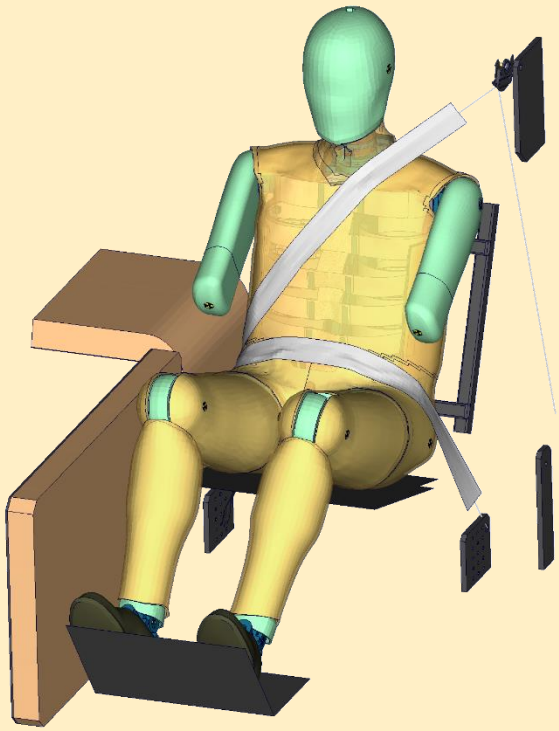
Documentation

VTC Validation Report

PDB LS-DYNA

WorldSID 50th – Version 8.1



User's Manual
VTC Validation Report for Model v8.1
March 13, 2024

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1. Stage 1

To make sure that the dummy model behaves like its physical counterparts the version 8.1 of the WorldSID 50th was validated according to ISO 15830[1] on different levels. The validation was performed for the **S2 (mm-s-ton)** and the **S3 (mm-ms-kg)** unit system.

1.1 Mass properties according to ISO 15830-2

Table 1 shows the mass properties of the dummy model compared to the ISO 15830-2 (2022).

Item	Hardware Mass [kg]	ISO 15830-2 Range [kg]		Model Mass [kg]
Head	4.29 ± 0.05	4.24	4.34	4.29
Neck	2.86 ± 0.02	2.84	2.88	2.86
Thorax/abdomen/shoulder	20.56 ± 0.35	20.21	20.91	20.56
Lower Torso	19.30 ± 0.20	19.10	19.50	19.30
Two half Arms	3.52 ± 0.08	3.44	3.60	3.52
Two Upper Legs	11.72 ± 0.08	11.64	11.80	11.72
Two Lower Legs	10.12 ± 0.14	9.98	10.26	10.12
Clothing	1.62 ± 0.16	1.46	1.78	1.62
Total	73.99 ± 1.08	72.91	75.07	73.99

Table 1: Mass properties

1.2 External dimensions according to ISO 15830-2:2022(E)

The considered external dimensions of the dummy model are shown in Figure 1 and Figure 2. The measured values in comparison to ISO 15830-2:2022(E) can be found in Table 2.

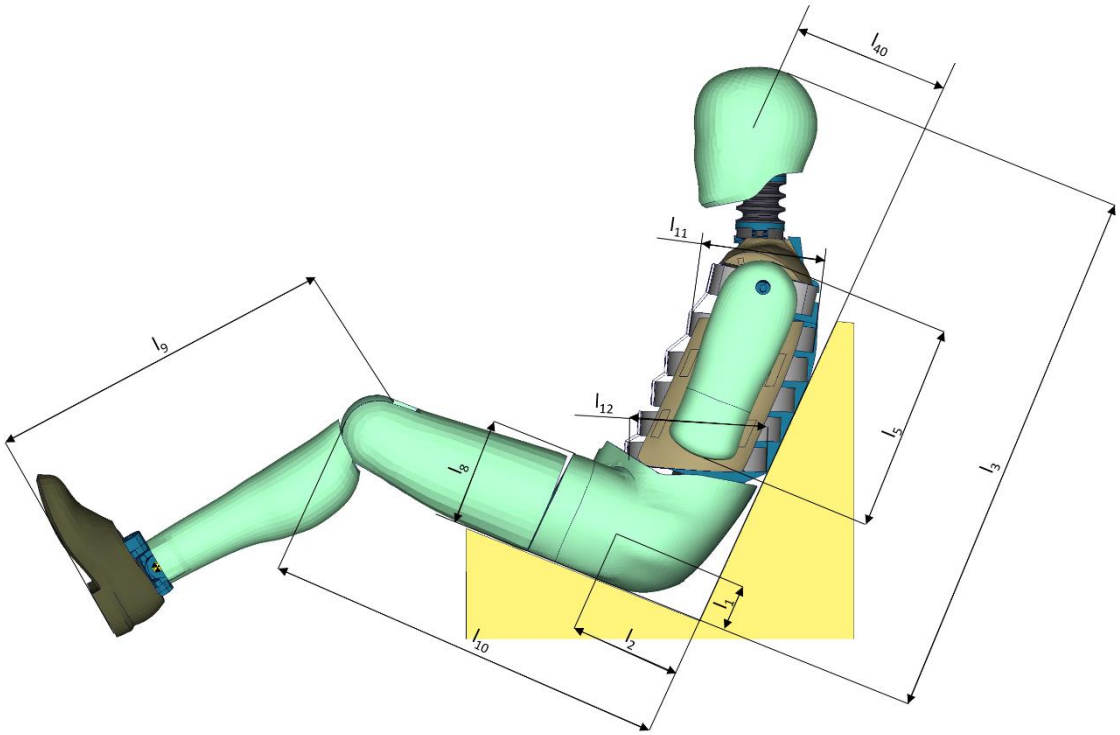


Figure 1: Dummy external dimensions side view

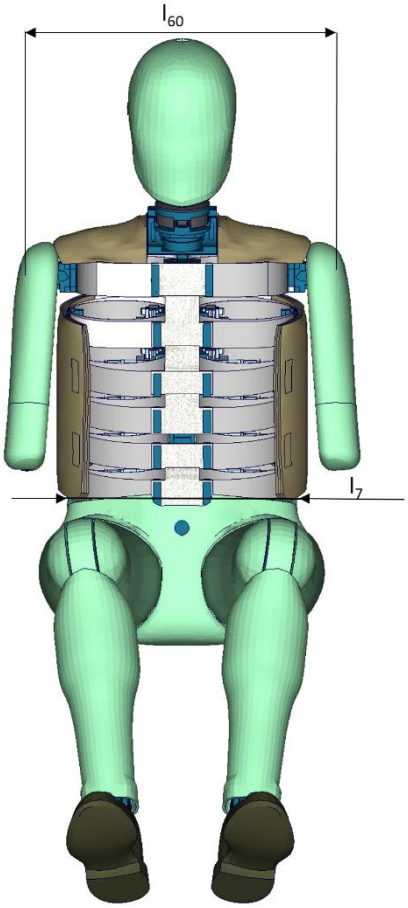


Figure 2: Dummy external dimensions front view

Linear parameter	Symbol	ISO 15830-5:2022 [mm]	Model data [mm]
Hip pivot height	l_1	85 ± 10	88
Hip pivot to back line	l_2	175 ± 10	167
Seated height	l_3	865 ± 20	871
Head reference mark to seat	l_{40}	250 ± 20	258
Arm length	l_5	330 ± 10	337
Width across shoulder	l_{60}	435 ± 10	441
Waist width	l_7	340 ± 10	337
Thigh clearance	l_8	170 ± 10	174
Knee to shoe height	l_9	580 (l) / 588 (r) ± 35	580
Knee to back line	l_{10}	665 ± 15	654
Thorax rib 1 front to back	l_{11}	205 ± 10	204
Abdomen rib 2 front to back	l_{12}	225 ± 10	225

Table 2: Dummy external dimensions overview

1.3 Range of motion ISO 15830-1:2022(E)

The range of motion of the dummy model in comparison with ISO 15830 is shown in Table 3. All design target angles are soft stop angles. Whereas the angles of the dummy model are hard stop angles.

Motion	Design target [°]	Measured [°]	Model data [°]
Shoulder flexion	180	172 contact, 190 forced	190
Shoulder extension	45	40 contact, 50 forced	50
Shoulder abduction	100	101.5	101
Shoulder adduction	0	-1	-2
Ankle plantarflexion	40	-	40
Ankle dorsiflexion	55	-	55
Ankle inversion/eversion	30	-	30

Table 3: ISO15830-1:2022(E) Range of motion overview

1.4 Sensors according to ISO 15830-3

All mentioned sensors in ISO 15830-3 are also present in the dummy model.

1.5 Certification according to ISO 15830-2

1.5.1 Head drop test

The disconnected head drops on a rigid plate. Then the head accelerations are measured. Two configurations are used: frontal and lateral drop test. The configurations are depicted in the following figure.

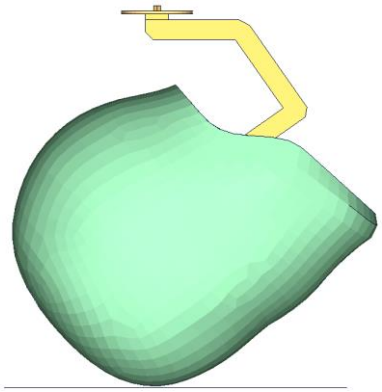


Figure 3: Head drop test frontal

Frontal drop	
Peak resultant acceleration [g]	205 to 255
Peak lateral acceleration y [g]	<15
Subsequent to main peak [%]	<10

Table 4: Frontal head drop test specifications

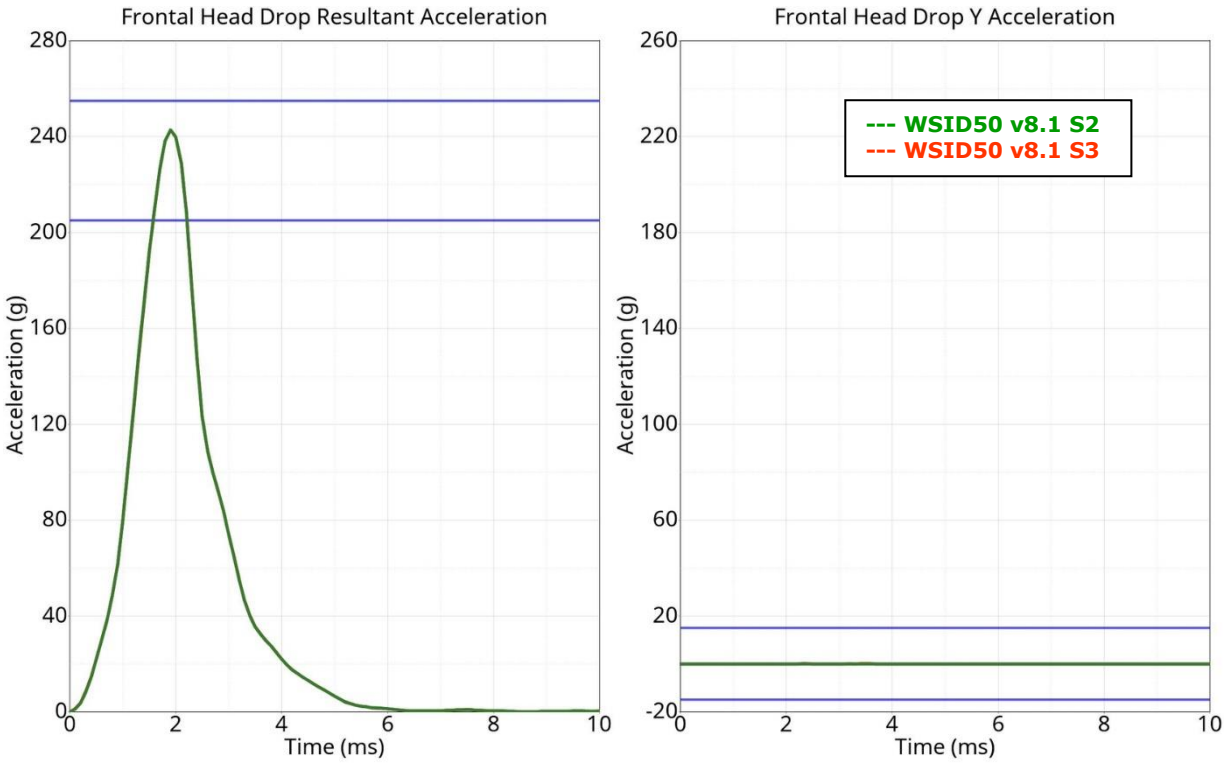


Figure 4: Frontal head drop test certification

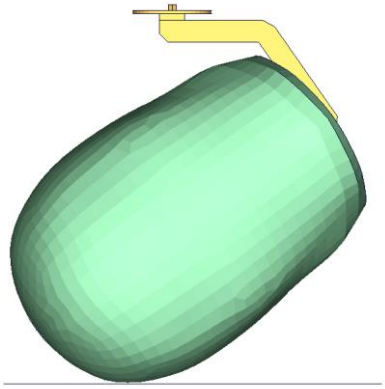


Figure 5: Head drop test lateral

Lateral drop	
Peak resultant acceleration [g]	104 to 123
Peak lateral acceleration X [g]	<15
Subsequent to main peak [%]	<10

