

# Automotive Seat Design Considerations Through Comparative Study Of Anti Whiplash Injury Criteria

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**Abstract**—Although whiplash injuries can occur in any kind of crash, an occupant's chances of sustaining this type of injury are greatest in rear-end collisions. When a vehicle is struck from behind, typically several things occur in quick succession to an occupant of that vehicle. An objective for this research paper is to compare the relation between the anti whiplash criteria, their effectiveness & possibility of verifying the defined performance limits by various consumer rating groups, insurance agencies, and regulatory authorities. This research paper describes work done by different OEMs worldwide on Whiplash injuries. It focuses on methodologies, test requirements; instrumentation and setup defined in protocol by different groups on passive safety i.e. GTR7, EuroNCAP, IIHS and RCAR. This research was carried with methodology / process specified in GTR 7 i.e. use of dynamic sled testing and static measurements by R point and H point methods using HPM with HRMD and other different protocols. Lastly we observed significant contribution of seat backset parameter to whiplash injuries in dynamic sled test. Means higher the backset more is relative head rotation v/s torso leading to whiplash injuries. Seat system design parameters such as R / H point, Seating Torso angle and Head restraint profile, seat geometry govern Backset dimension.

**Keywords**—Automobile Passive safety, Backset, BioRID, Euro-NCAP, GTR7, Head Restraint Measurement Device (HRMD), Hybrid III Dummy, IIHS, Injuries in rear accidents, RCAR, Seat head restraint, Whiplash injuries

## I. INTRODUCTION

Whiplash injuries are a set of common symptoms that occur in motor vehicle crashes and involve the soft tissues of the head, neck and spine. Symptoms of pain in the head, neck, shoulders, and arms may be present along with damage to muscles, ligaments and vertebrae, but in many cases, lesions are not evident. The onset of symptoms may be delayed and may only last a few hours; however, in some cases, effects of the injury may last for years or even be permanent. The relatively short-term symptoms are associated with muscle and ligament trauma, while the long-term ones are associated with nerve damage. Whiplash injuries are a world-wide problem.

In the European Community, there are over 1 million total whiplash injuries a year and the cost of these injuries in the EC is estimated to be €5 to €10 billion per annum and rising (Kroonenburg and Wismans, 1999; EEVC Report No 167). In the United Kingdom (UK) the cost of long-term injuries alone has been reported as £3billion. (UK Cost Benefit Analysis: Enhanced Geometric Requirements, EEVC Report, September 2007, <http://www.eevc.org>) In the Republic of Korea, rear end collisions account for 34 per cent of all car to car collisions and cause 31 per cent of fatalities and 37 per cent of injuries. Additionally, rear impact collisions cause 260,000 neck injuries in 2002 or 57 per cent of all neck injuries in car to car collisions in Korea. In Japan, rear impacts account for 31 per cent of collisions resulting in bodily injury. Of these crashes, 91 per cent of the

injuries or 309,939 are minor neck injuries. In 2004, among rear impact collisions resulting in bodily injury, 81.7 per cent of male and 88 per cent of female drivers of the impacted vehicles sustained minor neck injuries [1], [2]. Based on National Analysis Sampling System (NASS) data, the United States of America estimated that between 1988 and 1996, 805,581 whiplash injuries occurred annually in crashes involving passenger cars and LTVs (light trucks, multipurpose passenger vehicles, and vans). Of these whiplash injuries, 272,464 occurred as a result of rear impacts. For rear impact crashes, the average cost of whiplash injuries in 2002 dollars is \$9,994 (which includes \$6,843 in economic costs and \$3,151 in quality of life impacts, but not property damage), resulting in a total annual cost of approximately \$2.7 billion. Although the front outboard seat occupants sustain most of these injuries, whiplash is an issue for rear seat passengers as well. During the same time frame, an estimated 5,440 whiplash injuries were reported annually for occupants of rear outboard seating positions (HR-1-8). Whiplash, although officially classed as a minor injury, is the most commonly occurring injury in motor vehicle crashes. Insurance data suggest 10% of all whiplash injuries are long term and 1% of whiplash injuries having permanent impairment [1], [2].

The rapid urbanization in India after independence has resulted in the faster development of 23 metropolitan cities as per the 2001 census. While the alarming increase in road accidents has become a major concern in the country, which takes

away more than 90,000 lives every year, a significant share of it is from the major cities. During 2010, 499,628 road accidents were reported by all States/ Union Territories (UTs). Of these, about 23.9% (119,558) were fatal accidents. The number of persons killed in road accidents was 134,513, i.e. an average of one fatality per 3.7 accidents. The proportion of fatal accidents in total road accidents has consistently increased since 2001 from 17.6% to 23.9% in 2010. The severity of road accidents, measured in terms of persons killed per 100 accidents, has also increased from 19.9 in 2001 to 26.9 in 2010 [6].

