EEVC WG20 Report – Working Document 80

Updated State-of-the-Art Review on Whiplash Injury Prevention

March 2005

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Summary

Rear impact and WAD type injury is a serious problem in terms of both injury and cost to society. 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.

Both mean and peak acceleration appear to be important crash severity parameters together with delta-v. Women have about twice the injury risk compared to men. Energy absorbing seats, active head restraints and good head restraint geometry all seem to be beneficial, based on claims evidence. Multiple test severities must be considered to avoid optimisation for a single condition and to test seat integrity at higher severity. Injuries other than neck injuries and impact types other than rear impacts need to be considered in the definition of a future test procedure.

Recently, more information regarding the choice of a neck injury criterion and a tolerance level has been published. Two injury criteria, N_{km} and NIC_{max} appear to correlate to long term neck injury risk. There are also risk curves available for the two criteria. The new data on injury criteria would fill the most important shortcoming identified by the EEVC ad-hoc working group (EEVC WG12 doc157).

The actual injury, causing the typical WAD symptoms, is however still unknown (though several hypotheses exist), and the injury mechanism has thus not been established. The evaluation of the currently proposed injury criteria (LNL, N_{km}, T1-rebound velocity, NIC, NDC, IV-NIC etc.) and the calculations of the associated risk curves are however not founded in biomechanical research but instead statistically derived from field accident data and reconstructions of real world accident situations. Provided that the EEVC Steering Committee will approve of validation of injury criteria based on statistical analysis of field accident findings, the WG20 appears to have a reasonable chance of establishing a test procedure proposal in accordance with its terms of reference (ToR of October 2003). Preliminary, unpublished results from EU-Whiplash2 (May 2004) do however call for caution. They indicate better correlation to injury risk with LNL. Therefore further work to investigate the statistical methods behind these studies is needed and this adds some uncertainty about the time frame of the WG20 ToR.

1 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. In year 2000 EEVC Steering Committee asked the EEVC WG12 to create an ad-hoc working group to investigate the possibility of developing an EEVC view on rear impact and WAD injury. The ad-hoc group, in its report (EEVC WG12 doc157), found that there was significant amount of research data available and that interesting and promising research project were ongoing. It recommended the EEVC Steering Committee to start up a new activity with the aim of developing a proposal for a new European regulatory test for whiplash injury (AIS1 neck injury) protection in rear-end collisions.

The EEVC Steering Committee initiated one new working group, WG20, and it also gave the WG12 additional terms of reference regarding the selection of an appropriate crash dummy for the rear impact test procedure.

WG20 Terms of Reference:

EEVC WG20 - Rear Impact test procedure(s) and the mitigation of neck injury

1. Develop test procedure(s) for rear-end collisions, with a prime focus on neck injury reduction (Whiplash).
2. Draft proposal(s) and report to the Steering Committee within one year of the first meeting.
3. Evaluate the proposed test procedure(s) in laboratory conditions and, if needed, make appropriate adjustments to the procedure(s).
4. Write final test procedure proposal(s) and report to the Steering Committee within two years of the group's first meeting.

Terms of Reference explanatory comments.

- The test procedure(s) should include a dynamic sled based test using generic crash pulses, unless it can be shown to be inappropriate.
- Test conditions should be appropriate with regard to real world accident data.
- Appropriate injury criteria, to be measured in the dummy, will be selected in association with EEVC WG12.
- In order to ensure that one injury risk (neck) is not reduced with an increase in other injuries (e.g. spine, or soft tissue), due regard should be given to a holistic approach to rear impact injury risk reduction.
- The test procedure(s) must address the range of vehicle properties that can influence occupant loading as a function of the vehicle crash pulse, e.g. use of the seat-belt system and the seat system with vehicle body attachment points.
- The procedure must include consideration of active safety systems that are triggered by crash sensor information, pre-crash sensor information or occupant interaction(s) and position.
- The test procedure(s) assessment parameters must correlate to injury risk.

- A close relationship should be established with EEVC WG12, the Biomechanics group, regarding the selection of the most appropriate dummy, injury criteria and injury risk probability relationships. WG20 will be responsible for co-ordination with WG12.
- WG20/WG12 will select the most appropriate size of dummy for the test procedure(s).
- WG20 will supply WG12 with all the necessary input data regarding crash conditions, instrumentation and requirements and the interface between dummy and test set-up.
- Any procedure(s) must have regard to other impact conditions and impacts severities, to avoid sub-optimisation of safety system design, as well as existing standards and regulations.

The aim of the present report was to upgrade the review of the EEVC Ad-Hoc group on whiplash injuries (EEVC WG12, Document N°157). 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

The WG12 Chairman has introduced the following 5-step approach that will lead to the selection of a crash dummy:

1) Selection of biofidelity requirements

2) Review and analysis of biomechanical evidence for injury criteria

3) Review of other dummy requirements

4) Review of existing dummies and their performance

5) Recommendation of one dummy

2 Summary of Task Reports

2.1 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 3g. 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. Women have about twice the injury risk compared to men. However, most of the 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 are known. Those injuries leading to WAD symptoms lasting more than one month were found to occur at approximately 20km/h and 5g respectively, while those recovering within a month had approximately 10km/h and 4g respectively. The average values for occupants classified as WAD Grade 2 and 3 was approximately 16km/h and 5g. 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 impact speeds there is an increased risk of uncontrolled seat back deflection or failure 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 trends world wide (except deviations from different social security and insurance systems in various countries).

2.2 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 the 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. 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. This method is denoted “black-box approach” within EEVC WG20.

Current injury criteria are acceleration based, like NIC, velocity based (T1 rebound velocity), displacement based (IV-NIC and NDC) or load based, like N_{km} and LNL. A few of these proposed injury criteria, e.g. NIC, have been used in different versions and this must be taken into account when making comparisons. IIWGPG uses a combination of such measurements in a seat performance criterion. 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.) The term WAD - Risk Assessment Parameters (WAD-RAP) was introduced as a replacement for “injury criteria” in the present situation where the actual injury causing the WAD symptoms is unknown.

From a regulatory perspective it is essential that there is a good correlation between the WAD-RAP and risk. Any given WAD-RAP should be accompanied by a risk function. Some recent findings, verified according to Principle 3 above, indicate that NIC_{max} and N_{km} fulfil these requirements. These findings are based on data from a few Toyota car models and were primarily evaluated in a mathematical model. A wider data sample covering more car models as well as an evaluation of the applicability of the criteria in sled testing would be desirable.

2.3 Dummy Development

Currently the dummies, which are most likely to be useful for rear impact testing, are the BioRID II and the RID2 or RID^{3D}. 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 RID is more recently released. The prototype RID^{3D} is a further development of the RID2 with improvements in the rebound phase and in ramping. One advantage of the RID2 / RID^{3D} is its slightly wider instrumentation capability, - the lumbar load cell and its capabilities to handle oblique impacts. All three dummies still have practical limitations, which are likely to be solved throughout the course of their use. There is an ongoing world wide evaluation of these, which has lead to stepwise adjustments. This process is expected to make them acceptable in a regulatory framework. Appropriate setting up and certification procedures are also evolving during this 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. For head restraint geometry evaluation the H-point machine was extended with a Head Restraint Measuring Device (HRMD) which is used in a rating procedure by RCAR. Various versions of the H-point machine exist and the difference between the versions requires investigation. Recent ADAC testing has indicated significant reproducibility problems in the set-up of the H-point machine and the HRMD.

2.4 Car Design, Seat Design

Vehicle structures are reported to be getting stiffer, since the mid 1990s and this trend in increasing stiffness is continuing. This may be due to enhanced crash performance driven by among other requirements (e.g. the low speed insurance impact test and high speed frontal tests) and may have lead to an increase in whiplash type injuries. Although some attempt could be made at the local softening of perimeter structures of the vehicle the biggest gains in mitigating whiplash injuries is expected to come from the enhancement of seat back and head restraint performance.

