Evaluation of Seat Protection in Low to Medium Severity Rear Impacts by Means of the BioRID II and Double Peak Crash Pulses

Ted Olsson[a], Niklas Truedsson[a], Astrid Linder[a,b], Andrew Morris[a], Brian Fildes[a]

[a]Accident Research Centre, PO Box 70A, Monash University, Victoria, Australia
[b]Department of Machine and Vehicle Systems, Chalmers University of Technology, Göteborg, Sweden

Laurie Sparke, Holden Ltd, Australia

Abstract - Whiplash injuries (AIS 1 neck injuries) are still common in rear impacts, but research has shown the importance of seat design in order to reduce this type of injury. The aim of the study was to evaluate a number of seat configurations to assess the whiplash injury risk at different severities.

A total of 21 sled tests were performed with 4 different severities and 5 different seat configurations. The dummy used was the BioRID II. The crash pulse was of the double peak type with either 60 or 120 m/s^2 as a maximum. The Delta-V was either 15 or 25 km/h.
The results show that seat design and restraint systems have a significant impact on the dummy kinematics in a low to medium severity rear impact. NIC_{max} values between 7 and 35 m^2/s^2 were produced. Furthermore, upper neck tension forces (Fz) between 180 and 1680 N were produced. Several other parameters were evaluated including the upper neck moment, and head angular acceleration.
The result shows that the same Delta-V generated with different pulse shapes can significantly alter the dummy response. Also of importance is that the dummy possibly needs to be more biofidelic in medium severity rear impacts since there is a risk of an artefact in the interaction between the head restraint and the upper back of the dummy. This is likely to be the case for the Hybrid III dummy as well.

The anti-whiplash seats included in this study are likely to provide increased protection in low and medium severity rear impacts. A good seat design as determined by the BioRID involves controlled displacement and yielding of the seat above a certain severity in combination with support for the whole spine.

Keywords: whiplash, neck injury, rear impact, seat, BioRID

Introduction - Seat design seems to be the most crucial parameter in reducing the number of whiplash injuries occurring in rear impacts. Parkin et al., (1995), Håland et al., (1996), Krafft (1998), Svensson et al., (1998) and Hofinger et al., (1999) among others, have shown that seatback stiffness, upholstery characteristics and head restraint design, and other parameters, are important in reducing both the risk and the severity of a AIS 1 neck injury.

Krafft et al., (2001) has shown that there is a correlation between injury risk and change of velocity (Delta-V) as well as mean acceleration in a rear impact. The knowledge was gained by evaluation of crash pulse recorder data from four different Toyota models in Sweden and a medical interview with the occupant. In the study, which included forty nine occupants, it was found that nearly all sustained whiplash injuries and displayed symptoms for more than one month when the Delta-V was higher than 15 km/h and the peak acceleration was more than approximately 100 m/s^2. Based on these new insights into the complexity of the influence of impact severity on the risk of AIS (AAAM, 1990) 1 neck injuries several impact severities might be needed to evaluate the protective performance of different seat designs.

Aim - The aim of the study was to evaluate a number of seat configurations to assess the protective performance at different severities in rear impacts.

Materials and Methods - Five different seat configurations were exposed to four different impact severities in a HyGe sled. The acceleration pulse shape was a double pulse shape with two peaks at the same level of acceleration. The impact severities were chosen at two different Delta-Vs, 15 km/h and 25 km/h, and two different peak acceleration levels, 60 m/s^2 and 120 m/s^2 (Figure 1). The acceleration levels were chosen from field data representing a medium and high risk of AIS 1 neck injuries (Krafft et al., 2001).

A 50[th] percentile male BioRID II dummy (Davidsson, 1999) was positioned in the seat in the normal restrained position and was subjected to each of the four conditions. It is thought that the BioRID II offers the closest approximation of occupant motion. Therefore, this dummy was used in this study. The study was limited to examining five types of seat configurations, one dummy size and position and four different impact severities.

SEATS – Five different seat designs were exposed to four different impact severities. A total of 21 new seats were used in the test series, one for each test. Two different anti-whiplash seats were tested, chosen on the basis that preliminary results from real-world crashes show a significant decrease in AIS 1 neck injury risk for the occupants of these seats in a rear impact.

