PARAMETERS INFLUENCING THE RISK OF AIS1 NECK INJURIES IN FRONTAL AND SIDE IMPACTS

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ABSTRACT

In order to gain more knowledge of the neck injury scenario in frontal and side impacts, a statistical study of parameters influencing risk of neck symptoms (AIS1 neck injuries) was performed. The data set consisted of 445 occupants in frontal impacts and 302 occupants in side impacts in Volvo cars. Information regarding the accident, the car, occupant characteristics, behaviour and sitting posture at the time of impact, and neck symptoms (including duration) was collected and analysed.

Both in frontal and side impacts, the parameter of tensed neck muscles, crash severity and occupants, whose heads were struck against the interior of the car, turned out to have a significant effect on risk of neck symptoms.

Key words: Neck, Frontal impact, Side impact, Accident analysis, Whiplash

NECK INJURIES CLASSIFIED AS AIS1 (AAAM, 1985), often referred to as whiplash injuries or whiplash associated disorders (WAD, Spitzer et al 1995) are not life-threatening, but are important due to long term consequences of a small proportion of those injuries (Nygren 1984, Norin et al 1997). Statistics from several countries indicate an increase in the occurrence of neck injuries during the last few decades (Ono et al 1993, van Kampen 1993, von Koch et al 1994 and Morris et al 1996). Since injuries of this type are extremely costly, in social terms, because of their long-term consequences (von Koch et al 1994), a great deal of human suffering can be avoided and the cost to society lowered by reducing the incidence of neck injuries.

Rear end impacts account for the highest risk of AIS1 neck injury (Morris et al 1996, Lundell et al 1998). However, AIS1 neck injuries occur in all types of accident, and a notable number of AIS1 neck injuries are found in frontal impacts as well as side impacts (Jakobsson, 1997, Morris et al, 1996 and Temming and Zobel, 1998). In order to reduce the total number of AIS1 neck injuries, all types of crash configurations are important to consider.

The complexity of the various human, car and impact related factors causing the broad set of symptoms included in the diagnosis of WAD, is tremendous. No single injury mechanism has so far been proposed as responsible for all the symptoms. In a rear end impact situation, several different mechanisms have been suggested by different researchers. Those concerned include classic hyper extension mechanism (White and Panjabi, 1990); pressure gradient due to initial swift head motion (Aldman 1986 and Svensson et al 1993); rebound mechanisms (von Koch et al 1995); relative vertebrae motions (Ono et al 1993, McConnell et al 1993, Jakobsson et al 1994) and several other. The pressure gradient theory (Aldman 1986) is suggested for other crash directions as well (Svensson et al, 2000). In frontal impacts, Walz and Muser (1995) proposed that shearing forces between the upper vertebrae occur in the first phase (when the cervical spine was formed as an s-shape) and these could be injurious to the neck.

In rear end impacts, several different parameters have been found to affect the neck injury risk. Gender, occupant stature, seating position, sitting posture and impact characteristics are factors found to influence the risk of injury (Carlsson et al 1985, Lövsund et al 1988, Olsson et al 1990, Jakobsson et al 1994, Spitzer et al 1995, Morris and Thomas 1996, Otte et al 1997, Krafft 1998, Temming and Zobel 1998, Langwieder et al 2000 and Jakobsson et al 2000).

In frontal or side impacts, few studies have been made, trying to identify parameters influencing risk of AIS1 neck injuries. Morris and Thomas (1996) identified belt usage as being associated with increased neck injury risk in frontal impact. Temming and Zobel (1998) found gender to be the most predicting human factor in all impact configurations. The authors also concluded that no effect of occupant stature on the risk of injury could be identified in side impacts, nor any uniform effect of occupant weight. In frontal impacts, Kullgren et al (2000) have found that the shape of the crash pulse particularly influences the risk of long-term consequences to the neck.

Classifying the duration of AIS1 neck injuries is difficult. Kullgren et al (2000) defined long-term consequences as occupants having continuous symptoms (at least every other week) for more than 6 months. If the occupants recovered within 6 months their injuries were classified as short-term consequences. Quebec Task Force (Spitzer et al 1995) defined those patients with symptoms remaining more than 6 months after the crash as long-term consequences. In a Swedish hospital study it was found that most of the patients with passing symptoms had recovered within 3 months (Olsson et al 1988). Only 6-7% of the patients with initial neck symptoms had recovered between 3 months and 3 years. The duration of the symptoms was very dependent on personal factors and rehabilitation programs. Thus, in order to obtain a clear distinction between passing and persistent symptoms, a recovery time within a couple of months would include most patients with passing symptoms, while more than 1 year could be a suitable time limit for patients with persistent symptoms (Bunketorp 2000).

The objective of this study is to identify parameters related to AIS1 neck injuries in frontal and side impacts, both with respect to symptoms reported initially and with respect to symptom duration.

METHODS AND MATERIALS

The method used was to analyse (statistically) a dataset of frontal and side impacts containing information about the impact, the car and the occupants at the time of impact, as well as neck symptom duration.

VOLVO'S STATISTICAL DATABASE: All new Volvo cars sold in Sweden are covered by a three-year damage warranty issued by the Volvia insurance company. Crashes in which the repair costs exceed a specified level (currently SEK 35,000, approx. US$ 4,500) are investigated by Volvia's claim inspectors. The information regarding these crashes forms the basis of Volvo's statistical accident database. Photos and technical details of the cars (e.g. damage) are continuously sent to the Traffic Accident Research department. The owner of the car answers a questionnaire (shortly after the accident) to gather detailed information about the accident and the occupants. Injury data is gathered from medical records and analysed by a medical doctor on the Volvo accident research team.

