# Whiplash Prevention Evaluation Test Protocol

# Version I

**December 2025**

**IIHS**

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# Contents

# OVERVIEW

## Purpose

This protocol outlines the methods for the Insurance Institute for Highway Safety (IIHS) evaluation of seats, head restraints, and occupant restraint systems in rear-impact crashes. In this evaluation, vehicle seats and relevant restraint systems are replicated in a sled environment to simulate a rear-impact crash with a BioRID-II anthropomorphic test device (ATD) as the human surrogate. The test isolates each restraint system (seat, head restraint, and seat belt) from the vehicle and exposes it to the same acceleration pulse, facilitating a comparative assessment of the effectiveness of vehicle restraint systems in rear-impact crashes.

This is the first IIHS vehicle ratings program to include computer simulations in the assessment. The computer simulations will replicate the seat, restraints, and BioRID dummy and calculate their motion to predict the same outputs as the physical test.

Automaker simulations will help IIHS address safety for more occupants and more impact scenarios without increasing the testing burden. Following this IIHS protocol, automakers will provide either simulation results or physical test results for two load cases (16-km/h and 24-km/h delta V pulses, initially). IIHS will audit one of the two tests and ensure that the results align with IIHS physical tests. If the results do align, both automaker tests will be accepted as part of the evaluation.

This successor protocol to our *Vehicle Seat/Head Restraint Evaluation Protocol, Dynamic Criteria* adds one evaluation pulse (24 km/h) to the original (16 km/h) crash pulse introduced in 2004 (IIHS, 2020). With future updates, we plan to increase the value of our physical audit tests by adding more occupant sizes and impact scenarios using computational model simulations. These tools will help us build assessments to encourage robust seat and restraint designs that can protect more occupants.

## Workflow

1. IIHS notifies the automaker of its intent to test a specific vehicle make/model.
2. (Within 3 months of notification) IIHS receives seat and target seat points (bolt locations, center-recliner and head-restraint post points, etc., in the *IIHS Rear Impact Seat Information__.xlsx* template) from the automaker. IIHS measures the seat with the H-point manikin according to Section 1.3.2 in this protocol, using the center-recliner and head-restraint-post points provided by the automaker to set the seatback. If the torso angle is within 24° to 26°, the H-point, torso angle, head point, and head-restraint point are collected.
3. From Step 2 above, IIHS provides the automaker with:
    - Manikin points (H-point, back of head, torso angle)
    - Seat setup points (center recliner, head restraint post, backset measurement point on head restraint, highest point on head restraint, heel point)
    - Head restraint horizontal and vertical adjustment position (i.e., notch location)
    - BioRID (physical) certification report for the scheduled test
    - Audit test date
4. Automaker prepares verification data for submission using one of the following methods:
    - Physical test data (both 16-km/h and 24-km/h results)
    - Simulation test data (both 16-km/h and 24-km/h results)
    - Both simulation and physical test data (must have both pulses for each). Only one pair (simulations or physical tests) must pass the audit to be used for the assessment (e.g., if the 24 km/h gets audited and the physical test results from the automaker pass the audit but the simulations do not, then the physical tests from the automaker can still be used as part of the assessment).
5. (Within 5 months of notification) Automaker submits results for the 16-km/h and 24-km/h tests. For simulation, since pulse variability can affect test outcomes, IIHS recommends that automakers submit multiple simulations for each load case that span that range of variability observed for the IIHS sled. IIHS will provide these pulses. Using the methods in Section 9, IIHS will choose the submission with the pulse closest to audit test for the audit approval.
6. Audit testing
    - IIHS randomly selects an audit test (16 km/h or 24 km/h).
    - IIHS conducts the physical test using seat and manikin targets from Step 3 of this workflow.
    - IIHS compares the automaker's physical or simulation verification test data against the IIHS physical test data using the methods outlined in the Auditing Methods section of this protocol.
    - The workflow optimizes the automaker's ability to pass the audit test by providing the automaker with the targets used by IIHS before the automaker runs simulations or physical tests and by allowing the submission of multiple pulses. Resubmission of verification data after IIHS conducts the audit will not be allowed.

## Definitions

For the purpose of this procedure, the following definitions shall apply.

*Head restraint* means a device designed to reduce the risk of injury to the cervical vertebrae in the event of a rear impact by supporting an occupant's neck and head so they can be accelerated together with the torso as the seat and head restraint are driven forward.

*Integrated head restraint* or *fixed head restraint* means a head restraint formed by the upper part of the seatback, or a head restraint that is not height-adjustable and cannot be detached from the seat or the vehicle structure except using tools or by partially or totally removing the seat furnishings.

***Adjustable head restraint*** means a head restraint that is capable of being positioned to fit the morphology of the seated occupant. The device may permit horizontal displacement, known as tilt adjustment, and/or vertical displacement, known as height adjustment.

***Active head restraint*** means a device designed to improve head restraint geometry during an impact.

***Automatically adjusting head restraint*** means a head restraint that automatically adjusts the position of the head restraint when the seat position is adjusted.

***Locking*** refers to the process of fitting an adjustable head restraint with a device that prevents users from inadvertently moving it from its adjusted position, such as when a rear-seat occupant uses a front-seat head restraint as a handhold when getting in or out of the vehicle.

A locking device may be fitted to both the horizontal and vertical adjustments of the head restraint. A locking device must incorporate a mechanism that requires intervention to allow head restraint adjustment, after which the mechanism should reset automatically.

***H-point manikin*** means the device used for the determination of "H" points and actual torso angles. (SAE International, 2021).

***HRMD*** (Head Restraint Measuring Device) means a separate head-shaped device used with the H-point manikin to measure the static geometry of a vehicle head restraint. It was developed under the sponsorship of the Insurance Corporation of British Columbia  (Gane, 1999). The HRMD is equipped with two probes to measure head-restraint height and backset. The height probe projects horizontally, level with the top of the head, to provide a reference line for the vertical measurement to the top of the restraint. The backset probe simulates the rear profile of the head and neck and projects horizontally to provide the horizontal measurement to the restraint.

Head Restraint ***Height*** is defined as the measurement between the top of the head restraint and the calculated top of the head point or the height probe of the HRMD.

Head Restraint ***Backset*** is defined as the measurement between the rearmost surface of the HRMD head and the front surface of the head restraint


### Head Restraint Measurement Positions

***Down*** is defined as the lowest possible position of an adjustable head restraint.

***Up*** is defined as the highest possible position of an adjustable head restraint.

***Back*** is defined as the rearmost possible position of an adjustable head restraint.

***Forward*** is defined as the forwardmost possible position of an adjustable head restraint.


***Verification data*** is test data from either simulation or physical tests that an automaker provides to IIHS to be used for a safety assessment.

***Certification*** is the process for approving a physical entity (e.g., BioRID-II) for use in a safety assessment.

***Computer Aided Engineering (CAE) model*** is a simulation of a physical entity (e.g., BioRID, vehicle seat) that computationally approximates the static geometry and dynamic behaviors of the physical entity, using equations for the physics of motion, materials and contacts.

***Qualification*** is the process for approving a (CAE) model for use in a safety assessment

## Seat selection

The seat content selection for physical testing will be defined by the seat in the vehicle with the highest volume take rate for each make/model. If a make/model is new and does not have historical volume take rates, either the previous generation or the automaker's prediction can be used.

Seat content (e.g., lumbar adjuster) for an automaker's seat models do not have to identically match the physically tested seat. It is up to the automaker's discretion how to build their model to best match the physical test outcomes.

IIHS will purchase or acquire seats directly from the automaker and/or their suppliers and take responsibility for shipping costs.

# TEST METHODS

## 1    IIHS physical test procedure

### 1.1    General test requirements

#### 1.1.1    Coordinate system

The cartesian coordinate reference frame for measurements is as follows: +X forward (i.e., direction of sled motion), +Y right, +Z down

IIHS will collect the left front-seat bolt hole (LFSBH) (Figure 1) as a local reference point for the seat. This point can be used for conversions between different coordinate systems.

**Figure 1**
**Left front-seat bolt hole (LFSBH) measurement location**
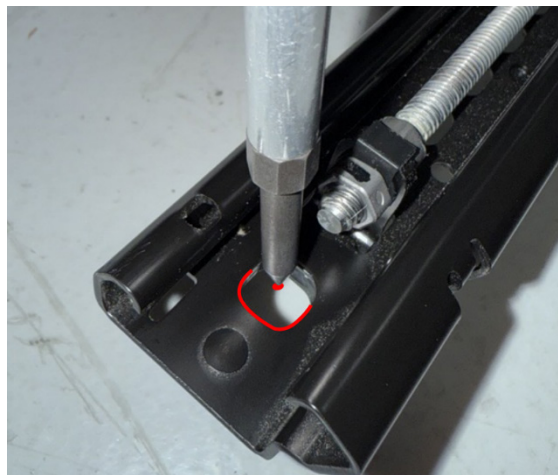


#### 1.1.2    Videography
1.    A lateral left view (orthogonal to the plane of motion) that captures the entire event from the onset of acceleration to 100 ms past the end of head contact time.

2.  A lateral right view (orthogonal to the plane of motion) that captures the entire event from the onset of acceleration to 100 ms past the end of head contact time.
3.  A lateral right view following the sled reference frame (orthogonal to the plane of motion) that captures the entire event from the onset of acceleration to 100 ms past the end of head contact time.

Note: Timestamps provided by IIHS on video files align with the RAW (unshifted) data.

## 1.2  Sled and vehicle environment

Tests are run with production seats in a simulated vehicle environment on a dynamic test sled.

### 1.2.1  Acceleration sled

The dynamic test is intended to simulate a typical rear crash in which the struck vehicle is initially stationary or moving forward very slowly. Consequently, an acceleration sled is required for these tests. To accommodate different sled types and different relationships between sled motion and the recording of test data, test time will be indexed using the sled acceleration as described in Section 1.4: Crash pulse.

### 1.2.2  Laboratory environment

The temperature in the test laboratory should be 22.5 ± 3 degrees Celsius (67–78 degrees Fahrenheit) with a relative humidity of 10%–70%. The BioRID-II test dummy and seat being tested shall be maintained at this temperature at least 3 hours prior to the test.

### 1.2.3  Attachment of seat/head restraint to sled

The seat, including all of the adjustment mechanisms and hardware that normally connect it to the vehicle floor (e.g., longitudinal adjustment rails), should be securely fastened to the test sled platform. The attachment should be made so that the seat's orientation relative to horizontal is the same as it would be in its intended vehicle. The actual height of the seat from the sled platform may be different from its height above the vehicle floor. A simulated floor and toepan, consisting of a horizontal section sufficiently large to rest the dummy's feet and connected to a section oriented 45 degrees from horizontal and at least 30 cm long, are attached to the sled platform. Both surfaces should be covered with short-piled carpet. The horizontal floor portion should be mounted at the same height relative to the seat bolts/rails as the heel rest point (Section 1.2.4). The fore/aft position of the toepan should be adjustable. Figure 2 shows an example seat both in the vehicle and mounted on the sled platform.

**Figure 2**
**Attachment of seat to test sled compared with vehicle installation**
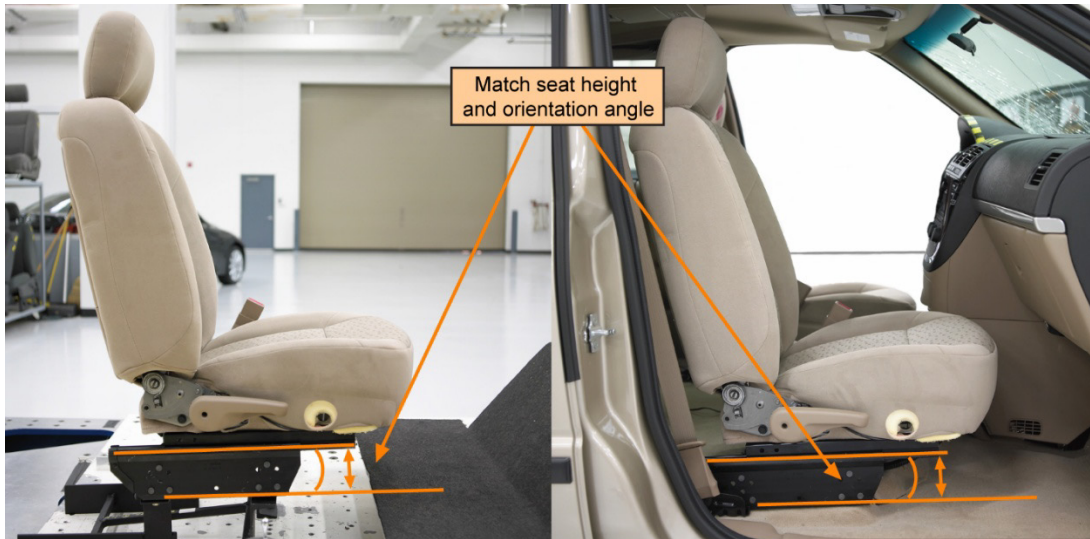


### 1.2.4 Determine heel rest point location

The heel rest point is defined in the vehicle (with removable floor mats removed) by using the accelerator pedal as follows.

Find the geometric center point of the accelerator pedal contact surface (laterally and vertically). Place a straight edge between the accelerator pedal and the fixed carpeting on the vehicle floor so that the straight edge is tangential to the accelerator pedal surface at the center point. The heel rest point location is then the contact point of the straight edge on the vehicle floor (Figure 3).

