GENDER ANALYSIS ON WHIPLASH SEAT EFFECTIVENESS: RESULTS FROM REAL-WORLD CRASHES

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ABSTRACT

The objective was to study the effectiveness of whiplash protection concepts in cars due to gender and the effectiveness of various concepts based on real-world injury outcome. In the study the influence on whiplash symptoms lasting longer than one month and those leading to permanent medical impairment was studied. In average the existing whiplash concepts were more effective for males than females. The risk reduction regarding permanent medical impairment was approximately 45% for females and approximately 60% for males. RHR in Saab, Volvo WHIPS and Toyota WIL, all had approximately 50% lower risk of whiplash injuries leading to permanent medical impairment compared to cars with standard seats.

Keywords: Neck, Whiplash, Protection, Rear impacts, Gender

OUT OF NON-FATAL INJURIES, whiplash injuries represent an important part of the injury outcome in car collisions. Concerning modern cars on the Swedish market, whiplash injuries account for approximately 70 % of all injuries leading to permanent medical impairment (Kullgren et al 2007). In Germany the incidence of whiplash injuries was 35% of all traffic injuries in cars 1990 based on insurance data (Hell et al 1998) and in the UK the number was 46% during the same period of time, based on hospital data (Galasko et al, 1993). Not all occupants who suffer whiplash injury develop chronic symptoms. Eight to ten percent suffered impairment at least one year after the collision (Nygren, 1984; Galasko et al, 1996). A Canadian study (Spitzer et al, 1995) found that 2.9% were still absent from usual activities or work one year after the event. Spitzer et al (1995) stated that patients who still have symptoms lasting six months or more after injury are defined as chronic.

Many studies have shown that females have higher risk of sustaining a whiplash injury than males. Carlsson (2010) have summarised 13 different studies (Figure 1) showing the relative injury risk for females compared to males. According to these studies the injury risk vary from approximately 1.5 to 3 times higher risk for females, even under similar crash conditions.

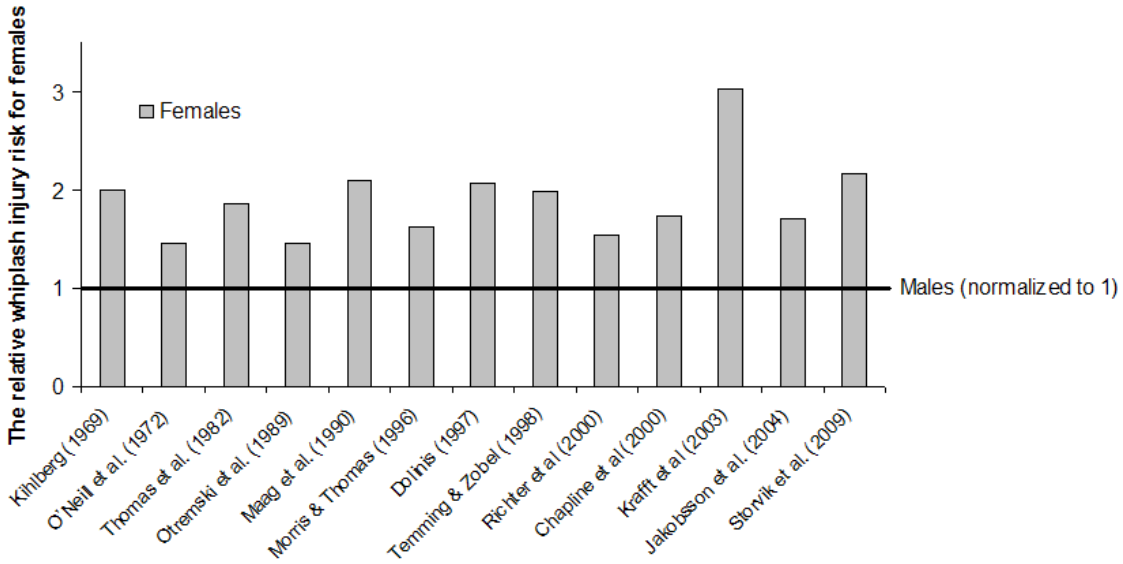

Fig. 1 - Relative whiplash injury risk for females compared to males (from Carlsson 2010).

