WHIPS - Volvo's Whiplash Protection Study

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Abstract — Whiplash Associated Disorders (WAD) resulting from rear end car impacts is an increasing problem. WAD are usually not life-threatening, but are one of the most important injury categories with regard to long-term consequences.

This paper explains Volvo's Whiplash Protection Study (WHIPS), which is the result of more than ten years of concentrated research efforts in the area of neck injuries in car collisions, with the focus on rear end car impacts. The study follows the whole chain from accident research to the development of a seat for increased protection against WAD.

Results from Volvo's accident research are summarized. Existing biomechanical knowledge regarding possible injury mechanisms are presented and discussed. Based on the interpretation of accident research and biomechanical knowledge, guidelines for improved protection against WAD in rear end impacts are presented.

Requirements and test methods based on the guidelines are explained. An important part of the study is a new rear end impact dummy, BioRID. Test results using the new dummy are presented.

Finally, the paper explains the design of a new seat for increased WAD protection, the WHIPS-seat.

Results from the accident research and biomechanical research emphasize the importance of considering the whole spine of the occupant and, accordingly, the whole seat when addressing WAD in rear end impacts. Low and moderate impact severity crashes should be focused. Also important to consider are the individual differences between occupants, the seating position and the variety of seating postures.

All results, including sub-system testing, mathematical modeling, sled testing, as well as geometrical parameters show that the WHIPS-seat will have a considerable potential for offering increased protection against WAD in rear end impacts.

Keywords — WHIPS, whiplash, neck injury, rear impact, BioRID

INTRODUCTION

Neck injuries, often referred to as whiplash injuries or whiplash associated disorders (WAD, Spitzer et al. 1995) and classified as AIS 1 (AAAM, 1990) are not life-threatening, but nevertheless are the most important injury category with regard to long-term consequences (Nygren 1984). 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.

A study, known by the acronym WHIPS (Whiplash Protection Study), was undertaken by Volvo to identify ways and means of achieving this aim, focusing rear end impacts. The study model is illustrated in Figure 1. WHIPS combines experiences from accident research and computer modeling with existing biomechanical knowledge, synthesized into three biomechanical guidelines. In order to be able to evaluate design concepts, the biomechanical guidelines are 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, has been developed. WHIPS has previously been presented by Lundell et al (1998 a,b) and the BioRID I was presented by Davidsson et al (1998b).

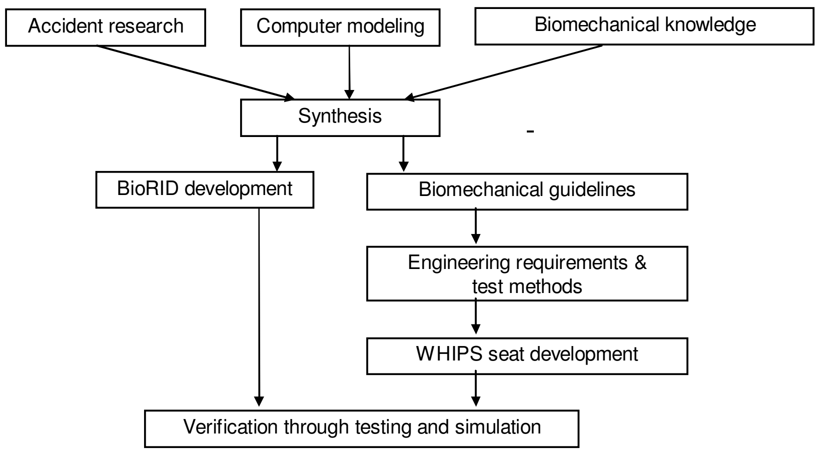

Figure 1. Volvo's Whiplash Protection Study (WHIPS)

ACCIDENT RESEARCH

Statistical accident data

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. 4500 US$) are investigated by Volvia's claim inspectors. The information on these crashes forms the basis of Volvo's statistical accident database. Volvo has collected data from accidents involving Volvo cars in Sweden for almost 30 years. The database currently contains data from over 25.000 accidents with over 45.000 occupants. 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 to gather detailed information about the accident and the occupants. Injury data is gathered from medical records and analyzed by a medical doctor in Volvo's accident research team.

The data set used in this analysis is limited to a subset of Volvo 200 and 700 models, during the period 1975-1998. Only adults (above 15 years of age) are included in the study. In the database, neck injuries include all neck discomfort and pain (cervical region) reported by the occupants themselves and found in the medical records. In this database, no information on long-term disability is included.

The distribution of neck injuries and risk of sustaining neck injuries, in different types of accident, can be seen in Figure 2. The graph is based on a subset of 18366 belted drivers.

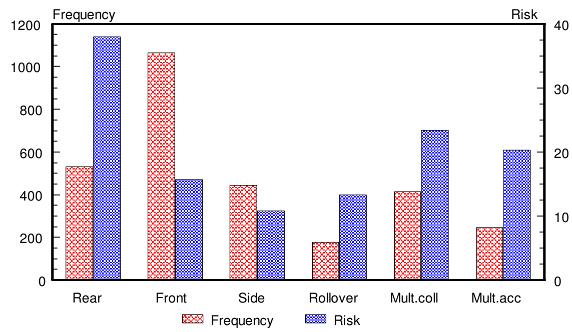

Figure 2. Distribution and risk of neck injuries (AIS 1) in different types of accident.

In Figure 2, the risk of neck injury in different types of impact is compared. As can be seen; the risk of sustaining a neck injury is higher in rear end impacts than in any other crash type. In the material considered, the neck injury risk is defined as the number of persons with AIS 1 neck injury divided by the total number of persons involved in the specific impact type.

The distribution of neck injuries in different types of accident, as in Figure 2, shows that neck injuries can be found in all types of accident. The highest frequency can be found in frontal impacts.

In a further analysis, rear end impacts are focused. In this database, most of the injuries in rear end impacts are of severity AIS 1 (98.3 %). The frequency of different types of AIS 1 injury in rear end impacts is shown in Figure 3. The graph is based on a subset of 2163 occupants (driver, front seat passenger and outboard rear seat passengers).