THE DATASET OF THIS STUDY: For this study, all frontal and side impacts during 1996 and 1997 were selected from Volvo's statistical database. A couple of years after the impact, additional questionnaires were sent out asking for further details regarding sitting posture, awareness of and preparation for the accident, as well as the characteristics and duration of neck symptoms, if any.

The dataset used in this analysis was limited to those answering the additional questionnaire; a subset of frontal and side impacts with Volvo cars. Only adults (over 15 years of age) are included in the study.

A total of 349 frontal impacts involving 445 occupants, and a total of 224 side impacts involving 302 occupants, are included in this study. For all the risk analyses, except for seat belt usage effect, the unbelted occupants are excluded (20 occupants in frontal impacts and 12 occupants in side impacts). Thus, all findings (except regarding seat belt usage) are based on belted occupants only.

DEFINITION OF SYMPTOMS AND RISK: *Initial symptoms* include all reported neck pain or discomfort resulting from the accident classified as AIS1 neck injuries according to AAAM (1985), mostly self-reported. Occupants recovering from the symptoms within three months are grouped as having *passing symptoms. Persistent symptoms* include occupants reporting symptoms one year after the accident, occurring at least once a month, described as seriously interfering with activities, or occurring weekly, described as hampering activities. The rationale for the chosen definitions is to clearly separate the two groups of passing and persistent. Based on earlier studies and clinical experiences (Olsson et al 1988) only a few recover within the period of three months to one year after the accident, whereby the above two levels and conditions were chosen.

The risk is defined as the number of occupants with the specific symptom type (initial, passing or persistent) divided by the total number of occupants in the specific situation. Based on confidence intervals, conclusions regarding statistical significance are drawn. The significance level used is 5%.

PARAMETERS ANALYSED: Parameters on which this study focused are listed in table 1. The choice of parameters was based on findings in previous studies.

Table 1 - Parameters analysed in this study

	Analysed parameters
impact characteristics	impact direction, near/far side impacts, outside/toward compartment impact, EBS, deformation extent
occupant characteristics	gender, age, stature, weight
seating/occupant parameters	seating position, sitting posture, turned head, preparation, muscle tension, steering wheel grip
safety systems	seat belt usage, belt pretensioner activation, airbag activation
occupant kinematics	head impacts

The parameters were studied with respect to risk of initial (all AIS1 neck injuries), passing (recovery within three months) and persistent symptoms (symptoms of certain degree 1 year after the collision). Due to the different kinematics, frontal and side impacts were separated in the analyses.

RESULTS

NECK INJURY

Among the 445 occupants involved in frontal impacts, 107 (24%) reported initial neck injury in the questionnaire. The corresponding figures for the side impacts, were 80 of the 224 occupants (26%).

The recovery trend of the total amount of occupants can be seen in figure 1. According to the definition, all the neck-injured occupants are found in the group of occupants with initial symptoms. 39 occupants in side impacts and 47 occupants in frontal impacts reported no symptoms after 3 months. They are grouped as occupants with passing symptoms. In the group of occupants with persistent symptoms, 32 occupants in side impacts and 35 occupants in frontal impacts can be found.

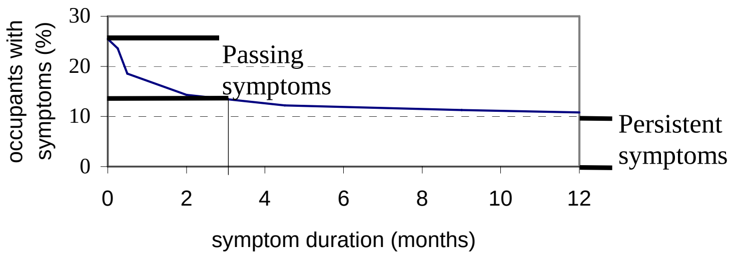

Fig. 1 - Symptom duration for the occupants in this dataset, indicating occupants with passing and persistent symptoms.

IMPACT CONFIGURATION:

Frontal impacts: In frontal impacts, no significant difference between straight and angled impacts against the car front can be seen, neither for initial, passing nor persistent symptoms.

Side impacts: The risk of initial symptoms as related to impact direction is presented in table 2. For drivers and passengers in left rear seat, the number of cases for different impact directions is calculated and stored according to a clock diagram, see table 2. For front seat passengers and passengers in the right rear seat, the impact directions are mirrored, i.e. impact direction 1+2 for drivers correspond to impact direction 10+11 for front seat passengers. In table 2, passengers in the middle rear seat are excluded.

Table 2 - Risk of initial symptoms in different impact directions for side impacts

Impact direction	1-2 o'clock Far side	3 o'clock Far side	4-5 o'clock Far side	7-8 o'clock Near side	9 o'clock Near side	10-11 o'clock Near side
Risk	9 %	31 %	25 %	38 %	25 %	24 %
Total no.	33	81	8	8	119	67

As can be seen in table 2, there is a tendency that the risk of initial symptoms is higher in side impacts angled from the rear (7-8 o'clock). This is, however, based on a small sample of numbers. The risk of 9% in the impact direction of frontal angled far side (1-2 o'clock) is significantly low as compared to frontal angled near side (10-11 o'clock). The tendency of different risk of initial symptoms for different impact directions can be seen for passing and persistent symptoms in a corresponding way.