Prevention of whiplash injuries in rear impacts has been focused on the car seats. During the 70's and the 80's the geometry of the head rests dominated the activities of research (O´Neill et al, 1972; States & Balcerak, 1973; Kahane, 1982; Lövsund et al, 1988) and since the late 90's seats with whiplash protection devices have been introduced on the market involving larger parts of the seat than just the head rests. The mechanical properties and design of the seat and seatback affect the whiplash injury. Seatbacks have become much stiffer during the last decades that might have been negative for the injury (Foret-Bruno et al, 1991; Parkin et al, 1995; Viano, 2008). The protection is achieved through improved geometry and dynamic properties of the head restraint or by re-active or 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 human body and to absorb energy in the seatback.

To date several main concepts exist, for example Reactive Head Restraint (RHR) that is fitted 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 for example Audi (until MY2007), 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 seatback 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, Audi and Volkswagen (from MY 2007) has also introduced seats without active or reactive parts in the headrest, but with an improved design aimed at reducing the number of whiplash injuries.

Studies have been presented showing the effect of the Saab RHR and Volvo WHIPS indicating an injury reducing effect of approximately 20-50% (Viano and Olsén, 2001, Farmer et al 2008,2002, Jakobsson, 2004, Krafft et al, 2003, Kullgren et al 2007, Kullgren and Krafft, 2008, Jacobsson et al, 2008). Mostly the effect of different whiplash protection solutions has not been separated for gender. However since injury risk differs dramatically between men and women there is a need to evaluate the risk separately. Jakobsson (2004) found a higher injury reducing effect for women than for men in a Volvo with WHIPS than without. But there is a need to investigate the performance for different design concepts since they vary and partly address different possible injury criteria.

OBJECTIVES OF THE STUDY : The objective was to study the effectiveness for males and females of cars fitted with whiplash protection systems, but also the effectiveness of various concepts aimed at protecting whiplash injuries based on real-world injury outcome. In the study the influence on whiplash symptoms lasting longer than one month and those leading to permanent medical impairment was studied.

MATERIAL/METHOD

The study was based on three different datasets:

1. Whiplash injuries in rear-end crashes reported to the insurance company Folksam between 1995 and 2007
2. Occupants insured in Folksam with a verified permanent medical impairment
3. Two-car crashes reported by the police between 1995 and 2008

To calculate the proportion of injuries leading to symptoms lasting longer than one month, all whiplash injuries in rear-end crashes reported to the insurance company Folksam between 1995 and 2007 were used (Dataset 1). The material constituted of all rear-end crashes for car models included in the Folksam Car Model Safety Ratings 2009 (Folksam, 2009). In total 11 026 reported whiplash injuries were included. To calculate the proportion of occupants with permanent medical impairment, the same dataset was used but matched with a dataset of all occupants insured in Folksam with a verified permanent medical impairment (Dataset 2). However, only accidents before year 2008 could be used as it takes up to 3 years to verify if an occupant will sustain a permanent medical impairment.

To calculate relative risk of an injury (only initial symptoms) in rear-end crashes, all two-car crashes reported by the police between 1995 and 2008 were used (Dataset 3), in total 22 505 crashes. In the first two datasets both drivers and front seat passengers were included. In the third dataset only drivers were included.

The relative risk of injuries leading to symptoms lasting longer than one month was calculated by multiplying the relative injury risk in rear-end crashes (from Dataset 3) by the proportion of injuries with symptoms lasting longer than one month (from Dataset 1). The relative risk of whiplash injury leading to permanent medical impairment was similarly calculated by multiplying the relative injury risk (from Dataset 3) with the proportion of occupants with permanent medical impairment (from Dataset 1 and 2).

