Evaluation of Seat Performance Criteria for Rear-end Impact Testing

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Folksam Research and Chalmers University of Technology
Objective

• Overall objective
  – Seat performance criteria to be used in rear-end impact seat tests with BioRID II.

• This presentation
  – Differences compared to interim report and ESV paper
  – Materials and Methods
  – Results
  – Discussion
  – Conclusions
Difficult to develop injury risk curves for WAD

- Traditional approach
- Whiplash Associated Disorders

Phase 1
Phase 2
Phase 3
Studies of injury thresholds for a dummy

• PMHS studies
  — Assessment of injuries and relate these to symptoms
  — PMHS parameter measurements to be related to dummy measurements

• Volunteer studies
  — Sub-injury level
  — Volunteer parameter measurements to be related to dummy measurements

• Reconstruction of accidents using Human Body Models
  — Injury thresholds for some tissues unknown
  — Initial posture of occupants unknown
  — Human Body Model parameter measurements to be related to dummy measurements

• Reconstructions of accidents using crash test dummy
  — Initial posture of occupants unknown
  — Large number of cases required
Principle method

- Find correlations between injury risks, as calculated from insurance data, and BioRID measurements

Folksam insurance data
Injury Claim data from rear-end impacts

Measure of risk of injury
Measurements from sled tests with the BioRID

Correlation coefficient $R^2 = \text{measure of the strength of the relationship}$
Methods: Data used

**Insurance data**
- Folksam insurance data; 1998 and 2011
  - Only drivers
  - Only neck related injuries
  - Only rear +/-30 deg.
  - Only data with complete records
- All with initial symptoms
- Risk of symptoms for more than one month (> 1 month)
- Risk of permanent medical impairment (Permanent)

**Seat test data**
- Test by
  - Thatcham, 2004 and 2012
- BioRID II build level E or G
- H-point tool:
  - TechnoSports, Inc.,
  - Automotive Accessories, Ltd.
Methods: Grouping insurance data

- Individual vehicle models… Audi A3 ≠ VW Golf
- Similar risk
- Seats from different vehicles in which the seat design was (about) the same

![Graph showing risk vs NIC (m²/s²)]
**Methods: Insurance data**

<table>
<thead>
<tr>
<th>Ford with STD</th>
<th>Saab with STD newer</th>
<th>Volvo with WHIPS</th>
</tr>
</thead>
<tbody>
<tr>
<td>Focus</td>
<td>Saab 900</td>
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<td>Mondeo</td>
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<table>
<thead>
<tr>
<th><strong>Hyundai with STD</strong></th>
<th><strong>Saab with SAHR</strong></th>
<th><strong>Volvo with WHIPS</strong></th>
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<td>07-</td>
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<td>Matrix</td>
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<td>Santa Fe</td>
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<table>
<thead>
<tr>
<th><strong>Mercedes with STD</strong></th>
<th><strong>Toyota with STD</strong></th>
<th><strong>VW group with STD</strong></th>
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<tbody>
<tr>
<td>A-class</td>
<td>Avenis</td>
<td>Seat Ibiza/Cordoba</td>
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<tr>
<td>C-class</td>
<td>98-04</td>
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<tr>
<td>E-class</td>
<td>93-01</td>
<td>Seat Ibiza</td>
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<td>CLK</td>
<td>96-01</td>
<td>03-</td>
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<td>E-class</td>
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<td>VW Polo</td>
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<table>
<thead>
<tr>
<th><strong>Opel with STD</strong></th>
<th><strong>Toyota with WIL</strong></th>
<th><strong>VW group with STD</strong></th>
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<tr>
<td>Astra</td>
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<td>Corsa</td>
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<td>Omega</td>
<td>03-</td>
<td>Seat Toledo/Leon</td>
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<td>Vectra</td>
<td>94-03</td>
<td>Skoda Octavia</td>
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<td>Zafira</td>
<td>96-98</td>
<td>VW Bora</td>
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<td>VW Golf</td>
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<table>
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<tr>
<th><strong>Peugeot with STD</strong></th>
<th><strong>Volvo with STD older</strong></th>
<th><strong>VW group with STD</strong></th>
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<tbody>
<tr>
<td>206</td>
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<td>307</td>
<td>01-</td>
<td>Audi A6</td>
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<td>406</td>
<td>04-</td>
<td>95-97</td>
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<tr>
<td>605</td>
<td>96-94</td>
<td>Audi TT</td>
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<tr>
<td>607</td>
<td>90-98</td>
<td>03-05</td>
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<td>307</td>
<td>01-</td>
<td>Seat Altea</td>
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<tr>
<td>Saab 900</td>
<td>88-93</td>
<td>05-</td>
</tr>
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<td>Saab 9000</td>
<td>85-97</td>
<td>Seat Toledo/Leon</td>
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<table>
<thead>
<tr>
<th><strong>Saab with STD older</strong></th>
<th><strong>Volvo with STD</strong></th>
<th><strong>VW group with STD</strong></th>
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<tbody>
<tr>
<td>Saab 900</td>
<td>94-98</td>
<td>Audi A3</td>
</tr>
<tr>
<td>Saab 9000</td>
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<td>AUDI TT</td>
</tr>
<tr>
<td></td>
<td></td>
<td>98-02</td>
</tr>
</tbody>
</table>

