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Prevention of Neck Injury in Frontal Impacts

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Prevention of Neck Injury in Frontal Impacts

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ABSTRACT: *'Whiplash' or Soft Tissue Neck Injury (STNI) has traditionally been recognized as a car-to-car rear impact phenomenon; studies worldwide verify that the risk of sustaining neck injury in a car crash is approximately three-fold the risk of sustaining the same injury in other crash-types. In general, as such injuries are not characterized by a high risk of threat-to-life (as measured by internationally adopted injury severity scales such as the Abbreviated Injury Scale), prevention of them has perhaps not been seen as a high priority. However, in recent times, it has been recognized that such injury can be very debilitating to those afflicted and costs to society as a result of the injury can be correspondingly high.*

Techniques have therefore evolved over the past 5-10 years that are aimed at the prevention of neck injury, mostly in rear impacts, and these are predominantly based on current understandings of the actual injury coupled with the injury mechanism. Such studies usually indicate that the design of vehicle seat and head restraint is critical in the prevention of neck injury.

However, neck injury does not only occur in rear-end crashes. Some studies have shown that the risk of sustaining neck injury in front and side impacts is between 15-20%. As these crash-types occur more frequently than rear impacts, the actual exposure to neck injury could be higher than in rear impacts. However, so far there have been no design techniques specifically aimed at neck injury prevention in such impacts.

Recently, two studies of real-world crashes have examined the effects of airbags in frontal impacts. These are reported in this paper. Both studies have shown that the deploying airbag in conjunction with a seat belt in a frontal crash can significantly reduce the incidence of neck injury in a frontal impact. The first is an on-going study of vehicle crash performance and occupant injury which is being conducted by Folksam Insurance in Sweden using data obtained from on-board crash recorders. The second study uses preliminary data from an on-going study of vehicle crash performance and occupant injury, which is being conducted by the Monash University Accident Research Centre.

1. Introduction

The term "whiplash" was first used in 1928 by Dr Harold Crowe to encompass neck motion and injury in car crashes. Since this date, whiplash has been the subject of extensive research throughout the vehicle safety community. However, the only thing that can be said with any degree of certainty about whiplash is that it is a by-product of car crashes. All other hypotheses about whiplash mechanism, pathology and treatment remain invalidated to a large degree although significant progress has been made in recent times.

The classical view is that "whiplash" is an inertial response of the body to the forces exerted upon it, in which the head and neck undergo an excursion but in which neither suffers any direct blow. Traditional descriptions of the movement of the head and the neck are restricted to the sagittal plane due to a rear-end collision. More up to date definitions also include movement patterns that may occur in frontal and side impacts although the rear end collision is by far the most reported when considering whiplash injuries.

2. Injury Mechanisms

2.1 Hyperextension

If the head is forcibly moved rearward beyond its anatomical range of motion, then cervical extension injuries occur. This usually happens in rear impacts as the head and neck hyper-extend over the seat-back and/or head restraint. First of all, the struck vehicle is

accelerated forwards; after a delay of about 100 milliseconds, the torso and shoulder are impelled forwards by the seat-back and join the acceleration. As the shoulders move forward, they pull the neck forwards from under the head imparting a backwards and upwards rotation to it. Because of its mass, the head resists being pulled forwards and lags behind the forwardly displaced shoulders. The result is extension of the head/neck in relation to the shoulders. Once the inertia of the head is overcome however, it too starts to accelerate. Because of the leverage afforded by the neck, head acceleration soon outstrips that of the shoulder and the head is ultimately catapulted into flexion (with the injury consequences such as those described previously). Relative to the trunk, the head acceleration can be as high as 12g in the extension phase and 16g in the flexion phase. As a result of hyper-extension, there may be tearing or avulsion of the anterior longitudinal ligament and/or tearing of the anterior flexor muscles. The intervertebral discs are also subjected to strain and may be displaced which can result in interference with function of and cause pain in the nerve roots, which supply the upper extremity. The oesophagus and the pharynx can also be subjected to strain.

