The development and real world performance of WHIPS

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Abstract

Soft tissue neck injuries in rear end impacts represent one of the most important types of injury in car crashes regarding both frequency and long-term consequences. The injury mechanisms are yet not fully understood, thus making it essential to base the development of protection systems on knowledge from real world data.

WHIPS (Whiplash Protection System) was introduced 1998 in front seats of Volvo cars. It is a robust seat and head restraint design including an energy absorbing recliner mechanism, which will enable the seat back to move to some extent with the occupant rearward during a rear end impact. WHIPS was developed using a working method based on real world data combined with dummy testing and computer simulation. Analysis of several independent accident data sets have shown that the neck injury reducing effect of WHIPS as compared to previous Volvo seats is substantial, both for initial neck symptoms and long-term symptoms.

Since 1999, rear-end impacts of Volvo cars in Sweden have been investigated on a regular basis, including one-year post accident follow-up. The analysis in this study regarding influencing factors and the injury reducing effect of WHIPS is based on a total of 2521 front seat occupants (above 14 years of age without prior neck problems), 74% of these are in Volvo cars equipped with WHIPS and 26% are in Volvo cars of model year 1999 without WHIPS.

The present data confirms earlier studies, showing substantial neck injury reducing effects of WHIPS as compared to previous Volvo seats for all situations studied. Neck injury reducing effects of WHIPS for different impact severities are presented, both for initial neck symptoms and neck symptoms lasting more than one year. The injury reducing effect is highest for impact severities of approximate WHIPS recliner activation or higher, however a noticeable effect is even seen for minor impact severities, which account for the vast majority of impacts. Occupant characteristics and sitting posture are important influencing factors. Factors such as turned head and increased head to head restraint distance, increases neck injury risks in this study.

In addition to showing the good performance of WHIPS, the real world data also demonstrates that the WHIPS development method used was a feasible approach. The feedback from WHIPS real world performance may guide further development of neck injury mitigation systems.

Introduction

Soft tissue neck injuries are on the most frequent types of injury in car crashes. Most of the injuries recover within a shorter while, although as many as 10% of all the initial injured occupants may have long-term problems, making this to an important injury both with respect to frequency and long-term problems. Soft tissue neck injuries can be a result of all types of crashes, however the highest risk is found in rear end impact. Soft tissue neck injuries account for the majority of all injuries in rear-end impacts.

Head restraints were introduced in cars in order to support the head and avoid hyperextension of the neck in a rear-end impact. Studies based on accident data with and without head restraints showed head restraints to have a neck injury reducing effect (Asberg 1973, O'Neill et al. 1972). Volvo cars have been equipped with head restraints as standard in the front seat since mid 1970: ies. Head restraints close to the head, high and rigidly attached are believed to be most effective. This can be achieved by a fixed design or by adjusting the head restraint position during the crash by more or less active systems (Wiklund and Larsson 1998). However, even with head restraints, neck injuries are reported in rear-end impacts, suggesting that the performance of the whole seat is important.

The development of WHIPS

A study known by the acronym WHIPS (Whiplash protection study) was undertaken by Volvo cars to identify ways and means of achieving the aim of substantially reducing soft tissue neck injuries in rear end impacts (Lundell et al. 1998a, Jakobsson et al. 2000). The study took part in the early 1990: ies, before the issue of soft tissue neck injuries had reached high on the international agenda. Thus, no test procedure was available for evaluating different design concepts. This pioneer study combined experiences from accident data research and early computer modeling with existing biomechanical knowledge, synthesized into, what was named as, three biomechanical guidelines. In order to be able to evaluate design concepts, the three defined biomechanical guidelines were broken down into engineering requirements and test methods. As a parallel process a physical crash test dummy for low and moderate speed rear-end impacts, named BioRID, was developed (Davidsson et al. 1998).