Within seat design, good head restraint geometry has been shown to be important in mitigating soft tissue neck injuries, although occupant kinematic control and effective energy management are also shown to be of importance.

Seat back yield-strength has increased and along with other parameters is leading to a rise in reported injuries. Current research suggests that where high seat back yield strength is used in conjunction with ‘good’ head restraint geometry a reduction in injuries is observed.

New improved head restraint and seat systems have been shown to be effective at improving the neck injury protection. For such systems to be effective, energy absorbing capability could be employed to reduce occupant energy whilst controlling head and thorax motion and good head restraint geometry could be utilised to gain early contact between head and head restraint.

Any future dynamic whiplash test assessment may have to feature a range of impact velocities to prevent sub-optimisation of these systems.

2.5 Test Procedures

Several proposals for procedures for whiplash protection assessment in rear impact have been brought forward and partly implemented in different forums (e.g. ISO, IIWPG, SNRA, ADAC, EuroNCAP, NHTSA) in recent years. Static as well as dynamic test procedures have been developed. Most of them have the same origin and are gradual upgrades that have been included as new knowledge has become available. Most of the procedures include a dynamic sled test of the seat using a modern rear impact dummy. The speed changes proposed are first of all 15-16km/h and in some cases additional tests in the range 10 to 30km/h have been proposed. The low speed tests are intended to avoid sub-optimisation and the high speed tests are proposed for evaluating seat integrity. Currently a generic acceleration pulse is commonly used. Several injury criteria or assessment parameters are suggested. A static geometrical head restraint rating is currently used by RCAR.

2.6 Research Programs (On-going 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) www.passivesafety.com/whiplash2.
- 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. A decision on a test procedure is expected in the spring 2004. It will not include a final decision on a crash dummy nor on any injury criterion.
- 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.
- NHTSA is working on upgrades of FMVSS 202 and 203. An evaluation of the currently available dummies is carried out. An FMVSS 202 NPRM has been postponed until November 2004, awaiting further input on a dynamic optional test.
- Examples of other active research laboratories:

  TU Graz, Austria

  Allianz ZT, Munich, Germany

  ETH, Zurich, Switzerland

  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).
- ACEA repeatibilty and reproducibility of proposed rear impact whiplash protection test procedures.

3 Conclusions

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. The WAD symptoms are well documented but the actual injury remains to be established even though several injury locations and injury mechanisms have been suggested. The dynamic motion of the human head-neck system during a rear end collision is known. To date several special test dummies and test devices have been developed for the assessment of WAD injury and several test procedures have been developed, static and dynamic.

Both mean and peak acceleration appear to be important crash severity parameters together with delta-v. Women have about twice the injury risk compared to men. Energy absorbing seats, active head restraints and good head restraint geometry all seem to be beneficial, based on claims evidence. Multiple test severities must be considered to avoid optimisation for a single condition and to test seat integrity at higher severity.

The WAD-RAP's NIC_{max} and N_{km} appear to correlate to real world risk of WAD causation and risk curves have been presented based on field accident findings from a limited number of Toyota car models.. New data from EU-Whiplash2 provide other indications with LNL being the most interesting criterion. F Further work is needed before a WAD risk assessment parameter (LNL, N_{km}, T1-rebound velocity, NIC, NDC, IV-NIC etc.) can be finally established. The exact injury site has still not been established and thus no biomechanical explanation to the injury causation is available. A biomechanical evaluation of an injury criterion is not expected in the near future. Injuries other than neck injuries and impact types other than rear impacts need to be considered in the definition of the test procedure.

The BioRID II and the RID2/RID3D are the best suited dummies for rear impact whiplash prevention testing.

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 the 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 in Sweden 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 and 20% (depending on accident data source and definition of long-term injury) 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.

A Swiss study on CSD in cases with long sick leave times showed that a history of neck injury (pre-existing damage or pre-existing signs and symptoms) has a significant influence on the overall assessment (Schmitt *et al.* (2002)).

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 1100 Million Euro 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 200000 reported cervical spine injuries after rear-end collisions for the year 1990 only in former Western-Germany. For 2000 a higher amount of 2 Billion Euro for Germany can be assumed because of increased incidence (Hell *et al.* (2001)) 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 Dollars (IIHS)
- UK, 800 Million Pounds (Direct Line)
- Canada, British Columbia/CDN 270 Million US Dollars (ICBC)
- European Union, *roughly at least* 10 Billion Euro (Whiplash 1)

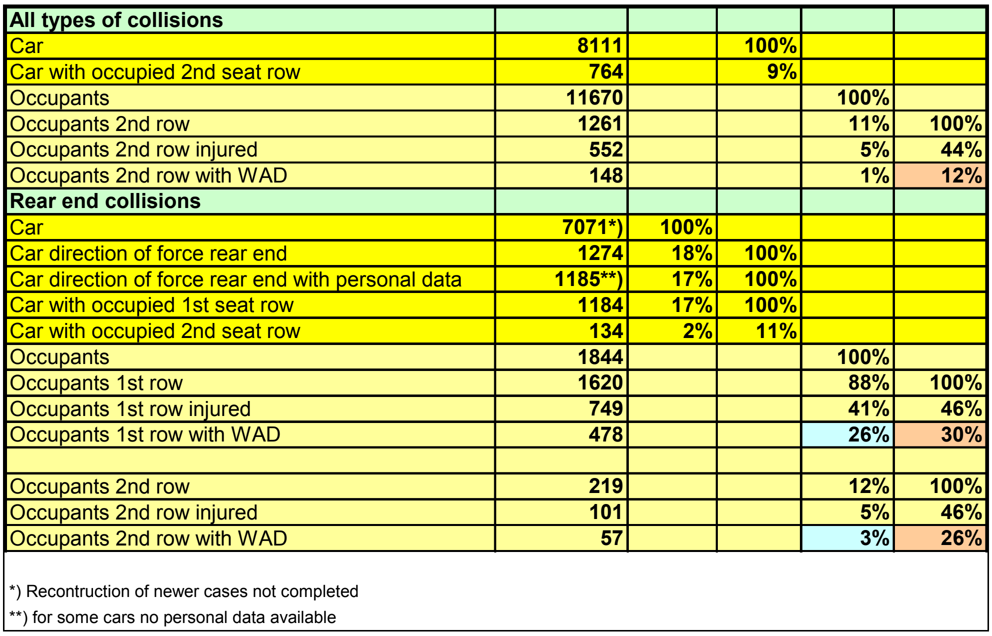
Accident Conditions and Risk Groups

The medical and societal consequences of neck injuries due to rear impacts 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 15000 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 an impact angle between -5 and 5° 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 as detailed by Temming and Zobel (1998).

Females tend to have a higher injury risk compared with males (Hell *et al.* (1999); Maag *et al.* (1993); Krafft (1998); Ydenius and Kullgren (2001); Berglund (2002)).

The risk of permanent disability was four times higher for females than for males in the rear seat (Krafft *et al.* (2002)).

A preliminary analysis of current GIDAS data shows the distribution of WAD with regard to the seating position (c.f. Table 1-1, Lorenz, Sferco 2003).