**VW group with STD medium**

- **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**

- **Audi A4**: 95-00
- **Audi A6**: 95-97
- **Audi TT**: 98-05
- **Skoda Superb**: 02-05
- **VW Passat**: 97-05

**VW group with RHR**

- **Audi A3**: 03-04
- **Audi A4**: 05-06
- **Seat Altea**: 01-06
- **Audi A6**: 05-06
- **VW Touran**: 03-05
- **Seat Toledo/Leon**: 05-05
- **Skoda Octavia**: 05-05
- **VW Golf/Jetta**: 04-05
- **VW Passat**: 05-05
## Methods: Seat test data

<table>
<thead>
<tr>
<th>Groups</th>
<th>Model</th>
<th>Prod. year</th>
<th>Year tested</th>
<th>Test Facility</th>
<th>BioRID II version</th>
<th>H-point machine ²</th>
<th>Backset (mm)</th>
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<tbody>
<tr>
<td>Hyundai</td>
<td>Hyundai Santa Fe</td>
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<td>2004</td>
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<td>G</td>
<td>AA</td>
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<tr>
<td>Ford</td>
<td>Ford Focus I</td>
<td>99-06</td>
<td>2004</td>
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<td>TS</td>
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<tr>
<td>Mercedes</td>
<td>Mercedes C-class</td>
<td>93-01</td>
<td>2004</td>
<td>Thatcham</td>
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<tr>
<td>Opel</td>
<td>Opel Astra</td>
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<td>2004</td>
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<td>SAAB 900</td>
<td>94-98</td>
<td>2006</td>
<td>Autoliv</td>
<td>G</td>
<td>AA</td>
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<tr>
<td></td>
<td>9000</td>
<td>85-97</td>
<td>2012</td>
<td>Thatcham</td>
<td>G</td>
<td>AA</td>
<td>48</td>
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<td></td>
<td>9-5</td>
<td>98-09</td>
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<td>AA</td>
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<td>TS</td>
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<td>Yaris</td>
<td>99-05</td>
<td>2004</td>
<td>Thatcham</td>
<td>G</td>
<td>AA</td>
<td>66</td>
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<tr>
<td>Volvo</td>
<td>700/900</td>
<td>82-98</td>
<td>2012</td>
<td>Thatcham</td>
<td>G</td>
<td>AA</td>
<td>17</td>
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<td>2006</td>
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<td>AA</td>
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<td>VW small</td>
<td>VW Polo</td>
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<td>2004</td>
<td>Thatcham</td>
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<td>AA</td>
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<tr>
<td>VW medium</td>
<td>Seat Altea</td>
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<td>2004</td>
<td>Thatcham</td>
<td>G</td>
<td>AA</td>
<td>65</td>
</tr>
<tr>
<td>VW large</td>
<td>Skoda Superb</td>
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<td>2004</td>
<td>Thatcham</td>
<td>G</td>
<td>AA</td>
<td>85</td>
</tr>
<tr>
<td>VW RHR</td>
<td>Audi A6</td>
<td>05-06</td>
<td>2005</td>
<td>Autoliv</td>
<td>E</td>
<td>TS</td>
<td>55</td>
</tr>
</tbody>
</table>