Previously extensive accident research & study happened with different groups worldwide (UNECE – GRSP i.e.GTR7 document, Euro-NCAP, IIHS and RCAR) on Whiplash injuries. Injury data assessment and test protocols were defined by various consumer rating groups, insurance agencies and regulatory authorities on passive safety.

## II. UNDERSTANDING WHIPLASH

Although whiplash or neck injuries can occur in any kind of crash, an occupant's chances of sustaining this type of injury are greatest in rear-end collisions. When a vehicle is struck from behind, typically several things occur in quick succession to an occupant of that vehicle. First, from the occupant's frame of reference refer fig 1.

- The back of the seat moves forward into his or her torso.
- Straightening the spine and
- Forcing the head to rise vertically.
- As the seat pushes the occupant's body forward, the unrestrained head tends to lag behind.

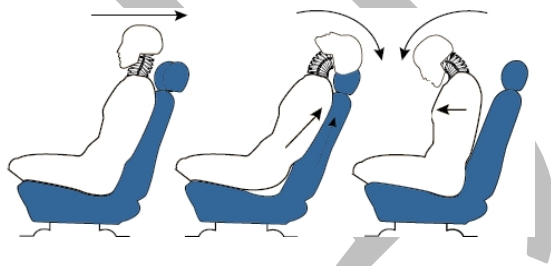


Figure 1. Whiplash Phenomenon

### A. Whiplash Biomechanics

Change shape, first taking on an S-shape and then bending backward. Third, the forces on the neck accelerate the head, which catches up with - and, depending on the seat back stiffness and if the occupant is using a shoulder belt, passes - the restrained torso. This motion of the head and neck, which is like the lash of a whip, gives the resulting neck injuries their popular name; refer fig 2.

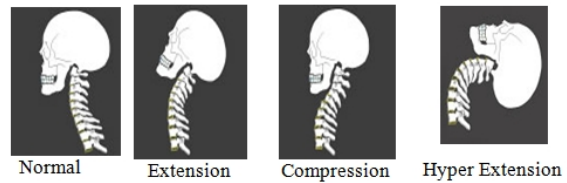


Figure 2. Spine rotations in dynamic Whiplash

There are many hypotheses as to the mechanisms of whiplash injuries. Despite a lack of consensus with respect to whiplash injury biomechanics, there is research indicating that reduced backset will result in reduced risk of whiplash injury. For example, one study of Volvo vehicles reported that, when vehicle occupants involved in rear crashes had their heads against the head restraint (an equivalent to 0 mm backset) during impact, no whiplash injury occurred. By contrast, another study showed significant increase in injury and duration of symptoms when occupant's head was more than 100 mm away from the head restraint at the time of the rear impact. In addition, the persistence of whiplash injuries in the current fleet of vehicles indicates that the existing height is not sufficient to prevent excessive movement of the head and neck relative to the torso for some people. Specifically, the head restraints do not effectively limit rearward movement of the head of a person at least as tall as the average occupant. Biomechanically, head restraints that reach at least up to the centre of gravity of the head would better prevent whiplash injuries, because the head restraint can more effectively limit the movement of the head and neck.

In a recent report from the Insurance Institute for Highway Safety (IIHS), Farmer, Wells, and Lund examined automobile insurance claims to determine the rates of neck injuries in rear end crashes for vehicles with the improved geometric fit of head restraints (reduced backset and increased head restraint height). Their data indicate that these improved head restraints are reducing the risk of whiplash injury. Specifically, there was an 18% reduction in injury claims. Similarly, computer generated models in USA have shown that the reduction of the backset and an increase in the height of the head restraint reduces the level of neck loading and relative head-to-torso motion that may be related to the incidence of whiplash injuries. With respect to impact speeds, research and injury rate data indicate that whiplash may occur because of head and neck movements insufficient to cause hyperextension. Staged low speed impacts indicate that mild whiplash symptoms can occur without a person's head exceeding the normal range of motion [2].

This means that previous focus on preventing neck hyperextension is insufficient to adequately protect all rear impact victims from risks of whiplash injuries. Instead, to effectively prevent whiplash, the head restraint must control smaller amounts of rapid head and neck movement relative to the torso. In summary, whiplash may also be caused by smaller amounts of head and neck movements relative to the torso, and

that reduced backset with increased height of head restraints better control these head and neck movements. So it is recommended that the head restraints should be of sufficient height and positioned closer to the occupant's head.

