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Evaluation of Seat Performance Criteria for Future Rear-end Impact Testing

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Evaluation of Seat Performance Criteria for Future Rear-end Impact Testing

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Summary

In the past, EEVC WG12 and 20 have evaluated rear-impact dummies and reviewed associated injury criteria and assessment reference values for seat performance evaluations (Hynd et al. 2007 and Hynd and Carroll 2008). The BioRID II was 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 are 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 of 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 a generic sled acceleration pulse, the use of the BioRID II and its current positioning procedure.

Real-life injury risk was calculated for 32 individual car models and for 17 groups of similar seat designs from data provided by Folksam. When grouped data was introduced, i.e. by dividing applicable data into groups with similar seat designs, the reliability of the insurance data was raised, while the dummy measurements remained constant. The number of insurance cases ranges from 32 to 1023 for individual car models and from 132 to 1023 for groups with similar seat designs. Regression coefficients (r^2) were calculated and the data presented graphically. Two types of injury risks were used in this study: those that had documented symptoms for more than one month and those that were classified as a permanent medical impairment as the consequence of a rear-end impact. These injury risks were compared to crash test dummy parameter values from sled tests performed with a BioRID II in 16 km/h *medium* Euro-NCAP pulse.

It was found that the analysis of groups of similar seat designs provided the most reliable results. Analysing individual data clearly showed that the insurance cases were too low per seat model to be used in an evaluation of seat performance criteria. In conclusion, the results obtained in the analysis of individual data did not invalidate the results obtained using grouped datasets. This conclusion was based on the observation that the correlations found in the analysis of grouped datasets could exist also for individual car model data.

When comparing groups of seats, the analysis showed that the Neck Injury Criterion (NIC), the maximum rearward Occipital Condyle x-displacements in a coordinate system that moves with the T1 and the maximum L1 x-acceleration were the parameters that best predicted the risk of developing permanent medical impairment, and symptoms for more than one month given that the occupant had initial symptoms following a rear-end impact. The maximum rearward head rel. T1 angular displacement, T1 x-acceleration and upper neck shear load (U.N.F_x, head r.w.) were parameters that also could predict the risk of permanent medical impairment and symptoms for more than one month. These results are supported by recent studies.

In comparison with a previous report, this study includes additional seat tests data which allowed additional data points to be included in the regression analysis. An expanded insurance claim database, about three times more insurance claims, was included in the analysis, which made the results more reliable. The insurance data was compensated for differences in the definitions of short term symptoms

and permanent medical impairment during the accident data sampling period. This reduced errors that could have been introduced by the market share change during the sampling period for the various vehicle models included in this study.

In the future, a logistic regression including error estimation that covers all available insurance and test data should be carried out. The advantage of such an analysis would be that data could be included independent of the number of accidents. Another advantage of this is that a larger proportion of the data would be from tests and real life accidents with newer cars than those included in this study. Therefore the recommended parameters to use in seat evaluations would be more suitable for modern car seat systems.

Acronyms

AA	Automotive Accessories
BioRID	Biofidelic Rear-end Impact Dummy
EEVC WG12	European Enhanced Vehicle-safety Committee, Working Group 12 Crash Dummies
GTR-7	Global Technical Regulation No 7 on Head Restraints; an informal group under the Working Party on Passive Safety (GRSP), Vehicle Regulations, Transport, United Nations Economic Commission for Europe
HCT	Head Contact Time
Head r.w.	Head rear ward
H-point	Hip-point
HRMD	Head Restraint Measuring Device
HRV	Head Rebound Velocity relative the sled in the x-direction
IIHS	Insurance Institute of Highway Safety
IIWPG	International Insurance Whiplash Protection Group
LNL	Lower Neck Loads index
L.N.F	Lower neck loads
NIC	Neck Injury Criterion
N_{ij}	Neck Injury Criterion: combination of tension/compression and flexion/extension moments
N_{km}	Neck Load Criterion: combination of shear and flexion/extension moments
OC rel. T1 disp.	Occipital Condyle displacement in the T1-frame
r^2	Coefficient of determination
RHR	Reactive Head Restraints
RID	Rear-end Impact Dummy
SAHR	Saab Active Head Restraint
SRA	Swedish Road Administration
SE	Standard Error
STD	Standard head restraint, i.e. traditional seat without anti-whiplash design

TS	TechnoSports
U.N.F	Upper neck loads
WHIPS	Whiplash Protection System
WIL	Whiplash Injury Lessening

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1 Introduction

Several studies have already compared rear-end crash test results with real life performance with the main goals either to recommend new or to evaluate existing test methods used to assess the risk of symptoms following a rear-end impact. Since factors such as choice of dummy, handling and instrumentation of the dummy, and crash pulse used have major effect of the outcome of these studies, they must be taken into account.

One of the first studies to combine dummy and real life data was that by Heitplatz et al. (2003). They found that the lower neck moment recorded in crash tests with dummies, with rigid or semi flexible spines such as the Hybrid III dummy and RID 2, respectively, placed in OEM seats, correlated with insurance claims for these seats (data from Gesamtverband der Deutschen Versicherungswirtshaft). The study approach adopted introduces some limitations on the generalization of their results; only three seat models, selected for good, average and poor performance, were included; the number of crashes per seat model was 79, 152 and 96, respectively. This means the generalization of the results has less validity for seat types other than those tested. If a normal distribution 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, of any duration, between the seats included in the study.

Kuppa (2004) used whiplash insurance injury claims from two cars only, the *Saab 900* and *Saab 9-3*, along with corresponding rear-end impact sled tests to develop an injury risk curve based on head-to-torso-rotation of the Hybrid III dummy. He conducted a logistic regression, using only the two datasets 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 correlate very well to peak lower neck moments; this had already been suggested to correlate to injury risk in rear-end impacts (Prasad et al. 1997). Despite incomplete control of vehicle acceleration, and the fact that data for only 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 with dynamic testing of 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 Global Technical Regulation for Head restraints (GTR-7).

The injury reducing effect of the Whiplash Protection System *(WHIPS)*, 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 first study showed that both the short and long term symptoms were reduced in the *WHIPS* seat by 33% and 53%, respectively, compared with 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 little difference in peak head-to-torso rotation and that neither of the seats had acceptable performance according to the dynamic injury criteria suggested by Kuppa et al. (2005). Those findings contradicted 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 one month duration of neck injury symptoms. In the reconstructions, the BioRID II was placed in the same type of seat as in the vehicle struck and the vehicle accelerations were reproduced. The results of the study provided a link between real-world neck injury symptoms and average dummy readings. It also provided indications of thresholds for a 10% risk of neck injury symptoms persisting for more than one month. The parameters suggested for further study 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;
- The neck injury criterion N_{km} (Schmitt et al., 2002) that takes the combination of shear loads and flexion/extension moments at the upper region of the neck into consideration;
- Maximum upper neck loads; and
- Maximum T1 x-acceleration.

Cappon et al. (2005) correlated crash test parameters by 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 were used. In one of the two parts of this study, the injury risk of each vehicle model was estimated using insurance claims in combination with the number of vehicles registered in the data collecting 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}, N_{ij}, LNL, upper and lower neck loads, and neck-thorax junction and sled average x-accelerations. Cappon et al. found an acceptable correlation of the lower neck shear load, measured in a RID^{3D}, with their accident data. They also found a reasonable correlation between the NIC as measured in the BioRID II and real life risk.

Kullgren et al. (2003) compared the symptom duration of 110 occupants, who had been involved in rear-end impacts, with parameter values obtained in reconstructions of the impacts by using a mathematical model of the BioRID II and seats. They showed that the NIC and N_{km} clearly predicted a neck injury with high accuracy; for both initial symptoms and duration of more than one month. The study also presented data showing that, when using a mathematical model of the BioRID II, 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 the BioRID II.

Boström and Kullgren (2007) compared the 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 the NIC, N_{km}, upper neck loads, rebound velocity, T1 accelerations and head-to-contact time in their analysis. They found a positive correlation between good real-life performance and performance in dynamic tests; however they did not suggest criteria to be used in future seat evaluations. Nevertheless, in their comparisons of dummy results in tests with seats both with and without anti-whiplash systems, the 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 largely to the reduced injury risk observed in the seats with anti-whiplash systems.

Farmer et al. (2008) investigated the relationship between the 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 the better performing seat systems in dynamic sled tests have a 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 fields 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 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 mentioned that variables other than sled test variables, such as insurance state group, crash damage, or vehicle price, could have reduced the expected correlations.

Ono et al. 2009 used mathematical modelling to reconstruct volunteer, cadaver experiments and real life rear-end impact accidents with known initial, short and long term risk of neck injury symptoms, as well as 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 loads to assess the risk of these injuries. The Whiplash Associated Disorder category 2 and higher (WAD2+) injury risk curves were suggested for NIC values and neck loads (Upper M_y, Lower F_x and F_z).

Davidsson and Kullgren published an EEVC report (2011a) and an ESV paper (2011b) in which the risk of short term symptoms and the risk of permanent medical impairment when the car occupant had acute symptoms following a rear-end impact was correlated with BioRID II measurements were studied. They used a limited number of seats models. This report is an update of those two earlier works. The differences between the study approach used and results obtained are given in the discussion section.

In the past, EEVC WG12 (Biomechanics) have evaluated several low severity rear impact dummies, 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, the mechanisms responsible for the symptoms presented after rear-end impacts, and the injury threshold were not available. The reports concluded that this lack of biomechanical data makes it difficult to evaluate the proposed injury criteria or injury thresholds. Consequently, the EEVC working groups suggest comparing real-life data with crash test dummy parameter values and injury criteria values from sled tests in order to evaluate the applicability of crash test methods to assess the risk of whiplash injury in rear-end impacts.

2 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 is done by finding a correlation between whiplash injury risks, as calculated from real-life insurance data, and crash test dummy values. Parameters and injury criteria that correlate with injury risk will then be recommended for additional studies in which injury risk functions and reference values can be developed.

To meet this objective, crash test results will be compared with injury claims rates for groups of seats of the same seat design. An example of such a group would be all cars from Volvo in which only WHIPS seats of the same version were installed. In addition, crash test results are also compared with injury claims rates for individual car models (Appendix 1).

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). However, the comparison in this study report is made with grouped data based on seat design and the real-life accident data is more robust. Moreover, it has been suggested that permanent medical impairment data is more robust than data on acute symptoms; the use of permanent medical impairment data, as in the present study, may lead to more reliable results. In addition, the Swedish compensation system applied by Folksam provides for a uniform compensation policy that is applied throughout the collection region; compensation is limited to reimbursement of medical cost and loss of income. This policy reduces the influence of variables other than collision and car related variables.

3 Material and methods

3.1 Insurance data

Whiplash injury claims from crashes that occurred between 1998 and 2011, at +/-30 degrees from straight rear-end and in the driver position only, as reported to the insurance company Folksam were used in this study. In total 22 045 drivers that reported initial injuries were included in the data base of which 7 453 were included in this study. Insurance claims were used to verify whether the reported whiplash injuries led to long-term symptoms.

