THE WHIPS SEAT - A CAR SEAT FOR IMPROVED PROTECTION AGAINST NECK INJURIES IN REAR END IMPACTS

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ABSTRACT

Neck injuries resulting from rear end car impacts have attracted increasing attention in recent years. Although usually not life-threatening these injuries can have long-term consequences. The exact mechanism of injury has not yet been established. Several probable mechanisms occurring at different phases during the crash sequence have been suggested by researchers.

Biomechanical guidelines and test methods are presented, being part of the results of Volvo's Whiplash Protection Study (WHIPS). The biomechanical guidelines are based on an extensive review of accident experience and biomechanical research aimed at reducing the risk of neck injuries in rear end impacts.

A new seat concept, the WHIPS seat, developed using these guidelines and requirements, is explained in detail. The WHIPS seat comprises new recliners as well as a modified backrest and head restraint. The WHIPS recliner is designed to give a controlled rearward motion of the backrest in a rear end impact; thereby improving the closeness to the occupant's head and back, absorbing energy and reducing the occupant's forward rebound.

Test results are summarized, and, seen in relation to the suggested engineering guidelines, show a considerable potential for improved neck injury protection in rear end impacts.

INTRODUCTION

Neck injuries, often called 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 have reported an increase in the occurrence of neck injuries during the last decades. (Ono et al. 1993, van Kampen 1993, von Koch et al. 1994 and Morris et al. 1996). Due to their long term consequences, these injuries are very costly for society (v Koch et al. 1994). Consequently, there is much to gain in terms of avoidance of human suffering and costs for society by reducing the occurrence of AIS 1 neck injuries.

At Volvo, a study has been performed, with the aim of reducing the risk of neck injuries in rear end impacts. The working name for the study was Whiplash Protection Study, with the acronym WHIPS.

WHIPS combines experiences from accident research and computer modeling with existing biomechanical knowledge, summarized into three biomechanical guidelines, see Figure 1. In order to be able to evaluate design concepts, the biomechanical guidelines are broken down into engineering requirements and test methods.

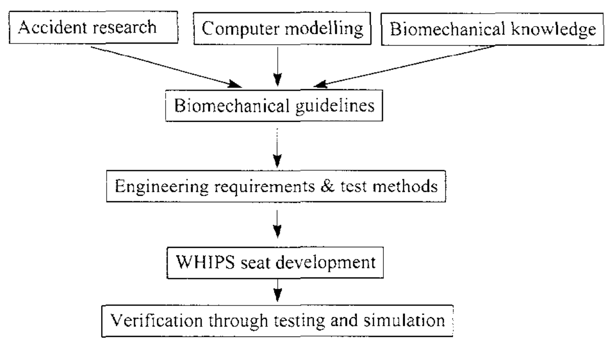

Figure 1. Volvo's Whiplash Protection Study (WHIPS)

The Volvo Whiplash Protection Study has previously been described in detail by Lundell et al. (1998).

This paper focuses on the seat design and test performances of the WHIPS seat. As an introduction, the background for the requirements is briefly described, comprising mainly accident research and the biomechanical guidelines.

The WHIPS seat will come into production in the new S80 Volvo model which is introduced in 1998.

ACCIDENT RESEARCH

AIS 1 neck injuries (also called whiplash injuries) are reported in all crash configurations (Morris et al. 1996 and Jakobsson, 1997). However, the risk of sustaining a neck injury is higher in rear end impacts as compared to other crash types (Morris et al. 1996). Volvo accident data indicates a neck injury risk for rear end impacts which is approximately double the rate for frontal or side impacts (Lundell et al. 1998).

The frequency of different bodily injuries in rear end impacts is shown in Figure 2. The graph is based on a subset of 605 belted drivers, in Volvo 700 and 900 models between 1985 and 1995 (Volvo Accident Data Base, ref. Lundell et al. 1998).

