Development of Whiplash Associated Disorders for Male and Female Car Occupants in Cars Launched Since the 80s in Different Impact Directions

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Abstract The aim was to investigate the development of Whiplash Associated Disorders (WAD) leading to long-term consequences for drivers separated for gender in cars introduced at different year intervals and in different impact directions. An additional aim was to analyze the influence of various whiplash preventive concepts on WAD in rear impacts.

The developments were studied for cars grouped into 5-year intervals according to year of introduction separated for frontal, side and rear-end impacts and for gender. All drivers (24,452) reporting WAD during the years 1998-2012, and those reporting symptoms > 1 month as well as those with permanent impairment, were included. Whiplash preventive concepts were grouped according to car make and concept.

A reduction in risk of long-term consequences after reporting initial symptoms of WAD were found in rear-end and side impacts comparing cars introduced on the market 1980-84 and 2005-2009. No reduction was found in frontal impacts. This clearly shows that more focus on preventive interventions for frontal impacts is needed.

Existing seat concepts aimed at lowering the risk of WAD were found to reduce the risk of long-term consequences after reporting initial symptoms of WAD. However, seats with energy absorption in the seat back, passive seats or reactive seats are more effective for females than seats with Reactive Head Restraints, which showed no major reduction of WAD with long-term consequences compared with standard seats.

Keywords WAD, whiplash, whiplash symptoms, impairment, gender.

I. INTRODUCTION

Whiplash Associated Disorders (WAD) constitute a major problem for the society and the affected occupants. WAD account for the vast majority of injuries leading to permanent medical impairment (pmi) [1, 2]. They constitute one of the largest problems resulting from road traffic crashes. In Sweden they account for approximately 50% of all traffic injuries leading to long-term consequences [1]. Harder et al [3] reviewed 2810 claims of WAD of which 1551 included other injuries as well. It was found that 25% of those with WAD recovered within a week compared to 19% of those claiming also for other injuries. One year after the crash, 1.9% of those suffering only WAD and 4.1% of those with multiple injuries had not recovered. A Canadian study [4] found that 2.9% were still absent from usual activities or work one year after the event. Spitzer also stated that patients who still have symptoms lasting six months or more after injury are defined as chronic.

WAD is generated in all impact directions [5-7]. In a Swedish study from the late 1990s it was found that 30% of all WAD with long-term symptoms occurred in frontal impacts. Approximately 50 % and 10 % occurred in rear-end and side impacts respectively [8]. Whiplash preventive measures have mostly been focused on rear impacts.

Since the late 1990s more advanced concepts aimed at reducing the risk of WAD have been introduced on the market [6, 9-11]. 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 [12]. The main ways to lower the risk of WAD in rear impacts are to minimize 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

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concepts exist, for example Reactive Head Restraint (RHR), WHIPS (Whiplash Prevention System) in Volvo and Jaguar, WIL (Whiplash Injury Lessening) in Toyota. RHR was firstly introduced in Saab cars in 1998 (SAHR) [9] and was further developed in 2003. The RHR concept 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 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 [6, 10]. The seat back in a crash moves rearwards and yields in a controlled way to absorb energy. The Toyota system WIL [11] has no active parts and is only working with improved geometry and softer seat back. Several manufacturers, such as Ford, Audi and Volkswagen (from MY 2007) have also introduced passive seat concepts without active or reactive parts in the headrest, but with an improved design aimed at reducing the risk of WAD.

Studies have been presented showing the effect of the Saab RHR and Volvo WHIPS indicating a reducing effect in WAD of approximately 20-50% [13-18]. Mostly the effect of different whiplash protection solutions has not been separated for gender. However, since risk for WAD differs dramatically between males and females, there is a need to evaluate the risk separately.

In 2004 consumer test programmes were introduced (IIWPG and Folksam/SRA) [12]. And since 2009 the European New Car Assessment Program (Euro NCAP) has implemented a whiplash rear-end test. Consumer test programmes have probably speeded up the implementation on the market and to improve the performance. In order to improve the situation further, it is however important to measure the real-world performance of existing whiplash prevention concepts for future activities in prevention, legislation and consumer testing.

Many studies have shown that females have higher risk of WAD than males. Carlsson [19] have summarized 13 different studies showing the relative injury risk for females compared to males in rear impacts. According to these studies the injury risk varies from approximately 1.5 to 3 times higher risk for females, even under similar crash conditions. Jakobsson [15] found a higher reducing effect of WAD for females than for males comparing Volvo cars with WHIPS and without. But there is a need to further investigate the performance for different design concepts since they vary and partly address different possible injury criteria.

Concerning WAD, the effect of model year and design improvements are rarely investigated for other impact directions than rear end. In frontal collisions in car models from the early 1990s, driver airbags combined with seat belt pretensioners were found to have a high protective effect on WAD in Toyota cars even though mainly head and chest injuries were addressed with the protection device [20]. The influence of side impact protection systems such as side airbags and curtains on WAD have not been evaluated. It has been hypothesized that curtain airbags may reduce the risk of WAD [21].

The aim of this study was to investigate the development of Whiplash Associated Disorders (WAD) leading to long-term consequences for drivers separated for gender in cars introduced at different year intervals and in different impact directions. An additional aim was to conduct a deeper analysis of the influence of various whiplash preventive concepts on WAD leading to long-term consequences separated for gender. In the study the influence on symptoms of WAD lasting longer than one month and those leading to permanent medical impairment was studied.