All types of collisions					
Car	**8111**		**100%**		
Car with occupied 2nd seat row	**764**		**9%**		
Occupants	**11670**			**100%**	
Occupants 2nd row	**1261**			**11%**	**100%**
Occupants 2nd row injured	**552**			**5%**	**44%**
Occupants 2nd row with WAD	**148**			**1%**	**12%**
Rear end collisions					
Car	**7071*)**	**100%**			
Car direction of force rear end	**1274**	**18%**	**100%**		
Car direction of force rear end with personal data	**1185**)**	**17%**	**100%**		
Car with occupied 1st seat row	**1184**	**17%**	**100%**		
Car with occupied 2nd seat row	**134**	**2%**	**11%**		
Occupants	**1844**			**100%**	
Occupants 1st row	**1620**			**88%**	**100%**
Occupants 1st row injured	**749**			**41%**	**46%**
Occupants 1st row with WAD	**478**			**26%**	**30%**
Occupants 2nd row	**219**			**12%**	**100%**
Occupants 2nd row injured	**101**			**5%**	**46%**
Occupants 2nd row with WAD	**57**			**3%**	**26%**

*) Recontruction of newer cases not completed

**) for some cars no personal data available

Table 1-1: WAD with regard to seating Position, preliminary analysis of GIDAS data (Lorenz, Sferco 2003)

In Germany, females show a higher injury occurrence (x 1.4 in GDV investigations, x 2.0 in VW investigations (Final report Whiplash I 2003)). Older people showed an increased risk for higher level CSD injuries (QTF III neurological deficits) (Final report Whiplash I 2003).

Viano (2003) points to the importance of seat stiffness and torso mass in the early neck responses and differences between male and female related to whiplash.

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 by 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)).

WAD Grade 1 = Microlesion (microscopic muscular damage)

WAD Grade 2 = Macrolesion (major muscular/bone/ligament etc.. damage)

WAD Grade 3 = Nerve cell defect/irritation.

The classification into Grades of WAD is an attempt to predict the likelihood of long-term whiplash symptoms. It has been shown that occupants classified as Grades 2 to 3 also have longer duration of symptoms than those classified as Grade 1 or those not injured in the neck. If the duration of symptoms is possible to measure, such classification is to prefer. There are many definitions of long-term injury in literature, from symptoms lasting more than 1 month to more than 1 year.

Most occupants recovering do recover within 2 weeks, but the recovering time varies up to several years. It is possible to classify them according to:

- No neck injury
- Short-term = symptoms less than 1 month, 3 months, 6 months or less than 1 year
- Long-term = symptoms lasting longer than for the short-term symptoms

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 (GDV study 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, 2002); Kullgren *et al.* (2003)). However, only a few 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 4.4g respectively, while occupants not reporting an injury had corresponding values of 7.7 km/h and 3g, see Table 1-2.

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 3g (Fig. 3). This finding is also supported from several volunteer tests (McConnell *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 20km/h and 5.3g 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 16km/h, 5g and 11g.

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 (Figures 1-1 to 1-3) (Krafft *et al.* (2002)). When designing a crash pulse for crash testing, the crash recorder results suggests that acceleration should typically be between 5 and 7g for 80ms to represent occupants with symptoms more than 1 month.

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

Table 1-2: 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))

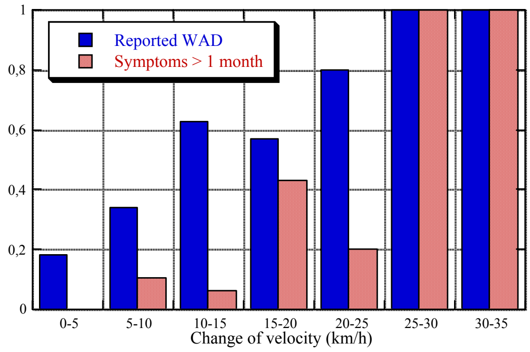


Figure 1-1: Injury risk in intervals of change of velocity for occupants with WAD for less than or more than 1 month (Krafft *et al.* (2002))

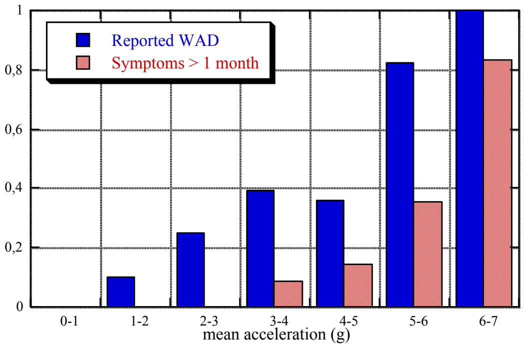


Figure 1-2: Injury risk in intervals of mean acceleration for occupants with WAD for less than or more than 1 month (Krafft *et al.* (2002))

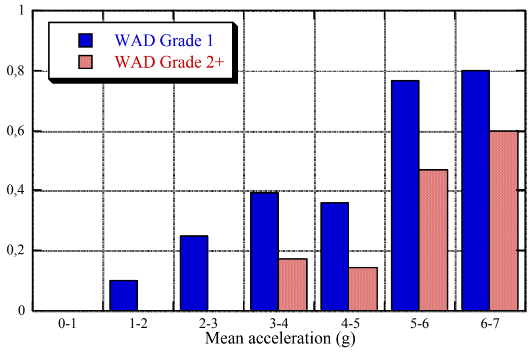


Figure 1-3: Neck injury risk (WAD1 and WAD 2+) in intervals of mean acceleration (Krafft *et al.* (2002)

Test Methods Based on Real-World Accident Data

To test the utility of previously discussed test criteria and parameters taken to evaluate different seat/head-restraint constructions, proposals of dynamic sled test programmes or standards have been developed (Langwieder and Hell (2001); Folksam/SNRA (2003); ADAC (2003)). Based on accident analysis the tests were developed to represent crashes where most WAD are reported (delta v 16km/h, average crash pulse 4-7g, no collision angle). Based on studies aimed at studying the predictability of some proposed neck injury criteria some criteria have been found to predict these injuries; NIC max and Nkm. Also velocity of the head in the rebound phase (T1) seem to be able to mirror whiplash injury risk. It was found that these values should be minimised by a good seat/head-restraint construction (Hell (2001); Folksam/SNRA (2003)).

A different sled test method was proposed for assessing CSD injury risk, using a bi-modal low speed rear impact pulse (Heitplatz *et al.* (2002)). Three different seats were tested with the Hybrid III, BioRID II and the RID2 (Heitplatz *et al.* (2003)). Several parameters, following the three phases of the impact, were used for the verification of the proposed sled test to real accident data: for the first phase NIC, for the second phase the lower neck moment $-M_y$ and a new proposed parameter LNL-index (Lower Neck Load Index) and for the third (rebound) phase the rebound velocity (T1). The LNL-index combines the three force components and two of the moment components measured at the base of the neck.

The results of the sled tests have been compared with real world accident statistics from GDV for the three different seats. A seat with a poor field performance should also have poor test results and vice versa. The Hybrid III and RID2 dummies showed correlation to the real world claims data when the lower neck extension moment is used as an assessment criterion. Also, the newly proposed LNL-index with the RID2 has shown good correlation to the real world claim data in this initial study.

Validation of Neck Injury Criteria Using Real-Life Rear End Crashes with Recorded Crash Pulses

The recorded crash pulses from real-life rear-end crashes were used in mathematical simulations with BioRID II dummy. Using NIC_{max} and N_{km} as criteria, the results of the simulations predict a neck injury with initial symptoms or with symptom duration of more than one month with high accuracy (Kullgren *et al.* (2002)).

Conclusions

Rear-end collisions resulting in Cervical Spine Distortion Injuries are a major concern for 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. In a study using crash recorder data from a few Toyota car models, Folksam in Sweden found no long-term WAD symptom cases at mean accelerations below 3g. This finding is also supported by 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 15km/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 20km/h and 5g, while those recovering within a month had approximately 10km/h and 4g. The average values for occupants with WAD symptoms of Grades 2 and 3 was approximately 16km/h and 5g, while the occupants with Grade 1 symptoms had 10km/h and 4g. 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.