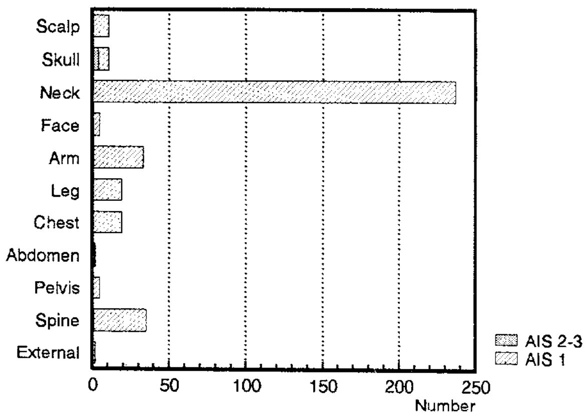

Figure 2. Injury distribution for rear end impacts.

As can be seen in Figure 2, AIS 1 neck injuries are by far the most common injury type in rear end impacts. Nygren (1984) has reported similar findings.

Neck injuries are reported at all impact speeds (Jakobsson 1997 and Otte et al. 1997). From accident research as well as tests with volunteers, it is shown that people sustain neck injuries frequently even in impacts with very low severity (Olsson et al. 1990, Morris et al. 1996, Siegmund et al. 1997). An example of this was presented in Lundell et al. (1998), as shown in Figure 3. The graph is based on a subset of 1467 belted drivers in Volvo cars involved in a rear end impact.

In Figure 3, the injury risk is shown to be almost constant irrespective of the degree of vehicle deformation. Severity measures based on deformation depth are obviously not good predictors of neck injury risks. Other factors, such as whether stiff vehicle structures have been involved or not, have shown to be more related to neck injuries in some studies (Olsson et al. 1990). Figure 3 also tells that in order to significantly help reduce the number of AIS 1 neck injuries in rear end impacts, minor and moderate crash severity must be the main focus since they account for the majority of the incidences.

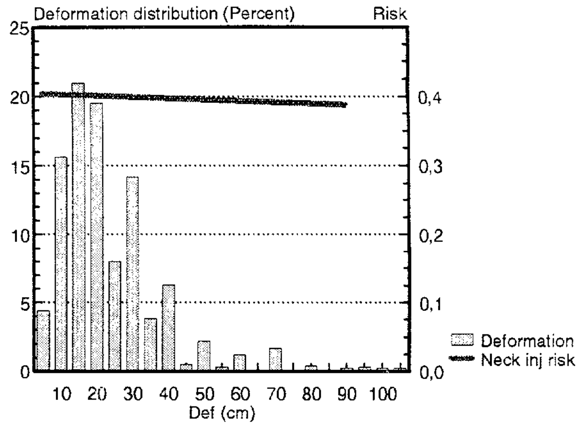

Figure 3. Vehicle Deformation Distribution and Neck Injury Risk vs. Vehicle Deformation.

Knowledge of the individual differences are important when analysing accident data as well as designing protection systems. Women are more likely to sustain a neck injury in the event of a rear end impact (Lövsund et al. 1988, Spitzer et al. 1995, Krafft et al. 1996, Morris et al. 1996, Minton et al. 1997, Otte et al. 1997, Lundell et al. 1998). There is also an increase of neck injury risk for taller occupants (Lundell et al. 1998). However, this becomes only clear when considering the occupants by gender, since the height distribution for men versus women differs and these two factors interfere.

Volvo accident data shows that medium height women are at the same level of risk as tall men (Lundell et al. 1998). This indicates that the height of the head restraint is not the only issue related to the reduction of neck injuries. Although head restraints are important, the height of the head restraint is, however, not a guarantee that the occupant will not be injured. This is also supported by volunteer tests (Brault et al. 1998).

Another factor influencing the risk of neck injury in rear end impacts is seating position in the car. Volvo accident statistics report a significantly higher risk of the driver sustaining a neck injury than the passengers (Lundell et al. 1998). Lundell et al. hypothesized that the differences between the driver and front seat passenger could be mainly due to different seating postures. Drivers are probably more prone to bend forward and away from the seat backrest and head restraint than passengers, who are more relaxed and probably more likely to rest their head against the head restraint. The relationship between increased distance to the head restraint and risk of neck injury has been shown, both in accident studies (Olsson et al. 1990, Jakobsson et al. 1994) as well as in studies based on tests with volunteers (Deutscher 1996). Also, 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). One reason for this could be a more rigid, uniform and less elastic design of the rear seats than the front seats.