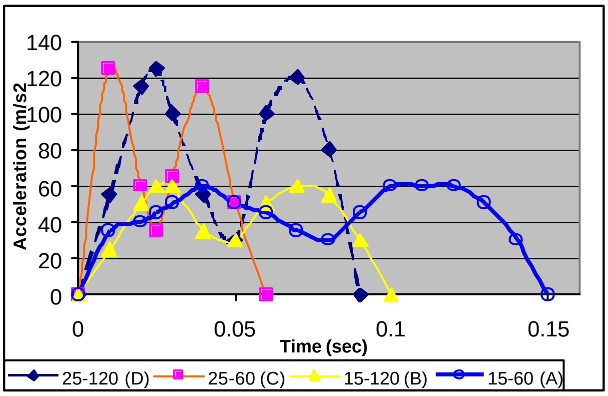

Figure 1. *The four different severities and the pulse shape, Delta-V 15 and 25 km/h and peak accelerations close to 60 and 120 m/s^2.*

Seatbelt – The same type of seatbelt and geometry was used in all tests because it was believed that the measurement of the belt force in the rebound phase would be more comparable.

Seat cushion – If available, the seat cushion adjustment was put in its lowest position and the lumbar support was unengaged in all tests.

Seat back angle – The seat back angle was adjusted so that the coordinate system of the dummy head was parallel to the coordinate system of the room. The seat back angle of the Volvo seats was 19?, Saab 21?and the Holden seats 22?.

Head-head restraint distance – The head-head restraint distance depended on the normal position of the BioRID dummy. For the Saab and Volvo seats the distance was 50 mm in all tests and for the Holden seat it was 90 mm in all tests.

The Volvo seat - The seat is a production seat that is installed in all new Volvo cars (Jakobsson et al. 2000). The seat has energy absorbing recliners, a fixed head restraint and modified backrest, among other features. No modifications were made to the seat except for the change of seatbelt buckle.

The Saab seat – The seat is currently installed in all new SAAB vehicles (Wiklund and Larsson, 1998) and one of its features is the active head restraint which was put in the highest position. The seat also absorbs energy in the recliner area and has a modified backrest. The seats used at Delta-V 15 km/h could be folded forward and had a leather cover.

The seats used at Delta-V 25 km/h could not be folded forward and had a fabric cover. A seat belt pretensioner is fired when a rear impact occurs above a certain severity in Saab vehicles. No seatbelt pretensioner was fired in any test performed. No modifications were made to the seats except for the change of seatbelt buckle.

Holden seat with head restraint in lowest position - The Holden seat with head restraint put in the lowest position.

Holden seats with headrestraint in highest position - The Holden seat with the head restraint put in the highest position.

Reinforced seat - The reinforced seat was a Holden seat with the back frame reinforced and head restraint put in lowest position. Three bars were attached to the seat back frame and also mounted onto the sled. One reinforcement bar attached to the top horizontal back frame bar and two bars attached to the recliners on either side. This made the back frame very stiff.

Table 1. *Test number, seat types and impact severities in the sled tests.*

Number	Seats	Impact severity
605	Volvo WHIPS	(D) 25 km/h, 120 m/s2
37	Volvo WHIPS	(C) 25 km/h, 60 m/s2
606	Volvo WHIPS	(B) 15 km/h, 120 m/s2
607	Volvo WHIPS	(B) 15 km/h, 120 m/s2
608	Volvo WHIPS	(A) 15 km/h, 60 m/s2
609	Saab 9-5 SAHR	(D) 25 km/h, 120 m/s2
610	Saab 9-5 SAHR	(C) 25 km/h, 60 m/s2
611	Saab 9-3 SAHR	(B) 15 km/h, 120 m/s2
612	Saab 9-3 SAHR	(A) 15 km/h, 60 m/s2
597	Holden HR up	(D) 25 km/h, 120 m/s2
599	Holden HR up	(C) 25 km/h, 60 m/s2
598	Holden HR up	(B) 15 km/h, 120 m/s2
600	Holden HR up	(A) 15 km/h, 60 m/s2
593	Holden HR down	(D) 25 km/h, 120 m/s2
595	Holden HR down	(C) 25 km/h, 60 m/s2
594	Holden HR down	(B) 15 km/h, 120 m/s2
596	Holden HR down	(A) 15 km/h, 60 m/s2
601	Holden reinforced	(D) 25 km/h, 120 m/s2
603	Holden reinforced	(C) 25 km/h, 60 m/s2
602	Holden reinforced	(B) 15 km/h, 120 m/s2
604	Holden reinforced	(A) 15 km/h, 60 m/s2

INSTRUMENTATION – For each test the BioRID II (Davidsson, 1999) was equipped with accelerometers at the pelvic, L1, T8, T1 and C4 levels. The dummy head was equipped with one accelerometer at the centre of gravity of the head and one at the inside top of the head. The upper neck was equipped with a load cell. The transducer data was sampled at 10.000 Hz and filtered according to the SAE J211 recommendations. Positive x-direction is forward and positive z-direction downward. Forward rotation around the y-axis is positive.