Table 5: Lateral head drop test specifications

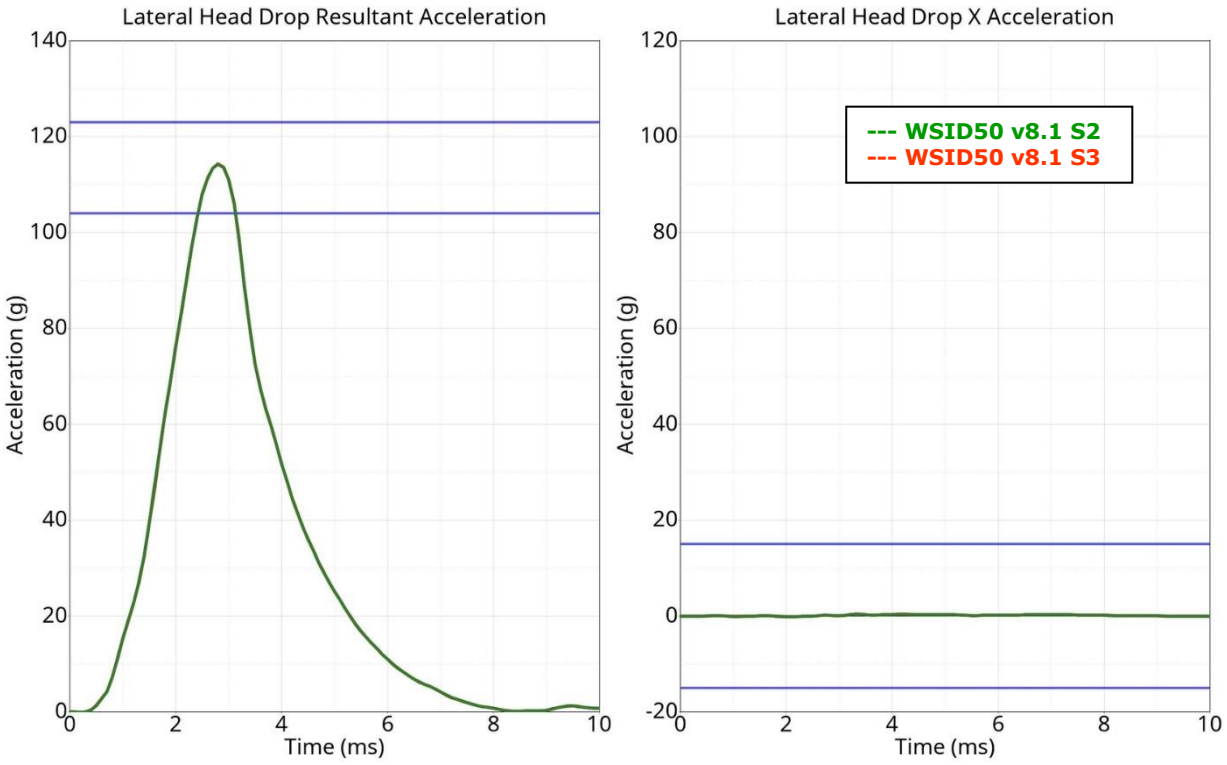


Figure 6: Lateral head drop test certification

1.5.2 Neck pendulum test

The test setup is depicted in the figure below. The neck is adapted to a long pendulum. The pendulum runs into a part of honeycomb to get decelerated, thereby causing the neck to bend against the load direction. As mass replacement, the head form is used instead of the original head.

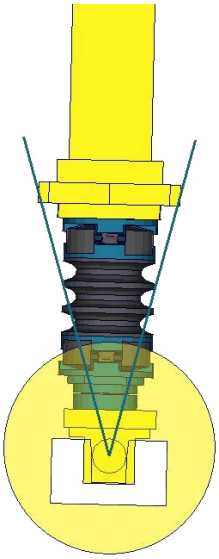


Figure 7: Neck pendulum calibration test setup

Neck pendulum	
Maximum angular displacement of the head β [°]	50 to 61
Decay time of β to 0 degrees [ms]	58 to 72
Peak moment at occipital condyle [Nm]	55 to 68
Peak moment decay time to 0 Nm [ms]	71 to 87
Peak forward potentiometer angular displacement [°]	32 to 39
Time of peak forward potentiometer angular displacement [ms]	56 to 68
Peak rearward potentiometer angular displacement δ [°]	30 to 37
Time of peak rearward potentiometer δ [ms]	56 to 68

Table 6: Neck pendulum test specifications

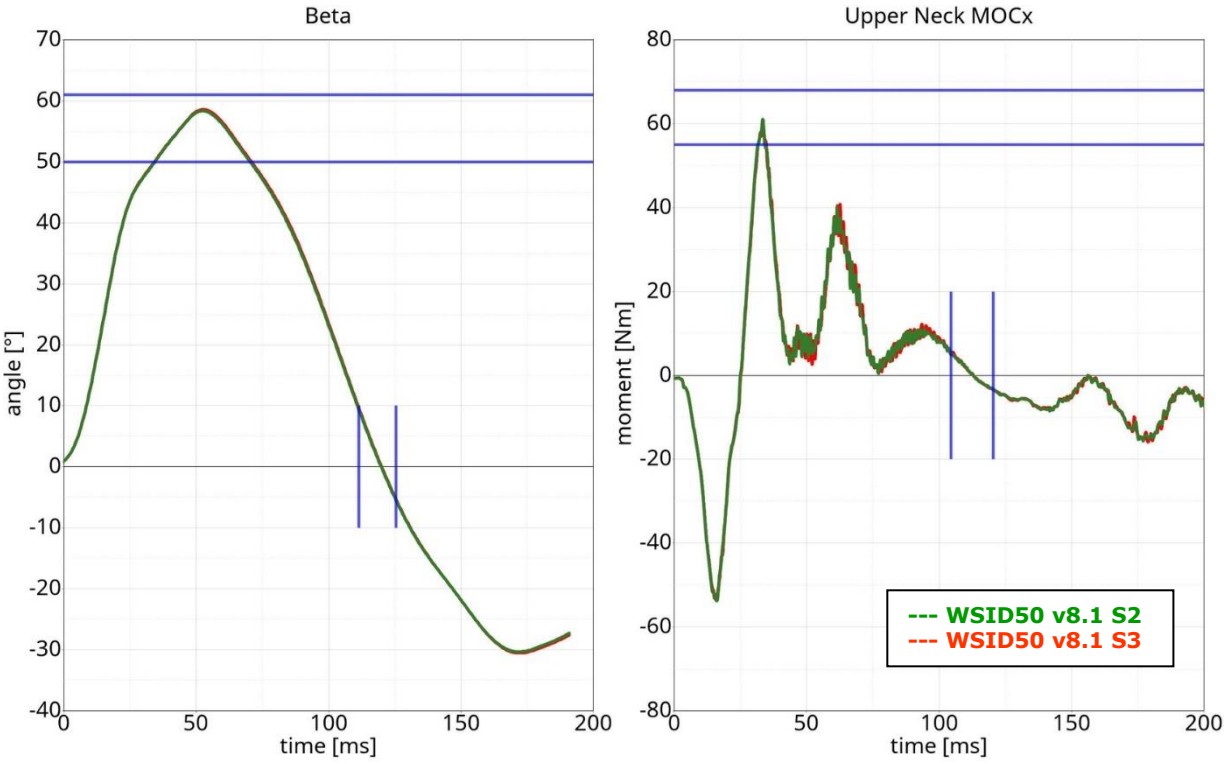


Figure 8: Neck pendulum test certification part 1

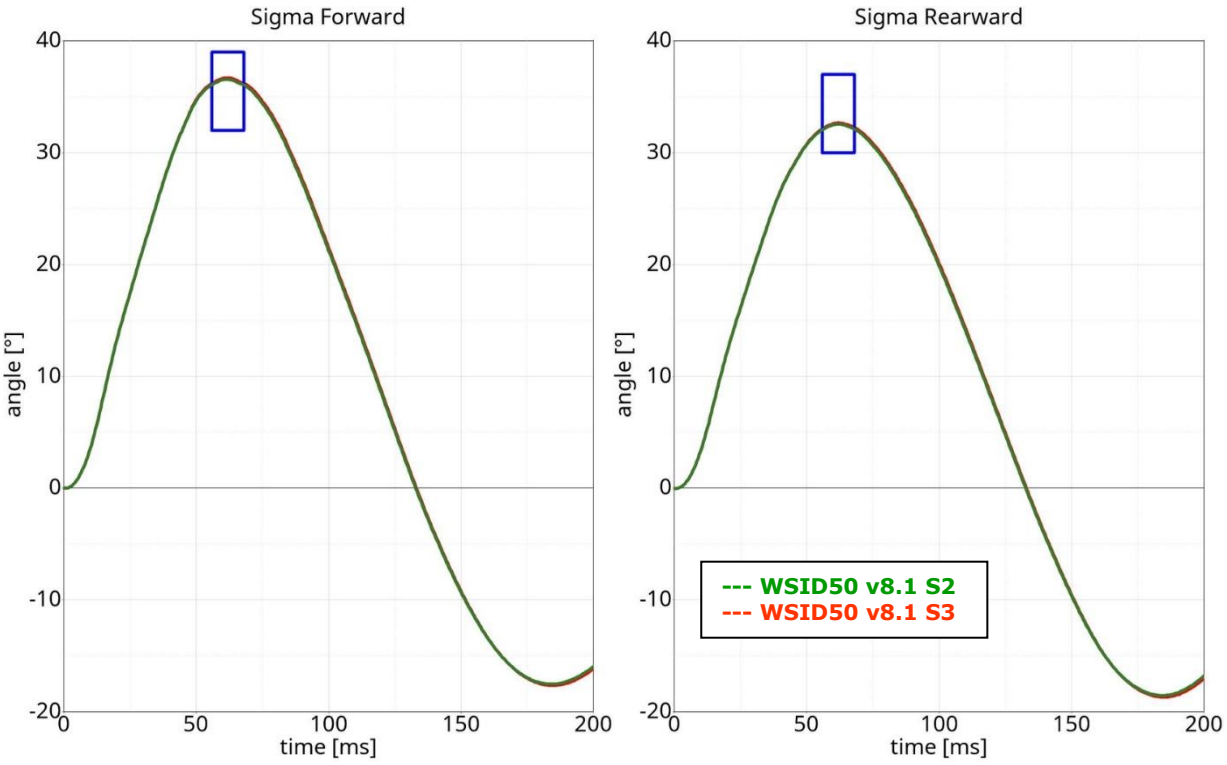
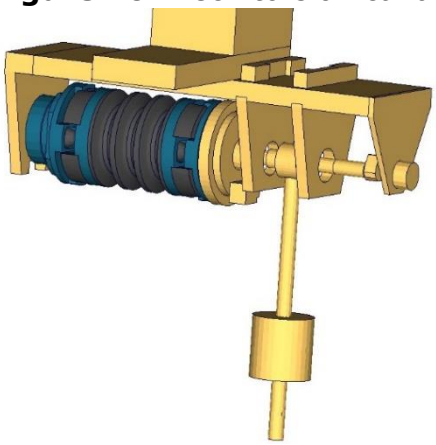


Figure 9: Neck pendulum certification part 2

1.5.3 Neck torsion test

The test setup is depicted in the figure below. The neck is mounted on the test master pendulum. There is an additional pendulum attached to one end of the dummy neck. Initially the whole system has the same velocity as the master pendulum. The master pendulum is then decelerated, leading to a torsion of the dummy neck due to the inertia of the additional pendulum.

Figure 10: Neck torsion calibration test setup



Neck torsion	
Peak torsion fixture rotation, z-axis[°]	41.9 to 51.2
Torsion fixture rotation decay time to 0 degrees [ms]	37.3 to 45.6
First peak torsion fixture angular rate[°/s]	1440 to 1760
Peak lower neck moment Mz [Nm]	34.6 to 42.9

