REAR IMPACT NECK PROTECTION BY REDUCING OCCUPANT FORWARD ACCELERATION – A STUDY OF CARS ON SWEDISH ROADS EQUIPPED WITH CRASH RECORDERS AND A NEW ANTI-WHIPLASH DEVICE

Maria Krafft, Anders Kullgren, Anders Ydenius, Folksam Research and Karolinska Institutet, Sweden
Ola Boström, Autoliv Research, Sweden
Yngve Håland, Chalmers University of Technology, Autoliv Research, Sweden
Claes Tingvall, Swedish National Road Administration, Sweden

ABSTRACT

By changing the seat force-deflection characteristics in an older car model without a certain whiplash-protection system, an after market Anti-Whiplash Device (AWD) was evaluated. The AWD is mounted under the front end of the seat-rails. In a rear impact, the forward acceleration of the occupant is reduced by a force controlled yielding of the seat front attachments. The aim was to evaluate the injury reducing effect of a principal system by studies of real-life accidents and crash tests. Approximately 8,000 cars were fitted with the AWD to the driver's seat and approximately 12,000 of the same car model formed a control group. All cars were equipped with a crash recorder, which measures the acceleration time history at the moment of impact. The risk of persisting symptoms (> 6 months) was significantly lower for drivers in cars fitted with AWD than without. The crash tests show that the risk is more than halved with the AWD than without.

Key words: whiplash, rear impacts, long-term consequences,

WHIPLASH INJURIES IN cars account for app 65% of all personal injuries leading to medical disability (Krafft 1998). In most cases, they occur in a rear-end collision. In Sweden (with app. 9 million inhabitants) the insurance companies have estimated that 25 000 occupants sustain initial AIS 1 neck injuries annually. About 25% of these will be absent on sick leave one week or more. About 1500 (6%) of these will develop permanent disability (Whiplashkommissionen, 2003).

Because of higher traffic density the number of rear-end collisions and thereby the number of whiplash injuries, has increased (van Kampen et al 1993). In other words, these situations are difficult to eliminate from the traffic environment in urban areas. Since injury in most cases occurs in collisions at relatively low speeds (rear-end collision), the opportunities for passive safety systems increase.

Traditionally, attempts have been made to prevent injury by changes in the headrest geometry. A headrest located less than 10cm from the head has proved more beneficial than a distance of more than 10cm (Olsson et al. 1990, Jacobsson 2004). But despite good headrest geometry, other characteristics of the car are of importance for the occurrence of injury. The risk of persisting symptoms is almost three times greater in a car from the 1990s than in models from the early 1980s (Krafft 1998). In the late 1980s, car seats were built with a stronger construction to reduce the risk of total seat collapse in rear-end collisions at high speeds. This seems to have a negative effect in rear-end collisions at lower speeds.

A number of studies indicate that the advantage of plastic deformations of the backrest is that they reduce the risk of whiplash injury (Viano 2003, Parkin et al. 1995, Boström et al. 1997, Håland et al. 1996). It has also been shown that high acceleration levels at the moment of impact increase the risk of injury (Krafft et al. 2002). More recent studies of more advanced whiplash protection systems show that where car seats provide controlled deceleration of the upper body, i.e. reduce the acceleration

forces on the individual, without the seat collapsing, they have a very favourable effect (Farmer et al. 2002, Viano and Olsen 2001, Jacobsson 2004).

The Swedish National Road Administration and Folksam evaluated whiplash protection in 13+14 new car seats (model year 2003 and 2004) through rear-end impact tests in 2003 and 2004. Since research has shown the major impact of the car seat on the risk of whiplash injury, the automotive industry has primarily focused on improving the seat construction. Consequently, rear-end impact tests of car seats provide a relevant idea of how well different models deal with the problems of whiplash. The results from the crash tests showed that the safety level varies considerably (Folksam/SNRA 2003, Folksam/SNRA 2004). There are new models (car seats) that subject the occupant to large loads even at a very low collision force.

Even though the new car market is consistently introducing more effective whiplash protection, it will be a number of years before the risk of injury declines significantly. It is therefore important to evaluate solutions that can be retrofitted in cars.

By a retrofit solution for the after market, the aim of the study was to evaluate the effect of a principal system that reduces the acceleration of the driver in order to decrease the risk of AIS 1 neck injury in rear impacts. The retrofit solution was evaluated through crash tests and real-life accidents. In this case, it involves a force limiter fitted under the front edge of the seat-rails. The seat's original construction is not affected.

MATERIAL AND METHOD

Autoliv was responsible for the development of the Anti Whiplash Device (AWD) for the chosen car model, Toyota Corolla 1993-97 models. Using results from Folksam's database of real-life accidents, where cars had been fitted with crash pulse recorders, the relationship between crash severity and the risk of whiplash injury was analysed. This formed an important basis for the design of the product. A number of crash tests were carried out to verify that the AWD did not aggravate the risk of injury for other passengers in the car, but also to test the activation levels of the protective device and how force is limited during the collision. The AWD meets current legal requirements. Dispensation was obtained from the Swedish National Road Administration to fit the AWD in the car fleet in question, as the car would not otherwise have been type approved. An ethical review of the whole research project was also carried out by Professor Per Lövsund at Chalmers University of Technology in Sweden.

