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Ad-Hoc Group on Whiplash Injuries

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Final report

EEVC European Enhanced Vehicle-safety Committee
Ad-Hoc Group on Whiplash Injuries
and
EEVC WG12 Advanced Anthropometric Adult Crash Dummies

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Summary

Several proposals for a test procedure for neck injury protection assessment have been published. A good deal of data are available to serve as a basis for the choice of; test set-up (e.g. full vehicle test, sled test), accident severity (delta-v, acceleration characteristic) and crash dummy type.

There is however a lack of information regarding the choice of a neck injury criterion and a tolerance level. There are however promising activities under way, for instance in the ongoing EU-project "Whiplash II".

The EEVC ad-hoc working group on whiplash injuries recommends that a new EEVC activity on rear impact is established. Although much research work has taken place there are still significant gaps in the knowledge base, before a full regulatory test procedures can be fully adopted. The ad-hoc group feels that a new EEVC activity would have an important role to play in initiating and evaluating new research to fill these gaps.

Future tasks for any new EEVC activity would include:

a) Test procedures
b) Test devices (crash dummies).
c) Assessment criteria
d) Validation

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Introduction

No regulatory test exists in Europe to assess injury risk in rear impacts, in particular low severity. A number of accident studies and claims statistics coming from the insurance industry clearly indicates that low severity rear impact can lead to neck injuries causing long-term disablement and discomfort. These injuries are usually classified as AIS 1 (Abbreviated Injury Scale) and often referred to as Whiplash injuries. The costs of such injuries are very high. Outside of the regulatory framework a number of organisations have been investigating WAD injury (Whiplash Associated Disorder). Two EU projects have supported some areas of this work. A rear impact, sled based test procedure, against which to assess vehicle seats has been proposed to GRSP and ISO. To date the EEVC has not been able to develop a viewpoint on rear impact and WAD type injury. The EEVC WG12 (Advanced Anthropometric Adult Crash Dummies) has become aware of some research taking place in rear impact dummy development. The EEVC Steering Committee asked the WG12 to create an ad-hoc working group to investigate the possibility of developing an EEVC view on rear impact and WAD injury.
The terms of reference for this ad-hoc group are:

* Review current research knowledge on whiplash associated disorder injuries, taking into account research world wide from, inter alia, research institutes and insurance organisations.
* Determine whether sufficient progress has been made to justify the creation of an EEVC Working Group to develop a test procedure for the evaluation of the risk of WAD injuries in rear impacts.
* Report the review findings to the EEVC Steering Committee within one year of the first meeting of the ad-Hoc Group.

In order to meet the needs of EEVC Steering Committee and WG12, a group has been formed with representatives from six counties. In order to develop a broad basis for any review by the steering committee the work was divided up into six tasks each being undertaken by one of the represented countries.

Tasks of investigation	(task leader)
1) Accident data and Insurance statistics	Germany
2) Biomechanics	Sweden
3) Dummy development	Netherlands
4) Car design, Seat design	United Kingdom
5) Test procedures	Italy
6) Research programs (ongoing and finalised)	France

This report summarises the activities of the ad-hoc group with recommendations for future actions based on their observations. The report includes the reports that were drafted by the task groups.

Summary of task reports

Accident data and Insurance statistics

From accident data and insurance statistics the impact severity in rear impacts is relatively well known, both when the occupants are uninjured and when they report whiplash injury. From crash recorder data at Folksam it was found that long-term WAD symptoms are rare at mean accelerations below 3 g. The finding is also supported by several volunteer test studies. Based on accident statistics from several countries, the majority of whiplash injuries are reported in crashes at medium impact severity, typically at a change of velocity between 10 and 15 km/h. However, most of these reported injuries are short-term injuries where the occupants recover within a couple of weeks.
Furthermore, there is knowledge regarding the impact severity when occupants sustain more long-term WAD symptoms. Based on crash recorder data from real world accidents (from a single car make), the average change of velocity and the mean acceleration is known. Those injuries leading to WAD symptoms lasting more than one month was found to occur at approximately 20 km/h and 5 g respectively, while those recovering within a month had approximately 10 km/h and 4 g respectively. The average values for occupants classified as WAD Grade 2 and 3 was approximately 16 km/h and 5 g. Therefore a proposed test speed and acceleration will vary, depending on whether the test is focusing on all reported whiplash injuries or on the more severe ones.
At higher speeds many seatbacks deform/collapse (risk for major injuries). A seat-back deflection test or a high-speed test could be added to cover this situation. To ensure that sub-optimisation is avoided, a low severity test

could also be added. Current accident data show similar results world wide (except deviations from different social security and insurance systems in various countries).
The accident data needed as a basis for a new EEVC working group is thus available. New accident studies (EU-Whiplash 2) will in the near future also give an improved overview of the current accident situation.

Biomechanics
The injury symptoms are well known but the injuries causing the acute symptoms are not completely known. The relation between acute injury and chronic pain is not fully understood.
The head and neck kinematics during whiplash trauma is relatively well known. Derived from these kinematics, several biofidelity requirements have been formulated and were used as a basis for the development of rear impact dummies.
Several injury criteria have been suggested but all of them would have to be better validated with respect to possible injuries before they could become commonly accepted. Three principle ways of verifying injury criteria were identified:

1) By identification, in the clinic, of the actual acute injury that causes chronic pain. This would probably tell us which injury mechanism is the cause and give an indication as to which injury criterion to use.
2) An alternative would be to evaluate proposed criteria against experimental data where certain injuries have been caused and where injury threshold levels can be identified (this will however leave an uncertainty about the relation between the observed injuries and the symptoms experienced by living patients)
3) By high quality evaluation of injury criteria against field accident data. Reconstruction crash tests and computer modelling may be used in parallel.

Current neck injury criteria are acceleration based, like NIC, velocity based (T1 rebound velocity), displacement based (IV-NIC and NDC) or load based, like Nkm. An injury criterion that correlates to injury risk is a requirement for a future test procedure. It would however be possible to identify such a criterion even if the injury and injury mechanism is not fully known. (Medical symptoms can often be treated even if the origin of the symptom is not fully understood.)
Although it may be appear to be valuable, from a pragmatic perspective, to aim at reducing the magnitude of any measured parameter it could lead to increased injury risk or not yield the expected gains. From a regulatory perspective it is essential that there is a good correlation between criteria and risk. Any given injury criterion should be accompanied by an injury risk function.

Dummy development
Currently the dummies, which are most likely to be useful for rear impact testing, are the BioRID II and the RID2. Each of these has been based on a different set of biofidelity requirements. A third alternative for rear impact is the American frontal impact dummy prototype, THOR, which has been evaluated with partly promising results. The BioRID II has the advantage of being more established and used in automotive industry, while the RID2 is just released. One advantage of the RID2 is its wider instrumentation capabilities, - the lower neck and lumbar load cells and its capabilities to handle oblique impacts. Both dummies still have practical limitations, which are likely to be solved throughout the course of their use. The issue of dummy performance during forward rebound is being addressed in the Whiplash II project. The ongoing world wide evaluation of the two dummies; BioRID II and RID2, will lead to adjustments that are expected to make them acceptable in a regulatory framework. Appropriate setting up and certification procedures are also expected to evolve during the evaluation process. The Hybrid III, although it is being used world wide, is not suitable for low severity rear impact testing due to its limited biofidelity.