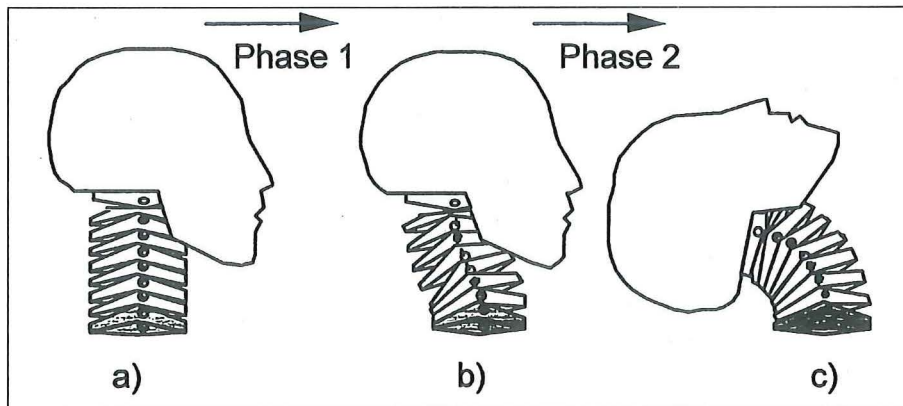


FIGURE 1: Schematic drawing of the head-neck motion during a rear collision
 Phase 1; Retraction motion
 Phase 2; Extension motion

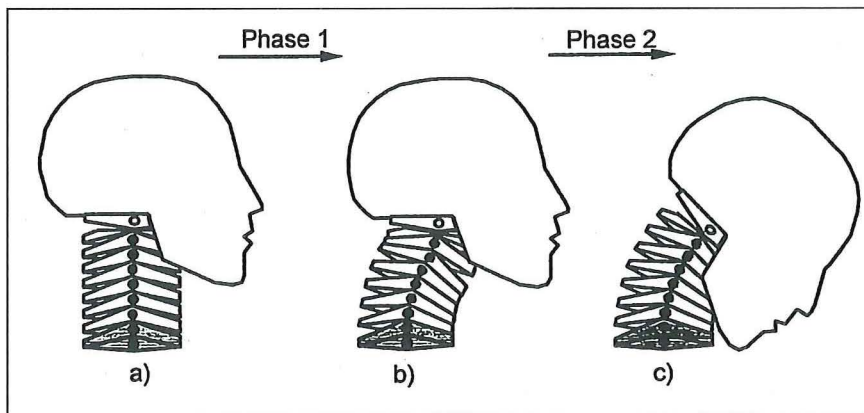


FIGURE 2: Schematic drawing of the head-neck motion during a frontal collision
 Phase 1; Protraction motion
 Phase 2; Flexion motion

2.2. Hyperflexion

A restrained occupant in a frontal crash will undergo translational head motion and as a result, the cervical spine will be forced into flexion or hyperflexion. During this motion, the ligamentous (predominantly the posterior longitudinal ligament, the interspinous ligament and the ligamentum nuchae) and muscular structures attached to the posterior arch of the vertebrae can be stretched or torn. Other injury outcomes in hyperflexion can include synovitis due to subluxation of the articular facets and compression fractures. Some authors comment that the chin provides a mechanical stop or limitation such that the stresses exerted in the cervical region could be expected to be below those producing injury.

Many studies have examined the risk of neck injury in different impact classifications. Larder et al (1985) found that in frontal impacts, 17% of occupants sustained a neck injury whilst for rear impacts, the rate was 31%. Galasko et al (1993) found that for injured drivers attending hospital, 52% were injured in a rear impact, 27% in a front impact and 16% in a side impact. Morris and Thomas (1996) found that soft tissue neck injury rate was about 16% in all impact types except rear impacts where the rate was 38%, more than twice the rate of any other impact type.