The AWD is fitted between the front edge of each seat rail and the floor. Figure 1 shows the protective device. The lower part of the device is anchored in the car floor and the upper part is fitted firmly to the car seat. In a rear-end collision, the plate is torn in the pre-pressed tracks , in a controlled manner. The collision force on the occupant is reduced through a gentler sequence of movements. In the elasticity deformation trading the AWD itself allows the seat to tilt a maximum of 15 degrees. Verified by sled tests, the risk of passenger ejection was not increased due to the AWD. Figure 2 is a sketch showing how the seat moves during the collision.

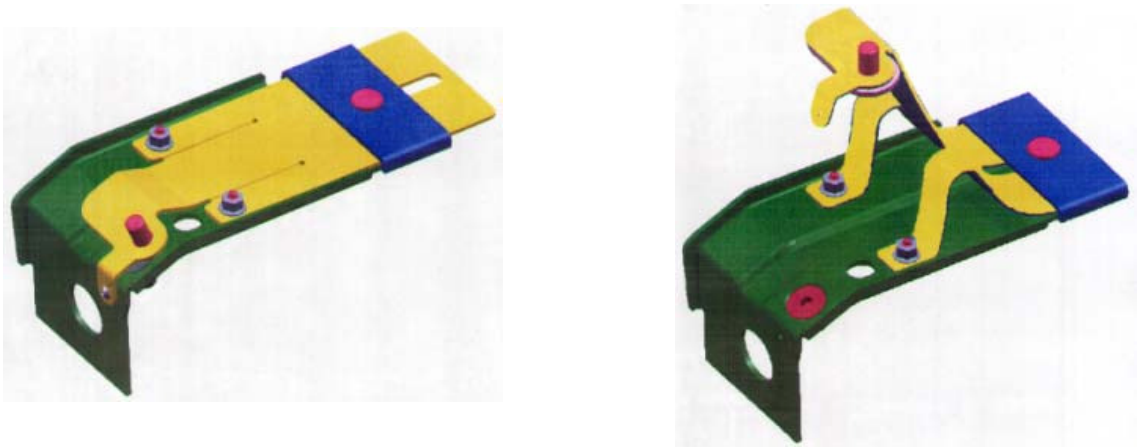


Figure 1. Sketch of the AWD, before and after a rear-end collision.

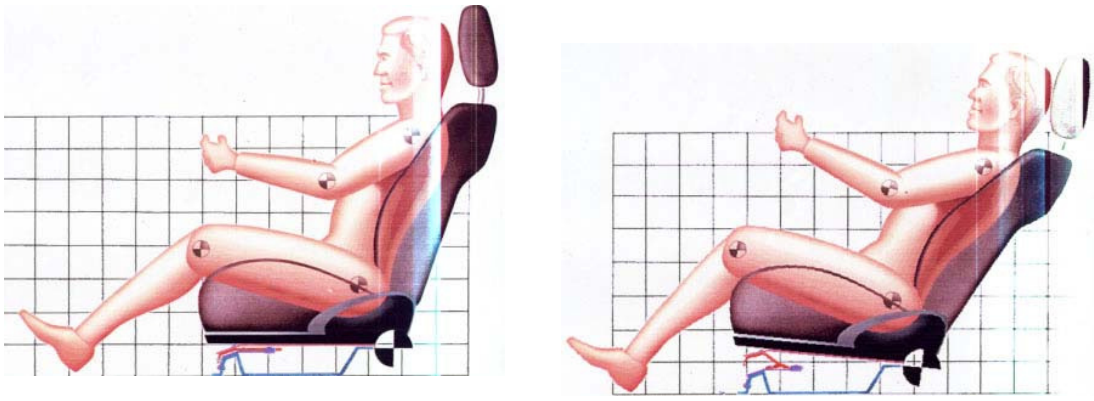


Figure 2. Sketch showing how the car seat moves at the moment of impact with AWD.

The following specification of requirements applied to the AWD:

- Activation by a lighter person (approximately 50-55kg) at a relatively low collision force (5g and 13km/h).
- NIC below 15 m^2/s^2 for the major part of crash pulses causing injury.
- Activation of the protective device should not increase the risk of any other personal injury. This was tested for high impact crashes in rear-end, frontal and side collisions as well as overturning accidents.
- Activation should not aggravate the risk of injury for back-seat passengers or children in a rear-facing child's seat in the rear.

The AWD was evaluated through real-life accidents involving the cars fitted with and without AWD, but also through updated crash tests. Since 2003, there has been sufficient knowledge of appropriate injury criteria to be able to evaluate whiplash protection in a rear-end collision through crash tests (Kullgren et al 2003, Eriksson and Kullgren 2003).