This study is partly a combined revision of two previous studies, Kullgren and Krafft [18] and Jonsson et al [21], with similar aims but in the present study the outcome of long-term consequences are adjusted to compensate for a more restrictive classification of symptoms leading to long-term consequences that has been evident during the sampling period. This was not done in the previous studies. Furthermore, the data set in the present study is larger that enables deeper analysis than previous studies.

II. METHODS

Data were collected from a dataset from Folksam Insurance Group, one of the largest insurance companies in Sweden. Insurance claims were used to verify if the reported symptoms of WAD, Grades 1, 2 and 3 according to Spitzer et al [4], led to any long-term symptoms. The WAD degree 1-3 is not classified in this study since the aim is to investigate the proportion of long-term symptoms irrespective of WAD degree. The definition of symptoms lasting longer than one month is that a medical doctor examined the occupant and the occupant claimed injury symptoms for more than four weeks, which corresponds to a payment of at least 2,000 SEK in the claims handling process used by Folksam. Definition of long-term consequences/medical impairment: In case an injured occupant is not recovered after approximately one year, a medical assessment is made by medical specialists to predict the impairment degree. The injured occupant is classified with a degree of medical

impairment, between 1-100% depending on the injury type according to the Swedish manual for "Grading Medical Impairment" [22].

All Swedish insurance companies use this manual [22]. The manual consists of instructions of how to set the degree of medical impairment and table works for all injury types and their consequences. In the impairment tables the degrees of impairment include physical and/or mental functional reduction as well as pain. In the case occupants have multiple injuries leading to medical impairment tables for cumulative degrees of impairments are included. The combined degree of impairments is usually a bit lower than the sum of impairment degrees for each injury. The medical impairment defined by this manual is independent of cause, occupation, hobbies or other special circumstances of the injured person. The occupant's injury data before and after the injury are collected, and an assessment is made based on the information. Minor impairments are most often set between 5 and 35 %, medium impairments between 30 and 70 % and serious impairments between 65 and 90%. WAD often results in between 3-18% of medical impairment degree. The whiplash symptoms are regarded as permanent when no additional improvement in the injured patient's mental or physical status has taken place, normally a maximum of three years after the crash. If the injured person is unsatisfied with the decision of impairment level, he or she can request a reassessment of their case through a public commission. The request is submitted to the insurance company and forwarded to the commission.

It has been found that medical expertise in Sweden gradually has been classifying long-term consequences from whiplash associated disorders more restrictively. A reduction factor to be used to compensate for this change in classification was calculated by studying the injury outcome for vehicles with identical introduction year over the sampling period. The risk of long-term symptoms, given reported initial symptoms, should not change over the sampling period. The reduction in the likelihood of classifying an injury as a permanent medical impairment appears to be linear over the sampling period, from 1998 to 2012, and was found to be 11% per year for a large number of vehicle models and for a representative distribution of males and females. In the same way, the reduction in classification of those with symptoms lasting longer than one month was found to be 6.5% per year. The adjustments were made by weighting the number of occupants with long-term symptoms according to the year of impact. In order not to change the total number of occupants with long-term symptoms the weighting was made based on accident year 2005, which is the mean accident year in the accident sample. All occupants with long-term symptoms in crashes occurring before 2005 were weighted lower and all after 2005 were weighted higher (Equation 1 and 2). By making an adjustment for accident year for each occupant, the outcomes from all groups of cars under study could be compared with each other.

x_{1m},adjusted = x_{1m}/1,065^(2005- $year_{accident}$), x_{1m} = occupant with symptoms > 1 month Eq (1)

x_{pmi} ,adjusted = x_{pmi}/1,11^(2005- $year_{accident}$), x_{pmi} = occupant with pmi Eq (2)

All adult drivers with reported WAD from crashes that occurred between 1998 and 2012 were selected for studying proportion of symptoms lasting longer than one month. When studying proportion of drivers with pmi crashes that occurred between 1998 and 2010 were used due to the time for decision of a permanent degree of medical impairment. Tables 1-2 show the distribution of drivers with reported WAD and those with long-term consequences. The tables show unadjusted numbers of drivers with long-term consequences. In total 52 225 drivers reporting initial symptoms were included to evaluate proportions of drivers with symptoms for more than one month (52% males, 43% females and 5% unknown). To evaluate proportions of pmi 50 343 drivers were included (52% males, 43% females and 5% unknown). In 3232 crashes (6%) the model year for the car was unknown.

TABLE 1. NUMBER OF DRIVERS REPORTING INITIAL WAD SYMPTOMS AND UNADJUSTED NUMBER OF OCCUPANTS WITH SYMPTOMS FOR MORE THAN ONE MONTH AND PERMANENT MEDICAL IMPAIRMENT.

1998-2012	Reported n (%)				symptoms > 1 month n (%)			
	Total	Male	Female	Unknown	Total	Male	Female	Unknown
Front	19375 (37)	10480 (39)	7661 (34)	1234 (46)	4307 (42)	2441 (47)	1811 (38)	55 (47)
Side	10196 (20)	5134 (19)	4588 (20)	474 (18)	2005 (20)	1013 (19)	968 (20)	24 (21)
Rear	22654 (43)	11430 (42)	10274 (46)	950 (36)	3803 (38)	1796 (34)	1969 (41)	38 (32)
Total	52225 (100)	27044 (100)	22523 (100)	2658 (100)	10115 (100)	5250 (100)	4748 (100)	117 (100)

TABLE 2. NUMBER OF DRIVERS REPORTING INITIAL WAD SYMPTOMS AND UNADJUSTED NUMBER OF OCCUPANTS WITH PERMANENT MEDICAL IMPAIRMENT.