Table 7: Neck torsion test specifications

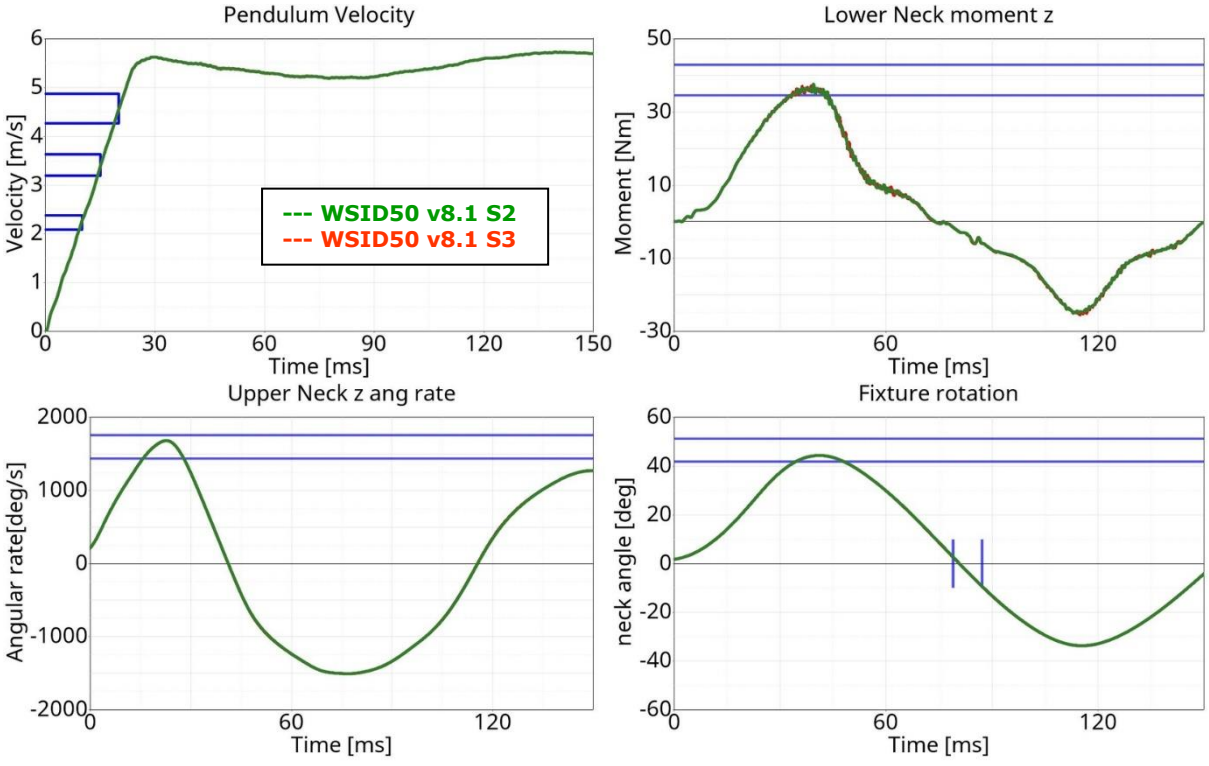


Figure 11: Neck torsion test certification

1.5.4 Shoulder pendulum test

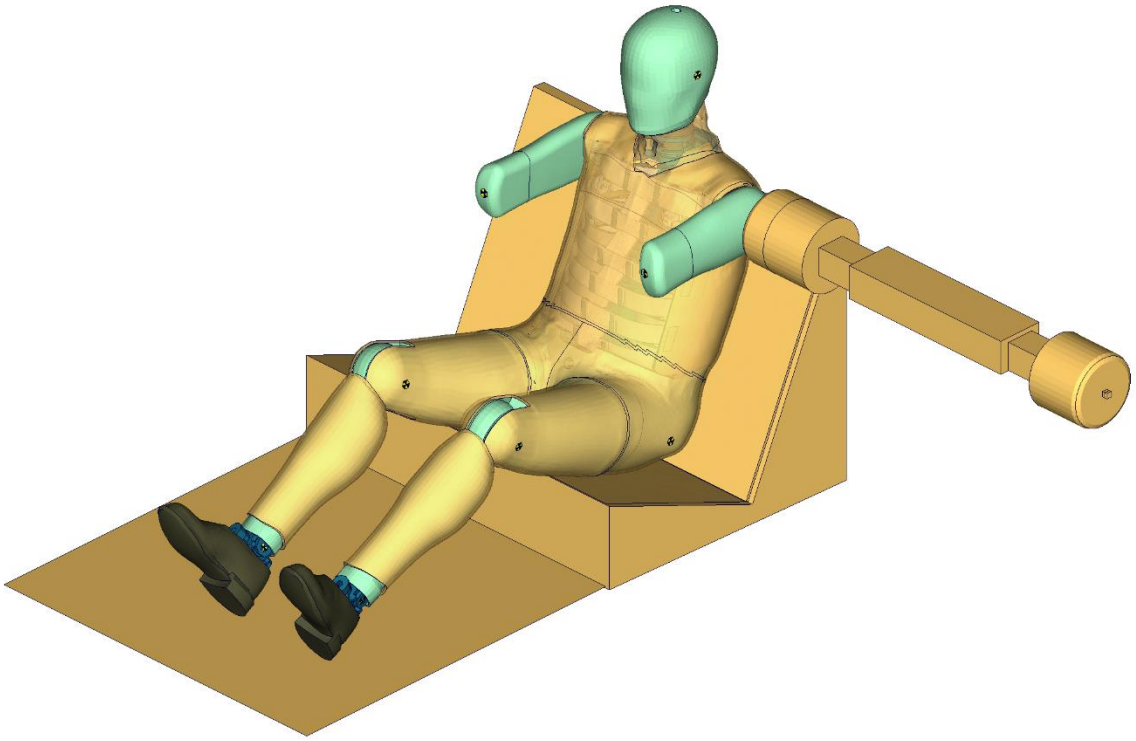


Figure 12: Shoulder calibration test setup

Shoulder pendulum	
Peak pendulum force [kN]	2.6 to 3.3
Peak shoulder rib deflection [mm]	35 to 45

Table 8: Lateral head drop test specifications

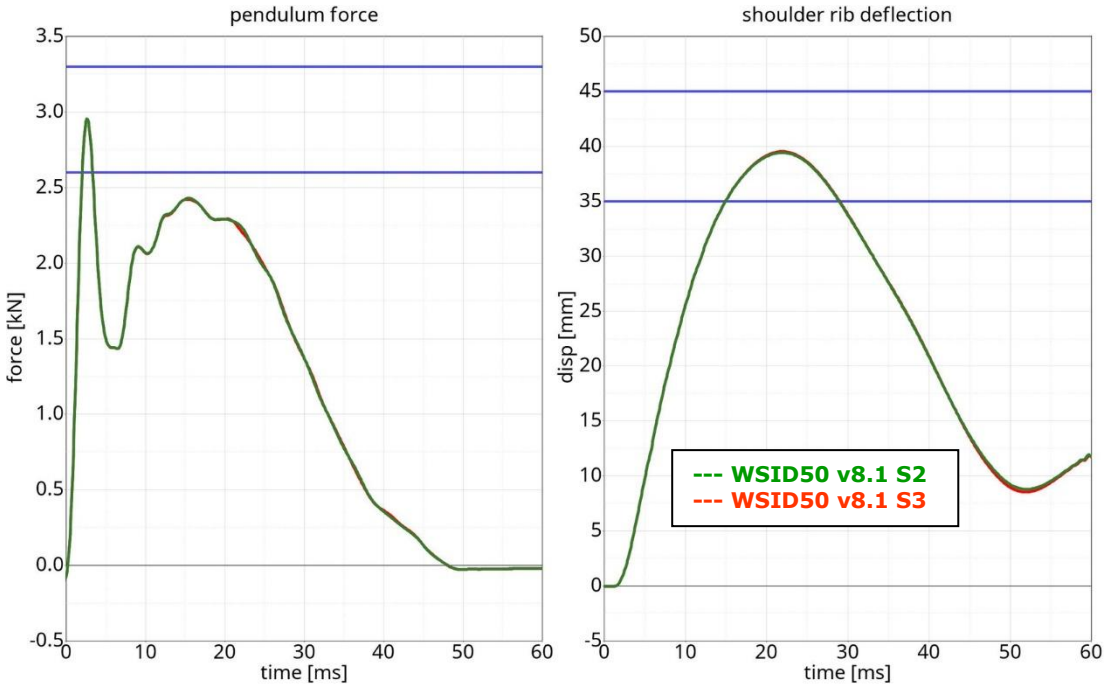


Figure 13: Shoulder calibration test

1.5.5 Thorax pendulum test

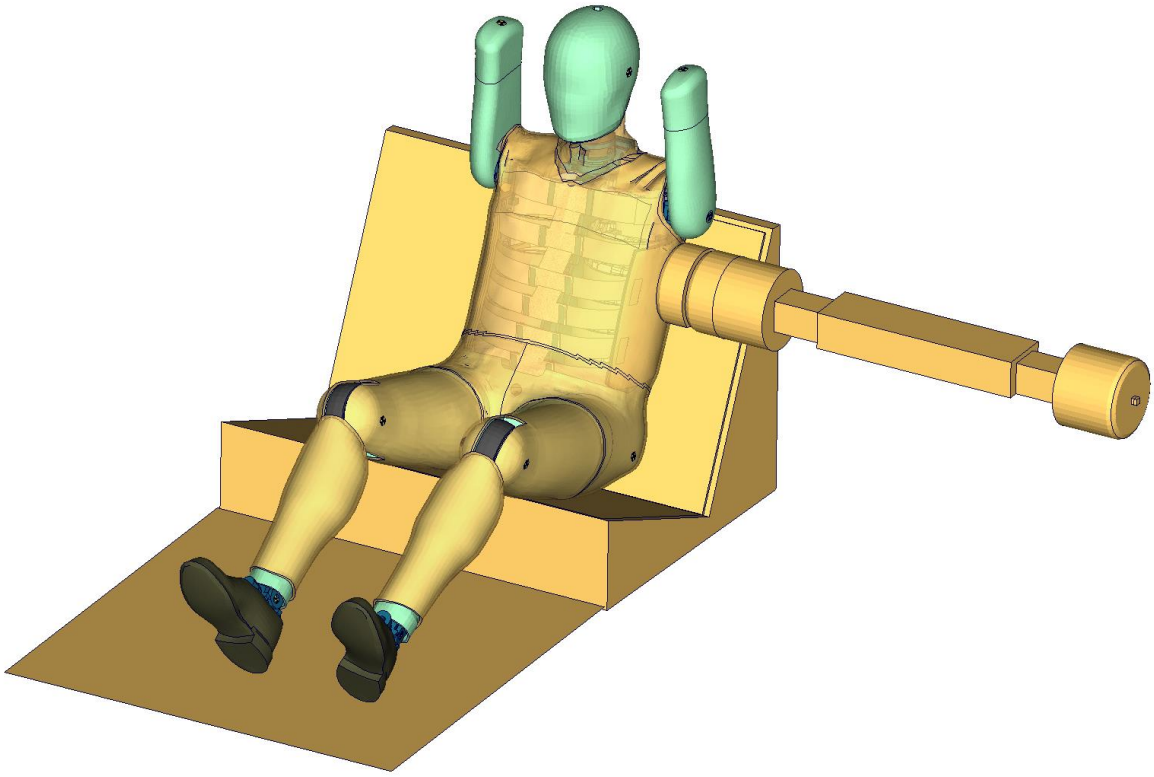


Figure 14: Thorax calibration test setup without arm

Thorax pendulum without arm	
Peak pendulum force [kN]	3.1 to 3.7
Peak T4 acceleration along y axis [g]	14 to 20
Peak T12 acceleration along y axis [g]	12 to 20
Peak thorax rib 1 deflection [mm]	35 to 45
Peak thorax rib 2 deflection [mm]	37 to 45
Peak thorax rib 3 deflection [mm]	33 to 41