INJURY CLASSIFICATION : Claims reports, sometimes also including medical journals, for all crashes with injured occupants between 1998 and 2007 were examined. Whiplash injuries reported in rear-end crashes within a range between +/-30 degrees from straight rear-end were selected.

Insurance claims were used to verify if the reported whiplash injuries led to long-term consequences. Occupants with symptoms lasting longer than one month 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 11 026 persons reporting a whiplash injury, 1425 (12.9 %) had symptoms lasting longer than one month (Table 1). In addition to that also occupants with permanent medical impairment according to the procedure used by Swedish insurance companies (Försäkringsförbundet, 1996) were noted. It may take up to 3 years until a final degree of impairment is set. However, a preliminary estimation of the degree of permanent medical impairment is determined about one year after the crash. The impairment degrees were verified and set by physicians. In total 900 (8.2%) occupants sustained a permanent medical impairment (Table 1).

Table 1. Number of reported whiplash injuries, injuries with symptoms > 4 weeks and those leading to permanent medical impairment.

Injury classification	n	%
Reported	11 026	100
> 4 weeks (1 month)	1 425	12.9
Permanent medical impairment	900	8.2

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 (R) 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. In the studies by Hägg et al. (1992) and Hägg et al (2001) the method used in this study to calculate relative injury risk is further described.

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 (R), 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 mass 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 2. Classification of combinations of injured drivers in the struck and striking car in rear-end crashes.

		Drivers in the striking car		Total
		drivers injured	drivers not injured	
Drivers in the struck car	drivers injured	x_1	x_2	$x_1 + x_2$
	drivers 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 the struck car and not in the striking car
x_3= number of crashes with injured drivers in the striking car and not in the struck car
x_4= number of crashes with no injured drivers in both cars

$$R = p_1 / p_2 = (x_1 + x_2) / (x_1 + x_3) \quad (1).$$

p_1 = injury risk in struck cars
p_2 = injury risk in striking cars

$$R_{modified} = R * m^k = (x_{1,\,adjusted} + x_{2,\,adjusted}) / (x_1 + x_3) * m^k \quad (2).$$

$$m = 2 * m_1/(m_1 + m_2) \quad (3).$$

$$x_{i,\,adjusted} = \sum_{j=1}^{m} (x_{i,j} * (1 + f * (Year_{actual} - Year_j))) \quad (4).$$

f = factor 0.015 (1.5% per year),
$Year_{actual}$ = the latest accident year in the sample
$Year_j$ = accident year j

Since the safety level of cars continuously increases, cars colliding different years will be exposed to cars they collide with that has different safety level. The factor is set to 1.5% per accident year (Hägg et al. 2001) corresponding to the average annual increased safety level of the Swedish car fleet. Equation (4) shows how the adjustment is made by adjusting the number of crashes with injured occupants in the struck cars, the nominator in equation (1). m_1 is the mass of the case cars and m_2 is the average mass of all cars the case cars collided with. *k* is the power stating the influence of mass for a given injury severity. For studies of all injuries *k*= 0.9 was used (Folksam, 2009, Krafft et al., 2009).

The variance of R (relative injury risk) was estimated as described in equation (5).

$$V(R) = (p_1^* / p_2^*)^x((1-p_1^*)/(x_1+x_2) + (1- p_2^*)/(x_1+x_3)) \quad (5).$$

where p_1^* / p_2^* is estimated by R, while p_1^* and p_2^* must be chosen arbitrarily (Hägg et al 1992).

The variances of the proportion of injured (prop) and the product R * prop were calculated as:

$V(prop) = prop * (1\text{-}prop)/n$

$V(R * prop) = prop^2 * V(R) + R^2 * V(prop)$

95% confidence intervals (95% CI) were calculated based on the variances above.

Chi-square test for equal distributions was used to study if the proportions of occupants with long-term symptoms (symptoms > 1month and permanent medical impairment) were significantly different between categories.

The whiplash injury risks were calculated for some different categories;

- If the car was fitted with a specially designed whiplash protection system or not. 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.