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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 (Table 2-1). 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)).

Pain in neck, shoulders and upper back
Weakness in neck, shoulders and upper back
Vision disorder
Dizziness
Headaches
Unconsciousness
Neurological symptoms

Table 2-1: Common WAD-symptoms

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 subcutaneous 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.) (Table 2-2). 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.

Muscles
Ligaments
Facet joints
Intervertebral discs
Nerve tissue

Table 2-2: Possible WAD-injury locations in the neck region

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.

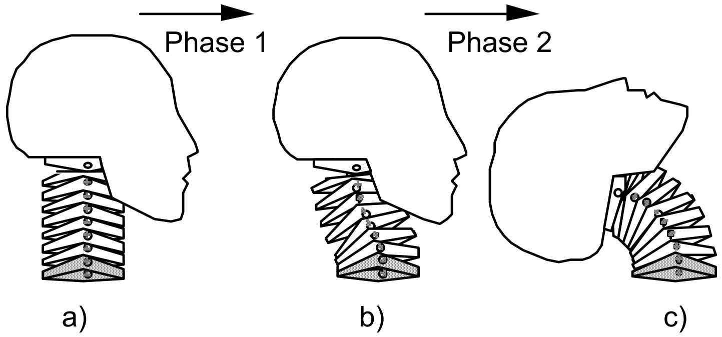

Figure 2-1a: Schematic drawing of the head-neck motion during the early part of a rear-end collision

Phase 1: Retraction motion

Phase 2: Extension motion

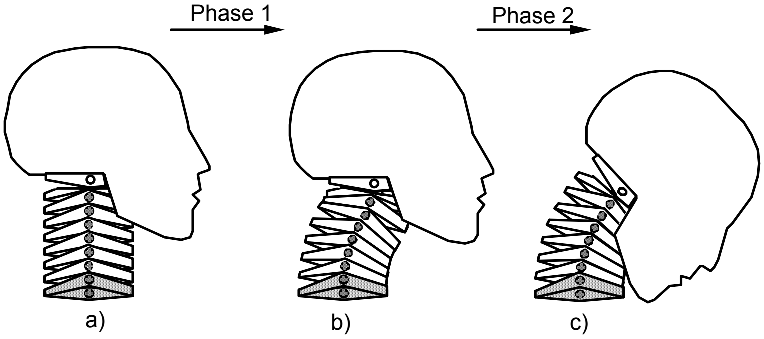

Figure 2-1b: Schematic drawing of the head-neck motion during rebound or during a frontal collision

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, N_{ij} (Kleinberger *et al.* (1998); Kleinberger *et al.* (1999)) and N_{km} (Muser *et al.* (2000)), use combinations of upper neck loads to predict the risk of injury to the skeletal spine.

The neck injury criterion, N_{ij}, was proposed to assess AIS 2+ neck injuries (not normally classified as "whiplash injuries") in frontal impacts including those with airbag deployment. This criterion could potentially be of interest if a high speed rear impact test was to be included. AIS 2+ neck injuries are however rare in rear impacts. N_{ij} is based on dimensional analysis of the load to the neck. It combines the effects of force and moment measured at the occipital condyles and is based on both the tolerance levels for axial compression and bending moment. The N_{ij} criterion is calculated by:

$$N_{ij} = \frac{F_z}{F_{int}} + \frac{M_y}{M_{int}} \qquad (1)$$

where F_z represents the axial force and M_y represents the flexion/extension bending moment. The index "int" gives a critical intercept value for the load and the moment, respectively. The intercept values for the 50th percentile Hybrid III male are proposed to be F_{int}(tension) = F_{int}(compression) = 4500N, M_{int}(flexion) = 310 Nm and F_{int}(extension) = 125Nm according to Eppinger *et al.* (1999). The threshold for injury levels based on N_{ij} is 1. Since the intercept values for the forces are based on the corresponding values for the Hybrid III and do not represent human physiological values, they must be redefined if a dummy other than the Hybrid III is used. . The N_{ij} may be of interest in high severity seat back integrity tests. There is however currently no validated dummy available and the frequency of AIS 2+ injuries in rear impacts is relatively small (>10% of the neck injuries in rear impacts according to GIDAS and CCIS databases).

The N_{km} criterion (Muser *et al.* (2000); Schmitt *et al.* (2001)) was proposed to assess neck injuries in rear impacts. It is a combination of moments and shear forces. The N_{km} criterion is calculated as

$$N_{km} = \frac{F_x}{F_{int}} + \frac{M_y}{M_{int}} \quad (2)$$

where F_x represents the shear force and M_y the flexion/extension bending moment. The index "int" gives a critical intercept value for the load and the moment. The intercept values for the 50th percentile Hybrid III male where F_{int}(anterior) = F_{int}(posterior) = 845N, M_{int}(flexion) = 88.1Nm, and M_{int}(extension) = 47.5Nm (Schmitt, 2001). The threshold for injury levels based on N_{km} is 1. Schmitt *et al.* (2001) have shown that N_{km} varies depending on the dummy used in the test.

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.* (2000), Ono *et al.* (1997) and Deng *et al.* (2000). Heitplatz *et al.* (2003) presented the Lower Neck Load – Index (LNL). It incorporates a combination of neck loads at T1-level. Indications of LNL correlation to injury risk were reported but the need for a more extensive evaluation of the LNL was also emphasised (Heitplatz *et al.* (2003))

$$LNL - index(t) = \left| \frac{\sqrt{My_{lower}(t)^2 + Mx_{lower}(t)^2}}{C_{moment}} \right| + \left| \frac{\sqrt{Fx_{lower}(t)^2 + Fy_{lower}(t)^2}}{C_{shear}} \right| + \left| \frac{Fz_{lower}(t)}{C_{tension}} \right| \quad (3)$$

The IV-NIC criterion developed by Panjabi *et al.* (1999) is based on the hypothesis that a neck injury occurs when an intervertebral extension-flexion angle exceeds its physiological limits. It is defined as the ratio of the intervertebral motion Θ_{trauma} under traumatic loading and the physiological range of motion $\Theta_{physiological}$. The IV-NIC is calculated by:

$$IV\text{-}NIC_i = \frac{\Theta_{trauma,i}}{\Theta_{physiological,i}} \quad (4)$$

This criterion still lacks a threshold. Using the IV-NIC requires a dummy neck capable of simulating intervertebral motion. At present, only the neck of the BioRID has this capacity in the sagittal plane. The biofidelity of the angular motion of the individual BioRID spinal units has however not been evaluated.

The NDC, proposed by Viano and Davidsson (2001), is based on the angular and linear displacement response of the head relative to T1, from volunteer tests. The criteria are given as corridors of the z versus angular and x versus angular displacement of the occipital condyle of the head relative to the T1. Working performance guidelines for NDC in the Hybrid III and the BioRID P3 for low speed rear impacts are proposed in four different categories: Excellent, Good, Acceptable and Poor. For the Hybrid III, the requirements for Excellent are:

- The head relative to T1 angle should be < 20 degrees.
- The x displacement of the head relative to the T1 < 30 mm.
- The z displacement of the head relative to the T1 < -15 mm.

The requirements for Good are:

- The head relative to T1 angle should be < 35 degrees.
- The x displacement of the head relative to the T1 < 50mm.
- The z displacement of the head relative to the T1 < -25mm.

The requirements for Acceptable are:

- The head relative to T1 angle should be < 50 degrees.
- The x displacement of the head relative to the T1 < 70mm.
- The z displacement of the head relative to the T1 < -35mm.

The requirements for Poor are:

- The head relative to T1 angle is > 50 degrees.
- The x displacement of the head relative to the T1 > 70mm.
- The z displacement of the head relative to the T1 > -35mm.