1998-2010	Reported n (%)				Pmi n (%)			
	Total	Male	Female	Unknown	Total	Male	Female	Unknown
Front	18959 (38)	10320 (39)	7431 (35)	1208 (47)	2073 (39)	1148 (42)	925 (35)	0
Side	9913 (20)	5031 (19)	4414 (20)	468 (18)	956 (18)	482 (18)	474 (18)	0
Rear	21471 (43)	10936 (42)	9649 (45)	886 (35)	2339 (44)	1107 (40)	1232 (47)	0
Total	50343 (100)	26287 (100)	21494 (100)	2562 (100)	5368 (100)	2737 (100)	2631 (100)	0

Comparisons regarding proportion of occupants with long-term consequences out of those reporting initial WAD symptoms were made for vehicle year of launch in 5-year intervals. Comparisons regarding effectiveness of seat concept aimed at reducing risk of WAD in rear-end impacts were made for groups of cars. First a comparison between cars fitted with whiplash protection and those without launched from 1998 and onwards and also those without launched before 1998. Secondly a comparison was made between different seat concepts. All these comparisons were also separated for gender. The various seat concepts were grouped into passive seats, those with Reactive Head Restraints (RHR), Volvo Whips, which is a reactive seat back, and standard seats without any advanced whiplash concept. Some manufacturers also have Pro Active Head Restraints (PAHR). There were too few of these in the data sample to be able to do any analysis. All makes and concepts included are listed in the Appendix.

Chi2-tests were used to test for significance and confidence intervals (95% CI) were calculated for the proportions of occupants with symptoms lasting longer than one month and those with permanent medical impairment out of those with initial reported symptoms of WAD.

III. RESULTS

The results from Tables 3-5 show symptoms reported in rear impacts to be most frequent for both sexes followed by frontal impacts and side impacts, both for those with symptoms lasting longer than one month and those with permanent medical impairment. Rear-end impacts account for 44% of the initial symptoms, frontal for 37% and side impacts for 19%. Females had a slightly larger proportion in rear-end impacts (46%) and smaller proportion in frontal impacts (34%).

TABLE 3. NUMBER (N) OF FEMALE AND MALE DRIVERS WITH SYMPTOMS FOR MORE THAN ONE MONTH (1M) AND THOSE WITH PERMANENT MEDICAL IMPAIRMENT (PMI) FOR FRONTAL IMPACTS IN 5-YEAR INTERVALS ACCORDING TO VEHICLE INTRODUCTION.

Frontal	symptoms > 1 month						pmi					
	Total		Male		Female		Total		Male		Female	
	n rep	n 1m	n rep	n 1m	n rep	n 1m	n rep	n pmi	n rep	n pmi	n rep	n pmi
<1979	1609	334.1	900	199.9	598	129.3	1607	150.0	900	89.0	596	61.0
1980-1984	3607	747.6	1976	423.1	1396	317.2	3601	350.8	1972	200.4	1395	150.3
1985-1989	3772	788.5	2158	471.7	1372	308.9	3760	345.5	2152	199.0	1366	146.5
1990-1994	3746	728.1	1999	398.5	1513	316.6	3702	297.9	1986	156.4	1487	141.5
1995-1999	3872	783.4	1956	418.2	1690	357.9	3750	303.2	1915	160.5	1617	142.7
2000-2004	1127	220.8	531	120.9	526	98.9	995	80.0	474	41.2	457	38.8
2005-2009	319	69.8	150	39.8	151	28.8	230	19.1	114	11.6	102	7.5
2010-2012	3	1.5	1	1.5	2	0.0	1	0.0			1	0.0
Total	18055	3673.8	9671	2073.6	7248	1557.6	17646	1546.4	9513	858.2	7021	688.3

TABLE 4. NUMBER (N) OF FEMALE AND MALE DRIVERS WITH SYMPTOMS FOR MORE THAN ONE MONTH (1M) AND THOSE WITH PERMANENT MEDICAL IMPAIRMENT (PMI) FOR SIDE IMPACTS IN 5-YEAR INTERVALS ACCORDING TO VEHICLE INTRODUCTION.

Side	symptoms > 1 month						pmi					
	Total		Male		Female		Total		Male		Female	
	n rep	n 1m	n rep	n 1m	n rep	n 1m	n rep	n pmi	n rep	n pmi	n rep	n pmi
<1979	921	177.9	497	94.2	377	79.9	918	77.9	495	39.6	376	38.2
1980-1984	1712	300.3	847	145.9	773	151.8	1709	135.9	844	61.7	773	74.2
1985-1989	1878	347.8	1019	183.6	760	158.5	1870	160.8	1016	89.2	756	71.6
1990-1994	1878	340.7	967	173.3	834	159.7	1857	129.5	958	61.7	823	67.8
1995-1999	2181	405.5	1024	188.1	1071	217.4	2089	162.9	987	81.1	1016	81.7
2000-2004	709	104.8	314	49.2	360	55.6	628	28.3	287	15.5	307	12.9
2005-2009	237	24.2	75	9.1	153	15.1	168	6.3	56	2.7	105	3.6
2010-2012	3	0.0	1	0.0	2	0.0						
Total	9519	1701.1	4744	843.4	4330	838.0	9239	701.6	4643	351.6	4156	350.0

TABLE 5. NUMBER (N) OF FEMALE AND MALE DRIVERS WITH SYMPTOMS FOR MORE THAN ONE MONTH (1M) AND THOSE WITH PERMANENT MEDICAL IMPAIRMENT (PMI) FOR REAR-END IMPACTS IN 5-YEAR INTERVALS ACCORDING TO VEHICLE INTRODUCTION.

