

AIS1 NECK INJURY REDUCING EFFECT OF WHIPS (WHIPLASH PROTECTION SYSTEM)

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ABSTRACT

Rear-end impacts involving Volvo cars from 1999-2002, including 1221 front seat occupants (above 14 years of age and without prior neck problems), are investigated with respect to AIS1 neck injury rate differences between those in WHIPS seats as compared to those in previous Volvo seats. The differences with respect to gender is explored.

The AIS1 neck injury reducing effect of WHIPS as compared to previous Volvo seats is 31% for initial neck symptoms and 51% for neck symptoms lasting longer than one year. The injury reducing effect is higher for women than for men. No clear explanation for the gender differences was found with respect to occupant size.

Key words: neck injuries, rear impacts, accident analysis, seats, whiplash

AIS1 NECK INJURIES are the most common type of injury resulting from rear-end impacts (Lundell et al. 1998a). Measures to reduce these kind of injuries have been taken by designing head restraints (IIHS 1999) and more recently by introducing active head restraints (Wiklund and Larsson 1998). In 1998, the Whiplash Protection System (WHIPS) was introduced in Volvo cars, based on research done through accident analysis and occupant modeling (Lundell et al. 1998a, Jakobsson et al. 2000). WHIPS's main feature is a completely new recliner mechanism, enabling the seat backrest to move rearwards in relation to the seat cushion when loading an occupant in a rear-end impact (Lundell et al. 1998b). During the motion, deformable elements within the recliners will absorb energy and thus reduce the occupant acceleration as well as forward rebound. Compared to previous Volvo seats, the seat backrest characteristics were modified for WHIPS and the head restraint was positioned slightly forward to give the whole spine and head an even support in a rear-end impact (Jakobsson et al. 2000).

Few studies have been made to evaluate the effectiveness of different AIS1 neck injury mitigation systems. Viano and Olsen (2001) studied rear-end impacts in Sweden, comparing Saab vehicles with SAHR to previous models without SAHR, including a total of 117 front seat occupants. The calculated injury reducing effect was 75%, if occupants with neck pain lasting shorter than one week were regarded as uninjured. The SAHR system was also evaluated in an automobile insurance claim study in USA by Farmer et al. (2003). When grouping the Saab cars together with other GM cars with active head restraints, the active head restraints were associated with a statistically significant 43% reduction in overall driver AIS1 neck injury claims as compared to prior models without active head restraints. In the study of head restraint geometry changes by Farmer et al., WHIPS as well as Toyota's Whiplash Injury Lessening (WIL) were also evaluated. The improved head restraint geometry of the Ford Taurus (2000-2001 MY) was associated with a non-significant 18% reduction in overall driver injury rates but a statistically significant 37% reduction among female drivers. The Taurus incorporated performance changes as well as better head restraint geometry. The effects of WHIPS and Toyota's WIL seat design changes were not statistically significant, but the estimated effect of WHIPS was

49%, with the highest effect for women. In a recent study, the performance of WHIPS was evaluated as compared to prior Volvo seats (Jakobsson 2004a, 2004b). Significant AIS1 neck injury reducing effects of WHIPS were calculated to 33% (15-47%) for initial neck injuries and 53% (16-74%) for symptoms lasting more than one year. The effect was calculated for 324 front seat occupants above 14 years of age without prior neck problems and at a moderate impact severity. The injury-reducing effect was found higher for women as compared to men; the reason for this will be explored further in this study.