In addition, a response outside the corridor places the response in the category "Poor". For the BioRID, the guidelines were 5 degrees higher for the head relative to T1 angle, 5mm more for the x displacement of the head relative to the T1 and the same as for the Hybrid III for the z displacement of the head relative to the T1 (Viano and Davidsson (2001)). 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)).

$$\mathrm{NIC} = 0.2 \times a_{\mathrm{rel}} + v_{\mathrm{rel}}^2 \qquad (5)$$

a_{rel} is the relative horizontal acceleration between T1 and the occipital joint,
v_{rel} is the relative horizontal velocity between T1 and the occipital joint.

In rebound, the rebound velocity or the seat belt load may be used as injury criteria.

The N_{ij}, N_{km}, 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.

International Insurance Whiplash Prevention Group (IIWPG) recently (Jan. 2004) presented performance assessment values that are expected to be used in their insurance rating programmes. These assessment values are based on various hypotheses on injury mechanisms and injury criteria.

They are intended to be simple and robust measurements that reflect the key concepts of the earlier proposed criteria.

The seats and head restraints first have to meet minimum geometric criteria. Seats that get geometric approval are then exposed to a sled test using a generic crash pulse and a BioRID II dummy. The dynamic test criteria are divided into two groups — seat design parameters and test dummy response parameters (Table 2-3). The seat design parameters are time to head restraint contact (max 70 ms) and T1 acceleration (max 9g) of which at least one has to be met. The dummy response parameters are the neck forces, shear (max 130N) and tension (max 600N) and neck distortion (retraction of the head relative to first thoracic vertebra, T1).

Initial Geometry	**Dynamic Test Results**					***FINAL RATING***
	HR Contact Time T_{HRC}	**Torso Acceleration T1g**	**Neck Shear Fx**	**Neck Tension Fz**	**Summary Dynamic Performance**	
Good Height ≥ -6 cm Backset ≤ 7 cm	**≤ 70 ms**	any value	**≤ 130 N**	**≤ 600 N**	***Pass***	***GOOD***
	any value	**≤ 9 g**				
	> 70 ms	**> 9 g**	any value	any value	*3.1.1.1 Fail*	**ACCEPTABLE**
	any value	any value	**> 130 N**	any value		
	any value	any value	any value	**> 600 N**		
Acceptable Height ≥ -8 cm Backset ≤ 9 cm	**≤ 70 ms**	**Any T1g**	**≤ 130 N**	**≤ 600 N**	**Pass**	
	Any T_{HRC}	**≤ 9 g**				
	> 70 ms	**> 9 g**	any value	any value	**Fail**	**MARGINAL**
	any value	any value	**> 130 N**	any value		
	any value	any value	Any value	**> 600 N**		
Marginal Height ≥ -10 cm Backset ≤ 11 cm	**No Dynamic Test**					
Poor Height ≤ -10 cm Backset > 11 cm						**POOR**

Table 2-3: IIWPG rating matrix

A rear impact test program was recently launched as a collaboration between the Swedish National Road Administration (SNRA) and the Swedish insurance company Folksam to give car buyers information about the crash performance of recent car models on the market (Krafft *et al.* (2004)). This programme uses a BioRID II dummy on an accelerating sled and includes3 test conditions at different velocity and acceleration (Table 2-4).

Test	**Speed**	**Mean acceleration**
1 – Low severity	16 km/h	4,5 g
2 – Mid severity	16 km/h	5,5 g
3 – High severity	24 km/h	6,5 g

Table 2-4: Test speed and acceleration

The SNRA/FOLKSAM procedure uses three assessment parameters, NIC, N_{km} and rebound speed with limits according to Table 2-5. The overall rating is based on point scores. In the calculation of points, the seats got points if each measured parameter exceeded critical limits as described in Table 2-5. Two limits per injury criteria were used and maximum 2 points for NIC_{max} and N_{km} and were given, while maximum 1 point was given for head rebound velocity. High point scores indicate poor protection levels.

Criterion	Lower limit	Upper limit	Green Low risk	Yellow Medium risk	Red High risk
NIC_{max}	> 15 m^2/s^2	> 18 m^2/s^2	≤ 15 m^2/s^2	$15 < NIC_{max} \leq 18$	> 18
N_{km}	> 0,3	> 0,4	≤ 0,3	$0,3 < N_{km} \leq 0,4$	> 0,4
Rebound velocity	> 4,5 m/s	> 6,0 m/s	≤ 4,5 m/s	4,5 < Vel. ≤ 6,0	> 6,0

Table 2-5: Critical limits and points

ADAC (2004) has launched a similar test programme in Germany. The tests are carried out using a BioRID II dummy on a decelerating sled at three delta-v levels, 10, 16 and 25 km/h. One additional seat integrity test is done with a 95th percentile Hybrid III dummy at 30 km/h delta-v. The assessment parameters and score system is not yet published.

The dummy instrumentation required for each of the injury criteria discussed in this section are shown in Table 2-6.

Injury Criteria and Risk Curves

Recently studies have shown predictability of some of the proposed whiplash injury criteria (Kullgren *et al.* (2003); Eriksson and Kullgren (2003)). Based on reconstruction of real-life crashes where the crash pulse was recorded, dummy readings have been compared with real-life injury outcome. The injuries were divided in duration of symptoms, less than one month and more than one month. The studies only involved 3 car models of the same make and the numbers of injured occupants were relatively low. In one study including 110 front seat occupants whereof 14 with symptoms more than one month, the crashes were reconstructed in computer simulations using a BioRID II Madymo model. In another including 45 front seat occupants whereof 9 with symptoms for more than one month, the crashes were reconstructed with sled tests using a BioRID II dummy. Despite the relatively low number of crashes it gives an indication of criteria possible to use and also injury reference values. It was found that both NIC_{max} and N_{km} predict whiplash injury risk, while NDC and lower neck moment were found to be less applicable using the BioRID II dummy. NIC_{max} of 15 and N_{km} of 0.3 corresponded to 10-20% risk of injury with symptoms for more than one month, see Figure 2-2 below. NIC_{max} of 15 and N_{km} of 0.3 also corresponded to 40%-50% risk of initial symptoms of whiplash injury. It was also indicated that both NIC_{max} and N_{km} separately influence the injury risk, why both are preferable to use to increase the predictability.

NIC	Head x-acc T1 x-acc
Nij	Occipital Fz Occipital My
Nkm	Occipital Fx Occipital My
NDC	Head angular displacement relative T1 Head horizontal and vertical displacement relative T1
LNL	T1 Fz T1 Fx T1 My
IIWPG	Occipital Fz Occipital Fx T1 x-acc Scull cap contact foil Neck retraction measurement (e.g. high speed camera)
Rebound	Seat belt load cell High speed film analysis Appropriate transducers for NICmin, Nkm, Nij, NDC etc.

Table 2-6: Required dummy instrumentation

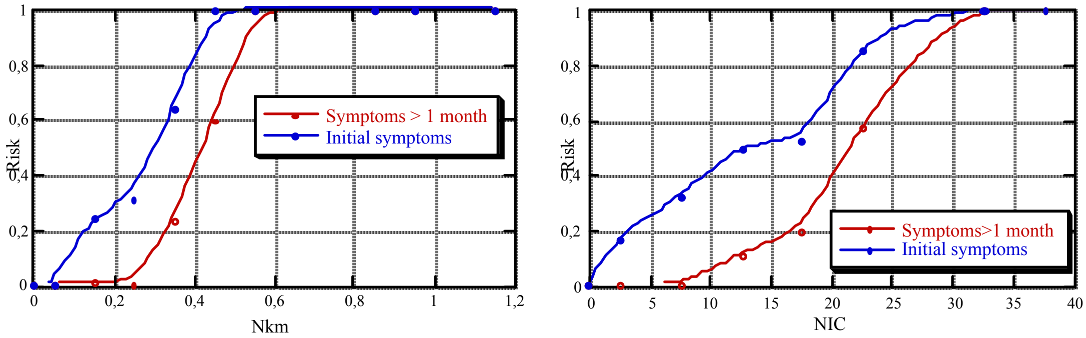

Figure 2-2: Schematic Neck injury risk curves

Recent unpublished findings within EU-Whiplash2 (May 2004) give somewhat contradictory indications. The LNL in combination with the RID 3D dummy in sled tests appears to give the most consistent correlation with the injury risk of the so called “statistical performance list” (SPL). The SPL is based on the risk of long term WAD symptoms in six common European car models. These recent findings call for a thorough investigation of the methods used in these different injury criteria evaluation studies.

