ANNEX D: Q10 VALIDATION REPORT

EPOCh Deliverable D2.3

Q10 dummy Validation Report

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49 pages

Enabling Protection for Older Children

SEVENTH FRAMEWORK PROGRAMME
THEME 7
Transport (including AERONAUTICS)

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EPOCh 218744

FINAL PROJECT REPORT

Work Package 2
Task 2.3
D2.3 - Q10 dummy Validation Report

by Kees Waagmeester, Arie Schmidt,
Mark Burleigh, Paul Lemmen
(Humanetics Europe GmbH)

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D2.3 - Q10 dummy Validation Report

Results of Certification Style Testing

by Kees Waagmeester, Arie Schmidt,
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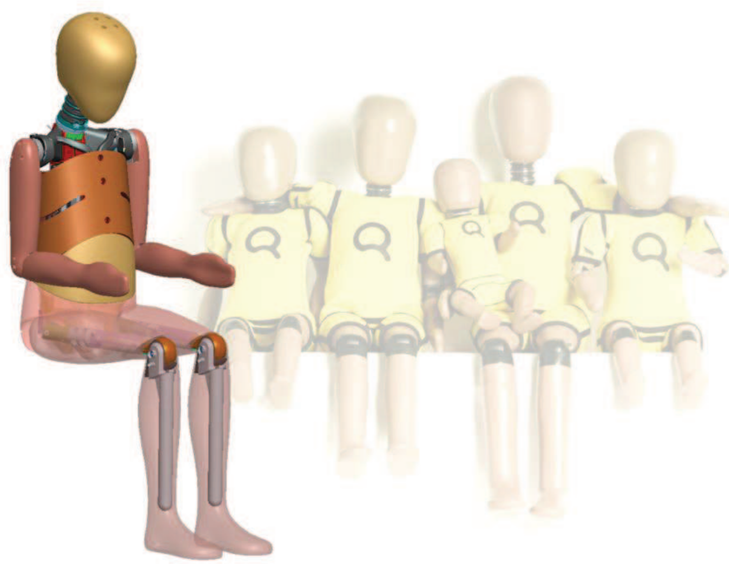

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Executive summary

The Q10 dummy was extensively evaluated on biomechanical performance, sensitivity, repeatability and durability to impact loading in head drop, neck pendulum and full body wire pendulum tests. Moreover certification procedures were developed.

Anthropometry

The dummy drawing dimensions are in compliance with the requirements. Measurements on the actual should be taken to confirm the compliance of the hardware. The Mass of several parts has to be tuned in the final design. This is the case for the upper and lower arm as well as the pelvis and lower leg.

Biofidelity

For frontal loading conditions it can be stated that the dummy correlates well with biomechanical targets specified in the Q10 design brief. It is recommended to increase the impact stiffness of the head to perform close to the middle of the corridor. For the neck it is recommended to modify the mould such that its stiffness increase in flexion occurs earlier (now at 45 degrees where is should be at 30 to 35 degrees).

For lateral impacts the dummy shows a response which is initially too stiff and at later stages too soft relative to side impact biofidelity corridors. Identical trends are found though for shoulders, thorax and pelvis meaning that the load distribution over the dummy is such that none of the regions is overexposed in case of distributed side impact loading. It is recommended to reconsider the clearance between the hip joint hardware and the sacrum block to allow more freedom for the iliac wing to deform in side impact conditions.

Sensitivity

Sensitivity studies show obvious trends to variations in impact speeds, impact direction and alignments.

Repeatability

Repeated tests show generally small variations in response of less than 2.5%. Only the T1- acceleration in the lateral shoulder impact test and the pubic symphysis load in the lateral pelvis impact tests show larger variations: 3.2% and 4.6% respectively. All the coefficients of variation are with the required 5%. It is concluded that the Q10 dummy can be used as a repeatable tool.

Durability

The durability of the dummy meets requirements as specified. Separate reports describe the durability shown in sled tests according to UNECE R44 and NPACS in detail.

Certification

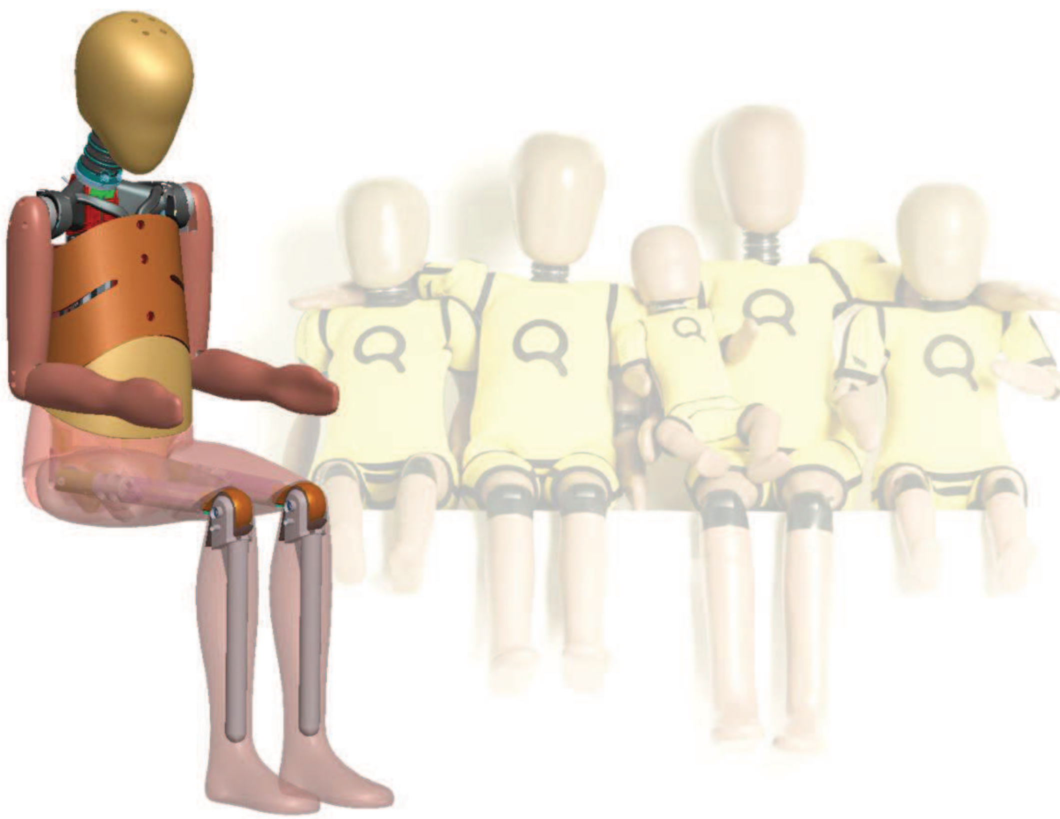
The certification procedures described in this report should be followed to obtain compatible dummy performance data. It is recommended to perform these dummy certification tests with a regular interval on each dummy. After collection of this test data from several dummies the certification corridors will be established.

1 Introduction

For the testing of Child Restraint Systems (CRS's) in Europe, that are currently performed under UNECE Regulation 44, the Q dummies are ready to replace the P dummies. The Q-dummy family currently consists of Q0, Q1, Q1.5, Q3 and Q6. To complete the Q-dummy family a dummy that represents older children, who make use of CRS's in cars, is needed. The Q10 dummy is currently under development in the EU funded FP7 project called EPOCh (see www.epochfp7.org) coordinated by TRL.

Following the presentation in the 2009 conference on size selection and design requirements and in the 2010 conference on the hardware realization and performance tuning, this report deals with the Q10 dummy validation test results. The dummy has been validated for anthropometry, biofidelity, sensitivity, repeatability and durability. Moreover the development of certification test procedures is presented. The validation tests were performed at component and full body level, using standard dummy certification test equipment like head drop table, neck pendulum and full body six wire suspended pendulum. Results for front and side impact are presented.

The UNECE R44 and NPACS sled testing evaluation work done in EPOCh will be presented in separate reports prepared under work package 3.



2 Objectives

In 2009 [i] EPOCh disseminated the specifications for the Q10 dummy and presented the prototype Q10 dummy in 2010 [ii]. This report presents results of the dummy validation, it includes component and full body level evaluations using standard certification test equipment like head drop table, neck pendulum and full body six wire suspended pendulum. The objective of this report is to show compliance with requirements [iii] on anthropometry, biofidelity, sensitivity to impact conditions, repeatability and reproducibility, handling and durability. Results for front and side impact are presented.

3 Method

The Q10 dummy performance will be compared to the requirement definition specified in the Q10 Design Brief [iii] to show level of compliance. A summary of the requirements definition was presented in the Conference Protection of Children in Cars, Munich 2009 [i]. Before the first two prototype Q10 dummies were released for evaluation within the EPOCh consortium in November 2010 their performance was tuned to obtain the best possible compliance with the requirements. This work was reported in the Conference Protection of Children in Cars, Munich 2010 [ii].

The Q10 dummy performance was tested with standard dummy test equipment: Head Drop Table, Neck Pendulum and Full-body Pendulum (mass 8.76 kg, diameter 112 mm, six-wire suspended). The test matrix executed at Humanetics in Watering, The Netherlands (Head drop and full-body pendulum tests) and in Heidelberg, Germany (Neck pendulum tests) comprised in total of 254 tests:

- 58 Head drop tests : 12 Frontal, 46 Lateral
- 64 Neck tests : 23 Flexion, 21 Extension, 20 Lateral flexion
- 21 Shoulder lateral tests
- 55 Thorax test : 33 Frontal, 22 Lateral
- 29 Lumbar Spine tests : 15 Flexion, 14 Lateral flexion
- 27 Pelvis lateral tests

The test matrix was developed to examine the dummy biofidelity, research the dummy sensitivity for impact speed and offsets, to assess the repeatability and to establish provisional certification test procedures.

4 Results

4.1 Anthropometry

For the anthropometry validation the overall dimension as shown in Figure 1 are used. A comparison of the drawing dimensions with the requirements specified in the Q10 Design Brief (ref. [iii] and [iv]) is given in Table 1. In Table 2 the actual mass distribution is compared with the requirements specified in the Q10 Design Brief (ref. [iii]).

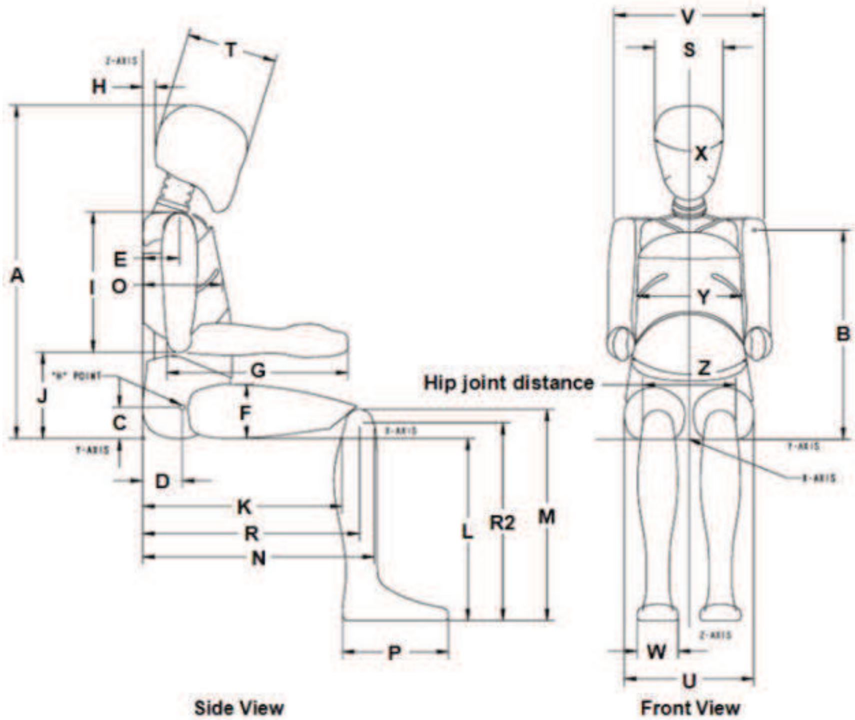


Figure 1: Q10 Overall dimensions

Table 1: Q10 dimensions drawing versus requirement

Description	Requirement ref. [iii] or [iv] in [mm]	Drawing dimension in [mm]
A1 - Sitting Height (head tilt)	747.6	733.7
A2 - Sitting Height (via T1)	747.6	748.4
B - Shoulder Height (top of arm)	473	472.5
C - Hip Pivot Height	65.9	65.9
D - Hip Pivot from Back Plane	90.4 (1)	90.4
- Hip Joint Distance	130.0 (1)	132.0
F - Thigh Height	114.0	114.0
G - Lower Arm & Hand Length	374.7	374.2
I - Shoulder to Elbow Length	292.9	291.6

Description	Requirement ref. [iii] or [iv] in [mm]	Drawing dimension in [mm]
J - Elbow Rest Height	189.6	181.0
K - Buttock Popliteal Length	417.5	414.9
L - Popliteal Height	405.7	405.7
M - Floor to Top of Knee	445.6	446.0
N - Buttock to Knee Length	488.4	485.4
O - Chest Depth at Nipples	171.2	171.0
P - Foot Length	220.0	220.0
- Standing Height (head tilt)	1442.5	1441.2
- Standing Height (via T1)	1442.5	1455.5
R - Buttock to Knee Joint	(none)	445.7
R2 - Floor to Knee Joint	(none)	414.0
S - Head Breadth	143.9	144.0
T - Head Depth	187.4	186.5
U - Hip Breadth	270.4	271.5
V - Shoulder Breadth	337.8	337.8
W - Foot Breadth	86.0	86.0
X - Head Circumference	534.5	534.0
Y - Chest Circum at Axilla	687.3	604.6
- Chest Circum at Nipples	684.9	633.6
Z - Waist Circumference	593.5	664.6

Note 1: The data of ref. [iv] are transformed form standing to sitting and scaled from 10 YO stature 1374 to 1442.5 for Q10.

Table 2: Q10 mass actual versus requirement

Description	Requirement ref. [iii] in [kg]	Actual Mass in [kg]
Head	3.59	3.59
Neck	0.60	0.63
Upper torso	5.15	5.14
Lower torso	9.70	8.05+0.98=9.03
Upper arm (each)	1.09	1.05+0.04=1.09
Lower arm + Hand (each)	0.90	0.83+0.07=0.90
Upper leg (each)	3.71	3.70
Lower leg + Foot (each)	2.52	2.44
Total body mass	35.5	34.7

4.1.1 Discussion and conclusion

From Table 1 and Table 2 it can be seen that dimensions and masses in general correlate well with design brief specifications that are based on the CANDAT database used for all Q-dummies ref. (ref. [iii]) and a publication of UMTRI (ref. [iv]).

4.1.1.1 Dimensions

The deviation in Sitting and Standing Height is explained by the fact that these dimensions are measured in full erected posture while the dummy is assembled with the head-neck system 27 degrees tilted forward. To enable comparison with erected posture the dimensions measured via T1 are given, in which case good correlation for the sitting height is obtained. For the Standing Height, it should be noted that an extra deviation is introduced by the pin-joint knee. In the human body it is a synovial joint that produces series of involute midpoints and transverse axes. The leading dimensions for the optimum knee joint location were K, L, M and N (ref. [iii]). In addition to the sitting and standing height the chest circumferences show deviations. Actual dimensions are smaller than specified values because the soft muscle tissue at nipple and axilla level is not represented in the dummy. Also the ribcage is made as a single curved conic part to prevent complex secondary bending stresses that would occur in a double curved rib cage. This geometry assumption restricts the possibilities to comply with all chest dimensions.

4.1.1.2 Mass distribution

The mass of the prototype dummies reviled to be too small, especially for the upper and lower arms and the pelvis. With an addition of some ballast items to the upper arms: 40 gram each, lower arms 70 gram each and the sacrum block 970 gram the dummy mass was increased towards an acceptable level. The dummy design will be reconsidered to incorporate the additional mass in the regular dummy parts.

4.2 Biofidelity

In this chapter the Q10 dummy biofidelity performance information for frontal and lateral impacts is presented per body region top down from head to pelvis.

4.2.1 Head

For the head biofidelity two criteria for head drops on a rigid plate can be evaluated (ref. [iii]):

Frontal 130 mm drop height: Biofidelity corridor limits based on EEVC scaling are: 113.1 – 194.2 G. The average measured value is 120.0 G.

Lateral 130 mm drop height: Biofidelity corridor limits based on EEVC scaling are: 116.1 – 200.0 G. The average measured value is 133.7 G.

In Figure 2 the frontal and lateral test setup are shown.

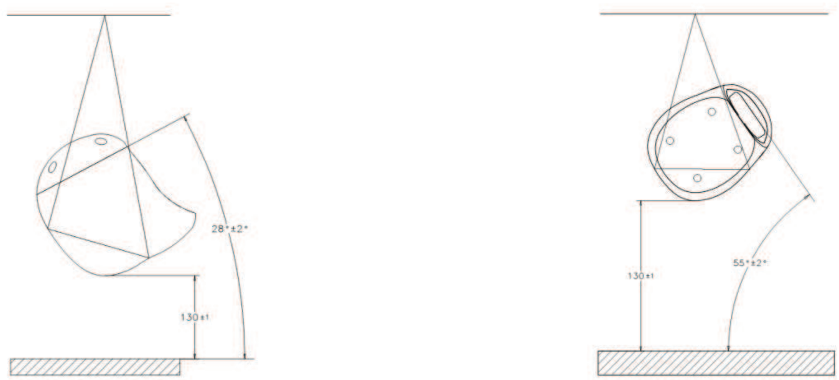


Figure 2: Head drop test setup Left: frontal test Right: lateral test

The head drops were performed with a half upper neck load cell replacement attached to the head base plate. The half load cell replacement is meant to incorporate the mass up to the OC joint. In Figure 3 the resultant head accelerations versus time are shown.

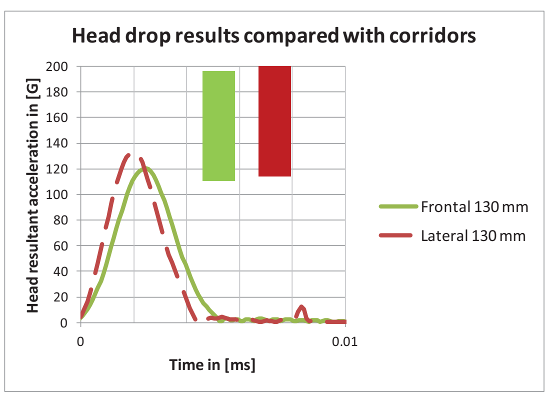


Figure 3: Head drop biofidelity results

Discussion and conclusion

It can be concluded that the head meets the frontal (130 mm) and lateral (130 mm) low in the EEVC corridors. This is in accordance with the results in ref. [ii]. In general the head stiffness will increase when the product ages. Therefore it is recommended to slightly increase the stiffness of the head such that its performance is at the lower side close to the middle corridor.