Given that the car is impacted perpendicular to the vehicles longitudinal direction (3 and 9 o'clock), there is a tendency (not significant) for higher risk of initial symptoms, if the car is hit in front of or behind the passenger compartment (i.e. outside) as compared to an impact affecting the compartment.

IMPACT SEVERITY:

Frontal impacts: In figure 2, the risk of initial neck symptoms is shown related to EBS (Equivalent Barrier Speed, Mackay and Ashton, 1973) in frontal impacts.

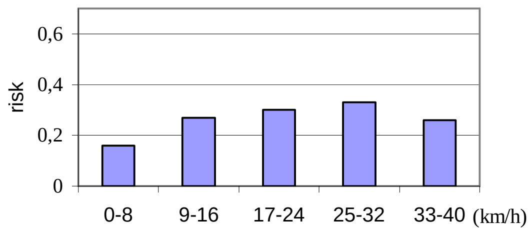

Fig. 2 - Risk of initial neck symptoms in frontal impacts vs. EBS. (Background data in appendix.)

A chi-2 test of the data in figure 2 showed that the risk of initial neck symptoms is significantly increasing (p=0,033) with increasing EBS.

Side impacts: The crash severity related parameters used for evaluation of neck injury risk in side impacts are: near/far side impacts, impact outside/toward the passenger compartment, deformation extent (greater/less than 15 cm).

In figure 3, the risk of initial symptoms is shown for impacts outside and toward the passenger compartment with deformation extent ≤15 cm and >15 cm, respectively (deformation extent according to reference CDC 1980).

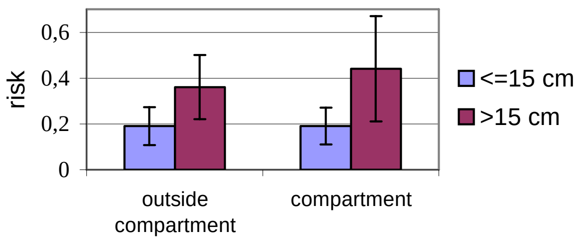

Fig. 3 - Risk of initial symptoms for impacts, outside and toward the passenger compartment, with deformation extent ≤15 cm and >15 cm, side impacts. (Background data in appendix.)

There is a clear tendency to higher risk of initial symptoms with increased deformation extent, see fig. 3. When including all impact directions, no general influence of severity risk for outside and toward compartment impact could be seen. If comparing occupant risk in far side and near side no notable difference could be seen.

OCCUPANT CHARACTERISTICS:

Gender: Figures 4a and 4b show that there is a general tendency of higher risk for women (however not significant), in frontal as well as side impacts.

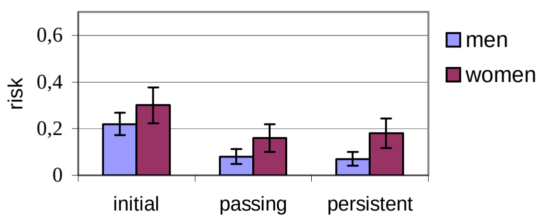

Fig. 4a - Risk of initial, passing and persistent symptoms vs. gender in frontal impacts. (Background data in appendix.)

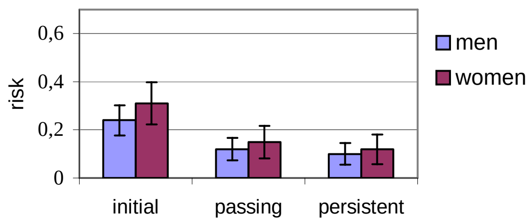

Fig. 4b - Risk of initial, passing and persistent symptoms vs. gender in side impacts. (Background data in appendix.)

Occupant age: The occupant age does not influence the neck symptom outcome in a notable way.

Occupant stature: The risk of initial symptoms for men and women divided in three groups of occupant stature is shown in figures 5a and 5b, for frontal and side impacts, respectively.

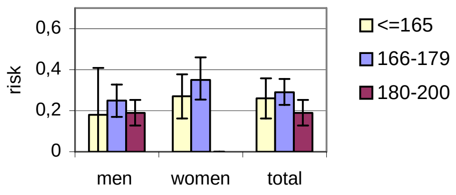

Fig. 5a - Risk of initial symptoms vs. stature (in cm) and gender in frontal impacts. (Background data in appendix.)

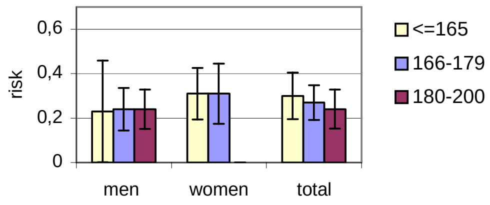

Fig. 5b - Risk of initial symptoms vs. stature (in cm) and gender in side impacts. (Background data in appendix.)

In neither of the two impact situations could a clear trend be found suggesting that the stature of the occupant influences the risk of sustaining an initial neck injury. The same pattern could be found for passing and persistent symptoms.

Occupant weight: Studying the effect of occupant weight on risk of neck injuries, no relationship can be found. In frontal impact there is a higher risk for women less than 60 kg as compared to heavier women. More analyses are needed in order to explain these findings.

OCCUPANT SEATING POSITION: In frontal impacts (fig 6a), female drivers have significantly higher risk of sustaining initial symptoms as compared to female front seat passengers. Female drivers have also a significant higher risk of sustaining initial symptoms as compared to male drivers. The findings are also valid for passing symptoms. For men there is no visible difference in risk depending on seating position. However the sample sizes of male passengers are very small (only 15 front seat passengers and 8 rear seat passengers).