REAL-LIFE ACCIDENTS:

In the spring of 2001, owners of Toyota Corolla 1993-97 models were offered free installation of the AWD to the driver's seat. Installation took approximately 25 minutes. There are approximately 20,000 cars of this model in Sweden. Approximately 8,000 owners had the AWD fitted, while the remaining 12,000 cars formed the control group.

During the period September 2001 to December 2003, 58 collisions took place in cars fitted with AWD and 82 in cars without the device. The cars were fitted with crash recorders that measure the acceleration time history in the principal direction of force during the time of impact.

Since 1992 crash recorders (Kullgren 1998) for measuring frontal impacts have been fitted in all large selling Toyota car models sold in Sweden. Since 1995 the same crash recorders were also fitted in Corollas for recording rear-end crashes. These Corollas, model year 95-97, were also used as reference cars to control for crash severity. All cars fitted with the AWD were also fitted with a crash pulse recorder.

The crash recorder is based on measuring the movements of a mass in a spring-mass system during a crash. The recordings are made on a photographic film by a light emitting diode attached to the mass. The crash recorder is further described by Kullgren (1998).

Out of the 58 crashes with an AWD fitted, 32 had a recorded crash pulse (Table 1). In the remaining 26 crashes the acceleration forces were too low to reach the threshold for the crash pulse recorder, which was 2-3 g, specific for each crash recorder. In 18 of the remaining 26 crashes with cars fitted with a AWD a change of velocity could be estimated by comparing deformation with other crashed vehicles with a recorded crash pulse. No estimation of mean acceleration could be done in these crashes. The remaining 8 crashes could not be investigated or photographed because these cars were insured by another insurance company.

Among the 82 crashes with reference cars, only 13 had a recorded crash pulse (only from Corolla model 95-97). A change of velocity could be estimated in 39 of the remaining 69 crashes and 30 were insured by another insurance company. The reason why only 13 out of 82 had a recorded crash pulse

was that only year model 95 to 97 had crash recorders fitted for measuring rear-end crashes. Also, in year model 95 and 96 the photographic film in the crash recorder was not properly tuned. Only 10% of these crash recorders worked properly.

Table 1. Number of rear crashes with and without AWD where a recorded pulse and estimated change of velocity have been made.

AWD	rear crashes (n)	Recorded crash pulse (n)	Estimated delta-v (n)	Total number with a delta-v estimation
Yes	58	32	18	50
No	82	13	39	52

Injury details were obtained from medical notes and interviews with the occupants. The interviewer, had no information about the crash severity or if the car was equipped with or without an AWD in each case. A follow-up of possible medical symptoms was carried out at least six months after the collision. The duration of symptoms was defined as follows: no injury, symptoms for more or for less than one month, and for more than six months. Occupants with earlier whiplash symptoms were excluded as well as multiple rear impacts.

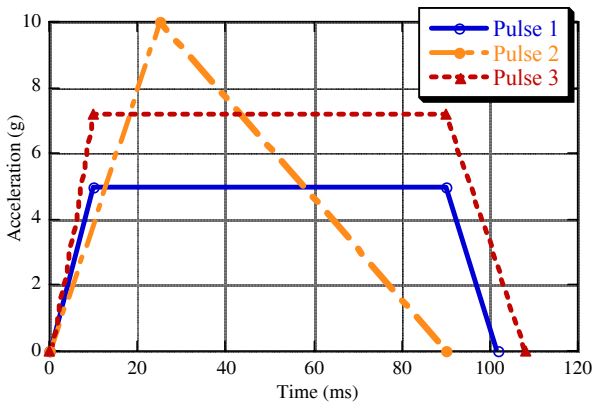
SEAT EVALUTATION TESTS:

The mechanisms, as well as the timing of occurrence, of neck injuries in rear end collisions are most likely more than one. Therefore, a set of injury criteria is needed to evaluate the ill-defined diagnosis of whiplash. In two previous whiplash ratings [Folksam and SNRA 2003 and 2004] Swedish National Road Administration together with Folksam used a BioRID II dummy, three crash pulses and three dummy parameters (NIC_{max}, N_{km} and Head Rebound Velocity). The crash tests of the seats were conducted using a Hyper-G sled, see test set-up in Figure 4. The three crash pulses (see Table 2 and Figure 3) represented a frequent crash with a small risk of neck injury, a crash with the highest combination of frequency and risk and, at last, a less frequent crash with a high risk. Based on real-life accidents with crash recorders Kullgren et al [2003] showed that both NIC_{max} and N_{km} from BioRID seat tests predicted a neck injury with initial symptoms or with symptom duration of more than one month with high accuracy. Also, Kullgren et al found risk curves for these injury criteria, see Figure 5 and 6.