Accident studies have found that lumbar spine injuries occur together with cervical spine injuries (Minton et al. 1997). The exact relationship is not stated, but it stresses the importance of regarding the whiplash problem as an issue concerning the whole spine, and thus neck injury protection systems must include the support of the whole spine.

There are some studies indicating that the seat belt system increases the risk of neck injury (Spitzer et al. 1995, Morris et al. 1996, v. Koch et al. 1995, 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 objective should be to design a system that will help reduce the occupant's rebound into the seat belt.

The WHIPS study is based mainly on experience from accident research. More than ten years of concentrated effort by Volvo, on the study of whiplash, 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. Minor and moderate severity crashes should also be focused on in order to achieve a true injury reduction in real world accidents.

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 when defining the design guidelines, as presented below, and when the guidelines were broken down into requirements.

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 all possible situations.

The three guidelines are:

- <u>reduce occupant acceleration</u>
- <u>minimize relative movements between adjacent vertebrae and in the occipital joint, i.e. the curvature of the spine shall change as little as possible during the impact</u>
- <u>minimize the forward rebound into the seat belt</u>

The first guideline, aiming to reduce occupant acceleration, does not have a direct connection to experiences from accident data, nor any traditional injury mechanism for neck injuries. The rationale for this guideline is basic crash dynamic knowledge, and the fact that if zero acceleration is reached no injury would be suffered. Volunteer tests have also shown that below certain occupant accelerations the likelihood of sustaining an injury is expected to be minor for most healthy persons. The fact that the proposed Neck Injury Criterion (NIC), is based on acceleration, supports the importance of monitoring occupant acceleration (Boström et al. 1996 and 1997).

Relative motion of the spine as a cause for whiplash injuries has been suggested by several researchers (Aldman 1986, Svensson et al. 1993b, Jakobsson et al. 1994, Boström et al. 1996, 1997, Ono et al. 1997a, 1997b). The knowledge gained from space technology, and also from the performance of rearward facing child seats in a frontal impact (Aldman 1964), tells us that the ultimate aim is to keep the spine as evenly supported as possible. If the spine is completely intact, no injuries are likely to occur.

The third guideline aims at reducing the rebound after rear end impact, in order to minimize the interaction with the seat belt. Seat belt interaction has been suggested as injury-producing, as already mentioned. The exact mechanism of these findings is not known. That discussion, however, is not necessary for rear end impact cases if the goal is to eliminate seat belt interaction in rear end impact.

We believe that if these guidelines are followed, the seat design will reduce the risk of neck injuries in rear end impacts. Since they are not conventional biomechanical criteria, described by biomechanical mechanisms, it is impossible, at this stage, to determine certain thresholds. The ultimate goal would be to reach zero loading as the output of the guidelines. And every reduction can be regarded as a step in the right direction. In order to be sure that improvements will also reduce the injury risk, all three guidelines should be addressed, since they are related, to some extent, to different theories.

ENGINEERING REQUIREMENTS

Having formulated the guidelines described above, the next task was to design a seat concept along these guidelines. In order to be useful in practice, the guidelines had to be further refined to a level which could easily be verified in testing.

Unfortunately, existing standard anthropomorphic test dummies have not proved to be applicable for studying human like spine movements in rear end impact testing (Scott et al. 1993, Szabo et al. 1994). The Hybrid III dummy family can, however, be used for evaluating the response of the seat in a rear end impact, but need 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, 1997b). Therefore, 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, with a segmented spine with humanlike curvature, is currently being developed as a Swedish joint venture and will be presented in the near future (Davidsson et al. 1998, Linder et al. 1998).

A mathematical occupant model with a segmented spine simulating human-like motion was developed (Jernstöm et al. 1993 and Jakobsson et al. 1994) and used as a tool for evaluating the effect of seat design (Lundell et al. 1998).