In side impacts, no specific tendency could be found, neither for initial symptoms (see fig. 6b) nor for passing or persistent symptoms.

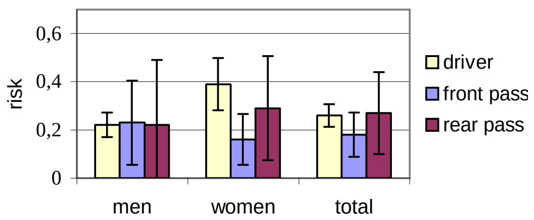

Fig. 6a - Risk of initial symptoms vs. seating position and gender in frontal impacts. (Background data in appendix.)

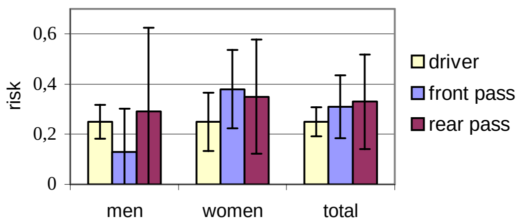

Fig. 6b - Risk of initial symptoms vs. seating position and gender in side impacts. (Background data in appendix.)

OCCUPANT SITTING POSTURE AND REACTION:

Different sitting postures: For three different general sitting postures (normal, upright and leaning forward) no difference in risk for neck symptoms were found. This is also the case for risk of neck symptoms depending on leaning sideways.

Turned head: In fig. 7a and 7b, the risks of the different symptoms as related to whether the head was turned prior to the crash or not are displayed. “Turned” includes those occupants who have indicated that their heads were turned to either right or left side prior to the impact. “Forward” are those who have answered that their head was facing straight forward. In the side impact subset, almost all of those being turned were turned toward the impact location.

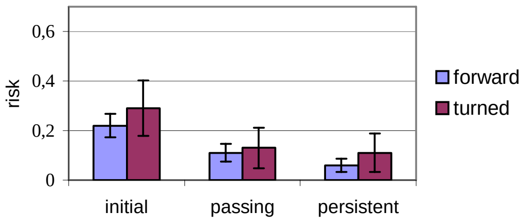

Fig. 7a - Risk of initial, passing and persistent symptoms vs. turned head in frontal impacts. (Background data in appendix.)

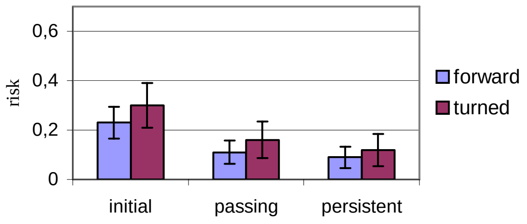

Fig. 7b - Risk of initial, passing and persistent symptoms vs. turned head in side impacts. (Background data in appendix.)

Occupants stating that they turned their head prior to impact had a somewhat higher risk both in frontal and side impacts (figures 7a and 7b). The findings are not significant.

Preparation and muscle tension: There was found no difference between the risk of neck symptoms between the occupants who were aware of the impending accident and those who were unaware. However, when studying specific preparation activities at the time of impact, it was found that neck (incl. shoulders) muscle tension significantly influenced the risk of symptoms, see figures 8a and 8b.

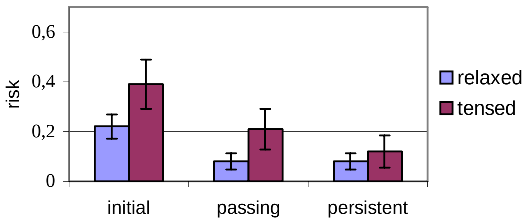

Fig. 8a - Risk of initial, passing and persistent symptoms related to neck muscle tension in frontal impacts. (Background data in appendix.)

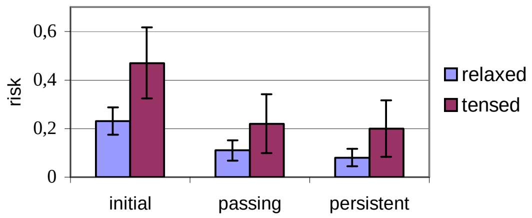

Fig. 8b - Risk of initial, passing and persistent symptoms related to neck muscle tension in side impacts. (Background data in appendix.)

Tensed neck muscle has a significant effect on initial symptoms, regardless of impact situation, figure 8a and 8b. The effect of muscle tension on passing neck symptoms is statistically significant in frontal impacts. For the whole dataset, divided into gender, the significant difference for initial symptoms is valid for both women and men. Also, women with tensed muscles have a higher risk of sustaining initial neck symptoms as compared to men. Drivers who stated they held the steering wheel tight had a higher risk of sustaining neck symptoms.

SAFETY SYSTEMS:

Seat belt usage: In this material there are only 20 cases of unbelted occupants among the frontal impacts, and only 12 unbelted occupants in side impacts.

Based on this limited data, there is a tendency toward increased risk of initial symptoms for belted occupants in frontal impacts. The number of unbelted occupants is too few in order to study the risk of passing or persistent symptoms.

In side impacts there was no clear difference in injury risk for belted and unbelted occupants.

Belt pretensioners in frontal impacts: A total of 15 belted passengers had activated pretensioners without an activated airbag (passenger seat where there was no airbag installed). These occupants were compared to belted occupants without activated pretensioners or bags. There was no detectable effect of pretensioners in injury outcome with respect to any symptom category, however the cases are too few in order to draw any conclusions.

Airbags (including belt pretensioners): There was a slight trend of reduced risk of symptoms for occupants with deployed airbags (including belt pretensioners) in frontal impacts, however not significant.