Note 2: TS refers to TechnoSports, Inc., USA and AA refers to Automotive Accessories, Ltd., UK
Methods: Studied parameters

- 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 ($F_x$, $F_z$, and $M_y$, before head contact stop)
- Maximum and minimum Lower Neck Loads ($F_x$, $F_z$, 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)
- Maximum Head rel. T1 angular displacement
- Head Contact Time (HCT)
- Maximum Head Rebound Velocity (HRV)
Methods: Compensation for classification over accident year

- This allowed for inclusion of cars popular towards the end of the sampling period.

<table>
<thead>
<tr>
<th></th>
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<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>-1978</td>
<td>17,1%</td>
<td>14,3%</td>
<td>11,3%</td>
<td>5,5%</td>
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</tr>
<tr>
<td>1979-1981</td>
<td>17,2%</td>
<td>14,9%</td>
<td>9,6%</td>
<td>6,5%</td>
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<tr>
<td>1982-1984</td>
<td>19,2%</td>
<td>14,2%</td>
<td>9,9%</td>
<td>5,7%</td>
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</tr>
<tr>
<td>1985-1987</td>
<td>18,0%</td>
<td>14,2%</td>
<td>10,0%</td>
<td>6,6%</td>
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</tr>
<tr>
<td>1988-1990</td>
<td>14,5%</td>
<td>13,4%</td>
<td>9,9%</td>
<td>6,8%</td>
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</tr>
<tr>
<td>1991-1993</td>
<td>16,8%</td>
<td>11,6%</td>
<td>8,6%</td>
<td>5,8%</td>
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</tr>
<tr>
<td>1994-1996</td>
<td>12,4%</td>
<td>12,4%</td>
<td>8,8%</td>
<td>5,9%</td>
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<td>1997-1999</td>
<td>16,9%</td>
<td>12,0%</td>
<td>8,7%</td>
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<tr>
<td>2000-2002</td>
<td>2,6%</td>
<td>7,4%</td>
<td>5,8%</td>
<td>4,7%</td>
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<tr>
<td>2003-2005</td>
<td></td>
<td>5,8%</td>
<td></td>
<td></td>
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<tr>
<td>2006-2008</td>
<td></td>
<td></td>
<td></td>
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</tr>
<tr>
<td>All model years</td>
<td>16,5%</td>
<td>13,4%</td>
<td>9,6%</td>
<td>6,0%</td>
<td></td>
</tr>
</tbody>
</table>

% should be equal over the accident years
Differences compared to interim report and ESV paper

"Whiplash risk reduction after adjustment for accident year"
## Results: Correlation $R^2$ values