Rear-end	symptoms > 1 month						pmi					
	Total		Male		Female		Total		Male		Female	
	n rep	n 1m	n rep	n 1m	n rep	n 1m	n rep	n pmi	n rep	n pmi	n rep	n pmi
<1979	1749	294.4	893	138.2	747	149.2	1745	165.0	890	81.8	746	83.2
1980-1984	3521	584.1	1776	268.4	1575	305.1	3503	345.6	1768	155.0	1565	190.6
1985-1989	3802	625.8	2089	321.7	1569	297.7	3784	373.6	2077	196.5	1564	177.1
1990-1994	4146	644.6	2162	311.9	1829	329.4	4069	363.8	2118	178.5	1800	185.3
1995-1999	5382	733.4	2559	317.6	2621	415.0	5010	358.5	2408	144.1	2419	214.4
2000-2004	2036	205.8	909	85.2	1046	120.6	1684	84.8	766	35.6	858	49.2
2005-2009	772	93.1	316	31.7	417	60.1	453	22.5	192	6.4	240	16.0
2010-2012	11	3.0	4	0.0	6	3.0	1	0.0	1	0.0		
Total	21419	3184.1	10708	1474.7	9810	1680.2	20249	1713.7	10220	797.9	9192	915.8

TABLE 6. PROPORTIONS OF FEMALE AND MALE DRIVERS (%) WITH SYMPTOMS FOR MORE THAN ONE MONTH (1M) AND THOSE WITH PERMANENT MEDICAL IMPAIRMENT (PMI) IN RELATION TO NUMBER OF REPORTED WAD (INCLUDING 95% CI) FOR FRONTAL IMPACTS IN 5-YEAR INTERVALS ACCORDING TO YEAR OF INTRODUCTION.

Frontal	symptoms > 1 month			pmi		
	Total	Male	Female	Total	Male	Female
<1979	20.8 ± 2.0	22.2 ± 2.7	21.6 ± 3.3	9.3 ± 1.4	9.9 ± 2.0	10.2 ± 2.4
1980-1984	20.7 ± 1.3	21.4 ± 1.8	22.7 ± 2.2	9.7 ± 1.0	10.2 ± 1.3	10.8 ± 1.6
1985-1989	20.9 ± 1.3	21.9 ± 1.7	22.5 ± 2.2	9.2 ± 0.9	9.2 ± 1.2	10.7 ± 1.6
1990-1994	19.4 ± 1.3	19.9 ± 1.8	20.9 ± 2.0	8.0 ± 0.9	7.9 ± 1.2	9.5 ± 1.5
1995-1999	20.2 ± 1.3	21.4 ± 1.8	21.2 ± 1.9	8.1 ± 0.9	8.4 ± 1.2	8.8 ± 1.4
2000-2004	19.6 ± 2.3	22.8 ± 3.6	18.8 ± 3.3	8.0 ± 1.7	8.7 ± 2.5	8.5 ± 2.6
2005-2009	21.9 ± 4.5	26.5 ± 7.1	19.1 ± 6.3	8.3 ± 3.6	10.2 ± 5.6	7.3 ± 5.1
Total	20.3 ± 0.6	21.4 ± 0.8	21.5 ± 0.9	8.8 ± 0.4	9.0 ± 0.6	9.8 ± 0.7

TABLE 7. PROPORTIONS OF FEMALE AND MALE DRIVERS (%) WITH SYMPTOMS FOR MORE THAN ONE MONTH (1M) AND THOSE WITH PERMANENT MEDICAL IMPAIRMENT (PMI) IN RELATION TO NUMBER OF REPORTED WAD (INCLUDING 95% CI) FOR SIDE IMPACTS IN 5-YEAR INTERVALS ACCORDING TO YEAR OF INTRODUCTION.

Side	symptoms > 1 month			pmi		
	Total	Male	Female	Total	Male	Female
<1979	19.3 ± 2.5	19.0 ± 3.4	21.2 ± 4.1	8.5 ± 1.8	8.0 ± 2.4	10.2 ± 3.1
1980-1984	17.5 ± 1.8	17.2 ± 2.5	19.6 ± 2.8	8.0 ± 1.3	7.3 ± 1.8	9.6 ± 2.1
1985-1989	18.5 ± 1.8	18.0 ± 2.4	20.9 ± 2.9	8.6 ± 1.3	8.8 ± 1.7	9.5 ± 2.1
1990-1994	18.1 ± 1.7	17.9 ± 2.4	19.1 ± 2.7	7.0 ± 1.2	6.4 ± 1.6	8.2 ± 1.9
1995-1999	18.6 ± 1.6	18.4 ± 2.4	20.3 ± 2.4	7.8 ± 1.1	8.2 ± 1.7	8.0 ± 1.7
2000-2004	14.8 ± 2.6	15.7 ± 4.0	15.4 ± 3.7	4.5 ± 1.6	5.4 ± 2.6	4.2 ± 2.2
2005-2009	10.2 ± 3.9	12.2 ± 7.4	9.9 ± 4.7	3.8 ± 2.9	4.9 ± 5.6	3.4 ± 3.5
Total	17.9 ± 0.8	17.8 ± 0.0	19.4 ± 1.2	7.6 ± 0.5	7.6 ± 0.8	8.4 ± 0.8