Conclusions of Injury Criteria

- 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.
- Several injury criteria have been suggested but in published studies only two of them, NIC and N_{km}, have been thoroughly evaluated.
- There are three ways that injury criteria could be verified:
  - By identification of the actual acute injury that causes chronic pain. This would probably tell us which injury mechanism is the cause.
  - 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)
  - 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. Injury risk curves have been developed for NIC_{max} and N_{km} (Kullgren *et al*. (2003); Eriksson and Kullgren (2003)).

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Annex 3: Dummy Development

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. One study of Roberts *et al.* (2002) extends the focus of dummy biofidelity also to dummy back – seat back interaction using pressure measurements in the seat.

In general all dummies presented need to be used in a thermally stable environment of about 20°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. There are various versions of the HRMD around the world. There is no clarity on what the differences between the versions are and what influence this has on static measurements. Recent ADAC testing indicate significant reproducibility problems in the set-up of the H-point machine and the HRMD which calls for further investigation.

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, 3.5G peak)). At a later stage the comparison was made with PMHS tests at a slightly higher impact level (10 km/h, 12G peak). This evaluation also gave good results for BioRID II (Philippens (2002)). 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 segmented spinal structure (Kim (2001); Philippens (2002)), on the other hand this segmented spine also causes the most realistic interaction with the seat back (Roberts, 2002). A comparison of the BioRID II and prototype BioRID P3, which are almost similar, shows that the dummy is reproducible as well. The latest version, the BioRID II e, also has a lower neck load cell, which was missing in previous versions.

Strengths: good kinematics, repeatable & reproducible

Limitations: 2D spine and neck, sensitive to ringing in the spine

Hybrid III Dummy (and TRID Neck)

The Hybrid III 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); Philippens (2002)). The main problems in low severity impact relate to the rigidity of the spine (Roberts (2002)), 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. The Hybrid III may however be considered for dynamic seat stability testing at higher crash severity.

Strengths: repeatable and reproducible; 3D neck; large instrumentation capabilities

Limitations: limited kinematics for low severity rear impact

RID2 and RID^{3D} 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 average 50th percentile 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.

The RID^{3D} is an extension to RID2, designed also for frontal and frontal-oblique impact. It was developed within the European Whiplash2 project for whiplash evaluations in almost all impact modes. Only side impact is not taken into account in the RID^{3D} evaluations. The changes with respect to RID2, include different clothing and a modified neck. The current preliminary results show that RID^{3D} has a similar rear impact response with respect to RID2, improved ramping up and better rebound kinematics. The dummy is currently evaluated in frontal and oblique (rear and frontal) impact. The frontal range of application will be between 20-30 km/h, although no tests have been run to evaluate the dummy in this range yet.

Strengths: repeatable and reproducible; large instrumentation capabilities; good kinematics

Limitations: ramping up for RID2, T1 rotation for RID2 and RID^{3D}

THOR Dummy (and THOR Beta Neck)

The THOR dummy is commercially available at GESAC and also FTSS has a THOR dummy available, called THOR-FT. 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. The interaction with the seat back is better than in Hybrid III, but worse than BioRID II (Roberts (2002)). 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 used for rear impact testing, are the BioRID II and the RID2, and possibly RID^{3D} when it is released. The rear impact performance and biofidelity of these dummies was found to be very similar. The BioRID II has the advantage of being more established and accepted in automotive industry and also the interaction with the seat back seems very human-like. The advantages of the RID2 are the instrumentation possibilities in the lumbar region of the spine and the capability of handling oblique rear impact. Moreover, the successor RID^{3D} has the advantages of an improved rebound response and the possibility to handle (oblique) frontal impacts as well. All RID dummies still have practical limitations, which are solved throughout the course of their use. None of the dummies seems to have an established and well-documented certification procedure for the neck and/or spine. The Hybrid III is not suitable for low severity rear impact, due to its limited biofidelity, even though it is being used world wide with and without a TRID neck.

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Annex 4: Current status in Car Design and Seat Design

Introduction

This review of current knowledge in the various areas of whiplash research has been undertaken to update the data generated by the original WG12 ad–hoc group.

Review of Current Knowledge: Car Design/Seat Design

Soft tissue neck injuries very frequently occur in motor vehicle crashes and are most evident in low speed impacts. Current research work by the automotive insurance industry 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. It has been shown that structural characteristics do have a significant influence over injury outcomes in low speed rear impacts. The following summarises 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, in the insurance literature, are between 10-30 km/h (Hell (1998)), however, a great variety of engagement levels, vehicle to vehicle, are often seen. A higher pulse was estimated to have occurred where stiff vehicle structures engage (Hell (1998)). Cars produced from the mid 1990's have a stiffer structure than those produced before this time and that this increasing stiffness trend is continuing (Muser (2001); Avery (2001)). During low speed insurance crashes Linder (2001) reported that the newer vehicles tested produced stiffer acceleration pulses with higher peak magnitudes 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, based on low speed damagability crash tests, which supported this 'increasing stiffness' trend. It is hypothesised that this trend may well lead to a rise in injury and claims. Recent real world insurance data (Langweider (2001)) supports this hypothesis by indicating a corresponding rise in injury risk for these latest stiff vehicles compared with older 'less-stiff' 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 had 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, have shown that pulse shape, peak magnitude and signal length do not vary significantly between vehicles of different masses. These tests based on different Ford models, impacted by the same bullet vehicle, indicated that modern vehicle structures exhibit similar performance characteristics, at least by this manufacturer.

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, as assessed by the BioRID dummy. 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) presented 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, as assessed by the BioRID dummy. Peak NIC and Peak Fz 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 the study by Avery and Zuby (2002) three different car seats, all unused, were tested using seven different pulses to assess the effect of pulse characteristics on BioRID 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. No other assessment parameters were reported

A further study by Linder (2002) suggested that a similar deltaV could be generated in laboratory crash tests on a wide variety of vehicles with varying duration's of crash pulse. She also stated that in the real world, similar deltaV's are produced by various duration and shapes of crash pulse with the same car model.

In a further study by Avery and Zuby (2003) three different unused car seats were subjected to three differing artificial crash pulses which exhibited similar pulse characteristics, but were modified in a controlled manner. All three pulses were of the same length, peak g and deltaV. However, one peak was unimodal with an early bias to the peak, one bimodal with a late bias, and a third a multi-modal iteration of the first. In this study it was found that the presence of multi-modality did not effect the ATD (BioRID) responses. There is no way to show whether the seat filtered the response or whether the dummy may be insensitive to such small changes in pulse characteristic. The rear-biased pulse had a small influence, but it was suggested that this was essentially due to the delay in the onset of acceleration and was deemed to be insignificant. The author's conclusion was that a simple unimodal pulse would be suitable to evaluate soft tissue neck injury.

Seat Design

There is evidence to suggest 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 place once adjusted.