3. Injury Mitigation

Injury mitigation techniques have traditionally focused on preventing neck injuries in rear impacts since the

view remains that this type of injury is seen as a rear impact phenomenon. The techniques that exist for injury prevention in rear impacts predominantly involve seat design and head restraint design.

3.1 Seat and Head Restraint Design

When properly positioned, the head restraint should prevent extreme hyperextension of the neck and minimize the relative motion between the head and torso. This means that it has to be positioned close to the back of the head.

However, it is possible that a head restraint even if it is positioned close to the back of the head, does not act to reduce the risk of soft tissue neck injuries. According to studies done by Minton et al (1999), and Morris et al (1996) [BF1] no significant correlations between head restraint adjustment parameters and disability could be found. [BF2]

Modern seat backs are very strong and resilient and during a rear impact, they may rebound the torso of the car occupant. The rebound of the occupant is then stopped when the torso is suddenly decelerated by the seat belt. According to vKoch et al (1995), the occupant's forward velocity due to rebound may be up to 30% higher than the velocity of the car. Other studies have shown that when the seat yields in a rear impact, neck injuries are statistically less likely to occur (Larder et al, 1985, Parkin et al, 1995).

Based on an analysis of the NASS database and of dummy sled tests, Prasad et al. (1997) [BF3] concluded that stiffer seats could increase the incidence of minor to moderate neck injuries in the real world.

Experimentally, a Swedish study using a RID neck-form attached to a Hybrid III dummy found that increased

stiffness of the seat back frame resulted in slightly increased maximum head-torso displacement. However, a stiffer lower seat-back cushion combined with a deeper upper seat-back cushion resulted in a clear reduction of the head-torso displacement (Svensson et al.1993[BF4]).

Seat stiffness and hence rebound is an assuming greater importance as a factor in neck injury causation. However, what does the rebound theory imply for the mechanism of neck injury? Rather than hyperextension as an injury mechanism, hyperflexion of the head neck due to interaction of the occupant with the seat belt during rebound appears to be an important factor.

By allowing the seat to deform in a controlled manner, the occupant's acceleration can be reduced and thereby also reduce the rebound which is also one of the guidelines that should give increased protection against neck injuries (Jakobsson et al. 1999). The seat back should absorb energy and its frame stiffness and upholstery characteristics should be adapted to the corresponding parameters of the head restraint (Hell et al.1999[BF5]).

There are at least three different anti whiplash seats on the market. There are two general principles involved in the designs of such seats. The first principle is aimed at minimizing the relative head torso movement. The second principle allows the occupant to move backward until both the head and the spine are supported from the seat at almost the same time and this means that the relative movement is reduced.

4. Injury Prevention in Frontal Impacts

Neck injury prevention in frontal impacts has received very little

attention internationally even though studies have shown that this injury, whilst rarely life-threatening, can inflict very serious disability on those afflicted. Sometimes, the disability is permanent. At present, there are a few scales exist which allow analysis of disability, although Gustafsson et al (1985) developed the Risk of Serious Consequences (RSC) scale which has much applicability to road crash outcomes. However, the AIS scale, which is the most universally accepted injury scale is essentially a measure of threat to life in crashes rates neck injuries as AIS 1 (minor) although the long-term consequences can be permanent. Conversely, an occupant can make a full recovery from a chest injury of AIS 2 to 4.

It is probably true to say that there are no vehicle safety features which have been implemented in vehicles with the *specific* intention of preventing neck injury unlike the attention which has been devoted to neck injury in rear impacts (described above).

However, when steering wheel airbags were introduced into modern vehicles, there was some expectation in the research community that neck injuries may be prevented in a frontal crash. The main purpose of steering wheel airbags is the prevention of skull and brain injuries by reducing the likelihood of severe interaction between the driver's head and the steering wheel in a frontal impact. However, it is also conceivable that the deploying airbag can also prevent the risk of injury by retarding the rate of acceleration of the head and neck thus preventing the risk of the types of injuries that were described above. This would tend to support research conducted by Kullgren et al (1998) in which it was proposed that the main factor influencing the risk of neck injury seems to occur during the phase

when, and shortly after, seat belt contact has occurred and the occupant starts decelerating.