### **B. Whiplash Mechanism**

Biomechanics wrt injuries occurring due to the rear impact accidents. In case of rear accidents; seat and occupant's upper body interact relatively. Whiplash injuries occur due to excessive relative rotation of the head wrt torso. With respect to impact speeds, research and injury rate data indicate that whiplash may occur because of head and neck movements insufficient to cause hyperextension. It is reported that in rear crashes an equivalent to 0 mm backset during impact, no whiplash injury occurred. By contrast, another study showed significant increase in injury and duration of symptoms when backset more than 100 mm. In summary, whiplash may also be caused by smaller amounts of head and neck movements relative to the torso, and that reduced backset with increased height of head restraints better control these head and neck movements.

## **III. UNECE – GRSP I.E. GTR 7 (2008)**

### **A. Applicability**

The application of a head restraint GTR uses the revised vehicle classification and definitions of Special Resolution No. 1. There has been extensive discussion of the applicability of this GTR. The application of USA Federal Motor Vehicle Safety Standard (FMVSS) No. 202 is different to UNECE Regulation No. 17 [7]. FMVSS No. 202 requires head restraints in all front outboard seating positions and regulates head restraints optionally installed in the rear outboard seating positions for vehicles up to 4,536 kg. UNECE Regulation No. 17 requires head restraints in all front outboard seating positions of vehicles, of category M1, N1, M2 < 3.5T and allows for optional type approval of head restraints in other seating positions, or in other categories like N2, M3, etc.

It was proposed that the GTR, as it pertains to front outboard seats, should apply to vehicles up to 4,536 kg. The United States of America presented justification (HR-4-4), developed in 1989, when the applicability of their regulation was increased to 4,536 kg. By extending the applicability from passenger cars to include trucks, buses, and multipurpose passenger vehicles, there was an estimated reduction of 510 to 870 injuries at an average cost of \$29.45 per vehicle (1989 dollars). USA presented further analysis (HR-10-3) that showed an additional 348 injuries reduced when the requirements of the GTR are applied to Category 2 vehicles (light trucks) between the ranges of 3,500 – 4,500 kg GVM. Japan presented 2004 data (HR-4-10) showing the breakdown, by vehicle weight, of crashes resulting in whiplash injuries. They show 7,173 (2.3 per cent) rear impacts involving vehicles with a GVM over 3,500 kg that resulted in bodily injury. There is consensus to recommend a wide

application in the GTR. Specifically those head restraints in all front outboard seating positions for Category 1-1 vehicles, for Category 1-2 vehicles with a gross vehicle mass of up to 4,500 kg, and for Category 2 vehicles with a gross vehicle mass up to 4,500 kg.

Given the variability in target population in different jurisdictions, such as the differing data from USA and Japan, it was recommended that the GTR should be drafted to have a wide application to vehicles, to maximize the ability of jurisdictions to effectively address regional differences in whiplash crash characteristics. The GTR would establish that if a jurisdiction determines that its domestic regulatory scheme is such that full applicability is inappropriate, it may limit domestic regulation to certain vehicle categories or mass limits. The jurisdiction could also decide to phase-in the requirements for certain vehicles. A footnote was added to the GTR text to make it clear that jurisdictions can decide to limit the applicability of the regulation. This approach recognizes that niche vehicles that are unique to a jurisdiction would best be addressed by that jurisdiction, without affecting the ability or need for other jurisdictions to regulate the vehicles. When a Contracting Party proposes to adopt the GTR into its domestic regulations, it is expected that the Contracting Party will provide reasonable justification concerning the limitation of the application of the standard.

### **B. Purpose**

The informal group was unable to define a purpose that correlated with injury since the mechanisms are not well understood. Therefore, more general text was developed from the definition of head restraints. The recommended text for the purpose is: "This GTR specifies requirements for head restraints to reduce the frequency and severity of injuries caused by rearward displacement of the head."

### **C. Static backset requirements**

For height adjustable head restraints, the requirements shall be met with the top of the head restraint in all height positions of adjustment between 750 mm and 800 mm, inclusive. If the top of the head restraint, in its lowest position of adjustment, is above 800 mm, the requirements of this regulation shall be met at that position only. When measured in accordance with Annex 4 of GTR7, the backset shall not be more than 55 mm. Based on a determination by each manufacturer may be allowed the option to measure in accordance with Annex 5, GTR 7 as an alternative, in which case the backset shall not be more than 45 mm. In the case of Annex 4, if the front outboard head restraint is not attached to the seat back, it shall not be possible to adjust the head restraint such that the backset is more; refer fig 3.