The guidelines were broken down into the following engineering requirements:

- Reduce occupant acceleration
  - ◊ The guideline can be verified by measuring the dummy acceleration in sled tests. The positions in the dummy most relevant to evaluate are in the thoracic and pelvic regions, since they are closest to the area of seat interaction and not affected much by the dummy design (e.g. standard chest or pelvis accelerometer or accelerometer at the lower neck).
- Minimize relative movements between adjacent vertebrae. For this guideline, there are no dummies existing today that would give an appropriate response in a crash test. Therefore, the WHIPS seat was developed mainly by using a mathematical model with the segmented spine together with sub-system tests, as well as geometry requirements combined with engineering judgement in order to address different occupant sizes and postures.
  - ◊ The seat backrest and head restraint should geometrically support the curvature of the back and neck as precisely as possible, i.e. by positioning them as close as possible to the occupant. This applies in particular to the head restraint. Thus a requirement for closeness was included, together with a requirement for the height of the head restraint.
  - ◊ No local hard or soft structure in the seat backrest should force the spine into localized bending. An impactor subsystem test, to determine the local distribution of force-deflection characteristics throughout the seat backrest as well as the head restraint, was used to simulate a human spine's interaction with the seat. At this stage, the goal was to make the force vs. deflection characteristics of the seat backrest and head restraint as uniform as possible throughout their combined height. If the seat follows the shape of the occupant well (in accordance with the above requirement), uniform characteristics will tend to restrain the body evenly and thus exert minimal relative movements to the head and spine.
- Minimize the forward rebound into the seat belt.
  - ◊ This guideline can be satisfied by having good energy absorption of the seat backrest during an impact, i.e. a high hysteresis. In other words, designing the seat towards lower elastic energy build-up during impact will reduce the forward rebound into the belt. A quasi-static sub-system test of the backrest was added during the initial engineering phase. In a later stage, the effect of the rebound was also evaluated in sled tests, using Hybrid III adult dummies.

The above are the main requirements. Additional requirements were also used in order to map the behaviour of the seat and to estimate the performance of a human in the event of rear end impact.

Since the engineering requirements are broken down from guidelines describing a requested behaviour, rather than defined injury mechanisms, it is not possible to establish biomechanical thresholds for the different requirements. 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 focus has been to reduce the risk of neck injuries in low to medium severity rear end impacts. These impacts are at speeds well below those of existing regulatory rear end impact testing. This means typically in the interval of 15 - 30 km/h (approx. 10 - 20 mph), car to car, impact speed.

THE WHIPS SEAT SYSTEM

In the Whiplash Protection Study, the above requirements were used to develop a new seat concept. The new concept is based on a production Volvo seat. The WHIPS system in the seat consists of two new recliners, together with a modified backrest and head restraint. These are further described below.

The WHIPS recliner is designed to give a controlled rearward motion of the backrest in a rear end impact. For this purpose, the production recliner was modified by adding the WHIPS mechanism. In a rear end impact of sufficient severity the WHIPS mechanism is activated and then controls the motion of the backrest in relation to the seat base. This motion may be divided in two phases, as shown schematically in Figure 4.

The two phases are actually, in most cases, overlapping to some extent. The degree of overlap depends upon several parameters such as occupant weight and posture, and also impact severity.

A more detailed description of the two phases follows below.

In a rear end impact, the seat is accelerated forward with the car. Due to the inertia of the occupant, the back of the occupant is then pressed into the seat. When the forces from the occupant acting upon the seat backrest exceed a certain level, the WHIPS system will be activated. Hence no external sensor system is needed to activate the WHIPS system.

The purpose of the first phase is: 1) to let the occupant sink into the seat, thereby reducing the distance between the head and the head restraint, 2) to create an initial rearward motion of the backrest which does not move the head restraint away from the head, and 3) to keep occupant acceleration levels low, by letting the backrest move rearwards in a controlled way.

This is accomplished by the first phase being a rearward motion of the seat backrest, the nature of this motion being essentially translational, i.e. without rotation. However, depending upon the pre-impact posture of the occupant, the motion characteristics of the backrest are to some extent adaptable and adjust to the occupant's position relative to the backrest. For example, if the occupant is leaning forward before impact, this may give an initial tilt-forward motion of the backrest.

The purpose of the second phase is to limit occupant acceleration to a low level. This is accomplished by a rearward reclining of the backrest, while absorbing energy in a controlled and gentle way.