Several occupant-related factors have been suggested to influence the AIS1 neck injury outcome. Women have been shown to have a higher risk of injury as compared to men (Chapline et al. 2000, Morris and Thomas 1996, Temming and Zobel 2000). The rate of AIS1 neck injuries varies with age. The initial AIS1 neck injury rate is greater for the age group 20 to 50 than for the older and younger age groups (Lundell et al. 1998a, Temming and Zobel 2000). Lundell et al. (1998a) and Temming and Zobel (2000) studied initial AIS1 neck injury rate, comparing stature and gender. Their data indicated that injury rate increases with increasing stature for both genders. The existence of prior neck problems of any kind was found related to increased rate of AIS1 neck injuries (Jakobsson 2004a, 2004b). Data from the same database as the present study showed that those reporting prior neck problems have a significantly higher rate ($p=0.000$) of sustaining or aggravating AIS1 neck injuries from the impact. Several studies have identified the driver to have a significantly higher rate as compared to the front seat passenger (Jakobsson et al. 2000, Berglund et al. 2003, Jakobsson 2004a, 2004b). This could partly be explained by differences in sitting postures. Turned head and increased head to head-restraint distance were found, related to increased AIS1 neck injury severity or rate (Sturzenegger et al. 1994, Jakobsson 2004a, 2004b).

The aim of this study was to evaluate the AIS1 neck injury reducing effect of WHIPS (Whiplash Protection System) based on accident data, with a special focus on differences in gender and other occupant characteristics.

METHOD

All new Volvo cars sold in Sweden are covered by a three year damage warranty by the Volvia insurance company. Single rear-end impacts from 1999 in Sweden involving Volvo cars from model year 1999 or later are selected by Volvia. The accident research team at Volvo Cars Safety Centre sends out a questionnaire (within two months) to the occupants in the selected cases to provide detailed information about the accident and the occupants. The occupant information includes seating position, gender, age, stature, weight, awareness of accident, muscle tension, reaction, head impact, occupant's best recollection of sitting posture during impact including distance to head restraint, head rotation and sideways lean, as well as general injury data. Those answering the questionnaire (approx. 65%) are included in the database. Car crash damage is retrieved from the repair details provided by the insurance company to the Volvo Cars accident research team. One year after the accident, a follow-up questionnaire is sent to the occupants asking for details of neck symptoms, if any, as well as prior neck problems (yes/no/unknown). Information regarding prior neck status as well as neck-related problems following the impact are all based on questionnaire data, and no information is shared with insurance claim files. The database contains a total of 4242 occupants in 2724 cars, of which 2231 occupants in 1536 cars are registered in the one-year post-accident follow-up data. A total of 1221 front seat occupants above 14 years of age and with no prior neck problems, involved in rear-end impacts 1999-2002 are included in the sub-set in this study. Rear seat occupants, 227, children (<15 years old) in the front seats, 105, those with unknown neck injury outcome, 128, and an additional 550 with prior neck problems are excluded. The cases are all single rear-end impacts, including angled, offset as well as 100% overlap impacts to the rear structure of the car. Two thirds of the occupants were sitting in a WHIPS seat.

Initial neck symptoms are defined as all symptoms and signs, from the impact, in the neck area (AIS1 neck injuries) reported by the occupant in the one-year follow-up questionnaire. Those having problems one year after the accident occurring at least once a month and described by themselves as seriously interfering with activities or occurring weekly and described by themselves as hampering activities are classified as *persistent* neck symptoms.

Impact severity is estimated from car damage information as written in the insurance repair report. Depending on what structure that is repaired, the cars are grouped into minor and moderate impact severity. *Minor impact severity* includes cars where only the rear bumper has been repaired, and in some cases minor damage to the car structure, without repair of the rear longitudinal members. Cars are grouped into *moderate impact severity* when the rear longitudinal members are deformed in any direction, thus even high severity impacts are included in the moderate severity group.

Statistical methods used are the Chi²-test and logistic regression; the AIS1 neck injury rates for different parameters are also illustrated in graphs with 95% confidence intervals. AIS1 neck injury rate is defined as the number of people with AIS1 neck injury divided by the total number of people involved in the specific population. The injury reducing effect of WHIPS is defined as the AIS1 neck injury rate difference between occupants in WHIPS as compared to the reference seat divided by the AIS1 neck injury rate of the reference seat.

The reference seat in this study is a previous Volvo front seat without WHIPS. The reference seats are found in model year 1999 Volvo S40, V40, S70 and V70 vehicles. WHIPS seats are found in S40, V40, S70 and V70 of model years 2000 and later, and in all S60, S80 and the new V70 models. There were no changes in the rear structure of the S40, V40, S70 and V70 between model years 1999 and 2000.