TABLE 8. PROPORTIONS OF FEMALE AND MALE DRIVERS (%) WITH SYMPTOMS FOR MORE THAN ONE MONTH (1M) AND THOSE WITH PERMANENT MEDICAL IMPAIRMENT (PMI) IN RELATION TO NUMBER OF REPORTED WAD (INCLUDING 95% CI) FOR REAR IMPACTS IN 5-YEAR INTERVALS ACCORDING TO YEAR OF INTRODUCTION.

Rear-end	symptoms > 1 month			pmi		
	Total	Male	Female	Total	Male	Female
<1979	16.8 ± 1.8	15.5 ± 2.4	20.0 ± 2.9	9.5 ± 1.4	9.2 ± 1.9	11.2 ± 2.3
1980-1984	16.6 ± 1.2	15.1 ± 1.7	19.4 ± 2.0	9.9 ± 1.0	8.8 ± 1.3	12.2 ± 1.6
1985-1989	16.5 ± 1.2	15.4 ± 1.5	19.0 ± 1.9	9.9 ± 1.0	9.5 ± 1.3	11.3 ± 1.6
1990-1994	15.5 ± 1.1	14.4 ± 1.5	18.0 ± 1.8	8.9 ± 0.9	8.4 ± 1.2	10.3 ± 1.4
1995-1999	13.6 ± 0.9	12.4 ± 1.3	15.8 ± 1.4	7.2 ± 0.7	6.0 ± 0.9	8.9 ± 1.1
2000-2004	10.1 ± 1.3	9.4 ± 1.9	11.5 ± 1.9	5.0 ± 1.0	4.6 ± 1.5	5.7 ± 1.6
2005-2009	12.1 ± 2.3	10.0 ± 3.3	14.4 ± 3.4	5.0 ± 2.0	3.3 ± 2.5	6.7 ± 3.2
Total	14.9 ± 0.5	13.8 ± 0.7	17.1 ± 0.7	8.5 ± 0.4	7.8 ± 0.5	10.0 ± 0.6

Females have a higher proportion of WAD symptoms lasting longer than one month and with permanent medical impairment compared with males in rear-end impacts, Table 3-5. In the other impact directions no significant differences were found.

A general trend was found that the newer the car the lower proportion of drivers with symptoms lasting longer than one month as well as those with pmi in both rear-end and side impacts (Table 3-5). In frontal impacts no difference between the years of introduction was found. However, for drivers with pmi an indication of a small drop was found after 1990. Between the introduction years 1980-84 and 2005-09 the proportions of drivers with permanent medical impairment dropped by approximately 51% in rear-end crashes (62% for males and 44% for females), and in side impacts the reduction was similar, 53% (32% for males and 65% for females), Tables 6-8. Regarding drivers with symptoms lasting longer than one month, the reduction was approximately 27% in rear-end impacts (33% for males and 26% for females). In side impacts the proportion of male and female drivers with symptoms lasting longer than one month dropped by 32% (30% for males and 49% for females).

Even though the risk of WAD in rear impacts in newer models has decreased, still WAD in rear impacts is most common. Car model intervals with more new cars have generally a higher proportion of rear impacts and lower of side and frontal impacts compared to older cars.

Given reported initial WAD symptoms, females were found to have 24% higher risk of symptoms lasting longer than one month compared to males (11.0±0.6 compared to 8.9±0.5) and also 20% higher risk of injuries leading to permanent medical impairment (4.4±0.4 compared to 3.7±0.4), Table 9-10. The risk reduction (pmi) of seats with whiplash protection compared with seats without and launched after 1997 was approximately 40% (4.4±0.6 compared to 2.6±0.7). The whiplash systems were found to have a significantly higher effect for males than for females (approximately 65% higher). For females the reduction regarding permanent medical impairment was approximately 30% (5.1±1.0 compared to 3.1±1.2) and for males approximately 50% (3.9±0.9 compared to 1.9±0.9).

TABLE 9. NUMBERS OF DRIVERS AND PROPORTIONS OF WHIPLASH SYMPTOMS > 1 MONTH FOR FEMALES AND MALES IN SEATS WITH AND WITHOUT WHIPLASH PROTECTION CONCEPTS.

	symptoms > 1 month						pmi					
	Total		Male		Female		Total		Male		Female	
	n rep	n 1m	n rep	n 1m	n rep	n 1m	n rep	n pmi	n rep	n pmi	n rep	n pmi
Whiplash prot.	2486	261.7	1147	107.6	1224	152.8	1966	86.7	922	29.7	959	57.1
W/O MY>1998	4450	591.5	1989	246.3	2291	344.3	3974	292.5	1824	119.9	2008	172.6
W/O MY<1998	14467	2332.0	7565	1121.8	6289	1183.1	14297	1334.7	7467	648.5	6222	686.2
Total	21403	3185.1	10701	1475.7	9804	1680.2	20237	1714.0	10213	798.1	9189	915.8

TABLE 10. NUMBERS OF DRIVERS AND PROPORTIONS OF WHIPLASH SYMPTOMS OF PERMANENT MEDICAL IMPAIRMENT (PMI) FOR FEMALES AND MALES IN SEATS WITH AND WITHOUT WHIPLASH PROTECTION CONCEPTS.