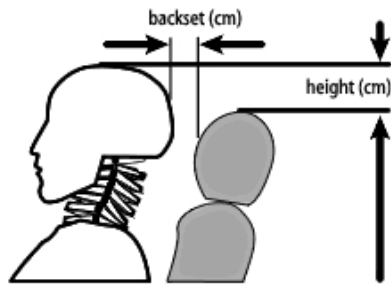


Figure 3. Seat backset and head restraint height

#### D. Dynamic requirements

Dynamic performance requirements based on a determination by each Contracting Party or regional economic integration organization, either a Hybrid III 50th percentile male dummy or a BioRID II 50th percentile male dummy shall be used to determine compliance. If a BioRID II dummy is used, the head restraint shall meet the requirements. Those are reserved until BioRID II requirements are included in this regulation or adopted in the national regulation of a Contracting Party or regional economic integration organization, head restraints shall comply with Hybrid III requirements. If a Hybrid III dummy is used, the head restraint shall meet the requirements. Hybrid III Requirements When tested during forward acceleration of the dynamic test platform, in accordance with Annex 9 of GTR 7, at each designated seating position equipped with a head restraint, the head restraint shall conform to below requirements.

1. Maximum rearward angular rotation < 12 deg between the head and torso of the 50th percentile male Hybrid III test dummy for the dummy in all outboard designated seating positions.
2. Maximum HIC15 value < 500; refer (1) below.
3. HIC15 is calculated as follows: For any two points in time, t1 and t2, during the event which are separated by not more than a 15 millisecond time interval and where t1 is less than t2,

Using the resultant head acceleration at the centre of gravity of the dummy head, HIC is expressed as a multiple of 'g' (the acceleration of gravity).

$$HIC = \left[ \frac{1}{(t_2 - t_1)} \int_{t_1}^{t_2} a \cdot dt \right]^{2.5} (t_2 - t_1) \quad (1)$$

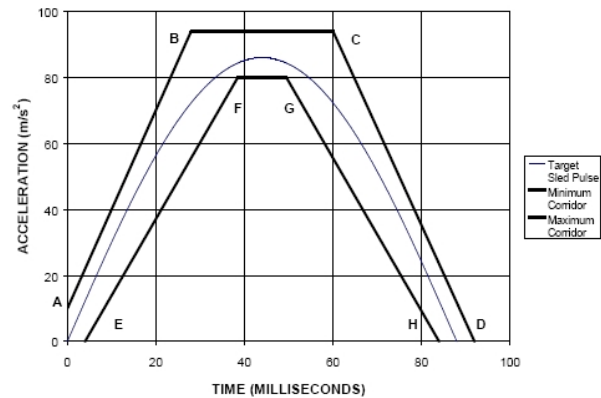


Figure 4. Dynamic sled test pulse

Where t1 and t2 are the initial and final times (in second) of the interval during which HIC attains a maximum value and acceleration 'a' is measured in 'g' (standard gravity acceleration). Note also the maximum time duration of HIC, (t2 - t1) is limited to a specific value, usually 15 ms; refer fig 4.

#### IV. ENCAP (PROTOCOL 2008)

Tests have been introduced in Euro NCAP that assesses the performance of front seats and head restraints in relation to the risk of whiplash-associated neck disorders in low severity rear-end collisions. In the absence of a clearly understood and generally accepted cause for these symptoms, the aim of this new procedure is to reflect real world seat performance, to highlight seats with known good and poor performance and to provide the maximum incentive to manufactures to move towards best practice in seat design. Based on real world evidence and a review of the state-of-the-art in dummies, whiplash test experience and the real-world performance of commercially available seats on the market, a test procedure and criteria were developed that take into account both geometrical aspects and dynamic performance of the seat in three meaningful test severities.