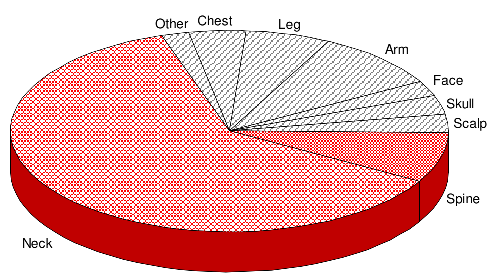

Figure 3. Distribution of AIS1 injuries in rear end impacts

As can be seen in Figure 3, AIS 1 neck injuries are by far the most common injury type in rear end impacts, and regarding this material, the injury type to consider. The second largest group is spine injuries (thoracic and lumbar spine).

Figure 4 shows the neck injury risk and distribution as a function of EBS (Equivalent Barrier Speed, Mackay and Ashton, 1973). The subset is 1297 Volvo cars involved in rear end impacts.

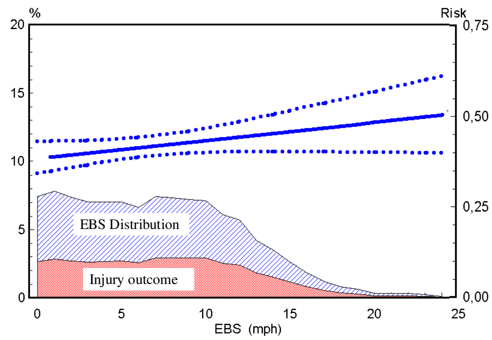

Figure 4a. Neck injury risk including 95% confidence interval as a function of Equivalent Barrier Speed (EBS). Distribution of EBS and injury outcome.

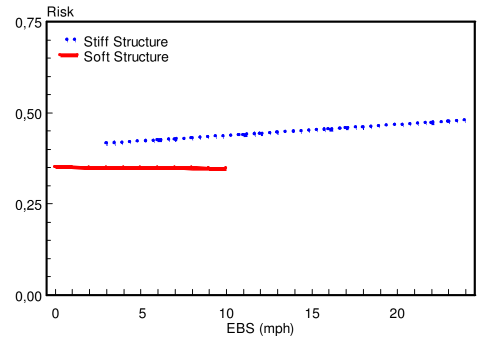

Figure 4b. Neck injury risk as a function of EBS with and without involvement of rear members.

In Figure 4a, the injury risk is shown to be almost constant irrespective of impact severity. EBS or impact speed, are probably not good predictors of neck injury risks. In some studies, however, car acceleration have shown to influence the risk of neck injuries (Olsson et al 1990, Krafft 1998). One indication of this can be seen in Figure 4b, where the injury risks differ for the same level of EBS depending on whether high pulse or low pulse is estimated. High pulse is defined as when the rear members have been involved during the impact. Engagement of stiff structure (high pulse) indicates a higher risk of neck injuries as compared to when the stiff structure has not been deformed (low pulse), but is however not statistically significant.

Figure 4a also shows the distribution of neck injuries as a function of EBS. Since the majority of all rear end impacts occur at low severity, the vast majority of the neck injuries are found in minor or moderate crashes.

This material indicates a tendency to a higher risk rate for front seat driver and passenger as compared to rear seat passengers, see Figure 5. There is a significantly higher risk of the driver sustaining a neck injury as compared to the passengers. There is also a noticeable difference between the front seat passenger and the rear seat passenger, which is, however, not significant. The data in Figures 5, and 7 is based on a subset of 2163 occupants (driver, front seat passenger and outboard rear seat passengers).

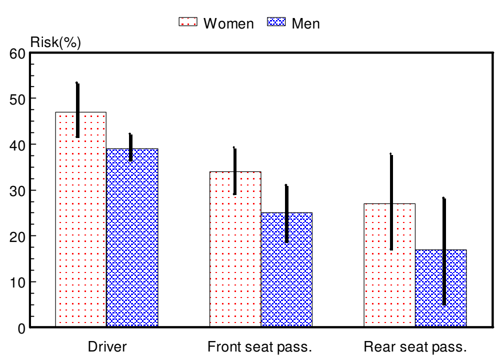

Figure 5. Neck injury frequency including 95% confidence intervals for men and women in

different seating positions.

Women are found to be more likely to sustain a neck injury in the event of a rear end impact as compared to men; see Figure 5.

Figure 6 shows that the risk increases in relation to the height of the occupant. This is more obvious when considering the occupants by gender, since the height distribution for men versus women differs and these two factors conflict. The material is also divided between drivers and passengers since the seating position effects the risk.

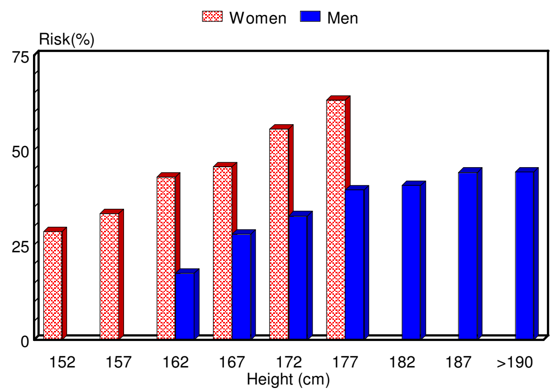

Figure 6a. Neck injury risk vs. gender and stature, drivers

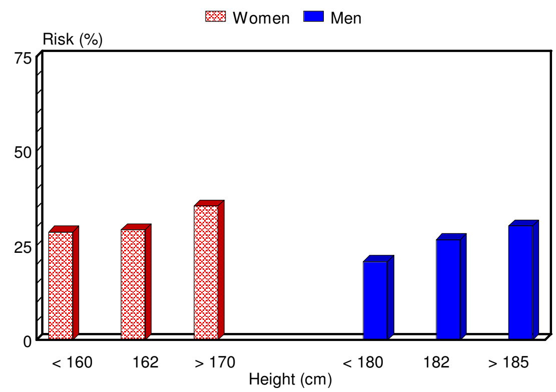

Figure 6b. Neck injury risk vs. gender and stature, front and outboard rear seat passengers

The data in Figure 6a is based on a subset of 1420 belted drivers, of Volvo cars, involved in a rear end impact. The data in Figure 6b is based on a subset of 610 front seat occupants and outboard rear seat passengers. Because of the limited number of occupants in this data only three height groups are used. For women these groups are; below 160 cm in height, between 160 and 170 cm in height and above 170 cm in height. For men the heights are selected in a corresponding way. By separating the occupants by gender as well as seating position (driver or passenger) an increase in injury risk can be clearly related to increase in occupant height.

