Whiplash Prevention Evaluation Rating Guidelines

Version I

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Insurance Institute for Highway Safety
988 Dairy Road
Ruckersville, VA 22968
researchpapers@iihs.org
+1 434 985 4600

iihs.org

CONTENTS

OVERVIEW

This document provides the rating guidelines for the Insurance Institute for Highway Safety (IIHS) whiplash prevention evaluation test of vehicle front seats (IIHS, 2025). The guidelines provide a standard for evaluating and rating the ability of forward-facing front seats and head restraints to prevent neck injury in low- to moderate-speed rear-end crashes.

The rating is based on the results of dynamic tests, physical or simulated, of vehicle seats on an acceleration sled with both 16-km/h and 24-km/h delta V crash pulses, using the BioRID-II dummy. Test procedures are described in the *IIHS Whiplash Prevention Evaluation Test Protocol (Version I)*.

Ratings are dictated by the sum of the accumulated demerits from both pulses, which are evenly weighted. Rating thresholds for the 16-km/h pulse are more lenient than the 24-km/h pulse because the 24 km/h was shown to be most relevant for modern seat designs using the BioRID-II dummy (Edwards & Brumbelow, 2023). Overall ratings thresholds are designed to allow automakers flexibility to optimize designs to address variability as more rear-impact assessments are added in the future, rather than suboptimize for the current two assessments.

The rating does not incorporate a static evaluation of head restraint position, since this is now included in U.S. Federal Motor Vehicle Safety Standard 202a (2009).

FRONT SEAT ASSESSMENT

Evaluation overview

Injury measures obtained from an instrumented BioRID-II dummy oriented for rear impact on an acceleration sled determine the likelihood that an occupant would have sustained whiplash injury. Fifteen different measures in each whiplash prevention test are required to complete the evaluation:

- Head acceleration (x, y, and z directions from the head's center of gravity)
- Upper neck axial force, anterior-posterior force, and anterior-posterior bending moment
- T1 vertebra acceleration (left side—x and z directions, right side—x direction)
- L1 vertebra acceleration (x and z directions)
- Pelvis acceleration (x, y, and z directions)
- Contact time between the head and head restraint
- Sled acceleration (x direction)

From these measurements, the metrics in Table 1 are calculated and used for assessment. Filtering outlined in Table 2 is used for measurement time-histories and calculations.

Table 1
Table of equations for calculated metrics

Test type	Calculation	Equation number
Physical test and simulation	$\text{Pelvis displacement} = \min\left(\iint a_{pelvis_x}dxdx - \iint a_{sled_x}dxdx\right)$	Equation 1
	$v_{region_x} = \int a_{region_x}dx$	Equation 2
	$v_{region_z} = \int a_{region_z}dz$	Equation 3
	$v_{region} = \sqrt{{v_{region_x}}^2 + {v_{region_z}}^2}$	Equation 4
	$\text{Head-to-pelvis relative velocity} = \min(v_{head} - v_{pelvis})$	Equation 5
	$Mocy = Upper\ y\ moment - Upper\ x\ force\ *\ .01778$	Equation 6
	$NKM = \frac{Fx(t)}{Fint} + \frac{Mocy(t)}{Mint}$	Equation 7
	$T1_{x_{acceleration}} = \max\left(avg(T1_{x_{acc(left)}}, T1_{x_{acc(right)}})\right)$	Equation 8

Table 2
Filters for time-history data, calculations, calculating ISO scores, and peak absolute error

Time-history data	Channel frequency class (CFC) filter
Head acceleration (x,y,z)	CFC 60
T1 left acceleration (x,z)	CFC 60
T1 right acceleration (x)	CFC 60
L1 acceleration (x,z)	CFC 60
Pelvis acceleration (x,y,z)	CFC 60
Upper neck force X	CFC 600
Upper neck force Z	CFC 600
Upper neck moment Y	CFC 600
Head-to-head-restraint contact	N/A
Sled acceleration	CFC 60 (CFC 180 for integration for delta V)

The evaluation metrics for whiplash prevention have been grouped into three design strategies:

- Head and spine support
- Stable head-to-head restraint interaction
- Management of energy transferred to the occupant.

The peak values of all metrics are only considered from T0 to the end of head contact time (after pulse shift in accordance with Sections 1.4.1 or 1.4.2 of the *IIHS Whiplash Prevention Evaluation Test Protocol (Version I)* (IIHS, 2025).

Head and spine support

The head-and-spine-support design strategy is represented by two metrics: head contact time and head-to-pelvis relative velocity. Head-to-pelvis relative velocity encourages spinal alignment and head contact time encourages early support of the head to maintain spinal alignment.

Head-to-pelvis relative velocity is the difference in head (x,z) resultant velocity and pelvis (x,z) resultant velocity and provides information on the relative motion of these two regions of the spine. This metric is based on work by Jakobsson & Norin (2002), which investigated differences in velocity across multiple regions of the spine. The entire region (head to pelvis) was chosen as an evaluation metric because of its correlation with insurance injury claim rates (Edwards et al., 2026). It is also correlated with head contact time while being more closely related to the principles of biomechanics related to injury.