The NIC_{max} (Neck Injury Criterion) reflects the violence of the relative movement between the head and the torso, and most often reaches its maximum value just before the head hits the headrest. N_{km} measures forces and moments at the connection of the neck to the head and reaches its maximum value during the period when the head is in contact with the headrest. Based on the change of velocity in frontal impacts when neck injuries start to occur, the tolerance value (where values above influences the rating) of Head rebound were chosen. Besides the NIC, N_{km} and Head Rebound a set of other dummy parameters were chosen, lower neck load (LNL-Fx, LNL-Fz, LNL-My), upper neck shear force and tension (Fx and Fz), T1 acceleration (T1). In addition a seat performance parameter were used, the time to headrest contact. The reason for using these extra parameters was that they were used in the literature and ongoing discussions of coming seat ratings and legal requirements.

Table 2. The change of velocity and mean acceleration for the three different crash tests; representing a low mid and high crash severity.

Test	Change of velocity	Peak acceleration	Mean acceleration
Pulse 1: Low severity	16 km/h	5	4,5 g
Pulse 2: Mid severity	16 km/h	10	5,5 g
Pulse 3: High severity	24 km/h	7.5	6,5 g



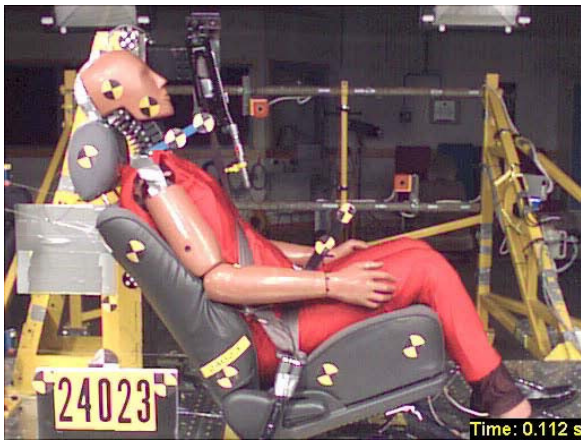


Figure 3. Three crash pulses used for the crash test. Figure 4. Test set-up for the crash tests.

Figures 5 and 6 show the relationship between risk of injury and the neck injury criteria NIC and Nkm. The data was collected from Ericsson and Kullgren (2003). At NIC 15 and Nkm 0.3 respectively, the risk of injury lasting more than 1 month is approximately 15%.

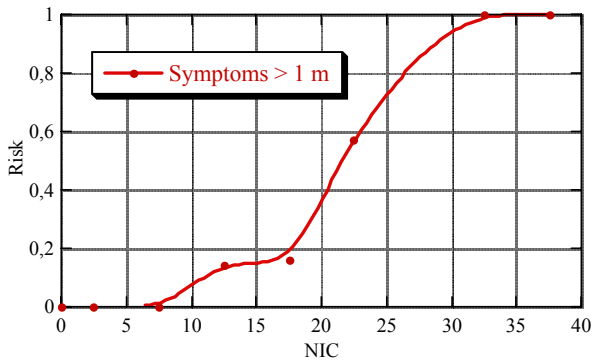


Figure 5. The relationship between persisting symptoms more than 1 month and the neck injury criterion NIC.

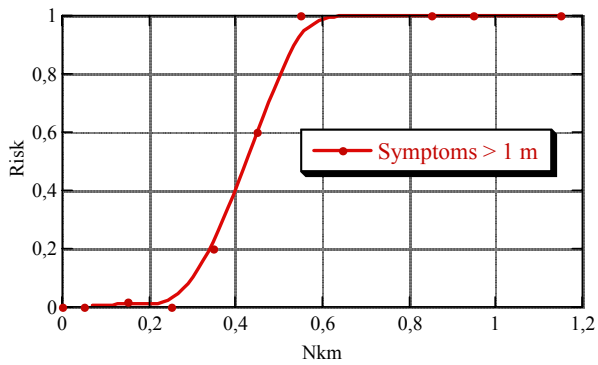


Figure 6. The relationship between risk of persisting symptoms more than 1 month and the neck injury criterion Nkm.

Reference Volvo V70 with and without WHIPS.

In order to relate the crash performance influence of the AWD for a Toyota Corolla 93-97 also the performance influence of the Whiplash Protection Recliner of a Volvo V70 was evaluated. The inclusion of the Whiplash Protection Recliner of a Volvo V70 has shown to significantly reduce the risk of both short-term and persistent neck injuries [IIHS 2002, Folksam 2003, Jacobsson 2004].

HEAD RESTRAINT GEOMETRY

The influence of head restraint geometry was also evaluated by conducting crash tests with the head restraint in the highest position, both with and without the AWD fitted. And furthermore, a crash test was conducted with the whiplash device and an extra head cushion* that lowered the head-to-head restraint distance and increased the head restraint height with approximately 2 cm.

* WhipGuard, manufactured by T.Landelius AB, Sweden

STATISTICAL ANALYSIS

Fisher's exact test was used to study the influence of AWD on short- and long-term injury consequences.