**Figure 3**
**Heel rest point location**
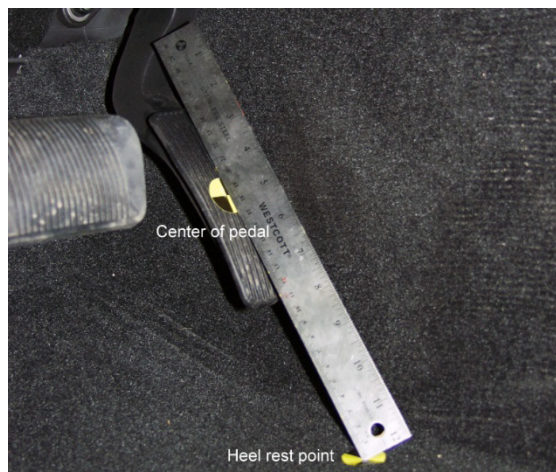
### 1.2.5    Restraints

1.2.5.1    Seat belts

A generic three-point lap/shoulder belt should be used during the test. If possible, any belt hardware integrated with the seat should be utilized (e.g., buckle or integrated shoulder belt).

If the automaker believes that a vehicle-specific belt will affect test outcomes, this should be indicated in the template *IIHS Rear Impact Seat Information.xlsx* and a vehicle-specific belt and anchor locations will be used for the test.

The belt should be placed across the dummy's torso, clavicle, and pelvis and be routed above the pelvis angle gauge (if equipped).

1.2.5.2    Activation for active elements

For each seat, the automaker should provide information on the presence of active elements (e.g., head restraints, seat belts) that would be expected to activate in a real crash of the same severity and would affect test outcomes. For each element that requires a trigger, time-to-fire (TTF) should be specified by the vehicle manufacturer. Supporting data will be requested.

### 1.2.6    Set seat adjustments

The seat adjustments should be set according to the following instructions.

Prior to setting seat adjustments, the seat shall be bolted to the sled in its position for testing, and the sled brakes should be engaged if available. Otherwise, the sled should have its movement restrained for the duration of setting up the seat, installing the H-point manikin, installing the dummy, and collecting all necessary measurements. Because the settings of some adjustments may affect the ranges of other adjustments, the seat should be set according to the order of the procedural steps outlined here. An initial seatback angle will be set in Step 1.2.6.8 based on target values from the automaker; the final setting will be established in Section 1.3.2. Head restraint position (manually, electrically or automatically adjusting) should be set according to the instructions in Step 1.2.6.9.

1.2.6.1    Initial seat adjustments

All seat adjustments should be set initially as follows. Appendix A provides more detailed descriptions and illustrations of these adjustments.
- **Seat track** should be in its rearmost position.
- **Seat height** should be set to its lowest position.
- **Seat tilt** should be set to the extreme of its range that puts the cushion angle closest to zero (horizontal). Step 1.2.6.2 describes the method for measuring the cushion angle.
- **Cushion height** should be set to its lowest position.
- **Cushion tilt** should be set to the extreme of its range that puts the cushion angle closest to zero (horizontal). Step 1.2.6.2 describes the method for measuring the cushion angle.
- **Lumbar support** should be set to its rearmost or least prominent position.
- **Upper seatback**, if separately adjustable from the lower portion, should be rotated fully rearward.
- **Cushion extension** should be set to its rearmost or least extended position.
- **Side bolsters** should be set to the widest position.

1.2.6.2    Measure seat cushion angle

Locate and mark a point on the forward edge of the top surface of the seat cushion and midway between the right and left edges of the cushion. Locate, mark, and record a second point that is 400 mm rearward along a line parallel to the direction of the sled movement (Figure 4) with a coordinate measurement machine (CMM). The sine of the cushion angle is the difference in the Z-coordinates (in mm) of these two points (first minus the second) divided by 400 mm.

**Figure 4**
**Seat cushion angle (400 mm measurement)**



1.2.6.3    Set seat track adjustment to midrange

Mark a hard point on the seat and record its location with a CMM. Move the seat to its most forward adjustment position and record the position of the marked hard point. Move the seat rearward until the marked hard point is midway between the two previously recorded hard point locations. The final position will depend on whether the seat track adjusts continuously or incrementally.

*Continuously adjusting seat track* – The mark on the seat support structure should align (± 2 mm) with the midtrack mark. Alternatively, the hard point should have an X-coordinate that is midway (± 2 mm) between the X-coordinates of the most forward and most rearward adjustment positions.

*Incrementally adjusting seat track* – If the midrange adjustment does not correspond to an indexed adjustment position (± 2 mm), then the seat should be set to the first indexed position rearward of the calculated midpoint.

1.2.6.4    Set seat height adjustment to midrange

Mark two hard points on the side of the seat on components that are attached to and move with the cushion frame — one near the front of the cushion and one near the rear. Record the locations of both points with a CMM or measure the vertical heights of the points relative to a fixed reference with a measuring tape. Use the seat height adjustment control(s) to move the seat to its highest position. If the front and rear seat heights are adjusted separately (dual control), then make sure that both the front and

rear of the seat are raised to their highest positions. Record the locations of the two hard points with the CMM or measure the vertical heights of the points relative to a fixed reference with a measuring tape. Then lower the seat until both hard points are midway between their highest and lowest positions. The final position will depend on the type of control used to adjust the seat height.

*Single-control seat height adjustment* – The final position of the seat will depend on whether seat height adjusts continuously or incrementally.

> *Continuously adjusting seat height* – The rear hard point should be ± 2 mm of the calculated midpoint.

> *Incrementally adjusting seat height* – If the midrange adjustment does not correspond to an indexed adjustment position (± 2 mm), then the seat height should be set to the first indexed position below the calculated midpoint.

*Dual-control seat height adjustment* – If the front and rear seat heights are adjusted separately, then lower the front hard point using the front adjustment control and lower the rear hard point using the rear adjustment control. The final position will depend on whether the seat height adjusts continuously or incrementally. Note that the front and rear seat height adjustments may need to be iterated to achieve the calculated midpoints.

> *Continuously adjusting seat height* – Both the front and rear hard points should be within ± 2 mm of the calculated midpoints. If this is not possible, then the rear hard point should be within ± 2 mm of the calculated midpoint and the front hard point as close as possible to the calculated midpoint.

> *Incrementally adjusting seat height* – If either the front or rear midrange adjustment does not correspond to an indexed adjustment position (± 2 mm), then the seat height should be set to the first indexed position below the calculated midpoint for the corresponding seat hard point.

1.2.6.5    Set seat cushion height adjustment

The cushion height adjustment uses the points marked on the top surface of the cushion in Step 1.2.6.2. Once the seat track and height are set to midrange, the points on the top surface of the cushion should be collected before adjusting the seat cushion height.

*Single-control seat cushion height adjustment* – Raise the cushion to its highest position and record the location of the rear cushion point (400 mm behind the front edge point). Lower the seat cushion to its midrange position. The final position of the seat will depend on whether the seat cushion height adjusts continuously or incrementally.

> *Continuously adjusting seat cushion height* – The rear cushion point should have a Z-coordinate midway (± 2 mm) between the lowest (initial) and highest positions.

> *Incrementally adjusting seat cushion height* – If the midrange adjustment does not correspond to an indexed adjustment position (± 2 mm), then the seat cushion height should be set to the first indexed position below the calculated midpoint.

*Dual-control seat cushion height adjustment* – Raise the rear of the cushion to its highest position using the rear adjustment control and record the location of the rear cushion point (400 mm behind the front edge point). Lower the rear of the cushion using the rear adjustment control so that the rear cushion point

is midway between the lowest (initial) and highest positions. Raise the front of the cushion using the front adjustment control until the cushion angle matches the angle recorded in Step 1.2.6.2. The final position will depend on whether seat cushion height adjusts continuously or incrementally.

> *Continuously adjusting seat cushion height* – The rear cushion point Z-coordinate should be ± 2 mm of the calculated midpoint, and the cushion angle should match (± 0.5 degrees) the angle recorded in Step 1.2.6.2.

> *Incrementally adjusting seat cushion height* – If the rear midrange adjustment does not correspond to an indexed adjustment position, then the rear cushion height should be set to the first indexed position below the calculated midpoint. Likewise, if the cushion angle in Step 1.2.6.2 cannot be matched (± 0.5 degrees) with the front midrange adjustment at an indexed position, then the front cushion height should be set to the next lowest indexed position.

### 1.2.6.6    Adjust upper seatback angle

If the head restraint moves with the adjustment of the upper seatback, then the upper seatback should be positioned as follows: otherwise, it should be left in the rotated fully rearward position designated in 1.2.6.1. Measure the angle relative to vertical of the head restraint support post or some flat part of the seatback frame. Without changing the adjustment of the lower seatback, move the upper seatback to its most forward position and measure the angle at the same location as the initial measurement. Adjust the upper seatback rearward until the angle is midway (± 0.5 degrees) between the most rearward and most forward angles.

### 1.2.6.7    Other seat adjustments

Any seat adjustments not specified in Steps 1.2.6.2 through 1.2.6.6 should remain in their initial adjustment positions as described in Step 1.2.6.1. If the seat is equipped with a movable armrest, it should be raised or placed in its stored position; adjustable lumbar supports should be fully retracted, adjustable cushion extension should be fully retracted, and adjustable lateral thigh supports and seatback supports (bolsters) should be set open or as wide as possible.

### 1.2.6.8    Set initial seatback angle

Once all other seat adjustments have been made, use the values supplied by the automaker for the position of the center of the head restraint post (CHRP) relative to the center of the recliner pivot (CoRP) of the seat (Figure 5) to set the initial seatback angle of the unweighted seat. This initial seatback angle will be maintained as long as the manikin torso angle is within 25±1 degrees after following steps in Section 1.3.3.

**Figure 5**
**Center of recliner pivot and center of head restraint post: measurement examples**



**(A) Center of recliner pivot (CoRP)**



**(B) Center of head restraint post (CHRP)**
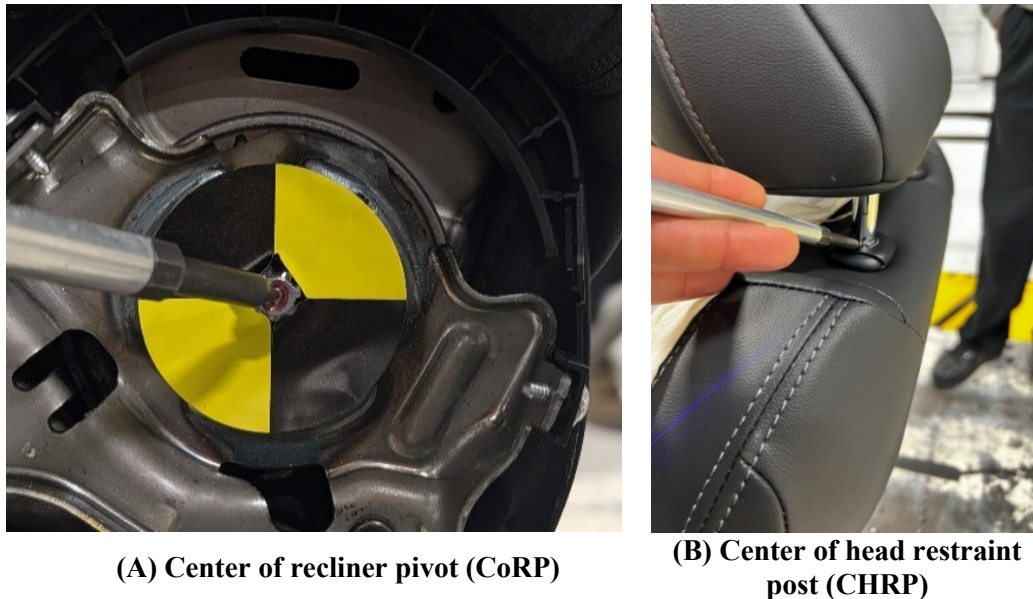
1.2.6.9    Head restraint test position

The head restraint, if equipped with locking vertical and horizontal positions, should be set in a position closest to the midrange vertically and midrange horizontally. Thus, the test position for the restraint depends on whether it is fixed or adjustable and, if adjustable, whether the adjustments lock. Automatically adjusting head restraints are tested as if they are fixed restraints, and the seat adjustments are set according to Section 1.2.6.

*Fixed head restraint*
No adjustment of the restraint is possible.

*Nonlocking adjustable head restraint*
The restraint is adjusted to its lowest vertical adjustment position and/or most rearward horizontal adjustment position.
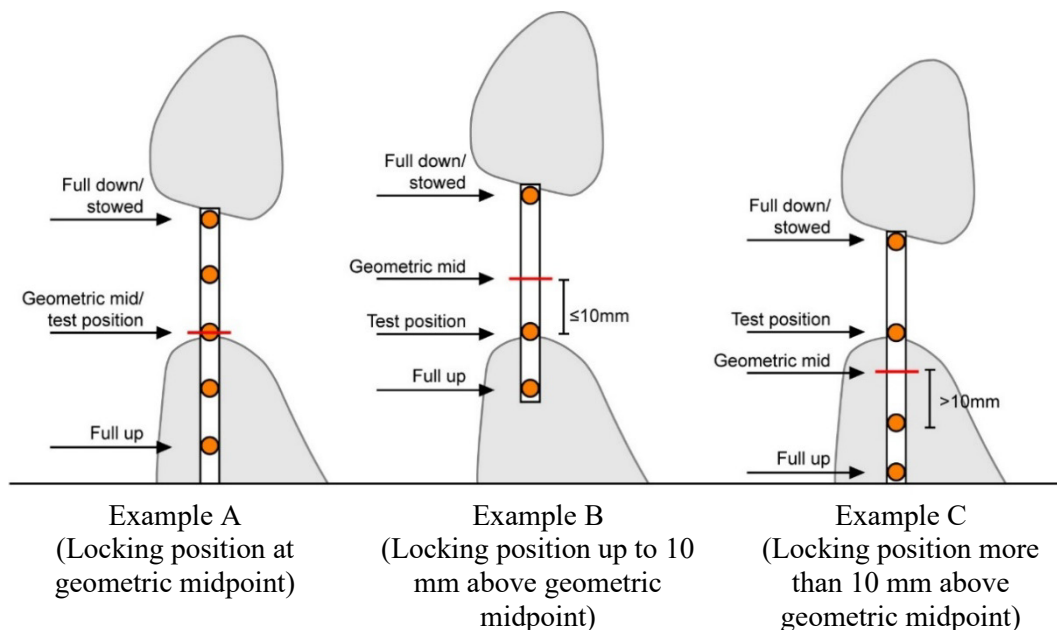
*Locking adjustable head restraint*
The restraint is adjusted to the midrange of its vertical and/or horizontal adjustment positions. Only locking adjustments are set to the midrange positions. For example, a restraint with locking height adjustment and nonlocking horizontal adjustment would be set to its midrange vertical position and most rearward horizontal position.