In Figure 7 the neck injury risk is presented for different age groups. The highest risk is in age groups 20 to 30 and 30 to 40 years. The lowest risk is found in the youngest age group. In the age groups above 30 to 40, the risk decreases with increasing age. Women are generally at higher or equal risk as compared to men, throughout the age range.

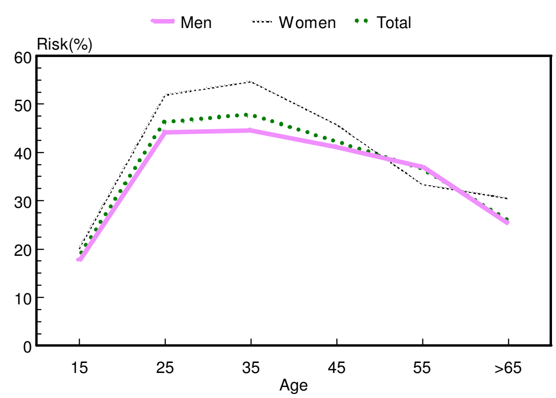

Figure 7. Driver neck injury risk as a function of age and gender

In-depth Accident Data Collection

In order to better understand the complex mechanisms behind whiplash injuries, in studying accident data, it is important to extend the statistical analysis with analysis of in-depth accident studies.

Volvo has presented two in-depth studies (Olsson et al 1990, Jakobsson et al 1994) with augmented accident data collection. The parameters most clearly related to risk of injury were included in those additionally collected; e. g. distance between the head and head restraint; whether the occupant was turning his/her head to the side at the time of the impact; and detailed information on deformation of the car. Conclusions were also drawn regarding characteristics of the head restraints.

Discussion of Accident Research Data

From accident investigations we have learned that there are many factors (design related as well as occupant related) that influence the risk of neck injury in a rear end impact. The combined effect of some of these factors is most probably also important.

Rear end impacts account for the highest neck injury risk; these are focused on as a first step. Neck injuries are by far the most common injury type in rear end impacts, found in this material as well as in others (Nygren 1984, and von Koch 1994). However, neck injuries occur in all types of accident, and the largest amount of neck injuries are found in frontal impacts. Morris et al (1996) and Temming and Zobel (1998) support these findings. In order to reduce the total number of neck injuries all types of crash configuration are important to consider, therefore.

Neck injuries are reported at all impact severities (Jakobsson 1997; Otte et al 1997; Lundell et al 1998a). It is obvious that in rear end impacts people frequently sustain neck injuries even in crashes with very low impact severity (Olsson et al 1990, Svensson 1993, Morris et al 1996, Siegmund et al 1997). This is also seen in Figure 4a. The acceleration rate (pulse shape), rather than impact speed or EBS, has been pointed out as having an influence on the risk of sustaining a neck injury (Olsson et al 1990, Krafft 1998). Figure 4b illustrates such findings by comparing neck injury outcome versus type of car body deformation. If stiff structure was involved, a higher neck injury risk was indicated. The conclusion can be drawn that it is important to focus on measures to reduce the acceleration of the car (including seats etc.), in order to reduce the acceleration of the occupants.

An increased distance between head and head restraint (and seat backrest), has shown a relationship to increased risk of neck injury. This has been shown in accident studies (Carlsson et al 1985, Olsson et al 1990, Jakobsson et al 1994) as well as in studies based on tests with volunteers (Deutscher 1996). This is probably also one explanation for the difference in injury risk for the driver as compared to the front seat occupant; because the driver can be assumed to move the head and upper body to a greater extent than the front seat occupant. Even though Minton et al (1997) report contradictory findings, closeness between the occupant and the seat back in the phase of load transmission is judged to be beneficial.

Injury to the thoracic and lumbar spine account for the second largest group of injuries in rear end impacts, see Figure 2. Minton et al (1997) found that lumbar spine and cervical spine injuries occur together. The exact relationship is not stated, but the finding stresses the importance of regarding the whiplash problem as an issue concerning the whole spine. It can not be denied that motions in the lower part of the spine certainly affect the motions in the upper part. Clinical experience has also found that treatment of lumbar spine injury will reduce cervical spine pain (Andersen 1995).

There is no doubt that the head restraint is an important factor in neck injury protection, but it is not the only factor that determines whether or not there will be an injury. The findings illustrated in

Figure 6a are interesting, since the medium height women are at the same level of risk as the tall men. This indicates that the height of the head restraint is not the only parameter related to the reduction of neck injuries. Although the head restraint is important, the presence of a head restraint is, however, not a guarantee that the occupant will not be injured. This is supported by the findings in the presented accident material as well as in volunteer tests (Brault et al 1998).

Several studies indicate that the front seat occupants are at a higher risk than rear seat occupants (States et al 1972, Carlsson et al 1985, Lövsund et al 1988). In Figure 5, the most obvious difference is between driver and passengers, disregarding out-board passenger seat occupancy in the vehicle. This difference could be explained by the assumption of different seating postures. However, to be certain it is necessary to collect additional information; seating postures, awareness of impeding accident and other statistics. The data presented in Figure 5 indicates a difference between front and rear seat passengers. Assuming them to have the same seating posture, etc. the difference could be related to the design of the seats; the rear seat offering more even support and less-elastic response.

There are some studies indicating that the seat belt system increases the risk of neck injury (Spitzer et al 1995, Morris et al 1996, Krafft et al 1996). This may be so, in some cases, but rather than discussing what to do about the seat belt system in a rear end impact, the goal should be to design a system that will reduce the occupant's rebound into the seat belt.

Women are at a higher risk of sustaining neck injury than men. The gender difference is clear, and independent of factors such as seating position, occupant height and age (Figures 5, 6 and 7). Several studies have also reported the same finding (Lövsund et al 1988, Spitzer et al 1995, Krafft et al 1996, Morris et al 1996, Minton et al 1997, Otte et al 1997, Temming and Zobel 1998). The reason for the gender difference is not evident. Anatomical and physiological differences may partly explain these differences.