The seat was equipped with one potentiometer attached to the upper cross member of the seat back and one at the centre level of the seat recliner (Figure 3). One belt force sensor over the shoulder (Figure 3) and one over the pelvis was used to measure the belt force. An electronic circuit was created when the head was in contact with the head restraint, which measured the head-head restraint contact time.

Film - A high-speed digital video camera and an on-board film camera recorded the tests at 1000 fps. The films were analysed using the software TrackEye. Head centre of gravity and T1 linear and angular displacement and also the head and T1 velocity at zero position before significant seat belt contact were derived from the video. The displacement data is further evaluated in Linder et al., (2001).

Calculations – The NIC_{max} was calculated according to Boström et al., (2000). The head angular acceleration was calculated as in Langwieder et al., (2000). The head and T1 rebound velocity relative to the sled is defined as the velocity after the dummy torso has no significant contact with the seat back and before significant belt force occurs.

Figure 2. *Test set-up for the sled tests with the BioRID II in a Holden seat.*

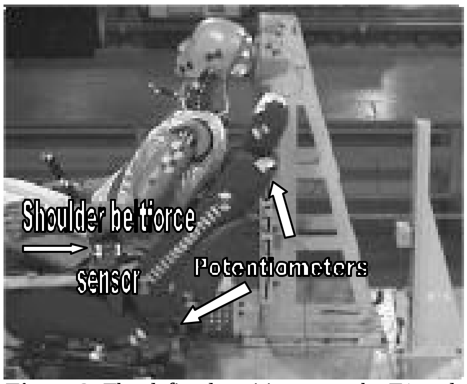

Figure 3. *The defined position were the T1 and head velocity was measured (Number 597).*

Results - Parameters that describe the dummy dynamics and the seat back interaction are presented as maximum values in Tables 1 and 2. In the A severity tests, only the Volvo and Saab systems produced NIC_{max} less than 15 m^2/s^2 which is the preliminary estimation for avoiding long-term injuries. Maximum NIC_{max} can occur both before and after head to head restraint contact. In the Holden seats the NIC_{max} always occurred before head to head restraint contact and in the Volvo and Saab seats always after head to head restraint contact. Maximum Fz (upper neck) tension and head angular acceleration always occurred during head to head restraint contact for all tests and was always higher in the Holden seats relative to the Volvo and Saab seats when comparing different severities.

The head angular acceleration was lowest in the Saab seats and highest in the reinforced Holden seats. The NIC_{max} , upper neck tension and head angular acceleration were all higher and the head-head restraint contact occurred later in the Holden seats with the head restraint down compared with the Holden tests with the head restraint up. Time until maximum belt force occurred was highest in the Volvo seats and lowest in the reinforced Holden seats. Depending on severity, the lowest belt force was found in either the reinforced Holden seats or the Volvo seats. The Mocy (upper neck moment) in the rebound phase always occurred after maximum belt force. The difference in velocity between T1and head in the rebound phase was generally lower in the anti–whiplash seats.

Generally the spine curvature was kept more intact in the Volvo and SAHR seats. The exception was test 605 with the Volvo seat where the dummy head centre of gravity came over the top of the head restraint due to ramping. This caused a higher NIC_{max} and upper neck tension force. A higher upper neck tension force was correlated with the dummy head striking the head restraint from above. In the D severity tests (Table 1) a certain degree of ramping could be seen in all tests. The least ramping was observed in the tests with the reinforced.

Table 2. *Recliner displacement, upper seatback reclining, NIC_{max}, head-head restraint contact time, upper neck tension (Fz), and head angular acceleration data from the tests.*