Midrange height position is determined by calculating the geometric midpoint between the lowest (locking or nonlocking) and highest locking vertical adjustments, considering only the vertical component of measurement. Similarly, midrange tilt position is determined by calculating the geometric midpoint between the rearmost and forwardmost locking horizontal adjustments, considering only the horizontal component of measurement. (Figure 6). The test position will then be selected based on the following conditions:

- Place the head restraint at the geometric midpoint if a locking position exists there (Figure 6, Example A).
- If there is no locking position at the geometric midpoint, raise the head restraint by up to 10 mm (Figure 6, Example B). If a locking position exists within this 10 mm of travel, that position will be the test position.
- If there is no locking position within 10 mm above the geometric midpoint, lower the head restraint to the next lowest locking position (Figure 6, Example C), that position will be the test position.

Once the vertical test position has been determined, the procedure should be repeated for locking horizontal adjustments moving the restraint forward instead of upward and rearward instead of downward.

**Figure 6**
**Examples of adjustment positions for head restraints with locking height (locking positions indicated in orange)**



| Example A (Locking position at geometric midpoint) | Example B (Locking position up to 10 mm above geometric midpoint) | Example C (Locking position more than 10 mm above geometric midpoint) |

*Seating adjustments: Seats with automatically adjusting head restraints*
The BioRID-II used in these dynamic tests represents an average-sized adult male driver or vehicle occupant. Consequently, seats equipped with head restraints that automatically adjust depending on other seat adjustments (e.g., seat track or height) should be set to a position that most likely would accommodate a seat occupant of the same size. The procedure described in *Guidelines for Using the UMTRI ATD Positioning Procedure for ATD and Seat Positioning (Version VI)* (IIHS, 2022) should be followed for seat positioning only. The UMTRI ATD positioning procedure must be conducted with the seat installed in a vehicle. Then the seat adjustments recorded are transferred to the test seat on the sled. The automaker can provide the CoRP and CHRP for this position (Figure 5), if applicable. If it is not possible to employ the UMTRI procedure to determine the appropriate seat position for an average-sized male seat occupant, then the seat should be set to the middle of its fore/aft adjustment range (see Step 1.2.6.3). Regardless of which method is used to determine the head restraint test position, the seat should

be moved rearward from the most forward position to the test position because the starting position can affect the final position of the head restraint.

## 1.3   Dummy and seating procedures

The dummy is positioned using targets determined in Step 2 of the Workflow section. Section 1.2 is used to define the position of the seat. Automaker-provided CoRP and CHRP points are used to set the seatback for an H-point manikin torso angle of 25°. Section 1.3.2 is used to seat the H-point manikin and collect the H-point and torso angle. Section 1.3.3 is used to calculate the head location and backset targets.

### 1.3.1   BioRID

These tests should be conducted with a BioRID-IIg or later revision dummy. The dummy should comply with both spine stature and dynamic response specifications before the test.

1.3.1.1   Spine curvature check

With the pelvis adapter plate placed on a level surface with the occipital condyle (OC) angle at $29.5 \pm 0.5$ degrees, the T2 angle at $37 \pm 0.5$ degrees, and the neck plate laterally level $\pm 0.5$ degrees, the distance (X) between the H-point and OC pin should be $156 \pm 5$ mm, and the distance (Z) between the H-point and OC pin should be $609 \pm 5$ mm (Table 1 and Figure 7).

**Table 1**
**BioRID-II spine curvature specifications**

| Measurement | Specification |
|---|---|
| Angle of occipital interface plate relative to horizontal | $29.5 \pm 0.5$ degrees |
| Angle of T2 vertebra relative to horizontal | $37.0 \pm 0.5$ degrees |
| Angle of neck plate (lateral) | $0 \pm 0.5$ degrees |
| H-point indicator to occipital condyle pin (horizontal) | $156 \pm 5$ mm |
| H-point indicator to occipital condyle pin (vertical) | $609 \pm 5$ mm |

**Figure 7**
**BioRID-II spine curvature check**
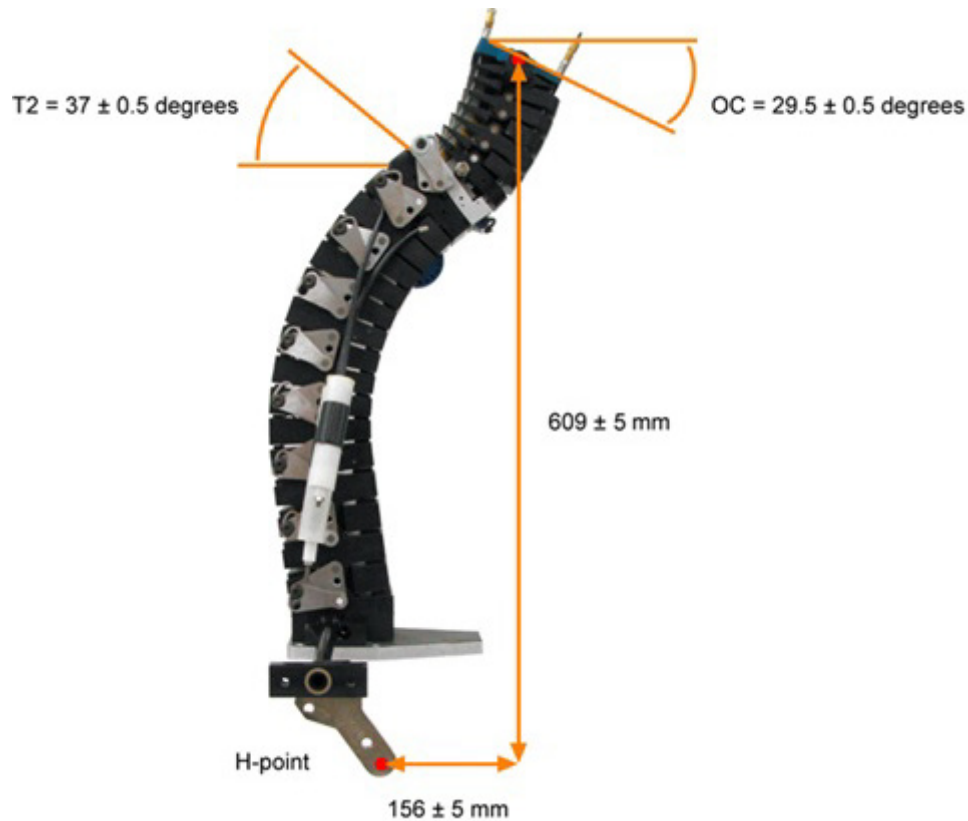


### 1.3.1.2 Certification

The BioRID dummy should comply with the BioRID dummy jacket validation test, lower torso validation test, and dummy certification test outlined the *United Nations Mutual Resolution No. 1 - Addendum 1 - Specifications for the Construction, Preparation and Certification of the 50th Percentile Male Biofidelic Rear Impact (BioRID-II UN) Anthropomorphic Test Device* (Economic Commission for Europe. 2022).

### 1.3.1.3 Clothing

The dummy should be dressed in two pairs of close-fitting, knee-length, spandex (e.g., lycra) pants and two close-fitting, short-sleeved spandex shirts. The under layer of clothes should be worn with the shiny/smooth side of the fabric facing out and the outer layer should be worn with the shiny/smooth side against the underclothes (i.e., dull side facing out). The dummies feet should be shod with size 11 (45 European or 27.9 cm) Oxford-style, hard-soled work shoes (e.g., MIL-S-13192P).

## 1.3.2 H-point manikin installation

Using an H-point manikin that has been calibrated according to SAE J826 (SAE International, 2021), follow these steps:

1.3.2.1 Adjust the torque of the manikin H-point locking nuts to set the frictional resistance so that approximately 1 g is required to move the back pan relative to the seat pan. The back pan should retain its position relative to the seat pan without assistance at 90° but move with only the force of gravity at all other positions. For the manikin IIHS uses for rear impacts, this torque value is 18 inch-pounds.

1.3.2.2 The seat shall be covered with a cotton cloth large enough to cover both cushions and seatback.

1.3.2.3 The cloth shall be tucked into the seat joint by an amount sufficient to prevent hammocking of the material.

1.3.2.4 The manikin seat pan and back pan shall be installed in the seat.

1.3.2.5 The lower legs shall be adjusted to the 50th percentile leg length setting, and the upper legs shall be adjusted to the 10th percentile leg length setting; these are the manikin settings closest to the FMVSS 208 requirement.

1.3.2.6 The legs shall be attached to the manikin and set to the 5th position (no.5) on the knee joint T-bar, which places the knees 25 cm apart.

1.3.2.7 With the legs attached and the back pan tilted forward, the manikin shall be positioned in the seat such that its central sagittal plane coincides with the longitudinal centerline of the seat.

1.3.2.8 The back pan shall be straightened to conform to the vehicle seatback.

1.3.2.9 The feet shall be placed as far forward as possible, with the heels on the floor and the soles not in contact with the simulated toepan.

1.3.2.10 The lower leg and thigh weights shall be attached to the manikin and the machine shall be levelled.

1.3.2.11 The back pan shall be tilted forward and the manikin assembly pushed rearward until the seat pan contacts the vehicle seatback. While tilting the back pan forward, a horizontal rearward load of 100 N shall be applied using the plunger if present or using a force gauge pressed against the hip angle quadrant structure.

1.3.2.12 The load application shall be repeated and, while keeping the pressure applied, the back pan shall be returned to the vehicle seatback and the pressure then released. Once the back pan has been returned to the vehicle seatback, one hand should be kept on the T-bar with light pressure for the duration of the following installation to make sure the manikin does not move.

1.3.2.13 A check shall be made to determine that the manikin is level, facing directly forward, and located in the centerline of the seat.

1.3.2.14 After checking the position of the manikin in the seat at the seatback position established in Step 1.2.6.8, the right and left buttock weights shall be installed. The eight chest weights shall be installed by alternating left to right.

1.3.2.15 Tilting the back pan forward to a vertical position, the assembly shall be rocked from side to side over a 10-degree arc – 5 degrees in each direction. This rocking shall be repeated for a total of three complete cycles while preventing any horizontal translation of the manikin seat pan.

1.3.2.16 The back pan shall be returned to the vehicle seatback, and the manikin shall be levelled again as in 1.3.2.10. To ensure the back pan is stable in the seat, apply and release a horizontal rearward load ($\leq$ **10 N**) to the back pan approximately at the center of the torso weights. Ensure no exterior downward or lateral loads are applied to the manikin at this time.

1.3.2.17 The feet shall be positioned as follows: each foot shall be alternately lifted off the floor via the instep, until no additional forward foot movement is available.

1.3.2.18 When each foot is placed back in the down position, the heel shall be in contact with the floor. The sole should not be in contact with the simulated toepan.

1.3.2.19 If the manikin seat pan is not level after the feet have been repositioned, a sufficient load shall be applied to the top of the seat pan to level it on the vehicle seat.

1.3.2.20 If the measured torso angle is not 25±1 degrees as measured on the flat portion of the left (calibrated) torso weight hanger bar that is welded to the back pan, record the values for the position of the CoRP and CHRP when weighted by the manikin and readjust the seatback to match the reference values provided by the automaker for the weighted CoRP and CHRP. After adjusting the seat to match the weighted CoRP and CHRP points, remove the weights from the chest and buttocks and repeat the steps to position the manikin, beginning with tilting the back pan forward and pushing the manikin rearward as in Step 1.3.2.11.

1.3.2.21 If the measured torso angle is still not 25±1 degrees after the described readjustment of the seatback in Step 1.3.2.20, then further readjustment must be made to achieve a measured torso angle in this range. Once further readjustment has been completed, remove the chest and buttocks weights and repeat the steps to position the manikin again. If more than three drops of the manikin are necessary to achieve a measured torso angle in range, the manikin should be fully removed from the seat after the third drop for 15 minutes to allow the seat to recover.

1.3.2.22 For seats with indexed manual seatback adjustment, if there is no adjustment position that places the measured torso angle between 24 and 26 degrees, place the seatback in the most reclined position that supports a torso angle less than 24 degrees for testing.

1.3.2.23 The torso angle, H-points (left/right), and seat setup points shall be recorded when the torso angle falls within the allowed range of 25±1 degrees.

### 1.3.3 Calculation of BioRID targets from manikin position

The BioRID test position is based on reference measurements made with the H-point manikin and calculated values for the back of the head position of the HRMD. In these steps, the HRMD is not installed on the manikin, rather, the location of the HRMD backset probe is simulated using calculations based on the rigid geometry of the manikin and the H-point and torso angle for a given manikin measurement. This method yields the same results for backset as the measurements from the physical HRMD. The determination of these calculated values will be described in this section.

1.3.3.1    Record the vertical and horizontal location of the H-point manikin's H-point marker on both the left and right sides using a CMM.