The highest neck injury risk age interval is from 20 to 40 years. Temming and Zobel (1998) and Krafft (1998) have reported similar findings.

Findings in accident analysis form an important part in the Whiplash Protection Study (WHIPS). They have been interpreted to give guidelines and requirements to be used in developing protection systems.

BIOMECHANICS AND GUIDELINES

The exact injury mechanism has not yet been established. Several mechanisms have been suggested by different researchers. In order to be able to know what engineering efforts to make, the accident experience and the results of all realistic injury mechanism research need to be condensed. An effort to do this resulted in the following three guidelines. The guidelines summarize a holistic approach to the whiplash problem, aiming to address all existing theories and cover a variety of different scenarios.

The three guidelines are; a) reduce occupant acceleration; b) minimize relative movement between adjacent vertebrae and in the occipital joint; in other words, minimize changes in the curvature of the spine during a crash, and c) minimize the forward rebound into the seat belt.

The aim of reducing occupant acceleration is not related directly to any established neck injury mechanism, but is based on fundamental crash dynamics and the fact that no injury would result if zero acceleration were achieved. Tests using volunteers have also shown that the probability of occupants sustaining injury below certain acceleration rate is low, in the case of most healthy individuals.

Several researchers have suggested relative motion of the spine as a cause for whiplash injuries (Aldman 1986, Svensson et al. 1993, Jakobsson et al. 1994, Boström et al. 1996 and 1997, Ono et al. 1997a and b). Experience gained from space technology, and from the performance of rearward facing child seats in a frontal impact (Aldman 1964), confirms that the ultimate objective must be to support the spine as uniformly as possible. If the spine remains completely motionless, injury is unlikely to occur. Boström et al (1996) presented a Neck Injury Criterion (NIC) which detects the initial relative motions in the cervical spine.

The aim of the third guideline is to reduce occupant rebound in a rear end impact, in order to minimize the interaction with the seat belt - a factor which is alleged to cause injury (von Koch et al 1995). The exact mechanism which applies in this case is not known. However, this knowledge is not essential, given that the goal is to eliminate belt interaction in rear-end impacts.

It is believed that if these guidelines are adhered to the seat design, the risk of neck injury in rear-end impacts can be reduced. Since the guidelines are not conventional biomechanical criteria, which can be described in terms of biomechanical mechanisms, it is impossible to assign specific thresholds to them at this stage. However, the ultimate goal of their application would be to achieve zero loading, while every reduction may be regarded as a step in the right direction. Furthermore, since the guidelines are related, to different theories to some extent, all three must be addressed to ensure that any improvements achieved will also reduce the risk of injury.

REAR END IMPACT TEST DUMMIES

The BioRID - Biofidelic Rear Impact Dummy

Unfortunately, existing standard anthropomorphic test dummies (mainly Hybrid III) - which were designed primarily for high speed, frontal-impact testing - have not proved applicable to the study of humanlike spine movements in rear end impact testing (Scott et al. 1993, Szabo et al. 1994). The Hybrid III dummy family can, to some extent, be used for evaluating the response of the seat in a rear end impact, but needs to be complemented with other test methods in order to cover all the biomechanical guidelines.

A more biofidelic neck, the RID-neck, to be used with the Hybrid III dummy for low speed rear end impact testing, was developed by Svensson et al. (1992), but the performance of the neck is restricted by the rigid thoracic spine of the HIII dummy (Lövsund and Svensson 1996).

In volunteer testing, it has been found that an essential part of neck kinematics is due to the torso push-up motion exerting compression forces in the cervical spine, and the angling of the T1 and the lower cervical vertebrae (Mc Connell et al. 1993, Siegmund et al. 1997, Ono et al. 1997a, and 1997b). In a volunteer study using X-ray cineradiography it was concluded that the development of a proper dummy capable of simulating cervical vertebral motions is strongly desirable, as existing dummies are not useful for evaluating non-physiological motions of the cervical vertebrae (Ono et al 1998). In order to obtain correct responses, especially with regard to the neck behavior, a test dummy with an anthropomorphic spine, enabling study of the effect of torso push-up motion, is required (Lövsund and Svensson 1996). A dummy for this purpose, named BioRID, has recently been developed as a Swedish joint venture. A prototype version, BioRID I, was presented in the fall of 1998 (Davidsson et al. 1998b, Linder et al. 1998), see Figure 8.

The BioRID I (Biofidelic Rear Impact Dummy) comprises a new articulated spine, a torso of silicon rubber and a modified Hybrid III pelvis. Head, arms and legs are those of a Hybrid III fiftieth percentile dummy. The complete spine is made of 24 individual segments which are connected by hinge joints; see Figure 8. In the cervical spine, wires are added to give a more humanlike motion combined with the bumper elements between the segments. Linear torsion springs and polyurethane bumpers provide the resistance to flexion and extension in the thoracic and lumbar spine. The spine has kyfosis and lordosis which will allow for the torso-push up motion and the angling motion of the T1 vertebra. The torso is molded in a soft silicone rubber, with more humanlike shape and improved mass distribution as compared to existing dummies.

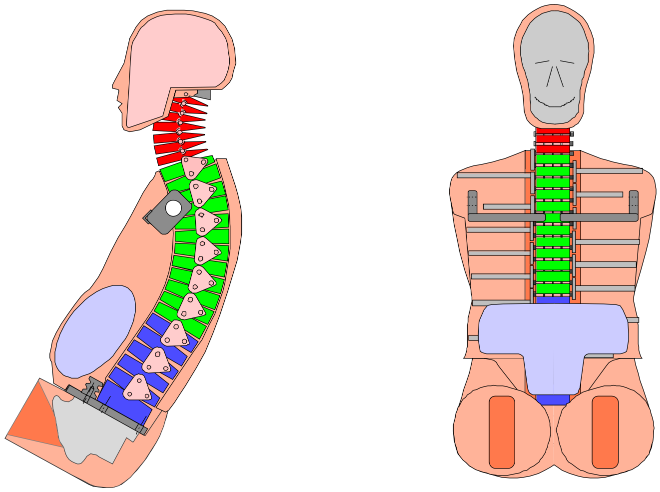

Figure 8. The BioRID prototype, BioRID I (ref Davidsson et al 1998b)

The BioRID I prototype was validated against volunteer tests (Davidsson et al 1998a). The kinematics of this dummy prototype show more human like kinematics in rear end impacts at ΔV=7 km/h as compared to the Hybrid III (Davidsson et al 1998b).