Medical expertise in Sweden has gradually been classifying whiplash associated symptoms more restrictively. Given that for vehicles with identical introduction year the risk of long term symptoms, given that you have initial symptoms, should not change over the sampling period a reduction factor in classification of symptoms can be calculated. This reduction in the likelihood of classifying an injury as a permanent medical impairment appears to be linear over the sampling period, from 1998 to 2011, and was found to be 15% per year for a large number of vehicle models and for a representative distribution of males and females. In the same way, the reduction in classification of those with symptoms lasting for longer than one month was found to be 7% per year. These changes were used to compensate the insurance data used in this study to be valid for the year 2010. By making an adjustment for accident year for each crash injury, the outcomes from all of the cars could be compared with each other.

Occupants who had a medical record of injury and claimed compensation for injury symptoms lasting longer than one month were defined as *symptoms >1 month* (Equation 1). These claims entitle the occupant to a payment of 2000 SEK (about 210 €). Data for both males and females were included in the analysis. Due to differences in injury classification over the sampling period, all data was compensated to that of the year 2010. In total, 2455 occupants (compensated) who reported whiplash injury sustained symptoms >1 month were included. The symptoms >1 month category includes both those who possibly recovered after one month or later and those later classified as sustaining a permanent impairment.

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

The second injury category is occupants with whiplash symptoms classified as having a *permanent medical impairment* (Equation 2). This classification is set primarily after approximately one year, but it usually takes a longer time to determine a final degree of permanent medical impairment. In rare cases, this can take even up to three years. Consequently, only data from accidents that occurred between 1998 and 2010 could be used. In total, 855 occupants (compensated to the year 2010) with permanent medical impairment were included.

$$Permanent\ medical\ impairment = \frac{\#\ persons\ with\ injuries\ classified\ as\ permanent}{\#\ initial\ symptoms\ reported} \quad (2)$$

3.2 Accuracy of data

All the variables included in this model can be considered 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 used 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:

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

The standard error (the estimate of the standard deviation) can be used when calculating confidence intervals for the injury risks. If x_j is the measured value for a given parameter, the confidence interval for 68% 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 (see Appendix 2). However, there will still be an uncertainty in these parameters. In the following sections, we will only plot the confidence intervals for the injury risk and not for the parameter values.

3.3 Grouping based on seat design

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 or principle of the seat design. Here we have chosen to group seat and corresponding insurance data for seats that have the similar design. 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 influences the sled test parameters, and when such seats are included in the same group, the parameter value scatter will be increased.

The seat groups analysed were Audi, *Ford*, *Hyundai*, *Mercedes*, *Opel*, *Peugeot*, *Saab*, *Skoda*, *Seat*, *Toyota*, *Volvo* and *VW* (Table 1). For some of these groups, traditional seats and anti-whiplash seat designs, older and newer models, and small, medium and large size groups from the same car producer were included. Very heavy cars and light cars were excluded from this analysis to reduce the differences in average vehicle weight between the groups (Table1). Gender distribution was not a reason for exclusion or inclusion in the groups. The resulting proportion of females in each group is given in Table 1. Table 2 lists the conditions in the particular sled test used to represent each group.

All criteria/parameter values used in the analysis were taken from one single seat test from each seat group. The following seat test data selection criteria were applied:

1. Thatcham data was selected. This was based on the availability of an H-point machine with an Head Restraint Measuring Device (HRMD) that had dimensions very close to the standard tool used today.
2. When multiple tests from Thatcham were available for a seat group, the number of accidents with initial symptoms was used to select the test to be used in further analysis. The test that had the largest number of entries in the insurance database for the group was used.
3. When more than one dataset was available for a particular vehicle model from Thatcham, or when the dataset first selected provided results that were deemed to be an outlier, when compare with the median values within the particular vehicle model, the dataset that was closest to the median values was chosen.

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

Ford with STD, n = 357, f = 52%, m = 1325 kg	
Focus	99-05
Mondeo	93-99
Hyundai with STD, n = 216, f = 67%, m = 1167 kg	
Accent	99-06
Atos	04-03
Atos	98-03
Elantra	04-
Elantra	96-03
Getz	03-
Matrix	01-
Santa Fe	00-05
Sonata	01-05
Mercedes with STD, n = 193, f = 44%, m = 1493 kg	
A-class	98-04
C-class	93-01
E-class	96-01
CLK	02-06
E-class	02-06
Opel with STD, n = 537, f = 51%, m = 1441 kg	
Astra	98-04
Corsa	00-06
Meriva	03-
Omega	94-03
Vectra	89-95
Vectra	96-98
Zafira	99-04
Peugeot with STD, n = 304, f = 57%, m = 1310 kg	
206	98-05
306	93-01
307	01-
406	96-04
605	90-98
607	99-
307	01-
Saab with STD older, n = 608, f = 49%, m = 1438 kg	
Saab 900	88-93
Saab 9000	85-97
Saab with STD newer, n = 144, f = 50%, m = 1453 kg	
Saab 900	94-98
Saab with SAHR, n=285, f=51%, m=1593 kg	
Saab 9-3	98-02
Saab 9-5	98-09
Saab 9-3	03-11
Toyota with STD, n = 556, f = 59%, m = 1345 kg	
Avensis	98-02
Camry	97-01
Corolla	98-02
Picnic	97-01
Previa	00-05
RAV4	95-99
Starlet	97-99
Lexus IS 200/300	05-
Toyota with WIL, n = 957, f = 63% m = 1314 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 old, n = 1023, f = 49%, m = 1023 kg	
700	82-98
900	91-98
Volvo with STD, n = 640, f = 50%, m = 1495 kg	
S40/V40	96-99
850	91-97
V70	97-00
Volvo with WHIPS, n = 248, f = 46%, m = 1533 kg	
C30	06-
S40/V40	00-03
S40/V50	04-
S60	01-99
V70	00-06
V70	07-
S80	98-06
S80	07-
VW group with STD small, n = 181, f = 64%, m = 1165 kg	
Seat Ibiza/Cordoba	99-02
Seat Ibiza	03-
Skoda Fabia	00-
VW Polo	02-
VW group with STD medium, n = 443, f = 56%, m = 1310 kg	
Audi A3	96-03
AUDI TT	98-02
Seat Toledo/Leon	99-04
Skoda Octavia	97-04
VW Bora	99-04
VW Golf	98-04
VW group with STD large, n = 629, f = 47%, m = 1518 kg	
Audi A4	95-00
Audi A6	95-97
Audi A6	98-05
Skoda Superb	02-
VW Passat	97-05
VW group with RHR, n = 132, f = 58%, m = 1477 kg	
Audi A3	03-04
Audi A3	05-06
Audi A4	01-06
Audi A6	05-06
Audi TT	03-05
Seat Altea	05-
Seat Toledo/Leon	05-
Skoda Octavia	05-
VW Touran	03-
VW Golf/Jetta	04-
VW Passat	05-07

In addition to analysis of representative values, a median criteria/parameter value for each seat group was also analysed. The analysis using median values was carried out to study the bias in the selection of the representative tests (for each of the seat groups) and to assess whether any other parameter could be a better predictor than those found in the main study. Additional details for the calculation of median injury criteria and parameter values can be found in Appendix 3.

3.4 Sled test data

All sled tests that were suitable and available for this study were conducted at Autoliv in Vårgårda, Sweden, from 2004 to 2006, and at Thatcham, UK between 2003 and 2006. In addition a new series of tests was carried out at Thatcham in 2012. Table 2 provides information on the sled tests selected for the analysis of grouped data. Additional information on the sled test conditions and insurance data details can be found in Appendices 1 and 2 (analytical data for individual car models and data used to assess sled test parameter variability). The sled tests carried out at Autoliv were conducted according to the Swedish Road Administration (SRA) and Folksam seat performance rating procedure. This was harmonized with the International Insurance Whiplash Prevention Group (IIWPG) rating procedure used by Thatcham. In brief, an H-point machine including a HRMD was used to adjust the seatback angle and to determine the H-point position. Thereafter the H-point machine was removed and a BioRID II, version E or G, was installed in the seat.

The main differences between the test series included were the make and build level of the H-point machine, the HRMD and the BioRID II (Table 2). For the comparison of grouped data, the largest number of test data that also had the highest number of injury claims in the Folksam data base was also available from Thatcham. In this work, the seat test data from Thatcham was used when the same for a particular seat was available from both facilities. However, the sled test data originates from five separate test series when representative tests were analysed and from eight test series when median values were analysed.

The sled acceleration chosen was the median risk and median frequency pulse (Krafft et al. 2005, Krafft et al. 2002), with a velocity change of 16 km/h, an average acceleration of 5.5 g and 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 seats tested were mostly new with the exception of those seats used to represent the performance of the Volvo 700/900 seats, Volvo V70 seats from 1997 - 2000, SAAB 900 seats from 1994 - 1997, SAAB 9000 seats and Toyota Corolla seats from 1998 - 2002.

3.5 Linear regression

A linear regression model was adopted to give an idea of how the parameters were correlated with the injury risk. To measure how well the model fit, a coefficient of determination, r^2 values, was 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 have been calculated for each correlation; this would be a measure of the reliability of the correlation. However, the number of samples is small but consistent for all parameters, i.e. 17 samples, which is why the significance level is not calculated.

The regression line is determined by fitting a line to the data. 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 II version, H-point machine, 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 machine [2]	Back set (mm)
Hyundai	Santa Fe	00-05	None	2004	Thatcham	G	AA	61
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
Peugeot	206	98-05	None	2004	Thatcham	G	AA	76
SAAB	900	94-98	None	2006	Autoliv	G	AA	30
	9000	85-97	None	2012	Thatcham	G	AA	48
	9-5	98-09	SAHR	2004	Thatcham	G	AA	56
Toyota	Corolla	98-02	None	2005	Autoliv	E	TS	65
	Yaris	99-05	WIL	2004	Thatcham	G	AA	66
Volvo	700/900	82-98	None	2012	Thatcham	G	AA	17
	V70	97-00	None	2006	Autoliv	G	AA	74
	V/S70	00-06	WHIPS	2004	Thatcham	G	AA	32
VW small	VW Polo	02-	None	2004	Thatcham	G	AA	63
VW medium	Seat Altea	04-	None	2004	Thatcham	G	AA	65
VW large	Skoda Superb	02-	None	2004	Thatcham	G	AA	85
VW RHR	Audi A6	05-06	RHR	2005	Autoliv	E	TS	55

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

Table 3: Parameters included in the analysis in this study:

Maximum Neck Injury Criterion (NIC)
Maximum neck load criterion (N_{km})
Maximum Lower Neck Loads index (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 (upward and downward)
Maximum L1 x- and z-acceleration
Maximum pelvis x- and z-acceleration
Maximum upper neck loads (U.N.F_x (head r.w.), U.N.F_z (tension) and U.N.M_y (flexion of head))
Minimum upper neck loads (U.N.F_x (head f.w.), U.N.F_z (compression) and U.N.M_y (extension of head)
Maximum lower neck loads (L.N.F_x (head r.w.), L.N.F_z (tension) and L.N.M_y (flexion of neck)
Minimum lower neck loads (L.N.F_x (head f.w.), L.N.F_z (compression) and L.N.M_y (extension of neck)
Maximum rearward Occipital Condyle x-displacement in the T1-frame (OC rel. T1 x-displacement)
Maximum upward Occipital Condyle rel. z-displacement in the T1-frame (OC rel. T1 z-displacement)
Maximum rearward T1 angular displacement around the y-axis (T1 y-rotation)
Maximum head rel. T1 angular displacement around the y-axis (Head rel. T1 y-rotation (flexion))
Minimum head rel. T1 angular displacement around the y-axis (Head rel. T1 y-rotation (extension))
Head Contact Time (HCT)
Maximum Head Rebound Velocity rel. to the sled in the x-direction (HRV)

3.6 Estimation of sensitivity

A study of the sensitivity to inclusion or exclusion of some selected data points were carried out. Here, one out of the 17 datasets was removed and the correlation coefficient r^2 value was calculated. This was repeated for all possible combinations for which each data point was excluded once. A total of 17 correlation coefficients was calculated. The maximum and minimum values calculated are given in the results section as a measure of the sensitive for each data point in the analysis.