The whiplash protections systems defined are Saab RHR (Reactive head restraint from Saab, also named SAHR)), RHR from other carmakers than Saab, WHIPS from Volvo and WIL from Toyota. Standard seats were defined as those not fitted with any specific anti-whiplash system and launched 1997 or later (MY 1997 and onwards).

RESULTS

Women were found to have approximately 50% higher risk of reporting an injury in rear-end crashes compared to men (relative risk of 1.37±0.02 compared to 0.89±0.02), see Table 3. Women were also found to have a double risk of symptoms lasting longer than one month compared to men (20.3±1.3 compared to 9.8±0.8) and also a double risk of injuries leading to permanent medical impairment (13.1±1.1 compared to 6.1±0.8), Table 3. From Table 3 it can also be seen that the risk reduction (permanent medical impairment) of seat with whiplash protection compared with seats without and launched after 1997 was approximately 50% (8.6±1.2 compared to 4.3±1.4). The whiplash systems were found to have a significantly higher effect for men than for women (from the chi^2-test). For women the reduction was approximately 45% (11.6±2.2 compared to 6.4±2.6) and for men approximately 60% (7.2±1.5 compared to 3.0±1.7).

RHR in Saab, Volvo WHIPS and Toyota WIL, all showed lower risk of whiplash injuries leading to permanent medical impairment as well as symptoms lasting longer than one month compared to cars with standard seats (Table 4). The reductions regarding occupants with symptoms lasting longer than one month were approximately 50% for SAHR (7.5±4.0 compared to 15.9±1.6), 35% for WHIPS (9.1±4.9 compared to 15.9±1.6) and 20% for WIL (11.8±3.5 compared to 15.9±1.6). Regarding permanent medical impairment the reductions were approximately 50% for the same three concepts, Saab-RHR (3.5±2.7 compared to 8.5±1.2), Volvo WHIPS (3.8±3.3 compared to 8.5±1.2) and Toyota WIL (4.1±2.0 compared to 8.5±1.2). For RHR in other cars than SAAB the reduction in risk seems less than for RHR in SAAB. The group of cars consists of many different models listed in Table 6 in the Appendix. The data are too few to differentiate between the RHR concepts in the car makes.

The reduction of injuries with symptoms lasting longer than one month was larger for men than for women for all whiplash concepts. However, significant differences were not found between all individual concepts regarding gender differences, but RHR Saab and all cars with RHR seats had a significant difference. The reduction of injuries leading to permanent medical impairment was more equal between the concepts for men and women, but an indication of large differences in reduction due to gender for the various seat concepts could be seen.

Table 3. Relative injury risk in rear-end crashes, numbers of injured (n), proportion and relative risk of a whiplash injury with symptoms > 1 month and of permanent medical impairment (PMI) for females and males in seats with and without whiplash protection concepts.

Sex	Seat concept	Relative injury risk	95% CI	n rep inj	n 1 month	n PMI	Prop-ortion 1 month	95% CI	Prop-ortion PMI (%)	95% CI	Relative risk 1 month (%)	95% CI	Relative risk PMI (%)	95% CI
F	Other			351	32	19	9,1	3,0	5,4	2,4				
F	No whiplash prot MY< 97	1,37	0,03	3490	527	383	15,1	1,2	11,0	1,0	20,6	1,7	15,0	1,5
F	No whiplash prot MY>97	1,44	0,04	1248	199	101	15,9	2,0	8,1	1,5	22,8	3,0	11,6	2,2
F	Whiplash protection MY>97	1,27	0,07	456	62	23	13,6	3,1	5,0	2,0	17,3	4,1	6,4	2,6
F	Total	1,37	0,02	5545	820	526	14,8	0,9	9,5	0,8	20,3	1,3	13,1	1,1
M	Other			351	25	12	7,1	2,7	3,4	1,9				
M	No whiplash prot MY< 97	0,87	0,02	3745	419	271	11,2	1,0	7,2	0,8	9,7	0,9	6,3	0,7
M	No whiplash prot MY>97	0,93	0,04	1020	135	79	13,2	2,1	7,7	1,6	12,3	2,0	7,2	1,5
M	Whiplash protection MY>97	0,92	0,05	365	26	12	7,1	2,6	3,3	1,8	6,5	2,5	3,0	1,7
M	Total	0,89	0,02	5481	605	374	11,0	0,8	6,8	0,7	9,8	0,8	6,1	0,6
T	Other			703	57	31	8,1	2,0	4,4	1,5				
T	No whiplash prot MY< 97	0,97	0,02	7241	946	654	13,1	0,8	9,0	0,7	12,7	0,8	8,7	0,7
T	No whiplash prot MY>97	1,08	0,03	2270	334	180	14,7	1,5	7,9	1,1	15,9	1,6	8,6	1,2
T	Whiplash protection MY>97	1,00	0,04	822	88	35	10,7	2,1	4,3	1,4	10,7	2,1	4,3	1,4
T	Total	1,00	0,01	11026	1425	900	12,9	0,6	8,2	0,5	12,9	0,7	8,2	0,5