RESULTS

FUNCTION OF THE AWD – REAL LIFE ACCIDENTS

As the cars were fitted with crash recorders, the function of the AWD could be evaluated. Since the device is mainly activated when a certain force is reached, the strongest relationship is seen between activation of AWD and the car's acceleration level. Figures 7 and 8 show that in real-life accidents the AWD may be activated at a change of velocity of 5 km/h (depending on the acceleration levels). At 15-20km/h, all AWDs were activated. As regards acceleration forces, the AWD starts to be activated at a mean acceleration of 2-3g. At 5g, all AWDs were activated. Of the rear-end collisions where the AWD was not activated, no driver sustained whiplash symptoms more than one month.

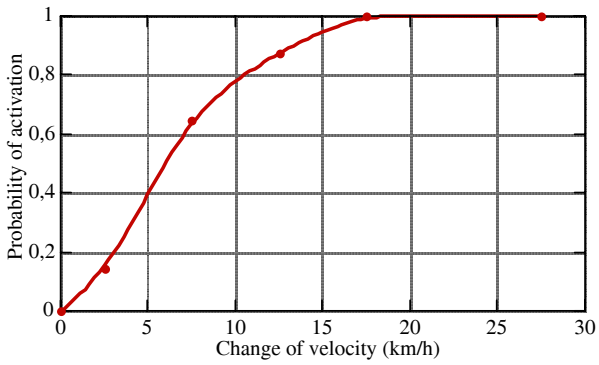


Figure 7. Probability of activation of AWD for different delta-v.

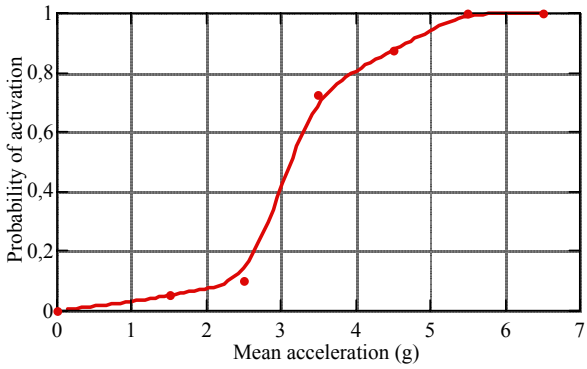


Figure 8. Probability of activation of AWD for different mean accelerations.

EVALUATION OF THE AWD – REAL LIFE ACCIDENTS

Table 3 shows the number of drivers and their injury status for different time periods, in cars with and without the retrofitted AWD, which were involved in a rear-end collision. The risk of persistent whiplash symptoms for more than six months was lower for drivers in cars fitted with the AWD than cars without ($p<0.05$). More cases are required to determine more accurately how good the effect is. There was no difference in the breakdown between male and female drivers in cars with and without the AWD. The crash severity was slightly higher for cars without AWD than with, both with regard to average change of velocity and mean acceleration, see Table 3.

Table 3. Injury status of drivers in car models with and without AWD involved in rear-end collisions.

Injury outcome	**With AWD**	**Without AWD**	**Injury reducing effect (Fisher's)**
Sympt > 6 months	1	9	
Sympt > 1 month	5	15	
Initial symptoms	14	31	
No neck injury	44	51	
Total	58	82	
Risk, sympt > 6 m	1/58 (2% +3/-2)	9/82 (11% +/- 7)	84% (p<0.05)
Risk, sympt > 1 m	5/58 (9% +/- 7)	15/82 (18% +/- 8)	52% (ns)
Risk, initial sympt.	14/58 (24% +/- 11)	31/82 (38% +/- 10)	37% (ns)
Average age	50,9	50,3	
Prop. male/female	57% / 43%	57% / 43%	
Average crash severity	8,2 km/h - 3,2 g	9,6 km/h - 3,4 g	

SEAT EVALUATION TESTS

Table 4 shows the test results of all Toyota Corolla seat tests. All dummy parameters (except LNL-Fz) were significantly reduced due to the AWD for the two lower collision force levels, where most whiplash injuries occur. For crash pulse 2, NIC decreased from 17.9 to 12.2 m^2/s^2, which corresponds to more than 50 % reduction in injury risk (fig 3). Below NIC 15 m^2/s^2, the risk of injury is considered low. For both headrest positions NIC was above the proposed tolerance level of 15 m^2/s^2 without an AWD and below with an AWD. With the headrest in its mid position Nkm was above the proposed tolerance level of 0.3 with and without the AWD and in its top position below with and without the AWD.

The evaluation tests showed that the AWD worked properly at crash severities where the majority of injuries occur. But at high force levels, approximately 2% of all rear-end collisions (Krafft et al 2002), the crash test results indicated that the device had no effect in the car model tested. The AWD absorbed as much energy as it could and ”bottomed out”, which was reflected in the results, and the values were not reduced. When the AWD ”bottoms out” the acceleration is more abrupt for the occupant and can even lead to higher values than without the AWD.

Table 4. Crash test results for models with and without AWD, at three different crash severities and at different headrest positions.

