THE EFFECT OF WHIPLASH PROTECTION SYSTEMS IN REAL-LIFE CRASHES AND THEIR CORRELATION TO CONSUMER CRASH TEST PROGRAMMES

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ABSTRACT

The objective was to study the influence of various types of car seats aimed at protecting whiplash injuries on real-life injury outcome. Furthermore, the aim was to study correlation between whiplash consumer crash tests and real-life injury outcome. In both cases the influence on long-term whiplash symptoms were studied.

Since 1997 various seats aimed at lowering the risk of whiplash injuries have been introduced in cars. The cars were divided into groups according to the safety technology used. Since 2003 consumer crash test programmes have been running. The correlation on group level between whiplash injury outcome in real-life crashes and the test results of consumer crash tests both in Sweden by Folksam and the Swedish Road Administration and by IIWPG were studied.

The results show that cars fitted with more advanced whiplash protection systems had 50% lower risk of whiplash injuries leading to long-term symptoms than cars launched since 1997 without whiplash systems. All three whiplash preventive technologies studied, RHR (Reactive Head Restraints), WhiPS (Whiplash Prevention System), and WIL (Whiplash Lessening System), showed lower risk of whiplash injury leading to long-term symptoms than cars fitted with standard seats.

A correlation was found between consumer whiplash crash tests and real-life outcome. It was found that cars rated in the worst group in the IIWPG and Folksam/SRA ratings had 43% and 60% higher risk of long-term symptoms in real-life crashes, respectively, than cars rated in the best group.

A limitation with the tests is that the consumer crash test programmes are conducted with the seat only, while the real-life injury outcome concerns the performance of the whole car.

It can be concluded that seats aimed at preventing whiplash injuries in general also lower the risk in real-life crashes. Furthermore it can be concluded that results from existing consumer crash test programmes for whiplash correlate with real-life injury outcome.

INTRODUCTION

In October 1997 the Swedish parliament decided upon the new road traffic safety policy in Sweden, the so-called Vision-Zero (Kommunikations-departementet 1997). An important part in the policy is to minimise health losses and not accidents or injuries in general. Health losses include fatal injuries and severe injuries where the person not is recovering within reasonable time, i.e. the focus is set on the public health problem.

Apart from fatalities, injuries leading to disability reported by insurance companies are a good indication of the number of serious road traffic injuries. They also give a good picture of both the typical injuries and the type of crashes that primarily should be in focus for road traffic safety actions. In Sweden more than 3,500 permanently disabled car occupants are reported every year (with a disability of at least 10% according to the classification used by Swedish insurance companies) (Försäkringsförbundet 1996). More than 50% of those are whiplash injuries. It is therefore important that the society focuses on reducing whiplash injuries.

In modern cars on the Swedish market, whiplash injuries account for approximately 70% of all injuries leading to disability (Folksam 2005). Most occupants reporting whiplash injuries recovers within a week, while between 5% and 10% will get more or less life lasting problems (Nygren 1984, Krafft 1998, Whiplashkommissionen 2003).

Whiplash prevention initiatives

Whiplash preventive measures have so far been focussed on developments of the seat. Since the 70s head restraints have been implemented more and more frequently. To date all seating positions in most car models are fitted with head restraints. The whiplash injury reducing effects of head restraints have been shown to be relatively low, between 5% and 15% (Nygren et al 1985, Morris and Thomas 1996). In order to increase the vehicle crashworthiness in high-speed rear end crashes, vehicle seats have become stiffer since the late 80s (Krafft 1998). Stiffer seats have probably increased the whiplash injury risks in low-speed rear-end crashes.

Based on this knowledge more advanced whiplash protection devices have been introduced on the market. The better protection is achieved through improved geometry and dynamic properties of the head restraint or by active devices that move in a crash as the body loads the seat. The main ways to lower the whiplash injury risk are to minimise the relative motion between head and torso, to control energy transfer between the seat and the body and to absorb energy in the seat back.