RESULTS

WHIPS INJURY REDUCING EFFECT

The injury reducing effect of WHIPS is calculated, based on front seat occupants above 14 years of age and without prior neck problems. The analysis presented is based on the impact severity groups defined. Moderate impact severity represents the approximate impact severity at which the WHIPS recliner will activate.

The injury reducing effect of WHIPS as compared to previous Volvo seats (reference) in moderate impact severity is 31% ($p=0.003$) with the confidence limits (C_L, C_U) = (13%, 45%) for initial AIS1 neck injuries and 51% ($p=0.01$) with (C_L, C_U)= (13%, 72%) for AIS1 neck injuries lasting longer than one year (persistent), Table 1. Comparison of AIS1 neck injury rates, including 95% confidence intervals, in moderate impact severity can be seen in Figure 1.

Table 1. Number of occupants and injured occupants, respectively, shown by seat and impact severity group, together with changes in AIS1 neck injury rate (injury reducing effect). P-values marked with * are considered statistically significant.

	Number of occupants			Injured occupants		Injury reducing effect	p-value (chi ² test)
	WHIPS	Ref.		WHIPS	Ref.		
Minor impact severity	552	302	Initial neck symptoms	126	83	16 %	0.16
			Persistent neck symptoms	27	21	30 %	0.22
Moderate impact severity	268	99	Initial neck symptoms	105	56	31 %	0.003*
			Persistent neck symptoms	24	18	51 %	0.020*
All impact severity	820	401	Initial neck symptoms	231	138	18 %	0.026*
			Persistent neck symptoms	51	39	36 %	0.034*

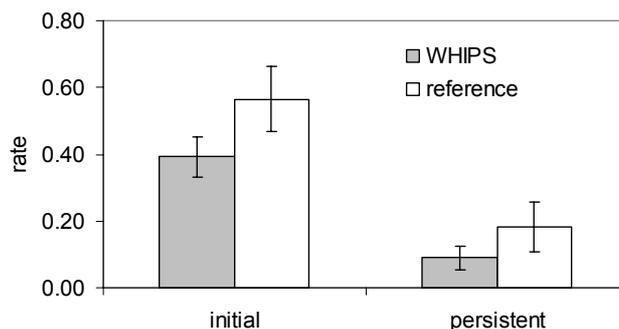


Figure 1. Rates of initial and persistent symptoms for occupants in WHIPS as compared to reference seat; front seat occupants without prior neck problems involved in rear-end impacts of moderate severity.

The reductions seen for occupants in minor impact severity are not statistically significant. However, when grouping both minor and moderate impact severity together, significant injury reducing effects of 18% ($p=0.026$) with the confidence limits (C_L, C_U) = (3%, 31%) for initial neck symptoms and 36% ($p=0.034$) with (C_L, C_U)= (5%, 57%) for persistent neck symptoms are found (Table 1).

Table 2. Distribution of influencing factors for front seat occupants above 14 years of age and without prior neck problems, at moderate impact severity. For age, weight and stature, mean \pm standard deviations are given.

	Cases	Drivers (%)	Gender (% men)	Age (years)	Weight (kg)	Stature (cm)	Rotated head (%)	< 10 cm Backset (%)
WHIPS	268	80	72	46 \pm 14	77 \pm 14	176 \pm 11	26	88
Reference	99	79	70	46 \pm 15	76 \pm 16	175 \pm 9	25	84

Occupant demographics and sitting postures in the WHIPS and the reference seat for the occupants in moderate impact severity, for whom the AIS1 neck injury reducing effect was calculated, can be seen in Table 2. The demographics (gender, age, weight and stature) and distribution of sitting position are rather equally distributed within the two groups. A multiple regression analysis was run, including the factors in Table 2, to check the influence of the factor's influence on WHIPS effectiveness. WHIPS turned out to be significant. Thus, the injury reducing effect of WHIPS can be considered reliable even when considering influencing factors in the area of occupant characteristics and posture as well as sitting position.