AWD	Head-rest	Pulse	NIC	Nkm	Head Rebound	HC	T1x	Fx	Fz	LNL-Fx	LNL-Fz	LNL-My
No	Mid	1	15,8	0,57	4,2	90	12,0	186	794	302	89	15,8
No	Mid	2	17,9	0,74	4,4	94	14,0	292	1027	363	89	17,1
No	Mid	3	20,8	0,66	4,4	~140	10,2	439	731	351	195	18,5
Yes	Mid	1	13,5	0,46	3,9	103	7,9	136	502	208	37	13,6
Yes	Mid	2	12,2	0,48	4,0	108	8,9	176	664	301	148	14,6
Yes	Mid	3	35,3	NA*	5,3	~140	12,2	711	1025	359	292	21,8
No	Top	2	17,6	0,25	4,6	96	9,9	130	797	293	134	15
Yes	Top	2	13,7	0,15	4,5	98	8,7	91	542	286	146	12,9
Yes+ head cushion	Top	2	10,6	0,15	4,23	44	7,6	64	393	215	153	7,4

*no head-to-headrest contact.

Table 5 shows the test results of the Volvo V70 with and without WHIPS (whiplash protection system) seat tests for all evaluated parameters. All dummy parameters were significantly reduced from values above the proposed tolerance levels to values below due to the Whips-recliner.

Table 5. Crash test results for Volvo V70 with and without Whips.

Whips	Headrest	Pulse	NIC	Nkm	Head Rebound	HC	T1x	Fx	Fz	LNL-Fx	LNL-Fz	LNL-My
N*	fix	2	16,7	0,32	4,7	48	12,0	131	712	488	413	16,3
Y	fix	2	11,8	0,25	2.9	51	8,2	32	358	212	164	7,8

*welded recliner

DISCUSSION

Chronic whiplash injury is common and serious. Society should therefore mobilise all positive efforts that can contribute to achieving better protection. A number of new car models are now launched with advanced whiplash protection, but a large proportion of models still lack good protection (besides traditional head restraints). The evaluation of the retrofitted whiplash protection device AWD shows that it is possible to accelerate the development for the used car market, but also as a possible solution for the new car market.

This is the first time that a randomised, controlled study has been implemented in the whiplash prevention area, making it unique. Safety systems in the road safety area are in most cases evaluated through crash tests and simulations. As regards the risk of whiplash injury, this was not possible, as previous systems were far too blunt to be able to evaluate different solutions. Combining real-life data from crash recorders with injury outcome has considerably improved development in the area. For example, through knowledge of when the accident risk is high or low. There is a considerable need to be able to verify more rapidly in future how new solutions function in practice. A combination of instrumented vehicles and controlled studies is necessary to obtain rapid and accurate answers to how these solutions satisfy the new requirements. It is reasonable to assume that future injury prevention research in the road transport area will be wholly dependent on the opportunity to combine the individual's tolerance to external force with different types of solutions in vehicles and infrastructure in models and simulations, based on real-life data.

In the development of the retrofitted AWD, the objective was to adapt the activation level of the protective device, with regard to crash severity, to the force interval that causes injuries in real-life accidents. The results from real-life accidents, involving cars fitted with crash recorders, showed that the AWD should be effective at change velocities above 10km/h and at mean accelerations above 3g. Another requirement was that the AWD should not be activated in normal use, e.g. by leaning back heavily. The results from real-life accidents, Figures 7 and 8, show that all protective devices were activated at a level when the risk of injury was below 20% compared to risk levels in Figures 9 and 10. The results indicate that the activation level of the AWD was well adapted to the levels that cause injuries. The Figures 9 and 10 show the average risk for Toyota Corolla 1993-97 models and Corolla 1998-2002 models. The risk of sustaining symptoms for more than one month increases at approximately 15km/h, reaching 100% at 25-30km/h. The same applies to mean accelerations from 4-5g, reaching 100% at 7-8g.

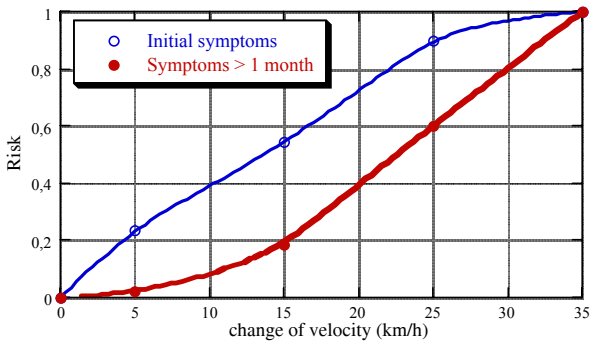


Figure 9. Risk of whiplash injury more than 1 month for different delta-v (data from Kullgren et al 2003).