##### A. Test procedure

The overall objective of the Euro NCAP whiplash seat assessment procedure is to reduce real world whiplash associated injuries in EU-27 by promoting the best practice in seat design amongst manufacturers and by increasing consumer awareness. With no significant advancement in knowledge of the injury mechanisms of whiplash, and little difference shown in real world performance of the two existing test procedures, the proposed Euro NCAP test is effectively a combination of the earlier IIWPG and SRA procedures with further refinements. For the time being, the focus is on whiplash protection of the driver and front passenger. The "best practice" approach aims to promote seat and head restraint designs that reduce the distance between the head and the head-restraint. This will support the head early and or absorb energy so that the differential movement between the head and neck is lowered, and hence the

risk of whiplash-associated injury is reduced. As the overall performance of the seat system is governed by both geometric and dynamic characteristics, the assessment includes a static and dynamic part. The use of sled testing, as opposed to whole vehicle testing, was found most straightforward, cost effective and acceptable for this purpose. The seat is mounted on the sled to a standardized method that approximates the basic geometry of the subject vehicle. The seat mount brackets replicate the correct seat rail angle and distance to the floor pan of each subject vehicle. The seats are set to achieve a  $25^{\circ} \pm 1^{\circ}$  torso angle of the H-point manikin fitted with an HRMD.

### B. Static assessment

Euro NCAP's geometric assessment is based upon the procedure for static geometric evaluation of head restraint geometry established by RCAR (Research Council for Auto-mobile Repairs) to encourage positioning of head restraints closer to the driver's head. Ideally the head restraint should be high enough to protect tall occupants and be at small distance to the head (small back set). Euro NCAP's criteria for geometry are more demanding than those used previously by other rating systems. After the seat is mounted onto the sled and set correctly, a modified SAE J826 H-point manikin is employed combined with the Head Restraint Measuring Device (HRMD) and is used to assess the design position of the head restraint with respect to the head. Furthermore, this measurement is used to define the H-point, head restraint geometry and other parameters used in set up of the test dummy. The Euro NCAP whiplash test protocol calls for three measurements on each individual seat and specifies maximum permissible skew (i.e. the positional differences between the left and right-hand H-points) on each installation, plus a maximum variation between the three drops. Consequently, static repeatability is controlled and dynamic variation due to a single outlying static measurement is rendered unlikely.

As a majority of motorists are still putting themselves at risk of neck injuries because of incorrectly positioned head restraints, Euro NCAP also assesses "worst case" geometry (or "ease of use") of the head restraint. This is achieved by checking whether the head restraint can be correctly positioned for different sized occupants, preferably without specific action from the occupant other than simply adjusting the seat track position to suit the leg length [3].

### C. Dynamic assessment

In the absence of a process to define representative vehicle specific pulses, the use of generic sled pulses has been preferred. Instead of using a single sled pulse, Euro NCAP has adopted three tests of different severity to avoid sub-optimization to a single pulse and to ensure seat stability at a higher test severity. These pulses cover the range of speeds at which the highest risk at short and long term injury is observed and at which severe neck injury claims peak, as shown

by Folksam amongst others. Accident data suggests whiplash tests should include crashes in the 16 km/h range (10 mi/h). The first pulse used is at 16km/h  $\Delta V$  pulse with a 5.5g mean acceleration, representative of one of the crash scenarios in which whiplash associated injuries would occur. This pulse, originally double wave in shape but simplified to a triangular pulse, has been used by IIWPG. The two other pulses used are trapezoidal in shape and simulate a "low" 16 km/h  $\Delta V$  (peak 5g) and "high" 24 km/h  $\Delta V$  (peak 7.5g). The latter pulses have been defined and exclusively used by SRA. The three pulses, shown in fig 5. are termed "low" (16km/h, SRA), "medium" (16km/h, IIWPG) and "high" (24km/h SRA) within the Euro NCAP whiplash scheme. Time corridors and requirements for  $\Delta V$ ,  $\Delta T$ , average mean acceleration and acceleration at T0 have accurately been defined to control the input pulses. All testing is carried out with the BioRID 50th percentile male test dummy developed to mimic the human response in low to moderate speed rear impacts. This dummy is considered the most human-like dummy available with respect to human response corridors and in comparison with other candidate dummies. Since 2000, various design iterations of the dummy have been released following the recommendations by the BioRID Users Group and others. Euro NCAP prescribes the use of the BioRID-IIg or subsequent versions. For the dynamic test, the head restraint is positioned in mid vertical and horizontal position where locks are fitted. If no locking is present under the definition of the test procedure then the most down and rear position is used. The BioRID is seated according to positioning data from the static measurements. Three individual tests are run using new identical seats using each of the three pulses. At each run, dummy variables (as well as the seat back angle deflection at the high severity test) are taken. In the final phase of the development of the Euro NCAP whiplash test and assessment procedure, a number of critical aspects have been thoroughly validated. These include the reproducibility in dummy positioning and accuracy of geometric assessment, the feasibility of sled pulse corridors, the repeatability of dummy measurements in relation to the limits and the discriminating resolution of the rating limits correlated to field data. Reproducibility of Static Measurements:

The test procedure involves the definition of seat geometry and dummy seated position. The static measurement has a significant influence on the dynamic test result and the overall score. The repeatability and reproducibility of the static definition is therefore critical to the testing process. Static measurements may differ due to variations in set up process, variations in measuring equipment and production variation in the seats themselves. Static measurement variation can be characterised both in terms of its repeatability and reproducibility using individual seats, and across a production batch of seats.