The RCAR head restraint measurement protocol (1999) uses the ICBC (Insurance Corporation of British Columbia) Head Restraint Measuring Device to assess geometrically 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 risk (Chapline (1999); Farmer (1999)). These US studies of real-world crashes indicated a reduction in injury severity in vehicles where head restraints were rated as 'good', according to the RCAR procedure, as opposed to those where the rating was 'poor'. Since the reporting period was the same it is suggested that this observation is independent of fraudulent claim effects. Vehicles with seat backs or head restraints, which fit higher and closer to the occupant's head have been associated with lower injury rates.

In a more recent IIHS study (IIHS Status Report, No.12 2002) the effectiveness of geometry improvements was illustrated. In it, injury claims for a Ford car model were compared were a seat was given a new head restraint with improved geometry (RCAR rating MARGINAL to GOOD). A corresponding 18% reduction in injury claims were observed.

During dynamic studies, using the BioRID dummy, 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 in its lowest position produced higher NIC and neck moments than when the seat was tested with the head restraint optimally adjusted.

The geometric properties were again showed to be of paramount importance in a study by Szabo (2002). In this paper three vehicles were fitted with modified head restraints with improved geometry. The seats were also fitted with foams of varying densities and thickness. In it the authors concluded that for these seats head to head restraint distance (backset) was more influential on occupant kinematics or dummy responses than local foam properties.

Studies have shown that seat structures 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. Kraftt (2001) suggested 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 five times lower incidence of whiplash injuries in the Swedish vehicle. However, both vehicles are based on identical GM structural platforms and probably share similar impact characteristics. The differences in injury outcomes were attributed to the 'poor' geometry of the Opel head restraint and its poorer seat performance, although other features may be contributory, e.g. seat padding and construction.

Viano (2001) advocated 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. This study suggested that the stiffer seats could produce higher dummy responses due to occupant 'ramp up' and poor head control.

It is suggested that 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 (dummy) accelerations than with an un-modified seat. It is suggested that 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 utilise 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 (the horizontal distance between the occupant's head and the head restraint) automatically. So called 'active' head restraints are now appearing on many vehicle 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 long enough to allow sufficient insurance data to be gathered to gauge its efficacy. 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 neck injury increased by 25%. Those reporting short-term injury remained static but those reporting long-term injury showed a 75% reduction. Laboratory tests support 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 what is suggested to be a more biofidelic rear impact dummy (BioRID) (Zuby (2001)) and therefore may have limited real world benefit.

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 and positions of the torso and head of the occupant absorbing crash energy. Several studies (O'Neil (2000); Hell (2001)) have demonstrated its performance advantages, when tested against other non-active seats under laboratory conditions.

Other anti-whiplash seat systems are also being introduced into passenger cars. Toyota have introduced WILS (Whiplash Injury Lessening System). This design has no moving elements but relies on control of the occupant kinematics through the use of varying foam stiffness. This allows the occupants energy to be absorbed thus reducing whiplash risk.

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 BioRID 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 (<15 km/h) was researched and was shown to be a possible injury mechanism. The highest frequency of whiplash injuries is reported to occur in impacts with a 16 km/h change in velocity. 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 test velocities (Langweider (2001)). 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 other injuries and possible ejection.

Insurance statistics from 2001-2003 have shown the real–world effectiveness of some “anti-whiplash” seat designs. Results from the IIHS insurance study have demonstrated, when compared to their previous models a 49% reduction in injury claims for the Volvo V70 seat. The Saab 95 showed a 43% reduction in claims when compared to the SAAB 9000 model (independent of vehicle structure). However there appeared to be an 18% rise in claims for injury in the Toyota Avalon models, fitted with the WILS system of energy absorbing foam against the previous pre-WILS model. However it was also noted that the geometry of both Toyota models was less good than the Swedish cars in the study suggesting that head restraint geometry was of importance in differentiating performance.

Research has focussed on neck injury and its mitigation. Studies have also shown that ‘low impact severity spinal injury’ (lumbar) can also be a problem. It is important that in any study to mitigate neck injury that other injuries are not increased thus a holistic approach to reducing spinal injury in rear impact should be encouraged through the use of appropriate test devices and procedures, that could detect inappropriate loading to the occupant, as might be generated through inappropriate active safety systems.

Summary

Vehicle structures are reported to be getting stiffer, since the mid 1990s and this trend in increasing stiffness is continuing. This may be due to enhanced crash performance driven by among other requirements (e.g. the low speed insurance impact test) and may have lead to an increase in whiplash type injuries. Although some attempt could be made at the local softening of perimeter structures of the vehicle it is suggested that the main focus of whiplash injury reduction should be with the enhancement of seat back and head restraint performance.

Within seat design, good head restraint geometry has been shown to be important in mitigating soft tissue neck injuries, although occupant kinematic control and effective energy management are also shown to be of importance.

Seat back yield-strength has increased and along with other parameters is leading to a rise in reported injuries. Current research suggests that where high seat back yield strength is used in conjunction with ‘good’ head restraint geometry a reduction in injuries is observed.

Active head restraints have been shown to be effective at improving head restraint geometry dynamically; however systems must be optimised through the use of a biofidelic rear impact dummy.

Insurance data suggests a significant reduction in neck injury is possible with active seat designs (both yielding seatback and active head restraints). However for such systems to be effective, good head restraint geometry must be utilised to gain early contact between head and head restraint. Some energy absorbing capability should also be employed to reduce occupant energy whilst controlling head and thorax motion.

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

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Annex 5: Test Procedures for the Evaluation of 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 tests as well as head restraint geometry assessment.

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

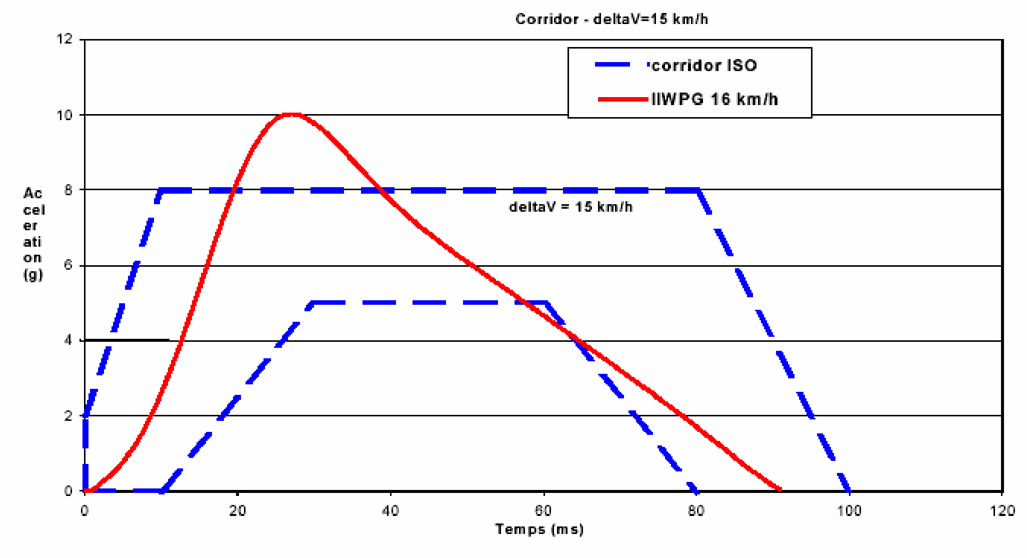
ISO found that these two areas needed further research/development before a complete ISO test procedure could be established.

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 is 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 are 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 have been three: 10, 16 and 30 km/h. The latest proposal (ISO, 2003) only includes one delta-v level, 15 ±1 km/h (Figure 5-1).

The low speed was earlier suggested to avoid sub-optimisation and to see if active protective systems also work at this low speed. The medium speed, 15 km/h, is the delta-v where most injuries occur. The highest test speed was earlier proposed to avoid seat collapse and to verify if the seat system ensures a certain level of safety also at higher crash severity.