Madymo occupant model

A mathematical occupant model with a segmented spine simulating humanlike motion was developed at an early stage of the WHIPS study (Jernstöm et al. 1993 and Jakobsson et al. 1994), see Figure 9. The occupant model was developed to acquire an understanding of occupant kinematics in rear-end impacts. Also, as a valuable tool in the qualitative evaluation of different engineering concepts, this model was used to study the effects of various seat design parameters, as well as different crash pulses and the effect of different occupant sizes. In the development of BioRID, the model was used as a tool when determining the interior joint stiffness of the spine.

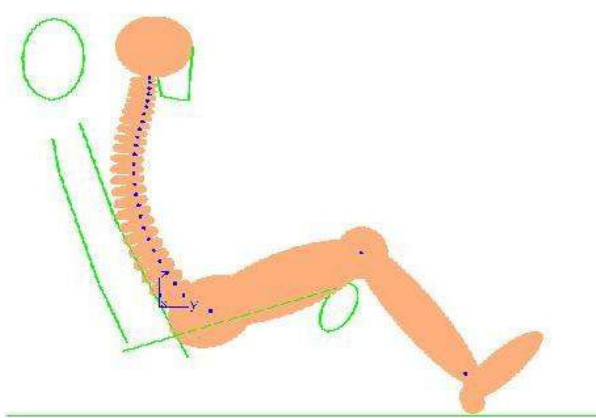

Figure 9. The Volvo mathematical occupant model (ref. Jakobsson et al 1994)

ENGINEERING REQUIREMENTS AND TEST METHODS

Having formulated the biomechanical guidelines described above, the next task in the study was to design a seat concept along these guidelines. However, to make them practically useful, the guidelines needed to be refined into system and component performance parameters, which could easily be verified by testing. Since the BioRID has only been available at a very late stage of the study, different approaches and new test methods had to be developed and used (Lundell et al 1998a). The guidelines were broken down into the following engineering requirements:

a) Reduce occupant acceleration; This guideline can be verified by measuring the dummy acceleration in sled tests. In a Hybrid III dummy, the positions most relevant to evaluate are in the thoracic and pelvic regions, since they are closest to the area of seat interaction and not greatly affected by the dummy design
b) Minimize relative movements between adjacent vertebrae; For this guideline, only BioRID would give an appropriate response in a crash test. Since the BioRID was not available during the development of the WHIPS seat, a combination of different methods was used. The methods included computer modeling using the Madymo occupant model with the segmented spine; dynamic sub-system tests; and geometry requirements combined with engineering judgment, in order to address different occupant sizes and postures (see further details in Lundell et al 1998a).
c) Minimize forward rebound into the seat belt; This guideline can be satisfied by ensuring high-energy absorption (i.e. high hysteresis) of the backrest during a crash. In other words, designing the seat for lower elastic energy build-up during impact can reduce forward rebound into the seat belt. A quasi-static sub-system test of the backrest was added during the initial engineering phase, while the rebound effect was also evaluated in subsequent sled tests, using Hybrid III adult dummies.

Apart from the main requirements described above, additional requirements were used to map the behavior of the seat and to evaluate human responses to rear-end impacts.

Since the engineering requirements are derived from guidelines describing a desired behavior, rather than from defined injury mechanisms, it is not possible to establish biomechanical thresholds for them. The goal is the largest possible reduction for all the requirements. A very important rule is never to increase any response related to the biomechanical guidelines, since it may then follow that reductions in the other responses will be countered and no real positive effect achieved.

The main focus of the study was to reduce the risk of neck injury in rear-end impacts of low to medium severity. These occur, typically, at speeds in the 10-20 mph range, well below those of existing regulatory rear-end impact testing.

NEW SEAT SYSTEM

In the Whiplash Protection Study, a new seat concept was developed based on the above requirements. The basis for the new design was a production Volvo seat. The WHIPS system in the seat consists of a new recliner, together with a modified backrest and head restraint.

The recliner is the part of a car seat used to attach the backrest to the seat base. Volvo seats are equipped with two recliners, one on each side. The basic function of the recliner is to facilitate adjustment of the reclining angle of the backrest. An impact-activated function was added to Volvo’s new WHIPS recliner. In a rear end impact, the recliner is designed to give a controlled rearward motion of the backrest relative to the seat cushion. For this purpose, the recliner has an additional mechanism, which controls the motion of the seat backrest in relation to the seat base. In a rear end impact of sufficient severity the WHIPS recliner is activated and then controls the motion of the backrest. This motion occurs in two phases, as shown in fig 10.

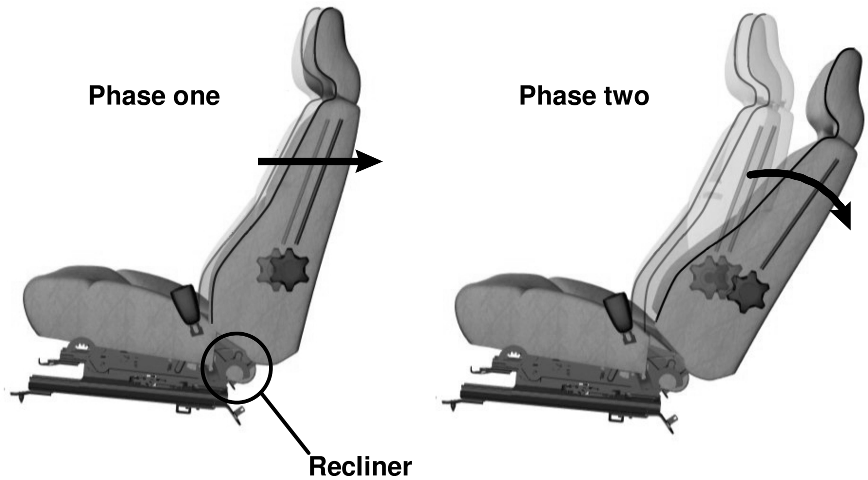

Figure 10. The WHIPS seat motion

The first phase is essentially a transitional rearward motion of the backrest. This phase has three purposes: firstly, to allow the occupant to sink into the seat, thereby reducing the distance between the head and the head restraint; secondly, to initiate a rearward motion of the backrest without moving the head restraint further away from the head and, thirdly, to limit the occupant acceleration level, by permitting the backrest to move rearwards in a controlled manner.