***** The data for calculation of relative injury risks is presented in Table 5 in the Appendix.

Table 4. Relative injury risk in rear-end crashes, numbers of injured (n), proportion and relative risk of a whiplash injury with symptoms > 1 month and of permanent medical impairment (PMI) for females and males in seats with various whiplash concepts.

Sex	Seat concept	Relative injury risk	95% CI	n rep inj	n 1 month	n PMI	Proportion 1 month (%)	95% CI	Proportion PMI (%)	95% CI	Relative risk 1 month (%)	95% CI	Relative risk PMI (%)	95% CI
F	All RHR seats	1,30	0,10	145	20	11	13,8	5,6	7,6	4,3	17,9	7,4	9,9	5,6
F	RHR SAAB	1,22	0,14	84	8	6	9,5	6,3	7,1	5,5	11,7	7,8	8,7	6,8
F	RHR other than SAAB	1,38	0,15	61	12	5	19,7	10,0	8,2	6,9	27,2	14,1	11,3	9,6
F	Volvo WhiPS	1,26	0,10	53	8	2	15,1	9,6	3,8	5,1	19,1	12,3	4,8	6,5
F	Toyota WIL	1,24	0,17	253	34	10	13,4	4,2	4,0	2,4	16,7	5,7	4,9	3,1
F	Cars with standard seats	1,43	0,04	1249	199	101	15,9	2,0	8,1	1,5	22,8	3,0	11,6	2,2
F	Total	1,37	0,02	5545	820	526	14,8	0,9	9,5	0,8	20,3	1,3	13,0	1,1
M	All RHR seats	0,96	0,08	142	9	2	6,3	4,0	1,4	1,9	6,1	3,9	1,4	1,9
M	RHR SAAB	0,93	0,09	87	5	0	5,7	4,9	0,0	0,0	5,4	4,6	0,0	-
M	RHR other than SAAB	1,01	0,13	55	4	2	7,3	6,9	3,6	4,9	7,3	7,0	3,7	5,0
M	Volvo WhiPS	0,90	0,07	72	4	3	5,6	5,3	4,2	4,6	5,0	4,8	3,7	4,1
M	Toyota WIL	0,97	0,17	146	12	6	8,2	4,5	4,1	3,2	8,0	4,5	4,0	3,2
M	Cars with standard seats	0,93	0,04	1018	134	78	13,2	2,1	7,7	1,6	12,2	2,0	7,1	1,5
M	Total	0,89	0,02	5481	605	374	11,0	0,8	6,8	0,7	9,8	0,8	6,1	0,6
T	All RHR seats	1,04	0,06	287	29	13	10,1	3,5	4,5	2,4	10,5	3,7	4,7	2,5
T	RHR SAAB	0,99	0,08	171	13	6	7,6	4,0	3,5	2,8	7,5	4,0	3,5	2,7
T	RHR other than SAAB	1,12	0,10	116	16	7	13,8	6,3	6,0	4,3	15,4	7,1	6,7	4,9
T	Volvo WhiPS	0,96	0,06	126	12	5	9,5	5,1	4,0	3,4	9,1	4,9	3,8	3,3
T	Toyota WIL	1,02	0,12	399	46	16	11,5	3,1	4,0	1,9	11,8	3,5	4,1	2,0
T	Cars with standard seats	1,08	0,03	2269	333	179	14,7	1,5	7,9	1,1	15,9	1,6	8,5	1,2
T	Total	1,00	0,01	11036	1425	900	12,9	0,6	8,2	0,5	12,9	0,7	8,2	0,5