Point	Time[ms]	a [g]	Point	Time [ms]	a [g]
A	0	2	E	10	0
B	10	8	F	30	5
C	80	8	G	60	5
D	100	0	H	80	0

Figure 5-1: Proposed acceleration corridor (ISO (2003)) together with the pulse of IIWPG (2004)

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. (Figure 5-2). Most of these test procedures have a common origin that has been gradually upgraded as new knowledge has become available.

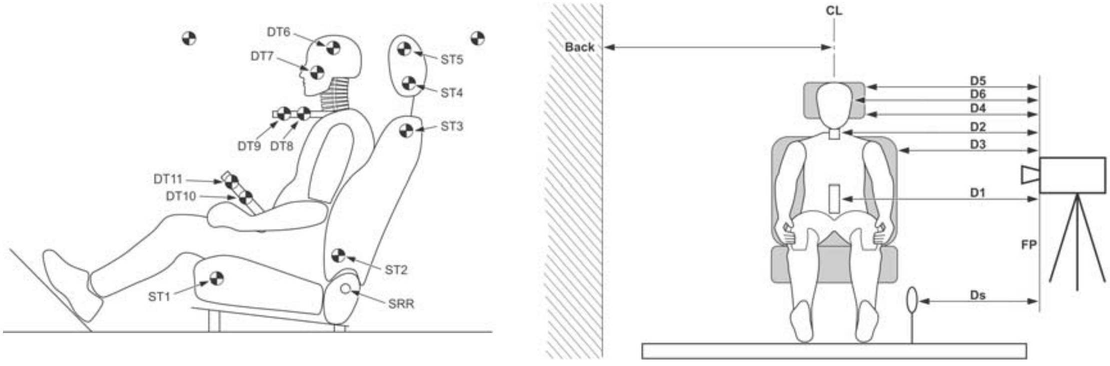


Figure 5-2: An example of photo target positions and camera position definitions for high speed video analysis (IIWPG (2004))

Some of the more established proposed injury criteria and the data required for the evaluation of the seat system are listed in Annex 2, Biomechanics. The performance requirements based on those criteria must be adapted to the chosen test procedure and the chosen dummy.

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 (Figure 5-3). Dynamic properties of the seat system are not taken into account. This method is also used as a part of the new IIWPG (2004) procedure.

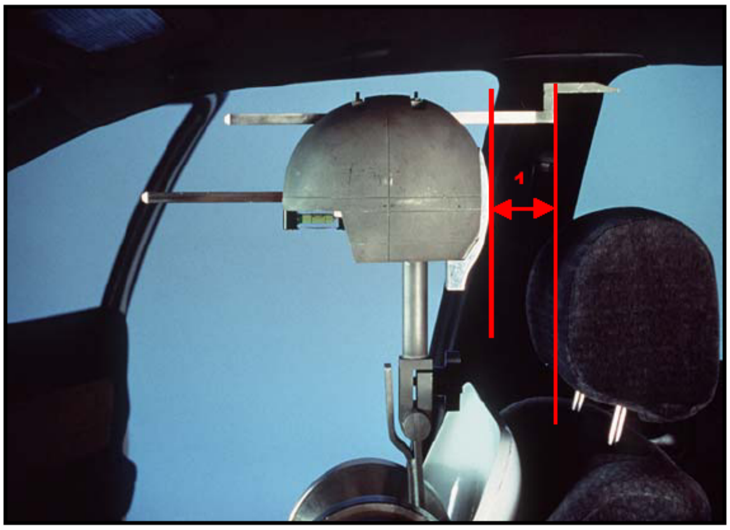


Figure 5-3: The test set-up for geometric head restraint evaluation (IIWPG (2004))

The NHTSA (2001) 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.

Recently, the German car owners association ADAC as well as the Swedish National Road Administration (SNRA) in collaboration with Swedish insurance company Folksam have carried out their own independent series of consumer tests. The test set-ups and the evaluation criteria are to a high degree similar to the ISO (2003) proposal.

The Swedish programme (Krafft *et al.* (2004)) uses a BioRID II dummy on an accelerating sled and includes3 test conditions at different velocity and acceleration (Table 5-1).

Test	**Speed**	**Mean acceleration**
1 – Low severity	16 km/h	4,5 g
2 – Mid severity	16 km/h	5,5 g
3 – High severity	24 km/h	6,5 g

Table 5-1: Test speed and acceleration

The German programme (ADAC, 2004) uses a BioRID II dummy on a decelerating sled at three delta-v levels, 10, 16 and 25 km/h. One additional seat integrity test is done with a 95th percentile Hybrid III dummy at 30 km/h delta-v.

Conclusions

- 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.
- 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 Finalised)

This document aims to give 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.

The research activity covers different aspects of rear impact protection development:

- basic human behaviour at low severity impact (volunteers) and high severity (PMHS)
- injury mechanisms
- accident data analysis
- comparison of dummy performance to human behaviour
- validity of injury criteria
- influence of impact conditions on injury risk

The NHTSA

Since (2001) the NHTSA has been 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.

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 were:

- 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

Swedish research programs (Chalmers, Autoliv, Volvo, SAAB, Folksam). 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]
- Accident data analysis to identify risk factors [Krafft et al., 2002; Berglund et al., 2003]
- Real accident reconstruction using Crash Pulse Recorder data for testing neck injury criteria [Eriksson et al., 2003]
- Product rating (see http://www.vv.se/for_lang/english/safety/whiplash_eng.pdf)

UK Spinal Injury Program

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.
- Study of effect of pulse shape characteristics on BioRID response [Zuby et al., 2002]

ISO

ISO/TC22/SC10/WG1 was given the task of compiling a specific test procedure to be adopted as a standard. A final proposal has been circulated for commenting (ISO, 2003). 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. Positioning procedures for RID2 and BioRIDII are annexed to the ISO (2003) proposal.

ACEA

Is evaluating the components of the various test procedure proposals. Crash dummies, injury criteria, seating procedures and many more issues are covered.

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, Kim et al. 2003]. Their conclusion is characterised by very severe critics towards the BioRID II and RID2. But the reference used to evaluate the performance of the dummies is the tensed volunteer which is not the base for the development of these dummies.

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 have been conducted around the world [Bortenschlager et al, 2003; Kim et al., 2003; Zellner et al., 2002; Edwards et al., 2002].

Other activities not involved in the above programs concern human characteristics related to rear impact behaviour (Willinger *et al.* (2002); Fréchède *et al.* (2003); Chancey *et al.* (2003)), accident data analysis (Hell *et al.* (2003); Schmitt *et al.* (2002)), influence of seat characteristics (Szabo *et al.* (2002)), crash pulse characteristics and its influence on injury risk (Heitplatz *et al.* (2002); Zuby *et al.* (2003)) and rating of products (ADAC (2003)).

Conclusions

Lot of data has been produced these last two years concerning the different aspects of rear impact injury protection development. The two specific dummies (BioRID II and RID 2) that are candidate to be the evaluation tool have been intensively tested by various teams. Both respond quite well with respect to the reference data used to establish the design specifications and to date no one can be proved to be better than the other. The Hybrid III which is based on data collected on tensed volunteers shows a completely different behaviour and does not appear appropriate to the represent the real victim situation. Several injury criteria are also candidate, the NIC and Nkm receiving the highest interest. But no decisive advantage can be attributed to a particular one. Real accident CPR data proved to be valuable information for testing injury criteria sensitivity and robustness. Product rating studies are now conducted in several EU countries and in the USA. Results show that rear impact protection increases with new products. But the correlation between the level of protection observed in real accidents and the results of rating tests is still an open question.

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