This study examines specifically the issue of neck injury in frontal impacts and explores possibilities that exist for neck injury prevention in this type of crash.

5. Methodology

Two sources of data have been used to evaluate the effects of airbags on neck injury reduction.

The first source of data were obtained from a sample of crashes that were investigated as part of an on-going study of driver injury and vehicle crash performance by the Accident Research Centre at Monash University. This

retrospective examination of crash-damaged vehicles. Only drivers who wore their seat-belts were included in the study. Determination of seat-belt usage was achieved with a high degree of certainty.

To assess collision severity in this study, Delta-V was calculated where appropriate. Analyses were made to ensure that the collision severity in both airbag-equipped and non-airbag equipped vehicles did not differ significantly (figure 3).

The second source of data have been gathered as part of an on-going study of vehicle crash performance and occupant injury that has been conducted by Folksam Research in

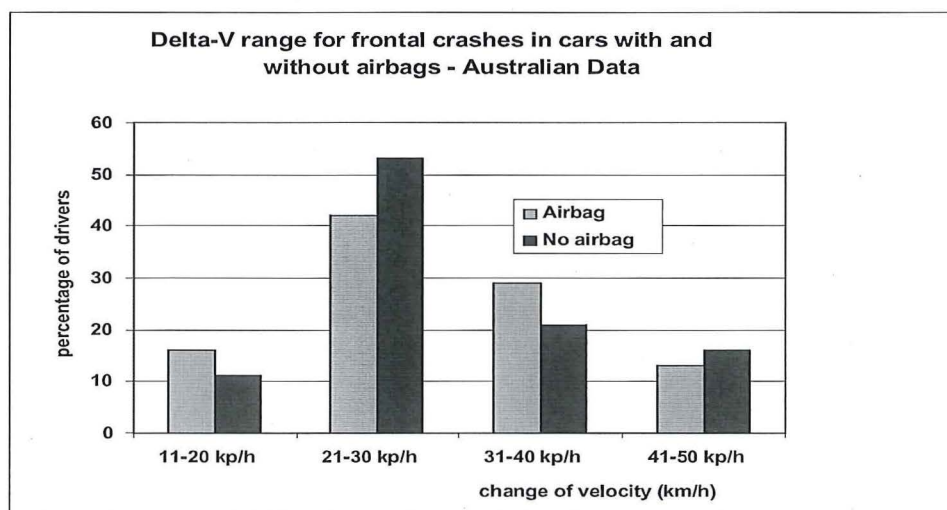


Figure 3

study examines injuries that were sustained by a sample of drivers involved in frontal impacts in which the principal direction of force (dof) was within 30-degrees of head-on. Vehicles were examined at recovery-garages, scrap-yards and panel-beating shops in Victoria, New South Wales, Queensland and Tasmania (depending on accident location) within a few days of the accident. An inspection was performed on each vehicle in accordance with the National Accident Sampling System procedure for

Sweden. This study includes injury outcomes to drivers involved in frontal impacts in where the crash pulses have been recorded using vehicle on-board crash-pulse recorders. To assess collision severity in this study, Delta-V and acceleration was used as measured by the crash pulse recorder. Analyses were made to ensure that the collision severity in both airbag-equipped and non-airbag equipped vehicles did not differ significantly and this analysis is shown in figure 4. A more complete

overview of the methodology can be found in Kullgren (1998).