To date several systems exist, for example RHR or AHR (Reactive Head Restraint or Active Head Restraint) in several car models, WhiPS (Whiplash Prevention System) in Volvo and Jaguar, WIL (Whiplash Injury Lessening) in Toyota. RHR was firstly introduced in Saab cars in 1998 (SAHR) (Wiklund and Larsson 1997), and is today the most common whiplash protection concept on the market. It exists in several models from for example Audi, Ford, Mercedes, Nissan, Opel, Skoda, Seat and VW. RHR is a mechanical system that actively moves the head restraint up and closer to the head and in a crash. Saab has apart from the head restraint also designed the seat back structure to better support the torso in a rear end crash. WhiPS was first introduced in Volvo cars in 1999 (Lundell et al 1998, Jakobsson 1998). The seat back is in a crash moved rearwards and yields in a controlled way to absorb energy. The Toyota system WIL (Sekizuka 1998) has no active parts and is only working with improved geometry and softer seat back. Ford has also introduced seats without active or reactive parts in the headrest, but with an improved design aimed at preventing whiplash injury.

Studies have been presented showing the effect of the Saab RHR and Volvo WhiPS indicating an injury reducing effect of approximately 40-50% (Viano and Olssén 2001, Insurance Institute for Highway Safety (IIHS) 2002, Jakobsson 2004, Krafft et al 2003). Apart from that the information of real-life performance of different systems is limited.

In recent years some consumer rating programs have been developed and introduced. In 2003 Folksam and the Swedish Road Administration (SRA) started crash testing of car seats, where each seat is exposed to three different tests. Also the German ADAC started crash testing of car seats using multiple tests for each seat (ADAC website). In 2004 the insurance initiative IIWPG (International Insurance Whiplash Prevention Group) started consumer crash testing in Europe and in the USA (IIHS and Thatcham websites). In those tests each seat was exposed to one test. Studies of the correlation between crash test results and real-life performance is rare.

Objectives of the study

The objective was to study the influence of various types of car seats aimed at protecting whiplash injuries on real-life injury outcome. Furthermore, the objective was to study correlation between whiplash consumer crash tests and real-life injury outcome. In both cases the influence on long-term whiplash symptoms were studied.

METHOD/MATERIAL

The study was based on two different data sources. To calculate the proportion of injuries leading to long-term symptoms all whiplash injuries in rear-end crashes reported to the insurance company Folksam between 1998 and 2006 were used. In total 6383 reported whiplash injuries were included. To calculate relative risk of an injury in rear-end crashes all two-car crashes reported by the police between 1998 and 2006 were used, in total 15587 crashes.

Injury classification

Claims reports including possible medical journals for all crashes with injured occupants between 1998 and 2006 were examined. Whiplash injuries reported in rear-end crashes within a range between +/-30 degrees from straight rear-end were noted.

Insurance claims were used to verify if the reported whiplash injuries led to long-term symptoms. Occupants with long-term symptoms were defined as those where a medical doctor examined the occupant and the occupant claimed injury symptoms for more than 4 weeks, which corresponds to a payment of at least 2000 SEK in the claims handling process used by Folksam. Out of the 6383 persons reporting a whiplash injury, 912 (13%) led to long-term symptoms according to that definition.

Calculation of relative injury risk

According to Evans (1986), when two cars collide with each other, the injury risk for Car 1 in relation to Car 2 can be expressed as the number of injured occupants in Car 1 in relation to the number in Car 2. This is equal to the risk of injury in car 1 in relation to the risk of injury in Car 2, which can be denoted as p_1 / p_2. Assuming that the probabilities p_1 and p_2 are independent, and that the injury risk in Car 2 can be expressed as the injury risk in Car 1 multiplied by a constant, four cases can be summed: x_1, x_2, x_3 and x_4. The relative injury risk in the whole range of impact severity is equal to equation (1). In this study the relative injury risk for the sum of all cars in each group studied was calculated.