GENDER DIFFERENCES

When divided into gender, the largest AIS1 neck injury reducing effect can be seen for women, Figure 2. The total injury reducing effect for women is 29 % as compared to 10% for men for initial symptoms. As can also be seen in Table 3, considering only moderate impact severity impacts for initial symptoms, the injury reducing effect for women is even higher (45%) as compared to 24% for men. For persistent neck symptoms the trend is similar, but actually higher injury reducing effects than for initial symptoms.

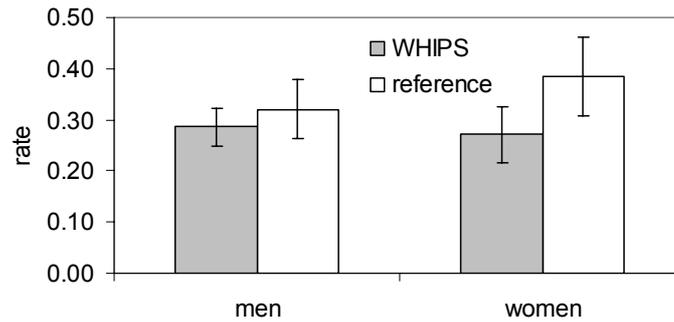


Figure 2. Rates of initial AIS1 neck injuries for men and women, respectively, in WHIPS as compared to reference seat, all impact severity.

Table 3. Number of occupants and injured occupants, respectively, separated by gender, seat and impact severity group, together with changes in AIS1 neck injury rate (injury reducing effect), separated by gender for moderate impact severity and all impact severity. P-values marked with * are considered statistical significant.

	Gender	Number of occupants			Injured occupants		Injury reducing effect	p-value (chi ² test)
		WHIPS	Ref.		WHIPS	Ref.		
Moderate impact severity	Men	193	69	Initial neck symptoms	79	37	24 %	0.069
				Persistent neck symptoms	19	12	43 %	0.12
	Women	75	30	Initial neck symptoms	26	19	45 %	0.007*
				Persistent neck symptoms	5	6	67 %	0.057
All impact severity	Men	572	250	Initial neck symptoms	164	80	10 %	0.34
				Persistent neck symptoms	35	22	30 %	0.18
	Women	247	151	Initial neck symptoms	67	58	29 %	0.019*
				Persistent neck symptoms	16	17	42 %	0.11

The reasons for the differences between men and women, and why the rates for men and women in WHIPS are equal are not obvious. An overview of the distribution with respect to possible influencing factors was made, for those in moderate impact severity impacts and for all impacts, respectively.

Sitting posture: Two main factors with respect to sitting posture were studied: rotated head at impact and self-estimated distance between head and head restraint during impact. The relative number of occupants with rotated head was rather similar for occupants in WHIPS seats and reference seats: 25% and 23%, respectively, for men, and 27% and 28%, respectively, for women. Regarding head to head-restraint distance, a larger proportion of men reported 10 cm or less in WHIPS (89%) as compared to reference seats (83%). For women, 85% in WHIPS and 86% in reference seats estimated a distance less than 10 cm.

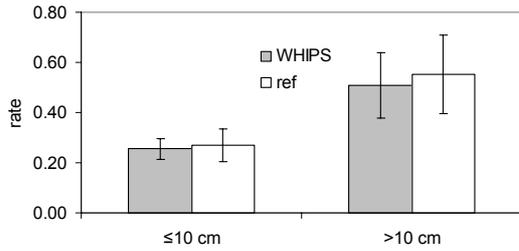


Figure 3a. Initial AIS1 neck injury rates with respect to head to head-restraint distance at time of impact for men, all impact severity.

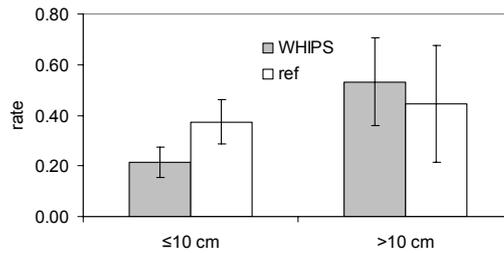


Figure 3b. Initial AIS1 neck injury rates with respect to head to head-restraint distance at time of impact for women, all impact severity.