4.2.2 Neck

For the neck biofidelity requirements in flexion, extension and lateral flexion are evaluated below. The tests were done with a Part 572 neck pendulum and a Q-dummy head form setup as shown in Figure 4.

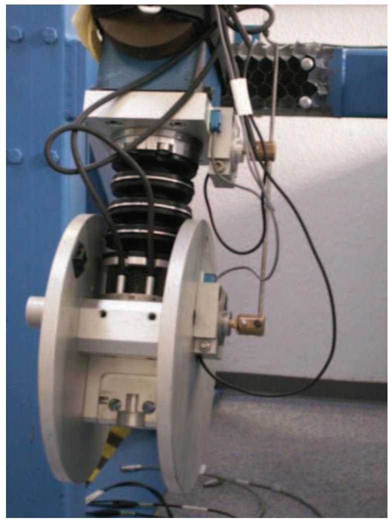


Figure 4: Q10 neck mounted on standard Part 572 neck pendulum with Q-dummy head form

4.2.2.1 Flexion

In Figure 5 the neck flexion bending performance in a Part 572 neck pendulum test is given in comparison with the flexion biofidelity corridor (ref. [iii]). The flexion response is in the lower range of the corridor and the stiffness increase that should occur about 30 to 35 degrees of head rotation is slightly late; actually it occurs around 45 degrees head rotation. The magnitude of the stiffness raise is correct. An improved performance could be obtained by increasing the rubber stiffness but that would affect the fracture toughness and therefore the durability of the part. Another possibility is to change the neck mould, but this may affect the response in other directions. The performance is considered to be adequate for the evaluation phase in the EPOCh project. A mould change will be considered later base on final EPOCh recommendations.

4.2.2.2 Extension

In Figure 6 the neck extension bending performance in a Part 572 neck pendulum test is given in comparison with the extension biofidelity corridor (ref. [iii]).

It can be concluded that the extension performance fits the corridor very well. No further adjustments are necessary and there is some room to allow changes as a result of the recommended mould change to improve flexion performance.

4.2.2.3 Lateral flexion

Figure 7 shows the neck lateral flexion bending performance in a Part 572 neck pendulum test in comparison with the lateral flexion biofidelity corridor (ref. [iii]). The Q10 development in the EPOCh project so far did not consider side impact performance tuning. It can be concluded that up to 45 degrees of head lateral flexion the performance is in the right order of magnitude.

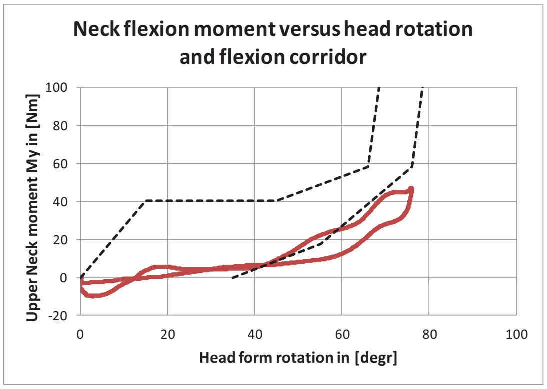


Figure 5: Neck flexion moment versus head rotation

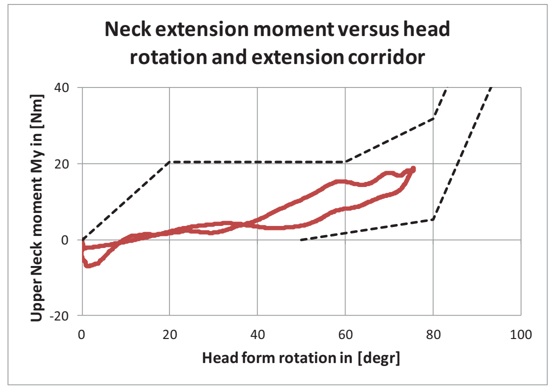


Figure 6: Neck extension moment versus head rotation

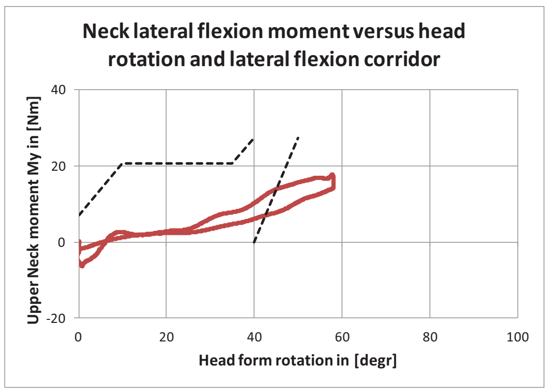


Figure 7: Neck lat. flexion moment versus head rotation

4.2.3 Shoulder lateral impac*t*

For the shoulder a lateral impact there was no requirement defined in the EPOCh project. The shoulder full body biofidelity test is done at a speed of 4.5 m/s with a full body pendulum (mass = 8.74 kg, diameter = 112 mm, six wire suspended). In Figure 8 the test setup in shown.

Figure 9 shows the pendulum force versus time in comparison with and scaled biofidelity corridor. The corridor of Figure 9 is based on scaling factors estimated by interpolation, using the shoulder impact corridor specified in the Q6 design brief and the corridor for adults.

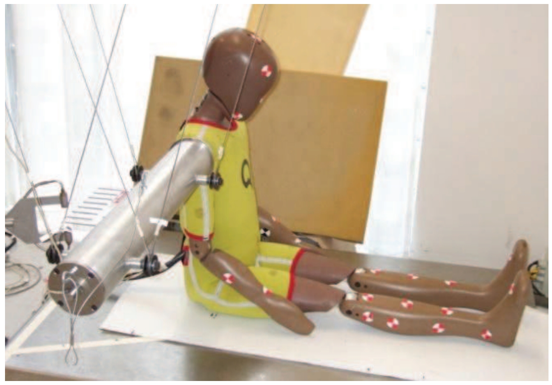


Figure 8: Q10 dummy in shoulder impact pendulum test setup

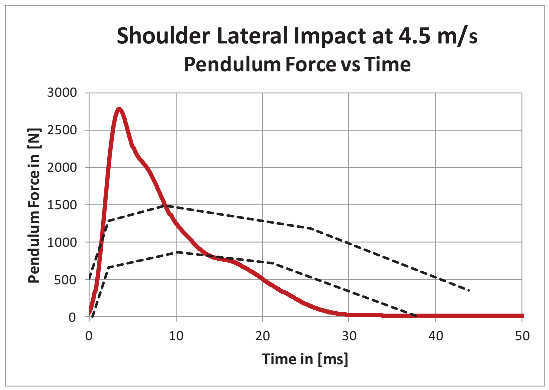


Figure 9: Lateral Shoulder impact force versus time

Discussion and conclusion

It can be observed that the initial response of the shoulder overestimates the stiffness whereas the response at later times gives lower stiffness. In relation to this result it should be remarked that:

The Q10 is an omni-directional dummy and performance tuning in either direction will affect the performance in the other direction. In the EPOCh project an optimal balance was sought for the Q10 performance in both directions with the focus on frontal impact.

As will be shown below similar trends with regards to lateral impact performance are observed for thorax and pelvis region. Hence the stiffness distribution in lateral impact is balanced between these body regions avoiding dominance of a single body segment in absorbing loads.

4.2.4 Thorax

4.2.4.1 Frontal impact

For the frontal biofidelity two pendulum test impact speeds are specified: 4.31 and 6.71 m/s. In Figure 11 and Figure 12 the pendulum test results for these two impact speeds are shown in terms of pendulum force versus average rib displacement in impact direction. The results are compared with the scaled biofidelity corridors (ref. [iii]). Three slightly different dummy postures are explored:

- Thoracic spine in vertical position with upper arms down along the thorax and the hand adjacent to the thighs. (This posture is commonly used for Q-dummies thorax impact (certification) tests so far and standard in this test series.
- Thoracic spine vertical position with arms forward, supported with rods under the elbows. (see Figure 10 right)
- Thoracic spine tilted forward about 12 degrees so that the sternum is parallel to the pendulum impactor face with upper arms down along the thorax and the hand adjacent to the thighs (not shown in Figure 10).

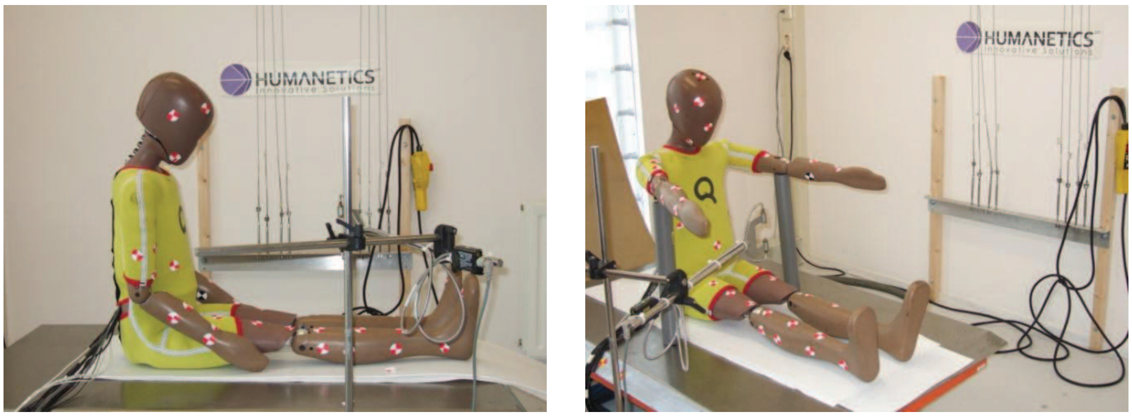


Figure 10: Q10 dummy positioning in thorax frontal impact tests
Left: Spine vertical posture (standard)   Right: Arms forward posture

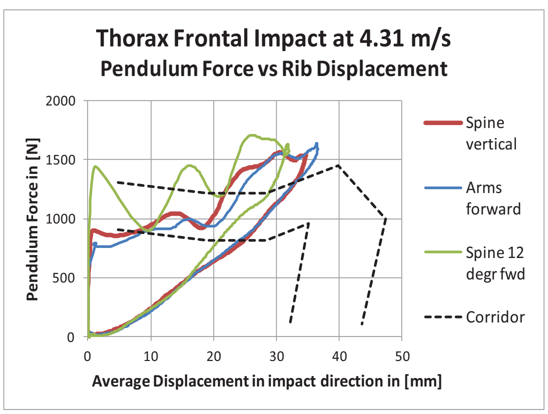


Figure 11: Thorax frontal pendulum impact 4.31 m/s

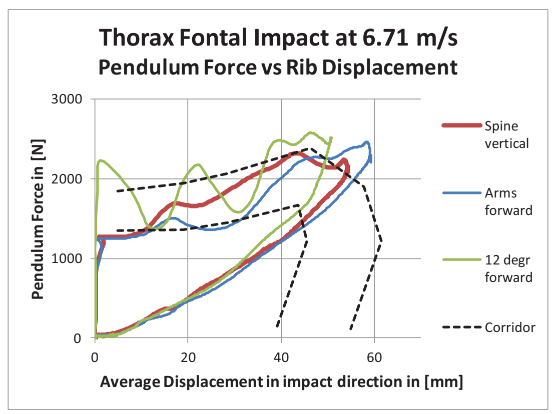


Figure 12: Thorax frontal pendulum impact 6.71 m/s

Discussion and conclusion

From Figure 11 (impact 4.31 m/s) and Figure 12 (impact 6.71 m/s) it can be observed that the rib cage response in general meets the corridors reasonably well, especially for 6.71 m/s. For the lower impact speed at 4.31 m/s the response is somewhat above the corridor, this is in line with the performance of the other Q dummies that have been made stiffer to prevent early bottoming out of the rib cage to the thoracic spine. Q10, however, having more room for displacements in the chest, has in comparison to other members of the Q family a better compliance with the corridors (see ref. [[v]]). The different postures explored show that there is sensitivity in the dummy response to this variable. This phenomenon is also observed in other dummies like the THOR currently under development in the THORAX project. However, there is no reason to deviate for the biofidelity test from the commonly used for Q-dummies thorax impact (certification) tests posture.

4.2.4.2 Lateral impact

For the lateral biofidelity two pendulum test impact speeds are specified: 4.31 and 6.71 m/s. In Figure 14 and Figure 15 the pendulum test results for these two impact speeds are shown in terms of pendulum force versus time. The results are compared with the biofidelity corridors as specified in the Q10 design brief (ref. [iii]).

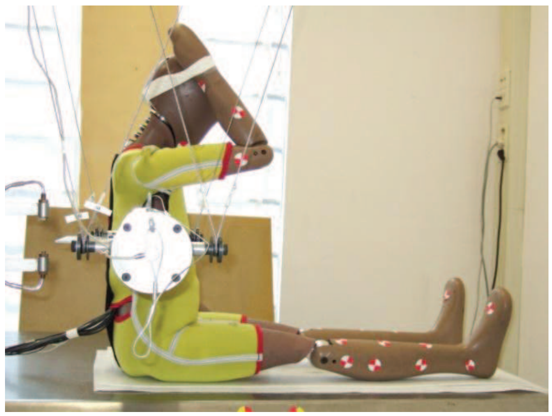


Figure 13: Q10 dummy positioning in thorax lateral impact tests

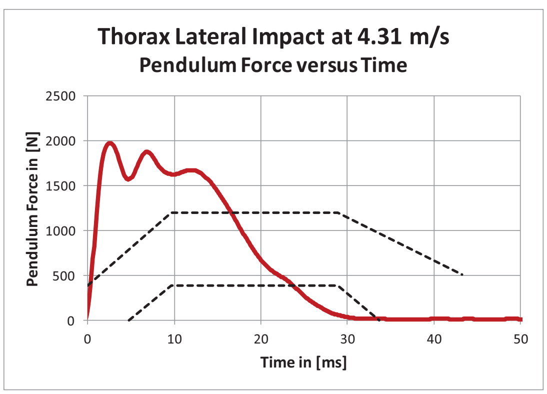


Figure 14: Thorax lateral pendulum impact 4.31 m/s

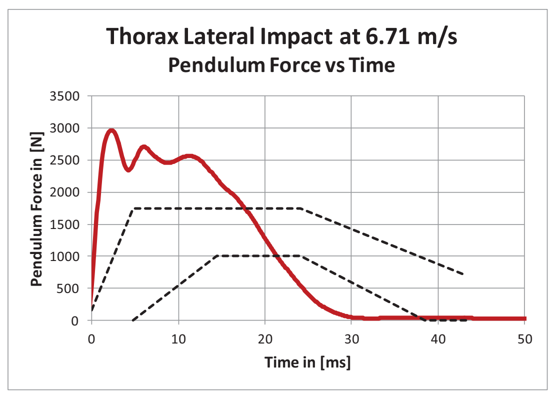


Figure 15: Thorax lateral pendulum impact 6.71 m/s

Discussion and conclusion

As for the shoulder the initial response of the thorax overestimates the stiffness whereas the response at later times gives lower stiffness. This is true for both impact speeds. Although performance tuning might be applied, this would affect the frontal performance and introduce an imbalance with the shoulder and pelvis (result shown below) under lateral loadings.

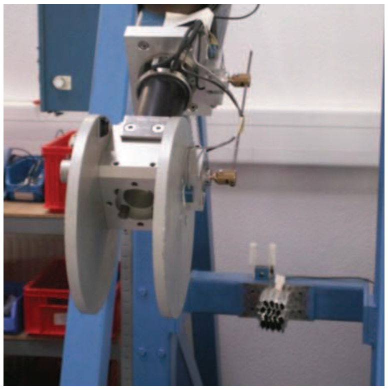
4.2.5 Lumbar Spine

The lumbar spine is made of a cylindrical rubber column therefore is the flexion and lateral flexion performance approximately the same. The tests were done with a Part 572 neck pendulum and a Q-dummy head form setup as shown in Figure 16. The head form has a special central block to compensate for the offset of the upper lumbar spine attachment bracket.

In Figure 17 test results obtained in dynamic and quasi-static tests are presented. The dynamic tests seem to show a slightly higher stiffness than the static tests:

Dynamic : 80 Nm/58 degr = 1.38 Nm/degr or 79.0 Nm/radial

Static : 80 Nm/74 degr = 1.08 Nm/degr or 61.9 Nm/radial



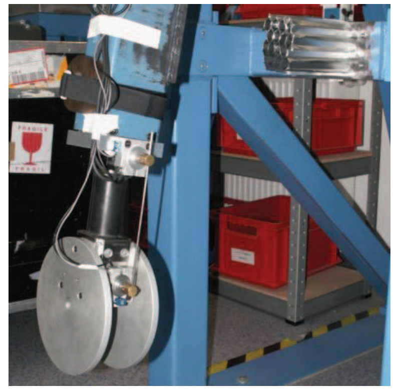


Figure 16: Q10 lumbar spine mounted on standard Part 572 neck pendulum with Q-dummy head form. Left: In flexion mode Right: In Lateral flexion mode

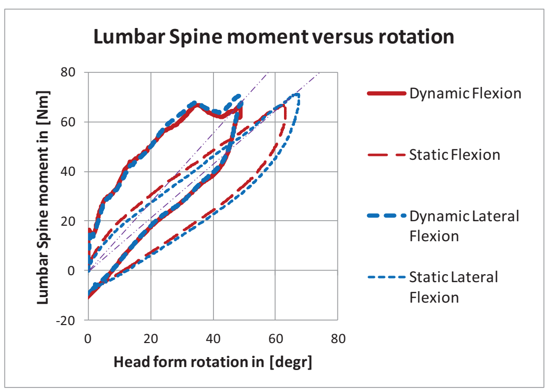


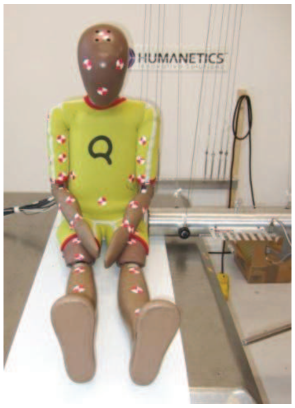
Figure 17: Lumbar Spine stiffness (dynamic and static)

Discussion and conclusion

The dynamically and statically measured stiffness' are significantly smaller than the scaled requirements (ref. [iii]) that is 137.1 Nm/rad for flexion and 142.8 Nm/rad for lateral flexion. The actual stiffness of a Q6 lumbar spine is about 50% of its scaled requirement (103 Nm/rad). During the performance tuning phase in October 2010 it was decided by the EPOCh consortium to set the target stiffness of the Q10 lumbar spine to 50% of the scaled requirements (68.6 Nm/rad for flexion and 71.4 Nm/rad for lateral flexion). The Lumbar spine tested in this test series complies with the requirement.