When the backrest has has absorbed the occupant's energy, and thus reclined to its rearmost position, a rebound takes place. The rebound is, however, significantly reduced, compared to a conventional seat, because of the plastic energy absorption in the WHIPS recliner.

The reclining angle of the second phase is limited to approximately 15 degrees. When the maximum angle has been reached, the recliner assumes the stiffness characteristics of the existing production recliner, and the seat will perform as a seat without a WHIPS system.

The WHIPS recliner is designed to be activated, and thus give protection, at low and moderate impact speeds primarily, which is when many whiplash injuries occur. The lower activation threshold depends on several parameters. The recliner is designed to operate primarily in the range of velocity change of approximately 10 - 20

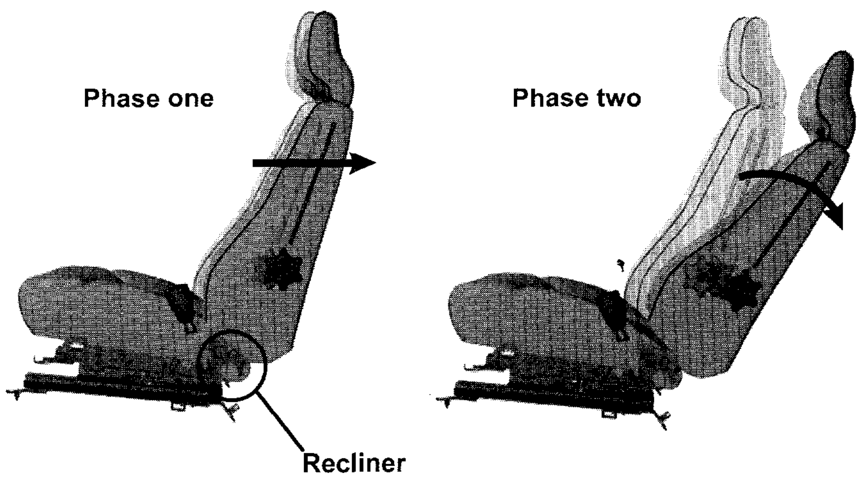

Figure 4. The WHIPS seat motion.

km/h. It will, however, give protection at higher velocities also.

Recliner Design - The WHIPS Function

The recliner is the part of the seat by which the backrest (squab) is attached to the seat base. The basic function of a recliner is to facilitate adjusting the reclining angle of the backrest. In Volvo seats, there are two recliners to each seat, one on each side. In the WHIPS recliner, an impact activated function is added.

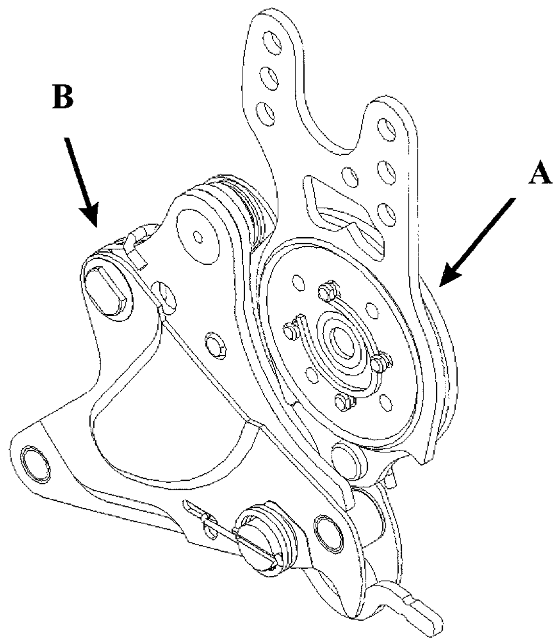

Figure 5. The WHIPS recliner.

The WHIPS recliner unit consists of two main parts (Figure 5): the mechanism for adjusting the static reclining angle (A) and the WHIPS system (B). These two parts are combined to form the complete WHIPS recliner unit.