A significantly lower AIS1 neck injury rate is found for occupants with 10 cm or less between head and head restraint (Figures 3a,b). A significantly lower rate in WHIPS as compared to the reference seat is seen for women sitting 10 cm or closer to the head restraint (Figure 3b). This is not seen for men, nor for occupants sitting more than 10 cm away (Figures 3a,b). Figures 3a,b are based on all impact severity. The same trend is seen when only considering moderate impact severity.

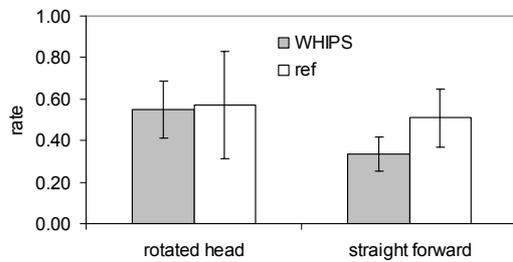


Figure 4a. Initial AIS1 neck injury rates with respect to head rotation posture at time of impact for men exposed to moderate impact severity impacts.

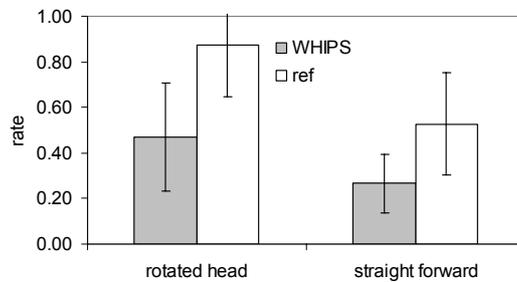


Figure 4b. Initial AIS1 neck injury rates with respect to head rotation posture at time of impact for women exposed to moderate impact severity impacts.

The AIS1 neck injury rates, comparing the two genders with respect to type of seat and head rotated posture, are shown in Figures 4a,b for occupants in moderate impact severity. Although not significantly different, statistically, women with rotated heads have a reduced AIS1 neck injury rate in WHIPS seats as compared with the reference seats (Figure 4b). This difference is not found for men (Figure 4a). When considering all impact severities, no difference between WHIPS and the reference could be seen for women, suggesting that the differences in Figure 4b could be attributed to WHIPS recliner activation.

Occupant characteristics: The mean values of weight, stature and BMI (Body Mass Index) are similar between the uninjured occupants and those with AIS1 neck injuries for the four groups divided by gender and seat type, Table 4. This indicates that the benefit of WHIPS for women is not directly related to a specific size of the occupant.

Table 4. Mean values \pm standard deviations for stature (cm), weight (kg) and BMI (kg/m^2) comparing injured and uninjured front seat occupants (above 14 years of age and without prior neck problems, all impact severity).

	WHIPS men		Reference men		WHIPS women		Reference women	
	Injured	Uninjured	Injured	Uninjured	Injured	Uninjured	Injured	Uninjured
Stature	181 \pm 7	180 \pm 6	180 \pm 7	179 \pm 7	168 \pm 20	167 \pm 6	167 \pm 6	166 \pm 6
Weight	85 \pm 13	82 \pm 12	84 \pm 14	82 \pm 13	65 \pm 11	65 \pm 10	66 \pm 11	65 \pm 14
BMI	26 \pm 3	25 \pm 3	26 \pm 4	26 \pm 4	23 \pm 4	23 \pm 3	23 \pm 4	24 \pm 4

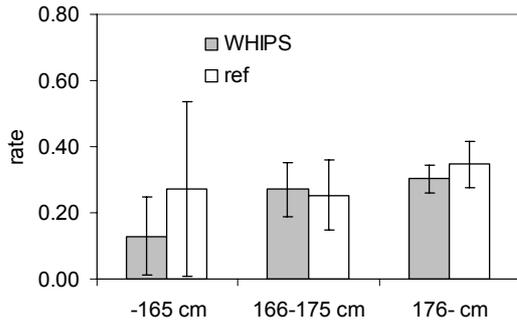


Figure 5a. Initial AIS1 neck injury rates with respect to stature for men, all impact severity impacts.