Figure 4

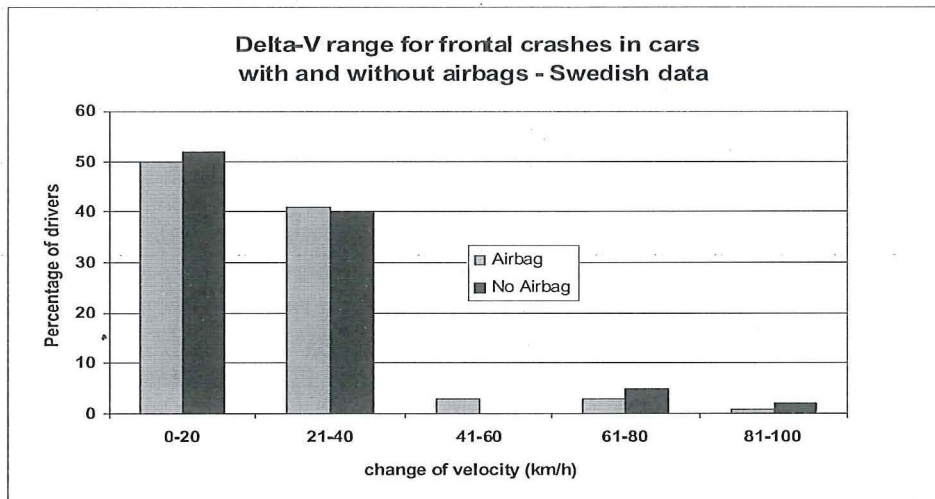


Figure 5

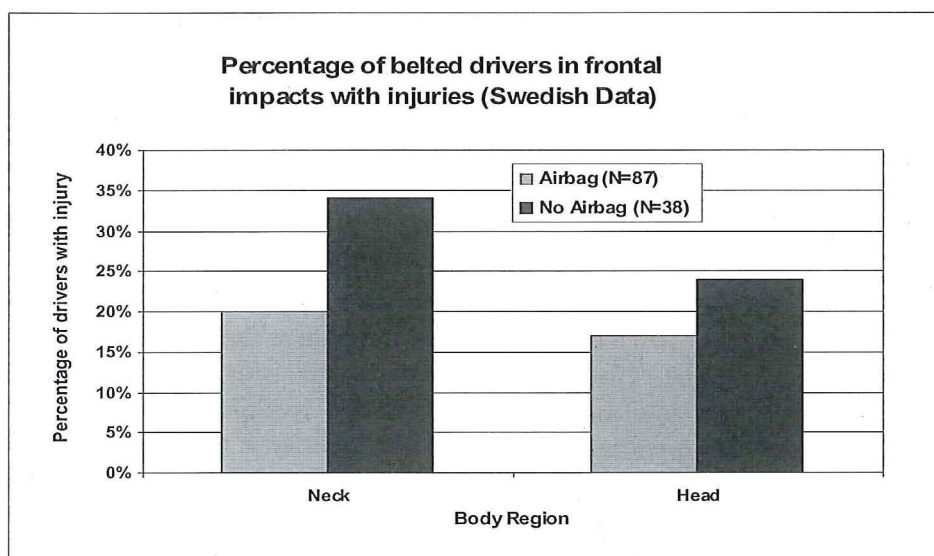
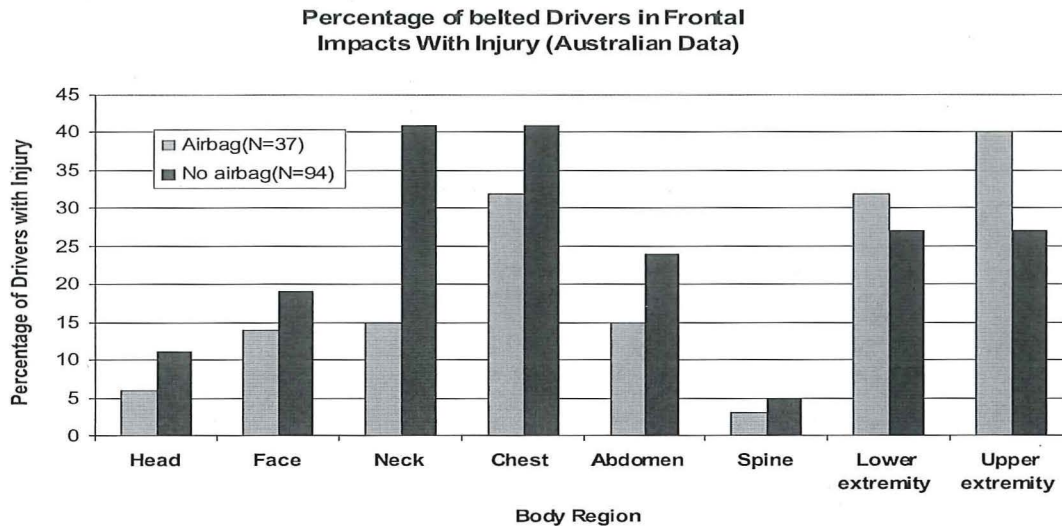