4.2.6 Pelvis lateral impact

The pelvis lateral full body biofidelity test should be done at a speed of 5.2 m/s. However in the test series there are tests available at 4.5 and 5.5 m/s. To estimate the response at 5.2 m/s the signals are linear interpolated. This is allowed because the pendulum force is found to be about linear with the impact speed in this interval (see Figure 43). In Figure 19 the lateral pelvis impact performance in terms of pendulum force versus time is shown in comparison with the scaled biofidelity corridor. The biofidelity corridor shown in Figure 19 is based on scaling factors estimated by interpolation using the pelvis impact corridor specified in the Q6 design brief and the corridor for adults.



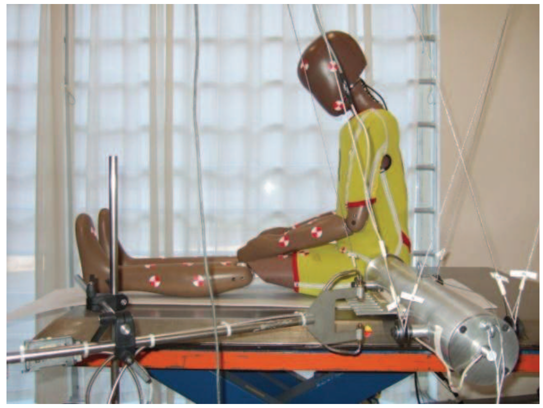


Figure 18: Q10 dummy positioning in pelvis lateral impact tests

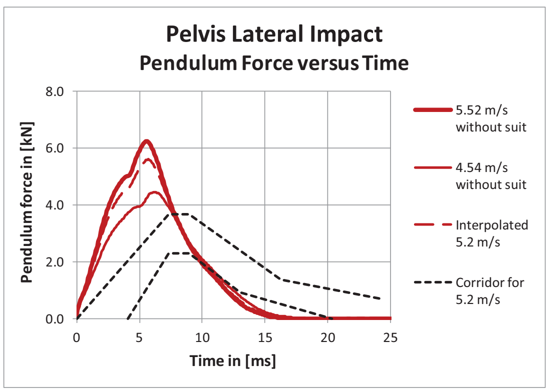


Figure 19: Pelvis lateral pendulum impact at 5.2 m/s

Discussion and conclusion

The pelvis response is in line with the lateral shoulder and thorax responses showing an initial response that overestimates the stiffness whereas the response at later times gives lower stiffness. Known side impact dummies like EuroSID-2 and WorldSID show a similar response character.

With regards to lateral impact it can be concluded that all three important body regions (shoulder thorax and pelvis) show initially an overestimated stiffness with a relative low stiffness at later times. This balances out the load distribution over the dummy torso in lateral impact. As a consequence none of these body regions will be overexposed to the load in the lateral pulse.

4.3 Sensitivity

In this chapter the Q10 dummy sensitivity performance information for frontal and lateral impacts is presented per body region top down from head to pelvis.

4.3.1 Head

For the head the sensitivity for impact angle variation relative to the standard impact angles was investigated (see Figure 20). In two impact conditions the impact angle was varied ±10 degrees. In Figure 21 and Figure 22 the results are presented as the average measured peak resultant acceleration together with the maximum and minimum measured values. For the nominal impact direction five (5) tests were completed and for the ±10 degrees impacts three (3) tests were done.

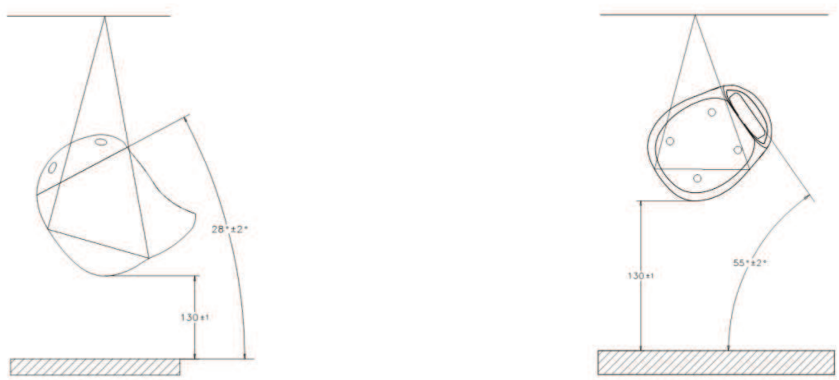


Figure 20: Head drop test setup   Left: frontal test   Right: lateral test

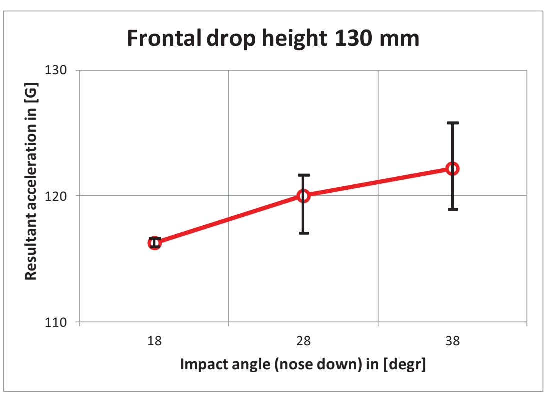


Figure 21: Frontal angle variation, 130 mm drop height

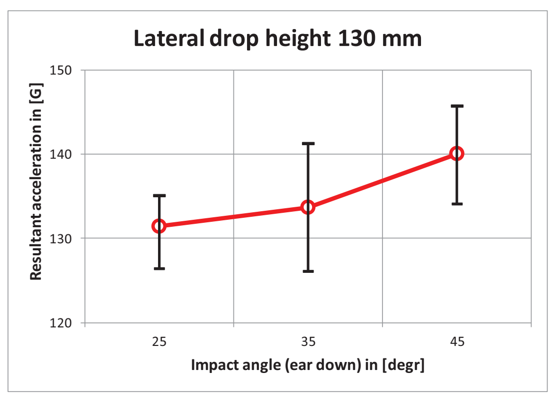


Figure 22: Lateral angle variation, 130 mm drop height

Discussion and conclusion

From Figure 21 and Figure 22 it can be seen that head is not sensitive for angle variation. The sensitivity found for ±10 degrees impacts is in the same order as the variation that can be expected for the impact tests in a single test conditions. This means that the head response is, as desired, not significantly sensitive for the small variations of the impact location.

4.3.2 Neck

For the neck no sensitivity assessment can be reported.

4.3.3 Shoulder lateral impact

For the lateral shoulder impact the sensitivity for speed, impact alignment offset and impact angular offset variation was investigated considering the peak pendulum force and T1 peak acceleration (measured on lower neck interface plane level). Figure 23 shows the sensitivity for the impact speed. Figure 25 and Figure 27 give the sensitivity for the angular offsets ±10 degrees from pure lateral impact in the horizontal plane. In Figure 26 and Figure 28 show the sensitivity for the impact alignment offsets ±15 mm from the lateral impact aligned with the centre of shoulder joint in the horizontal plane.

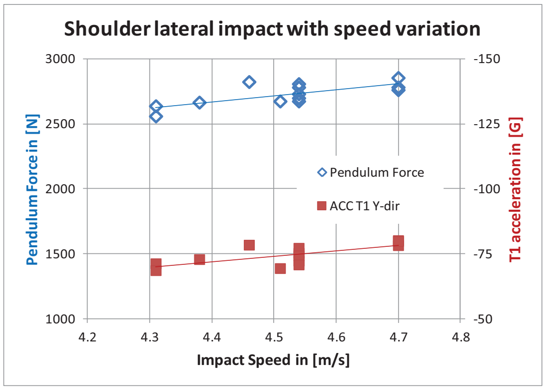


Figure 23: Shoulder lateral impact results versus speed

Discussion and conclusion

As can be seen from Figure 23 both pendulum force and T1 lateral acceleration increase with impact speed as one might expect. Variations in impact angle (compared to pure lateral impact, see Figure 24 left) and location (compared to impacts at centerline, see Figure 24 right) both result in a decrease of the pendulum force (see Figure 25 and Figure 26). This can be contributed to the introduction of rotation in the dummy. It appears though that the T1 lateral accelerations are insensitive to variations in the impactor alignment (Figure 28) while showing a large sensitivity to impact angle (Figure 27). The latter can be explained by the fact that the shoulder rubber is loaded in flexible bending mode when impacted from the rear, whereas for forward angle impacts the shoulder rubber becomes loaded in a compression mode which stiffens the load path in the dummy.

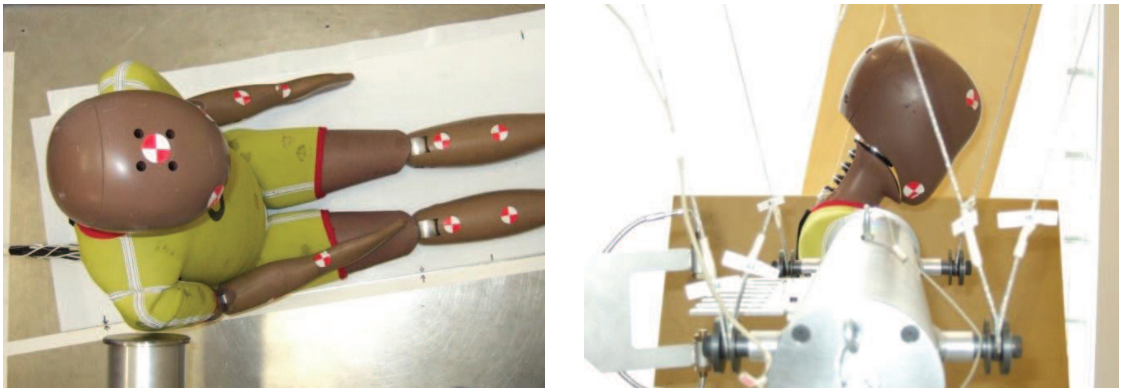


Figure 24: Q10 dummy positioning in shoulder impact sensitivity tests
Left: 10 degrees rearward offset Right: 15 mm forward offset

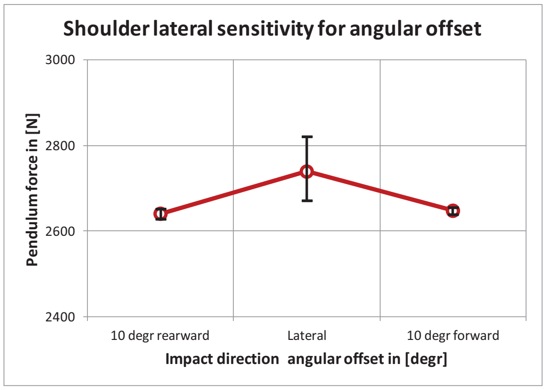


Figure 25: Impact force sensitivity for angular offset

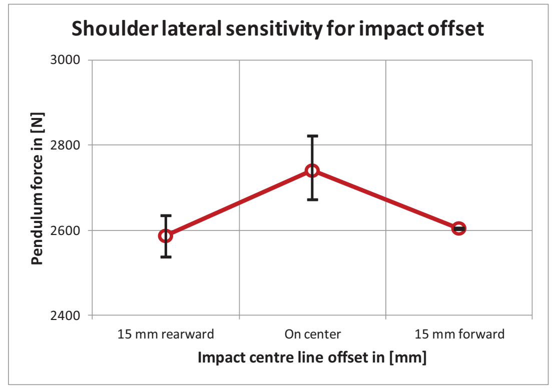


Figure 26: Impact force sensitivity for alignment offset

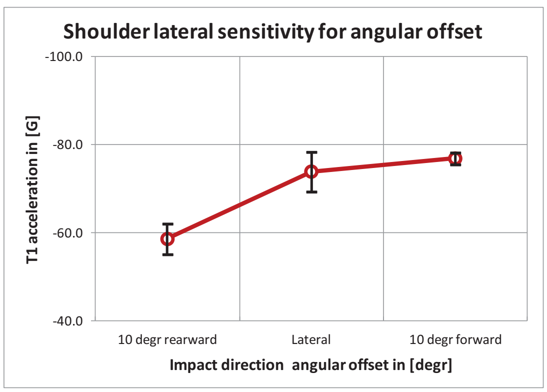


Figure 27: T1 acceleration sensitivity for angular offset

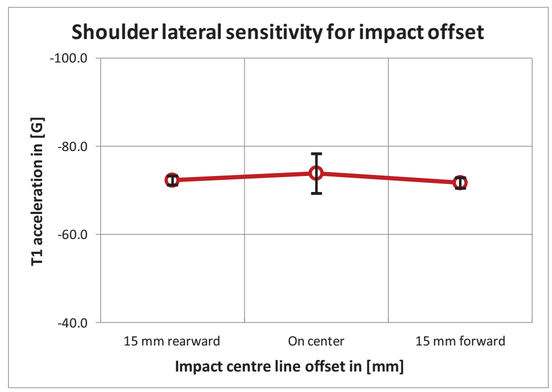


Figure 28: T1 acceleration sensitivity for alignment offset

4.3.4 Thorax

4.3.4.1 Frontal impact

For the thorax frontal impact the sensitivity for impact speed and angular offset from the pure frontal impact was investigated. In Figure 29 the sensitivity of pendulum force and chest displacement (Dx) for impact speed is shown for impact speeds of 4.3, 5.5 and 6.7 m/s. For the angular offset sensitivity the pure frontal impact test results at 4.3 m/s are compared with the results of impacts at the same speed with an angular off-set of 10, 20 and 30 degrees to the left hand side (two tests for each offset direction). It is assumed that the sensitivity will be symmetrical for both sides. In Figure 31 the results for the pendulum force are shown. In Figure 32 the results for the chest deflection are given. For the chest deflection the resultant displacement has been taken to allow for the combined X- (longitudinal) and Y- (lateral) displacement that can be calculated from the IR-TRACC and potentiometer signals. In Figure 33 the average 2-dimensional deflection trajectory of the sternum in X and Y direction is plotted for all four impact directions.

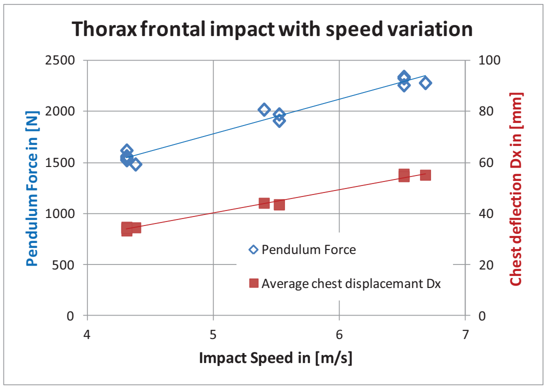


Figure 29: Thorax frontal impact results versus speed

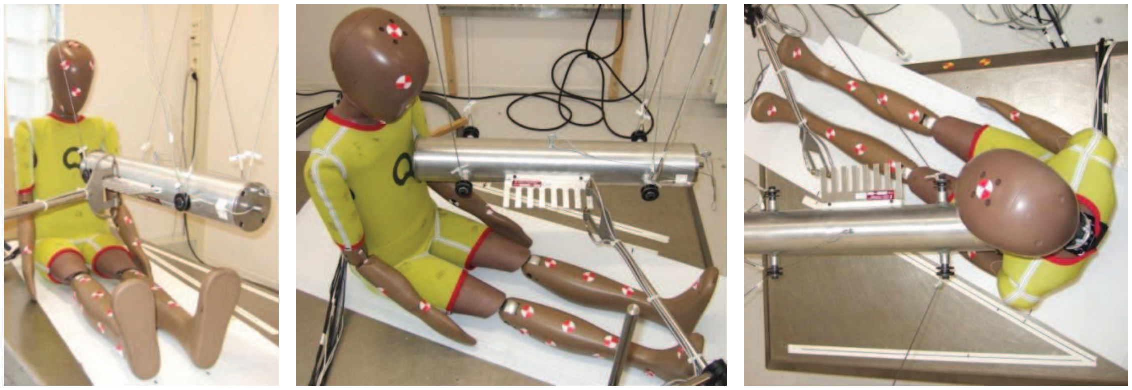


Figure 30: Q10 dummy positioning in frontal impacts with angular offset
Left: 10 degrees offset Middle: 20 degrees offset Right: 30 degrees offset

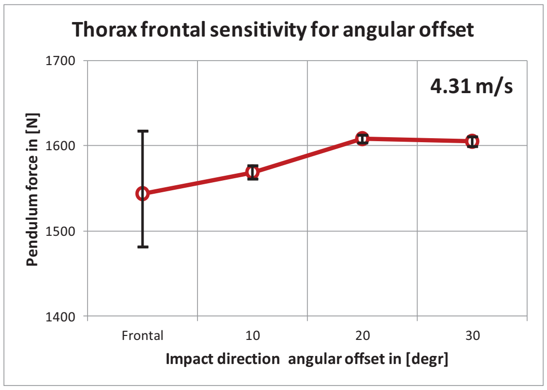


Figure 31: Pendulum force sensitivity for angular offset

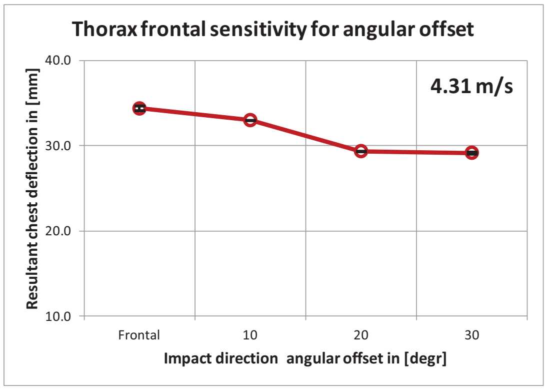


Figure 32: Chest deflection sensitivity for angular offset

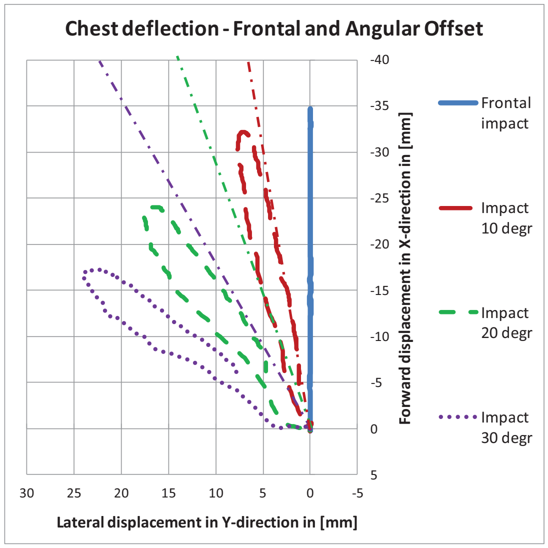


Figure 33: Chest deflections frontal and angular offset

Discussion and conclusion

In Figure 29 the pendulum force and chest deflection show sensitivity for the impact peed as expected. For the angular offset sensitivity the pendulum force increases slightly up to about 4% (Figure 31) whereas the resultant chest deflection decreases significantly up to about 15% (Figure 32). This may be contributed to the fact that the 2D-IRTRACC measures the displacement of the forward point of the chest which is not optimal in case of impacts with an angular offset. The X-Y displacement plots given in Figure 33 clearly show that the pure frontal impact results in a pure longitudinal chest deflection. However in case of impact with angular offsets the lateral displacement measured at the forward 2D-IRTRACC attachment points show an over proportional increase of the lateral chest deflection. For 20 and 30 degrees angular offset the 2D-IRTRACC records initially even a pure lateral chest deflection, later the deflection becomes an X-Y displacement. It is recommended to always assess the X-Y displacement to get the best possible indication of the chest deformation and to use the resultant deflection for injury assessment.