Head contact time is the time after the beginning of the sled test (T = 0) when the dummy's head contacts the head restraint and maintains that contact for at least 40 ms. Contact is indicated by an electrical contact switch attached to either the dummy's head or the head restraint. The head contact time metric encourages timely support of the head, reducing the risk of the head lagging behind the torso. Details for calculating head contact time can be found in Section 8.2 of the *IIHS Whiplash Prevention Evaluation Test Protocol (Version I)* (IIHS, 2025)).Note that minor breaks in time to head restraint contact (up to 1 ms) are permissible if it can be proven that these are due to poor electrical contacts. However, these must be investigated with reference to the film to ascertain whether the breaks in contact are not due to biomechanical phenomena such as dummy ramping, head restraint or seatback collapse, or "bounce" of the head during nonstructural contact with the head restraint.

Stable head-to-head-restraint interaction

The stable head-to-head-restraint interaction design strategy is represented by two metrics: maximum NKM and upper neck tension force.

NKM is a combination of upper neck shear force and anterior-posterior bending moment and is calculated using Equation 6 and Equation 7, where *Mint* is 47.5 Nm for extension and 88.1 Nm for flexion, and *Fint* is 845 N for both positive and negative shear force. The background for this metric was published by Schmitt et al. (2002). Maximum NKM is the maximum of the four following combinations of the NKM calculation:

- extension moment-posterior shear force,
- extension moment-anterior shear force,
- flexion moment-posterior shear force, or
- flexion moment-anterior shear force.

Upper neck tension measures the maximum force pulling the head axially away from the torso.

Both metrics encourage limiting the head-to-head-restraint contact as a load path for occupant restraint, thereby reducing the load and moments that can cause injury to the cervical spine. These metrics also encourage consideration of occupant motion relative to the head restraint, so that occupant ramping and head restraint shape and construction do not increase the risk of injury.

Management of energy transferred to the occupant

The management of energy transferred to the occupant is represented by two metrics: maximum T1 forward x acceleration and the pelvis displacement relative to the sled. Together these metrics encourage energy management in the seat so that less load is transferred to the occupant.

Maximum T1 forward x acceleration is the average of the highest acceleration recorded by a horizontally oriented accelerometer attached to the BioRID-II's T1 vertebral unit on both the left and right sides and is calculated using Equation 8. Lowering T1 acceleration encourages a reduction in the transfer of energy to the occupant, reducing forces and accelerations in the less supported portions of the spine.

Pelvis displacement is a double integration of the pelvis x acceleration relative to the sled x acceleration and is calculated using Equation 1. Larger pelvis displacement relative to the sled encourages energy dissipation though displacement.

Demerit table

Values greater than the listed demerit threshold in Table 3 will receive the listed demerit. For example, for the 16-km/h pulse, a maximum NKM value of 0.30 receives 0 demerits and 0.31 receives 1 demerit. All values are rounded to the decimal places shown in Table 3 prior to assessment.

Table 1
Demerits for 16-km/h and 24-km/h pulses

16 km/h		**+1 demerit line**	**+2 demerit line**	**Group total demerits [a]**
Head and spine support	Head–pelvis relative velocity (minimum) (abs_val) (m/s)	3.0 m/s	4.0 m/s	**0–3**
	Head contact time (ms)	n/a	80 ms	
Stable head-to-head-restraint interaction	Maximum NKM	0.30	0.50	**0–3**
	Upper neck tension maximum (N)	500 N	700 N	
Management of energy transferred to the occupant	T1 x maximum acceleration (g)	12.0 g	15.0 g	**0–3**
	Pelvis displacement (minimum) (mm)	−150 mm	−130 mm	
24 km/h		**+1 demerit line**	**+2 demerit line**	**Group total demerits [a]**
Head and spine support	Head–pelvis relative velocity (minimum) (abs_val) (m/s)	3.5 m/s	4.5 m/s	**0–3**
	Head contact time (ms)	n/a	80 ms	
Stable head-to-head restraint interaction	Maximum NKM	0.35	0.55	**0–3**
	Upper neck tension maximum (N)	500 N	700 N	
Management of energy transferred to the occupant	T1 x maximum acceleration (g)	14.0 g	17.0 g	**0–3**
	Pelvis displacement (minimum) (mm)	−190 mm	−170 mm	
			Total	0–18

Note. n/a = not applicable (because there is one threshold for the head contact time metric).

[a] Total demerits in each group are capped at 3.

WEIGHTING PRINCIPLES FOR OVERALL RATINGS

Table 2
Rating categories based on the sum of demerits from 16-km/h and 24–km/h pulses

	Good	Acceptable	Marginal	Poor
Total demerits (sum from Table 3)	0–3	4–6	7–9	10–18

NORMALIZATION FACTORS FOR AUDITING PEAK VALUES

The absolute error between the submitted data and the audit test results will be calculated for the metrics used for rating and normalized using the corresponding normalization factors (Equation 9 and Table 5). The submitted data will be considered to have met the peak metric acceptance criterion if the normalized absolute error is <u>lower than 1</u> for all peak metrics. Normalization factors are designed to prevent errors that cross more than 1 demerit threshold.

$$Normalized\ absolute\ error = \frac{\left|Result_{audit\ test} - Result_{verification}\right|}{Normalization\ factor} \qquad \text{Equation 9}$$

Table 3
Normalization factors for auditing automaker data submissions

Metric	Normalization factor (16 km/h)	Normalization factor (24 km/h)
Head–pelvis relative velocity (minimum) (abs_val) (m/s)	1	1
Head contact time (ms)	10	10
Maximum NKM	0.20	0.20
Upper neck tension maximum (N)	200	200
T1 x maximum acceleration (g)	3.0	3.0
Pelvis displacement (minimum) (mm)	20	20

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