Table 9: Thorax pendulum without arm test specifications

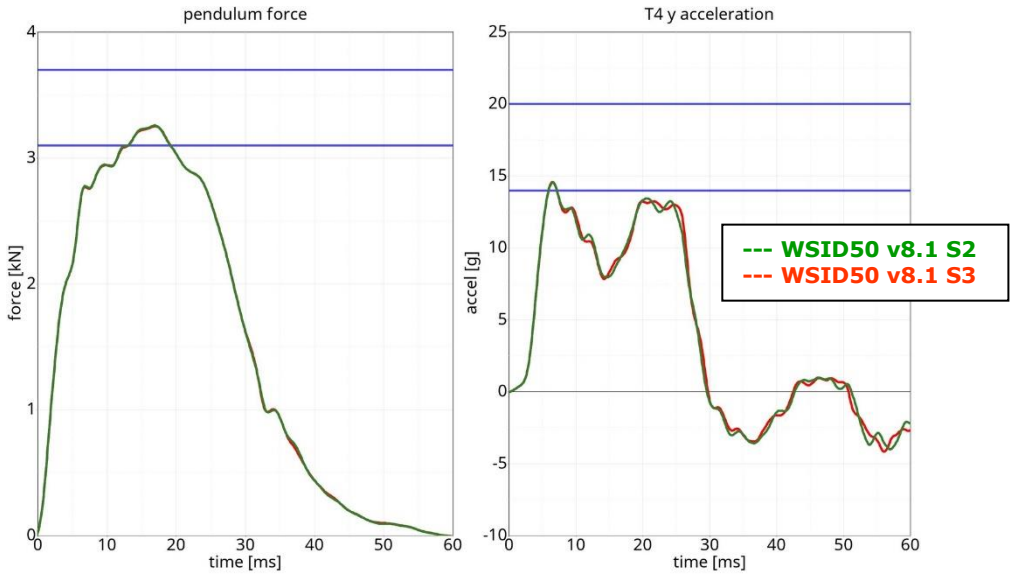


Figure 15: Thorax calibration test part 1

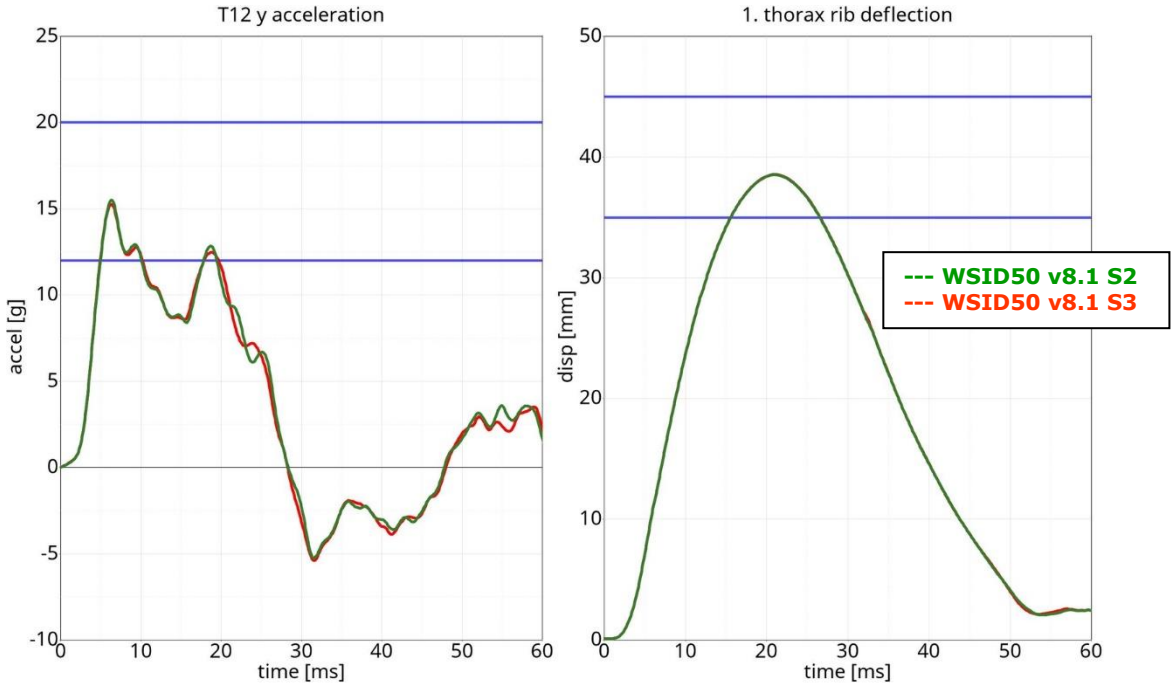


Figure 16: Thorax calibration test part 2

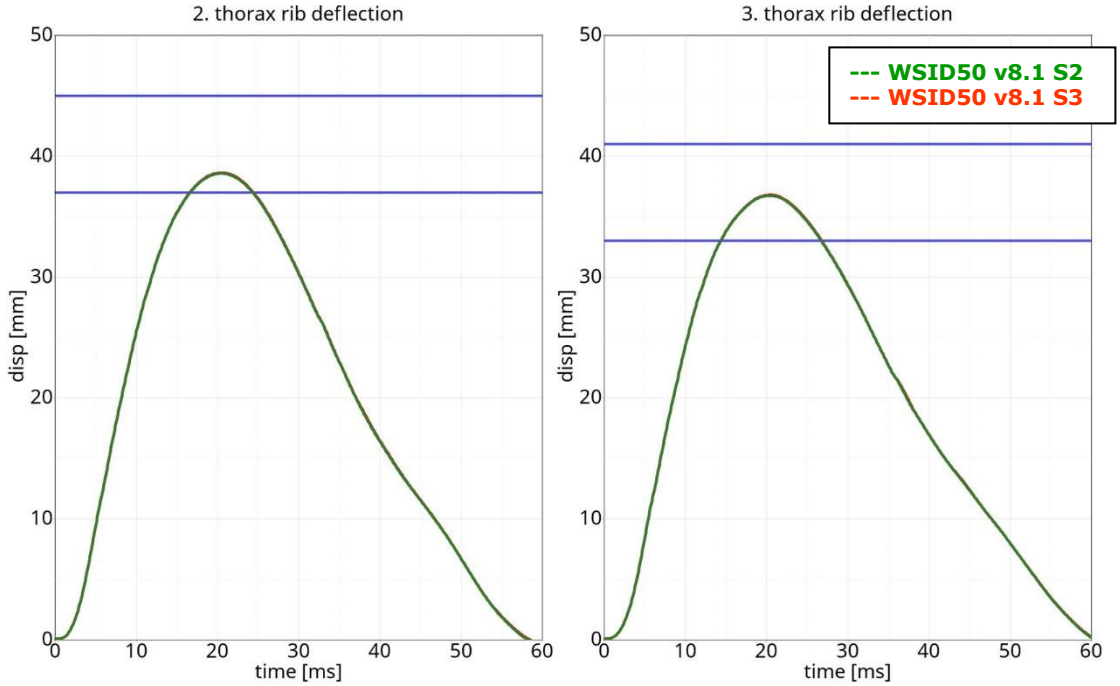


Figure 17: Thorax calibration test part 3

1.5.6 Abdomen pendulum test

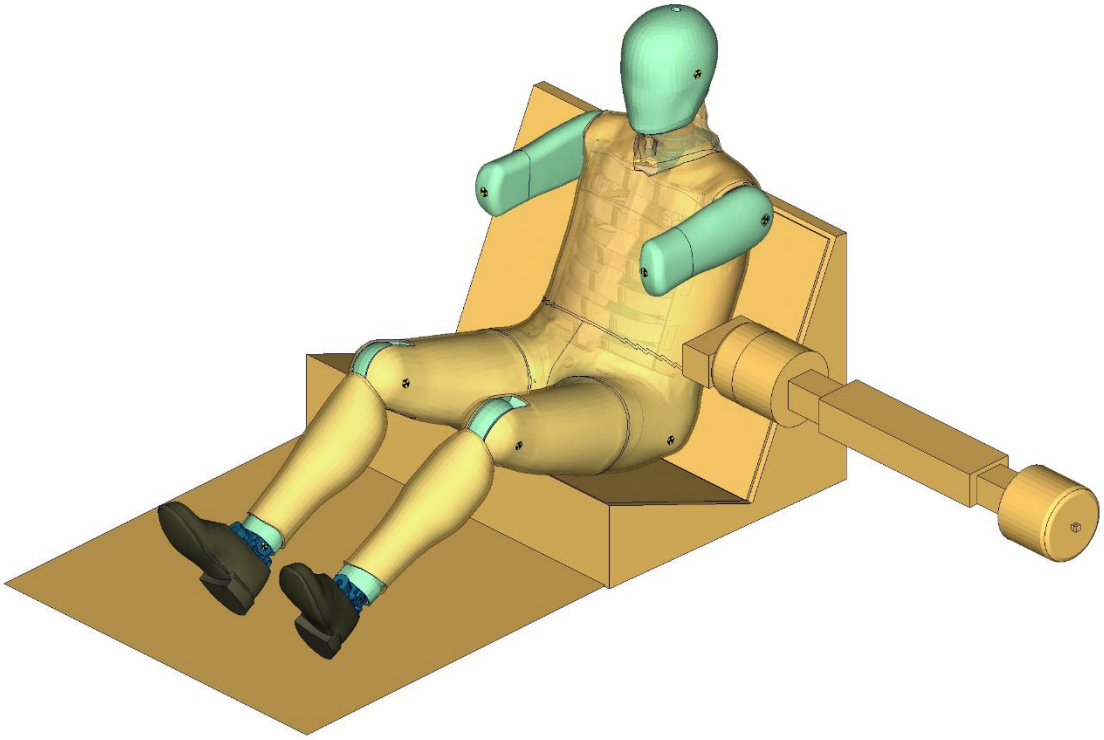


Figure 18: Abdomen calibration test setup

Abdomen pendulum	
Peak pendulum force [kN]	2.7 to 3.1
Peak T12 acceleration along y axis [g]	15 to 20
Peak abdomen rib 1 deflection [mm]	33 to 40
Peak abdomen rib 2 deflection [mm]	30 to 36