4.3.4.2 Lateral impact

For the thorax lateral impact the sensitivity for impact speed and angular offset from the pure lateral impact (see Figure 35) was investigated. In Figure 34 the sensitivity of pendulum force and chest displacement (Dy) for impact speed is shown for impact speeds of 4.3, 5.5 and 6.7 m/s. For the angular offset sensitivity the pure lateral impact tests at 4.3 and 6.7 m/s are compared with the results of impacts at the same speed with an angular off-set of 15 degrees rearward and 15 degrees forward from lateral (see Figure 35). Per offset direction two tests are performed. In Figure 36 and Figure 37 the results for the pendulum force are shown and in Figure 38 and Figure 39 the results for the chest deflection are given. For the chest deflection it should be noted that the lateral line on the rib cage will always deflect in lateral and forward direction. In the graphs Figure 38 and Figure 39 the displacement in lateral directions (Dy) has been used. In Figure 40 and Figure 41 the average 2-dimensional deflection trajectory of the lateral rib cage line in lateral (Y) and forward (X) direction are plotted for all three impact directions.

Discussion and conclusion

The pendulum force and chest deflection (Dy) in Figure 34 increase with impact speed as expected. For the angular offset sensitivity at 4.31 m/s the pendulum force increases about 10% relative to pure lateral in case of rearward angular offset while decreasing about 11% in case of forward angular offset (see Figure 36). At 6.71 m/s impact speed the pendulum force increases up to about 12% in case of rearward angular offset and decreases about 7% in case or forward angular (see Figure 37). The chest deflection in lateral direction (Dy) decreases significantly in case of rearward angular offset: 42% relative to pure lateral at 4.3 m/s impact speed (Figure 38) and 49% at 6.7 m/s impact speed (Figure 39). In case of forward angular offset the measured lateral chest deflection remains almost the same as in pure lateral impact. This means that the dummy behaves stiffer for rearward direction impacts, which is due to the attachment of the rib cage to the thoracic spine.

The X-Y displacement plots given in Figure 40 (4.31 m/s impacts) and Figure 41 (6.71 m/s impacts) clearly show that the pure lateral impact results in a combined lateral and forward deflection of the lateral 2D-IRTRACC to rib cage attachment points. This is a well known phenomenon in side impact dummies and resulted in the introduction of the 2-D IRTRAC's in the WorldSID dummies (for the small female WorldSID see ref. [[vi]]). The pronounced 2-D response in case of lateral impact is induced by the fixation of the ribcage at the thoracic spine. For pure lateral and forward angular offset impacts the lateral inward deflection of the rib is obvious. For the rearward angular offset impacts, however, the rib cage deflects initially mainly forward. The 2D-IRTRACC lateral rib attachment points seem to rotate around the rib attachment to the thoracic spine. It is recommended to always assess the X-Y displacement to get the best possible insight in the chest deformation. For the injury assessment the lateral deflection (Dy) might be used as common in side impact dummies or, once available for other dummies, like the WorldSID dummies, two criteria using X and Y displacements might be introduced. Though, this will need further biomechanical research.

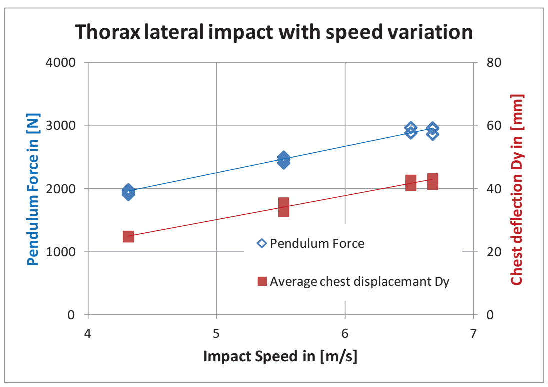
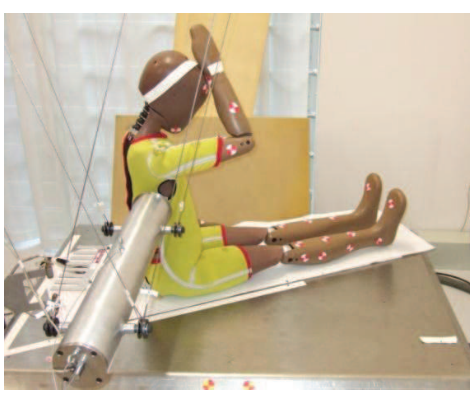


Figure 34: Thorax lateral impact results versus speed



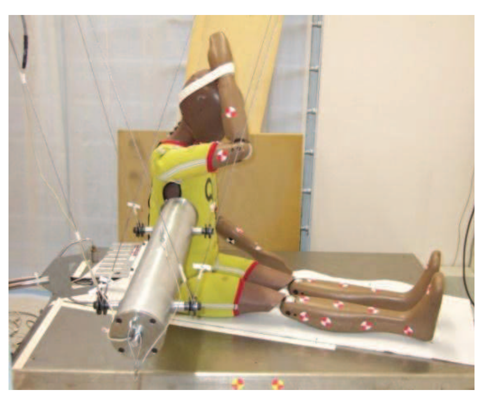


Figure 35: Q10 dummy positioning in lateral impacts with angular offset
Left: 15 degrees rearward offset **Right: 15 degrees forward offset**

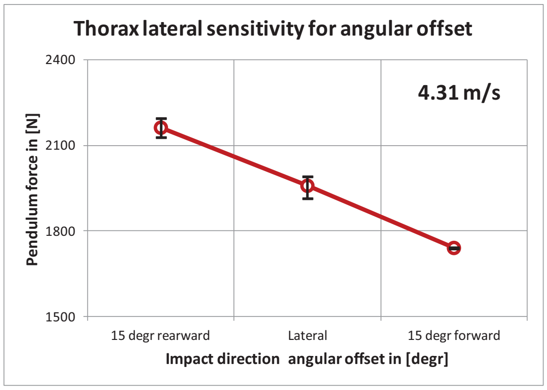


Figure 36: Pendulum force sensitivity for angular offset

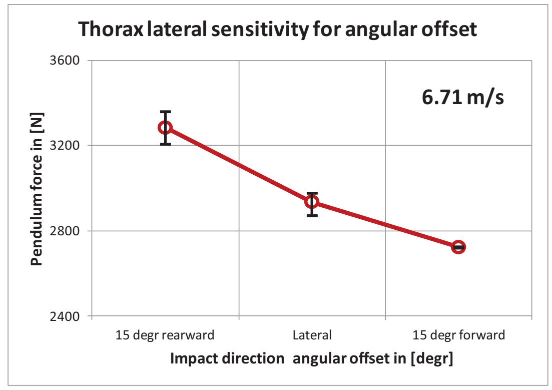


Figure 37: Pendulum force sensitivity for angular offset

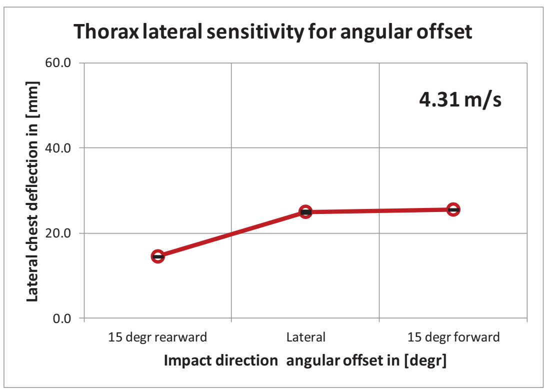


Figure 38: Chest deflection sensitivity for angular offset

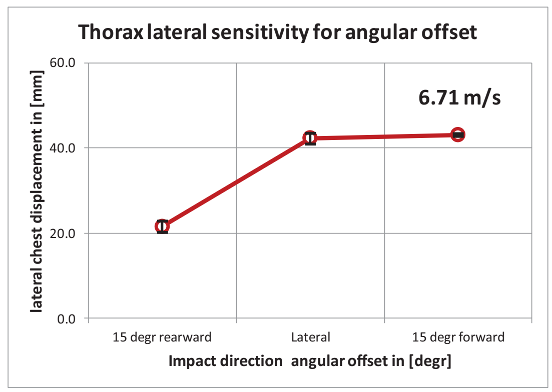


Figure 39: Chest deflection sensitivity for angular offset

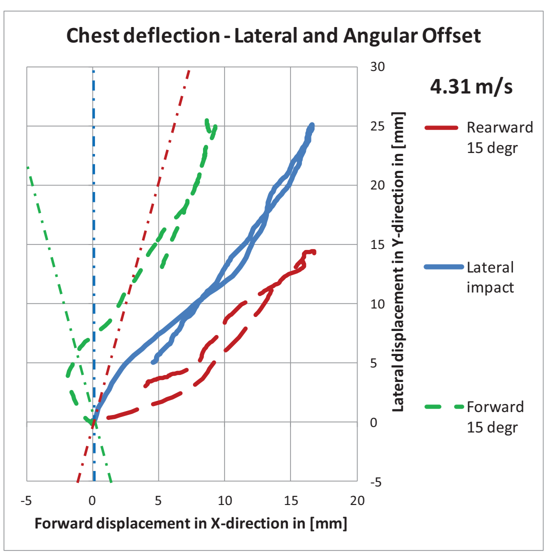


Figure 40: Chest deflections lateral and angular offset

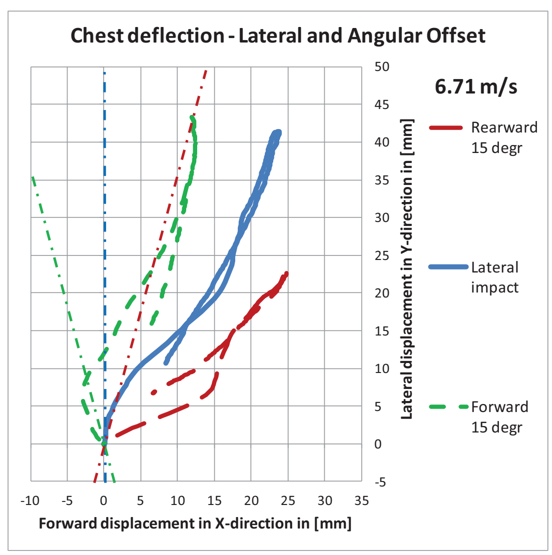


Figure 41: Chest deflections lateral and angular offset

4.3.5 Lumbar Spine

For the lumbar spine no sensitivity assessment can be reported.

4.3.6 Pelvis

For the pelvis lateral impact the sensitivity for impact speed and alignment offset was investigated. Figure 43 shows results for the pendulum force and pubic symphysis loads as function of impact speed. Figure 44 and Figure 45 show sensitivities of parameters to the impactor alignment. The offsets considered in these tests are 30 mm above the H-point and 30 mm forward of the H-point (see Figure 42). The impact speed is 4.5 m/s in all these offset sensitivity cases.

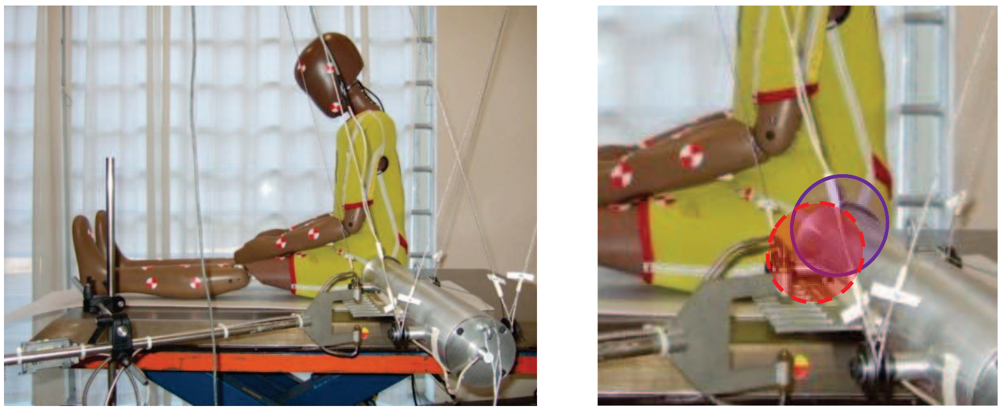


Figure 42: Q10 dummy positioning in pelvis lateral impact tests
Alignment offset: 30 mm above purple oval, 30 mm forward red dashed oval

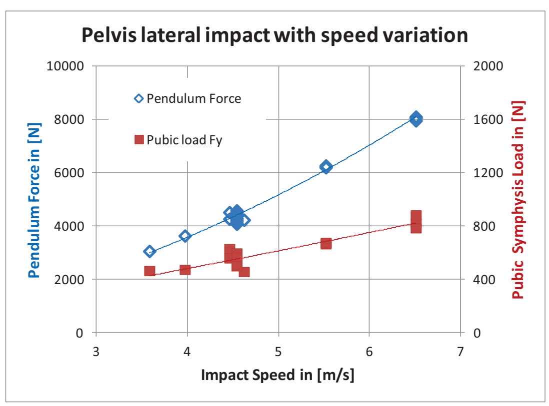


Figure 43: Pelvis impact results versus impact speed

Discussion and conclusion

In Figure 43 the pendulum force and pubic symphysis force show sensitivity for the impact speed as expected. Trend lines quadratic with the impact speed gives the best fit through the data points. When impacted 30mm above the H-point the pendulum force increases about 7% (Figure 44) and the pubic symphysis load drops with about 5% (Figure 45). This can be explained because in this case not only the upper leg thigh is exposed to the impact, but also the pelvis flesh part above the thigh and behind that the most lateral upper margin of the iliac wing. In an impact 30mm forward of the H-point the pendulum force is the same as in an impact aligned with the H-point (Figure 44). In that case the pubic symphysis load rises with 4% (Figure 45). It should be note pubic symphysis loads most likely are influenced by the bottoming out of the hip joint hardware against the sacrum block. This occurs in the current dummy at pendulum impact with speed larger than 4.0 m/s. This bottoming out will be considered in a pelvis redesign that should provide more clearance between the iliac wings and the sacrum block and more stiffness in the iliac wings.

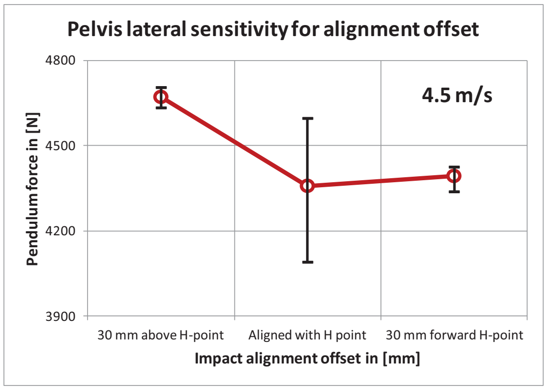


Figure 44: Impact force sensitivity for alignment offset

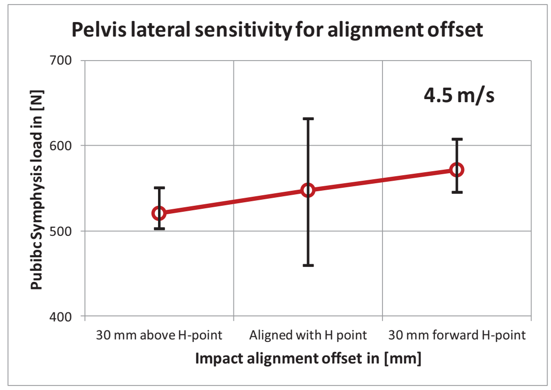


Figure 45: Pubic load sensitivity for alignment offset

4.4 Repeatability

The level of repeatability of dummy responses is often expressed in the Coefficient of Variation (CoV = Standard Deviation / Mean value). In component and full body impactor tests, that are considered to be highly repeatable the number of variables involved is small. In those tests the dummy, the impact pulse and the temperature of the setup are the main variables and a CoV of maximum 5% is considered to be acceptable. For a proper statistically valid CoV the minimum number of tests is seven (7), the test series performed in this dummy validation exercise comprises in general maximum five (5) and minimum two (2) tests of the same test configuration. Therefore an alternative approach is used: for each test result the relative deviation is calculated by: Deviation from the mean value of the group divided by the mean value of the group. Taking the standard deviation of the relative deviations of a number tests over group boundaries results in a statistical significant CoV values. Below per body region, top down from head to pelvis, tables are presented that show the test configuration considered and the CoV values obtained per composed group. In brackets the associated number of tests in the (composed) group is given. Tests that deviate more than 7% from the mean result of the group are excluded from the calculation.