	symptoms > 1 month			pmi		
	Total	Male	Female	Total	Male	Female
Whiplash prot.	10.5 ± 1.2	9.4 ± 1.7	12.5 ± 1.9	4.4 ± 0.9	3.2 ± 1.1	5.9 ± 1.5
W/O MY>1998	13.3 ± 1.0	12.4 ± 1.4	15.0 ± 1.5	7.4 ± 0.8	6.6 ± 1.1	8.6 ± 1.2
W/O MY<1998	18.8 ± 0.6	14.8 ± 0.8	18.8 ± 1.0	9.3 ± 0.5	8.7 ± 0.6	11.0 ± 0.8
Total	14.9 ± 0.5	13.8 ± 0.7	17.1 ± 0.7	8.5 ± 0.4	7.8 ± 0.5	10.0 ± 0.6

TABLE 11. NUMBER OF DRIVERS WITH INITIAL AND LONG-TERM CONSEQUENCES FOR VARIOUS SEAT CONCEPTS.

	symptoms > 1 month						pmi					
	Total		Male		Female		Total		Male		Female	
	n rep	n 1m	n rep	n 1m	n rep	n 1m	n rep	n pmi	n rep	n pmi	n rep	n pmi
Passive + Whips	1558	154.0	648	51.5	833	101.2	1259	48.6	535	19.5	670	29.1
Toyota WIL	1175	124.1	452	33.9	666	88.9	975	38.8	377	14.1	555	24.7
Volvo Whips	305	25.8	166	16.4	126	9.4	245	8.1	142	5.4	93	2.8
Passive-other	78	4.2	30	1.3	41	2.9	39	1.7	16	0.0	22	1.7
RHR all	890	103.7	478	52.1	375	51.6	685	35.2	377	7.3	278	28.0
RHR-Opel	104	10.4	52	5.1	46	5.3	96	6.9	49	3.4	41	3.5
RHR-Saab	354	43.4	201	23.4	135	20.0	291	14.0	168	2.9	108	11.1
RHR-VW-group	183	18.8	92	6.4	86	12.4	134	8.3	73	0.0	58	8.3
RHR-other	249	31.1	133	17.2	108	13.9	164	6.0	87	1.0	71	5.0
Standard seats	5906	807.8	2842	358.3	2835	447.0	5392	406.7	2653	180.7	2538	226.0
Total	8411	1071.8	4002	466.9	4065	601.2	7372	494.3	3584	211.2	3502	283.1

TABLE 12. PROPORTIONS OF DRIVERS (%) WITH LONG-TERM CONSEQUENCES FOR VARIOUS SEAT CONCEPTS.

	symptoms > 1 month			pmi		
	Total	Male	Female	Total	Male	Female
Passive + Whips	9.9 ± 1.5	8.0 ± 2.1	12.1 ± 2.2	3.9 ± 1.1	3.6 ± 1.6	4.3 ± 1.5
Toyota WIL	10.6 ± 1.8	7.5 ± 2.4	13.4 ± 2.6	4.0 ± 1.2	3.7 ± 1.9	4.4 ± 1.7
Volvo Whips	8.4 ± 3.1	9.9 ± 4.5	7.4 ± 4.6	3.3 ± 2.2	3.8 ± 3.1	3.0 ± 3.4
Passive-other	5.4 ± 5.0	4.3 ± 7.2	7.1 ± 7.9	4.3 ± 6.4	0.0 ± 0.0	7.7 ± 11.1
RHR all	11.6 ± 2.1	10.9 ± 2.8	13.8 ± 3.5	5.1 ± 1.7	1.9 ± 1.4	10.1 ± 3.5
RHR-Opel	10.0 ± 5.8	9.7 ± 8.1	11.6 ± 9.3	7.2 ± 5.2	6.9 ± 7.1	8.5 ± 8.6
RHR-Saab	12.3 ± 3.4	11.6 ± 4.4	14.8 ± 6.0	4.8 ± 2.5	1.7 ± 2.0	10.3 ± 5.7
RHR-VW-group	10.3 ± 4.4	7.0 ± 5.2	14.4 ± 7.4	6.2 ± 4.1	0.0 ± 0.0	14.3 ± 9.0
RHR-other	12.5 ± 4.1	12.9 ± 5.7	12.8 ± 6.3	3.7 ± 2.9	1.1 ± 2.2	7.1 ± 6.0
Standard seats	13.7 ± 0.9	12.6 ± 1.2	15.8 ± 1.3	7.5 ± 0.7	6.8 ± 1.0	8.9 ± 1.1
Total	12.7 ± 0.7	11.7 ± 1.0	14.8 ± 1.1	6.7 ± 0.6	5.9 ± 0.8	8.1 ± 0.9

Both Volvo Whips and Toyota WIL showed lower risk of WAD leading to pmi as well as symptoms lasting longer than one month compared to cars with standard seats (Tables 11-12). The reductions regarding occupants with symptoms lasting longer than one month were approximately 38% for Whips (8.4±3.1 compared to 13.7±0.9) and 23% for WIL (10.6±1.8 compared to 13.7±0.9). Regarding pmi the reductions were approximately 56% for Volvo Whips (3.3±2.2 compared to 7.5±0.7) and 47% for Toyota WIL (4.0±1.2 compared to 7.5±0.7). For the group RHR-all including all seats with reactive head restraints, the reduction in risk of pmi was 32% (5.1±1.7 compared to 7.5±0.7). The group of cars consists of many different models listed in the Appendix. The data are too few to differentiate between the RHR concepts.