Table 10: Abdomen pendulum test specifications

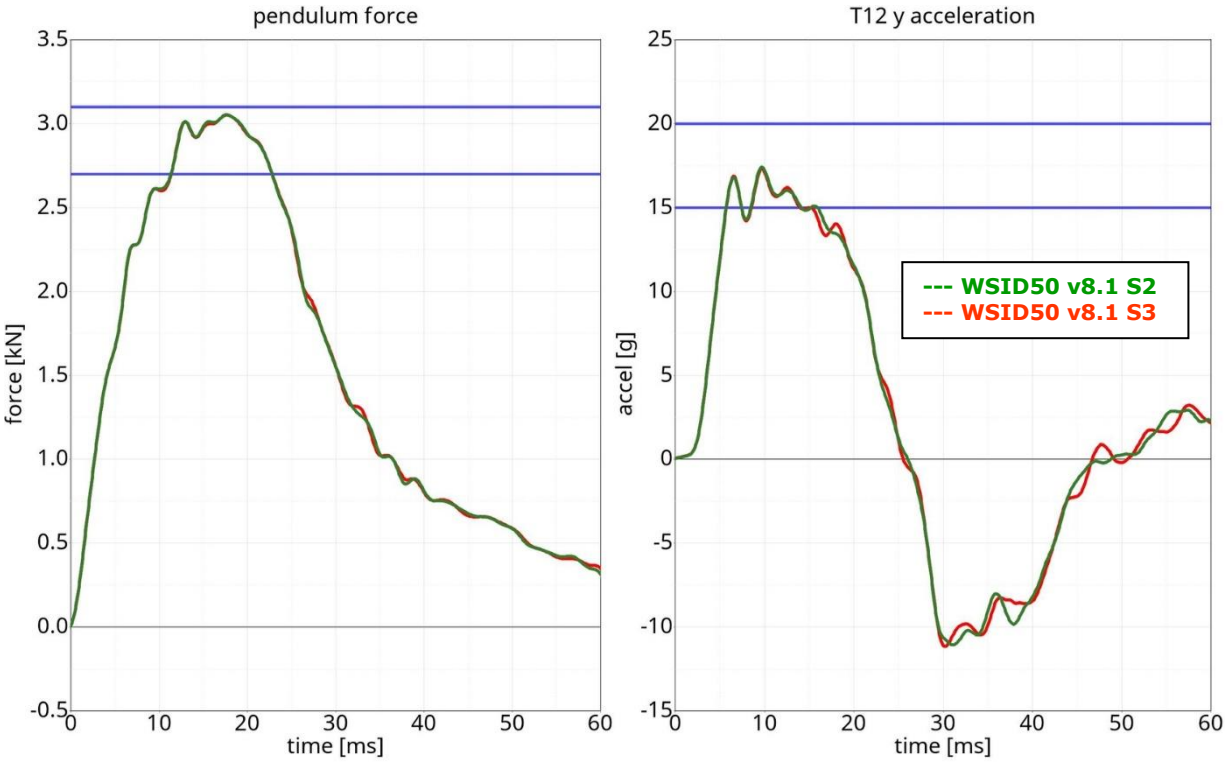


Figure 19: Abdomen calibration test part 1

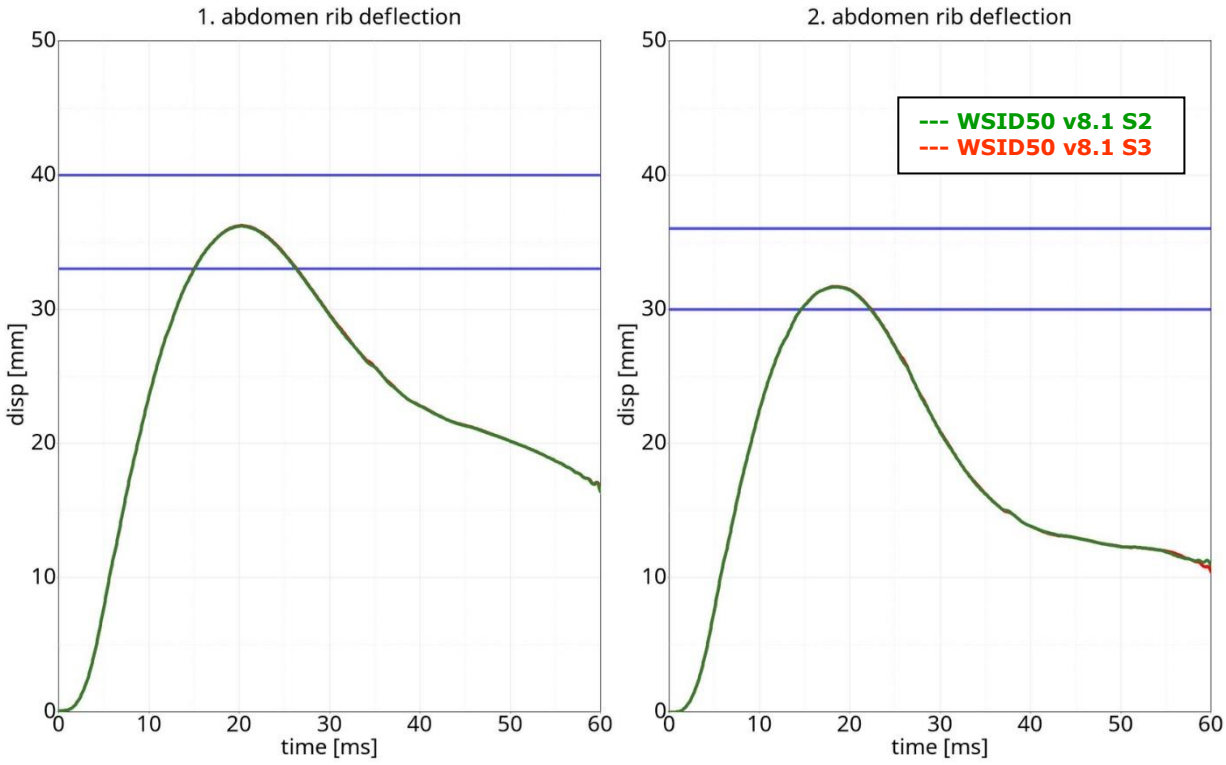


Figure 20: Abdomen calibration test part 2

1.5.7 Pelvis pendulum test

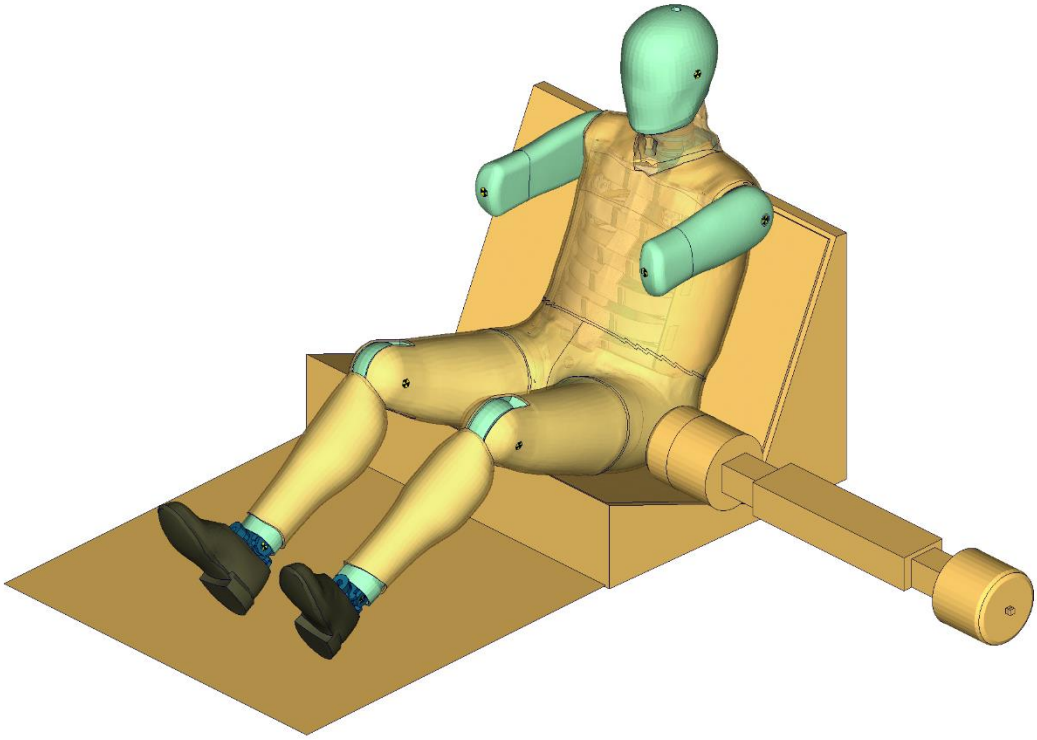


Figure 21: Pelvis calibration test setup

Pelvis pendulum	
Peak pendulum force [kN]	6.8 to 8.2
Peak T12 acceleration along y axis [g]	10 to 14
Peak pelvis acceleration along y axis [g]	37 to 47
Peak pubic force [kN]	1.25 to 1.55

Table 11: Pelvis pendulum test specifications

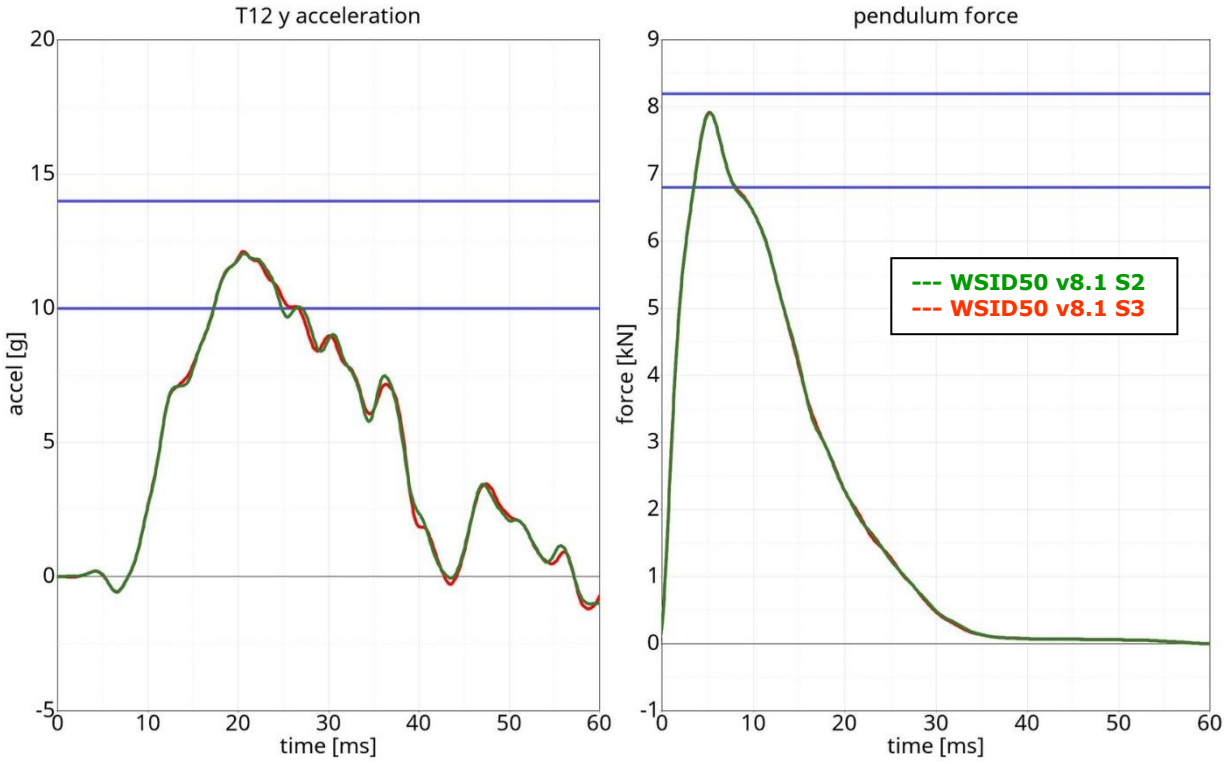


Figure 22: Pelvis calibration test part 1

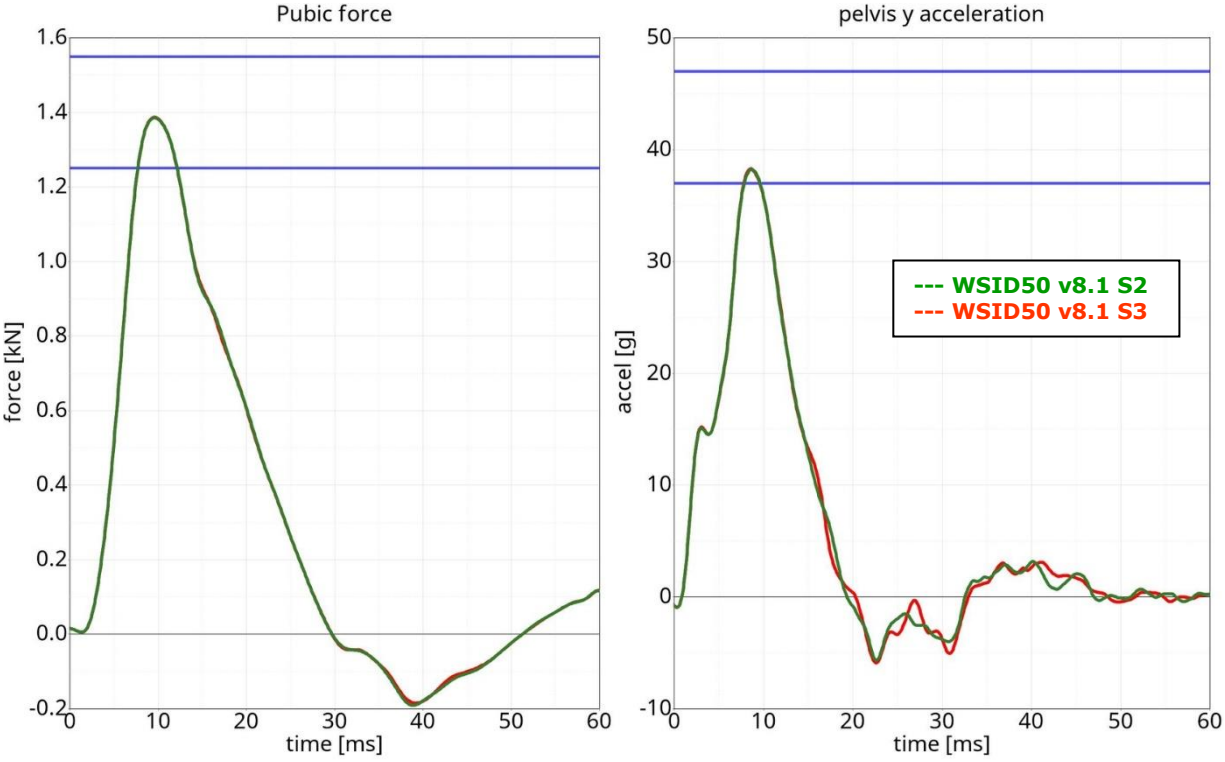


Figure 23: Pelvis calibration test part 2

2. Stage 2

For stage 2 the ISO 18571[2] ratings have to be calculated. If the ratings are within the allowed ranges, the dummy model passes stage 2.

There are additional criteria defined for the stage 2 test, shown in Table 12.

Simulation criteria	check
Max mass added < 5% simulation beginning total model mass	Good
Visual plausibility of animation check: no intersections	Good
Visual plausibility of animation check: no sticky nodes	Good
Visual plausibility of animation check: no shooting nodes affecting	Good

Table 12: Stage 2 Model simulation criteria check

2.1 Head neck

The validation of the head neck test needs to be done in two different angles. The angles are 90 and 75 degrees. A pulse of 35 g in y-direction was used for both setups. The setups are shown in Figure 24.

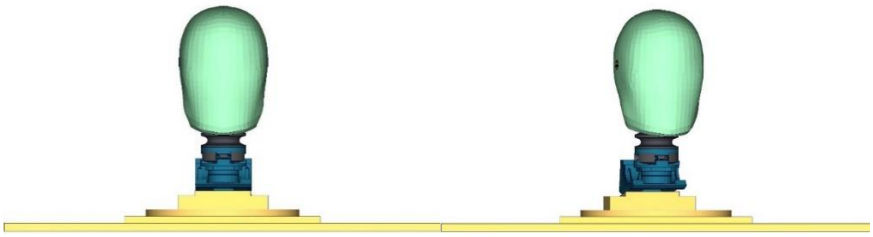


Figure 24: Head neck test setup 90 and 75 degrees

ISO18571 ratings for the head neck tests are shown in Table 13. Details about the output curves can be found in Figure 25 and Figure 26.

	Channel	S2 S_{Signal}	S3 S_{Signal}	S2 $S_{Loadcase}$	S3 $S_{Loadcase}$	S2 $S_{head-neck}$	S3 $S_{head-neck}$
Head-neck 90°	HEAD0000AV	0.892	0.894	0.867	0.867	0.866	0.865
	NECKUP00FO	0.821	0.816				
	NECKUP00MO	0.876	0.879				
	NECKLO00FO	0.818	0.814				
	NECKLO00MO	0.930	0.931				
Head-neck 75°	HEAD0000AV	0.903	0.903	0.864	0.864		
	NECKUP00FO	0.825	0.825				
	NECKUP00MO	0.858	0.860				
	NECKLO00FO	0.817	0.814				
	NECKLO00MO	0.916	0.917				