Car design, Seat design
Vehicle structures are reported to be getting stiffer. This may be due to enhanced crash performance driven by among other things, the low speed insurance impact and may have led to an increase in whiplash type injuries.
It has been noted that over recent years the seat back yield-strength has increased. A combination of increasing vehicle stiffness and seat yield strength is leading to a rise in reported whiplash injuries. Current research suggests that where high yield strength seats are used in conjunction with ‘good’ head restraint geometry a reduction in injuries is observed. Active head restraint systems have been shown to be effective in improving head restraint geometry dynamically, however systems must be optimised through the use of a biofidelic rear

impact dummy. Accident data have indicated that advanced whiplash protection systems give a reduction in injury risk.
Any future dynamic whiplash test would have to ensure adequate protection over a range of delta-v (possibly in the range: 10-30 km/h) to prevent component sub-optimisation.

Test procedures
Several proposals for rear impact test procedures have been brought forward in different forums (e.g. ISO) in recent years. Static test procedures have been developed and dynamic test procedures are being developed. Most of them have the same origin and are gradual upgrades that have been included as new knowledge has become available. The proposals mostly include a dynamic sled test of the seat using a modern rear impact dummy. The speed changes proposed are mainly near 10, 16 and 30 km/h. Currently a generic acceleration pulse is commonly used, but the choice between a generic pulse or a car specific pulse is still an issue. Several injury criteria are suggested but no one of them have attained adequate acceptance. A static geometrical head restraint rating is currently used by RCAR.

Research programs (ongoing and finalised),
A number of ongoing or finalised research initiatives, relevant for the development of a rear impact test procedure, are listed.

- EU Whiplash I (finished)
- EU Whiplash II (on going)
- Swedish research programs
- The International Insurance Whiplash Prevention Group The objective of this working group is to develop dynamic test procedures to evaluate and compare seat/head restrain designs.
- ISO (on going) The GDV initiated test procedure proposal is in circulation for comments.
- OSRP/USCAR (on going) The Occupant Safety Research Partnership of the United States Council for Automotive Research has conducted a rear impact evaluation program to compare the BioRID II and H-III
- Other active research laboratories:
  - TU Graz, Austria
  - Allianz ZT, Munich, Germany
  - University Ulm, Germany
  - Medical College of Wisconsin, USA : cadaver tests, thesis on facet injury mechanism
  - Wayne State University, USA : cadaver tests, thesis on facet injury mechanism
  - JARI, Japan : volunteer tests, thesis on facet injury mechanism
  - MacInnis Engineering, BC, Canada : volunteer tests, dummy evaluation
- A world wide evaluation of the two dummies; BioRID II and RID2 is under way
- UK spinal injury (First report published at the IMechE Vehicle Safety 2002 conference – volunteer & dummy testing plus human and dummy modelling -includes the derivation of design target corridors)

Recommendation
The ad-hoc group has determined that rear impact and WAD type injury is a serious problem in terms of both injury and cost to society. A lot of work has taken place in trying to quantify the problem and determine means of injury and cost reduction. To date several special test dummies and test devices have been developed to try and assess WAD injury and several test procedures have been developed, static and dynamic. There does not appear to be a consensus view as to the merits of the different procedures, static versus dynamic and within dynamic – sled based evaluation of a seat or fully vehicle. Although much research work has taken place there are still significant gaps in the knowledge base that the ad-hoc group feels should be filled, before a full regulatory test procedures can be fully adopted. Based on the findings of this report, the EEVC ad-hocworking group on whiplash injuries recommends that a new EEVC activity, on rear impact should be initiated.

The ad-hoc group suggests that a new activity would have to address a number of specific issues. This activity would preferably be divided between two working groups. The test procedure could be handled by one group, while the dummy and the biomechanics could be handled by the WG12. It is recommended that the two working groups are given terms of reference with a duration of two years. A preliminary test procedure proposal should be presented within one year of the first meeting. During the second year, the proposed test procedure should be evaluated and a final proposal should be presented to the EEVC Steering Committee. The following may give the Steering Committee further guidance in defining the terms and conditions for the new activity.

Future tasks for a new EEVC activity on neck injury protection in rear-end collisions would include:

a) Test procedures
In various countries both static positioning and dynamic tests are being used to assess the risk of WAD injuries in rear-end crashes. Some research activities have concentrated on the development of a sub-system type of approach (sled testing of seats) in developing and approving vehicle seats. Such an approach appears to be a very good one for product development but there is some concern that a sled based approval may exclude vehicle based impact conditions (vehicle specific pulses) which may be very important in generating WAD injury. A new EEVC working group would have to investigate and quantify the validity and the limitations of both sled test procedures and full vehicle test procedures.

b) Test devices.
Both static and dynamic assessment devices have been developed. There appears to be some concern that the anthropometry of the static device used in the RCAR assessment is not being very human like. This issue would need to be investigated if a static assessment was recommended, and alternatives proposed.

Two special rear impact dummies have been developed. There is no consensus as to their relative merits and potential problems, for regulatory use. A new frontal dummy (THOR) is also being evaluated for rear impact performance. There is also no consensus regarding the biomechanical targets. The new group must have the resources to develop such biomechanical targets and then to evaluate these devices and make a single recommendation as the current dummy (Hybrid III), often used for rear impact seat evaluation and development, is inappropriate. The European Whiplash II project addresses the comparison of different existing dummies in rear-end impacts. Appropriate certification and handling procedures will also need to be evaluated for the selected test device(s).

c) Assessment criteria
It is unclear what the precise mechanics of WAD injury are. Not knowing the injury mechanism(s) makes the task of selecting the correct injury criteria more difficult. A number of criteria have been proposed. There is a need to quantify each of the proposed criteria in terms of correlation with injury risk. Risk curves for the selected criteria will need to be developed in order to set acceptable threshold levels. Currently, the Whiplash II project is looking into this problem.

d) Validation
Any new test procedure will need to be validated in terms of checking that it will be effective in meeting its aims and that there are no ‘hidden features’ that might negate its effectiveness.

EEVC Ad-Hoc Group on Whiplash Injuries

Annex 1: Accident Data and Insurance Statistics

Incidence
The comparison of major accident samples from the German Motor insurers shows that the incidence of cervical spine injuries (also denoted whiplash injuries, cervical spine distortion injuries, CSD; or whiplash associated disorders, WAD) in Motor Vehicle Accidents has almost doubled in the last 20 years (Hell 1999). Morris and Thomas (1996) also show similar figures from UK. Swedish insurance data shows that the risk of whiplash injuries leading to long-term disability is found to have doubled comparing recent car models with car models introduced 20 years ago (Folksam, 2001), and do to date account for nearly 60% of injuries leading to long-term disability (Krafft 1998). The main public health problems concerning WAD are those leading to long-term disability. Between 5-20% (depending on accident data source) of all cases will end as long-term cases, these few long-term cases are responsible for a majority of the costs (Spitzer et al. 1995). Since most impacts lead to no injury or to temporary symptoms, the duration of symptoms needs to be separated in order to isolate representative crash conditions in which more long-lasting whiplash injuries occur.