The accident data research comprised statistical analysis (Carlsson et al. 1985, Lundell et al. 1998a) for identifying influencing factors and trends in injury risk, as well as in-depth studies (Olsson et al. 1990, Jakobsson et al. 1994) for understanding of the complex mechanisms behind soft tissue neck injuries.

Parameters influencing the risk of injury were studied using an occupant model with a complete and segmented spinal column. The model, shown in Figure 1a, was developed within the study and presented in Jakobsson et al. (1994). Using the model, an understanding of kinematics and kinetics was gained and the importance of studying the whole seat and not only the head restraint was shown obvious. The model was also an inspiration and design support in the development of the rear end impact dummy, BioRID, Figure 1b.

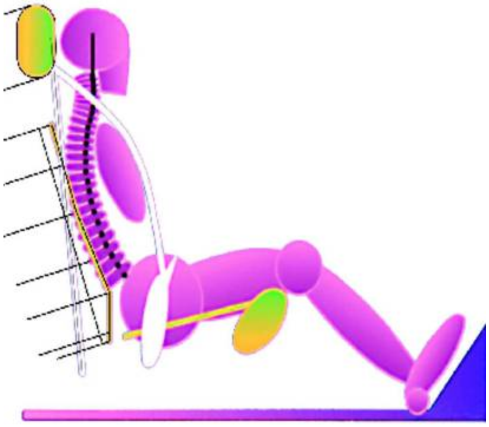

Figure 1a. 2D Madymo occupant model (Jakobsson et al. 1994)

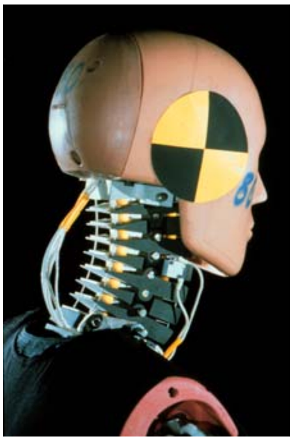

Figure 1b. BioRID

The three biomechanical guidelines developed were a substitute of the unknown injury mechanisms. In order to be able to know what engineering efforts to make, the accident data experience and the results of various proposed injury mechanism research needed to be condensed. An effort to do this resulted in what was called, the three biomechanical guidelines. The guidelines summarize a holistic approach to the soft tissue neck injury issue, aiming to address various proposed injury mechanism theories and cover a variety of different scenarios. The three guidelines are; (a) reduce occupant acceleration, (b) minimize relative spine movements, and (c) minimize the forward rebound into the seat belt. It was believed that if these guidelines are adhered to the seat design, the risk of soft tissue neck injuries in rear end impacts can be reduced (Jakobsson et al. 2000).

Engineering requirements and test methods were developed to address the biomechanical guidelines. Only in a late stage of the study, the rear end impact dummy, BioRID, was available, thus other methods were created and used (Lundell et al. 1998a, Lundell et al. 1998b).

As the result of the study, a seat with the same acronym WHIPS (Whiplash protection system) was developed. The basis for the seat design was the previous Volvo seats. The WHIPS system in the seat consists of a new recliner mechanism, together with a somewhat modified backrest characteristics and head restraint geometry (Lundell et al. 1998b). In a rear-end impact, the recliner is designed to give a controlled rearward motion of the backrest relative to the seat cushion, Figure 2.

Figure 2. The recliner motion of WHIPS

The procedure for the WHIPS development method follows the whole chain; from accident research and biomechanical knowledge; interpretation of this knowledge, condensed into guidelines and requirements; and finally seat development, validated by testing. When introduced in 1998, the injury reducing effect of WHIPS could not be predicted, mainly because of the limited knowledge of injury mechanisms as well as lack of quantifiable relationships between the injury mechanisms and the guidelines and requirements. Now, being on the market for almost 10 years, the injury reducing effect has been calculated based on real world data.

Injury reducing effects of WHIPS

Analysis of several independent accident data sets have shown that the neck injury reducing effect of WHIPS as compared to previous Volvo seats is substantial, both for initial neck symptoms and long-term symptoms.