4 Results

Linear regression for neck injury criteria and other parameters measured in a representative dummy test were conducted on grouped data. Correlations between the parameters and the two categories of injury risks are given in Table 4; plots of the injury risks versus the various parameters are shown in Figures 1-6.

Table 4: Correlation (r^2) between the peak value of the parameters and injury risks included. The results were based on the analysis of data from one representative sled test per seat group. Three values are provided for each parameter and injury risk: "Complete" refers to an analysis in which all 17 data points were included; Maximum and Minimum refer to the values obtained in the analysis carried out when one of the 17 datasets was systematically removed (Section 3.6).

Parameter	Permanent medical impairment			Symptoms > 1 month		
	Complete	Maximum	Minimum	Complete	Maximum	Minimum
NIC	**0.62**	**0.76**	0.50	**0.75**	**0.83**	0.68
OC rel T1 x-disp. (retraction)	**0.43**	0.49	0.39	**0.57**	**0.69**	0.52
Head rel. T1 y-rot. (extension)	**0.40**	0.47	0.39	**0.57**	**0.61**	0.53
L1 x-acc.	0.36	0.52	0.31	**0.44**	0.51	0.39
Pelvis z-acc.	0.35	0.51	0.13	0.23	0.33	0.13
Nkm	0.31	0.43	0.17	0.45	**0.62**	0.32
L1 z-acc.	0.29	**0.61**	0.18	0.25	0.50	0.18
L.N.Fx (head rw)	0.26	0.36	0.02	0.16	0.25	0.00
T8 x-acc.	0.25	0.38	0.19	0.36	0.51	0.28
U.N.Fx (head rw)	0.22	0.32	0.10	0.38	0.46	0.26
T8 z-acc.	0.20	0.35	0.11	0.13	0.26	0.05
L.N.My (negative)	0.18	0.26	0.07	0.34	0.39	0.23
T1 x-acc.	0.17	0.32	0.05	0.37	**0.62**	0.24
Head x-acc.	0.13	0.24	0.04	0.21	0.27	0.12
Head z-acc.	0.12	0.27	0.07	0.24	0.35	0.18
U.N.My (positive)	0.10	0.18	0.04	0.05	0.12	0.01
L.N.My (positive)	0.10	0.18	0.04	0.03	0.10	0.00
Head rel. T1 y-rot. (flextion)	0.09	0.21	0.04	0.16	0.31	0.08
T1 z-acc.	0.08	0.24	0.03	0.26	0.41	0.17
C4 z-acc.	0.08	0.21	0.03	0.24	0.36	0.15
U.N.Fx (head fw)	0.04	0.09	0.00	0.01	0.04	0.00
HCT	0.03	0.08	0.00	0.03	0.11	0.00
Pelvis x-acc.	0.03	0.18	0.01	0.02	0.17	0.01
OC rel T1 z-disp. (legthening)	0.03	0.23	0.01	0.01	0.21	0.00
U.N.My (negative)	0.03	0.08	0.00	0.11	0.22	0.03
T1 y-rot. (rearward)	0.02	0.06	0.00	0.01	0.02	0.00
L.N.Fz (tension)	0.02	0.11	0.00	0.00	0.06	0.00
LNL	0.02	0.09	0.00	0.11	0.20	0.03
C4 x-acc.	0.01	0.06	0.00	0.02	0.10	0.00
L.N.Fz (compression)	0.01	0.10	0.00	0.01	0.06	0.00
L.N.Fx (head fw)	0.01	0.08	0.00	0.10	0.20	0.03
HRV	0.01	0.17	0.00	0.10	0.18	0.03
U.N.Fz (tension)	0.00	0.06	0.00	0.04	0.12	0.00
U.N.Fz (compression)	0.00	0.04	0.00	0.01	0.12	0.00
T1 z-acc.	0.00	0.12	0.00	0.01	0.09	0.00

As can be seen in Table 4, the permanent medical impairment risk and risk of symptoms >1 month both showed correlations with the maximum NIC, maximum OC rel. T1 x-displacement. The head rel. T1 y-rot. (extension) showed a limited correlation with both injury risks. Maximum N_{km} and T1 x-acceleration showed a correlation with the risk of symptoms >1 month when one of 17 data points was disregarded in the regression analysis. In general the correlations (r^2 values) were higher for symptoms >1 month than for permanent medical disability. Notably, HCT and HRV showed only limited correlations.

Table 5: Correlation (r^2) between the peak parameter values and the injury risk; based on an analysis in which the median values for each parameter from each seat group were used (see details Appendix 3). Three values are provided for each parameter and injury risk: Complete refers to an analysis in which all 17 data points were included; Maximum and Minimum refer to the values obtained in the analysis carried out when one out of the 17 datasets was systematically removed (Section 3.6).

Parameter	Permanent medical impairment			Symptoms > 1 month		
	Complete	Maximum	Minimum	Complete	Maximum	Minimum
NIC	**0.48**	**0.73**	0.36	**0.67**	**0.79**	0.59
L1 x-acc.	**0.42**	**0.59**	0.39	**0.51**	0.57	0.49
OC rel T1 x-disp. (retraction)	0.37	0.47	0.31	**0.55**	**0.59**	0.50
Pelvis z-acc.	0.35	0.48	0.27	0.36	0.47	0.30
Head rel. T1 y-rot. (extension)	0.32	0.44	0.29	**0.51**	**0.58**	0.46
T1 x-acc.	0.22	0.39	0.09	0.47	**0.63**	0.36
T8 z-acc.	0.21	0.41	0.11	0.08	0.27	0.02
T8 x-acc.	0.18	0.27	0.14	0.26	0.38	0.19
Nkm	0.16	0.25	0.04	0.30	0.46	0.16
L1 z-acc.	0.16	0.46	0.12	0.19	0.49	0.11
U.N.Fx (head rw)	0.14	0.30	0.04	0.35	0.47	0.23
T1 y-rot. (rearward)	0.13	0.22	0.09	0.05	0.09	0.01
Head x-acc.	0.13	0.24	0.03	0.21	0.27	0.11
L.N.My (negative)	0.12	0.27	0.03	0.30	0.42	0.19
L.N.My (positive)	0.12	0.18	0.07	0.06	0.09	0.01
Pelvis x-acc.	0.11	0.19	0.01	0.13	0.24	0.03
Head z-acc.	0.10	0.24	0.07	0.21	0.31	0.17
T1 z-acc.	0.09	0.21	0.05	0.24	0.36	0.16
C4 z-acc.	0.09	0.20	0.04	0.26	0.36	0.19
U.N.Fz (compression)	0.07	0.12	0.01	0.11	0.18	0.05
U.N.My (positive)	0.07	0.12	0.02	0.03	0.07	0.00
L.N.Fx (head rw)	0.06	0.15	0.04	0.01	0.07	0.00
C4 x-acc.	0.03	0.10	0.01	0.06	0.11	0.00
L.N.Fz (tension)	0.03	0.13	0.00	0.00	0.03	0.00
Head rel. T1 y-rot. (flextion)	0.03	0.09	0.00	0.10	0.21	0.04
HCT	0.02	0.12	0.00	0.00	0.05	0.00
U.N.My (negative)	0.02	0.06	0.00	0.09	0.17	0.02
LNL	0.02	0.10	0.00	0.12	0.23	0.04
L.N.Fx (head fw)	0.01	0.08	0.00	0.11	0.21	0.04
L.N.Fz (compression)	0.01	0.15	0.00	0.00	0.09	0.00
OC rel T1 z-disp. (legthening)	0.01	0.11	0.00	0.00	0.09	0.00
U.N.Fx (head fw)	0.01	0.05	0.00	0.00	0.10	0.00
T1 z-acc.	0.01	0.08	0.00	0.05	0.08	0.03
HRV	0.00	0.19	0.00	0.07	0.16	0.03
U.N.Fz (tension)	0.00	0.06	0.00	0.05	0.14	0.00

A mathematical method to be used for selecting the most representative test, when there was more than one test available for each seat group, was neither developed nor 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 test data for each seat group (Table 5). As can be seen by comparing the results in Table 4 and Table 5, differences in correlation values, between the representative and median injury criteria and the parameter values as measured in the dummy, were small. When median values were used, the NIC appear to correlate less to the risk of symptoms >1 month and to permanent disability than when representative data were used.

In Figures 1 - 4 and 6, the lines between data points show groups of seats with and without ant-whiplash systems for which grouped data were available. These lines were included to enable a comparison between parameter values and injury risk, with a reduced influence of factors such as chassis design characteristics of the car make, car owner characteristics specific for the make, and partly vehicle weight.

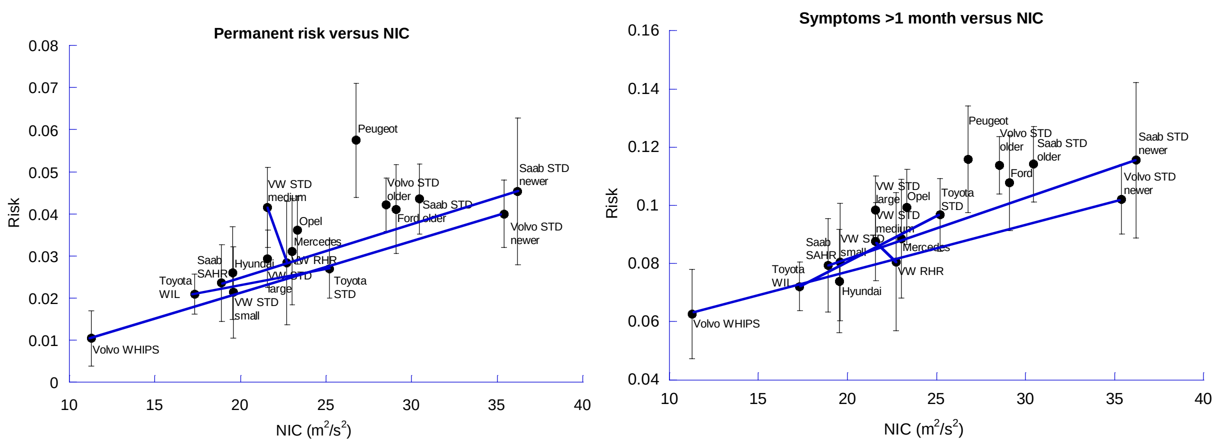

Figure 1: Risk of permanent disability and risk of symptoms >1 month versus maximum NIC for seventeen groups as defined in Table 1 (average ± 1 SE). Representative dummy values were used for the two diagrams.