Economical importance for society
The assumed socio-economic losses for rear-end collisions in Germany (calculated after German Injury Cost Scale) would amount up to 2 Billion Marks, that means about 1100 Million € only for rear-end collision cases for the year 1990 in the Federal Republic of Germany (West). At that time in about 54% of all car-to-car accidents with personal injury the accident pattern had been a rear end collision. An estimation based on the insurance statistics in Germany came to about 200.000 reported cervical spine injuries after rear-end collisions for the year 1990 only in former Western-Germany. For 2000 a higher amount of 1-2 Billion EURO for Germany can be assumed because of increased incidence (reported from German insurers) and the inclusion of former East Germany. Estimations of annual costs from other countries regarding whiplash injuries were also very high:

- USA, 10 Billion US$ (IIHS)
- UK, 800 Million Pounds (Direct Line)
- Canada, British Columbia/CDN 270 Million US$ (ICBC)
- NL, 1 billion Dutch Guilders (Dutch Transport Ministry)
- European Union, *roughly at least* 10 Billion Euro (Whiplash 1)

Accident conditions and risk groups
The medical and societal consequences of neck injuries due to rear impact are very important and the neck injury risk is the highest with this type of impact (see for example Galasko 1993 and Krafft 1998). The Institute for Vehicle Safety, Munich has established a large accident material of 15.000 car to car crashes representing every fifth collision from one year in Germany. A sub sample of 517 rear end collisions with passengers suffering from cervical spine distortion (CSD) injury had been analysed technically and medically. From the accident reconstruction a typical accident scenario was evaluated, which should define requirements for improved seat/head-restraint systems and proposes to set up a dynamic seat test standard, which should be integrated in existing safety crash tests. The data material shows that the typical accident configuration is a 0+/-5° angled impact with almost full overlap and a delta v between 10 and 20 km/h. Comparable results were found in an independent MHH Hannover accident investigation on behalf of VW (Temming 1998).

Females attend to have a higher injury risk compared with males (*Risk factor: small neck circumference*) (Hell et. al 1999, Maag et al 1993, Krafft 1998, Ydenius and Kullgren 2001, Berglund 2002).

Influence of car and seat characteristics
The dynamic behaviour of seat backs seems to influence the risk of WAD. Stiffer seats backs produce higher risk of WAD (Hell et al 1999, Parkin et al 1995, Foret-Bruno et al. 1991). A low positioned head-restraint increases injury frequency, even compared with seats with no HR (Hell et al. 1998).

The risk of CSD rises with decreasing car mass and increasing opponent mass (Eichberger 1996, Ryan 1993, Olsson et al 1990, Krafft 1998). Differences in mass reflect differences in change of velocity. A correlation between change of velocity and risk of both long-term and reported WAD has been shown (Krafft et al. 2001). Furthermore it has been shown that cars with similar weights may have large differences in risk of WAD (Krafft 1998), indicating that other factors than mass, such as car structure and seat stiffness, are strongly influencing the risk of WAD.

Classification of injuries

From the current medical point of view the AIS 1 neck injury, often called Whiplash Associated Disorder (WAD), could be divided into 3 grades (based on the medical findings) according to the Quebec Task Force (Spitzer et al. 1995). Many studies lack these definitions, which limits the possibility of comparisons.

WAD Grade 1 = Microlesion (microscopic muscular damage)
WAD Grade 2 = Macrolesion (major muscular/bone/ligament etc.. damage)
WAD Grade 3 = Nerve cell defect/irritation.

Influence of crash severity

Studies have been presented showing change of velocity for reported whiplash injuries. German figures show for rear-end collisions an average value of 15 km/h (GDVstudy to be published) Results from Folksam have been presented where crash severity, recorded with crash pulse recorders, have been correlated to injury risk (Krafft et al. 2001 and 2002). However, only 4 car models of one car make were involved. Average change of velocity and mean acceleration for occupants reporting a whiplash injury was found to be 14 km/h and 4,4 g respectively, while occupants not reporting an injury had corresponding values of 7,7 km/h and 3,0 g, see Table 1.

Neck injury has been studied both with respect to duration of WAD symptoms and to different grades of WAD, according to the Quebec Task Force (Spitzer et al. 1995), versus different crash severity parameters (Krafft et al. 2002). Crash severity was found to have a large influence on the duration of symptoms. Also grades of WAD were directly correlated to crash severity. Acceleration was found to be more important in explaining the risk of whiplash injury than change of velocity, indicating that when designing a crash test, focus should also be set on acceleration. It was also found that no one in the sample had WAD symptoms for more than 1 month as long as the mean acceleration was below 3 g (Fig. 3). This finding is also supported from several volunteer tests (Mc Connell et al. 1995, Ono and Kaneoka 1997, Siegmund et al. 1997).

In the study by Krafft et al (2002) the average change of velocity and the mean acceleration for those occupants with symptoms more than 1 month, were found to be 20 km/h and 5,3 g respectively. The average peak acceleration was approximately 11 g.

Regarding different grades of WAD, occupants classified as WAD Grade 2 or 3 were found to have values of 16 km/h, 5 g and 11 g.

Injury risk versus change of velocity and mean acceleration has also been compared to duration of WAD symptoms as well as to different grades of WAD (Figs 1, 2 and 3) (Krafft et al. 2002). Also average crash pulses were presented for different duration of symptoms. When designing a crash pulse for crash testing, the crash recorder results suggests that acceleration should typically be between 5 and 7 g for 80 ms to represent occupants with symptoms more than 1 month.

Table 1. Average values in crash severity for different injury classifications and categories for rear-end car collisions with 4 car models from one manufacturer, model year 1995-2001 (from Krafft et al. 2002) .

Injury classification	Category	Number of occup.	Delta-V (km/h)	Mean acc. (g)	Peak acc. (g)
All		94	10,4 +/- 2,0	3,6 +/- 0,3	7,9 +/- 0,7
Reporting	No reported neck injury	53	7,7 +/- 1,2	3,0 +/- 0,3	6,7 +/- 0,7
	Reported neck injury	41	13,9 +/- 2,6	4,4 +/- 0,4	9,5 +/- 1,0
Duration of symptoms	Symptoms < 1 month	26	10,3 +/- 2,1	3,9 +/- 0,5	8,7 +/- 1,3
	Symptoms > 1 month	15	20,0 +/- 4,8	5,3 +/- 0,6	10,8 +/- 1,4
Grade of WAD (Quebec Task Force)	WAD Grade 0	53	7,7 +/- 1,2	3,0 +/- 0,3	6,7 +/- 0,8
	WAD Grade 1	20	10,1 +/- 2,3	3,9 +/- 0,6	8,6 +/- 1,5
	WAD Grades 2 and 3	18(13+5)	16,2 +/- 3,8	4,8 +/- 0,6	10,1 +/- 1,5

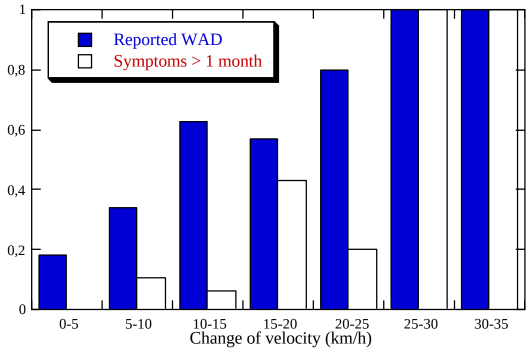

Figure 1. Injury risk in intervals of change of velocity for occupants with WAD for less than or more than 1 month (Krafft et al 2002).

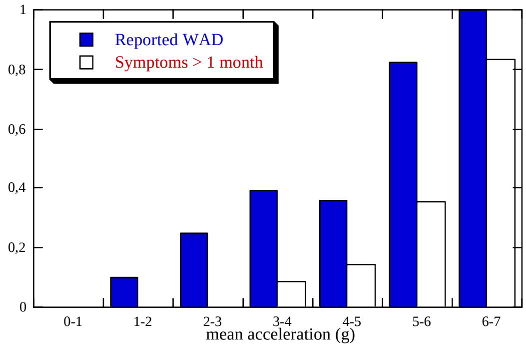

Figure 2. Injury risk in intervals of mean acceleration for occupants with WAD for less than or more than 1 month (Krafft et al 2002).