1.3.3.2    Average the collected position values for the right and left side H-point markers.

1.3.3.3    Calculate the location of the horizontal and vertical position of the point on the back of the head of the HRMD (this is a virtual point that corresponds to the screw on the center of the rear surface of the HRMD backset probe) relative to the H-point. Calculate the <u>horizontal position</u> of the back of the head using Equation 1, where $\theta$ is the measured torso angle. Calculate the <u>vertical position</u> of the back of the head using Equation 2, where $\theta$ is the measured torso angle. To locate these points in the global coordinate system, add them to the H-point marker average point from 1.3.3.2.
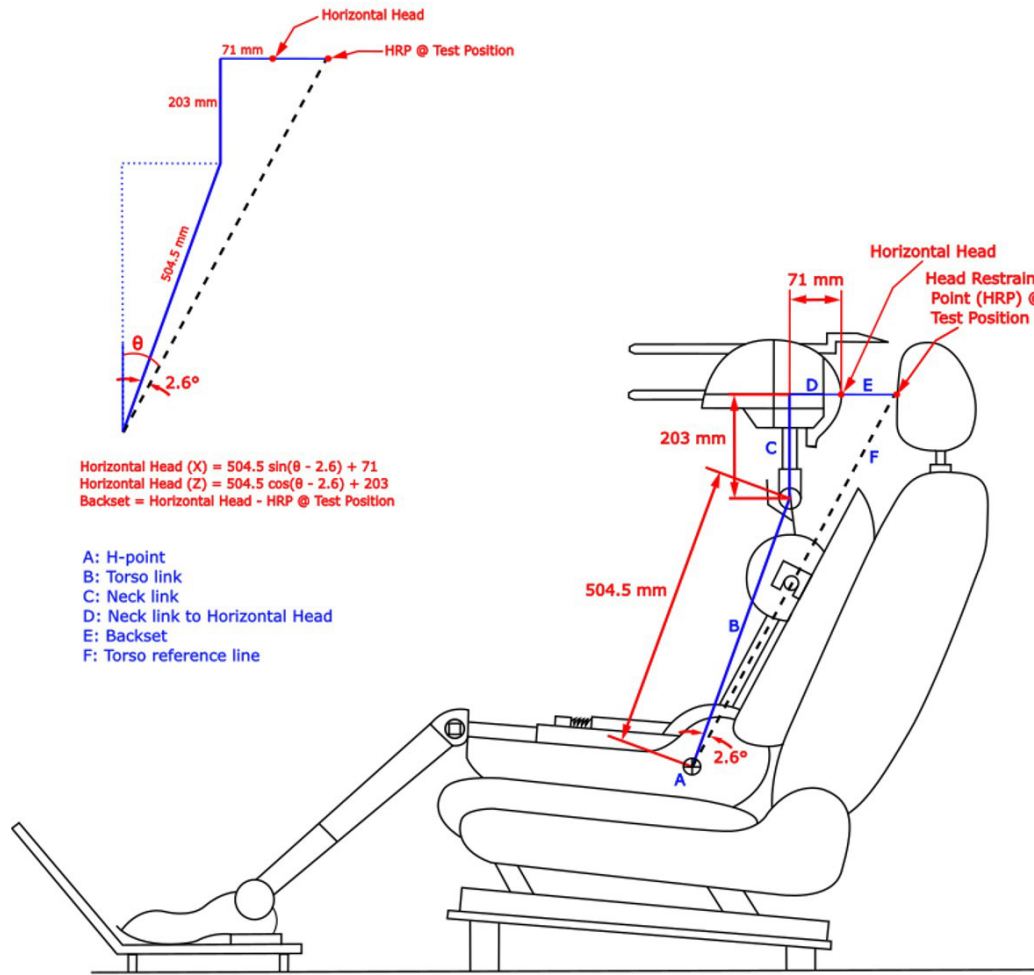
$$Horizontal\ head\ point\ (x) = 504.5 * \sin(\theta - 2.6°) + 71 \qquad \text{Equation 1}$$

$$Horizontal\ head\ point\ (z) = 504.5 * \cos(\theta - 2.6°) + 203 \qquad \text{Equation 2}$$

1.3.3.4    Calculate the vertical position of the top of the head using Equation 3.

$$Vertical\ head\ point\ (z) = Horizontal\ head\ point\ (z) + (-92) \qquad \text{Equation 3}$$

**Figure 8**
**Calculated HRMD back-of-head measurements**



(A) H-point from Step 1.3.3.2
(B) With the HRMD installed, the "torso link" linear distance from the H-point marker to the neck link pivot is 504.5 mm.
(C) With the head of the HRMD leveled, the vertical neck link distance from center of the pivot to the point where the back of the head is measured is 203 mm.
(D) The horizontal distance from the head pivot point to the back of the head is 71 mm.
(E) The backset is the horizontal distance between the Horizontal head point (Step 1.3.3.3) and Head restraint point @ test position (Step 1.3.3.6).
(F) The torso reference line represents the plane where the torso angle is measured

1.3.3.5    Set the head restraint to the test position described in Step 1.2.6.9.

1.3.3.6    Mark and record an identifiable point (Head restraint point @ test position) on vertical centerline of the head restraint that corresponds to the Horizontal head point (z) found in 1.3.3.3.

1.3.3.7    Measure and record the reference backset (E) as shown in Figure 8. This is the horizontal distance between the Horizontal head point (x) from Step 1.3.4.3 and the Head restraint point @ test position (x) from 1.3.3.6. The reference backset value (E) cannot be smaller than 0 mm; any calculated value less than 0 mm should be set to 0 mm.

### 1.3.4    BioRID Positioning

1.3.4.1    Allow the seat to recover for 15 minutes with nothing in it before installing the BioRID.

1.3.4.2    Align the BioRID's midsagittal plane laterally with the centerline of the seat.

1.3.4.3    Adjust the BioRID's midsagittal plane to be vertical; the instrumentation platform in the head should be laterally level.

1.3.4.4    Adjust the BioRID's pelvis angle to $26.5 \pm 2.5$ degrees from horizontal.

1.3.4.5    Position both left and right dummy H-Points $20 \pm 10$ mm forward of the location recorded in Step 1.3.3.2. Position both left and right H-Points $\pm 10$ mm vertically of the location recorded in Step 1.3.4.2, while keeping the pelvis angle at $26.5 \pm 2.5$ degrees. Note: It is recommended that the dummy be positioned as close as possible to the nominal target values; the tolerance window should be used only if there is difficulty achieving the required H-point target or backset value. The left and right H-point values should be within $\pm 10$ mm of each other both horizontally and vertically.

1.3.4.6    Adjust the spacing of the BioRID's legs so that the centerlines of the knees and ankles are $200 \pm 10$ mm apart.

1.3.4.7    Adjust the BioRID's feet and/or the adjustable toeboard so that the heels of the dummy's shoes are resting on the simulated vehicle floor and the tips of the shoes are resting on the toeboard 23–27 cm from the intersection of the heel surface and toe board, as measured along the surface of the toe board (Figure 9).

Note: If it is not possible to achieve the toe position as specified above, the feet should be positioned with the heels of the dummy's shoes resting on the simulated vehicle floor and the tips of the shoes resting on the toeboard, keeping the following in mind. The foot position should be set so that no joint of the BioRID leg or foot is at its endstop, the heel of the BioRID is not positioned in the intersection of the heel surface and toe board, and the pelvis location found in Step 1.3.4.5 is not altered by the position of the leg and foot.

**Figure 9**
**Proper BioRID feet positioning**
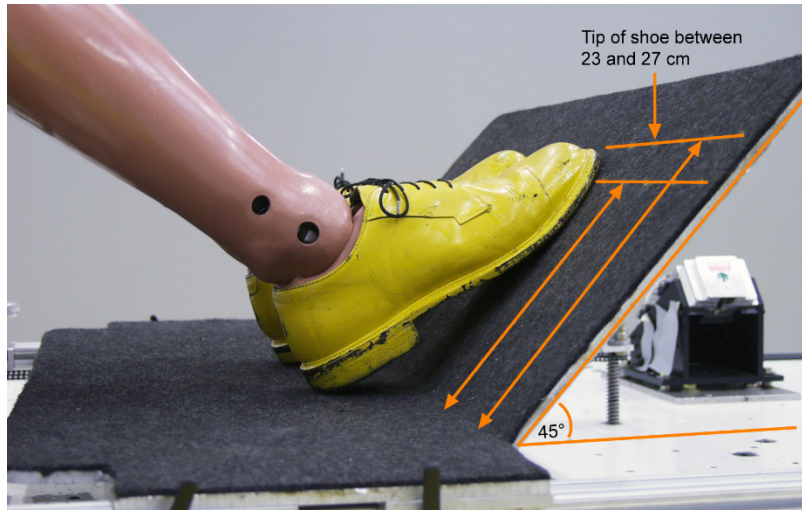


1.3.4.8    Position the BioRID's arms so that the upper arms contact the seatback and the elbows are bent so that the small fingers of both hands contact the top of the vehicle seat cushion with the palms facing the dummy's thighs.

1.3.4.9    Level the instrumentation plane of the head (front/rear and left/right directions) to within ± 0.5 degrees.

1.3.4.10   Measure the BioRID's backset (distance between the front of the head restraint and the back of the dummy's head) as follows:

A)   Record the most rearward point on the centerline of the dummy's skullcap. (Note: If using a measuring tape that contours to the shape of the skullcap, then this point is 9.5 cm from the top edge of the skullcap along the midsagittal plane of the skull.)

B)   The BioRID backset is the horizontal distance between the rearmost point on the dummy's head and the head restraint point @ test position marked in Step 1.3.3.6 (Figure 10).

**Figure 10**
**Measuring BioRID backset**



1.3.4.11 If the BioRID backset is different from the reference backset (Step 1.3.3.7) plus 15 ± 5 mm, then do the following:

A) Tip the head fore/aft no more than ± 0.5 degrees from level to meet the backset requirement.

B) If the BioRID backset still cannot be brought closer to the reference backset plus 15 mm, adjust the pelvis angle and H-point position within their respective tolerance bands, then begin with Step 1.3.4.4 and adjust the BioRID position accordingly.

C) If the above iterations still do not allow the backset to come within the specified tolerance for backset target and the H-point position is as far forward as the tolerance allows, then move the H-point forward of the allowed position the smallest distance that allows the backset requirement to be met.

### 1.3.5 Instrumentation, data acquisition, and processing

The instrumentation required to conduct an IIHS rear-impact evaluation is listed in Table 2.

BioRID-II includes a loadcell (or structural replacement) at the T1 vertebra; output of this sensor may be recorded at the tester's discretion. It is not recommended that sensors or a sensor mounting block be attached to the C4 vertebrae because of the potential for unintended interaction with the head skin that could affect the spine response. The measurement data shall be recorded according to SAE J211-1 (SAE International, 2022). Measurement data shall be considered for evaluation until the point in time at which the head rebounds from the head restraint or at 300 ms after $T = 0$, whichever occurs first.

**Table 2**
**BioRID and sled instrumentation**

| Measurement location | Measurement | Sensor type |
|---|---|---|
| Back of head | Time of head contact with head restraint | Switch to indicate contact with head restraint |
| Upper neck | A-P and L-M shear force and axial force | Loadcell (R.A. Denton model 4985J) |
| Upper neck | A-P moment | Loadcell (R.A. Denton model 4985J) |

| Measurement location | Measurement | Sensor type |
|---|---|---|
| Head center of gravity | Triaxial linear acceleration | Endevco 7264B-500 or similar |
| T1 vertebra – left side | Biaxial linear acceleration (A-P and I-S) | Endevco 7264B-500 or similar |
| T1 vertebra – right side | Uniaxial linear acceleration (A-P) | Endevco 7264B-500 or similar |
| L1 vertebra – left side | Biaxial linear acceleration (A-P and I-S) | Endevco 7264B-500 or similar |
| Pelvis | Triaxial linear acceleration | Endevco 7264B-500 or similar |
| Sled acceleration | Uniaxial linear acceleration (longitudinal) | Endevco 7264B-2000 or similar |

## 1.4   Crash pulse

The target sled acceleration and pulse specifications are given for the 16-km/h delta V pulse in Figure 11 and Table 3, respectively. The target sled acceleration and pulse specifications are given for the 24-km/h delta V pulse in Figure 12 and Table 4, respectively.

Sled accelerations should be measured by an appropriate accelerometer attached to the sled platform and recorded according to SAE International's Standard J211-1 (2022). Prior to establishing conformance with the acceleration pulse specification, any quiescent signal bias should be removed from the acceleration measurement. Conformance with pulse duration, peak acceleration, and timing are done with the signal filtered to channel frequency class (CFC) 60. 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. Figure C-1 shows the typical variation in accelerations for the 16-km/h delta V pulse from 50 tests conducted on the IIHS sled, and Figure C-2 shows the typical variation in accelerations for the 24-km/h delta V pulse from 40 tests conducted on the IIHS sled.
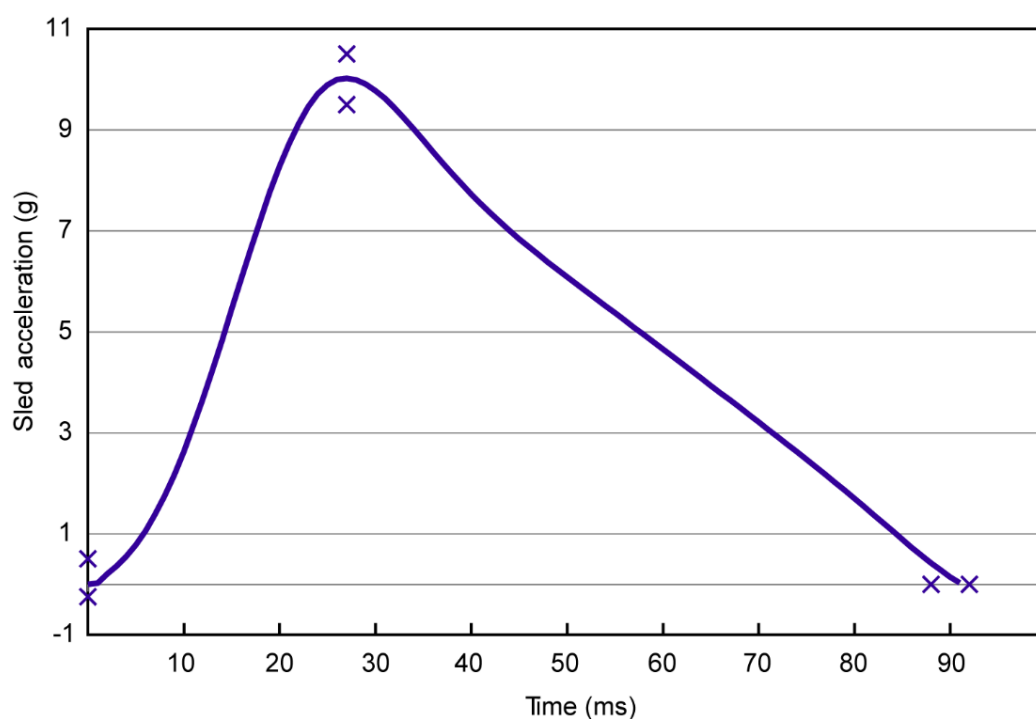
### 1.4.1   Test time indexing (16 km/h)

To normalize the time index among sled laboratory protocols with different T = 0 trigger levels, the time of the occurrence of the maximum acceleration is used as the reference for indexing time. The procedure is described as follows:

1.4.1.1   Record the X-acceleration of the sled in accordance with SAE J211-1 (SAE International, 2022).

1.4.1.2   Remove data channel DC bias by subtracting the average of the first 100 samples of the quiescent data channel signal from every test measurement.