Table 3: Head impact repeatability

Test configuration	Head acceleration
Frontal impact 130 mm	1.59% (12)
18 degrees	0.31% (3)
28 degrees	1.53% (6)
38 degrees	2.83% (3)
Lateral impact 130 mm	2.50% (22)
25 degrees LH- and RH- side	1.29% (6)
35 degrees LH- and RH- side	3.59% (10)
45 degrees LH- and RH- side	1.19% (6)
Lateral impact 200 mm	2.65% (20)
25 degrees LH- and RH- side	2.11% (4)
35 degrees LH- and RH- side	2.24% (10)
45 degrees LH- and RH- side	3.88% (6)
All tests together	**2.35% (54)**

Table 4: Neck bending repeatability

Test configuration	Upper neck moment	Head form rotation
Flexion	2.04% (11)	0.67% (11)
4.7 m/s	1.62% (3)	0.27% (3)
4.8 m/s	2.46% (5)	0.99% (5)
4.9 m/s	2.47% (3)	0.48% (3)
Extension	4.03% (11)	0.80% (11)
3.6 m/s	4.81 % (3)	0.75% (3)
3.7 m/s	5.31% (5)	1.11% (5)
3.8 m/s	1.79% (3)	0.43% (3)
Lateral Flexion	1.59% (11)	1.10% (11)
3.6 m/s	1.71% (3)	1.01% (3)
3.7 m/s	2.15% (5)	1.36% (5)
3.8 m/s	0.67% (3)	0.48% (3)
All tests together	**2.67% (33)**	**0.87% (33)**

Table 5: Shoulder impact repeatability (lateral impact)

Test configuration	Pendulum force	T1 Y-acceleration
Lateral impact	(see below)	(see below)
4.3 m/s	2.10% (3)	3.03% (3)
4.5 m/s	2.30% (7)	3.90% (7)
4.7 m/s	1.76% (3)	1.29% (3)
4.5 m/s 15 mm rearward	2.66% (2)	2.01% (2)
4.5 m/s 15 mm forward	0.10% (2)	2.36% (2)
4.5 m/s 10 degr rearward	0.64% (2)	*Excluded >7%*
4.5 m/s 10 degr forward	0.44% (2)	2.47% (2)
All tests together	**1.97% (21)**	**3.23% (19)**

Table 6: Thorax impact repeatability

Test configuration	Pendulum force	Rib deflection
Frontal impact	1.90% (24)	1.50% (24)
4.3 m/s	3.26% (5)	0.66% (5)
5.5 m/s	2.79% (3)	0.80% (3)
6.7 m/s	1.67% (4)	0.84% (4)
4.3 m/s, fwd 10 degr	0.70% (2)	0.54% (2)
4.3 m/s, fwd 20 degr	0.40% (2)	2.58% (2)
4.3 m/s, fwd 30 degr	0.50% (2)	5.10% (2)
6.7 m/s, fwd 10 degr	1.01% (2)	2.21% (2)
4.3 m/s, tilt 12 degr	0.80% (2)	1.04% (2)
6.7 m/s tilt 12 degr	1.03% (2)	1.97% (2)
Lateral impact	1.49% (21)	2.16% (19)
4.3 m/s	1.62% (5)	0.97% (5)
5.5 m/s	1.89% (3)	5.07% (3)
6.7 m/s	1.69% (5)	2.61% (5)
4.3 m/s, rearward 15 degr	2.18% (2)	0.60% (2)
6.7 m/s, rearward 15 degr	3.28% (2)	*Excluded >7%*
4.3 m/s, forward 15 degr	0.17% (2)	0.35% (2)
6.7 m/s, forward 15 degr	0.14% (2)	1.04% (2)
All tests together	**1.61% (45)**	**1.77% (43)**

Table 7: Lumbar Spine bending repeatability

Test configuration	Lower lumbar moment	Head form rotation
Flexion	1.15% (11)	2.52% (11)
4.3 m/s	1.20% (3)	0.49% (3)
4.4 m/s	0.52% (3)	1.00% (3)
4.5 m/s	1.57% (5)	3.76% (5)
Lateral Flexion	1.68% (11)	1.69% (11)
4.3 m/s	2.45% (3)	0.21% (3)
4.4 m/s	1.55% (5)	2.63% (5)
4.5 m/s	1.81% (3)	0.55% (3)
All tests together	**1.40% (22)**	**2.11% (22)**

Table 8: Pelvis impact repeatability (lateral impact)

Test configuration	Pendulum force	Pubic symphysis load
Aligned with H-point	1.70%(19)	4.62%(14)
4.5 m/s	2.04% (13)	4.99% (8)
5.5 m/s	0.55% (3)	0.85% (3)
6.5 m/s	0.91% (3)	5.95% (3)
30 mm above H-point 4.5 m/s	0.77% (3)	5.07% (3)
30 mm forward H-point 4.5 m/s	1.08% (3)	5.67% (3)
All tests together	**1.52% (25)**	**4.62% (20)**

Discussion and conclusion

The results presented in Table 3 to Table 8 show a good repeatability all over the dummy. Nearly all values remain below 2.5% except the T1 Y-acceleration in the shoulder lateral impact tests and the pubic symphysis load in pelvis lateral impacts tests. The T1 acceleration (CoV=3.2%) is obtained with an provisionally mounted accelerometer, maybe the double sided mounting tape on the slightly curved lower neck load cell flange was not very consistent. The relatively large variation of the pubic symphysis load (CoV=4.6%) maybe contributed to the fact that the iliac wing and hip joint hardware bottoms out against the sacrum block in impact with a speed larger than 4.0 m/s.

Overall it is concluded that the Q10 dummy can be used as a repeatable tool in crash test environments.

4.5 Durability

The 254 tests of the validation test program were performed on the dummy also used for the EPOCh project dynamic evaluation test program at TRL. For the neck tests a new neck was used. The validation tests on the dummy did not lead to damage to the dummy. It is concluded that the dummy is durable for the load levels reached in the biofidelity and certification tests.

The evaluation of the Q10 dummy under UNECE R44 and NPACS test conditions performed by DOREL, IDIADA and TRL revealed some durability related issues on the neck, torso (ribcage, shoulders and pelvis), lower legs and suit. Separate reports from EPOCh Work Package 3 dealing with these evaluation tests will address the durability issues in detail. During the EPOCh evaluation some improvements were implemented straight away, others based on EPOCh recommendations may be implemented later in a dummy update.

4.6 Certification Procedures

In this chapter the provisional certification procedures are specified per body region top down from head to pelvis. Certification corridors are not specified in this report because some parts may change in performance as a result of EPOCh-project recommendations and the results of several batches of products and of different test laboratories should be considered before corridors can be established.

4.6.1 Head

The head certification test set-up consists of a complete head including the accelerometer mounting hardware. Additional to the head a half steel upper neck load cell replacement (mass 0.15 kg, part number TE-010-1007) should be mounted to the lower side of the head base plate. The head should be equipped to record the X, Y and Z accelerations filtered at CFC1000. From these results the resultant head acceleration should be calculated. The following certification test impacts should be performed:

4.6.1.1 Frontal

With the head tilted 28 ± 2 degrees nose down (from pure facial impact) and a drop height of 130 mm. (as standard for Q-dummies).

4.6.1.2 Lateral

With the head tilted 35 ± 2 degrees ear down (from pure lateral impact) and a drop height of 130 mm. (as standard for Q-dummies).

4.6.2 Neck

The necks must be certified with the standard Part 572 neck pendulum with a head form that replaces the actual head. Between the pendulum base and the neck lower plate a special interface ring should be used (part number TE-010-2015). Between the upper neck plate and the head form the high capacity upper neck load cell (IF-217-HC) should be mounted. In the tests the pendulum acceleration (CFC180), the head form rotation obtained with the pendulum and head potentiometers (CFC600) and the upper neck moments Mx (side bending) and My (forward bending) (CFC600) should be recorded. For the deceleration of the pendulum 6 inch honeycomb is used. The certification test procedures to be followed are:

4.6.2.1 Flexion

For the neck certification flexion test the pulse should be between the following boundaries:

Pendulum speed: between 4.7 and 4.9 m/s

at 10 ms: 1.0 – 2.0 m/s;

at 20 ms: 2.3 – 3.4 m/s and

at 30 ms: 3.6 – 4.8 m/s.

The pulse corridor and the pulses of the tests performed are shown in Figure 46.

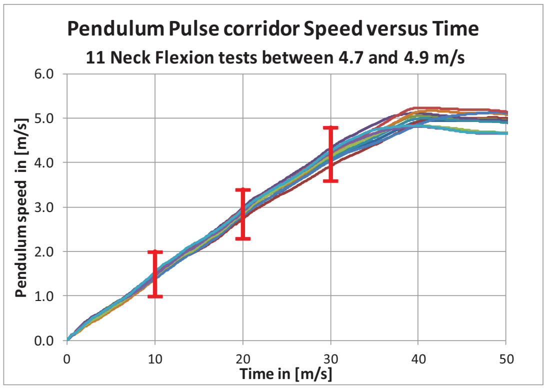


Figure 46: Pendulum pulse for neck flexion test

4.6.2.2 Extension

For the neck certification extension test the pulse should be between the following boundaries:

Pendulum speed: between 3.6 and 3.8 m/s

at 10 ms: 0.7 – 1.7 m/s;

at 20 ms: 1.7 – 2.8 m/s and

at 30 ms: 2.8 – 4.0 m/s.

The pulse corridor and the pulses of the tests performed are shown in Figure 47.

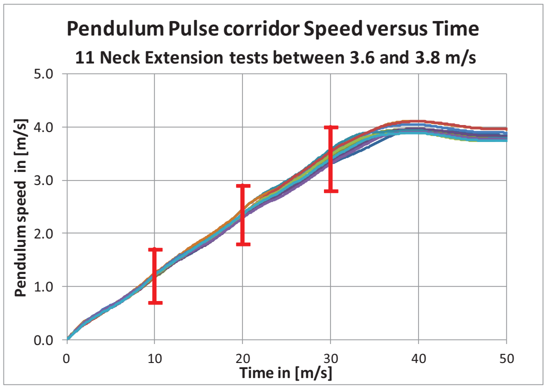


Figure 47: Pendulum pulse for neck extension test

4.6.2.3 Lateral flexion

For the neck certification lateral flexion test the pulse should be between the following boundaries:

Pendulum speed: between 3.6 and 3.8 m/s

at 10 ms: 0.7 – 1.7 m/s;

at 20 ms: 1.7 – 2.8 m/s and

at 30 ms: 2.8 – 4.0 m/s.

The pulse corridor and the pulses of the tests performed are shown in Figure 48.

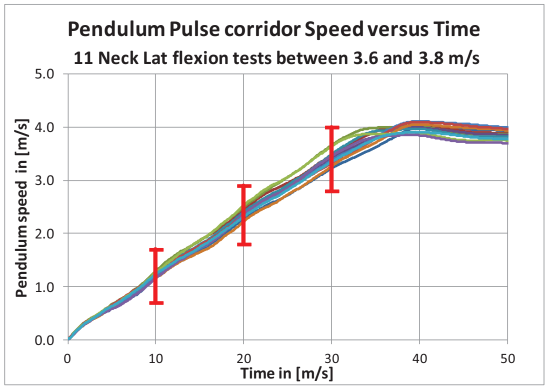


Figure 48: Pendulum pulse for neck lateral flexion test

4.6.3 Shoulder (lateral impact)

For the shoulder certification a full body lateral impact test should be done with a six wire, suspended pendulum (mass of 8.76 kg and a diameter of 112 mm). The pendulum speed should be between 4.2 and 4.4 m/s. The impact should be pure lateral with the pendulum aligned with shoulder joint. The dummy should be sitting with the thoracic spine vertical, the upper arms along the thorax and the legs stretched forward on two sheets of PTFE (Teflon) to minimize the friction. In the tests the pendulum acceleration (CFC180) should be recorded.

4.6.4 Thorax

For the thorax certification a full body frontal and lateral impact test should be done with a six wire suspended pendulum (mass of 8.76 kg and a diameter of 112 mm). The pendulum speed should be between 4.2 and 4.4 m/s. The impact should be pure frontal or lateral with the pendulum centerline in the middle between the IR-TRACC to ribcage attachment screws. The dummy should be sitting with the thoracic spine vertical and the legs stretched forward on two sheets of PTFE (Teflon) to minimize the friction. In the frontal test the upper arms should be along the thorax sides. In the lateral test the arm at the impact side should be taped to the head the enable free impact exposure to the side of the rib cage. In the tests the pendulum acceleration (CFC180) and both 2D IR-TRACCs (IR-TRACCs and potentiometers at CFC600) should be recorded.

4.6.5 Lumbar Spine

The lumbar spine must be certified with the standard Part 572 neck pendulum with a head form mounted to the upper lumbar spine interface. A special head form central block (part number TE-2651-14) that allows for the offset in the upper lumbar spine mount should be used. Between the pendulum and the lumbar spine lower mount a steel load cell replacement of high capacity load cell (IF-217-HC) should be used. In the tests the pendulum acceleration (CFC180) and the head form rotation with the pendulum and head potentiometers (CFC600) should be recorded. The certification test procedures to be followed are:

4.6.5.1 Flexion

For the lumbar spine certification flexion test the pulse should be between the following boundaries:

Pendulum speed: between 4.3 and 4.5 m/s

at 10 ms: 0.9 – 1.9 m/s;

at 20 ms: 2.3 – 3.4 m/s and

at 30 ms: 3.4 – 4.6 m/s.

The pulse corridor and the pulses of the 11 flexion tests performed are shown in Figure 49.

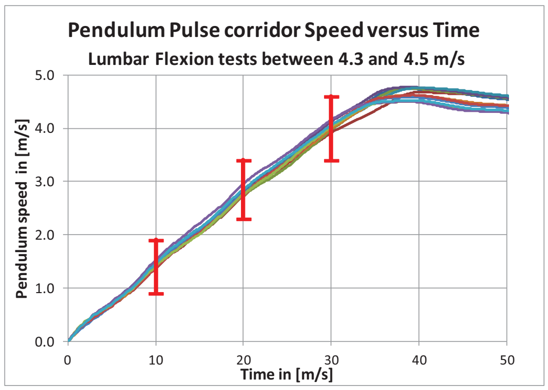


Figure 49: Pendulum pulse for lumbar flexion

4.6.5.2 Lateral Flexion

For the certification neck lateral flexion test the pulse should be between the following boundaries:

Pendulum speed: between 4.3 and 4.5 m/s

at 10 ms: 0.9 – 1.9 m/s;

at 20 ms: 2.3 – 3.4 m/s and

at 30 ms: 3.4 – 4.6 m/s.

The pulse corridor and the pulses of the 11 lateral flexion tests performed are shown in Figure 50.

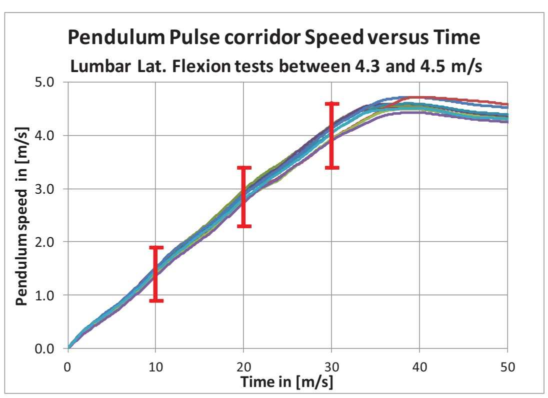


Figure 50: Pendulum pulse for lumbar lateral flexion

4.6.6 Abdomen

For the abdomen certification a component test, similar to that for the other Q-dummies, is required. The abdomen should be placed over the Q10 abdomen support block (Part number TE-010-9910) on a horizontal table. Ensure that the fit and the orientation of the abdomen on the support block are correct. The flat vertically guided top plate of the setup that is should load the abdomen front with the gravity loading of 2.05 kg. Within 10 seconds after application the "zero"-displacement point should be determined. Then the addition mass of 8.05 kg should be applied and after 2 minutes ±10 seconds the compression displacement relative to the "zero"-displacement point should be measured.

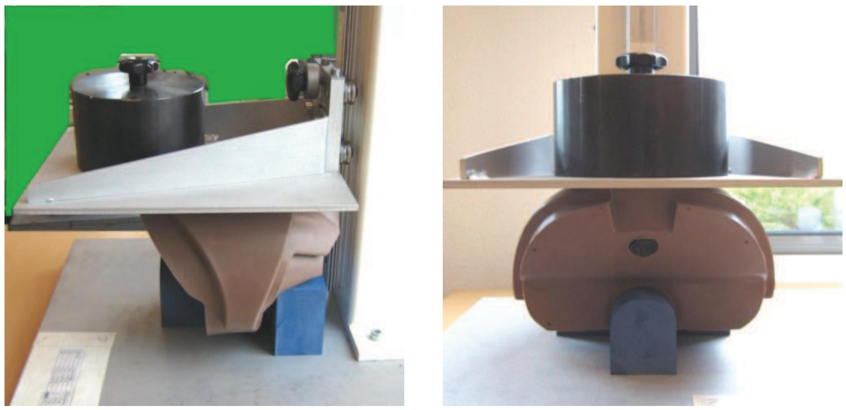


Figure 51: Abdomen certification test setup

4.6.7 Pelvis (lateral impact)

For the pelvis certification a full body lateral impact test should be done with a six wire suspended pendulum (mass of 8.76 kg and a diameter of 112 mm). The pendulum speed should be between 4.2 and 4.4 m/s. The impact should be pure lateral with the pendulum aligned with the hip joint (65.9 mm above the seating plane and 90.4 mm forward of the back plane). The dummy should be sitting with the thoracic spine vertical, the upper arms along the thorax with the hands on the lap and the legs stretched forward on two sheets of PTFE (Teflon) to minimize the friction. In the tests the pendulum acceleration (CFC180) and the pubic symphysis load (CFC600) should be recorded.

5 Conclusions and Recommendations

The Q10 dummy was extensively evaluated on biomechanical performance, sensitivity, repeatability and durability to impact loading in head drop, neck pendulum and full body wire pendulum tests. Moreover certification procedures were developed.

5.1 Anthropometry

The dummy drawing dimensions are in compliance with the requirements. Measurements on the actual dummy should be taken to confirm the compliance of the hardware. The Mass of several parts has to be tuned in the final design. This is the case for the upper and lower arm as well as the pelvis and lower leg.

5.2 Biofidelity

For frontal loading conditions it can be stated that the dummy correlates well with biomechanical targets specified in the Q10 design brief. It is recommended to increase the impact stiffness of the head to perform close to the middle of the corridor. For the neck it is recommended to modify the mould such that its stiffness increase in flexion occurs earlier (now at 45 degrees where is should be at 30 to 35 degrees).

For lateral impacts the dummy shows a response which is initially too stiff and at later stages too soft relative to side impact biofidelity corridors. Identical trends are found tough for shoulders, thorax and pelvis meaning that the load distribution over the dummy is such that none of the regions is overexposed in case of distributed side impact loading. It is recommended to reconsider the clearance between the hip joint hardware and the sacrum block to allow more freedom for the iliac wing to deform in side impact conditions.

5.3 Sensitivity

Sensitivity studies show obvious trends to variations in impact speeds, impact direction and alignments.

5.4 Repeatability

Repeated tests show generally small variations in response of less than 2.5%. Only the T1- acceleration in the lateral shoulder impact test and the pubic symphysis load in the lateral pelvis impact tests show larger variations: 3.2% and 4.6% respectively. All the coefficients of variation are with the required 5%. It is concluded that the Q10 dummy can be used as a repeatable tool.

5.5 Durability

The durability of the dummy meets requirements as specified. Separate reports describe the durability shown in sled tests according to UNECE R44 en NPACS in detail.

5.6 Certification

The certification procedures described in this report should be followed to obtain compatible dummy performance data. It is recommended to perform these dummy certification tests with a regular interval on each dummy. After collection of this test data from several dummies the certification corridors will be established.

Acknowledgements

The work described in this report was carried out by Humanetics Europe GmbH with the EPOCh consortium.

The authors and their organization would like to thank the European Commission for commissioning and funding the research in the EPOCh project.

The authors are grateful Marianne Hynd and Maria McGrath (TRL), Erik Salters (Dorel), Barbara Girard (University of Surrey) and Alejandro Longton (IDIADA) who contributed to the work and carried out the technical review of the report.

Glossary of Terms and Abbreviations

Anthropometry	Description of the human body in terms of external and internal dimensions as well as body segment mass distribution
Biofidelity	The level of humanlike behavior of a crash dummy under relevant impact conditions
CANDAT	Child ANthropometry DATabase developed by TNO in the early 90's of last century combining seven published anthropometry data sets as described in ref. [vii]
CRS	Child Restraint System
EEVC	European Enhanced Vehicle-safety Committee (www.eevc.org) This committee operates under the United Nation Economic Commission for Europe (UNECE) Work Party 29, Group Passive Safety (GRSP) based in Geneva, Switzerland.