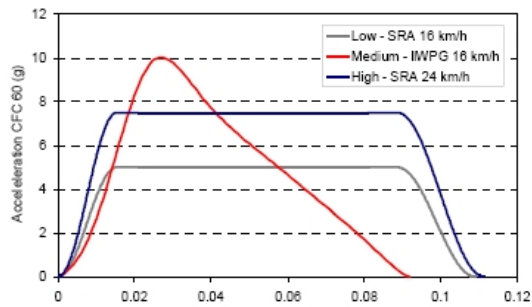


Figure 5. ENCAP Dynamic sled test pulse

## V. IIHS

The necessary first attribute of an effective head restraint is good geometry. If a head restraint isn't behind and close to the back of an occupant's head, it can't prevent a "whiplash" injury in a rear-end collision. Institute researchers regularly evaluate the geometry of head restraints in passenger vehicles based on the height and backset relative to an average-size male. A restraint should be at least as high as the head's center of gravity, or about 9 centimeters (3.5 inches) below the top of the head. The backset, or distance behind the head, should be as small as possible. Backsets of more than 10 centimeters (about 4 inches) have been associated with increased symptoms of neck injury in crashes.

### A. Geometric Rating

They are good predictors of how well people would be protected in rear-end crashes — drivers with restraints rated good are less likely than those with poor restraints to claim neck injuries. Head restraint geometric ratings for hundreds of passenger vehicles are listed by vehicle make and series. Various head/seat combinations are rated (not every available seat option in every series has been measured). The restraints are measured with the angle of the torso at about 25 degrees. Each restraint is classified according to its height and backset into one of four geometric zones — good, acceptable, marginal, or poor. Since 1995, the Institute has been publishing model-by-model ratings of head restraint geometry, based on a procedure for taking geometric measurements. The rating for a fixed head restraint is straightforward the zone into which its height and backset place it also defines its rating. The rating for a head restraint that adjusts in height and/or backset depends on whether it locks in the adjusted position. If it does not lock, its rating is defined by its height and backset in the down and/or rear position. If it does lock, height and backset are measured twice in the down position, and in the most favorable adjusted and locked position. The final rating is the better of the two, except that if the rating as adjusted is used, it's downgraded one category because so few motorists adjust their restraints. Many vehicle models have more than one seat option — if seat differences affect the head restraint rating, more

than one rating is shown. This procedure is used to rate the head restraints in 1995-99 models [4].

A modification of the above procedure has become an international standard available from the Research Council for Automobile Repairs (RCAR). Ratings for fixed head restraints and adjustable restraints that do not lock are unchanged under the RCAR protocol. For adjustable restraints that lock in position when adjusted, the rating is based on the midpoint of the best (highest and closest) and worst (lowest and farthest) positions in relation to an average-size male. Active head restraints that are designed to move closer to the backs of occupants' heads in rear-end crashes are not rated for geometry at this time. The Institute rates head restraints in 2000 and later models according to the RCAR procedure. Seat/head restraints with geometry rated good or acceptable (current and recent model cars) are tested in a simulated rear impact conducted on a sled to assess how well the seats support the torso, neck, and head of a BioRID dummy. The test simulates a rear-end crash with a velocity change of 10 mph (16kmph), approximately equivalent to a stationary vehicle being struck at 20 mph (32kmph) by a vehicle of the same weight. A seat/head restraint's dynamic rating depends on performance in the sled test. There are two sets of criteria for evaluating performance. The first criterion is related to two seat design parameters: time to head restraint contact (must be  $\leq 70$  ms to pass) and torso acceleration (must be  $\leq 9.5$  g to pass) [4].

### B. Dynamic Rating

The second set of evaluation criteria is the maximum neck shear force and maximum neck tension measured on BioRID during the test. These neck forces (classified low, moderate, or high) indicate how well or how poorly an occupant's head and neck would be supported in a rear impact at low to moderate speed. A seat that passes at least one of the seat design parameters and has low neck forces earns a dynamic rating of good. Seats with head restraints rated marginal or poor for geometry are not tested dynamically. They are assigned overall ratings of poor because of inadequate geometry. combination's overall evaluation. Seats with head restraints rated marginal or poor for geometry aren't tested dynamically. They're assigned overall ratings of poor because of inadequate geometry.