1.4.1.3   Filter the sled acceleration to CFC 60 as defined by SAE J211-1.

1.4.1.4   Find the measurement that corresponds to the maximum sled acceleration and note the time it occurs.

1.4.1.5   Subtract 27 ms from the time noted in Step 1.4.1.4 and use the resulting difference to re-index the time. If the difference is positive (> 0), then measurements recorded at the original T = 0 will now occur before T = 0. If the difference is negative (< 0), then measurements recorded at the original T = 0 will now occur after T = 0. The peak sled acceleration (filtered data) should occur at exactly 27 ms.

**Figure 11**
**16-km/h delta V – Target sled acceleration and specification corridors**



**Table 3**
**16-km/h delta V – Sled acceleration pulse specifications**

| Acceleration Pulse Characteristic | Minimum | Maximum |
|---|---|---|
| Acceleration at time = 0 ms | −0.25 g | 0.50 g |
| Acceleration at time = 27 ms | 9.5 g | 10.5 g |
| Time that sled acceleration returns to 0 g | 88 ms | 94 ms |
| Velocity change (delta V) | 14.8 km/h | 16.2 km/h |

### 1.4.2   Test time indexing (24 km/h)

To normalize the time index among sled laboratory protocols with different T = 0 trigger levels, the time of the occurrence of 1-g acceleration is used as the reference for indexing time. The procedure is described as follows:

1.4.2.1    Record the X-acceleration of the sled in accordance with SAE J211-1 (SAE, 2022).

1.4.2.2    If necessary, remove any data channel DC bias. Typically, the value of the average measurement over 100 samples of the quiescent data channel signal is subtracted from every test measurement.

1.4.2.3    Filter the sled acceleration to CFC 60 as defined by SAE J211-1.

1.4.2.4    Find and note the time that corresponds to the 1-g sled acceleration.

1.4.2.5    Subtract 3.7 ms from the time noted in Step 1.4.2.4 and use the resulting difference to re-index the time. If the difference is positive ($> 0$), then measurements recorded at the original T = 0 will now occur before T = 0. If the difference is negative ($< 0$), then measurements recorded at the original T = 0 will now occur after T = 0.

**Figure 12**
**24-km/h delta V – Target sled acceleration and specification corridors**
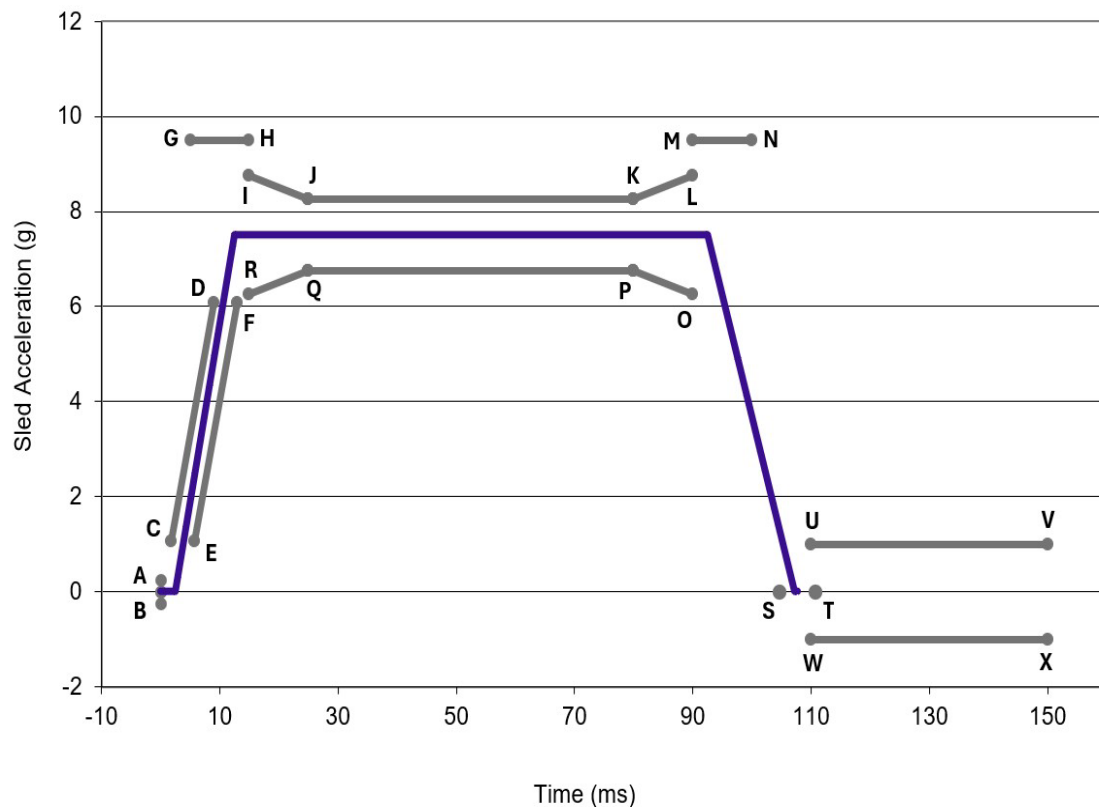
**Table 4**
**24-km/h delta V – Sled acceleration pulse specifications**

| Parameter | | | Target | Minimum | Maximum |
|---|---|---|---|---|---|
| Velocity change | | | 24.45 km/h | 23.25 km/h | 25.65 km/h |
| Mean acceleration | | | 6.44 g | 5.94 g | 6.94 g |
| Maximum acceleration | | | 7.50 g | 6.75 g | 8.25 g |

| | Time (ms) | Acceleration (g) | | Time (ms) | Acceleration (g) |
|---|---|---|---|---|---|
| A | 0 | 0.25 | M | 90 | 9.50 |
| B | 0 | −0.25 | N | 100 | 9.50 |
| C | 1.8 | 1.0714 | O | 90 | 6.25 |
| D | 9 | 6.0880 | P | 80 | 6.75 |
| E | 5.8 | 1.0714 | Q | 25 | 6.75 |
| F | 13 | 6.0880 | R | 15 | 6.25 |
| G | 5 | 9.50 | S | 104.7 | 0.00 |
| H | 15 | 9.50 | T | 110.7 | 0.00 |
| I | 15 | 8.75 | U | 110 | 1.00 |
| J | 25 | 8.25 | V | 150 | 1.00 |
| K | 80 | 8.25 | W | 110 | −1.00 |

# 2    Physical test procedure for verification data submission

Physical tests conducted for submission to IIHS as verification data should comply with Section 1 (IIHS physical test procedure section) with targets provided by IIHS as described in the following steps.

## 2.1    General test requirements

General test requirements should comply with Section 1.1.1 of the IIHS physical test procedure section.

## 2.2    Sled and vehicle environment

- The sled and vehicle environment should comply with Sections 1.2.1–1.2.5 of the IIHS physical test procedure section.

- The seat adjustments should be set according to Section 1.2.6, ensuring that the CoRP point (X and Z) relative to the left front-seat bolt attachment hole (LFSBH) of the unweighted seat aligns (± 5 mm) of the point located by IIHS in Step 2 of the Workflow section. The vertical distance between the heel point and LFSBH should be within ± 5 mm of the target used by IIHS in Step 2 of the Workflow.

- The seatback angle should be set using the CHRP relative to CoRP (Figure 5) horizontal and vertical distances (± 5 mm) for an unweighted seat provided by IIHS after the completion of Step 2 of the Workflow section. Larger tolerances may be accepted for manually adjustable seatbacks.

- The head restraint should be set to match the position provided by IIHS after the completion of Step 2 of the Workflow section. After the head restraint is positioned, the Head Restraint Point (HRP) @ Test Position should be located on the front surface of the head restraint at centerline within ± 5 mm of the vertical distance relative to the CoRP provided by IIHS after the completion of Step 2.

## 2.3 Dummy and seating procedure

The dummy and seating procedure should comply with Section 1.3 of the IIHS physical test procedure section, except that targets for H-point and backset should be those provided by IIHS after the completion of Step 2 of the Workflow section. The BioRID H-point should be $20 \pm 10$ mm forward and $\pm 10$ mm vertical of the manikin location provided by IIHS. BioRID's backset to the HRP @ Test Position should be the manikin backset provided by IIHS plus $15 \pm 5$ mm.

## 2.4 Crash pulse

The crash pulse used should comply with Section 1.4 of the IIHS physical test procedure section.

# 3 Simulation procedure for verification data submission

## 3.1 General simulation requirements

The simulation should replicate the occupant positions and the initial and boundary conditions from the physical test protocol and meet the requirements described in this simulation procedure.

### 3.1.1 Solver requirements

Simulation result submissions must have originated from (or been successfully traced back to) a Finite Element Model Explicit Solver (e.g., LS-DYNA). The solver software and version will be reported to IIHS using the *IIHS Rear Impact SIMULATION Data Submission Template.xlsx* template.

### 3.1.2 Hourglass energy

Automakers will self-report to verify that the hourglass energy for each of the components listed remains below 5% of its internal energy at all times.

- Dummy model
- Seat model
- All remaining model components

IIHS will require the submission of the global (i.e, whole model) hourglass and internal energy time-histories to verify the hourglass energy rate is correct for the model as a whole.

### 3.1.3 Added mass

Automakers will self-report to verify that the added mass for each of the components listed remains below 5% of their physical mass at all times.

- Dummy model
- Seat model
- All remaining model components

IIHS will require the submission of global (i.e., whole model) added mass time-history and the reported physical mass of the model to verify the added mass ratio is correct for the model as a whole.

### 3.1.4 Simulation setup

Simulations must be run at least until the end of head contact time with the head restraint plus 10 ms.

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### 3.1.5    Dummy sensor coordinate systems

The results of each channel must be reported in the coordinate systems in accordance with SAE J211 (SAE International, 2022).

### 3.1.6    Reporting

Automakers will report on all fields indicated in the *IIHS Rear Impact SIMULATION Data Submission Template.xlsx* template and the Data submission section of this protocol. The template requests information about:

- Solver version
- Model units
- Orientation of the global coordinate system
- Mesh quality
- Model mass
- Time step
- Dummy model
- Seat model
- Seating procedure
- Time-history outputs

## 3.2    Dummy model

### 3.2.1    Qualification

Only simulations conducted using pre-approved dummy models will be accepted for assessment. IIHS will determine whether to accept simulations after evaluating the evidence regarding model validity. Appendix D includes a list of all pre-approved dummy models for use in the assessment. Automakers using additional commercially available dummy models or modified versions thereof must seek IIHS approval before submitting results for virtual assessment.

A qualification procedure for rear-impact human surrogates is under consideration for future revisions to the protocol.

### 3.2.2    Seating procedure

Automakers are free to choose the most convenient seating procedure (e.g., settling by gravity, forcing position, etc.), provided that the final position in the simulation aligns with the position that would be achieved following Section 1.3.4 with the physical dummy. The following should be maintained until Time = 10 ms (with time zero defined based on the pulse shift described in Section 1.4):

- The dummy's midsagittal plane must remain within ± 2 degrees of the vertical direction.

- The head must remain level laterally and longitudinally (relative to ground) within ± 2 degrees.

- The absolute H-point position (not relative to recliner) must remain 20 ± 10 mm forward and ± 10 mm vertical of the H-point manikin settling location provided by IIHS.

- The pelvis angle must remain at 26.5 ± 2.5 degrees from horizontal.

- The centerlines of the dummy knees and ankles must remain 200 ± 10 mm apart.

- The backset must remain 15±5 mm forward of the H-point manikin calculated backset (horizontal distance between Horizontal head point (x) from Step 1.3.4.3 and the Head restraint point @ test position (x) from Step 1.3.3.6) provided by IIHS. Unlike the other requirements, this condition only needs to be maintained until Time = 5 ms.

## 3.3 Sled and vehicle environment

### 3.3.1 Model details and modifications

The automaker is responsible for modeling the vehicle environment (e.g., seat) with sufficient detail to accurately predict the response observed in the physical test.

Different vehicle environment models (e.g., material characteristics) may be used for the different load cases if it leads to improvements in the prediction of the physical test, except otherwise noted in this protocol.

### 3.3.2 Seat belt model

If the automaker believes that seat belt is relevant to the outcomes of these rear-impact tests, they should ensure the seat belt retractor mechanisms represent their physical counterparts as utilized in the physical tests (vehicle-specific or generic).