In a similar way the relative risk of injury in rear-end crashes can be calculated with the same technique, where the number of crashes with injured drivers in the struck car in rear-end crashes in relation to the number of crashes with injured drivers in the striking car are summed, see Table 1. The method used in this study to calculate relative injury risk has been further described by Hägg et al. (1992) and Hägg et al (1999).

The initially presented method is relevant for cars of similar mass. If Car 1 and Car 2 have unequal mass, the exposure to impact severity will be unequal as well. While crashworthiness rating based on real-life experience should preferably show the benefit or dis-benefit of mass, the current method would give too much attention to mass, as it would also include the benefit or dis-benefit for the colliding partner. When calculating the injury risk for car models relative to the average car, it is important that the relative injury risk for all car models can be compared with the identical average car. This is not the case if the influence of mass differences on the exposure for the collision partner is not compensated. The initial estimate, equation (1), must therefore be modified to take mass relations into account. The factor *m* was calculated for the car models in each group under study, and thus used to compensate the relative injury risk for the models in each group, see equation (2).

Table 1. Classification of combinations of injured drivers in the struck and striking car in rear-end crashes.

		Drivers in the striking car		Total
		driver injured	driver not injured	
Drivers in the struck car	driver injured	x_1	x_2	$x_1 + x_2$
	driver not injured	x_3	x_4	
Total		$x_1 + x_3$		

x_1 = number of crashes with injured drivers in both cars
x_2 = number of crashes with injured drivers in struck car and not in the striking car
x_3= number of crashes with injured drivers in striking car and not in struck car
x_4= number of crashes without injured drivers in both cars

$$R = (x_1 + x_2) / (x_1 + x_3) \qquad (1).$$

$$R_{modified} = R*m^{((M-Maverage)/100)} = = (x_1 + x_2) / (x_1 + x_3) *m^{((M-Maverage)/100)} \qquad (2).$$

M is the mass of the studied vehicle and $M_{average}$ is the average mass of all vehicles. In these calculations the factor *m* was set as 1.035, see Hägg et al. (1992), which means that the mass effect used to control for the exposure on impact severity was 3.5% per 100 kg. The relative risk of sustaining an injury with long-term symptom was calculated as the product of the relative injury risk and the proportion of occupants with long-term symptoms in relation to the number of reported whiplash injuries.

Categories of cars studied

The whiplash injury and disability risks were calculated for some different categories;

- If the car was fitted with a specially designed whiplash protection system. Those not fitted with whiplash protection system were divided in cars launched before and after 1997.
- Kind of whiplash protection system in cars launched after 1997.
- Performance in the IIWPG ratings.
- Performance in the Folksam/SRA ratings.

The whiplash protections systems defined are RHR-Reactive Head Restraint, WhiPS (Volvo) and WIL (Toyota). Cars with seats fitted with RHR were divided into Saab RHR and RHR in the other manufacturers. Standard seats were defined as those not fitted with any of the systems mentioned above. A group with standard seats tested in consumer ratings was also compared.

RESULTS

A summary of the results is presented in Table 2. Detailed number of crashes and injured for the calculation of relative injury risk is presented in Table 3 in the Appendix.

Cars fitted with more advanced whiplash protection systems had approximately 50% lower proportion of whiplash injuries leading to long-term symptoms as cars with standard seats launched after 1997. Also, the relative risk of a sustaining a whiplash injury leading to long-term symptoms was approximately 50% lower in cars fitted with more advanced whiplash protection systems than in cars with standard seats launched after 1997. Compared with cars launched before 1997 with standard seats the difference was even higher.

It was also found that cars with RHR, WhiPS or WIL, all had lower risk of whiplash injuries leading to long-term symptoms compared with cars with standard seats. Saab cars with RHR showed lower whiplash injury risk than the group of cars with RHR seats from other manufacturers.

Standard seats tested in consumer ratings had lower whiplash injury risk than other standard seats.