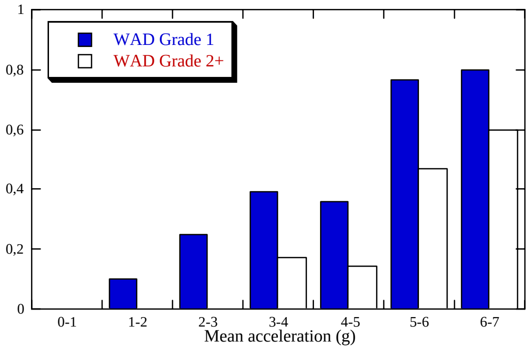

Figure 3. Neck injury risk (WAD 1 and WAD 2+) in intervals of mean acceleration (Krafft et al 2002).

Dynamic Test Standard derived from Accident Analysis

To test the utility of previously discussed test criteria and parameters taken to evaluate different seat/head-restraint constructions, a proposal of a dynamic sled test standard was developed (Langwieder 2001). Based on accident analysis it was developed aimed to represent a crash where most WAD are reported (delta v 16 km/h, average crash pulse 6-10g, no collision angle). Those were derived from different research groups as a synthesis. It was suggested that the parameters NIC, Flexion/Extension – momentum (Nkm), velocity of the head in the rebound phase (T1) and possibly also the Neck extension angle (Viano) seem to give a realistic rating of a seats potential to lead to or avoid a CSD. It was found that these values should be minimised by a good seat/head-restraint construction (Hell 2001).

Conclusions

Rear-end collisions resulting in Cervical Spine Distortion Injuries are a major concern for the modern society. From accident data and insurance statistics the impact severity when occupants are not injured and when they report whiplash injuries are relatively well known. From crash recorder data at Folksam it was found that no one sustained long-term WAD symptoms at mean accelerations below 3 g. This finding is also supported from several volunteer tests. Based on accident statistics from several countries, the majority of whiplash injuries are reported in crashes at medium impact severity, typically at a change of velocity between 10 and 15 km/h. However, most of these reported injuries are short-term injuries where the occupants recover within a couple of weeks. Furthermore, there is knowledge regarding the impact severity and more severe WAD categories. Based on crash recorder data the average change of velocity and mean acceleration for those injuries leading to WAD symptoms for more than one month was found to be approximately 20 km/h and 5 g, while those recovering within a month had approximately 10 km/h and 4 g. The average values for occupants with WAD symptoms of Grade 2 and 3 was approximately 16 km/h and 5 g, while the occupants with Grade 1 symptoms had 10 km/h and 4 g. A proposed test speed and acceleration will vary depending on focusing on reported whiplash injuries or on more severe ones.
At higher speeds many seatbacks deform/collapse (risk for major injuries). A seat-back deflection test or a high-speed test could be added to cover this. To ensure that sub-optimisation is avoided, a low severity test could also be added.

The current and ongoing accident data in general show comparable and similar results (except deviations from different social security and insurance systems in diverse countries). Therefore the basis for a new EEVC working group is given. Ongoing research programmes, such as Whiplash 2, will in future also give an overview about current accident statistics regarding whiplash.

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Annex 2: Biomechanics

Injuries and symptoms

The symptoms of injury following neck trauma in rear-end collisions include pain, weakness or abnormal responses in the parts of the body (mainly the neck, shoulders and upper back) that are connected to the central nervous system via the cervical nerve-roots. Vision disorder, dizziness, headaches, unconsciousness, and neurological symptoms in the upper extremities are other symptoms that have been reported (Deans et al., 1987; Hildingsson, 1991; Nygren et al., 1985; Spitzer et al., 1995; Sturzenegger et al., 1995; Watkinson et al., 1991). The neck injury symptoms appear to be very similar for all impact directions (Minton et al., 2000).

It is important to distinguish between initial symptoms and long term symptoms (Krafft, 2000). Long term (chronic) whiplash symptoms appear to be associated with central pain sensitisation (Sheather-Reid and Cohen, 1998; Johansen et al., 1999). The exact origin of this pain sensitisation has not been established. Successful treatment methods could possibly provide a clue. Byrn et al. (1993) reported significantly reduced symptoms during a time period after sub-cutanious sterile water injections on the back of the neck. Bogduk (2000) reported pain relief in about 50 percent of the patients after coagulation of the small nerves that innervate the facet joint that is associated with the painful dermatome.

Soft tissue injuries have been found in several different structures and locations in the neck region in experimental studies and autopsy studies. In a recent study Yoganandan et al. (2000) reported injuries to several ligaments, the intervertebral discs and the facet joint structures. Siegmund and Brault (2000) and Brault et al. (2000) presented indications of muscle injury due to eccentric muscle loading in the early phase of the neck motion in rear impacts. Taylor et al. (1998) reported interstitial haemorrhage in cervical dorsal root ganglia in an autopsy study of victims who had sustained severe inertial neck loading during impacts to the torso or to the head. The structures around the ganglia were mostly uninjured. These findings correlate to experimental findings in pigs of nerve cell membrane dysfunction in cervical spinal root ganglia reported by Svensson et al. (2000).

It appears likely that several types of neck injury may appear as a result of a whiplash trauma (muscles, ligaments, facet joint, discs, nerve tissue etc.). Several injury types may be present in the same patient at the same time. The relation between these possible injuries and the large set of known whiplash symptoms is unclear. It would be of particular interest to know which one (ones) of these injuries that would result in long term symptoms and central pain sensitisation. It would then also be of interest to know which injury mechanism is responsible for this particular injury.

At the initial symptom stage, arm pain and high symptom intensity seem to correlate to an increased risk of long term consequences (Sturzenegger, 1995; Karlsson et al., 2000). The apparent influence of the crash pulse on the risk of long term consequences in patients with initial symptoms (Krafft, 2000) indicate that there could be a separate injury and a separate injury mechanism behind the long term symptoms. This particular injury could in the acute stage often co-exist with other injuries that normally heal without causing residual pain. Sturzenegger et al. (1995) found a higher risk of long term symptoms in those patients that were injured in a rear end collision and this may indicate that one particular injury (which may cause long term symptoms) is more likely to occur in a rear impact.

In more peripheral parts of the body most of these injury types (tissue types) normally recover without long term pain and central pain sensitisation. Is there something special about the neck region that makes one or several of these injuries result in long term pain? Cavanaugh (2000) for instance, explained that the facet joint capsules are particularly rich in nerve endings why an injury at this point would be a likely reason for long lasting pain. This pain may cause referred pain in e.g. the shoulder region. Facet joint capsule strain and pinching has been shown in post mortem human subjects in rear impact testing (Yoganandan and Pintar, 2000b; Deng et al., 2000). It is however not known whether the same type of mechanisms may occur also in side impacts and frontal impacts. Is there some type of structure that is unique for the neck? The spinal nerve root ganglia would be an example of such a structure. Cavanaugh (2000) explained that injury to the dorsal root ganglia is likely to cause radiating pain to dermatomes of for instance the shoulders and the arms. These symptoms are, as mentioned earlier, known to correlate to increased risk of long term consequences. Cervical dorsal root ganglion injuries have been observed in various impact directions (Svensson et al., 2000, Taylor et al., 1998) and would explain the similarity in symptoms between different impact directions.

Neck kinematics

A number of experimental studies on volunteers and post mortem human subjects have been reported. There is a relatively good view of the overall body kinematics in different crash directions.