### 3.3.3 Seat and seat belt position

The vertical distance between the center of the seat recliner (Figure 5A) and the center of the left front attachment point hole (Figure 1) must remain within ±5 mm of the manikin drop value provided by IIHS until time > 5 ms (with time zero defined based on the pulse shift described in Section 1.4).

The angle between the seat recliner and the lateral head restraint post (measured at its intersection with the seatback) must remain within ±0.5 degrees of the manikin drop value provided by IIHS until time > 5 ms (with time zero defined based on the pulse shift described in Section 1.4).

The geometric location of the physical seat belt anchors, buckle, and D-rings relative to the physical seat shall be preserved in the simulation model.

### 3.3.4 Sled model

The seat and seat belt model (when applicable) must be attached to the sled (either rigidly or using a realistic bolt representation) at their corresponding attachment points.

The sled must be represented as a rigid body (even if limited to four nodes at the attachment points) and driven using prescribed motion.

The use of gravitational fields (i.e., body loads) to represent the pulse is not permitted.

## 3.4 Crash pulse

IIHS will provide automakers with:
1. An average (standard) pulse for each load case.

2. A range of feasible non-average pulses for each load case.

Automakers will be asked to:
1. Use the average (standard) pulses provided by IIHS for their simulation submissions.

2. (optionally) Submit simulation results using any or all of the non-average pulses provided by IIHS. These data will be used to identify the simulation result with the pulse most closely matching the physical test for audit purposes.


# DATA SUBMISSION


## 4    General data submission

Data submission formats and methods are under review and still in development. The methods and formats for data exchange described in this protocol will be used until formats can be finalized and submission tools are developed.


## 5    Physical test-specific data submission

### 5.1    Test data

Seat and dummy setup information and test outputs should be reported using the *IIHS Rear Impact PHYSICAL TEST Data Submission Template.xlsx.* All fields must be completed unless specified. Time-history data should have a minimum frequency of 10,000 Hz and at least 100 ms of data before sled trigger.


### 5.2    Video

1. A lateral left view (either stationary following the sled reference frame, or orthogonal to the plane of motion) that captures the entire event from the onset of acceleration to 100 ms past the end of head contact time.
2. A lateral right view (orthogonal to the plane of motion) that captures the entire event from the onset of acceleration to 100 ms past the end of head contact time.

Timestamp – Video must be timestamped in milliseconds aligned with RAW data
Format – .mp4 or .avi
Codec – H.264
Collection frame rate minimum – 500 fps
Replay frame rate – 10 fps


## 6    Simulation-specific data submission

### 6.1    General data

All points described in Section 3: Simulation procedure for verification data submission should be provided in binary format or reported in the *IIHS Rear Impact SIMULATION Data Submission Template.xlsx* provided by IIHS unless otherwise noted as optional. Time-history data should be provided from time zero (as defined in Section 1.4) to 10 ms after the end of head contact time and should have a minimum frequency of 10,000 Hz.

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## 6.2 Video

The following videos should be provided from simulations:
1. A lateral left view of the animation (filename: "Year_Make_Model_[16 or 24]_left.[ext]")
2. A lateral left view of the animation following on the sled reference frame (filename: "Year_Make_Model_[16 or 24]_left_follow.[ext]")
3. A lateral right view of the animation (filename: "Year_Make_Model_ [16 or 24]_right.[ext]")
4. A lateral right view of the animation following on the sled reference frame (filename: "Year_Make_Model_ [16 or 24]_right_follow.[ext]")
5. A frontal view of the animation (filename: "Year_Make_Model_ [16 or 24]_frontal.[ext]")
6. A rear view of the animation (filename: "Year_Make_Model_ [16 or 24]_rear.[ext]")
7. A top-down view of the animation (filename: "Year_Make_Model_ [16 or 24]_top.[ext]")
8. A bottom-up view of the animation (filename: "Year_Make_Model_ [16 or 24]_bottom.[ext]")

All videos must:

- Originate from a simulation output (e.g., d3plot) with a frequency of at least 1 step/ms.

- Be framed and adjusted so that the view is maximized while ensuring that the entire model is visible from beginning to end.

- Be taken from time zero to at least end of head contact time with the head restraint plus 10 ms.

- Meet the following specifications:

  Timestamp – Video must be timestamped in milliseconds aligned with RAW data
  Format – .mp4 or .avi
  Codec – H.264
  Replay frame rate – 10 fps
  File size – 1-10 MB

# AUDITING METHODS

## 7   Load case audit

After receiving the corresponding physical tests or simulations for verification, IIHS will select one of the two load cases at random (i.e., either the 16-km/h or the 24-km/h case) to audit the submitted data. IIHS will then conduct a physical test for the selected audit load case and determine whether the submitted data for that case successfully represents the physical test, based on the criteria described in Section 10. If the audited data meets said criteria, the submitted results for both load cases will be accepted for assessment.

In the near term, if the audited data fails to meet the requirements of the audit, IIHS will conduct an in-house physical test of the unaudited load case to complete the assessment and allow the vehicle to be eligible for the IIHS TSP award. The automaker will be responsible for providing the additional seat. IIHS will only conduct a physical test on the unaudited load case if the automaker has made a good faith effort to complete the verification data submission in accordance with this protocol.

# 8  Data processing at IIHS

## 8.1  Process overview

- All physical test data will be debiased according to Step 1.4.1.2. Simulation data will not be debiased except for upper neck force Z. Upper neck Z force can show an offset due to the mass of the head under the force of gravity and will be debiased using the average of the sensor output from 10 ms to 20 ms.

- All test and simulation data will be filtered using the CFC filters defined in Table 6.

- To align sled accelerations and occupant sensors, the time vector will be indexed using the methods described in Section 1.4.

- All peak values will be assessed only between T0 and the end of head contact time.

- The individual components of head (x, y, z), L1 (x, z), and pelvis accelerations (x, y, z) will be used to calculate the resultant accelerations of the corresponding bodies.

- The individual components of left T1 accelerations (x,z) will be used to calculate the T1 resultant acceleration.

- The pelvis displacement metric will be calculated with the sled x direction pointing forward using Equation 4.

- The sagittal velocity components of the head and pelvis will be calculated by integrating the corresponding accelerations using Equation 5 and Equation 6.The resultant velocity in the sagittal plane will be calculated using Equation 7.

- The head-to-pelvis relative velocity metric will be calculated using Equation 8.

- NKM will be calculated using Equation 9 and Equation 10, 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.

- T1 x acceleration maximum is calculated from the average of the left and right T1 x accelerometers using Equation 11.

- The simulation head contact time will be defined as the first time of non-zero contact force between the head and the head restraint. Non-zero contact force must have a duration of 40 ms to be considered the head contact time.

  The simulation end of head contact time will be defined as the step after the first zero contact force between the head and the head restraint after the beginning of head contact time.


## 8.2  Process details

### 8.2.1  Variable head contact adjustment (16 km/h and 24 km/h)

Head contact time is the time after the onset of sled acceleration (T0) that the dummy's head contacts the head restraint and maintains contact for at least 40 ms. End of head contact time is defined as the first time after the beginning of head contact time that the head loses contact with the head restraint.

Note: 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 video to ascertain whether the breaks in contact are not due to biomechanical phenomena such as ATD ramping, head restraint, or seatback collapse, or "bounce" of the head during nonstructural contact with the head restraint.

Sled accelerations meeting the specified corridors may have different timing that can lead to differences in head contact times recorded on identical seats tested at different labs. To eliminate variation in head restraint contact times between labs, the recorded head contact time must be adjusted to reflect the contact time that would be expected if the exact target pulse was achieved. The procedure for adjusting recorded head contact time is described as follows:

Note: All data referred to in this section must already be time-indexed as described in Section 1.4.1 or 1.4.2. See Appendix B for an example of how to adjust the head contact time.

8.2.1.1   Using the sled filtered acceleration (CFC 180), convert to meters per second by multiplying by 9.81. Integrate the 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.

8.2.1.2   (For 16-km/h pulse) Find the time in milliseconds at which the recorded sled velocity change reaches 4.00 m/s and use the next highest whole number. For example, both 61.3 ms and 61.8 ms should be converted to 62 ms. If the exact value is a whole number (e.g., 60.0 ms), no adjustment is necessary.

8.2.1.3   (For 24-km/h pulse) Find the time in milliseconds at which the recorded sled velocity change reaches 4.62 m/s and use to the next highest number. For example, both 61.3 ms and 61.8 ms should be converted to 62 ms. If the exact value is a whole number (e.g., 60.0 ms) no adjustment is necessary.

8.2.1.4   Subtract the time recorded in Step 8.2.1.2 or 8.2.1.3 from 70 ms. Add the difference to the time indexed head contact time from Step 1.4.1.5 (16 km/h) or Step 1.4.2.5 (24 km/h). The resulting value will be the official head contact time used for evaluation.

### 8.2.2   Equations and filters

**Table 5**
**Table of equations for calculated metrics**

| Test type | Calculation | Equation number |
|---|---|---|
| Physical test and simulation | $\text{Pelvis displacement} = \min\left(\iint a_{pelvis_x} dx dx - \iint a_{sled_x} dx dx\right)$ | Equation 4 |
| | $v_{region_x} = \int a_{region_x} dx$ | Equation 5 |
| | $v_{region_z} = \int a_{region_z} dz$ | Equation 6 |
| | $v_{region} = \sqrt{v_{region_x}{}^2 + v_{region_z}{}^2}$ | Equation 7 |
| | $\text{Head-to-pelvis relative velocity} = \min(v_{head} - v_{pelvis})$ | Equation 8 |

| Test type | Calculation | Equation number |
|---|---|---|
| | $Mocy = Upper\ y\ moment - Upper\ x\ force * .01778$ | Equation 9 |
| | $NKM = \dfrac{Fx(t)}{Fint} + \dfrac{Mocy(t)}{Mint}$ | Equation 10 |
| | $T1_{x_{acceleration}} = \max\left(avg(T1_{x_{acc(left)}}, T1_{x_{acc(right)}})\right)$ | Equation 11 |

**Table 6**
**Filters for time-history data, 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-headrest contact | N/A |
| Sled acceleration | CFC 60 (CFC 180 for integration for delta V) |

# 9    Pulse selection

IIHS will provide three pulses for each load case that fall within the corridors for pulse acceptance but span the range of variability observed in the IIHS sled. Appendix C and the *IIHS rear impact sled pulses.xlsx* spreadsheet contain the pulses that will be accepted.

IIHS suggests that automakers submit a simulation for each (three for 16 km/h, and three for 24 km/h) to improve their likelihood of passing the audit. After the audit test is complete, the pulse that aligns most closely with the delta V of the IIHS sled pulse will be chosen to compare with the IIHS physical test. The unaudited test will use the standard pulse.

Note: The IIHS acceleration sled is being replaced during winter 2026. After this is complete, the additional pulses will be provided based on the output variability of the new sled.

# 10  Test and simulation acceptance

IIHS will consider the submitted test or simulation accepted for assessment if:
1. All the points in Sections 2 or 3 have been followed for both load cases.
2. The data corresponding to the audited load case meets the criteria outlined in Section 10.1.

## 10.1  Acceptance criteria

- IIHS will audit time-history and peak metric data to determine data acceptance.

- For the submitted data to pass the audit, both the time-history and peak metric criteria as described in Sections 10.1.1 and 10.1.2 must be met.

### 10.1.1  Time-history data

- The ISO score for the head (x,y,z), T1 (x,z), L1 (x,z), and pelvis (x,y,z) resultant accelerations will be calculated using the submitted data with the results of the audit test after processing according to Section 8.

- The window for the ISO score will span from time zero (after shift) to end of head contact time plus 10 ms in the reference test (the IIHS physical audit test).

- The ISO score will be calculated according to Objective Rating Metric ISO 18571 published in Openvt.edu repository using the filters in Table 6 and the parameters in Table 7.

- The submitted data will be considered to have met the time-history acceptance criterion if the ISO score is greater or equal to 0.7 for the time-histories indicated in the first point.

**Table 7**
**ISO scoring parameter values**

| Parameter | Value |
|---|---|
| Exponent factor for calculating the corridor score between the inner and outer corridors ($k_Z$) | 2.0 |
| Relative half width of the inner corridor ($a_0$) | 0.05 |
| Relative half width of the outer corridor ($b_0$) | 0.5 |
| Exponent factor for calculating the phase score ($k_P$) | 1 |
| Maximum allowable percentage of time shift ($\varepsilon^*_P$) | 0.2 |
| Exponent factor for calculating the magnitude score ($k_M$) | 1 |
| Maximum allowable magnitude error ($\varepsilon^*_M$) | 0.5 |
| Maximum allowable slope error ($\varepsilon^*_S$) | 2.0 |
| Weighting factor of the corridor score ($w_Z$) | 0.4 |
| Weighting factor of the phase score ($w_P$) | 0.2 |
| Weighting factor of the magnitude score ($w_M$) | 0.2 |
| Weighting factor of the magnitude score ($w_S$) | 0.2 |

### 10.1.2  Peak metric data

- 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 12).