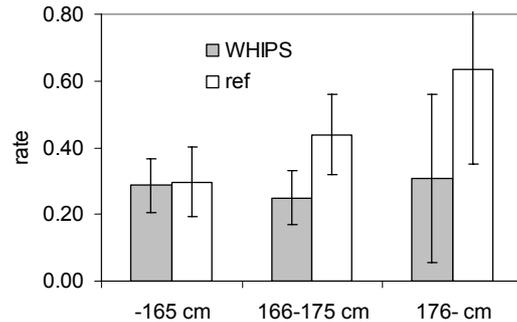


Figure 5b. Initial AIS1 neck injury rates with respect to stature for women, all impact severity impacts.

In Figures 5a,b the AIS1 neck injury rates are shown, comparing the two genders with respect to occupant stature and type of seat, for all impact severity. For mid-size occupants (166-175 cm), there is a reduction in injury rate, for women but not for men, between the reference seat and WHIPS. Figure 5b shows that the benefit for women is not because they are generally shorter. When comparing AIS1 neck injury rates with respect to occupant weight, the same trend is found as for stature.

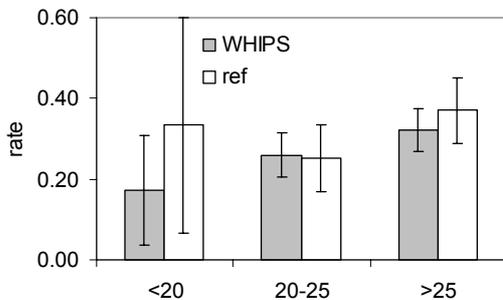


Figure 6a. Initial AIS1 neck injury rates with respect to BMI for men, all impact severity impacts.

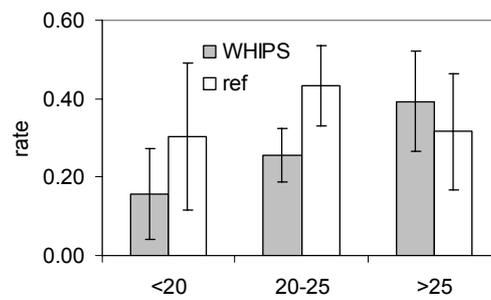


Figure 6b. Initial AIS1 neck injury rates with respect to BMI for women, all impact severity impacts.

Normal-sized women (BMI 20 – 25) have a significantly lower AIS1 neck injury rate for the WHIPS seat as compared to the reference seat (Figure 6b). For men and over- or under-weight women, no major differences were found (Figures 6a,b). This confirms that the benefit of WHIPS is not attributed to a specific occupant size or constitution, suggesting other factors than purely occupant size-related.

DISCUSSION

The data in this study offers a unique possibility for evaluating the effectiveness of a new seat design. For two thirds of the car models in the study, the only change in design between the two groups was the seat. In addition, the large amount of information for each case, such as details regarding occupant characteristics and sitting posture, makes it possible to compensate for factors not usually available in statistical databases.

Analysis of accident data constitutes an important source of knowledge and adds to the understanding of possible injury mechanisms as well as setting the course for improved design of injury protection systems. As in all studies involving individuals, the accuracy of the reported parameters can always be questioned. The information regarding the initial neck injury as well as details of the symptoms after one year were provided by the occupants through questionnaires. This method was chosen because it gave the best consistency between the cases. The alternative would have been to gather follow-up medical reports, but then there would be information missing as well as

the difficulties of interpretation by a third person. Providing all occupants with a questionnaire in which they report their problems in a consistent way may not be objective, but since the symptoms are mainly pain-based, which by definition is subjective, this method would give the best quality for the purpose of this study. In addition, it can be questioned how well one remembers the sitting posture at the time of impact. This question is relevant and the probability of inaccuracy of the responses needs to be taken into consideration in the interpretation of the results. However, since there are probably no major systematic difference of inaccuracy between the groups compared, the conclusions are probably not affected too much. Used in a careful way, the increased knowledge of influence of sitting posture gives valuable information in this study.