Dummy and sled used in dynamic test. Dynamic testing of seat/head restraints requires a dummy with a realistic spine and neck. Until the development of BioRID, or biofidelic rear impact dummy, existing dummies had rigid spines and necks that did not interact with vehicle seats the way human spines and necks do. BioRID was developed for rear impact testing by a consortium of Chalmers University, restraint maker Autoliv, Saab, and Volvo. This dummy, representing an average-size man, has a spine composed of 24 articulated vertebra-like pieces. The spine interacts with vehicle seats during tests in much the same way as a human spine. Plus BioRID's segmented neck can produce the motion observed by

human necks in real-world crashes in which vehicles are struck from behind. However, UNECE – GRSP has not concluded on the use of this dummy for GTR due to several discrepancies [4].

The device on which dynamic tests of seat/head restraints are conducted is a steel flatbed sled that runs on fixed rails. The sled is moved to simulate vehicle crash accelerations, recreating the forces on occupants inside vehicles during real-world crashes in slow to moderate rear impacts. The changing acceleration or deceleration over the time duration of a crash is referred to as a crash pulse and the key aspect of a sled is that it can be programmed to produce specific crash pulses. To evaluate seat/head restraints, vehicle seats and their attached restraints are fixed to the sled, which is accelerated to simulate a stationary vehicle that is rear-ended by another vehicle of the same weight going 20 mph. To accomplish this, compressed air is pumped into a special cylinder, thrusting a ram forward in a pre-programmed pattern of acceleration (crash pulse). Peak acceleration in the sled test is 10 g (5 g mean acceleration), and the duration is 91 ms [4].

## VI. RCAR

### A. Geometric Rating

Static Head restraint height and backset measurements shall be made with a standard H-point machine fitted with an HRMD representing the head of an average-size male. The head room probe from the H-point machine shall be removed and the two washers (supplied with the HRMD) shall be installed in the spaces remaining on the H-point pivot. The HRMD includes probes to aid the measurement of height and backset relative to the head. Measurements shall be made according to the procedures outlined in the “Instruction Manual of the Head Restraint Measuring Device” (ICBC, 1995), with three modifications [5]

- The legs of the H-point machine shall be configured in accordance with requirements of U.S. Federal Motor Vehicle Safety Standard (FMVSS) 208 to approximate the dimensions of the 50th percentile male Hybrid III dummy.
- The height and backset measurements shall be made with the adjustable seat back positioned to achieve a torso angle of  $25 \pm 1$  degree from vertical on the H-point machine with the HRMD installed.
- The seat shall be adjusted to the fully rearward position along the seat track to allow sufficient room for the feet of the H-point machine to be raised imaginative.
- Refer fig 6 below [5].