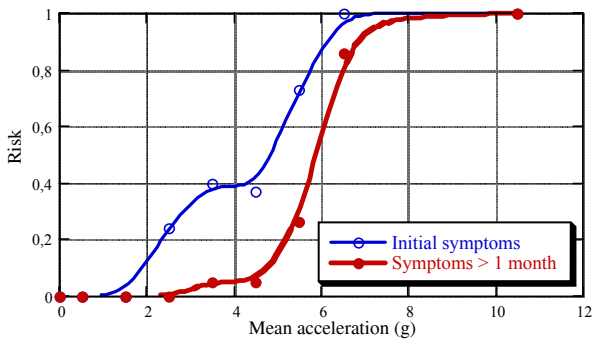


Figure 10. Risk of whiplash injury more than 1 month for different mean accelerations (data From Kullgren et al 2003).

When controlling crash severity for the 58 cars with AWD and the 82 without AWD different sources to get crash severity were used. In 32 cases with AWD and in 13 cases without AWD a recorded crash pulse was known. In 18 cases with AWD and in 39 cases without AWD change of velocity could be estimated from vehicle the deformations. The accuracy of these estimations is much lower than for the recorded crash severity. Kullgren (1998) showed that often estimations of change of velocity has an accuracy of +/- 20%, while the accuracy of the crash recorder is below 5% (Kullgren 1998). Due to this possible low accuracy of the estimated crash severity for many vehicles in this study, especially in the control group, the difference in average change of velocity for the cars with and without AWD respectively, could be larger than the presented difference in Table 3.

The results from both real-life accidents and crash tests indicate a considerable risk reduction in cars with the energy-absorbing whiplash protection device. The AWD appears to be able to approximately halve the risk of injury in the car model tested, but more cases are required to more accurately determine the effect. For crash severity levels where most whiplash injuries occur, the results from the crash tests showed that the risk of injury decreased sharply (more than halved). But the crash test results indicated that the AWD had no effect in the high severity collision, which was intended to illustrate when the risk of injury is very high. At these force levels, the AWD "bottoms

out" and the seat's original characteristics take over. Even though these accidents are relatively uncommon, approximately 2 % of all rear-end collisions, the risk of injury is very high, and approximately 30% of all persisting whiplash injuries in collisions with crash recorders occur above this force level. Consequently, there is potential for improvement here. It should be pointed out that in the two collisions, which nevertheless took place in cars with the whiplash protection device at a force level above 6g/20km/h, the drivers were not injured.

The performance of the AWD could be compared with the whiplash protection of other car models by comparing crash test results. In 2003 Folksam and SNRA in Sweden published consumer rating results of 13 + 14 car models (Folksam/SNRA 2003, Folksam/SNRA 2004). The crash test procedure used for the evaluation of the AWD was the same as used by Folksam/SNRA. In the Folksam/SNRA test cars were rated in three groups; poor, average and good. Cars with more advanced developed whiplash protection systems scored the best results, with one exception. Car models where no measures have been done scored worst. The results of the Corolla seat (headrest in mid position) with and without AWD were average and poor respectively.

There are a number of factors affecting the risk of sustaining a whiplash injury in a collision. Apart from the considerable differences in risk between different car models, there are a number of parameters for a given car model that are important for the occurrence of injury. Results from crash recorders show a clear relationship between crash severity and injury risk, particularly long-term whiplash symptoms. A number of studies have also shown that women run a higher risk than men. Age also affects the risk of being injured. Sitting posture, height and weight are also factors that have a partial impact. In this study, there was no difference in gender and age distribution between cars with and without the protective device. However, the crash sensor measurements showed that cars with the AWD had a slightly lower crash severity level than cars without. As a result, the protective effect might be slightly overestimated due to this difference. However, by studying what this difference means in increased injury risk in the risk relationships previously shown for crash severity and mean acceleration, see Figures 9 and 10, it does not detract from a positive protective effect.

The study indicates that there is considerable, still unutilised potential in the function of car seats in a rear-end collision. A large part of the research shows that there are three criteria that the car seat must deal with to reduce the risk of whiplash injury. It should reduce the acceleration forces for the occupant, i.e. the car seat should absorb as much as possible of the crash severity that the car is exposed to; the distance between the head and headrest should be small (and the headrest should be high); and the car seat should not to violently fling the occupant into the seat belt on the rebound. The car model in the study has relatively poor geometry, i.e. the headrest is low and there is a relatively large distance to the seat back and headrest, when sitting in a normal driving position. The evaluated AWD reduces the acceleration forces considerably, as well as the rebound into the seat belt. However, the headrest geometry is not improved. This indicates that the total level of protection would be even better for the car model concerned, if the headrest geometry were also more beneficial. The crash results improved by just raising the headrest to the maximum position and even more with an extra head cushion (Table 4).

Even though the new car market is consistently introducing more advanced protection, it will take many years before the number of people with whiplash injuries is reduced. A retrofitted whiplash protection device, which does not involve changes to the car seat's basic construction, is relatively inexpensive to produce and fit, and consequently of considerable interest in accelerating development towards lower risks of injury. The disadvantage of the evaluated AWD is that it must be adapted to each car model; it is not universal. In order to implement installation in common car models to a greater extent, car producers also need to become involved and take responsibility for their existing car models. As long as retrofitted protection is specific to each car model, the car industry must also take an active role in this issue.