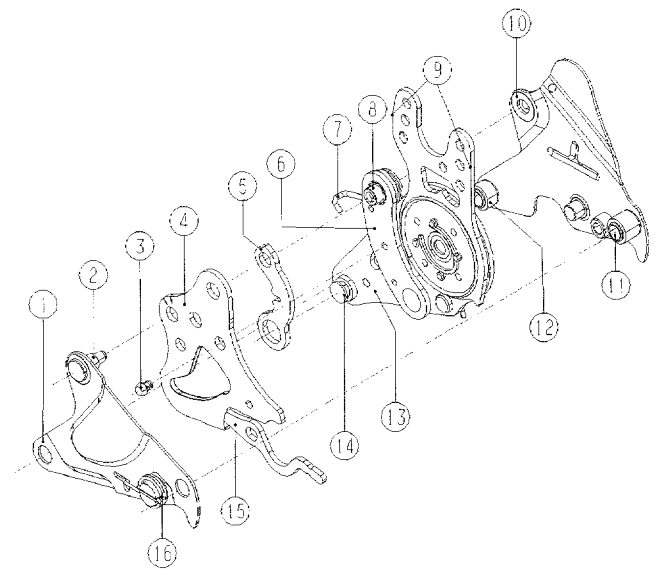

Figure 6. The WHIPS recliner, exploded view.

The details of the recliner are shown in Figure 6. The following elements are shown:

- Forward link arm; deformation element for energy absorption (5)
- Rear link arm (6)
- Return spring (7)
- Indicator (3)
- Pivot shafts for WHIPS motion (2), (8)
- Guide pin for WHIPS motion (14)
- Folding bracket (4), with WHIPS motion control window
- Side plates, outer (1) and inner (10), with attachment points to seat base (11) and (12)
- Conventional recliner mechanism (9) and bracket (13); the backrest frame is attached at (9)
- Latch (15) and spring (16) for quick folding of backrest

The complete recliner assembly is attached to the seat base by the side plates (1) and (10), at points (11) and (12). The folding bracket (4) is fixed to the side plates by the pivot point (2) and by the latch (15). The recliner mechanism (9) and bracket (13) are connected to the recliner base by the two links (5) and (6). The backrest is welded to the recliner at the upper attachment points (9).

The WHIPS recliner is secured against activation during normal use by the spring (7), by the plastic indicator (3), by a carefully chosen angle between the two links(5) and (6), and the shape of the window for the guide pin (14). When the forces from the occupant, acting upon the seat backrest in a rear end impact, exceed a certain level determined by the above design

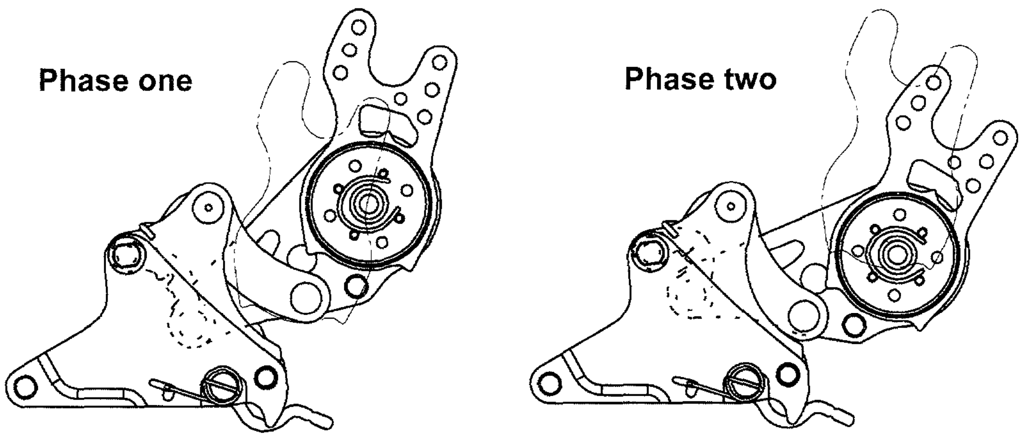

Figure 7. WHIPS recliner schematic motion.

elements, the WHIPS system is activated.

The WHIPS motion of the recliner is shown schematically in Figure 7.

