this study used measurements from the most representative test from each seat group. Such a selection could contribute to the fact that we could identify correlations whereas studies in the past could not. This selection approach was adopted since a study of this kind requires, for a proper comparison between real life data and sled test data, that seats used in the sled tests are representative of the seats installed in the cars involved in rear-end collisions and included in the used insurance data base. This does not mean that multiple tests with identical seats should be introduced in future test programs. We rather adopted this approach because it is likely that there were differences between the tested seats in each seat group. By introducing this selection we facilitated inclusion of the more representative test in the correlation analysis. The differences between the seats within one single seat group could be due to introductions of small differences in design over the time span. These differences could be due to foam thickness, foam properties, fabric selection, etc. In addition to these reasons, other sources for variability were present during the testing and which justify the used selection approach. The largest source was most likely the introduced by the lack of H-point and HRMD tool calibration routines at the time of testing. In this study we used test data which was generated using three different H-point tools which most likely could explain the differences in measured and used head-to-head restraint distances. A second source was the use of two different BioRID II build levels. The differences between these two build levels were mainly the position of the spine in relation to the exterior of the flesh. By selecting the most representative test data set for each seat group the problem using "old" seat test data could be reduced.

The sled test data used in this study was generated in different laboratories using almost identical test conditions. Over the time a few dissimilarities in the test conditions have been identified and could explain some of the observed variability (Davidsson and Kullgren 2011). This variability introduces a noise and it is expected that a better correlation would be obtained if all seat tests were carried out using the latest test protocol. However, using the latest test protocol and dummy build level may not produce more consistent results since some of the seat models included are no longer in production. This assumption is based on the hypothesis that the seat characteristics are more important than complying with the state of the art seating procedure to produce representative seat test results. The analysis carried out by Davidsson and Kullgren (2011, appendix 3) also suggested that the inconsistency level was limited for most of the parameters but was rather inflated for others, such as head rebound velocity, upper neck moments and a few of the lower neck loads, and that this inconsistency could possibly explain the limited correlations found in this study for some of the parameters.

It is unlikely that only one single parameter fully could assess risk of injury to all the different injury mechanisms that have been suggested in a rear-end impact. The results in this study support that several parameters should preferably be used.

One can discuss if the risks used in the current study were based on true injuries or not and if they were a direct result of the car crashes. Firstly, occupants with permanent symptoms were defined as those that have a classified degree of impairment by physicians. The same procedure is used for all Swedish insurance companies. The whole procedure setting a final degree of impairment may take up to three years after the crash. Symptoms >1 month is defined as those that has obtained a medical record of their symptoms. In these records the injury has most often not been verified as it most often was just a question of pain following a rear-end collision. Secondly, if the injuries/symptoms would only occur randomly or be influenced by factors not linked to the car crash, you would not see any differences in risk between car models. Despite the fact that there might be problems with quality of the risk estimate, large differences in risk can be shown. If the quality would be further improved it is expected that even larger differences in risk would be seen.

The inclusion of both males and females in the insurance data may introduce noise because females load the seat in real life accident differently from the males and this may also be reflected in the seat tests. In case we could compare dummy data and male data separately we expect a better correlation between dummy sled test data and injury risk. Unfortunately the number of cases in the insurance data does not allow comparing dummy data with insurance data for males only.

The injury risk has been reported to be higher for females than for males. In this study we did not compensate for differences in gender distribution between the different seat groups. However, for a majority of the included car groups in this study the numbers of insurance cases were almost identical for males and females (Table 1). For the groups denoted Toyota with standard seat, Toyota with WIL seat and VW group with RHR seat, the proportions of the insurance case in which the occupant was a female was 61%, 64% and 59%, respectively. For these three groups the estimated risks, which were used in the analysis in this study, were most likely somewhat higher than the risk if the female proportion were 50%. The effect of this shift in risk for these three groups on the presented results is expected to be small.

A perfect correlation was not expected since only a single generic crash pulse was included in the analysis. This generic pulse has been found to be representative of the crashes in the insurance data. But adding other pulses and adopting a statistical model that allow a combination of results from a number of crash pulses may provide a better correlation and further justify the obtained results.

Vehicle mass have been shown to influence injury risk in rear-end accidents. Risk of permanent injury is lower in heavy vehicles as compared to lighter vehicles according to the insurance data (Figure 4). Despite this difference, sled tests are generally carried out using generic crash pulses. In this study only data from a single generic crash pulse was included. Since not the actual vehicle specific pulse was used, including very light and very heavy vehicles could smokescreen any possible correlation between parameter values and injury risk. Therefore, car models with very low or high vehicle mass were excluded in the analysis.

Despite the exclusions of light and heavy vehicles, there were still differences in vehicle mass between the studied seat groups; seats with anti-whiplash systems were in general slightly heavier than those without (Figure 4). It could be hypothesised that the observed injury risk reductions were completely due to increased vehicle mass and not due to installation of anti whiplash systems or improved seat designs. However, the observed risk reductions were mainly due to design changes, as shown in Figure 4, and the observed correlations were therefore a function of measured dummy parameter values rather than just by coincidence.

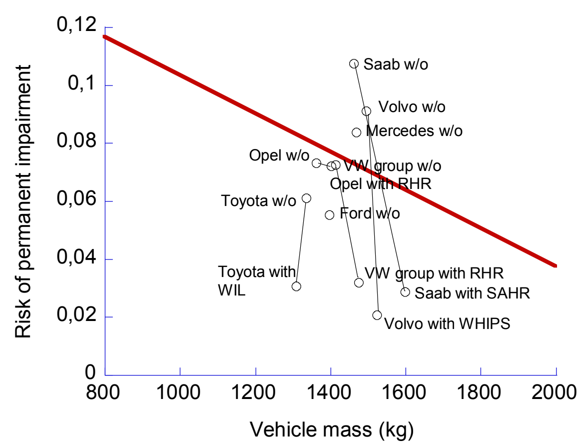


Figure 4: Risk of permanent impairment versus vehicle mass.

For the seat model groups the average risk and weighted representative vehicle mass was calculated and used. For the average car data, the tick line, was generated using all data available in the Folksam data base (n=13958). Note that the average risk also includs anti-whiplash seats and that during the sampling period such systems were more common in larger and thereby heavier cars than small and light cars.

CONCLUSION

The main finding in this study was that the neck injury criterion, NIC, and upper neck shear force appear to be the best predictors of long term and short term neck injury following a rear-end impact. Head vertical acceleration and Lower neck bending moment (flexion) was also found to correlate to some degree to the injury risks.

Another finding was that grouped insurance data based on characteristics of the seat system was useful since it reduced the uncertainties in the estimated risks.

We also conclude that other parameters may be shown to be useful when a larger data set becomes available and when new seat tests are carried out using the latest test routines, a calibrated H-point machine and the newest dummy version.

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