In Figure 1, it appear that, when anti-whiplash systems were introduced all car producers reduced the NIC values considerably 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 or criteria values. Despite these differences between the seat groups, it appears that seat designs which produce an NIC lower than 25 m^2/s^2 carry a risk, less than approximately 3.5% of causing permanent neck symptoms (normalized to year 2010) following a rear-end impact with initial symptoms (Figure 1).

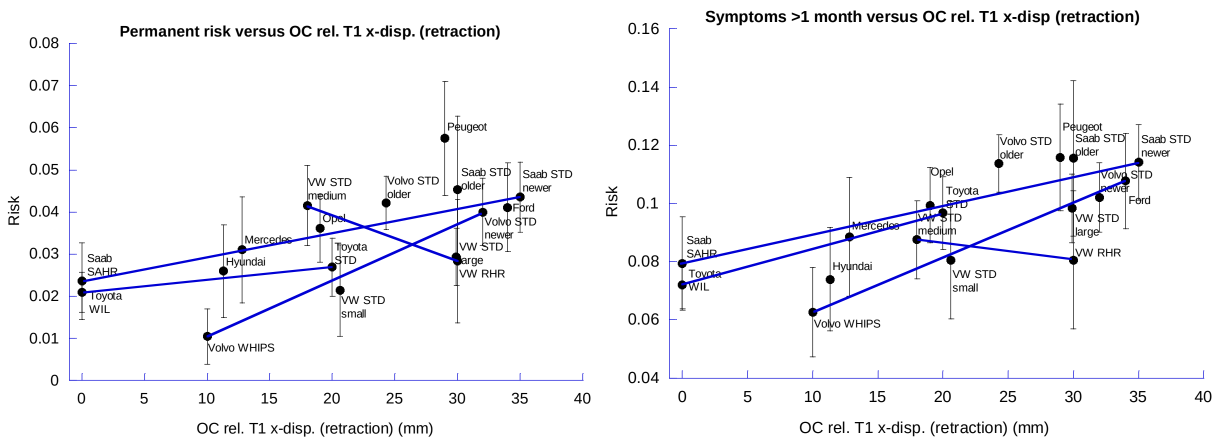

Figure 2: Risk of permanent disability and risk of symptoms >1 month versus maximum rearward Occipital Condyles rel. T1 x-displacement for seventeen groups as defined in Table 1 (average ± 1 SD. Representative dummy value were used for the two diagrams.

A similar relationship appears to be also for the OC rel. T1 x-displacement (Figure 2) and L1 x-acceleration (Figure 3). For the former parameter it appears that a 15 - 20 mm retraction relative T1 as expressed in a rotating T1 coordinate system results in a risk of permanent symptoms of 3.5% or less when there are initial symptoms. For the latter parameter it appears that an L1 acceleration should be kept under about 12 g to maintain a risk of permanent symptoms below 3.5% if an occupant has initial symptoms.

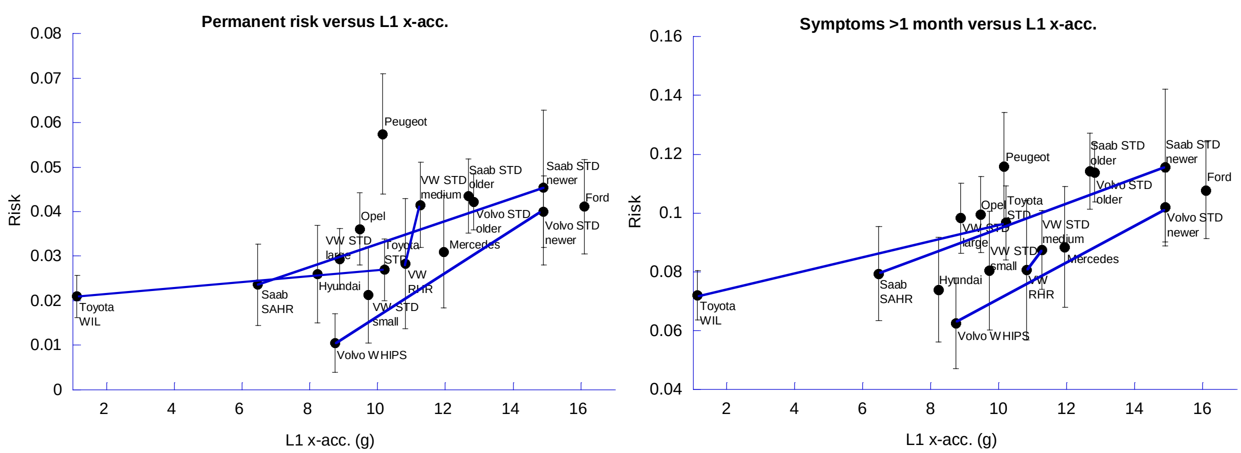

Figure 3: Risk of permanent disability and risk of symptoms >1 month versus maximum L1 x-acceleration for seventeen groups as defined in Table 1 (average ± 1 SE). Representative dummy values were used for the two diagrams.

Correlation between the maximum T1 x-acceleration and the risk of symptoms >1 month was increased largely when one dataset was not used in the determination of correlation; maximum correlations (r^2 values) were then 0.66 and 0.63 (Tables 4 and 5). The low correlations obtained when all datasets were used were due to high T1 x-accelerations measured in the Toyota seat with WIL (Figure 4).

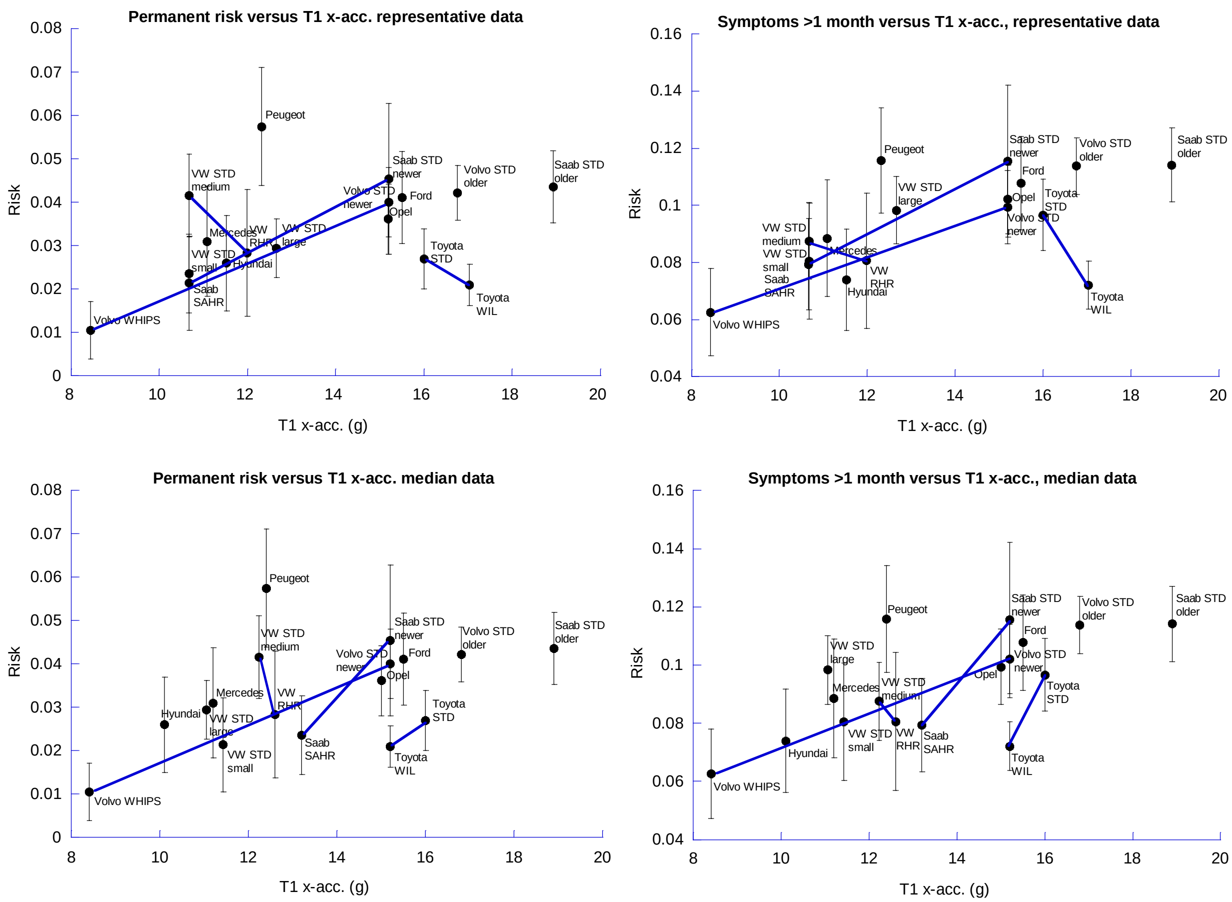

Figure 4: Risk of permanent disability and risk of symptoms >1 month versus maximum T1 x-acceleration for seventeen groups (average ± 1 SE). Top row: Representative dummy values. Bottom row: Median dummy values.

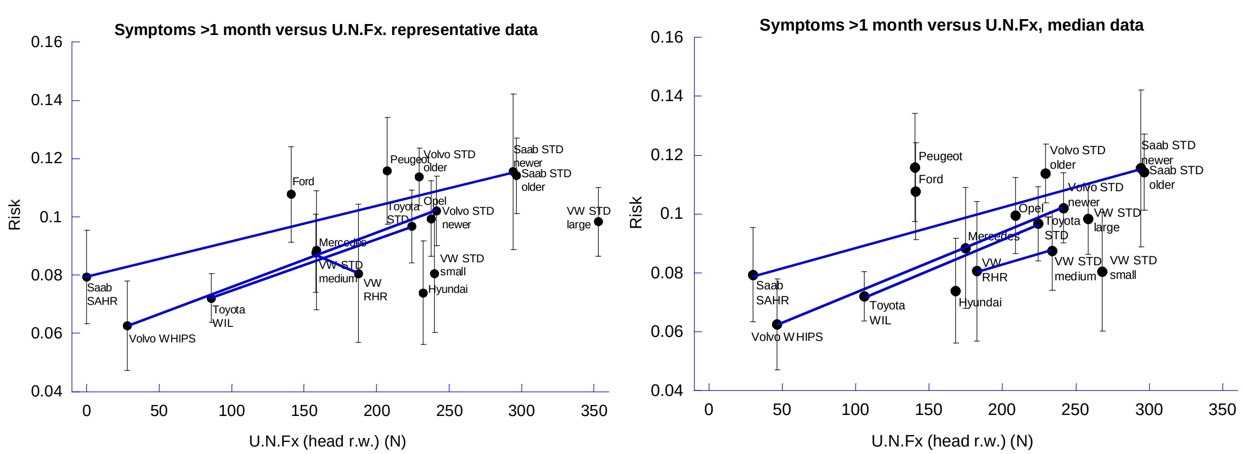

Figure 5: Risk of symptoms >1 month versus maximum upper neck shear load for seventeen groups as defined in Table 1 (average ± 1 SE). Left graph: Representative dummy values; Right graph: Median dummy values.