References

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ii Waagmeester, C.D. et al. (2010), *Q10 dummy Development Status Review - Biofidelity Performance Validation*, Protection of Children in Cars Conference, Munich, December 2010.

iii Waagmeester, C.D. et al. (2009), *Q10 Design Brief*, European Commission, EPOCh Project, Work Package 1, Task 1.2, EPOCh Deliverable D1.2, September 15, 2009.

iv Reed, M.P., Sochor, M.M., Rupp, J.D., Klinich, K.D., Manary M.M. (2009), *Anthropometric Specification of Child Crash Dummy Pelves through Statistical Analysis of the Skeletal Geometry*, Journal of Biomechanics 42 (2009) 1143-1145.

v Wismans, J., Waagmeester, K., Claire, M. L., Hynd, D., Jager, K. de, Palisson, A., Ratingen, M. van and Trosseille, X. (2008), EEVC Working group 12 and 18, Document number 514, *Q-dummies Report, Advanced Child Dummies and Injury Criteria for Frontal Impact*, April 2008.
(available from the EEVC website: http://eevc.org/publicdocs/publicdocs.htm)

vi Waagmeester, C.D. and Been, B.W. (2009), *Single rib and 2D rib deflection sensor drop table impact tests; sensitivity to impact load and impact direction*, APROSYS project Deliverable D528, Document AP-SP52-0058, February 04, 2009.

vii Twisk, D. and Beusenberg, M.C. (1993), *Anthropometry of Children for Dummy Design*, ECOSA Product Safety Research Conference, Amsterdam, The Netherlands 1993.

ANNEX E: Q-DUMMY MEASUREMENT CAPABILITIES

This Annex gives an overview of the set of instrumentation and measurement channels per body segment forth the Q10 dummy. The type of accelerometers, angular velocity sensors and load cells are generally interchangeable for all Q-dummies except the Q10 Neck and Lumbar Spine Load Cell. Channel count per region is given in Table 14. The specification per type of sensor is shown in Figure 51 Table 15. Special mounts are available to mount the instrumentation on the dummy.

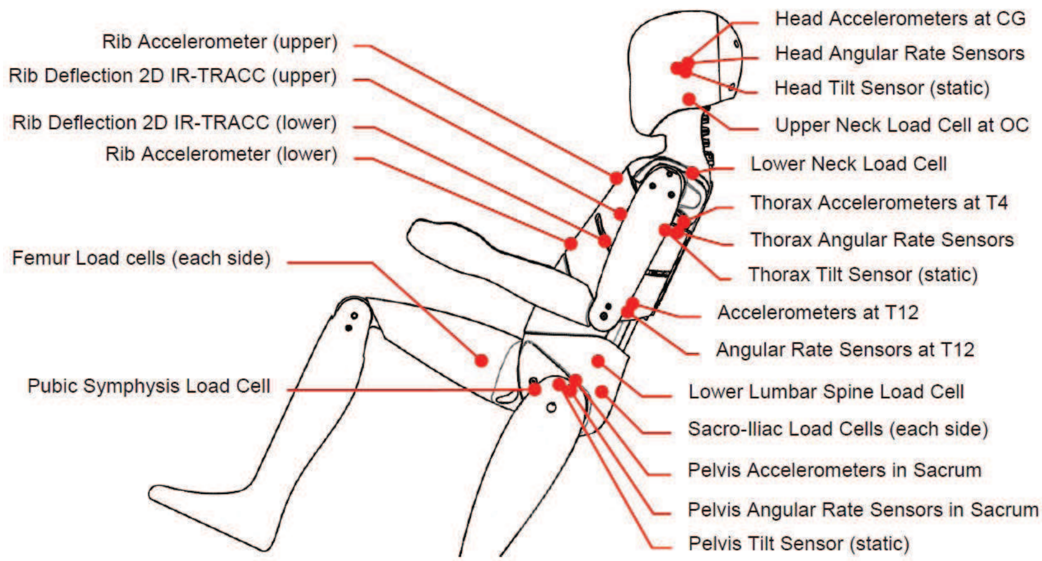


Figure 51: Q10 Overview of instrumentation options

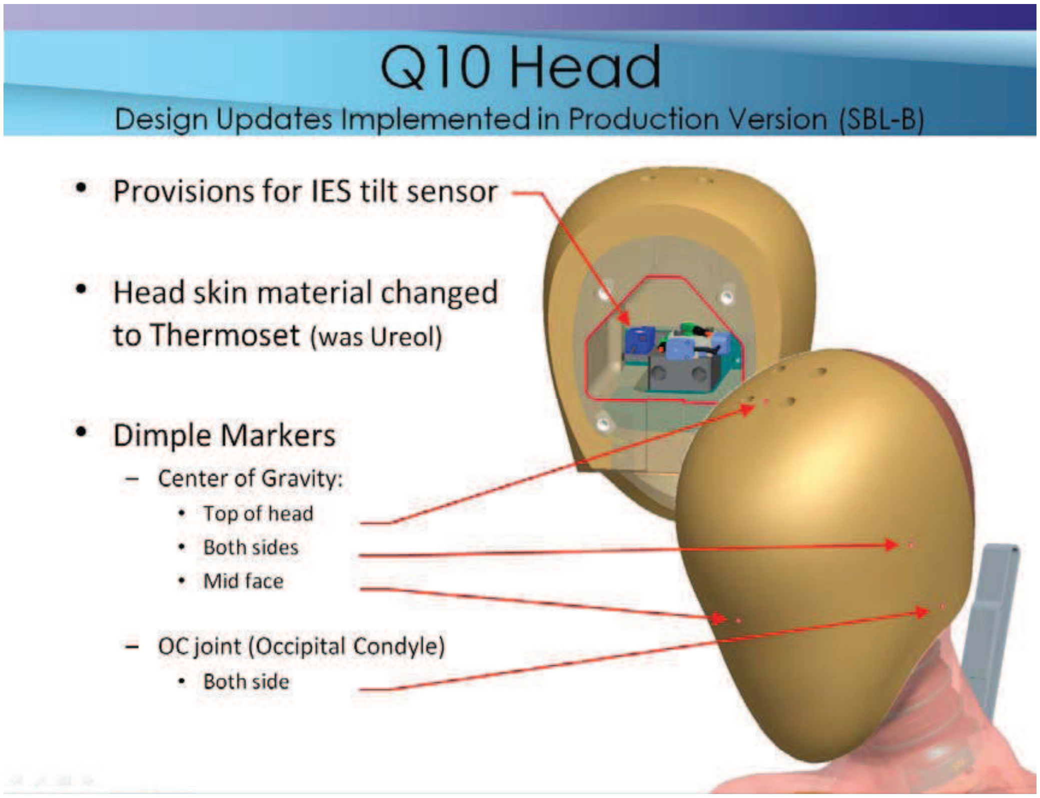
Table 14: Q10 dummy instrumentation and measurement channels per body segment.

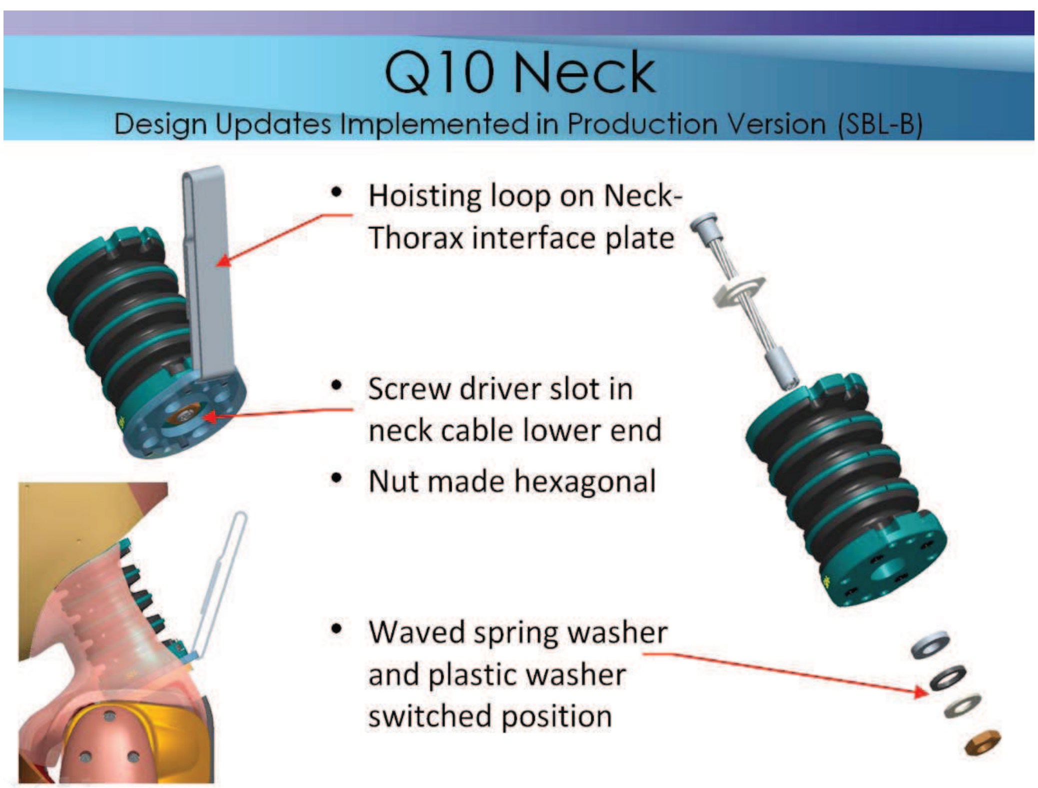
	Body segment	Instrumentation	Direction	# of channels
Q10 dummy			**Total**	**44 + (24)**
	Head	accelerometers angular velocity sensors	Ax, Ay, Az Wx, Wy, Wz	3 3
	Neck	load cell (upper neck) load cell (lower neck)	Fx, Fy, Fz, Mx, My, Mz Fx, Fy, Fz, Mx, My, Mz	6 6
	Thorax	T1 accelerometer T4 accelerometers T4 angular velocity sensors T12 accelerometers 2D-IR-TRACC (upper) 2D-IR-TRACC (lower)	Ay Ax, Ay, Az Wx, Wy, Wz Ax, Ay Dx and ϕz Dx and ϕz	1 3 3 2 2 2
	Lumbar spine	load cell	Fx, Fy, Fz, Mx, My, Mz	6
	Pelvis	accelerometers angular velocity sensors pubic symphysis load sacro-iliac load cells (to be designed, provisions only)	Ax, Ay, Az Wx, Wy, Wz Fy (side impact) Fx, Fy, Fz, Mx, My, Mz	3 3 1 (2 x 6)
	Abdomen	Twin pressure		
	Upper leg	femur load cell (to be designed, provisions only)	Fx, Fy, Fz, Mx, My, Mz	(2 x 6)

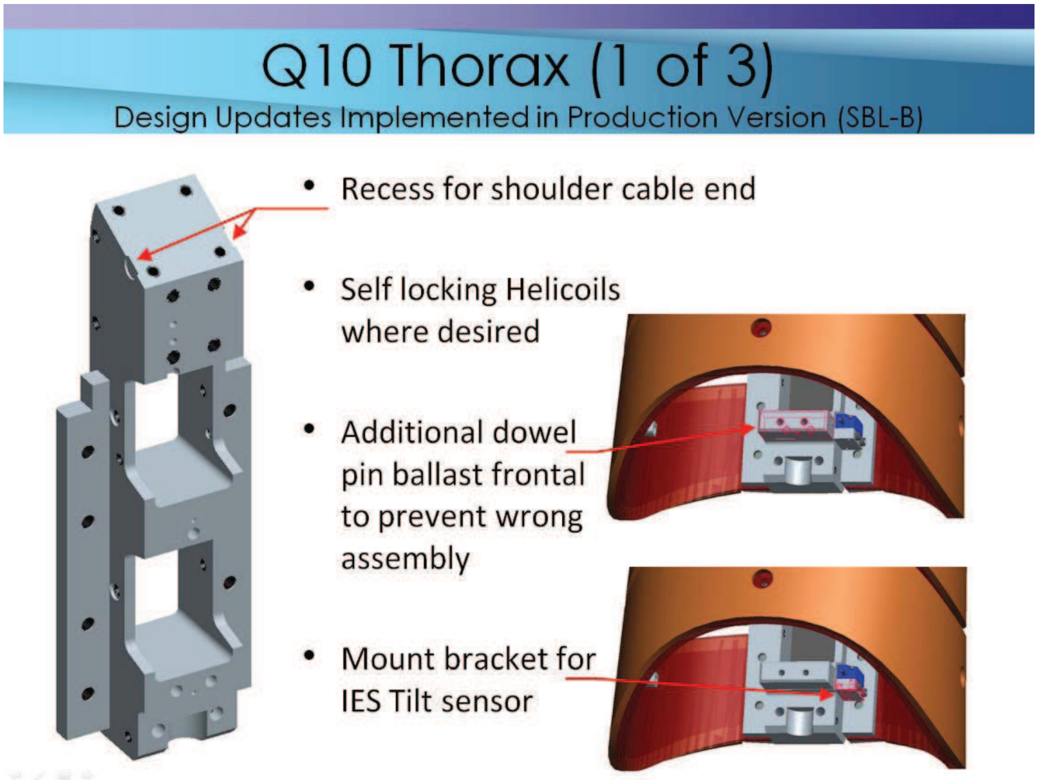
Table 15: Specification per type of sensor.

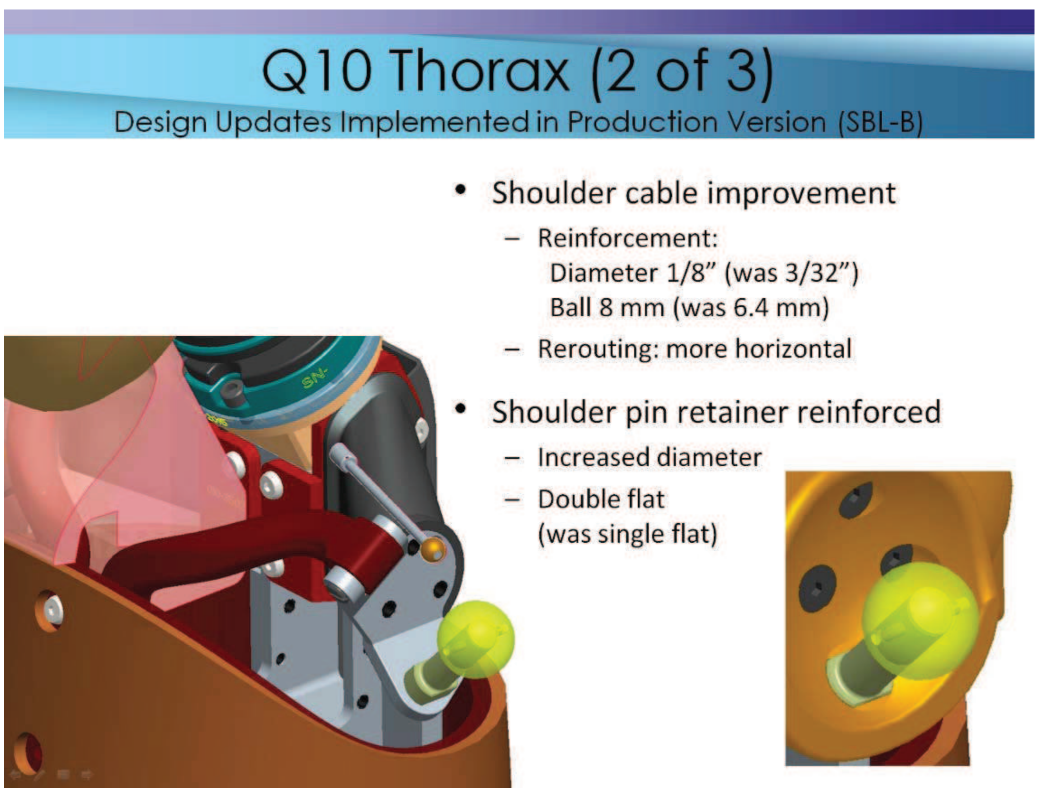
Sensor type	Manufacturer	Specification
Accelerometers	ENTRAN	EGAS-FS-50
	KYOWA	ASM-200BA
	ENDEVCO	7267A-1500 (not in head) 7264-2000 7264C-2000 7264A-2000 7264B-2000
	MSC	126M/CM
Angular velocity sensors	DTS	DTS ARS-12K
Displacement sensors	Humanetics	2D-IR-TRACC IF-372
Load cells	Humanetics	IF-217-HC (350 Ohm)