Among the side impacts, only 12 occupants had activated SIPSbags (side impact airbag) and due to the small numbers, no conclusions could be drawn.

OCCUPANT KINEMATICS – HEAD IMPACTS: The occupants were asked to indicate if their head had impacted any interior structure of the car (incl. airbags). Neck symptom risks with and without head impact in frontal and side impact, respectively, are plotted in figures 9a and 9b. For frontal impacts, the data has two restrictions; drivers only were considered and occupants only impacting the back of the head against the head restraint were considered as no impact.

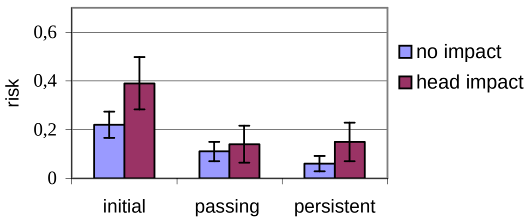

Fig. 9a - Risk of initial, passing and persistent neck symptoms for head impact of drivers in frontal impacts. (Background data in appendix.)

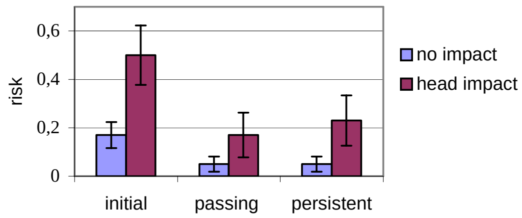

Fig. 9b - Risk of initial, passing and persistent neck symptoms for head impact of occupants in side impacts. (Background data in appendix.)

In frontal impacts there is a significantly higher risk of initial neck injuries when impacting any part of the interior of the car during the forward motion in a frontal crash (fig.9a). When impacts against airbags are excluded, the difference is even larger.

For side impact, as well, there was a significantly higher risk for initial, as well as passing and persistent symptoms, when the occupants' heads were impacted into the interior of the car (fig. 9b). When taking crash severity into account, it seems that the increased risk of symptoms for frontal impacts is not due to increased severity only, at least not when divided into different levels of EBS, see fig 10.

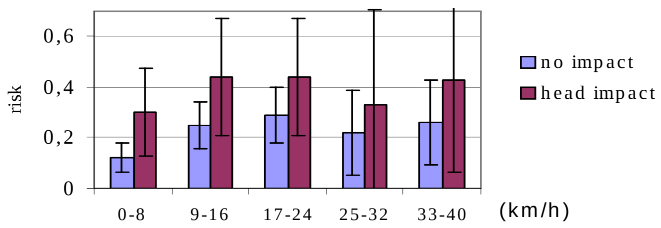

Fig. 10 - Risk of initial symptoms with and without head impact to the interior of the car, vs. EBS, in frontal impacts. (Background data in appendix.)

As illustrated by fig. 10, higher risk of initial symptoms can be seen for occupants with reported head impacts, compared to occupants with no reported head impacts, throughout all the levels of EBS.

Also, in side impacts, when grouping into the severity levels as displayed in figure 3, a trend can be seen for higher risk of initial neck symptoms for cases with head impacts, regardless of crash severity group.

NECK PROBLEMS PRIOR TO THE ACCIDENT: Self-reported, neck-related problems before the accident were checked against risk of sustaining neck symptoms obtained. There was a tendency of increased risk of neck symptoms if the occupant already had reported neck shoulder or head symptoms. However these finding are not significant. Due to small samples, no statements regarding passing and persistent symptoms can be made.

DISCUSSIONS

Knowledge of different parameters' effects on neck symptoms in various impact situations must be obtained in order to make further efforts in the area of reduction of AIS1 neck injuries in frontal and side impacts. This study offers the first step in mapping the parameters' influence and should be followed by parameter studies as well as in-depth studies.

In order to find the influences, a broad variety of parameters were analysed. The most prominent parameters, in this study, were of a kind not usually available in regular statistical accident data material, such as muscle tension and details about head impacts. The importance of having a wide range of information, when seeking influencing parameters, is emphasised. The number of observations in this study, however, was some times too small to allow evaluation of all interesting combinations.

The results should be regarded as a comparative study between the parameters evaluated. No effort has been made to compare absolute risk values with other studies, since risk values are very dependent on the collection criteria in the dataset. In this study the collection criterion limit of SEK 35,000 repair cost excludes minor impacts, which probably influences the total risk figures to higher absolute values. For the purpose in this study, it is not believed to influence the findings.

Due to the fact that some years passed between the accident and time when the additional questionnaire was sent out, the reliability of the answers (such as details regarding the sitting posture and head impacts) may be questioned. Phone calls and accompanying comments have indicated that many occupants seem to have a clear memory of the occurrence. There was also always a possibility of answering “unknown” to the questions, which several of the occupants did. Based on this, together with the experiences when manually going through all the questionnaires, the answers are judged to be relevant and consistent.

One of the most interesting findings was the clear influence of tensed neck (incl. shoulder) muscles. The parameter, whether they were aware of the impending accident or not, did not indicate any relation to neck symptoms, but the way the occupants prepared themselves did. A higher risk of sustaining neck symptoms was found when muscles were tensed. This was significant for initial neck symptoms in frontal and side impacts and for passing neck symptoms in frontal impacts. The tendency for increased risk of neck symptoms for tensed muscles is distinct, both for initial, passing and persistent neck symptoms. There are several questions to be asked related to these findings. Why is there a difference in neck symptom findings between awareness and muscle tension? Is it possible for the occupants to remember their actions at the time of impact? The answers to these questions can not be drawn based on this study. The influence of neck muscle tension as well as other actions of preparation activities should be further explored.