In the present analysis it was possible to exclude occupants with prior neck problems. Earlier studies based on the same data set have shown that prior neck problems is a significant influencing factor (Jakobsson 2004a, 2000b). For the purpose of this study it was an advantage to make the material as homogenous as possible and thus only include factors which are relevant for understanding the crash situation. As found in other studies, several factors have an influence on AIS1 neck injury outcome. In Figures 3a,b and 4a,b it can be seen that occupants with increased head to head-restraint distance and rotated head, respectively, have an increased AIS1 neck injury rate. The amount of increase differs for gender and seat type. Also, for differences in occupant characteristics, this study indicates that there is an increase for increased occupant stature (Figures 5a,b), which confirms findings in earlier studies (Lundell et al. 1998a, Temming and Zobel 2000). In this study, information regarding occupant sitting postures and characteristics was used to understand the reason for women having a higher benefit from WHIPS than men, as well as for making robustness in the calculation of the AIS1 neck injury reducing effect.

The AIS1 neck injury reduction seen for WHIPS in minor impact severity was not significant. The WHIPS recliner in the seat was not designed to be activated in that range of severity and the effect by the changes in head-restraint geometry and seat back characteristics was not large enough. However, when impact severity reaches the level of WHIPS recliner activation, a significant injury reducing effect of initial as well as persistent AIS1 neck injuries was seen for occupants in WHIPS seats as compared to previous Volvo front seats. AIS1 neck injury reduction was statistically significant even when including minor impact severity. The AIS1 neck injury reducing effect was higher for persistent symptoms than for initial symptoms. This is beneficial, since the long-term problems are those constituting most human suffering.

The AIS1 neck injury reducing effect was higher for women than for men, reducing the initial AIS1 neck injury rate for women down to approximately the same rate as for men in WHIPS. Possible explanations for this were explored among factors related to occupant characteristics and sitting posture. Consideration was taken for differences in impact severity, looking for possible explanatory factors both in the impact severity interval for probable WHIPS activation (moderate impact severity) and in the total number of impacts. With respect to occupant body size, it was found that mid-sized women with respect to weight, stature and BMI, were those with most AIS1 neck injury reduction, between the reference and the WHIPS. This indicates that the benefit of WHIPS for women is not mainly attributable to the fact that women are smaller. Differences in sitting posture indicate that at the severity of probable WHIPS activation, women with rotated head are extra beneficial. There is no data for proof, but it could indicate that women when rotated are more vulnerable than men, and that WHIPS, by its more gentle occupant support (reduced acceleration), is the solution for this type of injury mechanism. This study did not give a clear answer regarding the main differences in vulnerability between men and women. When more cases are available, it would be possible to stratify the data into even more specified groups, e.g. looking at possible differences in BMI for specific stature groups, which might give additional knowledge.

CONCLUSIONS

Compared to previous Volvo seats from the same car models, WHIPS reduces AIS1 neck injury rates significantly in rear-end impacts, both with respect to initial neck symptoms and neck symptoms lasting more than one year. The AIS1 neck injury reducing effect is based on front seat occupants above 14 years of age and without prior neck problems. Women have the highest benefit. The reason

for this was explored with respect to the influence of sitting posture and occupant characteristics. It was found that it was not due to women being smaller than men.

ACKNOWLEDGEMENTS

This study would not have been possible without the valuable help from Marie-Louise Kindal at Volvia Insurance (IF). We would also like to thank Arne Carlsson and Lennart Edvardsson at Volvia for their efforts, as well as Julia Sjöström and Arne Ran at Volvo IT, and Bengt Lökensgård, Åse Lund, Carina Kjellsson and Fredrik Möschlin at Volvo Cars in setting up the study and during the data collection process. Many thanks also to Irene Isaksson-Hellman at Volvo Cars for statistical guidance throughout the study.

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