Passive seats were found to have a lower risk of pmi for females compared with RHR. The results even indicate that the risk for pmi for females is higher compared with standard seats, Table 12. The risk for pmi is higher for females compared to males in seats with RHR (10.1±3.5 compared to 1.9±1.4).

IV. DISCUSSION

The results from the present study are very positive and show that efforts made by car manufacturers to reduce risks of WAD have been successful, although there are still potential improvements to make, especially regarding the differences in effectiveness found between males and females. It is also important to focus on other impact directions than rear-ends. WAD in rear-end and side impacts has decreased, while WAD in frontal impacts appear to be more or less constant.

Kullgren et al [20] showed a 41 % reduction of WAD in frontal impacts in cars equipped with seat belt pre-tensioners and frontal airbags compared to cars without. The airbag was introduced more widely in the Swedish market in the beginning of the 1990s. The indication of decrease in proportion of drivers with pmi after 1990 could be explained by this. However, it is clear that more effective preventive measures in frontal impacts are needed. Probably airbags, seat belt pretensioners and load limiters could be improved to take WAD into account.

In side impacts the proportion of drivers with long-term symptoms decreased between the introduction years 1980-1984 and 2005-2009. Side airbags and curtain airbags have been shown to reduce severe and fatal injuries in side impacts [23, 24]. But the influence on WAD has not been evaluated. Curtain airbags were introduced in Sweden in the beginning of 2000, which correlates well with the drop in proportion of long-term consequences. It seems like the proportions of long-term symptoms in side impacts dropped more for females than for males in cars launched between 1980-84 and 2004-09. One explanation could be that females benefit more than males from side airbags and curtain airbags due to anatomical differences.

In rear-end impacts a similar reduction as in side impacts was found between the introduction years. Lower proportions of occupants with symptoms leading to permanent medical impairment were found for both males and females in the car group 2004-2009 compared to 1995-1999. The study results also show a greater decrease for males than for females. The introduction of whiplash preventive seat concepts at the end of the 1990s, and the fact that they are more effective for males, corresponds well with the reductions found for the years of launch. This study also shows that the existing whiplash preventive seat concepts reduce the risk of WAD leading to long-term consequences and that they in general are more effective for males than for females.

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 20% regarding WAD with symptoms lasting longer than one month and approximately 40% for verified permanent medical impairment. However, it should be noted that even if studying symptoms lasting longer than just one month, the differences found between the various comparisons were large.

In the present study seats designed to absorb energy in the seat back, such as passive seats and Volvo Whips, had equal or even somewhat higher effectiveness for females compared to males, while seats with Reactive Head Restraints (RHR) showed very high reductions for males (approximately 70%) and no reduction for females. This clearly shows that there is a fundamental difference in protecting males and females regarding WAD. RHR focusing on geometric performance initially in the crash phase appears to only affect males. Understanding these differences will probably be a key knowledge in improving future seat concepts and also to improve consumer test programmes.

It is well known that females have a much higher risk for Whiplash Associated Disorders in rear impacts compared to males [25]. The results in the present study clearly show that the seats with RHR are much more effective for males than for females. They even appear to have no effect at all for females. Further research is important to clarify the findings in this study regarding differences in effectiveness between males and females for the various seat concepts. Based on modeling, Viano [26] 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 [19, 25].

WAD accounts for approximately 50 % of all injuries leading to permanent medical impairment, all crash directions included [1]. 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.

Apart from the variation in effectiveness between the concepts found in this study, results from existing consumer crash test programmes also indicate a large variation in protection [12, 27]. Some seats perform well even without more advanced whiplash protection systems, while some seats fitted with concepts aimed at reducing risk of WAD 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 cars that offer the best protection.

To improve the validity and reliability when studying whiplash risks and effectiveness of whiplash concepts two various definitions of long-term consequences were used, as it is well known that there are several reasons to report whiplash symptoms. In this way those occupants reporting whiplash symptoms without having any symptoms or those with very short-term symptoms (less than a week) were excluded.

In this study a payment of at least 2,000 SEK was used to define occupants with symptoms lasting longer than one month. At Swedish insurance companies a general payment of 500 SEK is made each week an occupant is claiming symptoms, but only if the occupant has visited a physician at a hospital or at a emergency care center. The maximum sum for this first general payment is 2,500 SEK corresponding to 5 weeks suffering. After the first month a more thorough examination is made whereby a first decision of a preliminary degree of permanent medical impairment is made by a physician one year after the crash for the occupant claiming symptoms. After three years a final impairment degree is decided. Depending on the degree of impairment and other factors, such as age and occupation, a payment is decided. This payments process and sums may vary considerably between different countries. So it is not recommended to use payments as an indicator for symptoms duration unless the procedures have been checked and verified in each specific country.

Limitations

Only proportions given reported WAD were studied and not the absolute risk of sustaining long-term consequences. Variations in the risk of reporting WAD are not covered. The differences between vehicle groups and gender could therefore be anticipated to be larger than the ones found.

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 risk of WAD [28], which means that heavier cars have an advantage in rear impacts that influences the result from real-world data.