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Permanent medical impairment</th>
<th>Symptoms &lt; 1 month</th>
</tr>
</thead>
<tbody>
<tr>
<td>NIC</td>
<td>0.70</td>
<td>0.73</td>
</tr>
<tr>
<td>OC rel. T1 x-displacement</td>
<td>0.46</td>
<td>0.57</td>
</tr>
<tr>
<td>L1 x-acceleration</td>
<td>0.40</td>
<td>0.44</td>
</tr>
<tr>
<td>Head rel. T1 y-rot. (extension)</td>
<td>0.39</td>
<td>0.57</td>
</tr>
<tr>
<td>Pelvis z-acceleration</td>
<td>0.33</td>
<td>0.22</td>
</tr>
<tr>
<td>L1 z-acceleration</td>
<td>0.30</td>
<td>0.24</td>
</tr>
<tr>
<td>$N_{km}$</td>
<td>0.27</td>
<td>0.44</td>
</tr>
<tr>
<td>T8 x-acceleration</td>
<td>0.27</td>
<td>0.38</td>
</tr>
<tr>
<td>L.N.Fx (head f.w.)</td>
<td>0.26</td>
<td>0.16</td>
</tr>
<tr>
<td>U.N.Fx (head r.w.)</td>
<td>0.22</td>
<td>0.39</td>
</tr>
<tr>
<td>T1 x-acceleration</td>
<td>0.19</td>
<td>0.39</td>
</tr>
<tr>
<td>T8 z-acceleration</td>
<td>0.19</td>
<td>0.10</td>
</tr>
<tr>
<td>L.N.My (negative)</td>
<td>0.18</td>
<td>0.34</td>
</tr>
<tr>
<td>T1 z-acceleration (upward)</td>
<td>0.12</td>
<td>0.27</td>
</tr>
</tbody>
</table>
## Results: Correlation $R^2$ values

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Permanent medical impairment</th>
<th>Symptoms &lt; 1 month</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Complete</td>
<td>Maximum</td>
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<tr>
<td>NIC</td>
<td>0,70</td>
<td>0,83</td>
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<tr>
<td>OC rel. T1 x-displacement</td>
<td>0,46</td>
<td>0,52</td>
</tr>
<tr>
<td>L1 x-acceleration</td>
<td>0,40</td>
<td>0,55</td>
</tr>
<tr>
<td>Head rel. T1 y-rot. (extension)</td>
<td>0,39</td>
<td>0,45</td>
</tr>
<tr>
<td>Pelvis z-acceleration</td>
<td>0,33</td>
<td>0,46</td>
</tr>
<tr>
<td>L1 z-acceleration</td>
<td>0,30</td>
<td>0,61</td>
</tr>
<tr>
<td>$N_{km}$</td>
<td>0,27</td>
<td>0,37</td>
</tr>
<tr>
<td>T8 x-acceleration</td>
<td>0,27</td>
<td>0,41</td>
</tr>
<tr>
<td>L.N.F$_x$ (head f.w.)</td>
<td>0,26</td>
<td>0,36</td>
</tr>
<tr>
<td>U.N.F$_x$ (head r.w.)</td>
<td>0,22</td>
<td>0,34</td>
</tr>
<tr>
<td>T1 x-acceleration</td>
<td>0,19</td>
<td>0,33</td>
</tr>
<tr>
<td>L.N.M$_y$ (negative)</td>
<td>0,18</td>
<td>0,26</td>
</tr>
<tr>
<td>T1 z-acceleration (upward)</td>
<td>0,12</td>
<td>0,28</td>
</tr>
</tbody>
</table>
Results: NIC versus permanent medical impairment

Permanent risk versus NIC

- Ford
- Hyundai
- Mercedes
- Opel
- Peugeot
- Saab STD
- Toyota STD
- Volvo STD
- VW STD
- VW RHR

Risk vs. NIC (m²/s²)
Results: Occipital rel. T1 x-disp. versus permanent medical impairment
Results: L1x-acc. versus permanent medical impairment

Permanent risk versus L1 x-acc.
Results: Head Contact Time versus permanent medical impairment
Discussion 1: Effect of outliers

R² = 0.39 for 17 datasets
R² = 0.66 for 16 datasets
R² = 0.81 for 15 datasets
Discussion 2: Is the risk reduction only due to vehicle mass increase?
Discussion 3: Differences compared to interim report and ESV paper