The same as for the T1 x-acceleration, correlation between maximum upper neck shear load (U.N.F_x, head r.w.) and the risk of symptoms >1 month improve when only 16 of the datasets are used in the analysis, although not to the same extent (Tables 4 and 5). Figure 5 indicates that the correlation may have been improved significantly if two of the datasets (Hyundai and Ford) were excluded from the analysis.

There seems to be no relation between HCT and the risk of permanent medical impairment or symptoms >1 month (Figure 6) following an accident that causes initial symptoms. Correlations (r^2-values) were below 0o03 for all risk values when representative and median data were used in the analysis (Tables 4 and 5). The diagrams however show that for all four car manufacturers, for which data are available with both standard seats and whiplash lessening system seats, the HCTs were lower for the seats with the whiplash lessening systems.

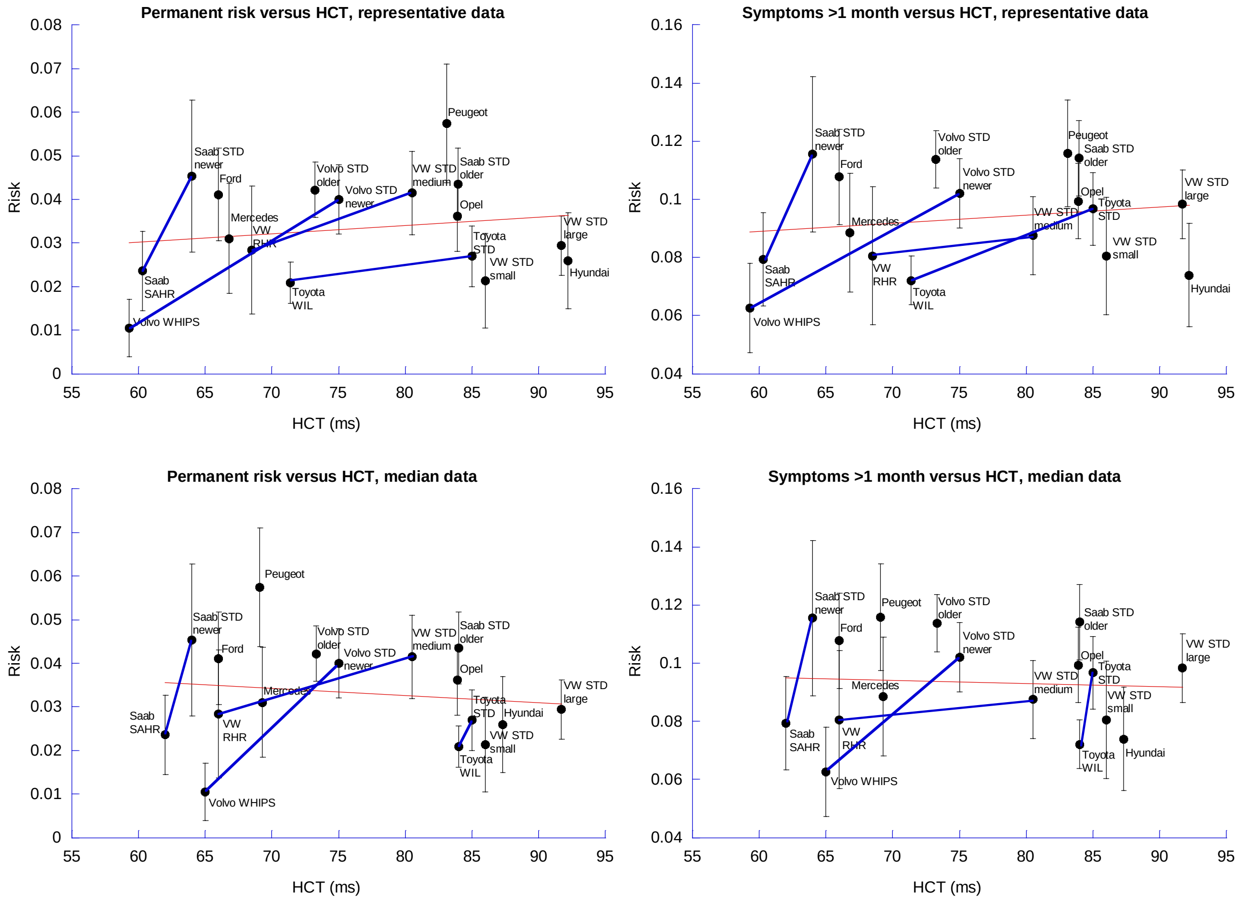

Figure 6: Risk of permanent disability and risk of symptoms >1 month versus maximum Head Contact Time for seventeen groups as defined in Table 1 (average ± 1 SE). Representative dummy values were used for the diagrams in the top row; median dummy values were used for the diagrams in the bottom row.

5 Discussion

By pooling models without anti-whiplash seat designs in one group, and those with anti-whiplash seat designs in another group, for each car manufacturer, it was expected that a better statistical analysis could be made. The injury risk estimate was found to be more reliable than using individual car model data; the vehicle related parameters were less influential than groups based on similar risk. The reason for the latter finding was due partly to the inclusion of vehicles with similar weight 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, to yield or absorb energy, or both, in a controlled manner. By 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 45%, *Toyota* a reduction of 22%, VW group a reduction of 32% and *Volvo* a reduction of 80% of permanent medical impairment (Figure 1). By analysing the results, one can make the following observations:

- Saab has managed to lower the value for all parameters measured by introducing SAHR except for maximum rearward T1 angular displacement and lower neck load (L.N.F_z, compression).
- Toyota managed to lower the value for all parameters measured except for some of the neck loads (U.N.F_z, compression, U.N.M_y, positive) and maximum pelvis x-acceleration.
- Volvo reduced all parameters measured except for maximum compressive neck loads (U.N.F_z compression and L.N.F_z, compression) and maximum pelvis x-acceleration. The head contact time (HCT) varied considerably between tests with Volvo seats with a WHIPSs.
- VW group RHR seats have lower values, for some of the parameters studied, than VW non-reactive seats. An examples of this is maximum lower neck loads (LNL). However, many parameters remained rather similar after the introduction of RHR seats or increased slightly, e.g. OC rel. T1 x-displacement, Neck Injury Criteria (NIC), Head Rebound Velocity (HRV), T1 x-acceleration, T8 x-acceleration pelvis x-acceleration

The analysis of these four car groups, indicates that by a general reduction, i.e. reduction of relative displacements, spine accelerations, neck loads and injury criterion, the risk of whiplash associated disorders can be substantially reduced. Criteria that appear to better explain whiplash risk were NIC and maximum OC rel. T1 x-displacement (Figures 1 and 3).

For evaluation of the robustness of the analysis, other groups were included in the analysis. They were Hyundai, Ford, large and small VWs, Mercedes, Opel, Peugeot, and popular but older Saab and Volvo models. These seats were not fitted with anti-whiplash systems. The regression analysis, including these seats (Tables 4 and 5) indicated that NIC, L1 x-acceleration and maximum OC rel. T1 x-displacement (Figures 1 - 3) predicted the risk of permanent injury as well as the risk of symptoms >1 month following a rear-end impact. These findings are partially in line with other studies on this matter, which suggested that the NIC (Kullgren and Boström 2007) are suitable for assessing seat performance in rear-end impacts. Other parameters that could predict the risk of symptoms >1 month were maximum T1 x-acceleration and upper neck shear load (U.N.F_x, head r.w.), since these indicated some type of correlation when suspected outliers were removed (Figures 4 and 5). For T1 x-acceleration the correlation (r^2 value) was 0.62 when the Toyota seat with a WIL dataset was disregarded in the analysis (Table 4). For U.N.F_x (head r.w.) correlation was 0.54 when Hyundai and Ford datasets were excluded from the analysis.

Ono et al. (2009) drew, with some exceptions, conclusions similar to those in this study, however they used a different approach. Ono and co-authors reconstructed many rear-end impacts using a detailed mathematical model of the human. Their study suggested that the NIC and neck loads, especially upper neck shear load and moment and lower neck axial load, should be used in the evaluation of seat performance in rear-end impacts. Ono and colleagues have since continued these studies; the results have been presented at meetings hosted by an informal group within United Nations (ECE WP29 GRSP GTR 7 Phase II). In addition to NIC and neck loads, Intervertebral Neck Injury Criterion (IV-NIC) has been suggested as a predictor for neck injuries. Table 6 presents the parameters, and associated limits, to be measured in rear-end seat tests according to the latest draft GTR document together with the parameters suggested in the present study.

Table 6: Suggested rear-end impact limits to be used in regulatory testing, compared with the results obtained in this study, for a 3.5% risk of permanent medical impairment when there were initial neck symptoms.

Parameter	Draft ECE WP29 GRSP GTR 7 phase II regulatory text	This study
NIC	30 m^2/s^2	25 m^2/s^2
(IV-NIC) in flexion	1.34 deg.	Not included in the analysis
OC rel. T1 x-displacement	−	22 mm
Head rel. T1 y-rot. (extension)	−	6 deg.
U.N.F_x (head r.w.)	730 N	210 N
U.N.F_x (head f.w.)	730 N	−
U.N.F_z (tension)	1130 N	−
U.N.M_y (flexion)	40 N	−
U.N.M_y (extension)	40 N	−
L.N.F_x (head r.w.)	730 N	−
L.N.F_x (head f.w.)	730 N	−
L.N.F_z (tension)	1480 N	−
L.N.M_y (flexion)	40 N	−
L.N.M_y (extension)	40 N	−
L1 x-acceleration	−	110 m/s^2
L1 z-acceleration	−	64 m/s^2
T1 x-acceleration	−	140 m/s^2

The findings of the present study were, 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 found. First, in the study by Zuby and Farmer (2008), the number of insurance cases for most of the car models was high. However, 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 can greatly influence the numbers used in the correlation study. Second, there are probably variations in the insurance data between the study by Zuby and Farmer and the present study. These variations could be associated with differences in injury coding, such as in compensation for property damage, compensation for injury claims, and social welfare system. Third, in the present study representative sled test datasets were used in the analysis for some of the groups included. However, this was done only when there was more than one dataset available for a particular vehicle model or when the dataset first selected provided results that were deemed to be an outlier in comparison with the median values of the datasets for the same group. For most groups the selection of dataset used in the analysis was based on facts that were not related to parameter values. Still, the use of representative datasets in the present study may have provided an analysis with more robust dummy values than in the study by Zuby and Framer. Fourth, Zuby and Framer used risk of symptoms when there was a rear-end impact, whereas this study used risk of persistent symptoms when the occupant exhibited initial symptoms following a rear-end impact. Data have shown that average vehicle velocity change and acceleration are higher for symptotic than for asymptotic rear-end impacts. This may explain some of the differences in the results obtained in this study when compared with Zuby and Farmer, since there was likely a better match in this study between dummy test conditions and those in the data base. While these four differences may be small, they can, in combination with the methods used to assess correlations in these two studies, which are both known to be very sensitive to outliers, provide a very different level of correlation, and as such, explain the divergence between the two studies.