A correlation was found between both IIWPG and Folksam/SRA ratings and proportion of injuries leading to long-term symptoms as well as for relative risk of sustaining a whiplash injury leading to long-term symptoms. Car seats rated in the worst group (Red) in the Folksam/SRA crash tests had 60% higher risk of long-term whiplash injury risk than car seats rated in the best group (Green+). Cars rated in the worst group (Poor) in the IIWPG crash tests had 43% higher risk compared with cars seats rated in the best group (Good).

Table 2. Proportions of injuries with long-term symptoms, relative injury risk in rear-end crashes and relative risk of a whiplash injury with long-term symptoms.

		Whiplash injuries leading to long-term symptoms			Relative injury risk in rear-end crashes		Relative risk of long-term symptoms
Type of study		Reported whiplash injuries (n)	Injuries leading to disability (n)	Proportion of injuries leading to disability (p_{dis})	Number of crashes	Relative injury risk (R)	Relative risk of disability ($R^* p_{dis}$)
Special whiplash protection system	Cars with a system	534	40	7,5%	1216	0,977	0,073
	Standard seats 97-	1571	213	13,6%	2488	1,051	0,143
	Standard seats -97	4109	635	15,5%	11883	0,970	0,150
Kind of whiplash protection system (Car models from model year 1997)	RHR	165	10	6,1%	433	1,11	0,067
	Saab RHR	114	6	5,3%	341	0,98	0,052
	Other RHR	51	4	7,8%	92	1,04	0,081
	WhiPS	89	6	6,7%	631	0,95	0,064
	WIL	264	20	7,6%	125	1,10	0,083
	Std seats tested in consumer ratings	196	20	10,2%	368	1,06	0,108
	Other std seats	1366	194	14,2%	2125	1,04	0,148
IIWPG rating	Good	253	17	6,7%	1083	0,95	0,064
	Acceptable	52	3	5,8%	49	1,24	0,071
	Marginal	86	5	5,8%	105	1,21	0,070
	Poor	205	18	8,8%	235	1,04	0,092
	Not tested seats	5615	836	14,9%	14107	0,98	0,146
Folksam/SRA rating	Green+	140	8	5,7%	729	0,98	0,056
	Green	314	21	6,7%	1089	0,98	0,066
	Yellow	77	4	5,2%	60	1,30	0,068
	Red	23	2	8,7%	40	1,03	0,089
	Not tested seats	5798	857	14,9%	14392	0,99	0,147

DISCUSSION

Whiplash injuries leading to permanent disability are serious and account for the vast majority of injuries leading to permanent disability (Nygren 1984, Krafft 1998). Many initiatives to reduce the problem have been taken, where most car manufacturers also include whiplash protection in their designs of new models (Lundell et al 1998, Wiklund and Larsson 1998). Many are also introducing more advanced whiplash protection systems in their models. Measuring the performance of recent introduced whiplash prevention technology is very important for future activities in legislation and consumer testing, such as EuroNCAP. In recent years many initiatives of consumer rating system aimed at measuring neck injury risk in rear-end crashes have been launched. But the correlation between real-life whiplash injury outcome and results from these consumer rating programmes has to date not been presented.

Existing consumer crash testing is focussed the seat performance since the seat plays a major role in protecting the occupants from whiplash injury. This approach is probably relevant in today's situation, where the seat plays a major role for the whiplash injury risk, but since real-life outcome concerns the performance of the whole car, the results could be influenced by the difference.

The definition of long-term symptoms used in this study was chosen because it takes several years, sometimes up to 6 years, until a degree of permanent disability can be finally set and verified according to the system used by the insurance companies in Sweden (Försäkringsförbundet 1996). To be able to use this definition crashes older than 6 years can only be used, which is not applicable to study whiplash preventive systems introduced the latest 6 years.

Due to the limited number of crashes and injured it was not possible to study the performance of single car models, only groups of cars. All various car models fitted with reactive head restraints (RHR) may have different performance in real-life crashes. In this study it was only possible to study the difference between Saab RHR and RHR for other manufacturers, such as Audi, Ford, Nissan, Opel and VW. No major difference between these could be verified.