- The submitted data will be considered to have met the peak metric acceptance criterion if the normalized absolute error is lower than 1 for all peak metrics.

$$\text{Normalized absolute error} = \frac{\left|Result_{audit\ test} - Result_{verification}\right|}{Normalization\ factor} \qquad \text{Equation 12}$$
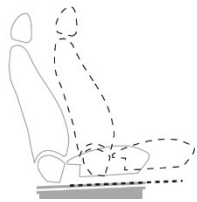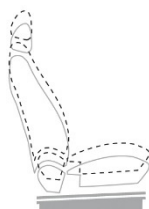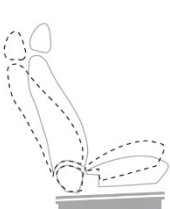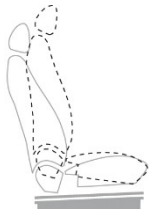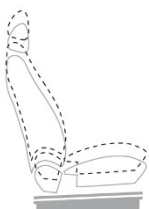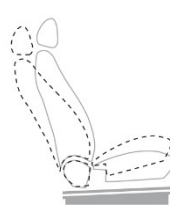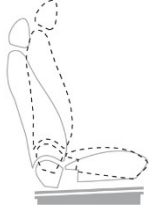
Note: All peak metrics used for rating will be subject to the peak metric acceptance criterion. Normalization factors for these metrics are published in *IIHS's Whiplash Prevention Evaluation Rating Guidelines* (IIHS, 2025).
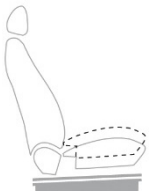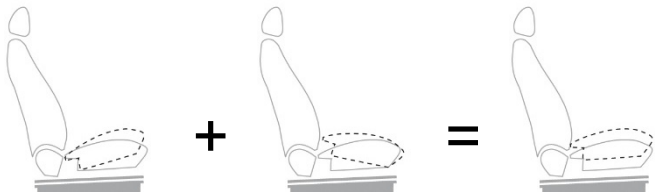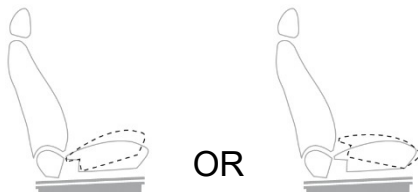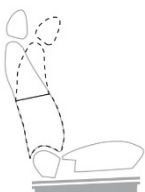
# REFERENCES
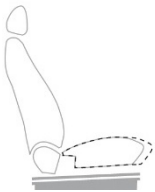
Economic Commission for Europe. (2022). *Inland transport committee. World forum for harmonization of vehicle regulations. Mutual resolution No. 1 (M.R.1) of the 1958 and 1998 Agreements. Concerning the description and performance of test tools and devices necessary for the assessment of compliance of wheeled vehicles, equipment and parts according to the technical prescriptions specified in Regulations and global technical regulation* (Amendment 3. Addendum 1. ECE/TRANS/WP.29/1101/Amend.3). https://unece.org/sites/default/files/2023-06/ECE-TRANS-WP.29-1101-Amend.3e.pdf

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SAE International. (2021). *Standard J826; Devices for use in defining and measuring vehicle seating accommodation.* https://doi.org/10.4271/J826_199507

SAE International. (2022). *Surface vehicle recommended practice J211/1; Instrumentation for impact test, Part 1: Electronic instrumentation.* https://doi.org/10.4271/J211/1_202208

## Appendix A: Seat adjustment definitions

| Definition | Image | Additional Images |
|---|---|---|
| **Seat Track** – An adjustment that moves the entire seat (seat cushion and seatback) in the fore and aft directions. |  | |
| **Seatback** – An adjustment that rotates the entire seatback, independently of the seat cushion, from a pivot at the seatback/seat cushion joint, therefore, changing the angle of the seatback relative to the seat cushion. |  | |
| **Seat Height –** An adjustment that moves the entire seat vertically (seat cushion and seatback in unison). This adjustment must keep the angle of the seat cushion the nearly the same relative to the ground. This can be one control (two-way) that moves the whole seat in unison or a combination of controls (four-way – a toggle or multiple knobs) that, when used together, keep the angle of the seat cushion nearly the same relative to the ground. | <br>Two-way<br>(one control) | <br>Four-way (toggle or multiple knobs)<br>NOTE: It is not possible to have four-way seat height AND seat tilt |
| **Seat Tilt** – An adjustment that rotates the entire seat (seat cushion and seatback in unison). This adjustment rotates a seat in such a way to significantly change the angle of the seat cushion, relative to the ground, from its full-down position. This adjustment can move either the front or rear of the seat to change the angle. | | <br>OR |

| Definition | Image | Additional Images |
|---|---|---|
| **Seat Cushion Height** – An adjustment that moves the seat cushion vertically, independent of the seatback, while keeping angle of the seat cushion nearly the same relative to the ground. This can be one control (two-way) that moves the whole seat cushion in unison or a combination of controls (four-way – a toggle or multiple knobs) that, when used together, keep the angle of the seat cushion nearly the same relative to the ground. |   Two-way (one control) |   Four-way (toggle or multiple knobs) NOTE: It is not possible to have four-way seat cushion height AND seat cushion tilt |
| **Seat Cushion Tilt** – An adjustment that moves the seat cushion, independent of the seatback, in such a way to significantly change the angle of the seat cushion, relative to ground, from its full-down position. This adjustment can move either the front or rear of the seat cushion to change the angle. | |   OR |
| **Lumbar Support** – An adjustment that causes the lower center portion of the seatback to protrude to provide support to the lumbar section of an occupant's spine. |  | |
| **Upper Seatback** – An adjustment that rotates only the upper portion of the seatback about a pivot point in the seatback. This adjustment will change the angle of the upper seatback relative to the lower portion of the seatback. |  | |

| Definition | Image | Additional Images |
|---|---|---|
| **Cushion Extension** – An adjustment that moves or extends a portion of the seat cushion forward so that the overall length of the cushion can be increased. |  | |
| **Side Bolsters** – An adjustment the moves the sides of the seatback or seat cushion so that the contour of the seat can be changed. |  | |
| **Head Restraint Height** – An adjustment that moves the head restraint vertically. |  | |
| **Head Restraint Tilt** – An adjustment that moves the head restraint horizontally. | |  OR  OR  |

## Appendix B: Example head contact adjustment (16 km/h)

Step 1.  Record sled acceleration.
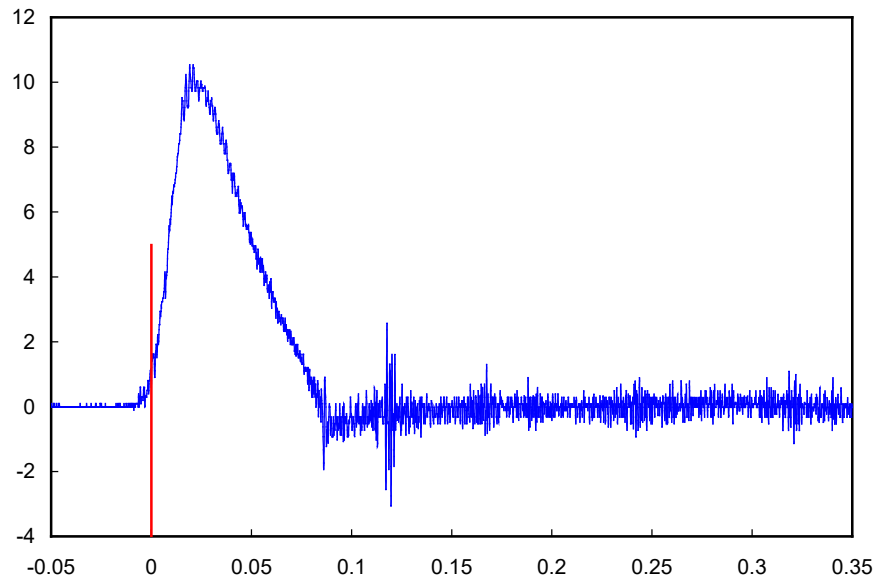


Step 2.  Remove signal bias.

Step 3.  Filter sled acceleration to CFC 60 to determine time shift and time shift all data (including head contact time).
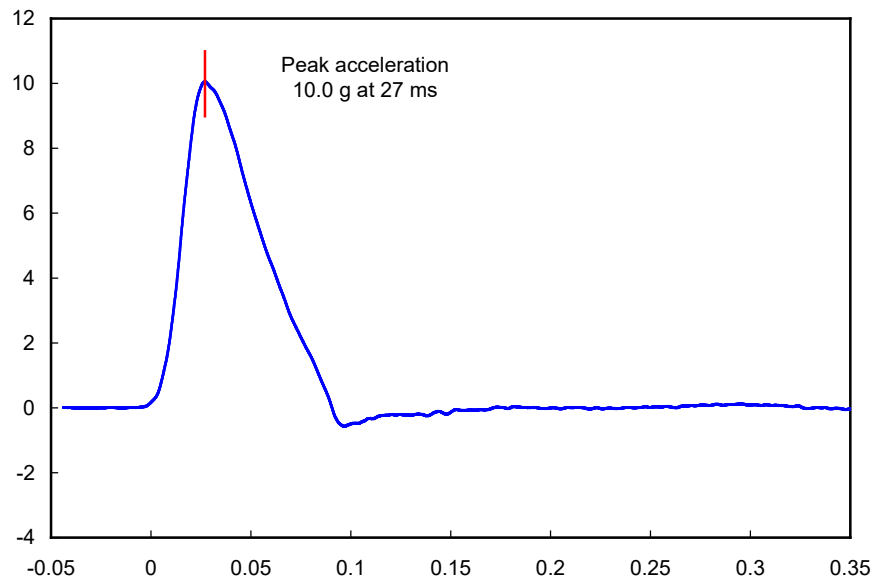
Step 4. Filter sled acceleration data to CFC 180.

Step 5. Convert the acceleration from gravity (g) to meters per second squared (m/s$^2$) by multiplying by 9.81.

Step 6. Integrate 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.
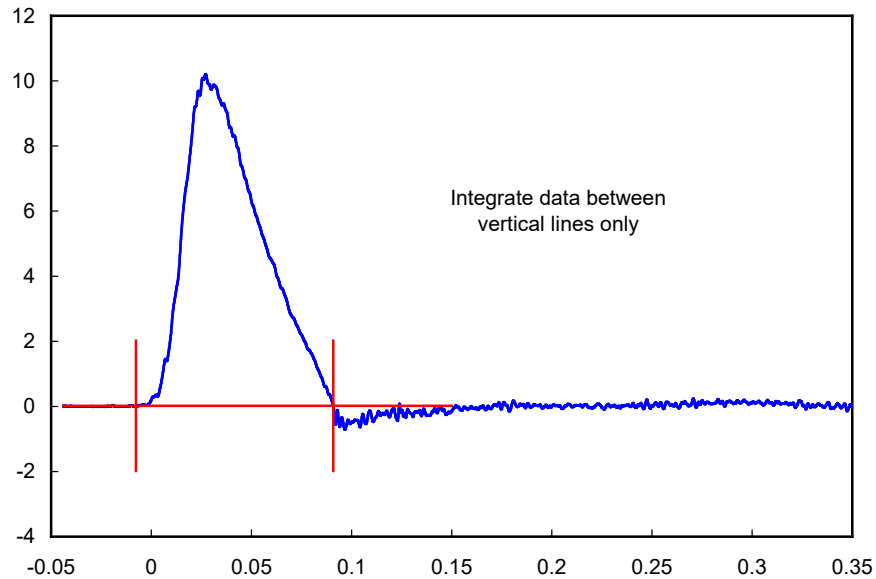