The real world performance of WHIPS was evaluated in an automobile insurance claim study in USA by Farmer et al. (2003) based on 112 occupants. The effect was not statistically significant, but the estimated effect of WHIPS was 49% as compared to previous Volvo systems, with the highest effect for women.

In 2004, Volvo Cars presented the injury reducing effect of WHIPS based on a larger amount of occupants in Volvo cars in Sweden (Jakobsson and Norin 2004). Compared to previous Volvo seats from the same car models, WHIPS showed to reduce soft tissue neck injury risks significantly in rear-end impacts, both with respect to initial neck symptoms and neck symptoms lasting more than one year. For 324 front seat occupants above 14 years of age without prior neck problems and at a moderate impact severity, 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 injury-reducing effect was found higher for women as compared to men.

Similar effects were shown by Folksam (Kullgren et al. 2007). The data also gives a relative measures to other seats than previous Volvo seats, indicating that WHIPS is one of the leading seats in the market with respect to soft tissue neck injury protection.

WHIPS accident data

In the continuous process of improving the protection in rear end impacts, analyzing accident data can be used to identify areas of potential improvements.

Method

A total of 2521 front seat occupants above 14 years of age and with no prior neck problems are selected from Volvo Cars' rear end impact database. The database consists of Volvo cars of model year 1999 or later involved in rear-end impacts (of any severity degree) in Sweden. The database collection procedure and content is described in detail in Jakobsson and Norin (2004) and contains to date a total of 6890 occupants, whereof 4250 with one year follow-up. 74% (1858) of the occupants in the subset selected (>14years old and no prior neck problems) are drivers (1475) or front seat passengers (383) in vehicles equipped with WHIPS and 24% (663) are drivers (527) or front seat passengers (136) in reference vehicles (model year 1999 Volvo S40, V40, S70 and V70 vehicles).

Initial neck symptoms are defined as all symptoms and signs, from the impact event, in the neck area reported by the occupant in a one-year follow-up questionnaire. Those having symptoms 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 method used is the Chi^2-test. The neck injury risks for initial and persistent symptoms are also illustrated in graphs with 95% confidence intervals. *Neck injury risk* is defined as the number of people with neck injury divided by the total number of people involved in the specific population. The *injury reducing effect* of WHIPS is defined as the neck injury risk difference between occupants in WHIPS as compared to the reference seat divided by the neck injury risk of the reference seat.

Results

The neck injury reducing effects of WHIPS are calculated, for the subset of front seat occupants above 14 years of age and without prior neck problems. As can be seen in Table 1, the mean injury reducing effects of WHIPS as compared to previous Volvo seats (reference) calculated in this data set varies from 21% to 47% depending on severity and symptom duration considered. More specifically, the injury reducing effects in moderate impact severity is 31% with the confidence limits (C_L, C_U) = (18%, 42%) for initial soft tissue neck injuries and 47% (20%, 65%) for soft tissue neck injuries lasting longer than one year (persistent), respectively. In minor impact severity the injury reducing effect is lower; 21% (5%, 34%) for initial symptoms and non-statistically significant 29% for persistent symptoms.

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

	Total number of occupants			**Number of occupants reporting neck injury**		**Injury reducing effect**	**p-value (chi^2 test)**
	WHIPS	Ref.		WHIPS	Ref.		
Minor impact severity	1213	482	Initial neck symptoms	260	130	21 %	0.015*
			Persistent neck symptoms	57	32	29 %	0.116
Moderate impact severity	645	181	Initial neck symptoms	234	95	31 %	0.000*
			Persistent neck symptoms	57	30	47 %	0.005*
All impact severity	1858	663	Initial neck symptoms	494	225	22 %	0.000*
			Persistent neck symptoms	114	62	34 %	0.007*

<u>Gender</u>

Generally there is a higher risk for women as compared to men, however not as obvious for the occupants in WHIPS seats. A higher injury reducing effect was seen for women than for men, suggesting that the WHIPS may be more effective in reducing the neck injury risk for women. Possible reasons for this were explored in Jakobsson and Norin (2004).