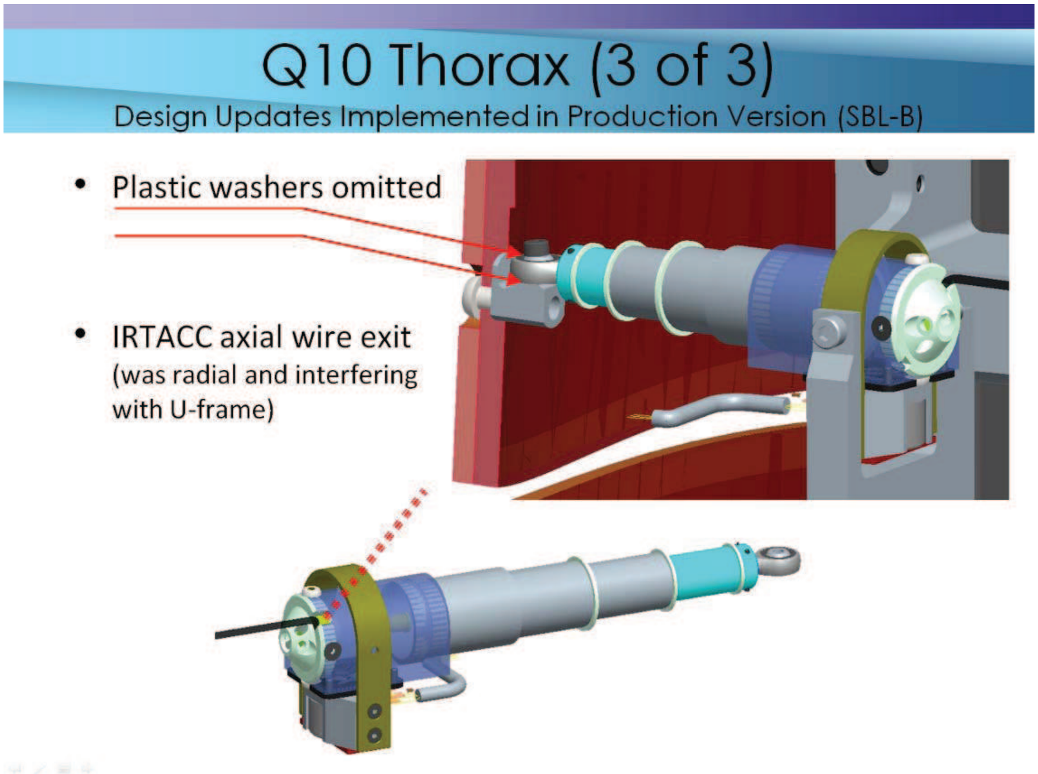
ANNEX F: UPDATES FROM PROTOTYPE TO PRODUCTION VERSION

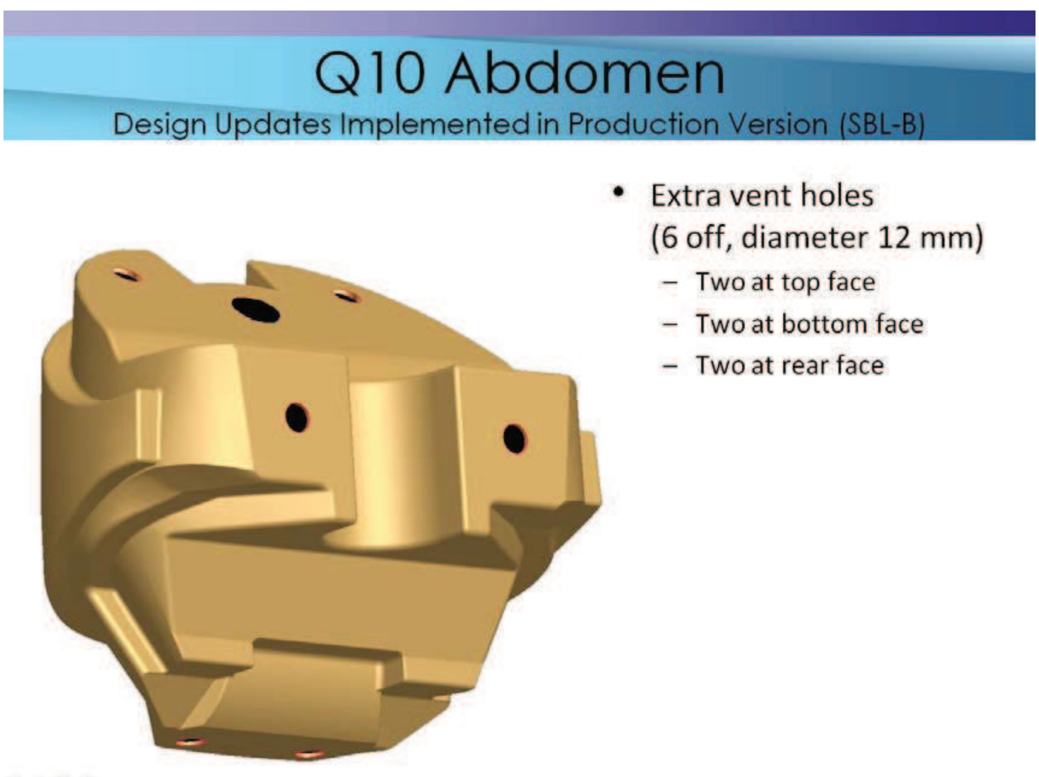


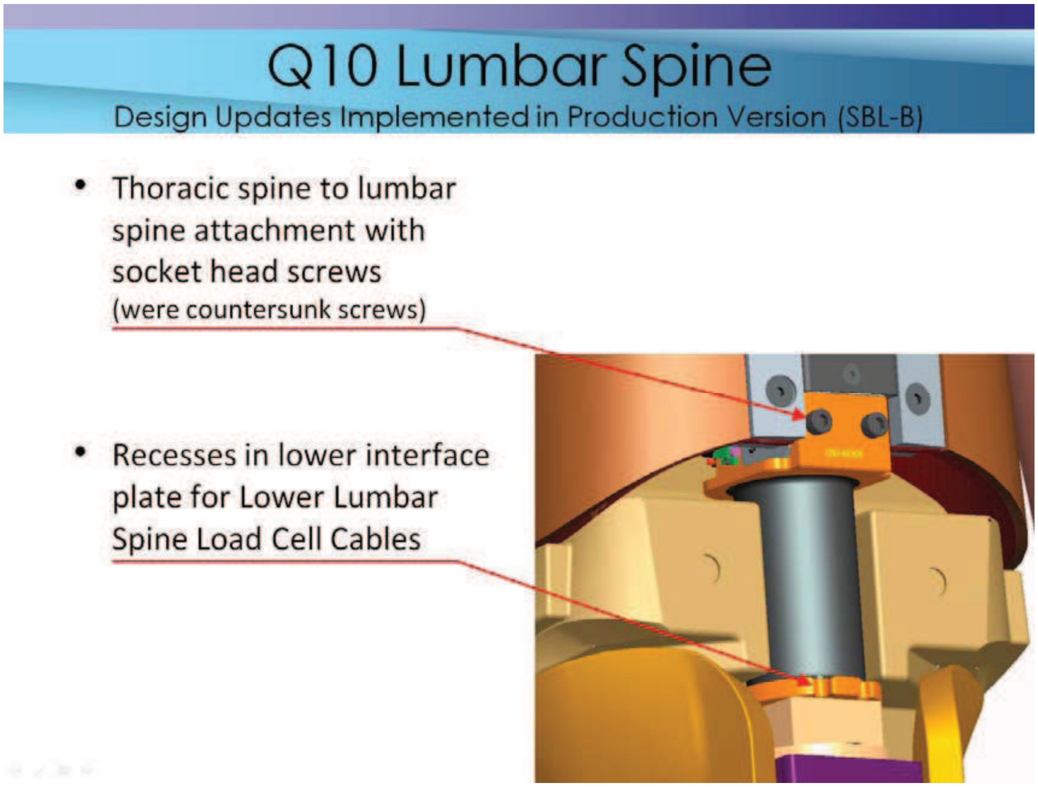


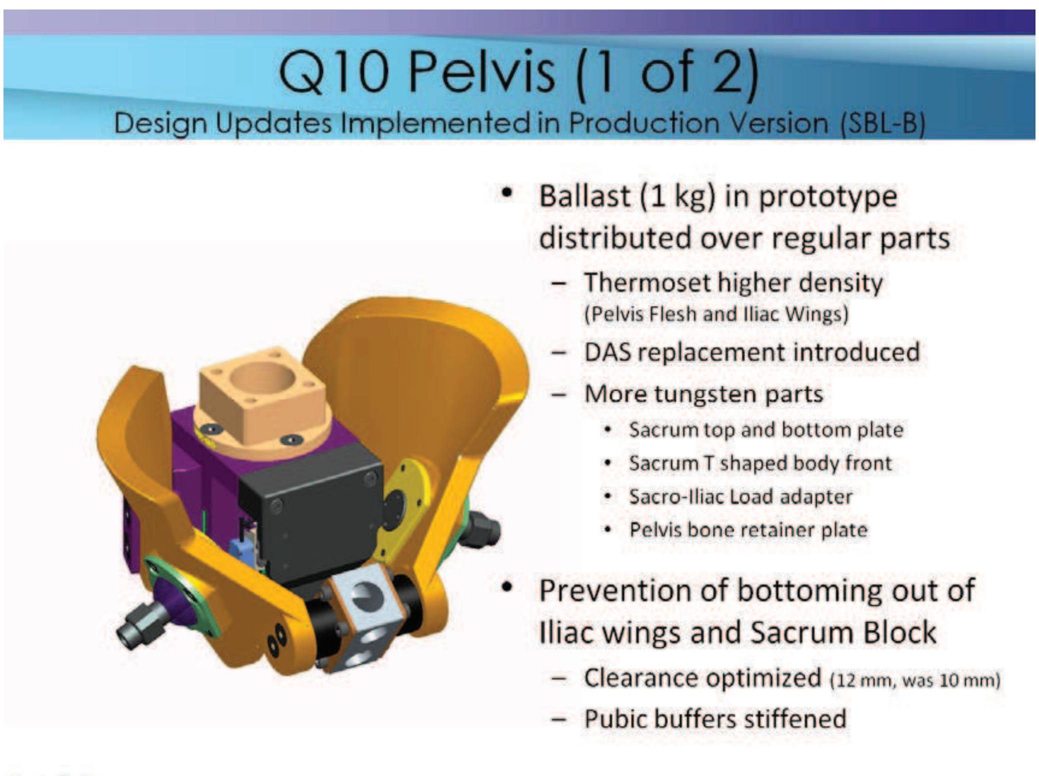

Q10 Thorax (1 of 3)
Design Updates Implemented in Production Version (SBL-B)
• Recess for shoulder cable end
• Self locking Helicoils where desired
• Additional dowel pin ballast frontal to prevent wrong assembly
• Mount bracket for IES Tilt sensor

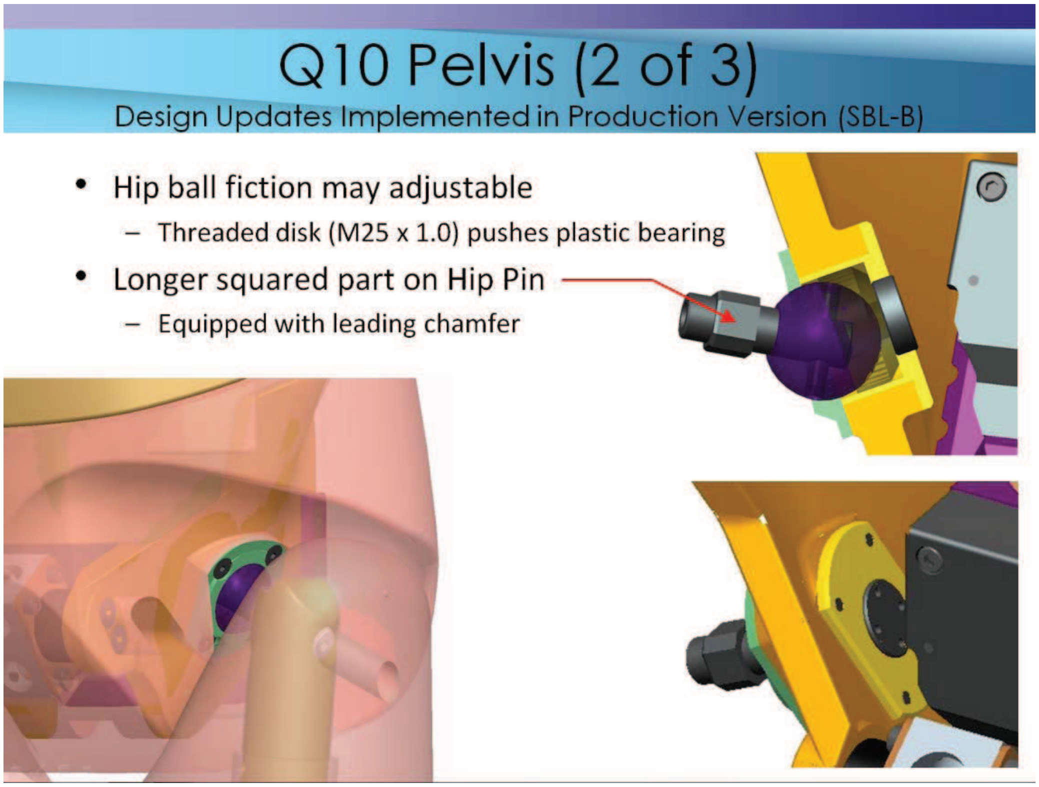

Q10 Thorax (2 of 3)
Design Updates Implemented in Production Version (SBL-B)
• Shoulder cable improvement
– Reinforcement:
Diameter 1/8” (was 3/32”)
Ball 8 mm (was 6.4 mm)
– Rerouting: more horizontal
• Shoulder pin retainer reinforced
– Increased diameter
– Double flat (was single flat)

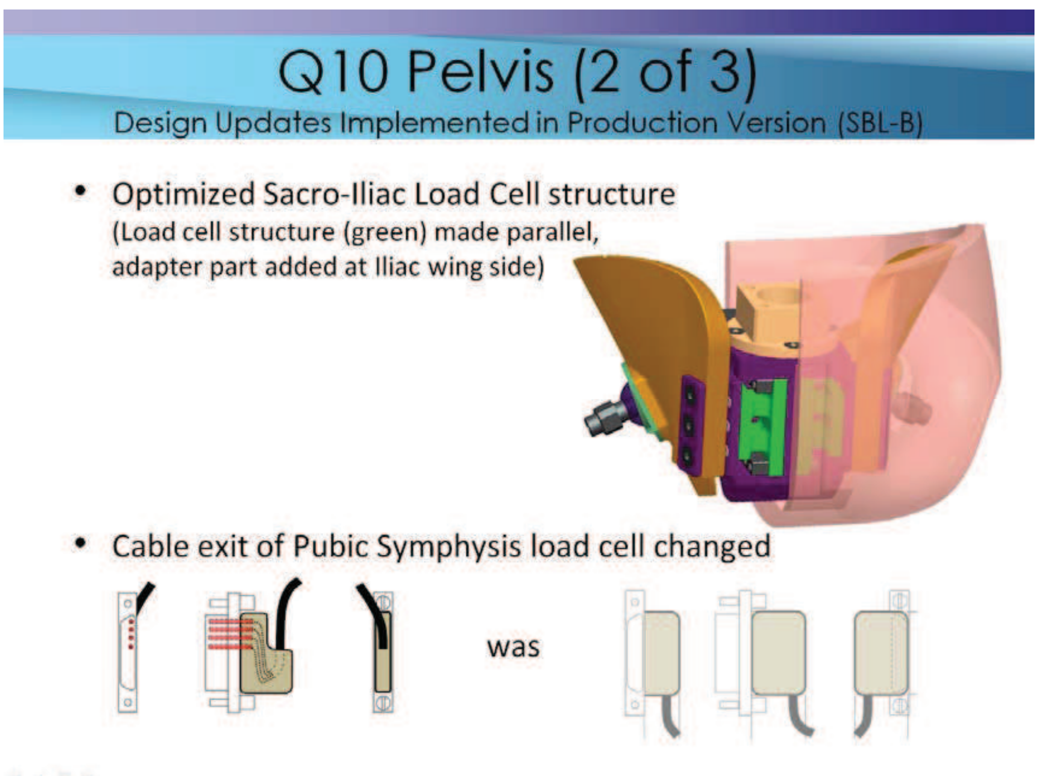

Q10 Thorax (3 of 3)
Design Updates Implemented in Production Version (SBL-B)
• Plastic washers omitted
• IRTACC axial wire exit
(was radial and interfering
with U-frame)

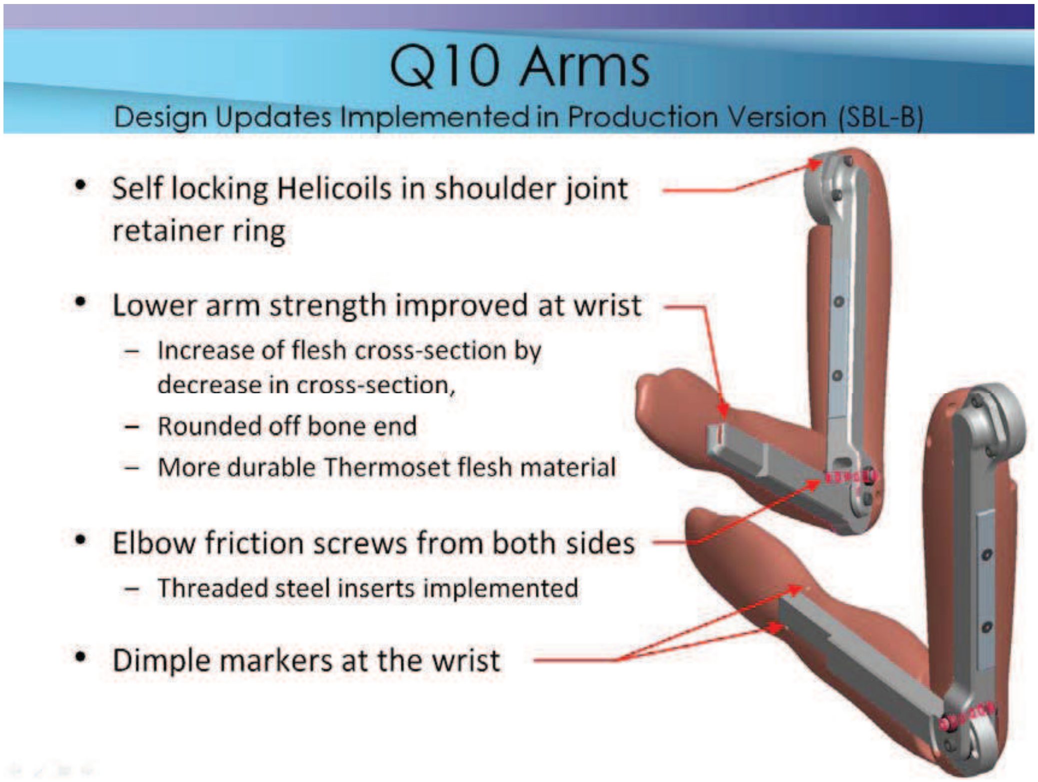

Q10 Abdomen
Design Updates Implemented in Production Version (SBL-B)
• Extra vent holes
(6 off, diameter 12 mm)
– Two at top face
– Two at bottom face
– Two at rear face

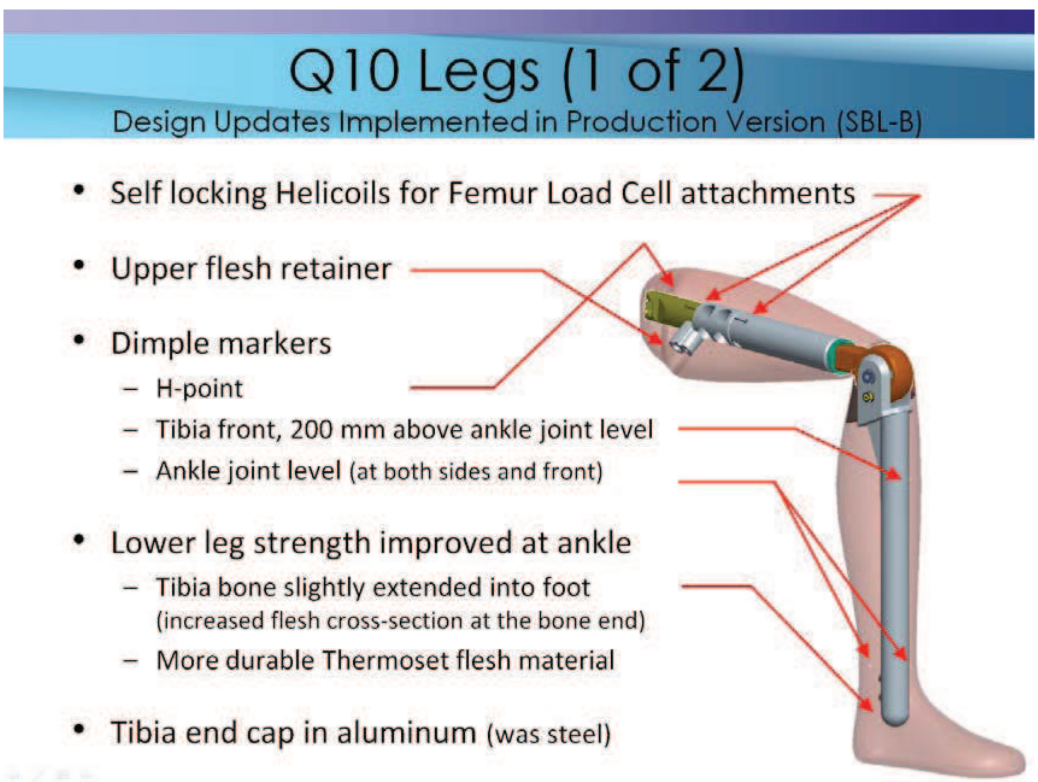

Q10 Lumbar Spine
Design Updates Implemented in Production Version (SBL-B)
• Thoracic spine to lumbar spine attachment with socket head screws
(were countersunk screws)
• Recesses in lower interface plate for Lower Lumbar Spine Load Cell Cables