Table 13: Head neck ISO18571 ratings

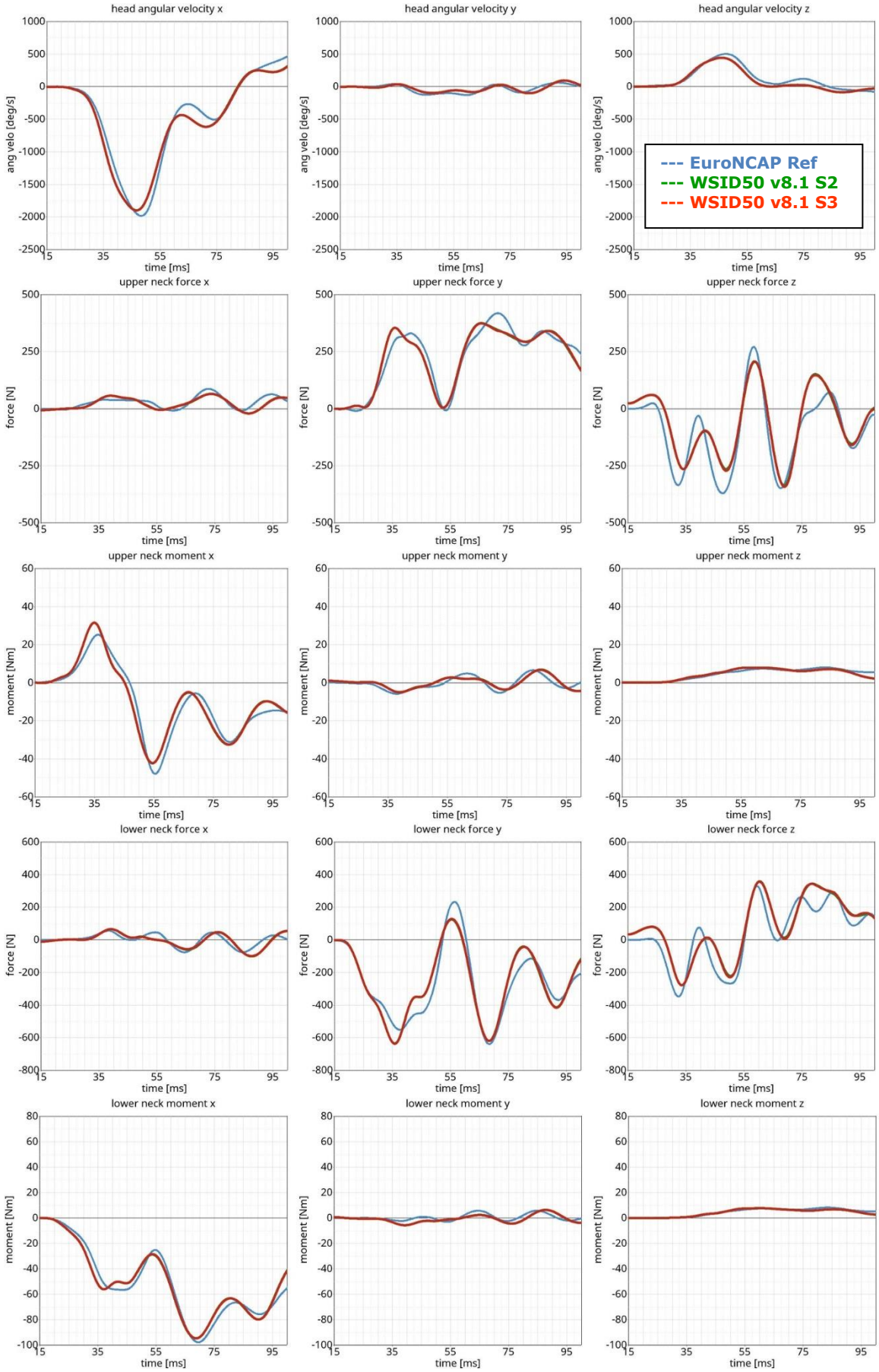


Figure 25: Head neck 90 degree test ISO18571 curve overview

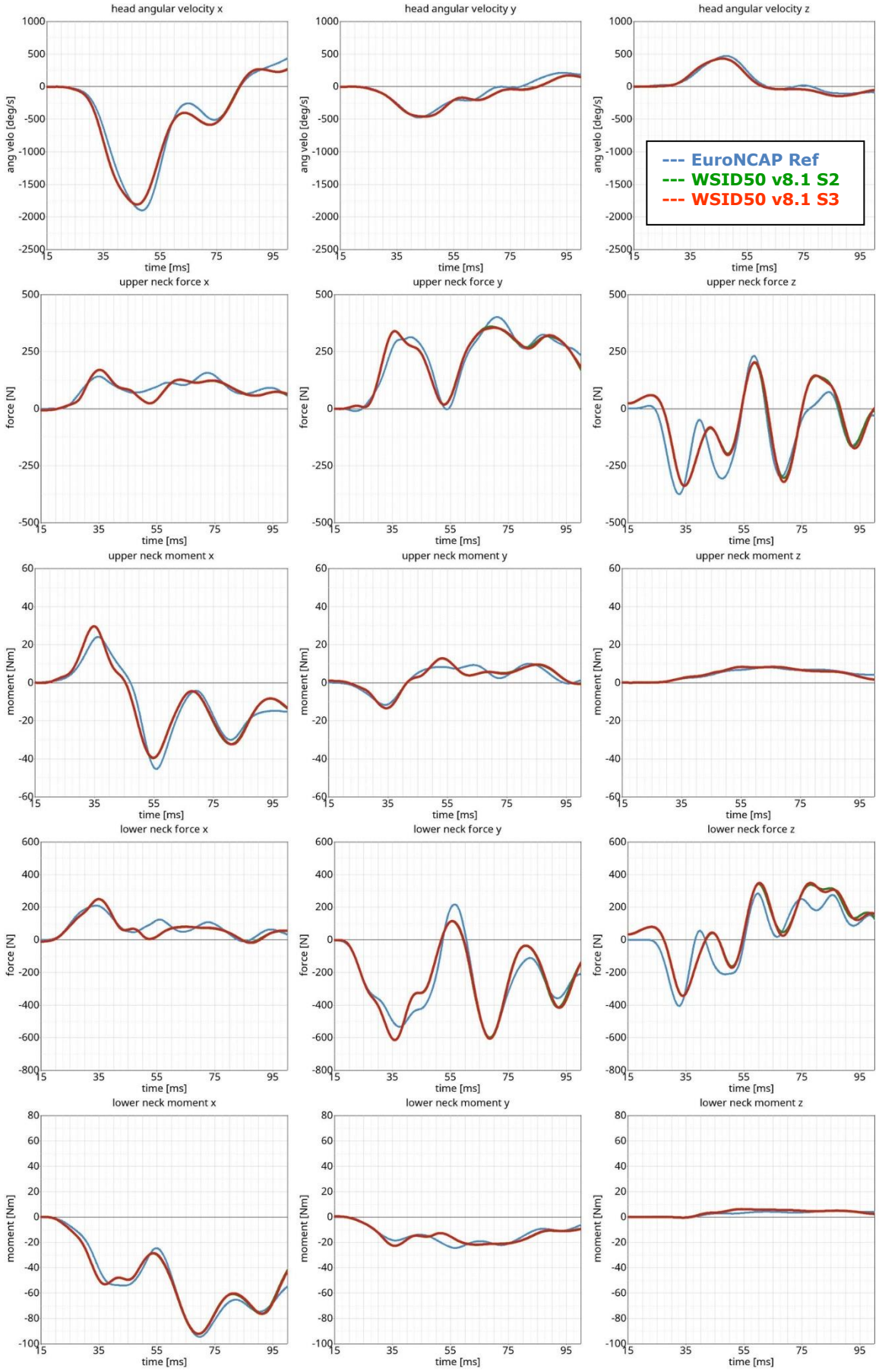


Figure 26: Head neck 75 degree test ISO18571 curve overview

2.2 Lumbar spine

The validation of the lumbar spine test needs to be done in two different angles. The angles are 90 and 60 degrees. A pulse of 35 g in y-direction was used for both setups. The setups are shown in Figure 27.

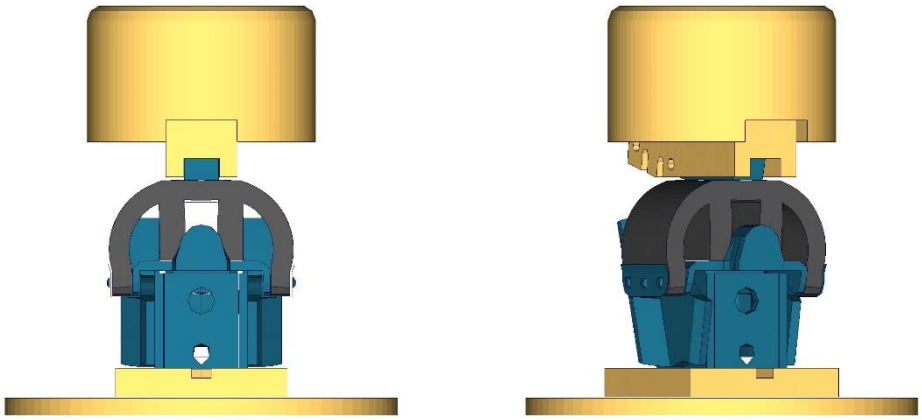


Figure 27: Lumbar spine test setup 90 and 60 degrees

ISO18571 ratings for the lumbar spine tests are shown in Table 14. Details about the output curves can be found in Figure 28 and Figure 29.

	Channel	S2 S_{Signal}	S3 S_{Signal}	S2 $S_{Loadcase}$	S3 $S_{Loadcase}$	S2 $S_{lumbar-spine}$	S3 $S_{lumbar-spine}$
Lumbar-spine 90°	LUSP0000FO	0.779	0.774	0.816	0.814	0.803	0.801
	LUSP0000MO	0.799	0.800				
	ABDO0001AV	0.871	0.866				
Lumbar-spine 60°	LUSP0000FO	0.756	0.756	0.789	0.789		
	LUSP0000MO	0.798	0.798				
	ABDO0001AV	0.813	0.813				