The second phase consists of a rearward reclining of the backrest. This motion has a center of rotation in the recliner area. The purpose of this phase is to continue the reduction in acceleration and to absorb the occupant's energy in a gentle, controlled manner so as to reduce his or her forward rebound after impact. Force reduction and energy absorption are achieved by plastic deformation of a metallic element in the recliner.

In most cases, the two phases actually overlap to some extent. The degree of overlap depends upon a number of crash parameters, including occupant weight and posture, as well as crash severity

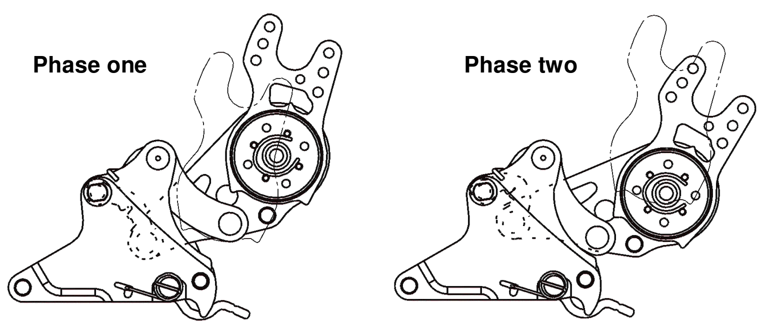

Figure 11. WHIPS recliner schematic motion

The motion of the WHIPS recliner is shown schematically in Figure 11. The WHIPS recliner unit consists of two main parts: the mechanisms for adjusting the static reclining angle, and the WHIPS system. These two parts are combined to form the complete WHIPS recliner unit. The recliner moves upwards and rearwards, but maintaining the same backrest angle, during the first phase of the WHIPS action (shown to the left in Fig 11). This movement is controlled by two links, which pivot around their two upper shafts. During the second phase of the WHIPS motion, the forward link is deformed, as shown to the right of Figure 11. Although this occurs typically when the recliner has completed the rearward movement of the first phase, it may also commence prior to this. The effect is to cause the recliner, and the backrest, to recline towards the rear. The plastic deformation characteristics of the forward link are progressive. The shape of the link affords two distinct force levels - an initial, lower level and a higher level towards the end of the deformation phase. The purpose of this is to accommodate a wide range of rear-end impacts energies.

The backrest was modified locally to provide more uniform force distribution along the occupant's spine.

Based on conventional Volvo head restraints, the new head restraint is of adequate height and fixed in position. Modification involved positioning the component slightly closer to the head and making it somewhat higher.

The seat is of the same rugged construction as Volvo production seats, which is several times stronger than required by current statutory provisions relating to rear impact backrest strength. This is achieved, for example, by providing recliners at each side of the seat. Since the strength of the new recliner matches that of the existing seat, the new design does not compromise the performance of the seat in high-speed collisions, ensuring that neither the front seat occupants nor the adult or child rear seat passengers are exposed to higher risk. This also applies to frontal impacts, in which a load may be imposed on the backrest from the rear, for example by luggage on the rear seat. The modified seat backrest is also equipped with the same side impact protection system (SIPS) as the present seat.

WHIPS is primarily designed to provide protection at low and moderate impact speeds, at which many whiplash injuries occur (i.e. at a car-to-car impact speed of 10 - 20 mph). The WHIPS seat is described in more detail in Lundell et al (1998b).

TESTING

Development testing

During the development of the WHIPS seat, both sub-system testing and sled testing was performed, using Hybrid III 5th, 50th and 95th percentile dummies. Mathematical simulation was also used as an important tool. Details can be found in Lundell et al (1998a).

One of the sub-system tests used was designed to develop uniform backrest characteristics by avoiding local hard or soft areas. The backrest was subjected to drop tests, by different impact forms simulating the torso and the head of the occupant. The impactor deceleration and displacement was recorded. Requirements for uniform deflection characteristics were established. Results show the measures taken to improve evenness in the backrest were successful

Another sub-system test was designed to measure the energy absorption of the backrest and WHIPS mechanism. The method used was to press a stiff dummy back form (ISO 6549) into the backrest by a hydraulic ram. Force-deflection was recorded during application of the force at different levels, and also during the release phase. This enabled the hysteresis and the resulting energy absorbing efficiency of the backrest, to be calculated for different load levels. Tests were performed on typical production seats as well as seats equipped with the WHIPS recliner. The results show the comparative better performance of the latter in terms of absorbed energy and also in the resulting lower post-impact rebound.

Test results using Hybrid III dummies are presented by Lundell et al (1998a and b). The results show that the acceleration peak value decreases by approximately 40% - 60% as compared to a typical production seat, under the same test conditions. The sled testing also confirmed that forward rebound towards the end of the impact is reduced.

Verification testing

In the verification sled tests, at the WHIPS seat final date, the BioRID I dummy was used.

A full-scale test was performed using a Volvo S80 car equipped with a WHIPS seat on the driver's side to verify the WHIPS function in a rear end impact. For reference, the front passenger seat was equipped with a Volvo S/V70 backrest i.e. without a WHIPS system. The WHIPS seat for the driver as well as the passenger reference seat was occupied by a belted BioRID I dummy. The car was impacted by a FMVSS 301 impact barrier (high, rigid barrier with a mass of 1820 kg) at an impact speed of 15 mph (24 km/h). The resulting ΔV of the S80 was 14 km/h, and peak acceleration 13g.

The acceleration measured at five locations throughout the spine and pelvis was lower for the driver in the WHIPS seat as compared to the passenger in the reference seat. In Figure 12, the acceleration of the T1 vertebra are displayed.