In general BioRID II datasets from Thatcham were given priority since they had access to an H-point machine with an HRMD that was very close in dimensions to the standard tool used today. The Thatcham datasets thereby enable the inclusion of tests that were carried out more recently. Two datasets were included in this analysis for which an older and un-calibrated H-point machine with HRMD was used (Table 2). When multiple tests, from Thatcham, that provided fair seat performance data, were available for a group, the number of accidents with initial symptoms was used to select the test to be used in further analysis. The test that was associated with the largest number of entries in the insurance database for the group was used. Despite this selection process, in a few groups a “representative” dataset was chosen and used in the analysis of correlation (Figures 1-6). This was done when more than one dataset available for a particular vehicle model from Thatcham or when the dataset first selected provided results that were deemed to be an outlier compare with the median values of the datasets for the same group. This selection procedure could have contributed to the fact that we could identify correlations, whereas studies in the past could not. This selection approach was adopted because 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 impacts and included in the insurance data base. This does not mean that multiple tests with identical seats should be introduced in future test programs. This approach was adopted to determine whether there could have been some differences between the seats tested in each seat group. By introducing this selection, we facilitated the inclusion of the more representative tests in the correlation analysis. The differences between the seats within one single seat group could be due to introductions of small changes in design over the time span. These differences could be due to foam thickness, foam properties, fabric selection, etc.

In addition to the reasons given above, other sources of variability were present during the seat testing, which justify the seat dataset selection approach used here. The largest source was most likely introduced by the lack of calibration routines for the H-point machine and HRMD used at the time of testing. The test data used in this study was generated by two different H-point machines which could most likely explain the differences in the head-to-head restraint distances measured. Another source was the use of two BioRID II versions. The differences between these two build levels were mainly the position of the spine in relation to the exterior of the flesh. By introducing the selection process mentioned above the problem using “old” seat test data was to some degree reduced.

The sled test data used in this study was generated in different laboratories using almost identical test conditions. With the time, a few dissimilarities in the test conditions have been identified, which could explain some of the variability observed. This variability introduces errors in the estimates in the present study; 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 presented in Appendix 2 also suggested that, while the inconsistency level was limited for most of the parameters, it 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 may explain the limited correlations found here for some of the parameters.

In the comparisons of real life data and seat test data using individual car model data (Appendix 1), it was clear that the confidence interval sizes were large in comparison with the range in injury risk. Hence, it was judged that an analysis using individual car model data is not possible at present. Although, the results do not invalidate the results obtained using grouped data, the uncertainty is currently too high to draw any conclusions.

The main findings in this study are somewhat different from earlier studies using similar methods and data (Davidsson and Kullgren, 2011a and 2011b). There are several reasons for this. First, all injury claim data used in this study have been adjusted to the classification of injuries used in 2010. The normalization factor was 15% per year for permanent disability risk; such compensation introduced significant changes to the risk estimates used in the analysis as compared with the previous studies. Second, the number of groups was seventeen in this study as compared with eleven and twelve, respectively, in the proceeding studies. The inclusion of test data and insurance data from older vehicle models introduces challenges; the parameter values were estimated using the BioRID II, for seats with a broader spectrum of performance in this study than the previous studies. Third, seat test data selection was carried out on the basis of test conditions rather than on being the most representative test dataset. Fourth, this study uses a data base with 22 045 cases of rear end impacts with reported initial symptoms, whereas the earlier EEVC report used a data base with only 11 562 cases.

It is unlikely that only a single parameter could fully assess the risk of injury to all of the various injury mechanisms that have been suggested for rear-end impact testing. The results of this study support the use of several parameters.

One can discuss whether the risks used in the current study were based on true injuries or not and whether they were a direct result of the car crashes. First, occupants with permanent symptoms were defined as those who have a classified degree of impairment given by a physician. The same procedure is used by all Swedish insurance companies. The whole procedure to set a final degree of impairment may take up to three years after the crash. Symptoms >1 month are defined as those people who have obtained a medical record of their symptoms. In such records the injury has usually not been verified, as it was most often just a question of pain following a rear-end impact. Second, if the injuries or symptoms only occurred randomly or were influenced by factors not linked to the car crash, one 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 were to be further improved, it is expected that even larger differences in risk would be found.

In this study insurance records are used to calculate the risk of developing symptoms lasting longer than one month or permanent medical impairment, when there were initial symptoms. These records have, in combination with BioRID II test data, been used to suggest parameters to be used in future rear-end impact tests. Preferably the risk measure used should be calculated as the risk of symptoms >1 month or permanent medical impairment when there is a rear-end impact. This would increase the quality of the risk estimates, since it appears that, for low severity rear-end impacts, initial symptoms are reported more frequently.

As stated, the risks reported in this study were related to initial symptoms, not to the occurrence of a rear-end impact, which is why they are rather high. Unfortunately, the risks of initial symptoms in rear-end impacts is not available for all vehicle models included. However, in approximately 35% of rear-end impacts, in Sweden, with modern cars initial symptoms were reported. This approximation can be used to relate the risk values found here in case there is a collision. For example if permanent medical impairment risk were 3.5% when there are initial symptoms, the impairment risk for a collision would be approximately 1.2%. It should be noted that the risks presented may not be compared directly to risks in other countries, since each country has its own guidelines for the classification of symptoms and medical impairments.

The type of risk measures used influences the study results. In general the risk of developing symptoms for >1 month or permanent medical impairment is proportional to the risk of initial symptoms following a rear-end impact (Kullgren and Kraft 2010). The study approach used here does not disqualify the findings presented. This approach rather introduces smaller differences between car models with better performance than for those with inferior performance.

The inclusion of both males and females in the insurance data may a wider scatter because females load the seat in real life accidents differently from the males, which may also be reflected in the seat tests. If we could compare dummy data and male data separately we would expect a better correlation between dummy sled test data and injury risk. Unfortunately the number of claims 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 car groups included here the numbers of insurance claims were almost the same for males and females (Table 1). For the groups denoted Hyundai, Toyota with WIL and VW STD small, the proportions of the insurance claims for female occupant was 67%, 63% and 64%, respectively. For these three groups the estimated risks, which were used in the analysis in this study, were probably somewhat higher than the risk for a female proportion of 50%. The opposite was most likely so for the group denoted Mercedes with proportions of insurance claims in which the occupant was a female was only 44%. The effect of this variation in risk, for these three groups, on the results presented 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. However, adding other pulses and adopting a statistical model that allows a combination of results from multiple crash pulses may provide a better correlation and further justify the results obtained.

Vehicle weight has been shown to influence injury risk in rear-end accidents. The risk of permanent injury and symptoms for >1 month are lower for heavy vehicles than for lighter vehicles according to the insurance data (Figure 7). Despite this difference, sled tests are generally carried out using generic crash pulses. In this study data from only a single generic crash pulse was used. Since the actual vehicle specific pulse was not used, including very light and very heavy vehicles could cloud any possible correlation between parameter values and injury risk. Therefore, car models with very low or high vehicle weight were excluded in the analysis.

Despite the exclusions of light and heavy vehicles, there were still differences in vehicle weight between the seat groups; seats with anti-whiplash systems were in general slightly heavier than those without (Figure 7). It could be hypothesised that the injury risk reductions observed were due to increased vehicle weight, rather than influenced by the installation of anti-whiplash systems or improved seat designs. However, the risk reductions observed were mainly due to design changes, as shown in Figure 7; the correlations found were therefore a function of measured dummy parameter values.

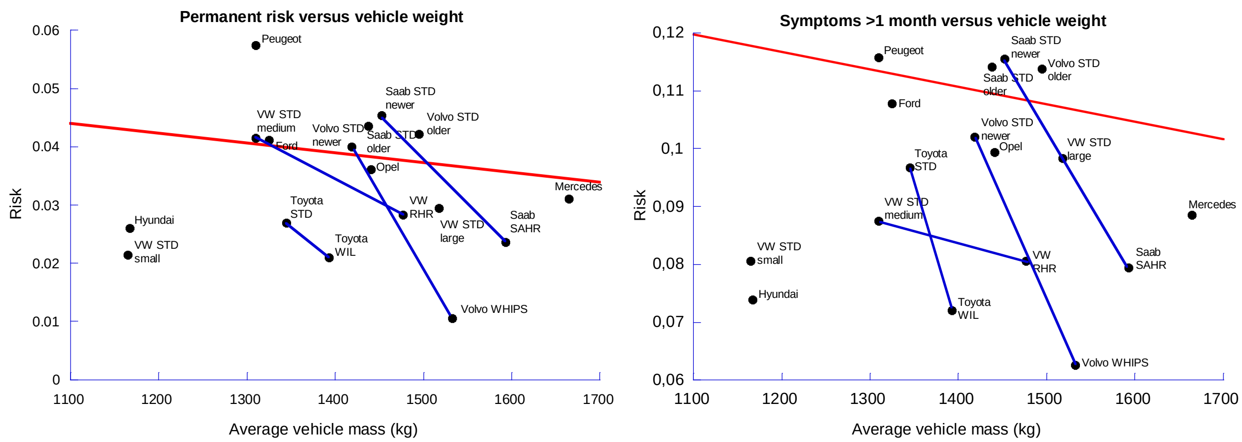

Figure 7: Risk of permanent medical impairment and risk of symptoms >1 month versus vehicle weight for the groups defined in Table 1. For the seat model groups the average risk and weighted representative vehicle weight were calculated and used. The red lines included represent the relation between vehicle weight and risks; linear regressions to datasets that originated from the 80 car models with the highest number of initial symptoms (min 73 cases per model) in the Folksam insurance data. The regressions were rather weak; r^2 was below 0.07 for both permanent medical impairment and symptoms >1 month. Note that the regressions were carried out using risks for both standard and anti-whiplash seats. During the sampling period anti-whiplash systems were more common in larger, and thereby heavier, cars than in smaller and lighter cars; hence relations between vehicle weight and risks would probably be even smaller if all vehicle models studied had identical seats.