During the first phase of the WHIPS motion, shown to the left in Figure 7, the upper part of the recliner moves rearwards. The motion is controlled by the two links (5) and (6), which rotate around the two pivots (2) and (8). The rear link is slightly longer than the forward link. This has the effect that the recliner, at the same time as it translates rearwards, also rotates upwards. As the backrest is attached to the recliner, this motion is also transferred to the backrest. However, because of elasticity, this rotational movement of the backrest is reduced and the resulting motion is essentially a translational rearwards motion. The exact motion depends upon several factors such as crash severity, occupant weight and occupant posture at impact.

During the second phase of the WHIPS motion, the forward WHIPS arm (5) is deformed, as shown to the right in Figure 7. The effect is that the recliner, and thus the backrest, reclines rearwards. This occurs typically when the recliner has completed the whole rearward motion of the first phase, but may also start before, so that the two phases overlap.

The force - deformation characteristics of the forward link are progressive. The shape of the link gives two distinct force levels; initially lower, higher towards the end of the deformation. The purpose to this is to accommodate the wide energy span of rear end impacts for which the recliner is designed to operate, considering both the variation in velocity change and in occupant size and weight.

As already mentioned, the two phases are actually, in most cases, overlapping to some extent. In order to control the mix of the two phases a guide pin (14) on the moving recliner bracket (9) moves in a window on the bracket (4). The window may be seen in Figure 6.

Indication and Service

When the recliner is activated in an impact, the indicator (3) is sheared and comes loose, giving a visual indication that the WHIPS system has been activated and needs service. Inspection of the indicator will be a normal service routine. Inspection will also take place when the vehicle goes to a workshop after a rear end impact. By folding the backrest forwards, as further explained below, the recliner may easily be inspected.

If the recliner has been activated in an accident, different service routines will be applied, depending upon the severity of the accident. In an impact of less severity, there will be no permanent deformation of the recliner, and only the indicator (3), the forward link (5) and the spring (7) need to be replaced. This solution will reduce service costs. In more severe impacts, which reach the recliner's upper working limit, the recliner and backrest can be replaced if the seat base is still intact.

The WHIPS recliner is equipped with a function for quickly folding the backrest forwards. By releasing the latch (15), the whole recliner assembly except the side plates, together with the backrest may be folded forwards, without using the normal recliner adjustment. This solution is primarily designed to facilitate the transport of long cargo on top of a forward folded passenger seat. With the introduction of the WHIPS recliner, this function is also included on the driver's seat, and will be used for inspection and service of the WHIPS recliner.

Backrest and Head Restraint

The backrest was locally modified to give a more even force distribution along the spine of the occupant, according to the biomechanical guidelines and engineering requirements. A sub-system test method for evenness was developed (Lundell et al. 1998). Using this method, it was found that increasing the support of the backrest foam would give more uniform characteristics. This was done by modifying the springs supporting the foam. The purpose of these springs is to give good comfort in the backrest and insulation against vibration. The springs were modified so that their characteristics during normal ride are unaffected, but for loads reached in a rear end impact their stroke is limited.

The head restraint is based on existing Volvo head restraints, having good height and being fixed in position (IIHS 1995, 1997). It was modified to be positioned somewhat closer to the head, and also somewhat higher than previously.

Other Aspects of the WHIPS Seat

In addition to what has been described above, the seat has the same strong structure as Volvo production seats. These seats are several times stronger than required by the existing legal requirements for seat backrest strength. This is accomplished partly by having recliners at both seat sides. The new recliner matches the strength of the existing backrest, meaning that the high speed crash performance has not been compromised by the new design. Thus, there is no increased risk in rear impacts, neither for the occupant of a front seat nor for adult or child occupants of a rear seat. This also applies to frontal impacts, when the seat backrest may be loaded from the rear, e.g. by luggage on the rear seat. The modified seat backrest is also equipped with the same side impact protection system (SIPS) as the standard seat.

Manufacture

The WHIPS recliner is assembled by the system supplier (Autoliv Sverige AB). The recliners are welded to the backrest by the backrest manufacturer (Autoliv Mekan AB), and the complete backrest is assembled to the seat by the seat manufacturer.

Each recliner is given its own individual number for the tracking system. The parts of the recliner are linked batch by batch to the individual number.