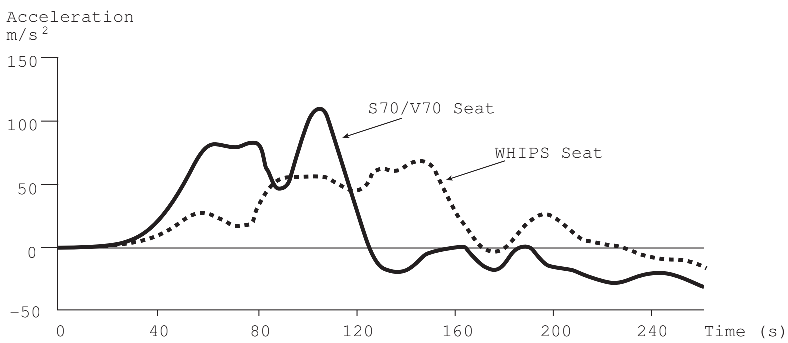

Figure 12. Horizontal occupant acceleration of T1 vertebra, BioRID I

Measurements for quantitatively calculating interior relative movements throughout the whole spine were not included in the test. However, the whole body motion could be studied, visualizing a more balanced support of the driver in the WHIPS seat as compared to the passenger in the reference seat.

The Neck Injury Criterion (NIC, Boström et al 1996) is a proposed criterion which detects the relative motions in the cervical part of the spine. In this specific test, NIC of the passenger in the reference seat (Volvo S/V70 seat) was calculated at 22 m^2/s^2, whilst that of the driver in the WHIPS seat measured 11 m^2/s^2. Although not fully validated, a NIC below 15 m^2/s^2 is suggested to reflect no risk for long-term impairment (Boström et al 1996, Eichberger et al 1998). The test results indicate that the S/V70 seat offers reasonably good protection, but with the WHIPS seat the lower limit for long-term neck injuries is not exceeded.

Evaluation of the differences in rebound of the two seats, confirms the development testing results. The BioRID I needs further validation and refinement before performing a quantitatively comparison of the rebound phase. However, the WHIPS seat offers a visually less aggressive interaction with the seat belt.

DISCUSSION

The procedure for the Whiplash Protection Study 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. We consider that this method represents a unique and holistic approach, which gives the study considerable weight. This study was initially presented during 1998 (Lundell et al 1998a), and has now been complemented with the development of a rear end impact dummy for improved quality in result and efficiency in testing. The development of a dummy capable of simulating cervical vertebra motions was necessary in order to simplify the evaluation of seat concepts with regard to rear end impacts. The use of BioRID I reduces the number of test methods for evaluation of the defined guidelines, and offers a more straightforward way of addressing WAD.

The study is based on experience from accident research. More than ten years of concentrated effort, in the study of whiplash by Volvo, has shown that it is important to consider the whole spine of the occupant and, accordingly, the whole seat, when addressing whiplash injury resulting from rear end impact. Further, in order to achieve a true injury reduction in real world accidents, minor and moderate crashes should be focused. The individual differences between occupants (gender, height and other), the seating position and the variety of seating postures must also be considered in order to get a true injury reduction in real world accidents. All these areas were considered in the Whiplash Protection Study (WHIPS).

The discussions on accident research, prior in this article, are a basis for the biomechanical guidelines. This study offers a deeper analysis than the first presentation of WHIPS; in Lundell et al 1998a. The findings confirm previously presented data and refined conclusions are also drawn regarding occupant height, age and seating positions.

The test results presented should be regarded as an indication of how great a reduction in WAD may be achieved. Thresholds can not be determined due to the nature of the requirements and the level of knowledge regarding injury mechanisms. Even though the Neck Injury Criterion (NIC) has to some extent been correlated to long-term consequences (Boström et al 1997, Eichberger et al 1998), it is most probable that several other criteria should also be regarded in order to cover the whole WAD-problem. Hence, when developing the WHIPS seat, a very important rule has been to address all aspects of the biomechanical guidelines. Increased response of any kind should be avoided, since reductions in other responses may be countered and no real positive effect achieved.

CONCLUSIONS

Volvo’s Whiplash Protection Study (WHIPS) presents a holistic method for dealing with the whiplash problem; combining accident experience with known biomechanical research and development of engineering tools. This is the only safe way when the injury mechanisms are not fully clarified. Three guidelines are identified; a) reduce occupant acceleration; b) minimize relative movement between adjacent vertebrae and in the occipital joint and c) minimize the forward rebound into the seat belt. It is suggested that if these guidelines are adhered to the seat design, the risk of neck injury in rear-end impacts can be reduced.

Fresh results from accident analyses show that drivers have a statistically significant higher neck injury risk as compared to all other out-board seat passengers. Occupants between 20 and 40 years of age are subjected to the highest risk of neck injury. Women also run a higher risk, irrespective of age and seating position.

The WHIPS study include development of a new seat, which has shown to have considerable potential in offering increased protection against neck injuries in rear end impacts.

The development of BioRID offers the Whiplash protection study an excellent tool for better evaluation of new systems for improved neck injury protection in rear end impacts.

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REFERENCES

AAAM (Association for the Advancement of Automotive Medicine); The Abbreviated Injury Scale, 1990 Revision; AAAM, Des Plaines, IL, USA; 1990.

Aldman, B. A Protective Seat for Children - Experiments with a Safety Seat for Children between One and Six.. Proc. of 8th Stapp Car Crash Conference, Detroit, 1964, pp 320-328.

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.

Andersen, J. Physiotherapist, Odder, Denmark; Personal communication, 1995.

Boström, O., Svensson, M. Y., Aldman, B., Hansson, H. A., Håland, Y., Lövsund, P., Seeman, T., Suneson, A., Säljö, A., Örtengren, T. A New Neck Injury Criterion Candidate - Based on Injury Findings in the Cervical Ganglia after Experimental Neck Extension Trauma. Proc. of IRCOBI Conference on Biomechanics of Impacts, Dublin, Ireland, 1996: pp 123-136.