A few parameter values were found that did not correlate or had a limited correlation with injury risk or long term symptoms. Additional analysis revealed that, for some of these parameters, a single dummy test result could be far from the others (outlier) and thereby largely reduce the correlation values (r^2). This applies to some of the lower and upper neck loads. This could be due to small errors in the particular seat-test setup, the properties of the seat tested, or to differences between the dummies used. It may also be that these parameters are suitable to predict injury risk for some seats but not for others.

6 Conclusions and recommendations

The main finding in this study is that the maximum NIC, the maximum rearward Occipital Condyles x-displacement, as expressed in a coordinate system attached to the T1, and the maximum L1 x-acceleration appear to be the best predictors of neck related permanent medical impairment and symptoms that persist for more than one month following a rear-end impact. The maximum neck extension, i.e. head rel. T1 y-rotation, L1 z-acceleration, T1 x-acceleration and the upper neck shear load when the head moved rearward relative the neck, were also found to correlate also somewhat to the injury risks.

Another finding was that grouped insurance data, based on similarities in the seat system design, were useful, since they allowed the establishment of larger groups which reduced the uncertainties in the estimated risks. Also, studies of correlations between BioRID test results and the risk of persistent symptoms, given that initial symptoms were reported, appear to be useful to distinguishing between seats that perform well and poorly.

The following limits separate seat models with fair performance with those with moderate to good performance and they are suggested for use in rear-end impact seat tests with the BioRID II (version g) and when the medium IIWPG crash pulse is used; NIC 25 m^2/s^2, maximum L1 x-acceleration 120 m/s2 and maximum Occipital Condyles x-displacement 22 mm. These suggested limits are based on the performance of the groups of seats included in this study and they must be tailored to the uncertainty of the methods used to measure them, particularly the maximum Occipital Condyles x-displacement. Other parameters are not ruled out; they may be found useful in seat performance tests when a larger dataset 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.

7 Recommendations for future work

Regression analysis using each accident as an entry in the analysis would be useful. Especially if this can be carried out on insurance data that lists the risk of symptoms for more than one month and permanent disability, respectively, in case one is involved in a rear-end impact. This type of analysis would provide risk functions for both symptoms that last longer than a month and permanent disability, which could be used with the BioRID II dummy in future evaluations of seat performance in rear-end impacts.

8 Acknowledgements

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Appendices

Appendix I: Individual seat analysis

To increase the number of data points used in the regression analysis individual car model data was also analysed.

Materials and methods

Sled tests that were suitable and for which the number of insurance claims were 30 or more were included in the individual car model analysis (Table 1-1).

Correlation between risks and parameters was carried out with the same method as that given in the main report, except for the difference that individual car model datasets were used instead of grouped car model datasets.

Table 1-1: Car model, type of seat system, year the seat was tested, test facility, BioRID II build level, H-point machine used, initial horizontal head-to-head-restraint distance (back set) and number of filed insurance cases of acute symptoms (sampling 1998-2011 used for symptoms >1 month and 1998-2010 used for permanent injury).

Make, model and production period	Seat system[1]	Test facility, version and H-point machine[2]	Year tested[3]	Backset (mm)	No. of cases 1998-2011	No. of cases 1998-2010
Audi A3 96-03	STD	TGAA	2004	59	60	59
BMW 3-Serie 98-05	STD	TGAA	2004	55	37	34
Ford Escort 96-01	STD	TGAA	2012	73	162	161
Ford Focus 99-05	STD	AETS	2004	55	64	58
Ford Mondeo 00-07	RHR	TGAA	2003	73	34	30
Honda CRV 98-06	STD	TGAA	2004	52	32	31
Mercedes C 93-01	STD	TGAA	2004	55	100	99
Mercedes E 96-01	STD	TGAA	2004	46	51	48
Opel Astra 98-04	STD	AETS	2003	72	65	65
Peugeot 206 98-05	STD	TGAA	2004	76	48	40
Peugeot 307 01-	STD	AETS	2006	51	30	22
SAAB 9000 85-97	STD	TGAA	2012	48	466	466
SAAB 900 94-97	STD	AGAA	2006	30	117	117
SAAB 9-3 98-02	SAHR	TGAA	2006	57	64	61
SAAB 9-5 98-09	SAHR	AETS	2004	40	101	91
SAAB 9-3 03-09	SAHR2	TGAA	2004	56	49	44
Skoda Fabia 00-	STD	AETS	2003	90	45	43
Toyota Avensis 03-08	WIL	AETS	2004	75	95	63
Toyota Corolla 02-07	WIL	AETS	2005	95	111	104
Toyota Corolla 98-02	STD	AETS	2005	65	88	88
Toyota Corolla V. 04-10	WIL	AETS	2005	95	46	46
Toyota Prius 04-09	WIL	TGAA	2006	66	40	39
Toyota Yaris 05-	WIL	TGAA	2006	92	65	63
Toyota Yaris 99-05	WIL	TGAA	2004	66	69	68
Volvo 700/900 82-98	STD	TGAA	2012	17	1023	1066
Volvo S40/V40 00-04	WHIPS	TGAA	2004	47	60	51
Volvo S40/V50 04-	WIL	AETS	2004	45	38	38
Volvo V/S70+S80 00-06	WHIPS	AGAA	2006	40	68	50
Volvo V70 97-00	STD	AGAA	2006	74	81	79
VW Golf/Bora 98-04	STD	TEAA	2003	-	77	77
VW Golf/Jetta 04-	STD	TGAA	2004	66	57	55
VW Passat 97-05	STD	TGAA	2004	-	253	250
VW Polo 02-	STD	TGAA	2004	63	41	39

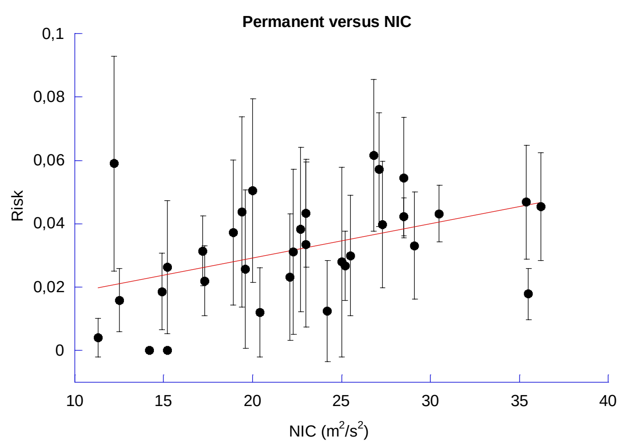
[1]None No system is activated before or during the impact.
[1]RHR Reactive Head Restraints
[1]SAHR1 or 2 Saab Active Head Restraint, version 1 or 2
[1]WHIPS Whiplash Protection System
[1]WIL Whiplash Injury Lessening
[2]First position: A refers to tested at Autoliv, T refers to tested at Thatcham
[2]Second position: E and G refers to BioRID build levels E and G
[2]Final positions: TS refers to TechnoSports, Inc, USA and AA refers to Automotive Accessories, Ltd., UK

Results

In Table 1-1, the correlation (r^2 values) between dummy parameter values and criteria and injury risk are presented for all combinations in which both sled test data and at least 30 cases of insurance claims were available (Table 1). Only the eight parameters with the highest r^2 values for permanent medical impairment are included in the Table 1-1. Figures 1-1 and 1-2 show a few of the results graphically; one data point per vehicle model.

Table 1-1: Measure of fit (r^2) in the individual car model regression (only r^2 values higher than 0.12 for any category of risk are included in the table below, n = 32).

Parameter	Permanent medical impairment	Symptoms >1 month	Number of datasets in the analysis
NIC	0.19	0.27	33
Pelvis z-acceleration	0.19	0.08	28
U.N.Fx (head r.w.)	0.16	0.20	33
L.N.My (extension)	0.15	0.16	33
Nkm	0.15	0.20	32
L.N.Fx (head f.w.)	0.14	0.01	33
L1 x-acceleration	0.08	0.21	28
OC rel. T1 x-displacement	0.09	0.16	24



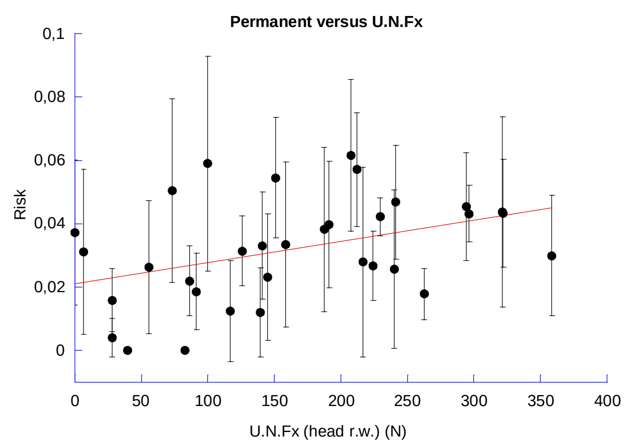


Figure 1-1: Risk of permanent disability versus NIC and upper neck shear load for each specific seat with more than 30 claims in the insurance data base (n = 32). The vertical bars in the figures are standard error bars for the injury risks estimated.

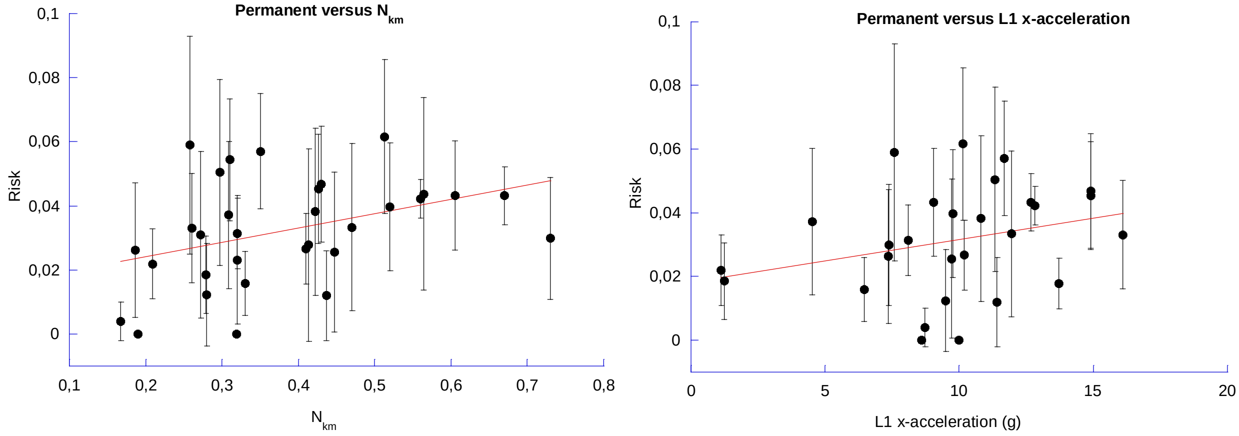


Figure 1-2: Risk of permanent medical disability versus L1 x-acceleration and OC rel. T1 x-displacement for each specific seat with more than 30 claims. The vertical bars in the figures are standard error bars for the injury risks estimated (n = 32).