Number	Max x-d. of recliner (mm) at time (ms)	Static x-d. of recliner (mm) at time (ms)	Max x-d. of upper frame (mm) at time (ms)	Static x-d of upper frame (mm) at time (ms)	NIC_{max} (m^2/s^2) at time (ms)	Start and end of head-restraint contact (ms)	Fz (kN) tension at time (ms)	Head angular acc. (rad/s^2) in extension at time (ms)
605 (D)	-65@72	-58	-248@129	-164	30@117	114-198	1.11@140	-2430@132
37 (C)	-54@121	-44	-204@182	-144	12@78	76-249	0.37@177	-310@129
606 (B)	-53@71	-47	-151@124	-94	10@78	78-180	0.40@110	-1070@104
607 (B)	-53@70	-49	-156@123	-100	9@92	80-180	0.42@108	-1050@103
608 (A)	-53@108	-49	-127@144	-75	7@62	60-204	0.18@107	-800@131
609 (D)	-36@138	-24	-226@136	-133	15@74	58-200	0.39@116	-108@127
610 (C)	-25@158	-13	-160@158	-81	9@87	70-216	0.20@104	-280@124
611 (B)	-17@87	-7	-114@102	-37	16@62	62-152	0.55@101	-920@106
612 (A)	-15@116	-4	-97@122	-27	8@73	72-172	0.20@121	-550@128
597 (D)	-55@108	-41	-215@133	-136	23@80	107-194	1.20@122	-2880@121
599 (C)	-41@152	-27	-167@154	-86	18@100	104-210	0.68@130	-1330@127
598 (B)	-37@86	-20	-130@94	-60	23@86	91-153	0.85@108	-2030@109
600 (A)	-30@117	-14	-103@123	-40	17@96	107-184	0.65@125	-1570@128
593 (D)	-56@106	-44	-218@125	-142	29@112	120-190	1.26@144	-2820@131
595 (C)	-39@156	-28	-183@160	-99	18@97	108-216	0.74@137	-1510@132
594 (B)	-33@90	-18	-120@87	-53	25@77	90-170	0.95@108	-3630@106
596 (A)	-31@115	-14	-98@118	-34	16@93	118-180	0.72@139	-2190@131
601 (D)	-13@84	-4	-20@84	-12	30@53	57-126	1.68@84	-3710@76
603 (C)	-6@99	-1	-2@142	-1	24@68	71-161	0.99@94	-2580@92
602 (B)	-9@70	-2	-5@56	-2	35@48	50-116	1.18@71	-2740@71
604 (A)	-5@98	0	-3@81	0	20@72	74-137	0.96@96	-2300@96

***Table** 3. Belt force, upper neck moment (Mocy) and head and T1 velocity relative the sled in the rebound phase from the tests.*

Number	Belt force (kN), shoulder + pelvis at time (ms)	Mocy (Nm) flexion in rebound at time (ms)	T1 vel. (m/s) in defined position	Head vel. (m/s) in defined position
605 (D)	0.9@400	18@475	3.0	3.9
37 (C)	1.3@380	24@475	2.8	3.0
606 (B)	1.2@270	23@385	1.9	2.4
607(B)	1.2@260	25@380	1.8	1.9
608 (A)	1.5@290	22@400	2.2	2.3
609 (D)	1.6@310	24@410	2.9	3.1
610 (C)	2.6@300	26@395	2.6	3.4
611 (B)	1.7@220	28@330	3.7	4.0
612 (A)	2.7@240	26@340	2.9	3.2
597 (D)	1.8@250	30@400	3.2	4.5
599 (C)	2.7@290	26@385	2.3	4.0
598 (B)	2.5@220	26@330	3.0	3.9
600 (A)	2.3@240	24@350	2.8	3.5
593 (D)	2.2@250	27@380	2.9	4.0
595 (C)	2.6@290	28@395	3.1	4.8
594 (B)	2.4@220	24@335	1.8	4.1
596 (A)	1.9@230	26@355	3.1	4.2
601 (D)	2.5@200	25@295	1.2	3.9
603 (C)	0.7@280	10@395	1.4	1.7
602 (B)	1.9@180	17@300	1.8	3.7
604 (A)	1.4@230	11@340	1.5	2.8

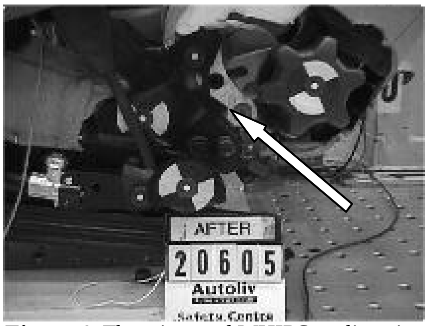

Figure 4. *The triggered WHIPS recliner in the Volvo seat (605), which allows recliner displacement and reclining of the seat back.*

Figure 5. *Deformation on the cushion in the Saab seat (609), which allows the reclining of the seat back.*

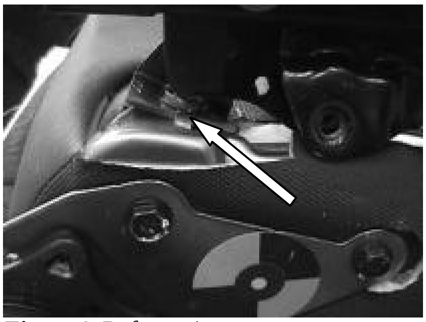

Figure 6. *Deformations at rear seat cushion adjustment brackets were observed in the Holden seat (595). This allowed the seat to move rearwards and rotate backwards*.