For frontal, as well as side impacts, one of the parameters shown to be most closely related to neck symptom risk was when the head impacted the interior structure. The reason for this is not obvious. The head impact risk was found independent of crash severity, at least according to the available crash severity measures. The finding of the influence of head impact is an important area to further analyse and will probably give valuable information to possible injury mechanisms.

Based on the available severity measures in side impacts, deformation extent was found related to risk of neck symptoms. In frontal impacts, a significant increase of neck symptoms with increased EBS was found. EBS is, however, an insensitive severity measure and does not reflect for instance, differences in pulse shape. Kullgren et al (2000) emphasise especially, the shape of the crash pulse as influencing the risk of long-term neck consequences. Crash recorder data should be explored further with the aim to find improved crash severity measures for prediction of neck symptoms.

Regarding impact configuration no parameter, clearly influencing the risk of neck symptoms, could be found. Though, for different impact directions in side impact there are some differences regarding neck symptom risk, however based on small numbers. The possible lower risk of far side angled impact situation (1-2 o'clock) could be due to the possibility to slide out from the chest part of the seat belt in combination with greater distance to possible impact areas. The influences of seat belt usage in frontal impact and head impacts support these possible explanations, as both have turned out to affect the risk of symptoms.

Based on the general findings of occupant characteristics, only gender affects the risk analysis in a systematic way. Even though not significant as a separate variable, significance was found in combination with seating position. When regarding the whole population no significant difference regarding seating position could be found. However, when genders were separated, female drivers were found to have a significantly higher risk than female front seat passengers. This could not be found for men, which could be affected by relatively few male passengers. This area needs to be scrutinised more closely, to give some more understanding of injury mechanisms.

In rear end impact situations, the risk of AIS1 neck injuries was found to increase with increased stature (Jakobsson et al, 2000), this trend could not be found for side and frontal impact situations, even if the genders were studied separately.

Regarding the influences of different safety systems, this study could not give any distinct directions. There was a slight tendency of reduced risk of symptoms for occupants with deployed frontal airbags. In Volvo cars, frontal airbag activation is combined with belt pretensioners, thus it cannot be determined by this study whether the main benefit is attributable the airbag or the belt pretensioner.

A part of the study was looking at the differences (if any) with respect to symptom duration. For this purpose, most of the occupants having initial symptoms (which include all reported AIS1 neck injuries), were grouped in those recovered within 3 months and those still having bothering symptoms after 1 year. The share of occupants with initial symptoms not being grouped in the two duration groups were larger than the 6-7% that recovered between three months and three years in the study by Olsson et al (1988). The main reason for this is probably that the occupants with minor symptoms after one year, was not included in the group of persistent symptoms. In this study, there was no specific tendency found with respect to type of symptom duration category. This issue is interesting to explore further.

CONCLUSIONS

In frontal as well as side impacts, occupants stating that they tensed the neck and/or shoulder muscles at the time of impact, were at a significantly higher risk of initial neck symptoms (AIS1 neck injuries), as compared to occupants not tensing their muscles. Muscle tension influences both the category of passing and persistent symptoms.

Occupants, stating that they impacted any interior structure, were found to be exposed to a significantly higher risk of initial neck symptoms. This is true even if crash severity is considered. In side impacts, significance was found in both passing and persistent symptoms. In frontal impact, a similar tendency could be seen, however not significant.

An increased risk of initial neck symptoms was found for increased crash severity, based on the measures available in this study (deformation extent in side impacts and EBS in frontal impacts).

Among the occupant characteristics (gender, age, weight, and stature), gender was found to be the parameter mostly related to neck symptoms, women having a higher risk. One situation where significant difference was found was between female drivers and male drivers.

Female drivers also have a significantly higher risk than female front seat passengers. However, this could not be found for male drivers as compared to male front seat passengers. The reason for the differences in gender could not be explained, except the fact that the number of male passengers were few in this study.

There was no distinct pattern of parameters influencing the duration of neck symptoms. The trend of symptoms lasting less than 3 months, were similar to the trend of symptoms lasting more than 1 year.

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REFERENCES

AAAM (Association for the Advancement of Automotive Medicine); The Abbreviated Injury Scale, 1985 Revision; AAAM, Des Plaines, IL, USA; 1985.

Aldman, B. An Analytical Approach to the Impact Biomechanics of the Head and Neck Injury. Proc. of 30th Annual AAAM Conference, Motreal, Quebec, 1986: pp 439-454.

Bunketorp, O; Orthopaedic specialist at Traffic Safety Registry, Sahlgrenska University Hospital; Personal communication; 2000

Carlsson, G., Nilsson, S., Nilsson-Ehle, A., Norin, H., Ysander, L. and Örtengren, R. Neck Injuries in Rear End Car Collisions; Biomechanical Considerations to Improve Head Restraints. Proc. of IRCOBI/AAAM Conference on Biomechanics of Impacts, Göteborg, Sweden, 1985: pp. 277-289.

Collision Deformation Classification (CDC) – SAE J224 MAR80. Report of the Automotive Safety Committee, approved January 1971, completely revised by the Motor Vehicle Safety Systems Testing Committee, March, 1980.

Jakobsson, L., Norin, H., Jernström, C., Svensson, S-E., Johnsén, P., Isaksson-Hellman, I. and Svensson, M.Y. Analysis of Different Head and Neck Responses in Rear-End Car Collisions using a New Humanlike Mathematical Model. Proc. of IRCOBI Conference on Biomechanics of Impacts, Lyon, France, 1994: pp. 109-125.