Discussion

Taking into account the large uncertainty of the risk values in the analysis of the individual car model data, the existence or the lack of correlations neither denies nor supports the results obtained in the analysis using groups based on similar seat design.

Including data on seats for which only 30 cases were available highly reduces the trustworthiness of the correlations obtained. The correlations found here could very possibly appear only by chance. This analysis partly explains the reason for the poor correlations reported in previous studies using individual car model data with only a few cases per model.

Appendix II: Variability of the sled-test parameter values

Variability study

There was some uncertainty in the values of both the insurance claim data and the dummy parameter data. Both types of uncertainties should ideally be taken into account in the analysis. However, the number of tests available for each seat group was limited; the standard error for the parameter data could not be estimated. In the main report, only the confidence intervals for the injury risk were plotted but not those for the sled test parameters. A schematic digram for how a plot including both confidence intervals can be seen in Figure 2-1.

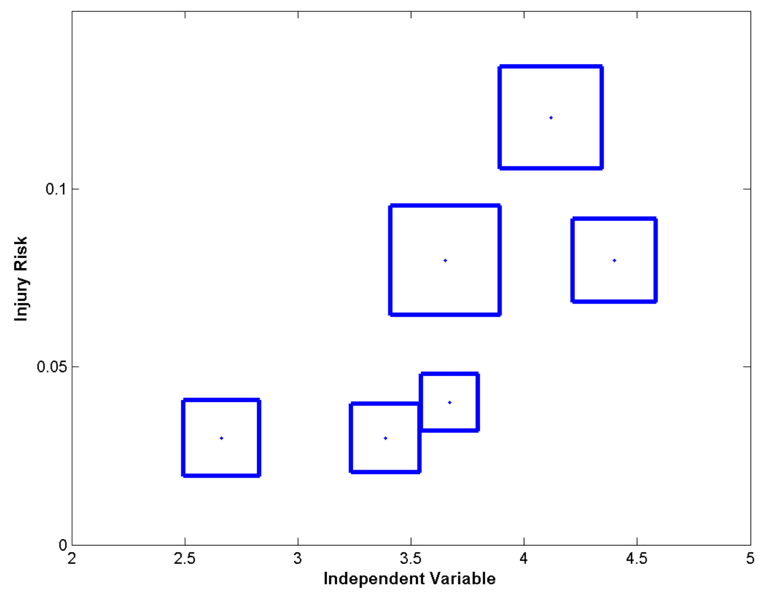


Figure 2-1: A diagram in which confidence intervals for both the injury risk and the independent variable, e.g. upper neck load, have been plotted.

In this part of the study the VW group test data is further analysed to study variability (Table 2-1). The result of this analysis is provided in Table 2-2. This shows that for some parameters the variability was large. Some explanations for some of the variability include the following: the tests were carried out over a three year period; at two separate test facilities, using different dummies, dummy versions; un-calibrated and different makes of the H-point machine and HRMD devices were used, the positioning protocols were not identical; seats from different car models were used; and seat covering of different materials.

The coefficient of variation (CV) was calculated for an improved understanding of the spread in response data between seat tests; CVs were calculated as the estimates of standard deviation expressed as a percentage of the mean peak value for each peak parameter or criterion value.

Table 2-1: VW group test conditions including test facility and build level, initial horizontal head-to-head-restraint distance (back set)

Make, model and production period	Test facility facility	BioRID II build level	H-point [1] machine	Year tested	Backset (mm)
VW Touran 03-	Thatcham	G	AA	2004	74
VW Touran 03-	Autoliv	E	TS	2004	80
VW Passat 05-07	Thatcham	G	AA	2006	59
VW Golf/Jetta 04-	Thatcham	G	AA	2004	66
VW Golf/Jetta 04-	Thatcham	G	AA	2006	64
Audi A4 01-06	Thatcham	G	AA	2006	57
Audi A3 03-04	Autoliv	E	TS	2004	80
Audi A6 05-06	Autoliv	E	TS	2005	55
Audi A6 05-06	Thatcham	G	AA	2006	58
Audi A6 05-06	Thatcham	G	AA	2004	57
Skoda Octavia 05-	Autoliv	E	TS	2005	76
Skoda Octavia 05-	Thatcham	G	AA	2006	91
Seat Altea 04-	Thatcham	G	AA	2006	58

[1] The two H-point machines that were used:

TS TechnoSports, Inc., USA.

AA Automotive Accessories, Ltd., UK .

Table 2-2: Mean, range and coefficient of variation for the 13 tests included in the VW group with reactive head restraint. Such tests can, if the mean value is low and far from the injury reference value, indicate a large variation in the test data despite a relatively good reproducibility. This is true for some of the neck loads for which the mean values are most likely below injury level.

	NIC (m2/s2)	Nkm	LNL	HCT (s)	HRV (m/s)	U.N.Fx (head r.w.) (N)	U.N.Fx (head f.w.) (N)	U.N.Fz (tension) (N)	U.N.Fz (compression) (N)	U.N.My (positive) (Nm)	U.N.My (negative) (Nm)	L.N.Fx (head r.w.) (N)	L.N.Fx (head f.w.) (N)	L.N.Fz (tension) (N)	L.N.Fz (compression) (N)	L.N.My (positive) (Nm)	L.N.My (negative) (Nm)	T1 x-acceleration (g)	T1 z-acceleration (upward) (g)	T1 z-acceleration (downward) (g)	Head x-acceleration (g)	Head z-acceleration (g)	C4 x-acceleration (g)	C4 z-acceleration (g)	T8 x-acceleration (g)	T8 z-acceleration (g)	L1 x-acceleration (g)	L1 z-acceleration (g)	Pelvis x-acceleration (g)	Pelvis z-acceleration (g)
Mean	23	0,4	3,2	68	4,8	183	-55	648	-90	19	-4	459	-32	325	-135	3	-16	13	5	-3	26	7	19	10	11	3	8	6	13	6
Max	28	0,6	3,8	92	5,3	265	-13	894	-69	30	0	551	-10	520	-71	27	-13	18	9	-2	33	9	25	11	13	4	12	8	15	7
Min	17	0,2	2,7	57	4,5	129	-299	502	-121	9	-8	360	-105	150	-322	0	-18	11	2	-6	24	6	17	8	0	3	2	4	11	4
CV (%)	11	**23**	12	12	4	**21**	**-142**	**18**	**-18**	**37**	**-68**	11	**-77**	**39**	**-48**	**230**	-11	15	**38**	**-35**	9	13	11	9	**32**	12	**46**	**26**	8	11
N	13	13	7	13	10	13	12	13	12	13	12	13	12	13	12	13	12	13	12	12	13	12	12	12	12	12	12	12	13	12

Appendix III: Test data used to estimate the median dummy injury criteria and parameter values

A mathematical method 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 analyses were carried out using the median value for each parameter for each parameter of all available seat test data (Table 3-1).

Table 3-1: Car groups, car models and production period, year the seat was tested, test facility, BioRID II build level, H-point machine, initial horizontal head-to-head-restraint distance (back set).

Groups	Model	Year tested	Test facility	BioRID II build level	H-point machine[2]	Backset (mm)
Hyundai with STD	Santa FE 00-05	2004	Thatcham	G	AA	61
	Accent 99-06	2004	Thatcham	G	AA	68
	Elantra 04-	2004	Thatcham	G	AA	100
Peugeot with STD	206 98-05	2004	Thatcham	G	AA	76
	307 01-	2006	Thatcham	G	AA	51
Mercedes with STD	C-class 93-01	2004	Thatcham	G	AA	55
	E-class 96-01	2004	Thatcham	G	AA	46
Opel with STD	Astra 98-04	2004	Thatcham	G	AA	72
	Meriva 03- (No AHR)	2004	Autoliv	E	TS	105
	Meriva 03- (No AHR)	2004	Thatcham	G	AA	79
Saab with SAHR	9-5 98-09	2004	Thatcham	G	AA	56
	9-5 98-09	2004	Autoliv	E	TS	40
	9-3 98-02	2006	Thatcham	G	AA	40
	9-3 03-	2004	Thatcham	G	AA	56
	9-3 98-02	2006	Thatcham	G	AA	57
Volvo with WHIPS	V/S70 00-06	2004	Thatcham	G	AA	32
	S40/V40 00-04	2004	Thatcham	G	AA	47
	S40/V50 04-	2004	Autoliv	E	TS	45
	V/S70 00-06	2006	Autoliv	G	AA	40
	S60 01-09	2004	Thatcham	G	AA	47
	S40/V50 04-	2006	Thatcham	G	AA	25
Toyota with WIL	Avensis 03-08	2004	Autoliv	E	TS	75
	Avensis 03-08	2004	Thatcham	G	AA	50
	Corolla 02-07	2005	Autoliv	E	TS	95
	Corolla 02-07	2005	Thatcham	G	AA	62
	Prius 04-09	2005	Autoliv	E	TS	72
	Prius 04-09	2006	Thatcham	G	AA	66
	Corolla Verso 04-10	2005	Autoliv	E	TS	95
	Yaris 99-05	2004	Thatcham	G	AA	66
	Yaris 05-	2006	Thatcham	G	AA	92
VW group STD small	Seat Ibiza 03-	2004	Thatcham	G	AA	77
	Seat Ibiza 03-	2004	Autoliv	E	TS	50
	Seat Altea 04-	2004	Thatcham	G	AA	65
	Skoda Fabia 00-	2004	Thatcham	G	AA	101
	VW Polo 02-	2004	Thatcham	G	AA	63
VW group STD medium	Audi A3 96-03	2004	Thatcham	G	AA	59
	VW Golf/Bora 98-04	NA	Thatcham	G	AA	NA
	Skoda Octavia 97-04	2004	Thatcham	G	AA	88
VW group STD large	Skoda Superb 02-08	2004	Thatcham	G	AA	99
	VW Passat 97-05	NA	Thatcham	G	AA	NA

VW group with RHR	VW Touran 03-	2004	Thatcham	G	AA	74
	VW Touran 03-	2004	Autoliv	E	TS	80
	VW Passat 05-07	2006	Thatcham	G	AA	59
	VW Golf/Jetta 04-	2004	Thatcham	G	AA	66
	VW Golf/Jetta 04-	2006	Thatcham	G	AA	64
	Audi A4 01-06	2006	Thatcham	G	AA	57
	Audi A3 03-04	2004	Autoliv	E	TS	80
	Audi A6 05-06	2005	Autoliv	E	TS	55
	Audi A6 05-06	2006	Thatcham	G	AA	58
	Audi A6 05-06	2004	Thatcham	G	AA	57
	Skoda Octavia 05-	2005	Autoliv	E	TS	76
	Skoda Octavia 05-	2006	Thatcham	G	AA	91
	Seat Altea 04-	2006	Thatcham	G	AA	58

[1]Test only included for complementary data

[2]TS refers to TechnoSports, Inc., USA; AA refers to Automotive Accessories, Ltd., UK.