Derived from the kinematics, several biofidelity requirements have been formulated and were used as a basis for the development of rear impact dummies. The typical neck loading in a car accident is caused by the acceleration of the torso resulting in an initial neck bending motion illustrated in Figure 1a. This event is usually followed by a rebound of the body due to the elastic recoil of the seatback. At the end of the rebound motion the neck may undergo a motion similar to the illustration in Figure 1b. The thoracic spine normally undergoes some type of bending motion in this type of event. In rear end collisions the thoracic kyphosis is straightened resulting in an elevation and a rearward tilt of the T1 vertebra (Davidsson et al., 1998; van den Kroonenberg, 1998; Ono et al., 2000). Several studies have focused also on the detailed motion of the cervical spinal segments during rear-end impact loading (Ono et al., 1997; Panjabi et al., 1999; Winkelstein et al., 1999; Youganandan and Pintar, 2000b; Deng et al., 2000). The intervertebral motion appears to deviate from normal physiologic human neck bending motion.

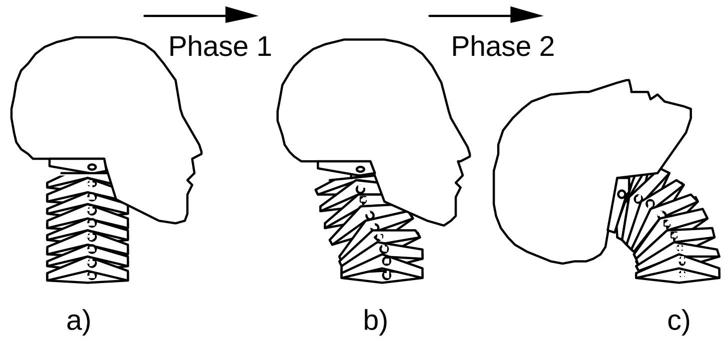

Figure 1a: Schematic drawing of the head-neck motion during the early part of a rear-end collision.
Phase 1: Retraction motion
Phase 2: Extension motion

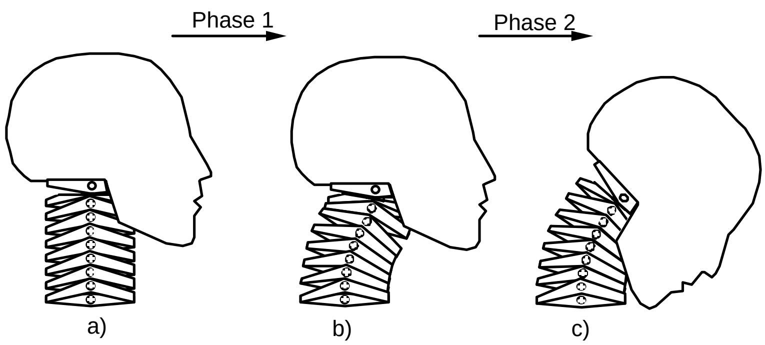

Figure 1b: Schematic drawing of the head-neck motion during rebound or during a frontal collision.
Phase 1: Protraction motion
Phase 2: Flexion motion

Injury Mechanisms and Injury Criteria

Several neck injury mechanisms and neck injury criteria have been proposed during recent years. Two criteria, Nij (Kleinberger et al., 1998; Kleinberger et al. 1999) and Nkm (Muser et al., 2000), use combinations of neck loads to predict the risk of injury to the skeletal spine. The IV-NIC (Panjabi et al., 1999) uses the angular displacement between adjacent vertebrae to estimate the risk of injury to various structures of the intervertebral joints. Viano and Davidsson (2001) introduced the Neck Displacement Criterion (NDC), a new injury criterion based on neck displacement. OC rotation was plotted against OC x-displacement and OC z-displacement and envelopes for different degrees of injury risk were proposed The correlation between these three injury criteria and the risk of long term soft tissue neck injury has not yet been established. The Neck Injury Criterion (NIC) (Boström et al., 2000) uses differential horizontal acceleration between the head and the T1 vertebra to assess the neck injury risk. The NIC was initially based on experimental injury findings summarised by Svensson et al. (2000). NIC would also function as a predictor of other types of injury mechanisms and indications of correlation between NIC and long term neck injury risk have been presented (Boström et al., 2000). The lower neck moment is sensitive to seat design parameters (Prasad et al.,1997; Song et al., 1996). Lower neck loads are also consistent with the facet-based injury mechanism supported by the works of Yoganandan et al, Ono et al., Deng et al. In rebound, the rebound velocity or the seat belt load may be used as injury criteria.

The Nij, Nkm, NIC, NDC and lower neck moment can be applied to current rear impact dummies. Reference values have to be adapted to the chosen dummy. The validity of all these criteria, in predicting the injury risk, needs to be established.

Conclusions

• The injury symptoms are well known both regarding type and duration.

• The injuries causing the acute symptoms are not known though several possibilities have been suggested in the literature. Several injuries may coexist and cause very similar symptoms. It is unknown if one or several of these injuries could cause chronic neck symptoms. The relation between acute injury and chronic pain is not known and the origin of the chronic pain is not known. Strong indications however exist for central nervous system pain sensitisation in the chronic stage.

• The head and neck kinematics during whiplash trauma is relatively well known. The Whiplash II project will add more data.

• Several injury criteria have been suggested but none of them have been adequately evaluated. Indications of correlation to injury risk in field accident data have however been presented for NIC.

• There are three ways that injury criteria could be verified:
1) By identification of the actual acute injury that causes chronic pain. This would probably tell us which injury mechanism is the cause.
2) Evaluation of proposed criteria against experimental data where certain injuries have been caused and where injury threshold levels can be identified (this will however leave an uncertainty about the relation between the observed injuries and the symptoms experienced by living patients)
3) By high quality evaluation against field accident data.

• An injury criterion with proven correlation to injury risk is a requirement for a future test procedure. Several promising candidates have been presented. It is not clear when such a criterion will be available. There are however several promising activities under way, such as the EU project Whiplash II, which will investigate this further. An injury risk function should also be developed for the criterion that finally is selected. Injury risk should be presented as a function of for instance mean acceleration or delta-v.

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Annex 3: Dummies used for rear impact protection evaluation

For car seat evaluations or ratings there are two basic methods available: a static evaluation and a dynamic evaluation. The static measurement estimates the quality of the head restraint position of which ratings are documented by RCAR, while the dynamic method relates the quality of the entire seat to measurements in rear impact dummies.

During the past few years several dummies have been evaluated for the use in rear impact testing. Some of these have been designed specifically for rear impact. The purpose is to introduce these dummies shortly and to present the findings of the evaluations in order to make a correct assessment of their validity for rear impact testing.

The evaluation of biofidelity has its main focus on kinematic behaviour and does not specifically focus on loads measured in dummies as compared to those calculated in human testing. The reason is that there are assumptions made for the calculations of the human neck loads, which are not easily comparable to dummy load measurements. For instance, the Occipital Condyle joint in a dummy is a hinge joint, while in the human the OC is surrounded by other load bearing tissue.

In general all dummies presented need to be used in a thermally stable environment of about 20^{o}C. The thermal sensitivity of the materials used and reports of the effects on the dummy's response are generally not available.

H-point machine with Head Restraint Measuring Device

For static measurement of the head restraint position with respect to the human head, the H-point machine was extended with a Head Restraint Measuring Device (HRMD). The extended H-point dummy is the only device related to static measurements. The procedure used and the associated quality rating is defined in a procedure by RCAR.

BioRID II dummy

This dummy was designed by Chalmers University of Technology (Davidsson, 1998 & 1999). The BioRID I was updated to the prototype BioRID P3, which is being manufactured by R.A. Denton Inc. under the name BioRID II.

The dummy has a multi-segment spine, representing all the vertebrae in the human body. The dummy shows biofidelic behaviour in most responses, compared to volunteer experiments performed earlier at a low delta V (7-9 km/h). Also the typical s-shape in the neck, causing head lag, is present in the BioRID II. The only differences found relate to the spine straightening and the head rotation, but these are rather minor. The dummy was shown to be very repeatable, but also sensitive to ringing of the spinal structure (Kim, 2001). A comparison of the BioRID II and prototype BioRID P3, which are almost similar, shows that the dummy is reproducible as well.