Table 14: Lumbar spine ISO18571 ratings

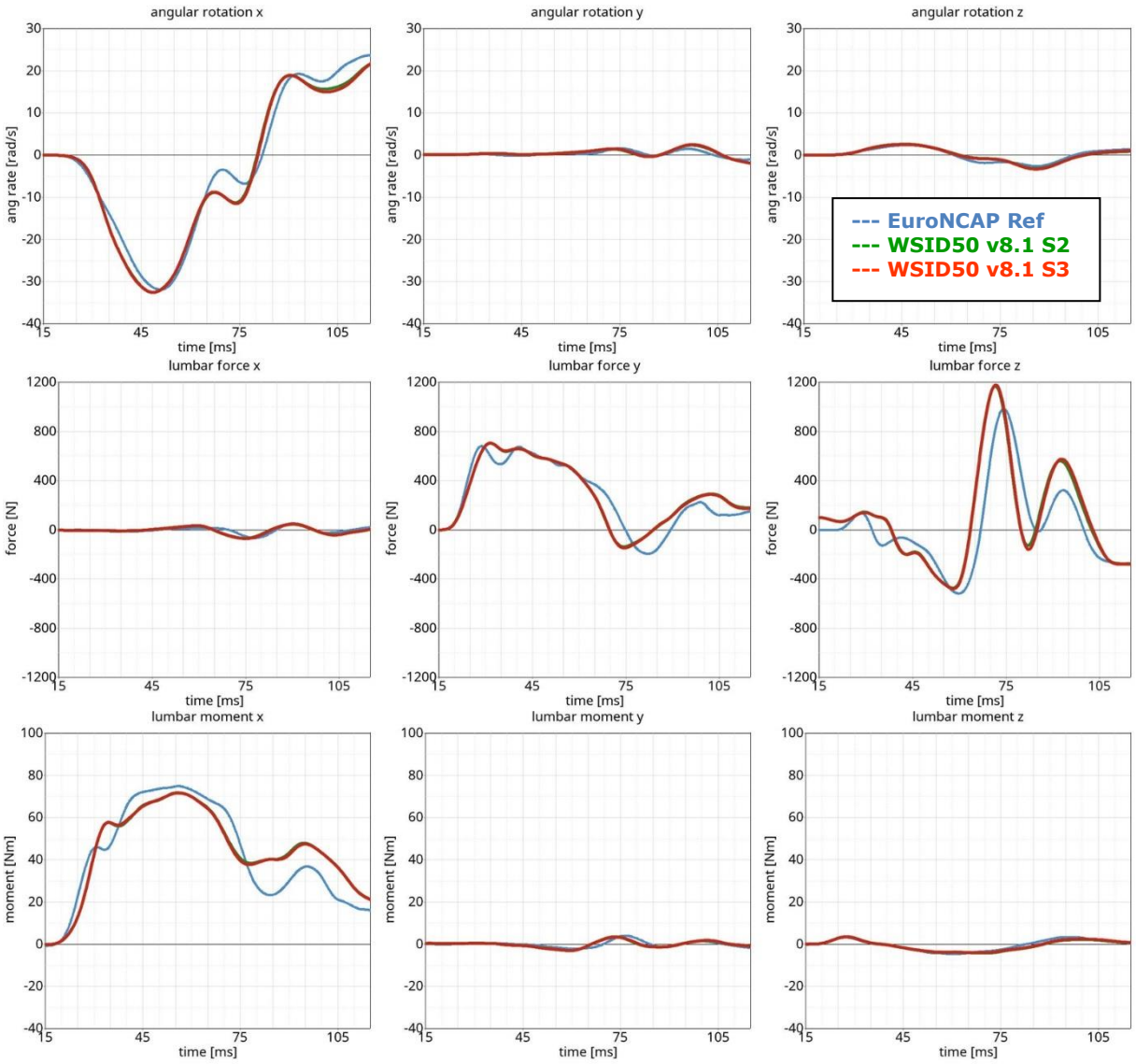


Figure 28: Lumbar spine 90 degree test ISO18571 curve overview

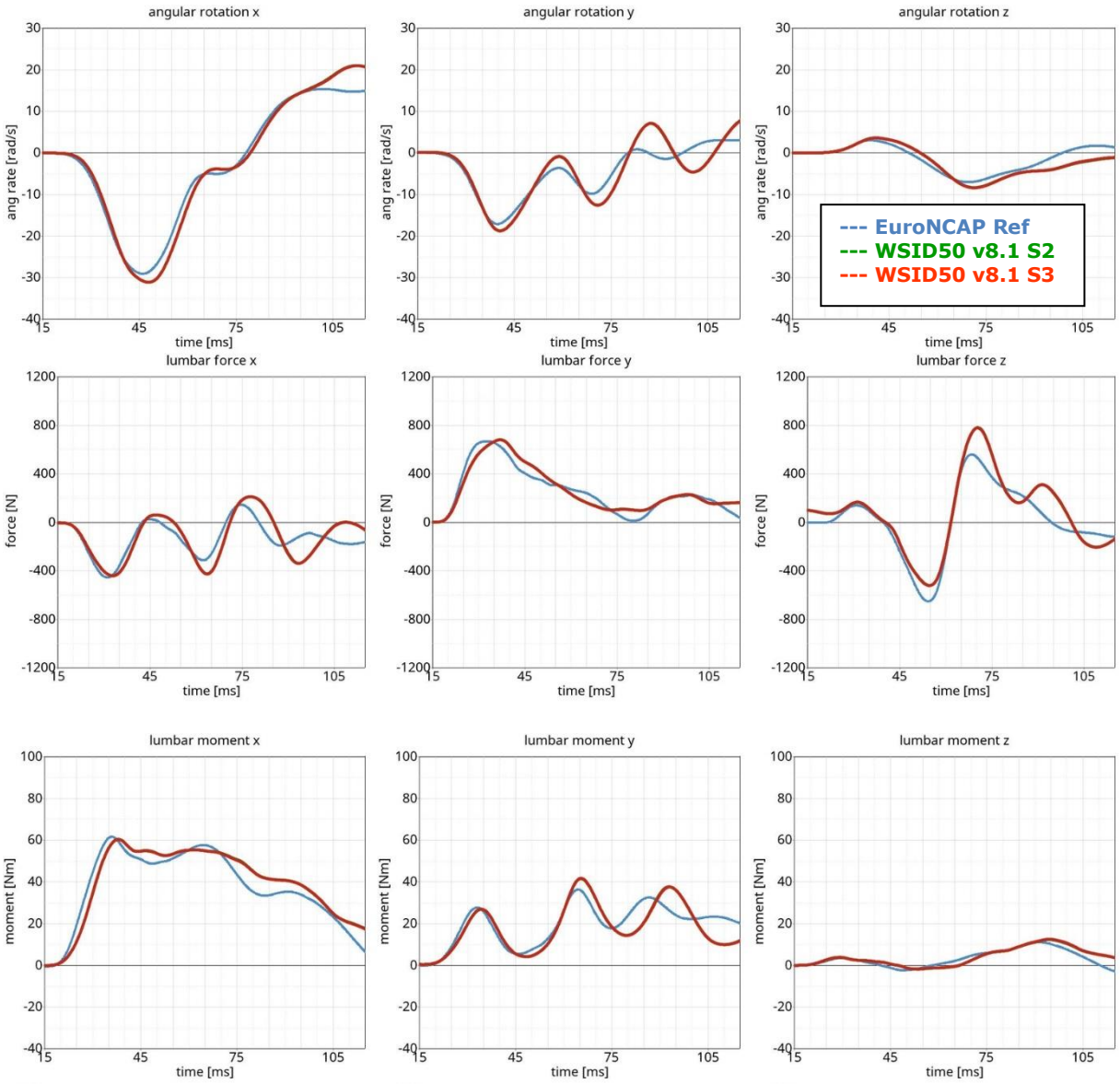


Figure 29: Lumbar spine 60 degree test ISO18571 curve overview

3. Stage 3

3.1 Farside sled test

There are two different velocities for the farside sled test. Low velocity is with 8 m/s, high velocity with 11 m/s. Figure 30 shows the farside sled test setup.

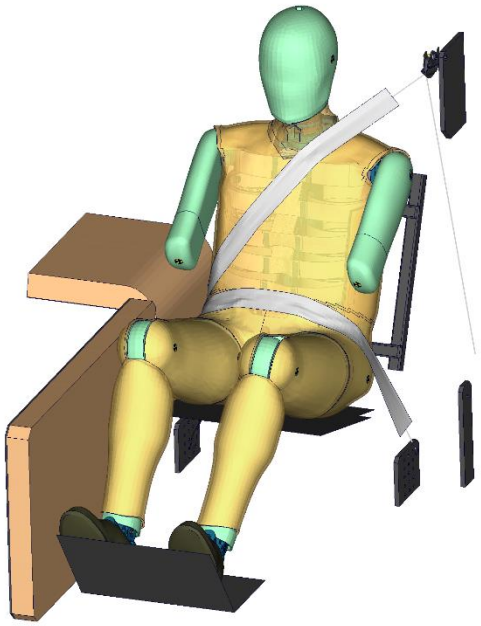


Figure 30: Farside sled test setup

An overview of the contact definitions of the farside sled test can be found in Table 15. The allowed ranges for the friction values defined in TB043-1 are 0.10 to 0.60.

Contact	Contact type (Dyna)	friction
Dummy-Seat	A-S-T-S	WorldSID-Seat: 0.2 WorldSID-Centre console: 0.2 WorldSID-Floor: 0.6
Dummy-Seatbelt	A-S-T-S	WorldSID(no arm)-Seatbelt: 0.2 WorldSID arm-Seatbelt: 0.6
Seatbelt-Seatbelt	A-S-S	0.1
Bukle-Console	A-S-T-S	0.2
Bukle-Seat	A-S-T-S	0.2
Seatbet-Seat	A-S-T-S	0.2

Table 15: Farside sled test simulation model contact setup

Again there are some additional simulation criteria defined in TB043-1. They are shown in Table 16.

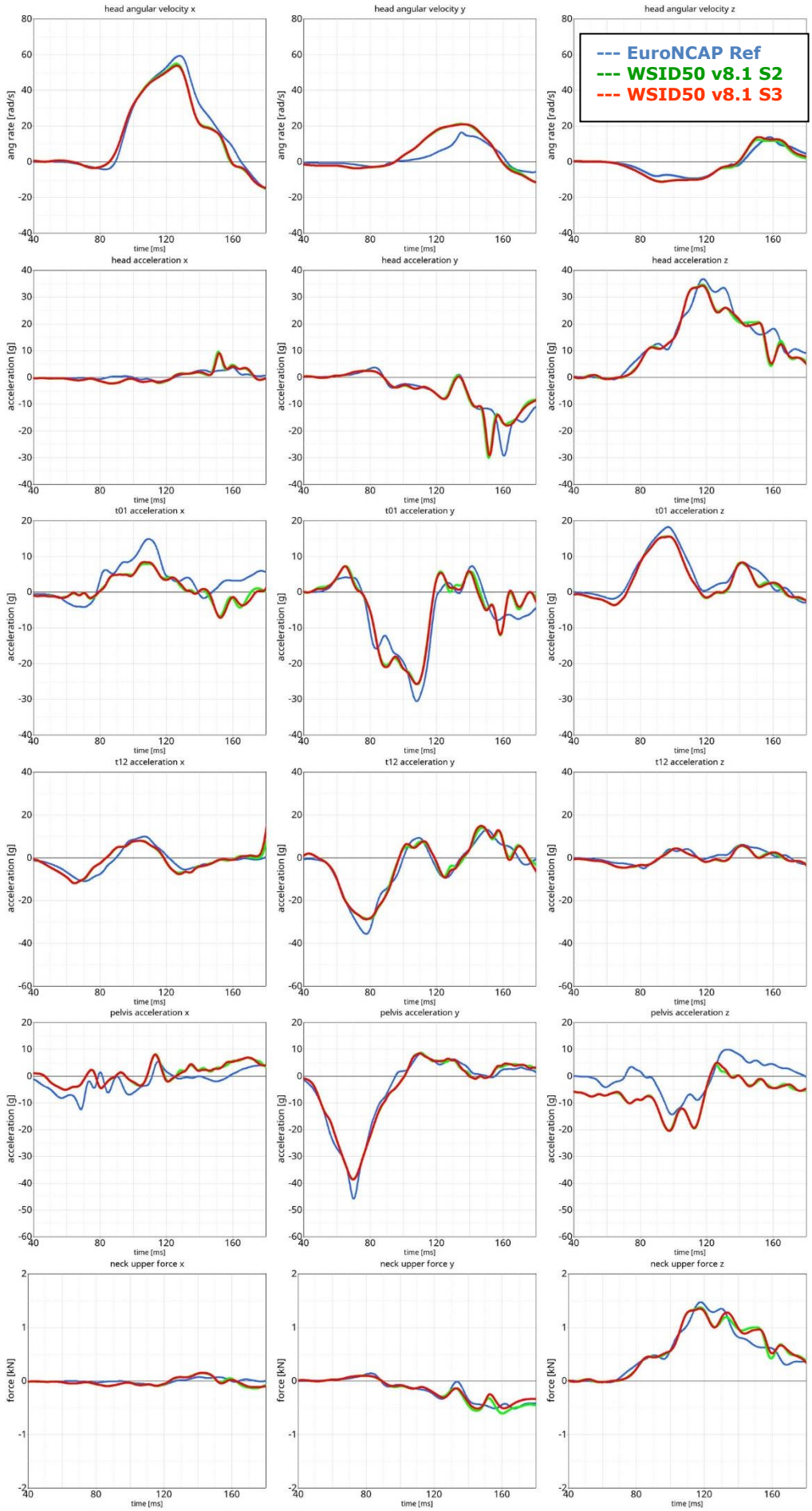
Simulation criteria	check
Max hourglass energy of full setup < 10% max internal energy	Good
Max hourglass energy of WorldSID components < 10% max internal energy WorldSID	Good
Max mass added < 5% simulation beginning total model mass	Good
Visual plausibility of animation check: no intersections	Good
Visual plausibility of animation check: no sticky nodes	Good
Visual plausibility of animation check: no shooting nodes affecting	Good
Less than 10mm h-point z-displacement in first 5ms of the simulation	Good

Table 16: Stage 3 Model simulation criteria check

ISO18571 ratings for the farside sled test with 8 m/s are shown in Table 17. Details about the output curves can be found in Figure 31.

	Channel	S2 S_{Signal}	S3 S_{Signal}	S2 $S_{Loadcase}$	S3 $S_{Loadcase}$
Farside 8 m/s	HEAD0000AV	0.841	0.835	0.791	0.792
	HEAD0000AC	0.769	0.773		
	THSP0100AC	0.739	0.733		
	THSP1200AC	0.806	0.795		
	PELV0000AC	0.770	0.769		
	NECKUP00FO	0.796	0.793		
	NECKUP00MO	0.654	0.683		
	LUSP0000FO	0.775	0.778		
	LUSP0000MO	0.816	0.820		
	ABRIRI02DS	0.939	0.941		

Table 17: Farside sled test 8 m/s ISO18571 ratings


head angular velocity x
head angular velocity y
head angular velocity z
--- EuroNCAP Ref
--- WSID50 v8.1 S2
--- WSID50 v8.1 S3
ang rate [rad/s]
head acceleration x
head acceleration y
head acceleration z
t01 acceleration x
t01 acceleration y
t01 acceleration z
t12 acceleration x
t12 acceleration y
t12 acceleration z
pelvis acceleration x
pelvis acceleration y
pelvis acceleration z
acceleration [g]
neck upper force x
neck upper force y
neck upper force z
force [kN]
time [ms]