Jakobsson, L. Whiplash Injury and Vehicle Design; In: Whiplash Injuries: Current concepts in Prevention, Diagnosis and Treatment of the Cervical Whiplash Syndrome; R. Gunzberg and M. Szpalski; Lippincott-Raven Publishers, Philadelphia, PA, USA, ISBN 0-397-51856-0, 1997: pp. 299-306.

Jakobsson, L., Lundell, B., Norin, H., WHIPS – Volvo's Whiplash Protection Study. Accident Analysis and Prevention 32; 2000: pp. 307-319.

van Kampen LTD; Availability and (Proper) Adjustment of Head Restraint in the Netherlands; Proc. of IRCOBI Conference on the Biomechanics of Impact, Eindhoven, Netherlands, 1993: pp.367-377.

von Koch, M., Nygren, Å., Tingvall, C. Impairment Pattern in Passenger Car Crashes, a Follow-up of Injuries Resulting in Long Term Consequences; Paper No. 94-S5-O-02; Proc. of 14th ESV Conference, Munich, Germany, 1994; p. 776-781.

von Koch, M., Kullgren, A., Lie, A., Nygren, Å. and Tingvall, C. Soft Tissue Injury of the Cervical Spine in Rear-End and Frontal Car Collisions, Proc. of IRCOBI Conference on Biomechanics of Impacts, Brunnen, Switzerland, 1995.

Krafft, M. A Comparison of Short- and Long-Term Consequences of AIS 1 Neck Injuries, in Rear Impacts. Proc. of IRCOBI Conference on Biomehanics of Impacts, Göteborg, Sweden, 1998: pp. 235-248.

Kullgren, A., Krafft, M., Nygren, A. and Tingvall, C. Neck injuries in frontal impacts: influence of crash pulse characteristics on injury risk. Accident Analysis and Prevention 32; 2000: pp. 197-205.

Langwieder, K., Hell, W. and Walz, F., Occurrence of Reported Cervical Spine Injuries in Car Accidents and Improved Safety Standards for Rear-End Impacts Accident Analysis and Prevention 32; 2000: pp.

Lundell, B., Jakobsson, L., Alfredsson, B., Jernstöm, C., Isaksson-Hellman, I. Guidelines for and the Design of a Car Seat Concept for Improved Protection Against Neck Injuries in Rear End Car Impacts. SAE Paper No. 980301, SAE International Congress and Exposition, Detroit, February 1998

Lövsund, P., Nygren, Å., Salen, B., Tingvall, C. Neck Injuries in Rear End Collisions among Front and Rear Seat Occupants. Proc. of IRCOBI Conference on the Biomechanics of Impacts, Bergisch Gladbach, Germany, 1988: pp. 319-326.

Mackay, M. and Ashton, T. Injuries in Collisions Involving Small Cars in Europe. SAE Tech. report No 730284, Automotive Engineering Congress, Detroit, Michigan, 1973.

Mc Connell, W.E., Howard, R.P., Guzman, H.M., Bomar, J.B., Raddin, J.H., Benedict, J.V., Smith, H.L., Hatsell, C.P. Analysis of Human Test Subject Kinematic Responses to Low Velocity Rear End Impacts. In: Vehicle and Occupant Kinematics; Simulation and Modeling (SP-975), SAE Technical Paper Series 930889, SAE International Congress and Exposition, Detroit, March 1993: pp. 21-30.

Morris, A. P. and Thomas, P. A Study of Soft Tissue Neck Injuries in the UK. Paper No. 96-S9-O-08. Proc. Of 15th ESV Conference, Melbourne, Australia, May 1996: pp 1412-1425.

Norin, H., Krafft, M., Korner, J., Nygren, Å., Tingvall, C. Injury Severity Assessment for Car Occupants using Disability Scaling. J. Clin. Epidemiol. Vol. 50, no 1, 1997: pp 95-103

Nygren, Å. Injuries to Car Occupants - Some Aspects of the Interior Safety of Cars. Acta Oto - Laryngologica - Suppl.395, ISSN 0365-5237, 1984.

Olsson, I., Bunketorp, O., Blåder, S., Lindh, M., Markhede, G., Romanus, B.; Nackbesvär efter bilolyckor; VTI