Influence of occupant age, stature and weight was not considered in this study. Studies have shown an influence of age and stature [7, 29, 30]. The risk of WAD is somewhat greater to the age group 20 to 50 than for the older and younger age groups. Increasing stature seems to influence the 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.

V. CONCLUSIONS

A reduction of the proportion of drivers with long-term consequences after reporting initial symptoms of Whiplash Associated Disorders (WAD) were found in rear-end and side impacts comparing cars introduced on the market 1980-84 and those introduced 2005-2009. No reduction was found in frontal impacts. This clearly shows that more focus on preventive interventions for frontal impacts is needed.

Existing seat concepts aimed at lowering the risk of WAD were found to reduce the risk of long-term consequences after reporting initial symptoms of WAD. However, some differences between the concepts could be identified. Seats with energy absorption in the seat back, passive seats or reactive seat backs are more effective for females than seats with Reactive Head Restraints (RHR). RHR shows no major reduction of WAD with long-term consequences compared with standard seats.

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VIII. Appendix

TABLE A. NUMBERS AND PROPORTIONS OF DRIVERS (%) WITH LONG-TERM CONSEQUENCES FOR VARIOUS SEAT CONCEPTS.

	Sympt > 1m				pmi			
Seat concept-make	n rep	n 1m	risk	CI	n rep	n	risk	CI
PAHR-BMW	5	0,0	0,0	± 0,0	1,0	0,0	0,0	± 0,0
PAHR-Mercedes	24	3,4	14,3	± 14,0	20,0	2,1	10,7	± 13,5
Passive-Audi	19	1,3	6,8	± 11,3	6,0	0,0	0,0	± 0,0
Passive-BMW	2	0,0	0,0	± 0,0	1,0	0,0	0,0	± 0,0
Passive-Citroen	1	0,0	0,0	± 0,0	1,0	0,0	0,0	± 0,0
Passive-Chevrolet	1	0,0	0,0	± 0,0	1,0	0,0	0,0	± 0,0
Passive-Ford	28	2,8	10,1	± 11,2	15,0	1,7	11,2	± 16,0
Passive-Honda	3	0,0	0,0	± 0,0	1,0	0,0	0,0	± 0,0
PassiveHyundai	26	1,4	5,3	± 8,6	17,0	1,7	9,9	± 14,2
Passive-Mitsubishi	9	0,0	0,0	± 0,0	5,0	0,0	0,0	± 0,0
Passive-Opel	2	0,0	0,0	± 0,0	1,0	0,0	0,0	± 0,0
Passive-Seat	2	0,0	0,0	± 0,0	1,0	0,0	0,0	± 0,0
Passive-Skoda	2	0,0	0,0	± 0,0			0,0	± 0,0
Passive-Suzuki	3	0,0	0,0	± 0,0	2,0	0,0	0,0	± 0,0
Passive-Toyota	1175	124,1	10,6	± 1,8	975,0	38,8	4,0	± 1,2
Passive-Volkswagen	8	1,6	19,4	± 27,4	3,0	0,0	0,0	± 0,0
Reactive seat-Volvo Whips	305	25,8	8,4	± 3,1	245,0	8,1	3,3	± 2,2
RHR-Alfa Romeo	1	0,0	0,0	± 0,0			0,0	± 0,0
RHR-Audi	37	1,4	3,7	± 6,1	33,0	1,2	3,7	± 6,5
RHR-Citroen	1	1,2	0,0	± 0,0	1,0	1,4	0,0	± 0,0
RHR-Ford	61	6,6	10,8	± 7,8	51,0	4,7	9,1	± 7,9
RHR-Honda	28	2,3	8,4	± 10,3	23,0	0,0	0,0	± 0,0
RHR-Hyndai	56	7,0	12,4	± 8,6	30,0	0,0	0,0	± 0,0
RHR-Jeep	1	0,0	0,0	± 0,0	1,0	0,0	0,0	± 0,0
RHR-Kia	9	3,0	33,5	± 30,8	1,0	0,0	0,0	± 0,0
RHR-Mercedes	4	1,3	32,2	± 45,8	3,0	0,0	0,0	± 0,0
RHR-Mazda	18	1,3	7,1	± 11,9	14,0	0,0	0,0	± 0,0
RHR-Nissan	17	4,2	24,7	± 20,5	13,0	0,0	0,0	± 0,0
RHR-Opel	104	10,4	10,0	± 5,8	96,0	6,9	7,2	± 5,2
RHR-Peugeot	17	0,0	0,0	± 0,0	12,0	0,0	0,0	± 0,0
RHR-SAHR1	285	30,6	10,7	± 3,6	243,0	11,5	4,7	± 2,7
RHR-SAHR2	69	12,8	18,6	± 9,2	48,0	2,5	5,2	± 6,3
RHR-Seat	7	1,4	19,6	± 29,4	5,0	1,7	33,7	± 41,4
RHR-Subaru	7	0,0	0,0	± 0,0	4,0	0,0	0,0	± 0,0
RHR-Skoda	32	3,9	12,3	± 11,4	21,0	0,0	0,0	± 0,0
RHR-Toyota	29	4,2	14,5	± 12,8	11,0	0,0	0,0	± 0,0
RHR-Volkswagen	107	12,1	11,3	± 6,0	75,0	5,4	7,2	± 5,8
Standard seats	5906	807,8	13,7	± 0,9	5392,0	406,7	7,5	± 0,7
Total	8411	1071,8	12,7	± 0,7	7372,0	494,3	6,7	± 0,6