***** The data for calculation of relative injury risks is presented in Table 5 in the Appendix.

DISCUSSION

Whiplash injuries account for the vast majority of injuries leading to permanent medical impairment (Nygren, 1984, Krafft, 1998). They constitute one of the largest problems resulting from road traffic crashes. Many initiatives have been taken to reduce the incidence and consequences of these injuries. Consumer test programmes such as IIWPG, Folksam/SRA and Euro NCAP have probably meant a lot to speed up the improvement on the market. The first car manufacturers to introduce such whiplash prevention or mitigation concepts were Volvo, Saab and Toyota (Lundell et al, 1998; Wiklund and Larsson; 1998, Sekizuka, 1998). To date most car manufacturers include whiplash protection in their designs of new models. It is important to measure the performance of

existing whiplash prevention concepts for future activities in prevention, legislation and consumer testing.

The results from this study are 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.

The results show that the effectiveness of whiplash protection systems is larger the more long-term consequences that are considered. In this study the effectiveness was approximately 30% regarding whiplash injuries with symptoms lasting longer than one month and approximately 50% for verified permanent medical impairment. But it should be noted that even if studying symptoms lasting longer than just one month, the differences found between the various comparisons were large.

Regarding the reduction in risk for the various anti-whiplash concepts it seems like most concepts lower the risk except from cars with RHR other than Saab. It is important to conduct further studies to verify differences between RHR in all car makes and models.

Apart from the variation in effectiveness between the concepts found in this study, also 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 seem to receive poor rating results. Identifying that a seat has a whiplash protection device is not enough. It stresses the need for both real-life studies and consumer test programmes to guide both manufacturers to focus on the most effective concepts and consumers to pick the best cars.

It is well known that females have a much higher injury risk in rear impacts compared to males. The results in this study clearly show that the existing whiplash seat concepts are more effective for males than for females. Further research is important to clarify the indications found in this study regarding differences in effectiveness between males and females for the various seat concepts exist. Based on modeling Viano (2003) pointed out that early neck displacements are greater in females because of a higher ratio of seat stiffness to torso mass. The seat stiffness is not sufficiently low in proportion to the female mass in comparison to males.

Since females seems to be much more vulnerable to whiplash injuries it is important for preventative measures to determine test criteria, trigger level of protection systems and critical levels of crash test severity mainly based on data related to females, and not based on mean values for the total population. Furthermore, the 50th percentile male dummy might limit the assessment and development of prevention systems that adequately protect both males and females since there might be anatomical differences that partly explain the risk difference (Carlsson, 2010).

In modern cars, whiplash injury accounts for approximately 70 % of all injuries leading to permanent medical impairment, all crash directions included (Malm et al., 2008). Even if half of the whiplash injuries in rear-end crashes could be avoided, whiplash will still be the most dominating injury leading to loss of health. Therefore further efforts are necessary to decrease the injury risk in other crash directions than rear-end.

LIMITATIONS OF THE STUDY : One fact that to some degree influences the results is that the real- world injury outcome concerns the performance of the whole car and not only the seat. For instance, there is a correlation between crash severity and whiplash injury risk (Krafft et al, 2005), which means that heavier cars have an advantage in rear impacts that influences the result from real-world data.