Strengths: good kinematics, repeatable & reproducible
Limitations: 2D spine and neck; limitations in instrumentation

Hybrid III dummy (and TRID neck)

This is the most commonly used dummy for both frontal and rear impacts, although it was originally designed for frontal impact. The performance at high severity rear impact seems rather good (Prasad, 1997), but the performance in low severity (whiplash) cases is rather poor (Scott 1993, Davidsson 2000, Cappon 2001a). The main problems in low severity impact relate to the rigidity of the spine, the limited flexibility of the hip joints and the stiff neck, showing no head lag. Even the addition of a more flexible 2D TRID neck (Thunnissen, 1996), does not result in a biofidelic response.

Strengths: repeatable and reproducible; 3D neck; large instrumentation capabilities
Limitations: limited kinematics for low severity rear impact

RID2 dummy

The RID2-α prototype dummy was originally designed and built within the European Whiplash Project (Cappon, 2001b). The dummy was later updated to a commercial version, called RID2, by FTSS (Cappon, 2001a).

The RID2 is a 2½ D dummy, which means that it is not meant for 3D use, but yet can handle oblique rear impacts. The back shape of the dummy is based on the UMTRI data and reflects the 50^{th} percentile male human back shape, ensuring human like seating. The dummy was evaluated against low severity volunteer tests (5g) and higher severity PMHS tests (12g). Most of the responses are biofidelic and the RID2 shows the typical s-shape in the neck. However, the dummy showed limited ramping up and lower neck rotations. Furthermore the dummy was found to be repeatable and reproducible.

Strengths: repeatable and reproducible; large instrumentation capabilities; good kinematics
Limitations: ramping up, T1 rotation

THOR dummy (and THOR Beta neck)

The THOR dummy is commercially available at GESAC. It is a frontal impact dummy with a more biofidelic frontal response than the Hybrid III, which has been evaluated for rear impacts as well. There is also a THOR Beta neck, which is a retrofit to the Hybrid III dummy. Also this neck has been tested in rear impact.

No papers or reports have been published on the THOR dummy and THOR Beta neck performance in rear impact. This part reflects the findings of internal evaluations at TNO as well as those found in a Japanese presentation at ISO. The rear impact performance of the THOR shows enough flexibility in the neck, but no head lag. There is very little flexibility in the spine and thus limited T1 rotation, neither is there any ramping up of the pelvis. Repeatability in rear impact is nevertheless very good.

Strengths: repeatable; extensive instrumentation capabilities
Limitations: moderate kinematics in low severity rear end impact

Discussion

The static measurement procedure defined by RCAR uses an extended H-point machine. The question of this method is, whether the quality assessment reflects the safety of a seat in dynamic rear impact. Furthermore, the Head Restraint Measuring Device is based on an H-point machine, designed to find the H-point of a seat. The back geometry of this machine may not reflect the human back geometry and therefore also the HRMD head may end up in a different position than found in the average human. This is of concern for the design process, since a different head restraint distance will be found in dynamic testing using a rear impact crash dummy.

Based on the findings in dynamic rear impact testing, the dummies which are most likely to be useful for rear impact testing are the BioRID II and the RID2. The BioRID II has the advantage of being more established and accepted in automotive industry, while the RID2 is just released. The advantage of the RID2 is the wider instrumentation capabilities, like the lower neck and lumbar load cells and its capabilities to handle oblique impacts. Currently, the BioRID II is being changed to allow lower neck load measurements. Both dummies still have practical limitations, which are solved throughout the course of their use. For either dummy a certification procedure for the neck and/or spine is being developed, but not documented and available officially. The Hybrid III is not suitable for low severity rear impact, due to its limited biofidelity, even though it is being used worldwide with and without a TRID neck.

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Annex 4: Report on Current Industry Status on Car Design / Seat Design

Revue of Current Knowledge: Car Design/Seat Design

Soft tissue neck injuries are the most frequently occurring injuries in motor vehicle crashes and are most evident in low speed impacts. Current research work has focused largely on the kinematics of the occupant and has illustrated the vital role that the head restraint and seat systems play in the prevention of an injury. Other factors also influence injury outcome and these include the stiffness of the partner vehicles and their relative structural engagement.

Vehicle Structure Research

There has been a limited amount of research work conducted into vehicle structural characteristics. However it has been shown that structural characteristics do have a significant influence over injury outcomes in low speed rear impacts. The following summaries the available body of research:

Since 1996, the Swedish insurer Folksam has fitted crash pulse recorders to record acceleration pulses occurring in real world crashes. Krafft (1998) reported that acceleration pulses can vary in shape, duration and magnitude in impacts that featured similar changes of velocity delta V. The risk of AIS1 neck injuries has been found to be related to both delta V and acceleration pulse. Injury symptoms are often reported to be similar in crashes where the calculated delta V's vary considerably. Zuby (1999) reported a great variety of impact pulses in car to car impact tests although many resulting pulses displayed common characteristics. Typical deltaV's at which injuries are most often reported are between 10-30 km/h (Hell, 1998), however, a great variety of impact types are seen with differing overlaps. A higher pulse was estimated to have occurred where stiff vehicle structures engage. It has been suggested that cars produced in the late 1990's have a stiffer structure than those produced before this time and that this stiffness trend will continue (Muser 2001, Avery 2001). During low speed insurance crashes Linder (2001) reported that the newer vehicles tested produced stiffer pulses with higher peak magnitudes and of a shorter duration at similar delta V's. Avery (2001) reported a comparison of vehicles produced during the 1980's, 1990's and 2000's, which supported this increasing 'stiffness' trend. This trend may well lead to an inevitable rise in injury claims. Recent real world insurance data supports this hypothesis by indicating a corresponding rise in injury risk for these latest stiff vehicles compared with older vehicles with similar seat designs. This steady increase in vehicle stiffness has been attributed to changes in vehicle design and has been driven by: NVH (noise, vibration and harshness); the increased emphasis on handling and ride requirements; the objective of minimising intrusion during offset deformable barrier tests; and the low speed insurance offset test. The insurance test may well have the biggest influence in local perimeter stiffness as the vehicle manufacturers strive to limit damage during the low speed, solid barrier test.

A Ford study by Heitplatz (2001), using the latest generation of cars, has shown that pulse shape, peak magnitude and signal length do not vary significantly between vehicle masses. These tests employing different Ford models, impacted by the same bullet vehicle, indicated that modern vehicle structures exhibit similar performance characteristics.

Insurance research by Avery (2001) has indicated that crash pulse characteristics vary between identical vehicles featuring different levels of bumper stiffness. The softer bumper systems induced more override and lead to a corresponding rise in cosmetic damage. However, the vehicle acceleration pulses produced were of a similar time duration and peak magnitude, leading to similar injury values. It can be hypothesised that, although local stiffness affects the onset of acceleration, it plays a less significant role in peak acceleration magnitude than the main chassis stiffness.

A study by Linder (2001) showed a comparison of five different seat designs tested using 4 different pulses. The same delta V produced with different peak accelerations generated differing dummy responses. Peak NIC and Peak Fz (as assessed by the BioRID dummy) were all more influenced by the change of acceleration pulse than the change of delta V, the highest valves being observed in identical seats where the peak crash pulse occurred earlier and at a higher magnitude.