• Seat test selection criteria modified
  – 12 Thatcham tests and 5 Autoliv tests
• Number of insurance cases and seat tests included
  – 2976 cases and 11 vehicle groups in 2011 report
  – 6665 cases and 12 vehicle groups in the ESV paper
  – 7453 cases and 17 vehicle groups in this report
• Accident sampling period reduced due to lack of control of crash direction prior to 1998
• Seat groups now more homogeneous
  – Vehicle mass range from 1023 to 1533 kg
  – 44% to 67% were females
Discussion 4: Injury risk measures

• About 35% of rear-end impacts in Sweden with modern cars results in initial symptoms
  3.5% risk in case you have initial symptoms = 1.2% risk in case you are in a collision
• Risk of initial symptoms and long term symptoms proportional for most vehicle models
Discussion 5: Compared to GTR Phase II

• Risk Curves of IV-NIC(R) for Flexion:
  — The Risk Curve ($R^2=0.49$) from 20 cases accident simulation
  — The Risk Curve ($R=0.72$) from PMHS tests (17km/h and 24km/h)
Conclusions 1

• Grouping of seats is an important aspect of the methodology
• Issues with the reliability of some of the seat tests
Conclusions 2

• NIC, Occipital condyles relative T1 x-displacement and L1 x-acceleration correlate with long term injury risk.

• Initial recommendations for tolerance levels have been made (NIC, Occipital condyles relative T1 x-displacement and L1 x-acceleration)

• Neck extension, Nkm, Upper Neck Fx and T1 x-acceleration may be candidates but appear to be sensitive to set model inclusion

• Additional parameters may predict PMI and long term symptoms.
End!

Many thanks to Thatcham and Autoliv for providing BioRID seat test data!
Remarks during the meeting

• There were remarks on some of the assumptions that was made to facilitate this study.
  — Compensation for coding differences of injury risk over the years the accidents were collected
  — Grouped data was used
  — Data was used that originated from tests that were carried out according to state of the art procedures. These procedures, calibration routines and dummy build level have been updated since then.
  — Single delta V and single acceleration pulses were used that did not match the insurance data
  — Were also injuries to other body regions included
• In the following pages additional information related to these comments will be presented.
Compensation for coding differences of injury risk

• Background
  – A continuously more strict attitude to accept a final impairment degree by the Swedish social insurance agency could be identified during the sampling period.
  – A method to compensate for this change have been developed that is independent of the introduction of improved seat systems or vehicle model updates.
  – Groups were established for which the year of first introduction was identical (grouped into 3 year periods)( a seat model change or similar results in a new year of introduction).
  – Average risks were calculated for these groups for 3 year intervals.
  – A trend line was calculated for each group.
  – These trend lines were found to be rather consistent among different groups (with identical year of first introduction).
  – An average trend line was calculated and used to compensate for injury impairment setting change.

• Text that explains how this was carried out (next page):
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. Identically, the reduction in classification of those with symptoms lasting for longer than 1 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 year 2010. By doing an adjustment for accident year for each crash injury outcomes from all cars could be compared with each other.
Grouped data was used

- For the included groups a thorough study to identify differences in seat design between vehicle models were carried out.
- Only groups with rather consistent seat designs were used in this study.
Data was used that originated from tests that were carried out according to state of the art procedures. These procedures, calibration routines and dummy build level have been updated since then.

- These routines are established mainly to reduce the scatter in responses and not to shift the responses.
- Carrying out this study with newest build level and calibration routines would most likely reduce scatter and improve the power of this study.
- Carrying out this study with second hand seats, of which a few would be rather old, is an option but also introduces uncertainties.
Single delta V and single acceleration pulses were used that did not match the insurance data

- The purpose with the study is to determine if a single test with the BioRID II can be used to assess risk of long-term symptoms following a rear-end impact.
- Hence a single representative pulse was used.
- A slightly higher delta-V would provide better match between the real life pulse and the test pulse.
Were also injuries to other body regions included

- Only neck related injuries that was cased in rear (+/-30 deg) end impacts were included.