meddelande 561, ISSN 0347-6049; 1988 (in Swedish)
Olsson, I., Bunketorp, O., Carlsson, G., Gustafsson, C., Planath, I., Norin, H. and Ysander, L. An In-depth Study of Neck Injuries in Rear End Collisions. Proc. of IRCOBI Conference on the Biomechanics of Impact, Bron, France, 1990: pp. 269-280.
Ono, K. and Kanno, M. Influence of the Physical Parameters on the Risk to Neck Injuries in Low Speed Rear-End Collisions. Proc. of IRCOBI Conference on the Biomechanics of Impact, Eindhoven, Netherlands, 1993: pp. 201-212.
Ono, K., Kaneoka, K., Wittek, A. and Kajzer, J. Cervical Injury Mechanism Based on the Analysis of Human Cervical Vertebral Motion and Head-Neck-Torso Kinematics During Low Speed Rear Impacts. Proc. of 41st STAPP Car Crash Conference, SAE P-315, Paper no 973340, Lake Buena Vista, Florida, Nov 13-14, 1997: pp 339-356.
Otte, D., Pohlemann, T. and Blauth, M. Significance of Soft tissue Neck Injuries AIS 1 in the Accident Scene and Deformation Characteristics of Cars with Delta-V up to 10 km/h. Proc. of IRCOBI Conference on Biomechanics of Impacts, Hannover, Germany, 1997: pp 265-283.
Spitzer, W.O., Skovron, M.L., Salmi, L.R., Cassidy, J.D., Duranceau, J., Suissa, S., Zeiss, E. Scientific Monograph of the Quebec Task Force on Whiplash Associated Disorders: Redefining ”Whiplash” and its Management. Spine (supplement) Volume 20, Number 8S, April 1995.
Svensson, M.Y., Aldman, B., Hansson, H.A., Lövsund, P., Seeman, T., Sunesson, A. and Örtengren, T. Pressure Effects in the Spinal Canal during Whiplash Extension Motion: A Possible Cause of Injury to the Cervical Spinal Ganglia. Proc. of IRCOBI Conference on the Biomechanics of Impact, Eindhoven, Netherlands, 1993: pp. 189-200.
Svensson, M.Y., Boström, O., Davidsson, J., Hansson, H-A., Håland, Y., Lövsund, P., Sunesson, A., Säljö, A. Neck injuries in car collisions – a review covering a possible injury mechanism and the development of a new rear-impact dummy. Accident Analysis and Prevention 32; 2000: pp. 167-175.
Temming, J., Zobel, R.. Frequency and Risk of Cervical Spine Distortion Injuries in Passenger Car Accidents: Significance of Human Factors Data. Proc. of IRCOBI Conference on Biomehanics of Impacts, Göteborg, Sweden, 1998: pp. 219-233.
Walz, F. Muser, M. Biomechanical Aspects of Cervical Spine Injuries. SAE paper No. 950658. Society of Automotive Engineers, Warrendale, USA, 1995
White, A. and Panjabi, M. Clinical Biomechanics of the Spine 2nd edition, J. B. Lippincott Company, Philadelphia, PA, USA, 1990

APPENDIX

Numbers of injured and total numbers for all figures.

Figure 2.

EBS (km/h)	0-8	9-16	17-24	25-32	33-40	Total
Neck injured	25	29	27	12	9	
Total	161	106	91	36	34	428
Chest injured	10	15	18	10	13	
Total	161	106	91	36	34	394

Figure 3.

	Outside compartment		Compartment		Total
	≤ 15 cm	>15 cm	≤ 15 cm	>15 cm	
Injured	17	16	17	8	
Total	88	45	91	18	242

Figure 4a.

	Initial symptoms		Passing symptoms		Persistent symptoms		
	Men	Women	Men	Women	Men	Women	Total
Injured	62	43	23	22	20	25	
Total	284	141	284	141	284	141	425

Figure 4b.

	Initial symptoms		Passing symptoms		Persistent symptoms		
	Men	Women	Men	Women	Men	Women	Total
Injured	44	33	21	16	19	13	
Total	181	107	181	107	181	107	288

Figure 5a.

	Stature (cm)	≤ 165	166-179	180-200	Total
Men	**Injured**	2	31	29	
	Total	11	122	151	284
Women	**Injured**	18	25	0	
	Total	66	72	3	141

Figure 5b.

	Stature (cm)	≤ 165	166-179	180-200	Total
Men	**Injured**	3	19	22	
	Total	13	78	90	181
Women	**Injured**	19	14	0	
	Total	61	45	1	107

Figure 6a.

		Driver	Front seat passenger	Rear seat passenger	Total
Men	**Injured**	55	5	2	
	Total	253	22	9	284
Women	**Injured**	31	7	5	
	Total	79	45	17	141

Figure 6b.

		Driver	Front seat passenger	Rear seat passenger	Total
Men	**Injured**	40	2	2	
	Total	159	15	7	181
Women	**Injured**	13	14	6	
	Total	53	37	17	107

Figure 7a.

Head position	Initial symptoms		Passing symptoms		Persistent symptoms		
	Forward	Turned	Forward	Turned	Forward	Turned	Total
Injured	65	18	32	8	17	7	
Total	292	63	292	63	292	63	355

Figure 7b.

Head position	Initial symptoms		Passing symptoms		Persistent symptoms		
	Forward	Turned	Forward	Turned	Forward	Turned	Total
Injured	37	29	17	16	14	12	
Total	161	97	161	97	161	97	258

Figure 8a.

Muscle tension	Initial symptoms		Passing symptoms		Persistent symptoms		
	Relaxed	Tensed	Relaxed	Tensed	Relaxed	Tensed	Total
Injured	59	37	22	20	21	11	
Total	272	95	272	95	272	95	367

Figure 8b.

Muscle tension	Initial symptoms		Passing symptoms		Persistent symptoms		
	Relaxed	Tensed	Relaxed	Tensed	Relaxed	Tensed	Total
Injured	50	21	24	10	17	9	
Total	217	45	217	45	217	45	262

Figure 9a.

	Initial symptoms		Passing symptoms		Persistent symptoms		
	Head impact	No head impact	Head impact	No head impact	Head impact	No head impact	Total
Injured	50	31	24	11	14	12	
Total	226	79	226	79	226	79	305

Figure 9b.

	Initial symptoms		Passing symptoms		Persistent symptoms		
	Head impact	No head impact	Head impact	No head impact	Head impact	No head impact	Total
Injured	32	32	10	11	10	15	
Total	190	64	190	64	190	64	254

Figure 10.

EBS (km/h)	0-8	9-16	17-24	25-32	33-40	Total
No impact	15	21	19	5	7	
Total	121	85	66	23	27	322
Head impact	8	8	8	2	3	
Total	27	18	18	6	7	76