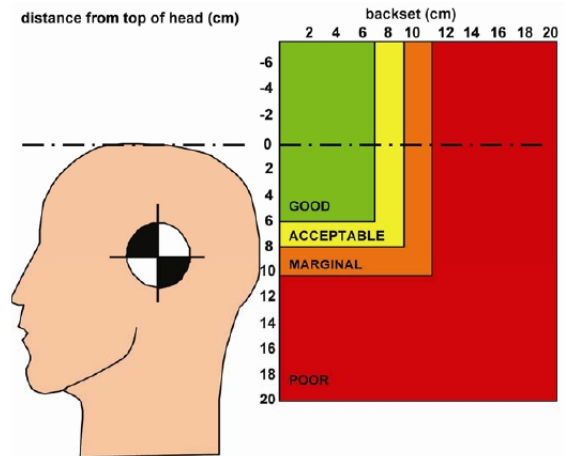


Figure 6. IHS & RCAR head restraint rating

### B. Dynamic Rating

Acceleration or Deceleration Sled test is intended to simulate a typical rear crash in which the rear-struck vehicle is initially stationary or moving forward very slowly. Consequently, an acceleration sled is recommended for these tests. A deceleration sled, on which the dummy is initially moving rearward at 16 km/h and then stopped, may be used if careful attention is paid to dummy positioning (step 5.9.5 BioRID positioning requirements). In either case, some sled motion is allowed at the initiation of the test ( $T = 0$ ). To accommodate different sled types and different relationships between sled motion and the recording of test data, test time will be indexed from the peak sled acceleration as described in section 7 of test protocol. Sled accelerations are measured by an appropriate accelerometer attached to the sled platform and recorded according to the Society of Automotive Engineers (SAE, 2003) Standard J211-1. Conformance with pulse duration, peak acceleration and its timing are done with the signal filtered to channel frequency class (CFC) 60. Refer fig 7; Velocity change ( $\Delta V$ ) is judged using velocity calculated from a CFC 180 signal. For  $\Delta V$  calculation, integrate the sled acceleration data from the last time the acceleration passes through zero at the beginning of the trace until the first time the acceleration passes through zero at the end of the trace. It shows the typical variation in accelerations from 50 tests conducted on a particular sled. Test Dummy Response Parameters Neck shear and tension forces are measured at the connection between the dummy's cervical spine and head using a load cell; same as IHS. The measured neck forces will be classified as low, moderate, or high depending on which region of the data point representing the maximum neck tension and maximum rearward neck shear force lies. Thus, low neck forces mean that measured forces are as low as or lower than 30 percent of seats with good geometry, when shear and tension are considered jointly; high neck forces mean that measured forces are higher than 75 percent of seats with good geometry. Although these criteria are based on 2004 model year seats, they will be maintained for

the foreseeable future. The goal was to establish force limits that were achievable with current design knowledge. Refer fig 8 for dynamic rating [5].

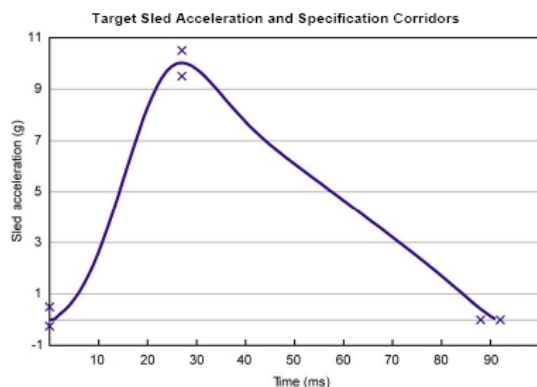


Figure 7. IIHS & RCAR target sled acceleration corridor

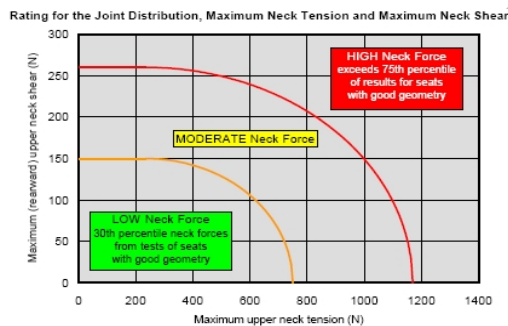


Figure 8. IIHS & RCAR dynamic rating

## VII. CONCLUSION

### A. Overall comparison of different protocols

Seating static backset is measured by R point and H point methods in GTR 7. ENCAP uses it uses static as well as dynamic criteria. RCAR & IIHS do geometric assessment as per Good, Acceptable, marginal and Poor rating basis. In GTR 7 dynamic test can be done using BioRID II or Hybrid III 50th %tile dummy. But other protocols do testing with BioRID only. GTR 7, IIHS and RCAR uses only one type of sled pulse; but ENCAP has set three severity types of sled pluses.

Dynamic assessment is done at design position of seat with specified design torso angle v/s other agencies do the test at 25 deg of torso angle. GTR 7 (2008) dynamic sled test is optional criteria for evaluation; but ENCAP, RCAR and IIHS have mandatory criteria for both static measurements and dynamic sled test performance.

Final whiplash assessment criteria in case of GTR 7 is R point Static backset less than 45mm or HRMD backset less than 55mm. Dynamic Head to torso Angular rotation less than 120. Limit the maximum HIC15 value to 500. In case of ENCAP, IIHS and RCAR does assessment with overall rating i.e. static and dynamic performances.

### B. Seat design parameters affecting Static Backset

Seating R/H point inversely relates to backset dimension; if R point vehicle X coordinate increase backset decrease and v/s. R point Z coordinate has no direct relationship on backset dimension. Seating torso angle inversely relates to backset dimension; if torso angle increase backset decrease and v/s. Seat head restraint profile inversely relates to backset dimension; if it increases backset decrease and v/s. Head restraint height has no direct relationship on backset dimension. Head restraint rod angle from vertical increases backset also increases.

In brief, seat system design parameters such as R / H point, Seating Torso angle and Head restraint profile, seat geometry govern Backset dimension. However, it is clear that by implementing state of the art seat design across the majority of cars sold, the effect of one of the dominant contributing factors to whiplash injury may significantly be reduced.

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