Figure 6



6. Results

Figure 5 shows the preliminary results from the Australian study of driver injury in airbag versus non-airbag vehicles.

This figure represents the percentage of drivers who sustained injury of AIS 1+ to different body regions in airbag-deployed and non-airbag vehicles.

As can be seen from the above figure, drivers in airbag-equipped vehicles are less likely to sustain injuries to most body regions, the exceptions being injuries to the upper and lower extremity. Of particular relevance to this study is the fact that restrained drivers were statistically significantly less likely to sustain a neck injury in the airbag-equipped vehicles compared to non-equipped vehicles ($p < 0.001$).

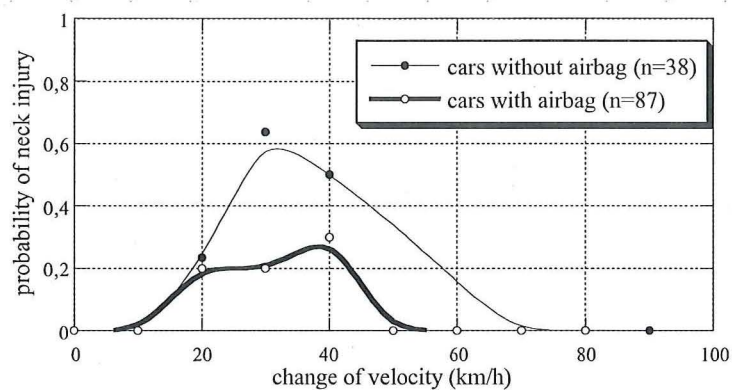
Figure 6 shows the results of the Swedish study although the results only show the injury rates for head and neck injury. Clearly in this study also, the risks of neck injury are reduced in the airbag vehicle compared to the non-airbag vehicle. However, it is also important to consider the reductions in head injury that are associated with airbag deployments.

Figure 7 shows that there is a significant reduction in neck injury risk for drivers in airbag-equipped vehicles compared with non-airbag vehicles. In fact, the injury risk in airbag equipped vehicles is some 60% lower than non-airbag vehicles. Figure 7 also shows that the risk of neck injury decreases substantially after a certain change of velocity is reached and this could be explained in part by increasing

probability of life-threatening injuries with associated under-reporting of neck injury. However, this does not fully explain the decline in injury risk after the change in velocity reaches 60km/h since the effect is noticeable in both airbag and non-airbag vehicles. It is probable that head contacts with the

vehicle interior, predominantly the steering wheel, are likely in non-airbag vehicles and this may explain the decline in neck injury risk at higher velocities. More field data especially involving front seat occupants would be beneficial.

Figure 7



7. Discussion

This preliminary study has raised a number of issues; firstly there is the obvious issue of airbag effectiveness. Concerns had previously been raised about the potential for injury that airbags occasionally generate, especially in the public domain. What is clear from the preliminary Australian data presented in this study is that airbags provide benefits to all body regions with the exception of injury to the extremities. With upper extremity injuries, the explanation is reasonably straightforward. Frequently drivers especially report that they sustain abrasions to the forearms through interaction with the deploying airbag. This is to be expected in some cases as most driver airbags contain vent holes through which exhaust gases escape during the deployment phase. These vent holes roughly correspond to the positioning of the driver forearm during deployment. Therefore if prevention of these injuries is to be sought, repositioning of the vent holes would solve the problem.