The results from this study is very positive and show that efforts made by car manufacturers to reduce whiplash injury risks has been successful, although there are still potential improvements to make. It is also positive that test results from consumer test programmes correlate with real-life performance. Also in this case there are still potential improvements to make to better mirror real-life injury risks. There is always a need to verify crash test results with results from real-world crashes.

Results from existing consumer crash test programmes indicate a large variation in protection. Some seats perform well even without more advanced whiplash protection systems, while some seats fitted with for example RHR received poor rating results. Identifying that a seat has a whiplash protection device is not enough. It stresses the need for consumer test programmes to be used as guidance for consumers in picking the best cars and it also stresses the need for validation of their performance in real-life crashes.

Finally, it is important to stress that further efforts should be made to improve car seats and also other safety technology to reduce whiplash injuries leading to permanent disability. Although the attempts made so far reduces the whiplash injury risk a lot, there is still a long way to go. In modern cars, whiplash injury accounts for approximately 70 % of all injuries leading to disability (Folksam 2005). Even if half of the whiplash injuries in rear-end crashes could be avoided, whiplash is still the most dominating injury leading to permanent disability.

CONCLUSIONS

- Cars fitted with advanced whiplash protection systems had 50% lower risk of whiplash injuries leading to long-term symptoms compared with standard seats launched after 1997.
- The whiplash prevention systems, RHR (Reactive Head Restrains), WhiPS or WIL, had lower risk of whiplash injuries leading to long-term symptoms compared with standard seats launched after 1997.
- A correlation was found between consumer crash test programmes and real-life whiplash injury outcome. Cars with seats rated as good in the consumer crash tests had lower risk of whiplash injuries leading to long-term symptoms compared with seats with poor results.

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APPENDIX

Table 3. Numbers of crashes with different combinations of injured occupants and relative injury risks in rear-end crashes.

		No. crashes	X_1	X_2	X_3	R	m	$R_{modified}$
Cars with and without whiplash protection	Seats with whiplash system	1216	351	461	501	0,95	1,03	0,98
	Standard seats from MY 1997	2488	711	1075	952	1,07	0,98	1,05
	Standard seats until MY 1997	11883	3093	5013	4986	1,00	0,97	0,97
Type of whiplash device	RHR	433	140	157	172	0,95	1,17	1,11
	Saab RHR	341	117	116	133	0,93	1,05	0,98
	Other RHR	92	23	41	39	1,03	1,00	1,04
	WHIPS	631	160	238	273	0,92	1,03	0,95
	WIL	125	43	53	39	1,17	0,94	1,10
	Standard seats tested 97-	368	96	170	149	1,09	0,98	1,06
	Other standard seats 97-	2125	618	912	807	1,07	0,97	1,04
IIWPG rating	Good	1083	306	400	459	0,92	1,03	0,95
	Acceptable	49	13	25	17	1,27	0,97	1,24
	Marginal	105	24	56	41	1,23	0,98	1,21
	Poor	235	76	97	86	1,07	0,98	1,04
	Good+Acc	1132	319	425	476	0,94	1,03	0,97
	Marg+Poor	340	100	153	127	1,11	0,98	1,09
	Not tested	14107	3724	5969	5830	1,02	0,97	0,98
Folksam/SRA rating	Green+	729	181	193	226	0,92	1,06	0,98
	Green	1089	293	279	332	0,92	1,07	0,98
	Yellow	60	17	22	12	1,34	0,97	1,30
	Red	40	16	9	9	1,00	1,03	1,03
	Above average	1099	295	285	333	0,92	1,03	0,95
	Below average	90	31	25	19	1,12	0,95	1,07
	Not tested	14392	3800	6115	5942	1,02	0,97	0,99
Total		15587	4155	6549	6438	1,01	0,99	1,00