CONCLUSIONS

- It is possible to reduce whiplash injuries in used cars by retrofitting whiplash protection devices.
- Results from crash test and real-life crashes both indicated a positive whiplash injury reducing effect of the after market whiplash device.
  - The crash tests indicated a 50% average reduction in risk. However, no effect was found in the high-speed crash at 24 km/h.
  - A significant positive effect for symptoms lasting for more than 6 months was found from analysis of real-life crashes.
- The study show that the principle of force-controlled yielding with energy absorption in the seat back to reduce occupant acceleration has a positive effect on the risk of sustaining a whiplash injury.
- The crash tests indicate that further reductions in injury risk could be achieved by improved head restraint geometry.

ACKNOWLEDGEMENTS

Thanks go to Magnus Petterson, Statistikkonsulterna, for valuable help with the statistical analysis and to Jan Odenmo and Tommy Andersson with staff at Autoliv for crucial support in the development of the AWD.

REFERENCES

Boström O, Krafft M, Aldman B, Eichberger A, Fredriksson R, Håland Y, Lövsund P, Steffan H, Svensson M Y and Tingvall C. Prediction of Neck Injuries in Rear Impacts Based on Accident Data and Simulations. Proc. IRCOBI Conference, Hannover, Germany, 1997. pp 251-264

Håland Y,Lindh F, Fredriksson R, Svensson M. The influence of the Car Body and the Seat on the Loading of the Front Seat Occupant´s Neck in Low Speed Rear Impacts. Proc of the 29th ISATA Conf. Florence, Italy. Paper no 96SAF020, 1996.

Eriksson L and Kullgren A. Influence of seat geometry and seating posture on NICmax and Nkm AIS1 neck injury predictability. Proc. of the Int. IRCOBI Conf. on the Biomechanics of Impacts, 2003.

Farmer C, Wells J, Lund A. Effects of Head Restraint and Seat Redesign on Neck Injury Risk in Rear-End Crashes. IIHS, Insurance Institute for Highway Safety, October 2002.

Folksam and Swedish National Road Administration. Whiplash Injury June 2003, Folksam SE-10660 Stockholm, Sweden, 2003.

Folksam and Swedish National Road Administration. Whiplash Injury May 2004, Folksam SE-10660 Stockholm, Sweden, 2004.

Jacobsson L. Whiplash Associated Disorders in Frontal and Rear-End Car Impacts. Biomechanical. Thesis for the degree o doctor of philosophy. Crash Safety Dividson , Dep of Machine and Vehicle Systems. Chalmers University of Technology, Sweden 2004.

van Kampen L.T.B. Availability and (proper) adjustment of head restraints in the Netherlands. Proc. Of the International IRCOBI Conf. on the Biomechanics of Impacts, September 8-10 , Eindhoven, The Netherlands, 1993. pp 367-378

Krafft M. Non-Fatal Injuries to Car Occupants - Injury assessment and analysis of impacts causing short- and long-term consequences with special reference to neck injuries, Doctoral thesis, Karolinska Institutet, Stockholm, Sweden, 1998.

Krafft M, Kullgren A, Ydenius A, Tingvall C. Influence of crash pulse characteristics on whiplash associated disorders in rear impacts – crash recording in rear life crashes. Traffic Injury Prevention 3(2): 2002.

Krafft M, Kullgren A, Lie A, Tingvall C. Utvärdering av whiplashskydd vid påkörning bakifrån – verkliga olyckor och krockprov. Rapport juni 2003. Folksam och Vägverket.

Kullgren A. Validity and reliability of vehicle collision data: The use of crash pulse recorders for impact severity and injury risk assessments in real-life frontal collisions. Thesis for the degree of Doctor in Medical Science. Folksam, 106 60 Stockholm, Sweden, 1998.

Kullgren A, Eriksson L, Boström O, Krafft M. Validation of neck injury criteria using reconstructed real-life rear-end crashes with recorded crash pulses. Proc. 18th Int. Techn. Conf. on ESV, paper no 344. Japan 2003.

Olsson I, Bunketorp O, Carlsson G, Gustafsson C, Planath I, Norin H, Ysander L. An In-Depth Study of Neck Injuries in Rear End Collisions, Proc. IRCOBI Conf. on Biomechanics, 1990. pp. 269-281

Parkin, S.; Mackay, G.M.; Hassan, A.M.; Graham, R., Rear End Collisions and Seat Performance - To Yield or Not to Yield. Proc. 39th annual AAAM, 1995. pp231-244

Viano D and Olsen S. The Effectiveness of Active Head Restraint in Preventing Whiplash. The Journal of TRAUMA Vol. 51, 2001. pp959-969.

Viano, Seat properties affecting neck responses in rear crashes: a reason why whiplash has increased, journal of Traffic Injury Prevention 4:214-227, 2003

Whiplashkommissionen www.whiplashkommissionen.se (Swedish whiplash commission), 2003.