In a yet-to-be-published Insurance study by Avery and Zuby (2002) three different car seats were tested using seven different pulses to assess the effect of pulse characteristics on dummy responses. It was found that the initial onset of acceleration and the peak magnitude had the largest influence on Peak NIC and Peak Fz than either signal length or delta V. (Note – It assumed that NIC and peak Fz are good predictors of whiplash injury risk)

Seat Design

There is good evidence that seat design plays a pivotal role in AIS 1 neck injury in the event of a rear impact (Svensson 1993). Recent studies have shown that seat and head restraint design is of greater significance in mitigating soft tissue neck injuries than vehicle stiffness (Viano 2001) and has indicated that seat stiffness, strength and geometry are of vital importance in injury causation (Hell 1998). Also influential is head restraint geometry and their ability to lock in position once adjusted rather than to move easily to another position with minimal effort.

The RCAR head restraint measurement protocol (1999) uses the ICBC Head Restraint Measuring Device to geometrically assess the performance of a head restraint. Although the static assessment of head restraint geometry is simplistic it has been shown to be effective in the assessment of injury risks (Chapline 1999, Farmer 1999). A US study of real-world crashes indicated a reduction in injury severity in vehicles where head restraints were rated as ‘good’ as opposed to those where the rating was ‘poor’. Vehicles with seats which fit higher and closer to the occupant’s head have been associated with lower injury rates.

During dynamic studies head restraint geometry has also been shown to be of significance. A study by Zuby (1999) illustrated that vehicles fitted with ‘good’ head restraint geometry often displayed lower dynamic dummy responses than those rated as ‘poor’. Linder (2001) found that a standard seat when tested with the head restraint down produced higher NIC and neck moments than when the seat was tested with the head restraint optimally adjusted.

Studies have shown that seats have become stiffer during the 1990’s. This can be attributed to increased comfort requirements (the addition of more electric adjustments) and for the stable deployment of thorax airbags). Studies have also shown the significance of the seat’s structural characteristics. Kraft (2001) has shown that where similar vehicles were fitted with differing seats differing injury outcomes can occur. The study compared injury outcomes of Saab 93 and Opel Vectra occupants and found a 5 times lower incidence of whiplash injuries in the Swedish vehicle. However, both vehicles are based on identical GM platforms and share similar structural characteristics. The differences in injury outcomes were attributed to the ‘poor’ geometry of the Opel head restraint and its poorer seat performance.

Viano (2001) has shown the advantages of higher seat back yield strength and taller seat geometry and Ono (1998) illustrated the advantages of energy absorbing, tuned foam in the reduction of occupant acceleration. However, an insurance study by Avery and Zuby featuring seats with similar ‘poor’ head restraint geometry but with differing yield strengths, showed that the stiffer seats can produce higher dummy responses due to occupant ramp up and poor head control.

A good seat design involves controlled yielding of the seat back in the event of a rear crash since this can reduce the relative motion between head and torso. Linder (2001) found that a standard seat when locally stiffened produced higher occupant accelerations than with an un-modified seat. Current production seats may induce neck injury in the event of a rear impact where seat stiffness is high but head restraint geometry poor. However seats that feature stiff seat backs, tall seat geometry and utilize energy absorbing foam, where used in conjunction with good head restraint geometry appear to be of significant benefit in injury reduction.

New seat systems have been designed to reduce the relative motion between head and torso by controlling backset automatically. So called ‘active’ head restraints are now appearing on many models and operate by using the occupants mass to deploy a spring cantilever system that reduces the backset whilst raising the head restraint to meet the occupants head.

Saab pioneered the fitment of active head restraints on their 9-5 model. (Wiklund 1998). This system has now been in the market place to allow sufficient insurance data to be assessed. In a recent study by Viano (2001) 85 rear end impacts were studied featuring two different types of Saab vehicles, fitted with standard seats. A second data set featured 92 similar Saab vehicles fitted with active head restraints were then compared. The percentage reporting no injury increased by 25%. Those reporting short term injury remained static but those reporting long term injury showed a 75% reduction. Laboratory tests supports these data by showing a corresponding reduction in dummy injury response values (Linder 2001). However some active systems have been designed and validated using the Hybrid III and so do not always deploy effectively when tested using a biofidelic rear impact dummy (Zuby 2001) and therefore may have limited real world benefit. (Note – It is believed that the BioRID dummy is a much more biofidelic dummy than the Hybrid III in rear impact)

Volvo pioneered a different approach with their anti-whiplash Whips seat (Jakobsson 1999). This seat uses a fixed head restraint featuring good geometry. However the seat also contains a recliner mechanism that is designed to allow a controlled rearward motion of the backset to maintain the relative acceleration of the torso and head of the occupant the energy of a crash has been absorbed. Insurance data is not yet available to support the benefit of the system, but several studies (O'Neil 2000, Hell 2001) have demonstrated its performance advantages when tested against other non-active seats under laboratory conditions.

In a comparison of five differing seat designs by Linder (2001) it was found that both active head restraints and active seat systems can reduce head relative to torso accelerations and that these seats produced lower dummy responses than standard seats.

It has been suggested that the elastic properties of the seat are also a characteristic that affects injury outcome (Muser 2000). Here the significance of the rebound phase of the occupant in low speed rear impacts was researched and was shown to be a possible injury mechanism. The highest frequency of whiplash injuries is reported to occur in impacts of 16 km/h change of speed and so most of the current research work has focused on tests using this delta V. However any future dynamic whiplash evaluation must include tests at other velocities (Langweider 2001). Seat tests at lower velocities will ensure the effectiveness of active head restraint systems to prevent sub-optimisation and tests at higher velocities will ensure that seats do not catastrophically fail leading to spinal compression injuries and seat ejection.

Summary

1. Vehicle structures are reported to be getting stiffer. This may be due to enhanced crash performance driven by among other things, the low speed insurance impact and may have lead to an increase in whiplash type injuries. Although some attempt could be made at the local softening of perimeter structures the main focus of whiplash injury reduction must be with the enhancement of seat back and head restraint performance. Good head restraint geometry has shown to be effective in mitigating soft tissue neck injuries.

2. Seat back yield-strength has increased for a number of reasons. Current research suggests that where high yield strength seats are used in conjunction with 'good' head restraint geometry a reduction in injuries is observed. Advanced seats, some of which are fitted with active head restraints, have been shown to be effective at improving head restraint geometry, however systems must be optimised through the use of a biofidelic rear impact dummy and be suitable for different sizes of occupant.

3. A combination of increasing vehicle stiffness and seat yield strengths is leading to a rise in reported whiplash injuries.

4. Initial Insurance data supports the improved performance of active designs. Active seat systems also show promise under laboratory conditions however there remains little real-world evidence as to their effectiveness.

5. Any future dynamic whiplash test assessment must feature a range of impact velocities to prevent component sub-optimisation.

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Annex 5: Test procedures for the evaluation whiplash injury protection in rear-end impacts

The need of reducing the number of whiplash injuries has forced many organisations, such as car or seat manufacturers or research organisations, to develop test procedures. This need takes origin from different research results and from the target of the various organisations. For example consumer organisations that may want to make a comparison between different manufacturers. There are, for example, full vehicle tests including vehicle to vehicle tests and barrier to vehicle tests; sled tests including full car body tests and seat tests; component testing including dynamic and quasi static test.

Recent proposals within ISO have included sled tests for dynamic seat and head-restraint testing. The sled has been chosen principally for the following reasons:

1. It’s not a destructive test for the car but only for the seats, and it is thus much less expensive than a full scale test or a car to car test, in which a car or two must be sacrificed.
2. An occupant in a car may be exposed to a variety of crash pulses, independently of the structure of the car. Although, the car structure may definitely be able reduce the injury risk, the seat structure will be the most important part to test.
3. It is easier to make direct comparisons between the results of different kinds of seats.