With regard to lower extremity injuries, the situation is not clear but overall this finding supports other studies of airbag deployments. One possibility is that the deploying airbag alters driver kinematics in the crash in a manner, which are as yet not fully understood. This could increase the probability of harsh contacts between the facia and the lower extremity resulting in injury.

Further exploration and discussion of injury trends will be made in a follow up study, which is planned for later in 2000.

The main issue in this study is that of neck injury prevention in frontal impacts. Firstly, it is important to reiterate that whiplash injuries do occur in frontal impacts although it is acknowledged that the risk is slightly

below that in rear impacts. However, all injury prevention techniques have been aimed specifically at reducing the risk in rear impacts (generally through improved seat and head restraint design). So far, evaluation of the success of such systems has not been possible due to a general lack of field data, but this emphasises the need for continued collection of in-depth field data if a true evaluation is to be attained. Of greater significance in this study is that airbags have been found to reduce the risk of neck injury in frontal impacts and this is seen as an encouraging finding.

Driver airbags were initially conceptualised in an attempt to reduce the risk of skull-brain injury in a frontal crash. The fact that they reduce the risk of neck injury is a clear bonus. The Swedish data shows that the risk of neck injury diminishes above a certain level of collision severity (as measured by Delta-V). Furthermore, a parallel study by Kullgren et al (2000) has shown that the neck injury risk also diminishes as acceleration duration increases. This may be explained by the fact that with increasing change of velocity, the probability of serious injury increases such that neck injury may become of secondary importance to the driver and this in turn leads to a general under-reporting. Alternatively, it could be that crashes involving higher changes in velocity have longer duration than low severity crashes and it is the pulse duration that determines injury outcome. This is also proposed in Kullgren et al (2000).

The data which suggests that neck injury is less likely for longer duration accelerations may be beneficial in the further refinement and development of neck injury criteria and a truly biofidelic neck respectively.

Furthermore, the actual mechanism of neck injury or at least one of the mechanisms is worthy of consideration. Previously it has

been assumed that hyperextension of the head and neck is the most important process in the generation of neck injury. This is why devices such as active and integral head restraints have developed despite conflicting evidence about the overall effectiveness of head restraints generally. However, this study has perhaps supported the view that hyperflexion is also important. If this supposition is considered in the context of the seat-rebound theory (where hyperflexion becomes more important in rear impacts) it is clear that hyperflexion as an injury mechanism is worthy of greater consideration

Finally there is the issue of the threshold of airbag deployment. Several previous studies have encouraged the use of deployments at higher thresholds than the commonly acceptable level of between 18-25kp/h, depending on manufacturer. The (Swedish) study has shown that neck injuries occur at relatively lower speeds and then decrease in collisions with a change in velocity above 55kp/h. In view of the fact that such benefits can be gained by deploying in the range that neck injuries are likely, it is suggested that it is important to operate the airbag at lower levels, comparable to the threshold incorporated in most current designs.

8. Conclusions

- Neck injuries can happen frequently in frontal crashes and as this crash type is more frequent compared to any other crash type, the exposure is likely to be higher even though the risk in rear impacts is clearly higher.
- 15% of Australian drivers in airbag-deployed vehicles sustained neck injury compared with over 40% in non-airbag vehicles. In the Swedish study presented

here, the figures were 20% and 35% respectively.

- It was found that airbags significantly decrease the number of neck injuries in both a Swedish study and a preliminary Australian study.
- Using crash-pulse recorders, it was found that in collisions with a change in velocity above 20km/h, the average neck injury reduction for airbag equipped vehicles was approximately 60% of that experienced in non-airbag vehicles.
- Swedish research suggests that airbag firing thresholds should be further explored if future data support the preliminary research presented in this study.

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