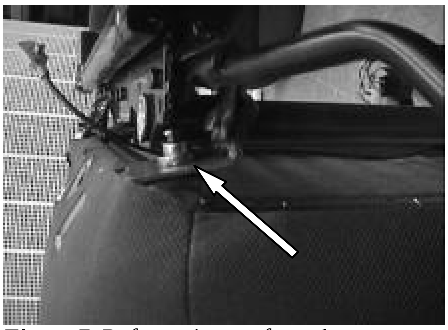

Figure 7. *Deformations at frontal seat cushion adjustment brackets were observed in the Holden seat (595). This allowed the seat to move rearwards and rotate backwards.*

Holden seat. However, a significantly straightening of the spine could be seen in the reinforced Holden seat tests which is likely to increase the intevertebral accelerations and displacements. In the D severity test with the Saab seat the upper back of the dummy got caught in the head restraint. This may have prevented the dummy from further ramping.

Deformations – The highest seat back deformation and recliner displacement was found in the tests with the Volvo seat. The WHIPS recliners in the Volvo seats triggered (Figure 4), which allowed the seatback to move backwards and recline. Seat back angle adjustment beam deformation was also noted in the higher severities. The Saab seats, except in severity A, sustained visible deformation on the seat cushion frame at the recliner attachment point (Figure 5). This allowed the seat back to recline.

In the Holden seats, except for the reinforced ones, the major deformations were in the seat cushion height adjustment brackets. The deformations allowed the seat to move rearwards and rotate. Seat back angle adjustment beam deformation was also noted in the higher severities. The recliner displacement was higher for the Holden seats not reinforced compared to the Saab seats, although it was not as high as in the tests with the Volvo seats.

Discussion - The results show that seat design and restraint systems have a significant impact on the dummy kinematics in a low to medium severity rear impact. The anti-whiplash seats included in this study are likely to provide increased protection in low and medium severity rear impacts. The medium severity rear impacts that have been highlighted recently by Krafft et al., (2001) have not been as carefully evaluated according to the literature.

Both the anti-whiplash seats and the BioRID II may have been optimised for low speed rear end impacts where most injuries occur. Therefore, may the result from the test with Delta-V 25 km/h and 120 m/s^2 have to be interpreted somewhat carefully. Nevertheless, Krafft et al., (2001) show that injuries lasting more than one month were a result of impacts with a Delta-V higher than 15 km/h and a mean acceleration of more than 50 m/s^2. This highlights the importance of including higher severities during evaluation together with the severity proposed by Langwieder et al., (2000).

The result shows that the same Delta-V generated with different pulse shapes can significantly alter the dummy response. The finding that the dummy may get caught in the active head restraint on the Saab seats shows the importance of a high dummy biofidelity. It is likely that a Hybrid III dummy would have a similar problem. However, Saab activates the seatbelt pretensioner above a certain severity and this may significantly reduce the ramping of the dummy. No seatbelt pretensioner was activated in any of the tests performed but it is believed that an activated pretensioner at the lap belt would be beneficial at a Delta-V of around 25 km/h.

It is now recommended that CFC 180 should be used for the T1 acceleration in the NIC_{max} formula for the BioRID II (Linder et al., 2001). According to the parameters evaluated, the two tests performed with the same seat and severity (606, 607) showed a similar dummy response.

The test with the reinforced seatback shows that a very stiff seatback should be avoided. In severity D for the reinforced Holden seat the ramping was less compared to the not reinforced Holden seats, but the straightening of the spine was greater. The Holden seats which were not reinforced showed a somewhat similar movement compared to the Volvo seat, although the recliner displacement and seat back reclining was not as high. These movements are likely to have reduced the injury values.

A different adjustment of the seat cushion might have influenced the result. A different position of the Saab head restraint would probably also influence the result as shown by Zuby et al., (1999). The high NIC_{max} in test 605 with the Volvo seat was probably caused by dummy ramping. An activated seatbelt pretensioner may have been beneficial in this test. It may be permissible for a specific seat back to recline more without causing excessive ramping, with an activated pretensioner at the lap belt or possibly an integrated seat belt compared to one without these.