<u>Seating position and sitting posture</u>

As seen in several other studies, drivers have a higher risk of neck injuries as compared to front seat passengers. This is seen for occupants in WHIPS regarding initial neck symptoms (Figure 4a), although not for persistent neck symptoms (Figure 4b).

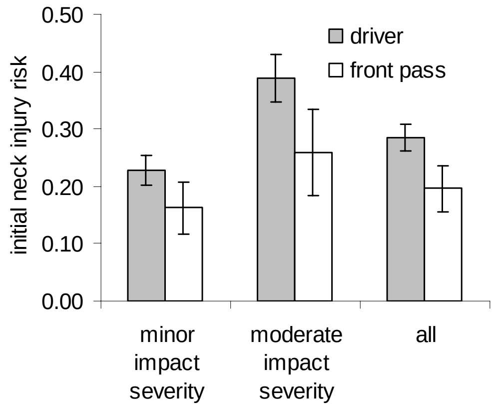

Figure 4a. Initial neck injury risk comparing drivers and front seat passengers in WHIPS

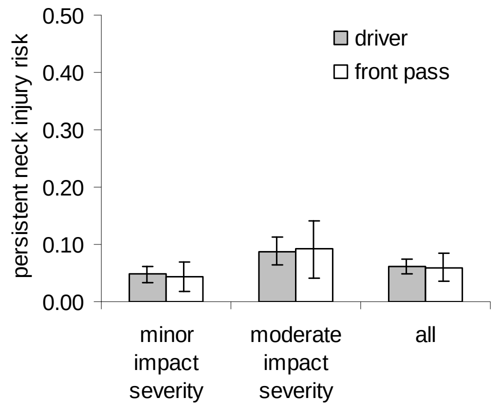

Figure 4b. Persistent neck injury risk comparing drivers and front seat passengers in WHIPS

The risk differences between drivers and front seat passengers can partly be explained by differences in sitting posture. Occupants responding that they had turned their head (rotated around z-axis to any degree) at the time of impact had a statistically significant higher risk of initial as well as persistent neck symptoms as compared to those facing straight forward, Figure 5. Drivers were more prone to have rotated head. Among those with known head rotation posture, 25% of the drivers as compared to 19% of the front seat passengers reported head rotation in any direction and degree during impact.

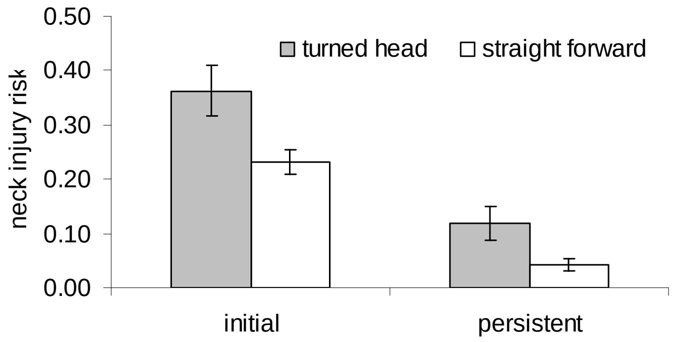

Figure 5. Soft tissue neck injury risk vs. head rotated posture at impact, all impact severity