TESTING

During the development of the WHIPS seat, both sub-system testing and sled testing was used. Mathematical simulation was also used as an important tool.

In the sled tests, presented below, the 50th percentile Hybrid III dummy was used. One reason for using the 50th percentile dummy was that, apart from it representing a mid-size male it may also, to some extent, be assumed to represent a tall female. Tall females were shown in the accident studies to be at higher risk. Tests were also run with the 5th percentile female and the 95th percentile male dummies.

Sled Test Results

Several parameters were studied in the tests. As explained above, low acceleration was chosen as a major criterion. The lower neck horizontal acceleration was chosen to be displayed here.

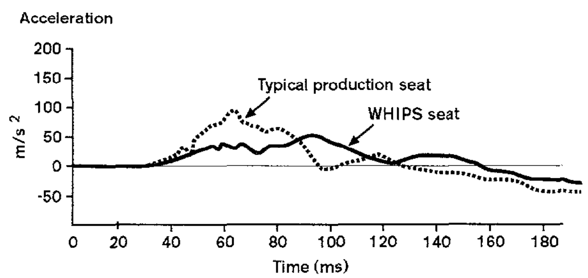

Figure 8. Sled test results, lower neck horizontal acceleration; Δv 10 km/h.

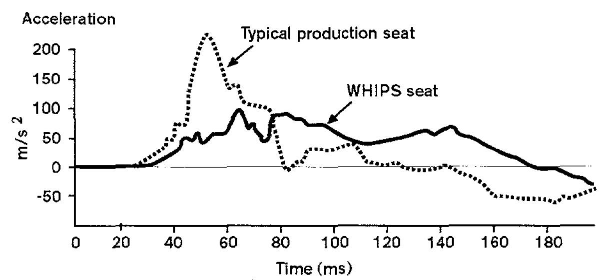

Figure 9. Sled test results, lower neck horizontal acceleration; Δv 20 km/h.

Sled test results are shown for a Δv of 10 km/h in Figure 8, and for a Δv of 20 km/h in Figure 9. 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.

DISCUSSION

The procedure for the Whiplash Protection Study follow the whole chain; from the accident research and biomechanical knowledge; the 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 a considerable strength to this study.

The study has focused on the whole seat, and not only the head restraint. This is important, since the motion of the whole spine effects the neck, and also for the reason that the exact injury mechanism is not known.

When developing the WHIPS seat, a very important rule has been to address all aspects of the biomechanical guidelines. Increased responses of any kind should be avoided, since reductions in other responses may be countered and no real positive effect achieved.

The sled test results presented should be regarded as an indication of how much reduction may be achieved. Thresholds can not be determined due to the nature of the requirements. There are only a few test results presented in this study. More measurements, different dummy sizes and seating postures were included in the holistic approach, combined with engineering evaluation, sub system testing, mathematical modelling and geometrical requirements, in order to know that injury reduction could be achieved. The results are consistent in giving reductions in line with the guideline parameters, thus leading to a reduced risk of injury.

CONCLUSIONS

In this study the WHIPS seat for improved whiplash protection was developed. The new seat is based on a production seat, and comprises two new recliners, together with a modified backrest and head restraint.

The development of the new seat was part of Volvo's Whiplash Protection Study (WHIPS).

The seat backrest was locally modified to give a more even force distribution along the spine of the occupant. The head restraint was modified to be positioned somewhat closer to the head and also somewhat higher.

The new seat recliner was designed to be activated in case of a rear end impact, and to operate primarily in low to moderate impact speeds, where many whiplash injuries occur. The WHIPS recliner is activated by the forces from the occupant, without any external sensor system. The seat backrest will move, together with the occupant, in two phases. Phase one is essentially a translational motion, improving the closeness and support of the occupant's back and head. The second phase gives a rearward reclining of the backrest, mainly to reduce acceleration and forward rebound by plastic deformation of a metal element in the recliner.

Test results presented in this paper show that the WHIPS seat reduces peak lower neck horizontal accelerations approximately by half. Further, the WHIPS seat reduces forward rebound. The WHIPS seat also gives improved closeness as well as improved distributed load support of the back and head.

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

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