Conclusions

- The same Delta-V produced by different mean and peak accelerations significantly altered the dummy response. A higher upper neck tension force was correlated with the dummy striking the head restraint from above. A good seat design as determined by the BioRID involves controlled displacement and yielding of the seat above a certain severity in combination with support for the whole spine. Ramping should be minimised since it could cause the dummy head to come over the top of the head restraint. Ramping could be reduced with an activated pretensioner acting on the lap belt at a Delta-V of around 25 km/h or possibly an integrated seatbelt. The anti-whiplash seats included in this study are likely to provide increased protection in low and medium severity rear impacts.

Acknowledgments

- The authors would like to thank Henrik Kjellgren and his co-workers at Autoliv Sweden and Rickard Fredriksson and Ola Boström at Autoliv Research for support during the setting up of the tests and analysis of the test results. We would also like to thank the Swedish National Road Administration who provided financial support for the reporting of this study and Vicki Xafis for the editing.

References

American Association for Automotive Medicine (AAAM), (1990): The Abbreviated Injury Scale – 1990 Revision, AAAM, Des Plaines, IL

Boström O., Fredriksson R., Håland Y., Jakobsson L., Krafft M., Lövsund P., Muser M., Svensson M.Y. (2000): Comparision of Car Seats in Low Speed Rear-End Impacts Using the BioRID Dummy and the New Neck Injury Criterion (NIC), Accident Analysis and Prevention, Vol. 32 No. 2, pp. 321-328

Davidsson J. (1999): BioRID II – final report, Report at Chalmers University of Technology, Department of Machine and Vehicle Systems, Göteborg, Sweden

Hofinger M., Mayrhofer E., Geigl B., Moser A., Steffan H. (1999): Reduction of Neck Injuries by Improving the Occupant Interaction with the Seat Back Cushion, Proc. IRCOBI Conference, Sitges, Spain, pp. 243-259

Håland Y., Lindh F., Fredriksson R., Svensson M.Y. (1996): The Influence of the Car Body and the Seat on the Loading of the Front Seat Occupant's Neck in Low Speed Rear Impacts, 29th ISATA, Florence, Italy

Jakobsson L., Lundell B., Norin H., Isaksson-Hellman I. (2000): WHIPS – Volvo's Whiplash Protection Study. Traffic Safety and Auto Engineering Stream, Accident Analysis and Prevention. 32, , pp. 307-319

Krafft M, Kullgren A., Ydenius A. (2001): The Correlation Between Crash Pulse Characteristics and Duration of Symptoms To the Neck – Crash Recording in Real Life Rear Impacts, Proc. 17th International Technical Conference on the Enhanced Safety of Vehicles, Amsterdam, Holland, paper no. 168

Krafft M. (1998): Non-Fatal Injuries to Car Occupants – Injury assessment and analysis of impact causing long and short term consequences with special reference to neck injuries, Ph.D. Thesis, Karolinska Institute Stockholm, Sweden, ISBN 91-628-3196-8

Langwieder K., Hell W., Schick S., Muser M., Walz F., Zellmer H. (2000): Evaluation of a dynamic seat test standard proposal for a better protection after a rear end impact, Proc. IRCOBI Conference, Montpellier, France

Linder A., Olsson T., Truedsson N., Morris A., Fildes B., Sparke L. (2001): Dynamic Performances of Different Seat Designs For Low To Medium Velocity Rear Impact, *(In preparation for the AAAM conference 2001)*

Parkin S., Mackay G., Hassan A., Graham R. (1995): Rear End Collisions and Seat Performance - To Yield Or Not To Yield, Proc. 39th AAAM Conference, Chicago, Illinois, pp. 231-244

Svensson, M.Y., Lövsund, P., Håland, Y., Larsson, S. (1998): The influence of seat-back and head restraint properties on the head-neck motion during rear-impact, Accident Analysis and Prevention 28, No. 2, pp 221-227

Wiklund K. and Larsson H. (1998): SAAB Active Head Restraint (SAHR) - Seat Design to Reduce the Risk of Neck Injuries in Rear Impacts, SAE International, International Congress and Exposition, Detroit, Michigan

Zuby D., Troy Vann D., Lund A., Morris C. (1999): Crash Test Evaluation of Whiplash Injury Risk, Proc. 43rd Stapp Car Crash Conference, San Diego, USA, pp. 267-278