In the calculation of relative injury risks only drivers were included. However, in the long-term injury data both drivers and front seat passengers were included. This might have influenced the outcome since the injury risk seems to depend on the seating position (Jonsson, 2008; Krafft et al, 2003). However, it will only influence the result if the distribution driver/front seat passenger differs between the investigated models. The same scenario concerns awareness of the occupant, previous neck symptoms, if the head was rotated and initial seating position.

Influence of occupant age, stature and weight was not considered in this study. Studies have shown an influence of age and stature (Berglund et al 2004, Temming and Zobel 1998, Jakobsson et al 2005). The injury risk is somewhat greater to the age group 20 to 50 than for the older and younger age groups. Increasing stature seems to influence the injury risk for both genders. It is reasonable to believe that there is a correlation between occupant age/stature and car size. But in the present study the size of the models are relatively mixed between the study groups and therefore the differences in

average age, stature or weight between the groups in the present study could be anticipated to be small, thus the influence on the results or conclusions should be limited.

CONCLUSIONS

In average the existing whiplash concepts were more effective for males than females. The risk reduction regarding permanent medical impairment was approximately 45% (11.6±2.2) for females and approximately 60% (7.2±1.5) for males.

Cars fitted with any kind of whiplash protection concept had approximately 50% lower risk (8.6±1.2 compared to 4.3±1.4) of a whiplash injury leading to permanent medical impairment compared with standard seats launched after 1997.

RHR in Saab, Volvo WHIPS and Toyota WIL, all showed lower risk of whiplash injuries leading to permanent medical impairment compared to cars with standard seats. The reductions regarding occupants that sustained permanent medical impairment were approximately 50% for the three concepts, Saab-RHR (3.5±2.7 compared to 8.5±1.2), Volvo WHIPS (3.8±3.3 compared to 8.5±1.2) and Toyota WIL (4.1±2.0 compared to 8.5±1.2).

Females had approximately 50% higher risk of reporting a whiplash injury (1.37±0.02 compared to 0.89±0.02) in rear-end crashes than males and they also had a double risk of a whiplash injury both with symptoms lasting longer than one month (20.3±1.3 compared to 9.8±0.8) and with those leading to permanent medical impairment (13.1±1.1 compared to 6.1±0.8) compared to males.

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APPENDIX

Table 5. Numbers of crashes with different combinations of injured occupants and relative injury risks in rear-end crashes.