Step 7. Find the time at which the velocity change reaches 4 m/s and use the next highest whole number. For example, for both 61.3 ms and 61.8 ms a value of 62 ms should be used. An exact value recorded (e.g., 60.0 ms) does not need to be adjusted.
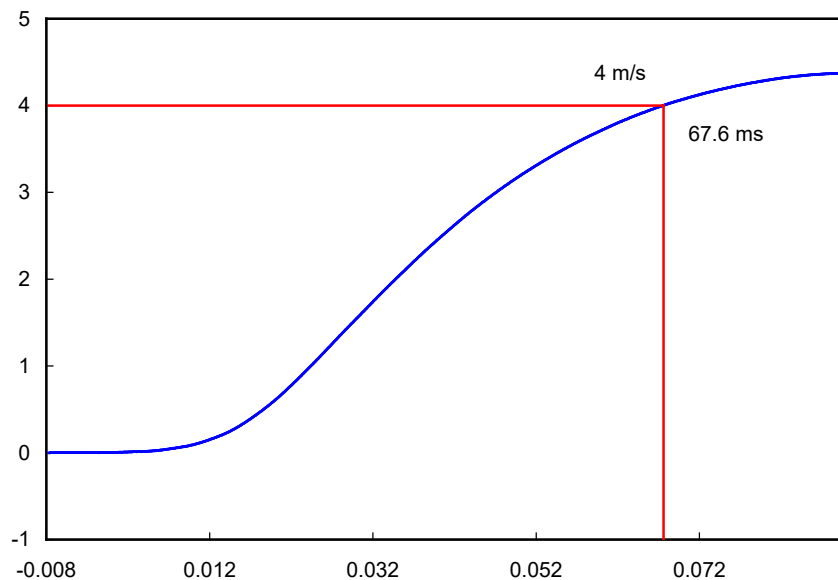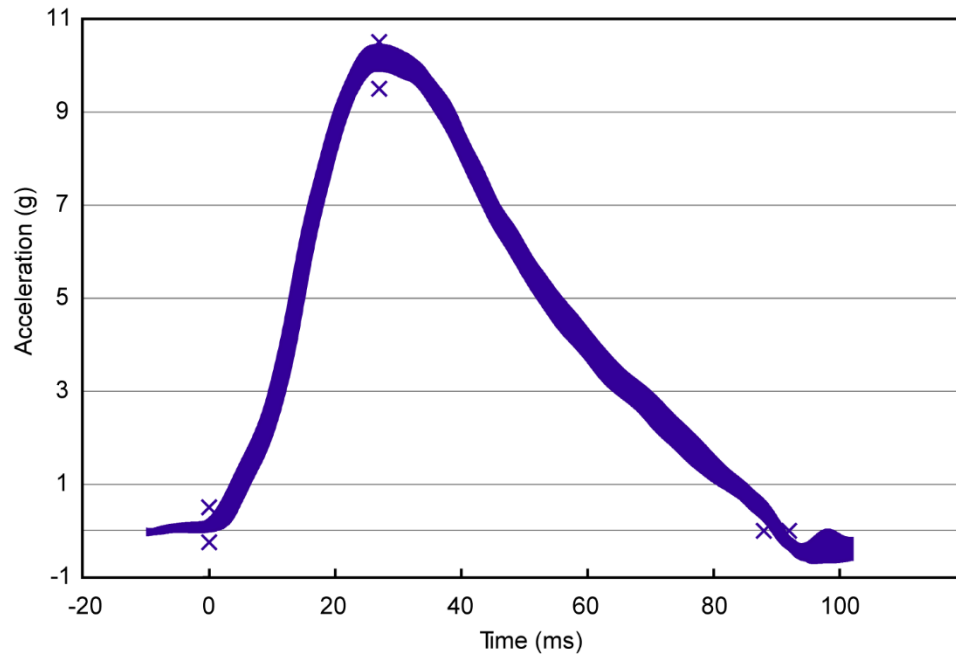
Step 8. Subtract the time recorded in Step 7 from 70 ms. Add the difference to the time indexed head contact time from Step 3. The resulting value will be the official head contact time (HCT) used for evaluation.
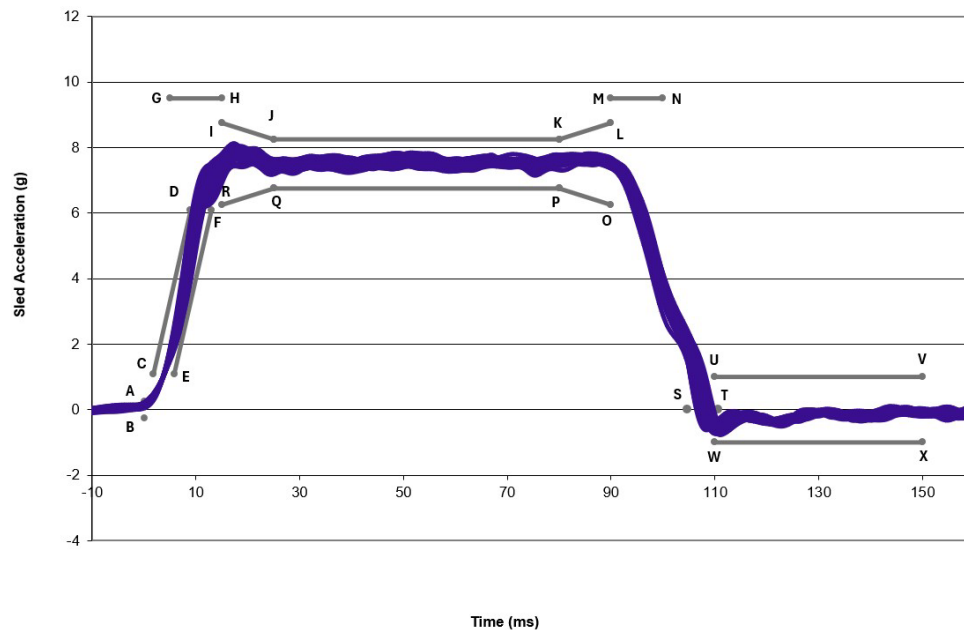
60 ms + 2 ms
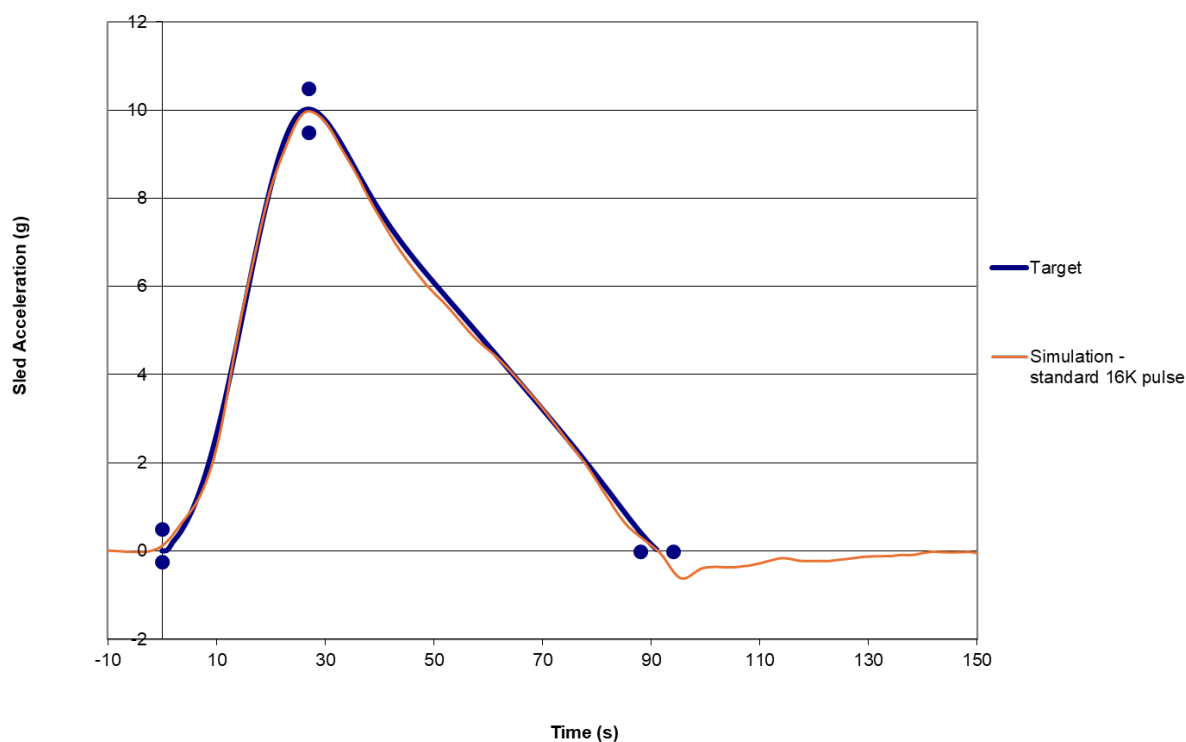HCT = 62 ms
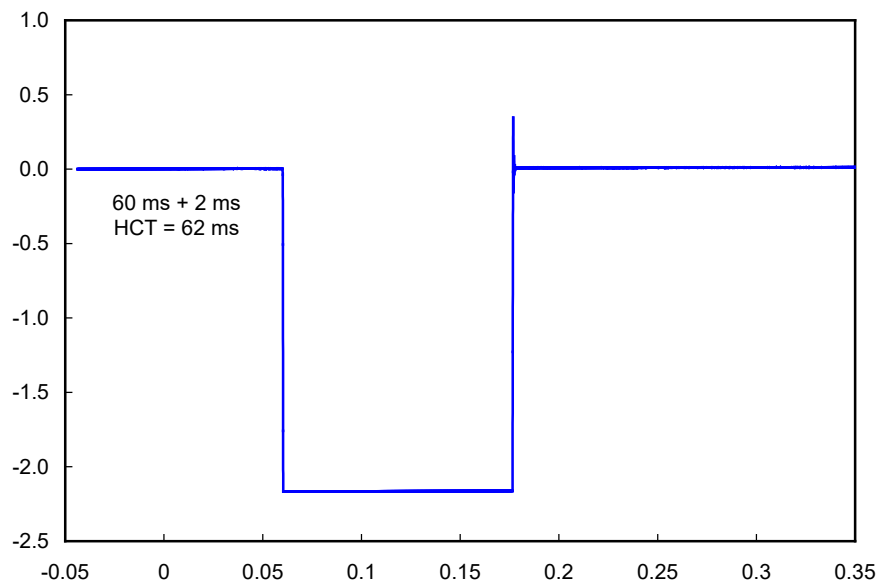
## Appendix C: Crash pulses

**Figure C-1**
**16-km/h delta V – Target sled acceleration and specification corridors**



**Figure C-2**
**24-km/h delta V – Target sled acceleration and specification corridors**

**Figure C-3**
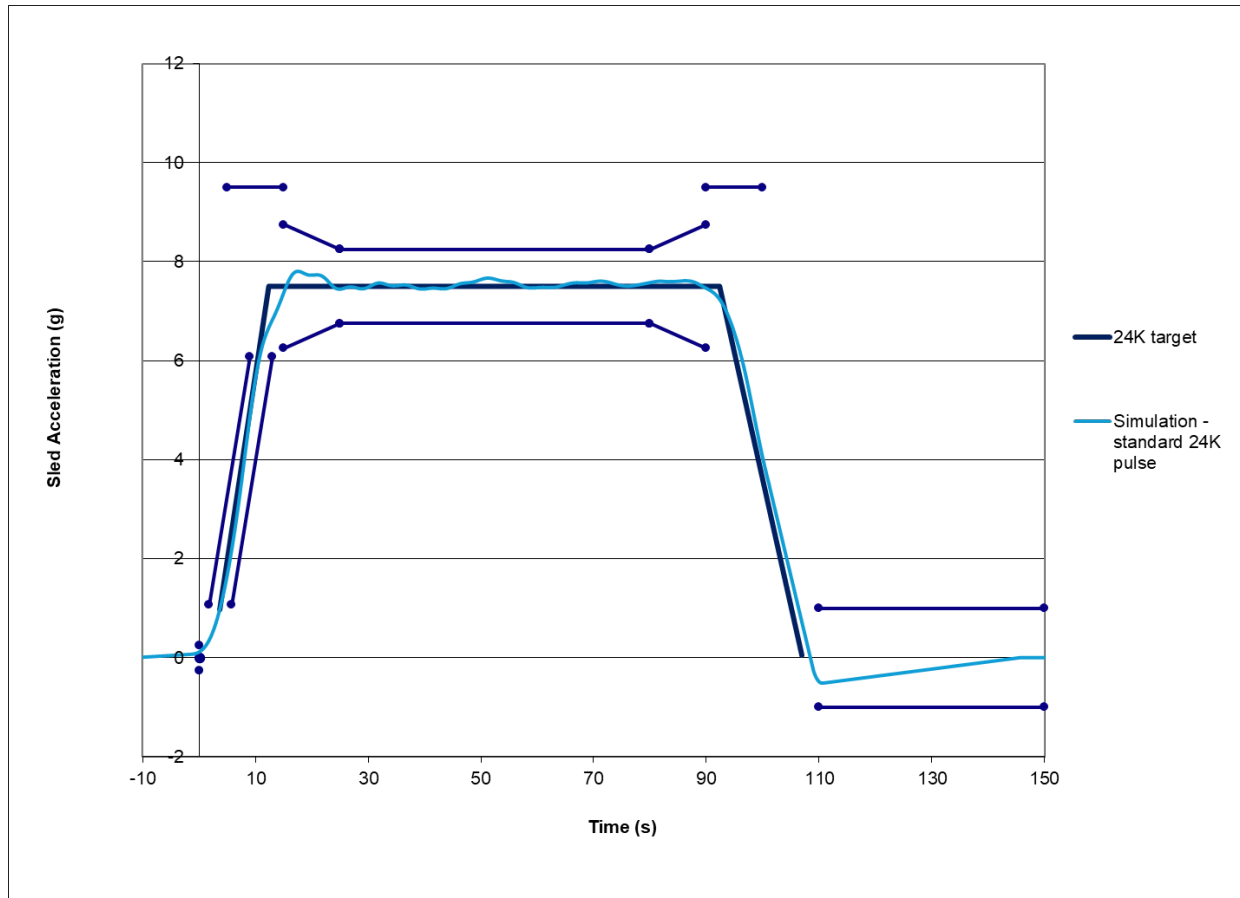**16-km/h delta V crash pulses for simulation**



**Table C-1**
**Parameters of the standard 16-km/h pulse for simulation (T0-zero cross)**

| Acceleration pulse parameters | Target | 16-km/h standard |
|---|---|---|
| Acceleration at time = 0 ms | 0.125 g ± 0.375 g | 0.12 g |
| Acceleration at time = 27 ms | 10.0 g ± 0.5 g | 10.0 g |
| Time that sled acceleration returns to 0 g | 91 ms ± 3.0 ms | 91 ms |
| Velocity change (delta V) | 15.5 km/h ± 0.7 km/h | 15.4 km/h |

**Figure C-4**
**24-km/h delta V crash pulses for simulation**



**Table C-2**
**Parameters of the standard 24-km/h pulse for simulation (T0-zero cross)**

| Acceleration pulse parameters | Target | 24-km/h standard |
|---|---|---|
| Velocity change | 24.45 km/h | 24.7 km/h |
| Mean acceleration | 6.44 g | 6.5 g |
| Maximum acceleration | 7.50 g | 7.8 g |

## Appendix D: List of approved dummy models

- DYNAmore GmbH LS-DYNA BioRID-II - Version 3.9 or newer
- To be determined: PAM-SAFE BioRID FE model – Version 4.0 or newer. (This model is being updated and will be reviewed for approval after completion.)


## Appendix E: List of templates and their use

*IIHS Rear Impact Seat Information.xlsx* is used by IIHS to receive seat setup information and manikin targets from automakers

*{testId} Dummy Seating Form.xlsm* is used by IIHS to collect measurements from the seat, manikin, and BioRID during the workflow and testing procedure. This sheet (incomplete) will be provided in Step 3 of the Workflow section and then again (complete with dummy setup information) after the completion of the physical audit test in Step 6 of the Workflow section.

*IIHS Rear Impact PHYSICAL TEST Data Submission Template.xlsx* is used by automakers to provide verification test data from physical tests to IIHS

*IIHS Rear Impact SIMULATION Data Submission Template.xlsx* is used by automakers to provide verification simulation data to IIHS

*Rear impact pulse summary.xlsx* provides time-history information for the accepted pulses for the 16-km/h and 24-km/h load cases. There is currently only one pulse for each load case.

The IIHS acceleration sled is being replaced during winter 2026. After this is complete, the additional pulses will be provided based on the output variability of the new sled.