Boström, O., Krafft, M., Aldman, B., Eichberger, A., Fredriksson, R., Håland, Y., Lövsund, P., Steffan, H., Svensson, M., Tingvall, C. Prediction of Neck Injuries in Rear Impacts Based on Accident Data and Simulations. Proc. of IRCOBI Conference on Biomechanics of Impacts, Hannover, Germany, 1997: pp 251-264.

Brault, J.R., Wheeler, J.B., Siegmund, G.P., Brault, E.J. Clinical Response of Human Subjects to Rear-End Automobile Collisions. Archives of Physical Medicine and Rehabilitation, Vol 79, January 1998.

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.

Davidsson, J., Deutscher, C., Hell, W., Linder, A., Lövsund, P., Svensson, M.Y. Human Volunteer Kinematics in Rear-End Sled Collisions. Proc. of IRCOBI Conference on Biomehanics of Impacts, Göteborg, Sweden, 1998a: pp. 289-301

Davidsson, J., Linder, A., Svensson, M.Y., Flogård, A., Håland, Y., Jakobsson, L., Lövsund, P., Wiklund, K. BioRID - A New Biofidelic Rear Impact Dummy. Proc. Of IRCOBI Conference on Biomehanics of Impacts, Göteborg, Sweden, 1998b: pp. 377-390

Deutscher, C. Movement of Car Occupants in Rear-End Accidents, Paper No. 96A5016, Int. Conf. ”Active and Passive Automobile Safety”, Capri, Italy, Oct. 1996: pp 147-154.

Eichberger, A., Steffan, H., Geigl, B., Svensson, M., Boström, O., Leinzinger, P.E., Darok, M. Evaluation of the Applicability of the Neck Injury Criterion (NIC) in Rear End Impacts on the Basis of Human Subject Tests. Proc. of IRCOBI Conference on Biomehanics of Impacts, Göteborg, Sweden, 1998: pp. 321-333.

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, USA, ISBN 0-397-51856-0, 1997: pp. 299-306.

Jernström, C., Nilson, G., Svensson, M.Y. A First Approach to an Implementation of a Human body Model for rear-Impact Modelling. Proc of 4th International MADYMO Users' Meeting, Eindhoven, Netherlands, September 6 and 7, 1993.

van Kampen, L.T.B. 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., Thomas, A., Nygren, Å., Lie, A., Tingvall, C. Whiplash Associated Disorder - Factors Influencing the Incidence in Rear-End Collisions. Paper No. 96-S9-O-09; Proc. of 15th ESV Conference, Melbourne, Australia; May 1996: pp 1426-1432.

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.

Linder, A., Svensson, M.Y., Davidsson, J., Flogård, A., Håland, Y., Jakobsson, L., Lövsund, P., Wiklund, K. The New Neck Design for the Rear-End Impact Dummy, BioRID I. Proc of 42nd Annual AAAM Conference, USA, 1998.

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 1998a

Lundell, B., Jakobsson, L., Alfredsson, B., Lindström, M., Simonsson, L. The WHIPS Seat - A Car Seat for Improved Protection Against Neck Injuries in Rear End Impacts. Paper no. 98-S7-O-08. Proc. of 16th ESV Conference, Windsor, Canada; June 1998b

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.

Lövsund, P., Svensson, M.Y. Suitability of the Available Mechanical Neck Models in Low Velocity Rear End Impacts. Paper No.96A5018; Int. Conf. "Active and Passive Automobile Safety", Capri, Italy, Oct. 1996; pp. 155-162.

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.

Minton, R., Murray, P., Pitcher, M., Galasko, C.S.B. Causative Factors in Whiplash Injury: Implications for Current Seat and Head Restraint Design. Proc. of IRCOBI Conference on Biomechanics of Impacts, Hannover, Germany, 1997: pp207-222.

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.

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., 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. and Kaneoka, K. Motion Analysis of Human Cervical Vertebrae during Low Speed Rear Impacts by the Simulated Sled. Proc. of IRCOBI Conference on Biomechanics of Impacts, Hannover, Germany, 1997a: pp 223-237.

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, 1997b: pp 339-356.

Ono, K., Kaneoka, K., Inami, S. Influence of Seat Properties on Human Cervical Vertebral Motion and Head/Neck/Torso Kinematics During Rear-End Impacts. Proc. of IRCOBI Conference on Biomehanics of Impacts, Göteborg, Sweden, 1998: pp. 303-318.

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.

Scott, M.W., McConnell, W.E., Guzman, H.M., Howard, R.P., Bomar, J.B., Smith, H., Benedict, J.V., Raddin, J.H. and Hatsell, C.P. Comparison of Human and ATD Head Kinematics During Low-speed Rearend Impacts. In: Human Surrogates: Design Development & Side Impact Protection (SP-945), SAE Paper No. 930094, SAE International Congress and Exposition, Detroit, March 1993.

Siegmund, G.P., King, D.J., Lawrence, J.M., Wheeler, J.B., Brault, J.R., Smith, T.A. Head/Neck Kinematic Response of Human Subjects in Low-Speed Rear-End Collisions. Proc. of 41st STAPP Car Crash Conference, SAE P-315, Paper no 973341, Lake Buena Vista , Florida, Nov 13-14, 1997: pp 357-385.

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.

States, J.D., Balcerak, J.C. Williams, J.S., Morris, A.T., Babock, W., Polvino, R., Riger, P., Dawley, R.E. Injury Frequency and Head Restraint Effectiveness in Rear End Impact Accidents. Proc. of 16th Stapp Car Crash Conference; LC 67-22372; Detroit, MI, 1972: pp.228-245.

Svensson, M. Y., Lövsund, P. A Dummy for Rear-End Collisions - Development and Validation of a New Dummy-Neck. Proc. of IRCOBI Conference on the Biomechanics of Impact, IRCOBI Verona, Italy, 1992: pp 299-310.

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.

Szabo, T.J., Welcher, J.B., Anderson, R.D., Rice, M.M., Ward, J.A., Paulo, L.R. and Carpenter, N.J. Human Occupant Kinematics Response to Low Speed Rear End Impacts. In: Occupant Containment and Methods of Assessing Occupant Protection in the Crash Environment, (SP 1045), SAE Technical Paper Series 940532, SAE International Congress and Exposition, Detroit, USA, 1994: pp. 23-35.

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