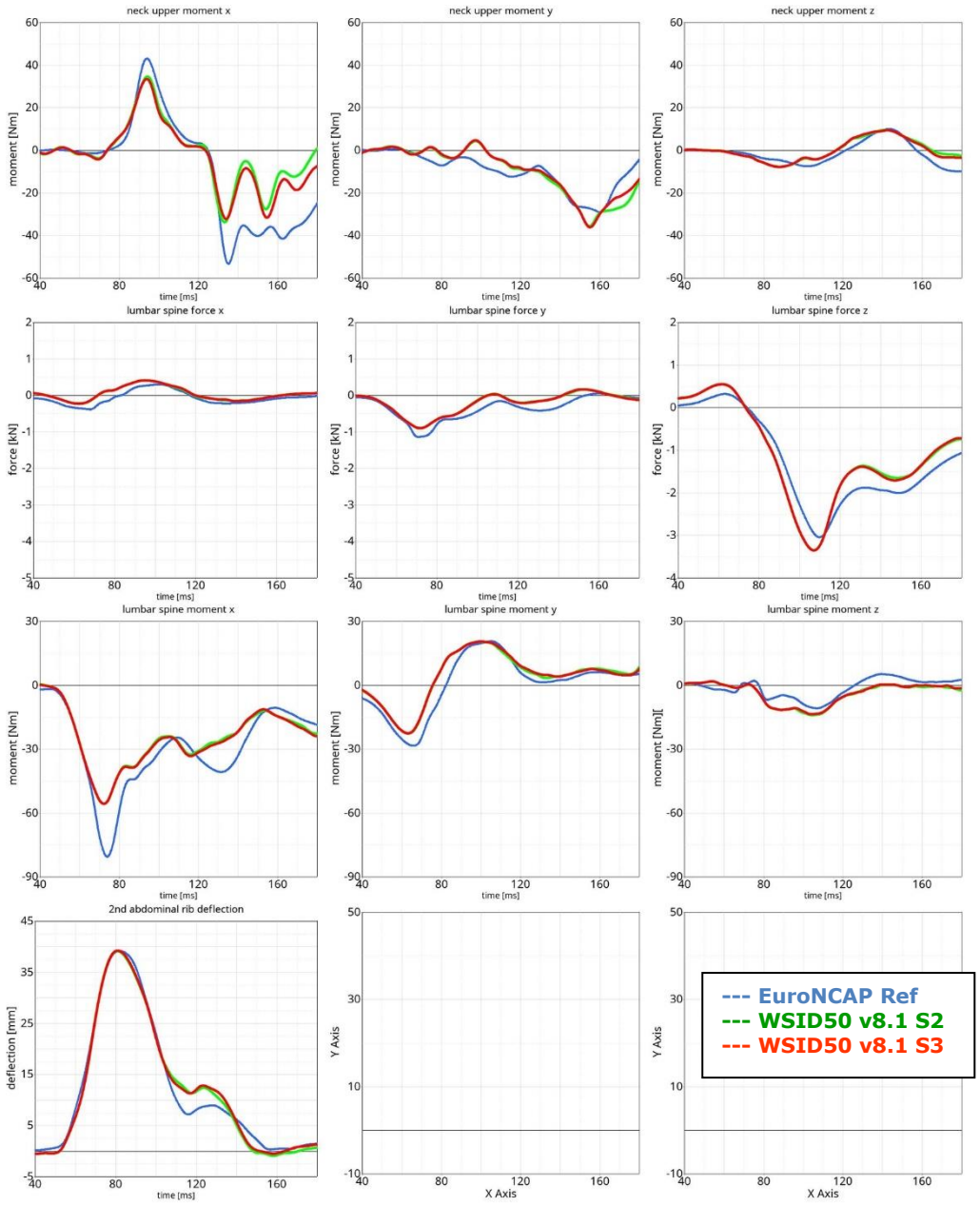
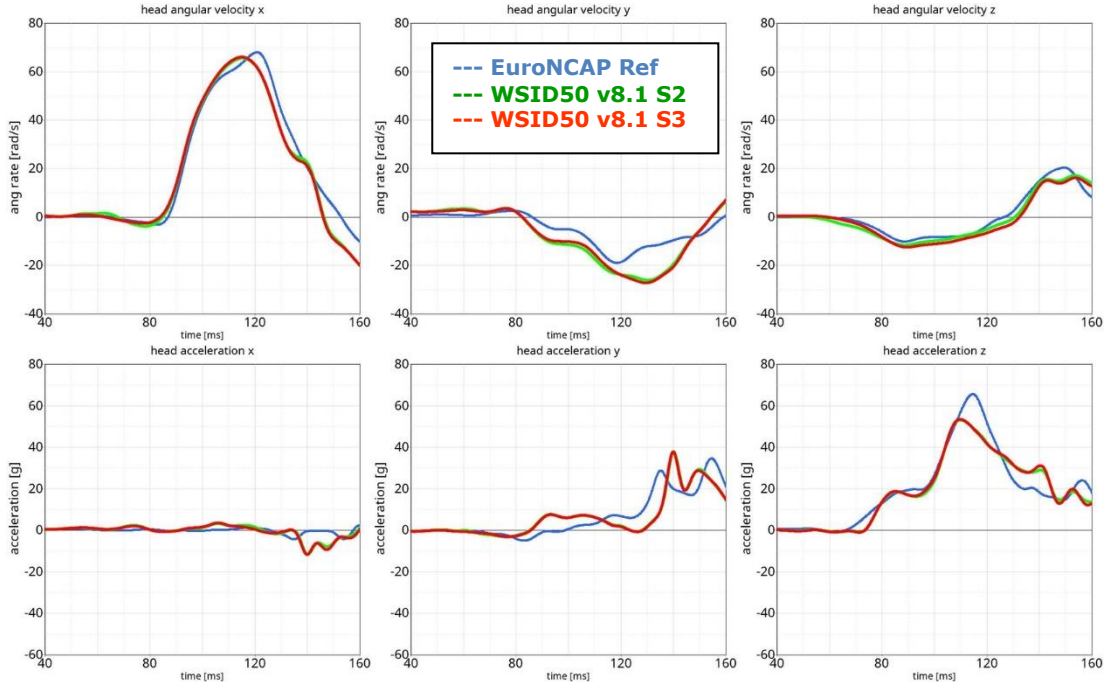


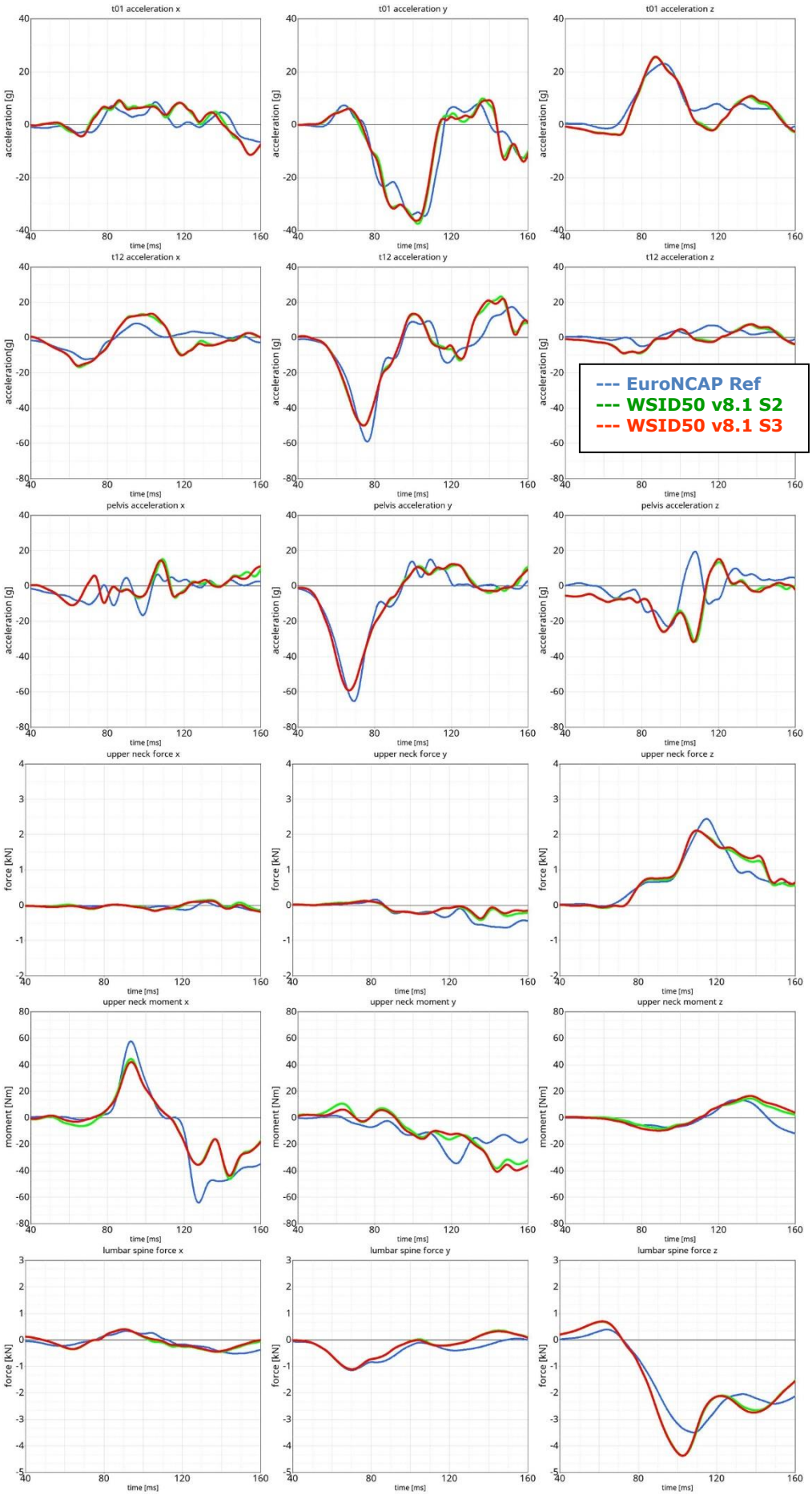
Figure 31: Farside sled test 8 m/s ISO18571 overview

ISO18571 ratings for the lumbar spine tests are shown in Table 18. Details about the output curves can be found in Figure 32.

	Channel	S2 S_{Signal}	S3 S_{Signal}	S2 $S_{Loadcase}$	S3 $S_{Loadcase}$
Farside 11 m/s	HEAD0000AV	0.834	0.833	0.747	0.744
	HEAD0000AC	0.746	0.742		
	THSP0100AC	0.730	0.719		
	THSP1200AC	0.711	0.703		
	PELV0000AC	0.691	0.697		
	NECKUP00FO	0.803	0.783		
	NECKUP00MO	0.628	0.624		
	LUSP0000FO	0.754	0.748		
	LUSP0000MO	0.677	0.691		
	ABRIRI02DS	0.894	0.897		

Table 18: Farside sled test 11 m/s ISO18571 ratings




t01 acceleration x
t01 acceleration y
t01 acceleration z
t12 acceleration x
t12 acceleration y
t12 acceleration z
pelvis acceleration x
pelvis acceleration y
pelvis acceleration z
upper neck force x
upper neck force y
upper neck force z
upper neck moment x
upper neck moment y
upper neck moment z
lumbar spine force x
lumbar spine force y
lumbar spine force z
acceleration [g]
force [kN]
moment [Nm]
time [ms]
--- EuroNCAP Ref
--- WSID50 v8.1 S2
--- WSID50 v8.1 S3

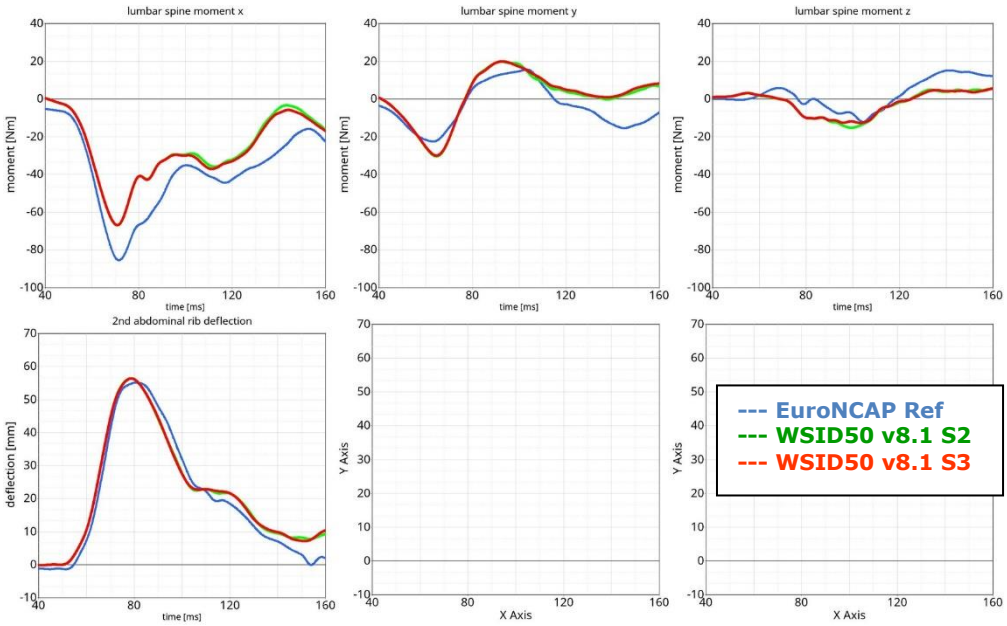


Figure 32: Farside sled test 11 m/s ISO18571 overview

4. Summary ISO18571

The ISO18571 rating summary can be found in Table 19.

	HN 90°	HN 75°	LS 90°	LS 60°	Farside 8 m/s	Farside 11 m/s
S2	0.867	0.864	0.816	0.789	0.793	0.752
S3	0.867	0.864	0.814	0.789	0.792	0.744
	Component rating				**Sled rating**	
S2	0.835				0.769	
S3	0.833				0.768	
	TOTAL ISO18571					
S2	0.802					
S3	0.800					

Table 19: Total ISO18571 ratings out of stage 2 and stage 3

The overall score of the component tests meets the requirement $S_{component} \geq 0.70$.

The overall score of the sled tests meets the requirement $S_{sled} \geq 0.61$.

5. Additional model information

Parameters
There are optional stiffness parameters available in the WorldSID 50th model. With these parameters the dummy model can be adjusted to get a different behavior for the certification tests.

IMPORTANT: THE VTC VALIDATION REPORT IS ONLY VALID FOR THE FOLLOWING PARAMETER SETTINGS

&head_opt=1.0
&neck_opt=1.0
&shd_opt=1
&trd_opt=3
&abd_opt=1
&pel_opt=1.0

Remark:
&head_opt &neck_opt &shd_opt and &pel_opt have only little effect for the VTC dummy validation.
The rib deflection parameters &trd_opt and &abd_opt do have a large impact for the VTC validation. With &trd_opt=5 and &abd_opt=3 the first validation stage is no longer passed.
More details about the parameter performance can be found in the dummy manual wsid50_pdb_v8.1_manual.pdf

LS-DYNA versions
The development and validation has been performed on different platforms. The following LS-DYNA versions have been used:

LS-DYNA Version	Date	Revision Nr.
R9.3 MPP	07/28/2022	730-g7bd1777
R11 MPP	07/02/2020	2736-g41bc835
R12 MPP	08/02/2022	4134-g382192fb50
R13 MPP	05/17/2022	2607-g2fce77a
R14 MPP	09/26/2023	2184-g1bb0ef67f0

Table 20: LS-DYNA versions

The results between different dyna platforms are comparable. For this report the LS-DYNA version R12-MPP-4134 was used.

Control-Cards
For all of the simulations the control cards of the dummy delivery model were used.

6. Literature

[1] ISO 15830 Part 1-5, Road vehicles – Design and performance specifications for the WorldSID 50th percentile male side impact dummy, 2022
[2] ISO/TS 18571, Road vehicles – Objective rating metric for non-ambiguous signals, 2014