Sex	Whiplash seat	Number of crashes	X1	X2	X3	R	R*f_{year}	Mass case cars	Mass other cars	*m*	$R_{modified}$	95% CI
M	Other	9	3	2	3	0,83	0,84	1961	1295	1,182	0,93	0,65
M	No whiplash prot MY< 98	8446	2033	2175	2827	0,87	0,94	1311	1335	0,992	0,87	0,02
M	No whiplash prot MY>98	1976	498	494	607	0,90	0,93	1569	1372	1,060	0,92	0,04
M	Whiplash protection MY>98	2970	744	778	899	0,93	0,98	1409	1360	1,016	0,93	0,05
M	Total	13401	3278	3449	4336	0,88	0,95	1371	1346	1,008	0,89	0,02
F	Other	6	2	2	1	1,33	1,33	1435	1431	1,001	1,25	0,79
F	No whiplash prot MY< 98	4309	1222	1745	914	1,39	1,51	1251	1334	0,971	1,37	0,03
F	No whiplash prot MY>98	872	262	314	192	1,27	1,31	1502	1375	1,040	1,27	0,04
F	Whiplash protection MY>98	1915	575	796	348	1,49	1,56	1315	1363	0,984	1,44	0,07
F	Total	7102	2061	2857	1455	1,40	1,50	1299	1347	0,984	1,37	0,02
Tot	Other	15	5	4	4	1,00	1,01	1750	1349	1,116	1,05	0,50
Tot	No whiplash prot MY< 98	13258	3261	3930	4142	0,97	1,05	1291	1334	0,985	0,97	0,02
Tot	No whiplash prot MY>98	2914	763	808	848	0,98	1,01	1548	1373	1,054	1,00	0,03
Tot	Whiplash protection MY>98	4981	1321	1579	1327	1,10	1,16	1372	1361	1,004	1,08	0,04
Tot	Total	21168	5350	6321	6321	1,00	1,07	1346	1346	1,000	1,00	0,01
Sex	Whiplash seat	Number of crashes	X1	X2	X3	R	R*f_{year}	Mass case cars	Mass other cars	*m*	$R_{modified}$	95% CI
F	All RHR seats	351	110	126	76	1,269	1,324	1539	1367	1,05	1,30	0,10
F	RHR other than SAAB	164	45	66	34	1,405	1,438	1482	1385	1,03	1,38	0,15
F	RHR SAAB	187	65	60	42	1,168	1,224	1589	1355	1,07	1,22	0,14
F	Toyota WIL	125	44	45	23	1,328	1,368	1286	1370	0,97	1,24	0,17
F	Volvo WhiPS	361	99	132	87	1,242	1,288	1548	1384	1,05	1,26	0,10
F	Cars with standard seats	1935	581	803	352	1,483	1,560	1313	1364	0,98	1,43	0,04
F	Other	4330	1227	1751	917	1,390	1,508	1252	1334	0,97	1,37	0,03
F	Total	7102	2061	2857	1455	1,399	1,496	1299	1347	0,98	1,37	0,02
M	All RHR seats	796	195	202	234	0,925	0,965	1582	1367	1,07	0,96	0,08
M	RHR other than SAAB	289	66	76	76	1,000	1,025	1539	1366	1,05	1,01	0,13
M	RHR SAAB	507	129	126	158	0,889	0,931	1607	1368	1,07	0,93	0,09
M	Toyota WIL	142	39	38	38	1,000	1,036	1387	1381	1,00	0,97	0,17
M	Volvo WhiPS	997	256	243	318	0,869	0,903	1585	1375	1,06	0,90	0,07
M	Cars with standard seats	2954	744	773	895	0,926	0,978	1403	1360	1,01	0,93	0,04
M	Other	8512	2044	2193	2851	0,866	0,940	1314	1335	0,99	0,87	0,02
M	Total	13401	3278	3449	4336	0,884	0,947	1371	1346	1,01	0,89	0,02
Tot	All RHR seats	1170	307	328	324	1,006	1,050	1569	1368	1,06	1,04	0,06
Tot	RHR other than SAAB	462	112	142	115	1,119	1,146	1519	1375	1,04	1,12	0,10
Tot	RHR SAAB	708	195	186	209	0,943	0,988	1602	1364	1,07	0,99	0,08
Tot	Toyota WIL	280	84	83	72	1,071	1,107	1341	1379	0,99	1,02	0,12
Tot	Volvo WhiPS	1386	355	375	427	0,934	0,970	1575	1377	1,06	0,96	0,06
Tot	Cars with standard seats	4985	1327	1581	1327	1,096	1,156	1368	1361	1,00	1,08	0,03
Tot	Other	13347	3277	3954	4171	0,971	1,054	1293	1335	0,99	0,97	0,02
Tot	Total	21168	5350	6321	6321	1,000	1,071	1346	1346	1,00	1,00	0,01

Table 6. Number of reported injuries, long-term consequences and proportions of long-tem consequences for various car makes with Reactive Head Restraints (RHR).

Seat concept	n rep inj	n 1 month	n PMI	Proportion 1 month (%)	Proportion PMI (%)
RHR Audi	10	1	1	10,0	10,0
RHR Ford	30	7	4	23,3	13,3
RHR Hyundai	3				
RHR Honda	5	1		20,0	0,0
RHR Mazda	6				
RHR Nissan	5				
RHR Opel	25	4	1	16,0	4,0
RHR Peugeot	2				
RHR Subaru	1				
RHR Skoda	4				
RHR VW	25	3	1	12,0	4,0
RHR other than SAAB	116	16	7	13,8	6,0
RHR SAAB	171	13	6	7,6	3,5
WhiPS Volvo	126	12	5	9,5	4,0
WIL Toyota	399	46	16	11,5	4,0