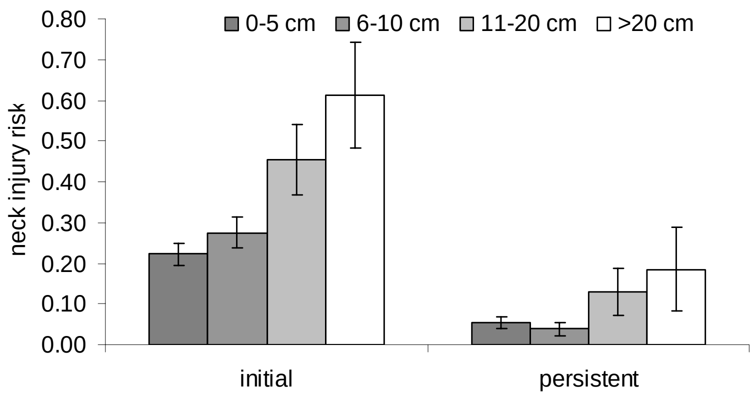

Figure 6. Soft tissue neck injury risk for different backsets, all impact severity

In addition, there is a trend that soft tissue neck injury risk increases with increased estimated head to head restraint distance (at the time of impact), Figure 6. The same trend is seen even when divided by driver / front passenger or gender. Among the occupants in WHIPS, the distribution of self-reported head to head restraint distance was similar between drivers and front seat passengers; 11% of the drivers as compared to 10% of the front seat passengers reported 10 cm or more in head to head restraint distance. Since this parameter is self reported and difficult both to remember and to estimate, results can only be drawn with respect to trends.

Discussions

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 be questioned. The information regarding the initial neck injuries as well as details of the problems after one year were provided by the occupants through questionnaires. This method was chosen because it gave the best consistency in what was asked and reported 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 is 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.

A volunteer study, measuring static sitting postures of car occupants on different positions in the car, reports a larger backset for the occupant in the driver position (hands on steering wheel) as compared to the front seat passenger position (hands in lap) (Jonsson et al. 2007). The authors suggest this to be a reason for the higher neck injury risk for drivers. The present study confirms the risk difference between drivers and front passengers, but do not show this large difference in backset between driver and front seat passenger. The accuracy in the self-reported distance in the questionnaire data is less than the difference measured in the more controlled volunteer measurement study, making it difficult to compare.

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 2004). 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 many studies, several factors have an influence on neck injury outcome (Temming and Zobel 2000, Jakobsson 2004). In Figures 4 and 5, it is shown that occupants with increased head to head-restraint distance and rotated head, respectively, have an increased risk, emphasizing the importance of occupant posture and behavior at time of impact.

WHIPS neck injury reducing effect is highest in moderate impact severity. The WHIPS recliner in the seat is designed to be activated in that range of severity. The relatively high injury reducing effect in minor impact severity is thus mainly attributed the changes in head-restraint geometry and seat back characteristics. There is an overall higher neck injury reducing effect for persistent symptoms than for initial symptoms. This is beneficial, since the long-term problems are those constituting most human suffering.

The neck injury reducing effects calculated in this study show good correspondence to the other studies by Farmer et al. (2003) and Kullgren et al. (2007). Also in all existing consumer tests using a crash test dummy (BioRID), WHIPS has scored in the highest rating group (IIWPG, Folksam / SRA). The robust and forgiving design of WHIPS is thus shown to be a good approach, especially when the exact injury mechanisms are difficult to establish and measure.

Basing the development of WHIPS on real world crash outcome was proven a successful method. The same method may be used in establishing the next steps of potential improvements. The results of this study may be used as guidance of future possible improvement areas of a world class performing seat, although it is not probable that such a large step as for WHIPS will be taken easily.

Conclusions

The present data confirms earlier studies, showing substantial neck injury reducing effects for occupants in WHIPS as compared to occupants in previous Volvo seats, for all the severity and symptom duration groups studied. The injury reducing effect is highest for impact severities of approximate WHIPS activation or higher, however a noticeable effect is even seen for minor impact severity, which account for the majority of impacts. Several factors influence injury risks. This study especially emphasizes the importance of occupant characteristics and sitting posture as influencing factors. This study indicates that factors such as turned head and increased head to head restraint distance, increase neck injury risks.

In addition to showing the good performance of WHIPS, the real world data also demonstrates that the WHIPS development method used was a feasible approach. The feedback from WHIPS real world performance may guide further development of neck injury mitigation systems.

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