Neck injuries is the most important injury type in rear-end impacts. The majority of these injuries occur at a delta-v of 10 to 15 km/h. This data emerged from the analysis of real world collisions. The delta-v levels proposed in the ISO proposals are three: 10, 16 and 30 km/h.

The low speed is suggested to avoid sub-optimisation and to see if active protective systems works also at this low speed. The medium speed is the delta-v where most injuries occur. The highest test speed is chosen to avoid seat collapse and to verify if the seat system ensures a certain level of safety also at higher crash severity.

In the different test procedures developed by different research organisations, we can find suggestions for the way in which the dummy should be positioned, the instrumentation, the high speed cameras and the photo targets needed and their positioning, etc. Most of these test procedures have a common origin that has been gradually upgraded as new knowledge has become available.

Some of the more established proposed injury criteria and the data required for the evaluation of the seat system are:

- The NIC (forward horizontal acceleration at head and T1 level);
- The N_{km} (based on the occipital F_x and M_y)
- The NDC based on head relative T1 displacement)
- The upper neck forces (F_x, F_z) and moment (M_y);
- The lower neck forces (F_x, F_z) and moment (M_y);
- Three axis accelerations of head centre of gravity and at the T1 level

- Head sagittal angular acceleration
- The neck extension angle
- The rebound velocity.

The performance requirements must be adapted to the chosen test procedure.

ISO/TC22/SC10/WG1 was given the task of compiling a specific test procedure to be adopted as a standard. During the development of this procedure, two specific needs became evident.

- An Anthropomorphic Test Device, addressed by WG5: ISO/TC22/SC 12
- Performance criteria expressed in biomechanical terms, addressed by WG6: ISO/TC22/SC 12

ISO found that these two areas needed further research/development before a complete ISO test procedure could be established.

Another evaluation system proposed for the head restraint, was developed by RCAR (Research Council for Automobile Repairs). This is a static method that evaluates the head restraint based on the geometric design and on the distances between the head and the head restraint itself. Dynamic properties of the seat system are not taken into account.

The NHTSA is working to upgrade the standard 571.202 for head restraints for passenger cars and for light multipurpose vehicles, trucks and buses. The proposal of the NHTSA would establish higher minimum height requirements for head restrains, and add a requirement limiting backset. It would also extend the requirement for head restrains to rear outboard designated seating positions; establish new strength requirements for head restrains; and place limits on the size of gaps and openings in head restraints. In addition, it would modify the dynamic compliance test and amend test procedures.

CONCLUSIONS

1) Several test procedures have been proposed for neck injury protection in rear end collisions. The currently most widely accepted method is a dynamic sled test of the seat system.
2) The background research of these proposals as well as the experience gained as some of these test procedures are being used will form a good input for a future EEVC working group in the development of a test procedure for regulatory testing.

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Annex 6: Research programs, on-going and finished

This document aims at giving a general view :
- on the main research programs (on going or recently finished) on whiplash injuries,
- as well as on the main active research laboratories involved in this field.

Whiplash I (finished) [Contract BRPR-CT9660221 / BE96-3770 / EU]
European consortium (PSA, Renault, Fiat, VW, TNO, GDV, Lear, FTSS, Graz university of technology), 1997-2000. The mains results are :
- Knowledge of real accidents permitting to guide the definition of crash scenario for test procedure
- Production of new bio-mechanical data from volunteer tests and cadaver tests. These data allowed the definition of a set of biofidelity requirements for human body substitute developments (dummies or mathematical models)
- Development of a rear impact dummy – RID2α
- Definition of a test procedure
- Benchmarking of European production seats

Whiplash II (on going) [Contract G3RD -CT2000-00278 / EU]
This European program is the continuation of the program Whiplash I. New members have joined to the Whiplash I consortium (Daimler Chrysler, Faurecia, Chalmers, Folksam, ETH, TRL). This project aims at : 1) consolidate the Whiplash I results (in particular for the rebound phase of rear impact) and 2) deal with the whiplash problem for frontal and oblique impacts. The results of this project concerning rear impact are :
- refinement of the knowledge of real accidents (long term injuries, more precise typical accident conditions)
- acquisition of new biomechanical data by volunteer and cadaver tests
- comparison of the existing dummies
- choice of injury criteria

Swedish programs (finished and ongoing)
Swedish research programs (Chalmers, Autoliv, Volvo, SAAB). The main results are :
- Acquisition of biomechanical data from volunteer tests [Davidsson et al. 1998]
- Development of a rear impact dummy – BioRID [Davidsson et al. 1999]
- Works on NIC [Boström et al. 1996]
- Spinal ganglion injury research, currently using a rat model [Svensson et al., 2000]

UK spinal injury program (finished, planned publication of results on June 2002)
Volunteer & dummy testing plus human and dummy modelling - includes the derivation of design target corridors).

IIWPG (on going)
The International Insurance Whiplash Prevention Group is formed of insurer-supported research centres (AZT, GDV, IIHS, and Thatcham). The objective of this working group is to co-ordinate their activities in whiplash injury prevention research, and in particular to develop dynamic test procedures to evaluate and compare seat/head restrain designs. The actual position of this group can be summarised as follows:
- Head restrains with good geometry are a necessary first step for whiplash injury prevention, but dynamic evaluation procedures also are needed.
- These procedures will be based on sled tests of seats/head restraints with standard pulses. Some full vehicle tests also may be included.
- A generic pulse of a ΔV of 15.8km/h was retained. Tests at lower and higher velocities should be also included.
- The group refuses the HIII, considers that the BioRID is the only dummy currently available with sufficient biofidelity in low to moderate speed rear impacts. The acceptability of RID2 will be re-evaluated when the modifications are completed and it becomes commercially available. It is anticipated that only one dummy type will be accepted for final use.
- The group considers that the current consumer tests are unhelpful or even counterproductive and could lead to future designs of unproven worth since the research into injury causation is still undefined.

- The group continue the research on crash pulse characteristics and dummy set-up procedures.

ISO (on going)
The GDV initiated test procedure proposal is in circulation for comments.

OSRP/USCAR (on going)
The Occupant Safety Research Partnership of the United States Council for Automotive Research has conducted a rear impact evaluation program to compare the BioRID II and H-III [Kim et al. 2001]. Their conclusion is characterised by very severe critics towards the BioRID II

Other active research laboratories than those involved in the above programs
- Medical College of Wisconsin, USA : cadaver tests, thesis on facet injury mechanism [Yoganandan et al. 2001].
- Wayne State University, USA : cadaver tests, thesis on facet injury mechanism [Deng et al. 2000].
- JARI, Japan : volunteer tests, thesis on facet injury mechanism [Ono 2001].
- MacInnis Engineering, BC, Canada : volunteer tests, dummy evaluation [Siegmund 2001]

Activities around the BioRIDII and the RID2
- A 50-percentile Female BioRID dummy **may** be developed if the financial support can be ensured. This project involves Thatcham, IIHS and other interested partners.
- A BioRID Users Group has been formed. This group works on the development of common procedures for seated position and many other things. They also give feedback to the producer of the BioRID II.
- Different programs (on going or planned) aiming at evaluation and comparison of the BioRIDII and RID2 around the world.

Conclusions
The ongoing and finalised research programs presented above have produced or will produce more data that would help the future EEVC working group (if created) to do good choices. Such a group can also play a role of interface between these research programs in order to converge them into an essential objective: the definition of a standard relative to the whiplash injuries mitigation for rear impact. Otherwise some of these programs could lead to a proliferation of test procedure, which consequently would produce negative effects on the interest of the European automobile industry and consumers.

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