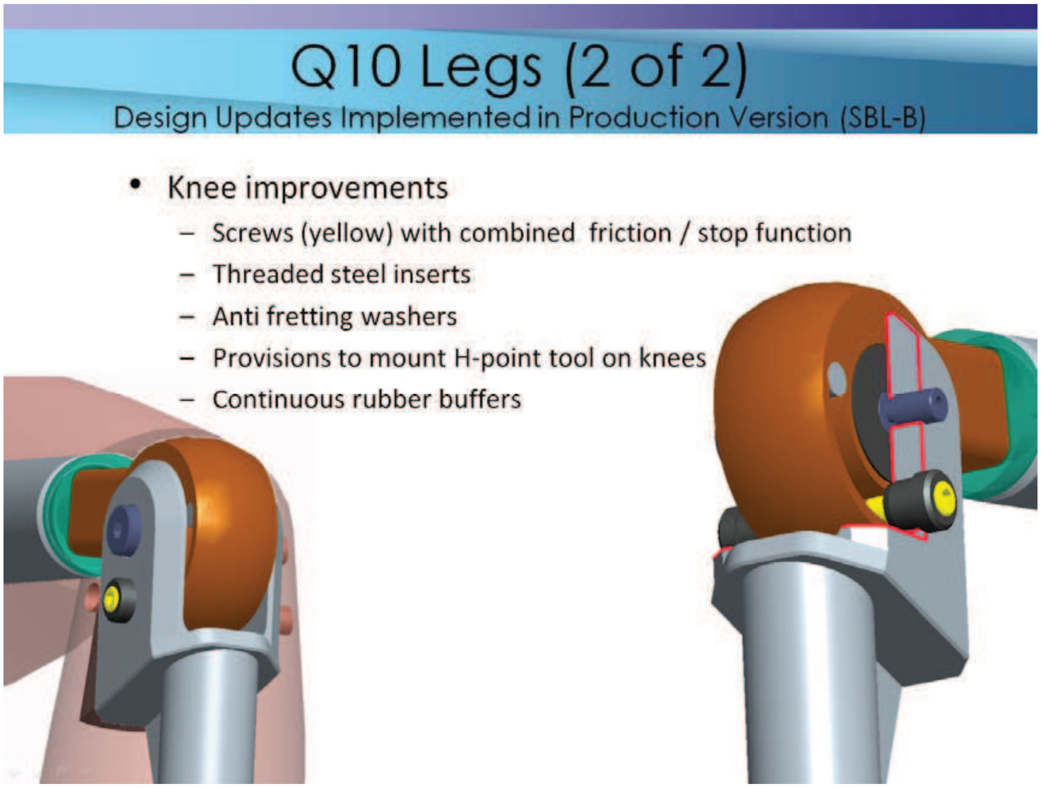

Q10 Pelvis (1 of 2)
Design Updates Implemented in Production Version (SBL-B)
• Ballast (1 kg) in prototype distributed over regular parts
– Thermoset higher density
(Pelvis Flesh and Iliac Wings)
– DAS replacement introduced
– More tungsten parts
• Sacrum top and bottom plate
• Sacrum T shaped body front
• Sacro-Iliac Load adapter
• Pelvis bone retainer plate
• Prevention of bottoming out of Iliac wings and Sacrum Block
– Clearance optimized (12 mm, was 10 mm)
– Pubic buffers stiffened

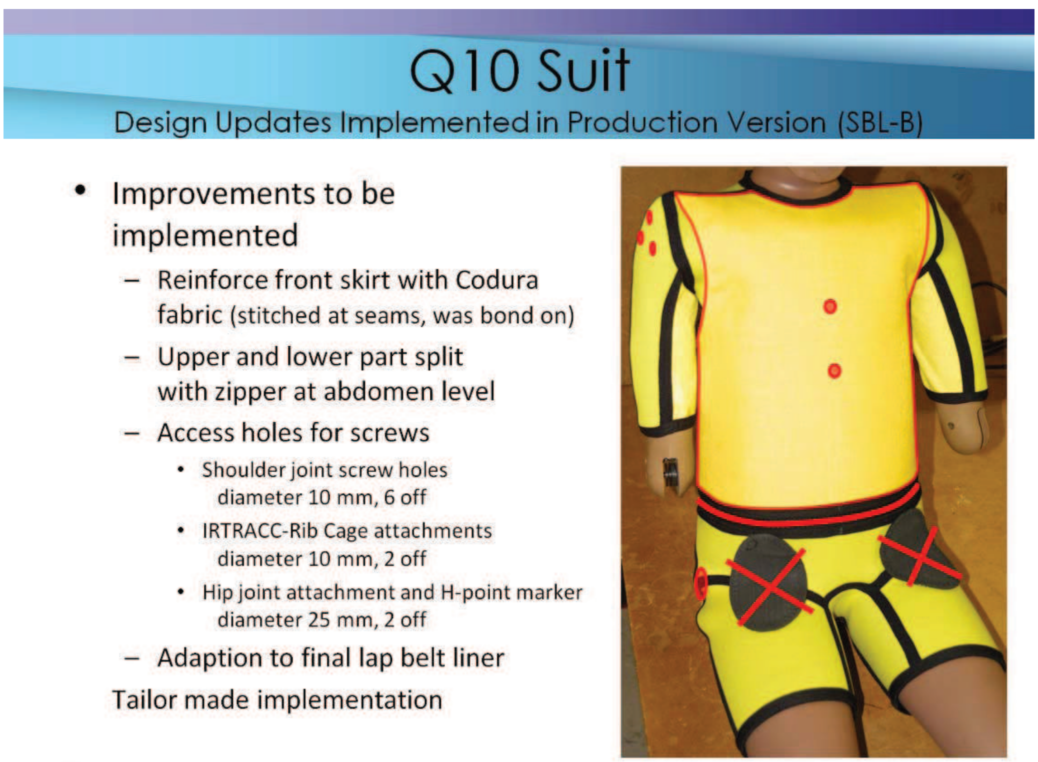

Q10 Pelvis (2 of 3)
Design Updates Implemented in Production Version (SBL-B)
Hip ball fiction may adjustable
– Threaded disk (M25 x 1.0) pushes plastic bearing
Longer squared part on Hip Pin
– Equipped with leading chamfer


Q10 Pelvis (2 of 3)
Design Updates Implemented in Production Version (SBL-B)
Optimized Sacro-Iliac Load Cell structure
(Load cell structure (green) made parallel, adapter part added at Iliac wing side)
Cable exit of Pubic Symphysis load cell changed
was


Q10 Arms
Design Updates Implemented in Production Version (SBL-B)
• Self locking Helicoils in shoulder joint retainer ring
• Lower arm strength improved at wrist
– Increase of flesh cross-section by decrease in cross-section,
– Rounded off bone end
– More durable Thermoset flesh material
• Elbow friction screws from both sides
– Threaded steel inserts implemented
• Dimple markers at the wrist


Q10 Legs (1 of 2)
Design Updates Implemented in Production Version (SBL-B)
• Self locking Helicoils for Femur Load Cell attachments
• Upper flesh retainer
• Dimple markers
– H-point
– Tibia front, 200 mm above ankle joint level
– Ankle joint level (at both sides and front)
• Lower leg strength improved at ankle
– Tibia bone slightly extended into foot (increased flesh cross-section at the bone end)
– More durable Thermoset flesh material
• Tibia end cap in aluminum (was steel)


Q10 Legs (2 of 2)
Design Updates Implemented in Production Version (SBL-B)
• Knee improvements
– Screws (yellow) with combined friction / stop function
– Threaded steel inserts
– Anti fretting washers
– Provisions to mount H-point tool on knees
– Continuous rubber buffers


Q10 Suit
Design Updates Implemented in Production Version (SBL-B)
• Improvements to be implemented
– Reinforce front skirt with Codura fabric (stitched at seams, was bond on)
– Upper and lower part split with zipper at abdomen level
– Access holes for screws
• Shoulder joint screw holes diameter 10 mm, 6 off
• IRTRACC-Rib Cage attachments diameter 10 mm, 2 off
• Hip joint attachment and H-point marker diameter 25 mm, 2 off
– Adaption to final lap belt liner
Tailor made implementation

ANNEX G: EPOCh EVALUATION TESTS

EPOCh Deliverable D3.2

Q10 Dummy as a tool for UN Reg.44

This deliverable is published December 08, 2011

128 pages

Enabling Protection for Older Children

SEVENTH FRAMEWORK PROGRAMME
THEME 7
Transport (including AERONAUTICS)

SEVENTH FRAMEWORK PROGRAMME

EPOCh 218744

FINAL PROJECT REPORT

Work Package 3
Task 3.2

Q10 Dummy as a tool for UNECE Reg.44

by M Pitcher (TRL), E Salters (Dorel), M Hynd (TRL), J Carroll (TRL), J Onyekwere (TRL)

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FINAL PROJECT REPORT

Q10 Dummy as a tool for UNECE Reg.44

By M Pitcher (TRL), E Salters (Dorel), M Hynd (TRL), J Carroll (TRL), J Onyekwere (TRL)

	Name	Date Approved
Administrative coordinator	Maria McGrath	08/12/2011
Technical coordinator	Marianne Hynd	08/12/2011

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Executive summary

The objective of Task 3.2 was to assess the ability of the Q10 dummy as a measurement tool for the UNECE Reg.44. A test programme matrix was defined, which contributed to Task 1.2, which specified requirements for the Q10 dummy capability. The capability of the prototype Q10 dummy was physically assessed in the test program according to the test matrices specified.

Two prototype Q10 dummies were assessed. One prototype Q10 was assessed by Dorel, in 65 UNECE Reg.44 front impact tests and the other was assessed by TRL in 50 UNECE Reg.44 dynamic tests.

The testing at DOREL was split into three phases:

- Investigating the sensitivity of the Q10 dummy to restraint loading from variations in test setup
- Investigating the sensitivity of the dummy to differences in child restraint design
- Investigating the durability of the Q10

The testing at TRL compared the performance of the Q10 with the P10.

The main aims were as follows:

- To assess whether the Q10 dummy measures as expected for the type of impact test. This was achieved by relating the loading measured by the Q10 to the kinematics of the dummy.
- To assess whether the dummy can detect differences in loading when the test set-up is varied.
- To investigate if the Q10 dummy is capable of picking up differences in child restraint design. The kinematics of the dummy and the measured loading were assessed.
- The research objective of the durability testing was to evaluate how many tests the Q10 dummy could withstand before breakages occurred. This study included monitoring the dummy maintenance, reporting how frequently they were conducted during the test programme. Comparisons were made to the maintenance of the P10 in UNECE Reg.44 testing.
- The aims of the comparison of the Q10 and the P10 were to assess their equivalence under Reg.44 test conditions and to suggest how the Reg.44 limits may need to be adjusted to maintain the status-quo with child car seats approved to the Regulation. The kinematics and the measured loadings were compared.

The team also investigated the ability of the dummy to recover between tests.

It was concluded that the Q10 is durable in the Reg.44 front impact tests. The Q10 measures loading as expected related to its kinematic behaviour. The component testing in task 2.3 showed that the Q10 is capable of producing repeatable results and this was borne out further in the results of the sled testing. The dummy can differentiate between different child restraint designs of the same type.

Comparison with the P10 showed that the kinematics of the Q10 is significantly different. The sophisticated thorax and shoulder design of the Q10 allows it to interact with the adult belt and achieves a more realistic restraint, unlike the P dummy, which slides out of the belt. This resulted in a difference in measured loading between the two dummies. Therefore revised limits were proposed for the Q10, for use in Reg.44 testing.

1 Introduction

The aim of Work package 3 was to assess the development of the dummy relating specifically to its ability to be used as a measurement device in test procedures. This document reports on task 3.2, the Q10 dummy requirements and its capability as a measurement tool for use in UNECE Reg.44 testing.

The approach taken in task 3.2 was to define test matrices for the dummy evaluation and to assess, dynamically, the dummy capability for use in the UNECE Regulation 44 (Reg.44) procedure. This included following the analysis through to the development of a proposal to expand the Reg.44 assessment criteria, to allow for the use of the new dummy in regulatory type testing.

The activities within this task will provide an insight and evidence to assist the future development of the Reg.44 and prove useful to the Q series dummy users.

2 Objectives

The objectives for this work package, as identified in the DoW document, are as follows:

1. Develop test matrices to assess performance of prototype for Reg.44 tests
2. Physical assessment of the prototype Q10 dummy for Reg.44 tests to include restraint loading, durability and sensitivity to child restraint design and recommendations for assessment of submarining behaviour (up to 114 assessment tests)[1]
3. Comparison of P10 and the new Q10 dummy during Reg.44 testing

2.1 Sensitivity

The first part of this task examined what is termed as dummy 'sensitivity'; in this instance sensitivity is defined as how the data recorded by the dummy can be influenced by different testing variables. There are a number of these variables that can influence how forces and accelerations differ between tests. These include: the type of seat being tested (booster seat-booster cushion), the quality of production of the seat being tested, the way in which a seat is installed on the test bench and the method of collecting data during the tests.

Testing completed by Dorel looked to establish how changes in these conditions influence the dummy results gained from each test. The first phase of testing investigated the sensitivity of the Q10 to restraint loading. In these tests the affect of variation in test set-up on the results, measured by the Q10, was investigated.

In the second phase a range of different child restraint designs were tested using the Q10. The different child restraints represented the range of child restraints currently available on the market. The Q10 should therefore be able to detect differences in measured loading.

Further details on the changes made to assess the Q10 dummy's sensitivity can be found in Sections 4.1 and 4.2 of this report.

[1] Assessment submarining behaviour was completed in this task, however the analysis and reporting of this data is reported in Task 2.4

2.2 Durability

A major factor in assessing the Q10 dummy was to establish whether the dummy was capable of performing in place of the P10 during a routine “Technical Service’s” Reg.44 assessment.

Due to the nature of dynamic testing, a dummy is required to undergo a number of impacts. Over time, impact testing can therefore cause significant damage to the dummy, or result in the dummy requiring maintenance or recalibration. During regular use, as a test house tool, a dummy is expected to last for at least 70 to 100 Regulatory type tests before parts may need replacing. The P-series dummy needs minimal maintenance. It is recommended that the neck is recertified after 10 tests; however recalibration only tends to be required at every other recertification. These adjustments follow a very simple procedure and can be made through adjustment of the neck cables (locally). All these factors must be a consideration when looking at the possibility of changing the main measuring instrument of a Reg.44 certification test.

As part of this task, Dorel conducted 40 dynamic tests with the specific aim of assessing durability of the Q10 dummy. However, all tests within this task have also noted any durability issues that were discovered during the course of testing. These issues have been collated in Appendix E and will be discussed under the durability Section 5.4.

2.3 Comparison of P10 and Q10

The work within Task 3.2 required the assessment of Q10 and P10 dummies to explore the differences in dummy behaviour and measurements under Reg.44 testing conditions. This included comparing the kinematics of each dummy in a number of booster seats and booster cushions.

The appropriateness of applying the current P10 Reg.44 limits to the Q10 was investigated. Revised limits for the Q10 were calculated where a significant performance difference was found, between the two dummies.

In addition to comparing Q series and P series dummies, a Hybrid III 10yr old dummy was included and tested for comparison. This was not part of the original task outline; however it was felt necessary to add this condition when developing the test methodology, to provide a more comprehensive picture of the dummies available. The Hybrid III dummy is accepted, in the USA FMVSS 213, as a standard impact testing measurement tool, and is reported to be more biofidelic that the current P series design.

2.4 Submarining

The aims of this task included the assessment of submarining behaviour during Reg.44 tests; this analysis was carried out by the University of Surrey. The data collected will be fully reported as part of Task 2.4. However, some of the qualitative observations made during dynamic testing are noted in this report (Section 7.3).

3 The Approach

This section outlines the approach used to assess the Q10 dummy as a measurement tool for use in UNECE Reg.44 type approvals.

In total 114 front impact tests were conducted during Task 3.2 of the EPOCh project.

These included:

- **50 tests** comparing the dynamic performance of the Q10 and the P10 dummies;
    - 4 of these tests were conducted to provide data on Hybrid III dynamic performance under the same test conditions;
- **12 tests** investigating the sensitivity of the dummy to the differing restraint design;
- **12 tests** investigating the sensitivity of the dummy to variation in test setup;
- **40 tests** investigating the durability of the Q10 during ECE Reg.44 tests

Further details on the exact changes in test setup for sensitivity testing can be found in Section 4.1 of this report. All dynamic testing conditions during the examination of sensitivity of restraint design and durability testing were in compliance with the Reg.44 regulation.

Further information on the impact sleds used by TRL and Dorel can be found in Appendix A.

3.1 Test conditions

Unless otherwise stated, all the tests conducted during this testing series were set up and executed according to Reg.44. A summary of the test conditions is shown in Table 1.

Prior to each phase of testing a calibration test was conducted as per the requirements of Reg.44. This pulse had to meet the Reg.44 test conditions; stopping distance 650 ± 30 mm, pulse inside corridor (Figure 1).

Table 1: Test conditions for dynamic performance testing

Condition	Details
Test bench	Reg 44 test bench & specified cushions
Anchorages	Belt anchorages A, B_0, C Rearmost ISOFIX anchorages
Sled mass	Heavy sled to minimise dummy inertia effects on the pulse TRL - 1130 kg, DOREL – 752.5 kg
Test pulse	Reg 44 front impact pulse (see Figure 1)
Impact Speed	50 +0/-2 km/h
Test conditions	Pre-impact speed, stopping distance as specified in Reg 44 (650 ± 50 mm)
Set-up instrumentation	Sled Uni-axial accelerometers Seat belt force load cells located as prescribed in Reg.44

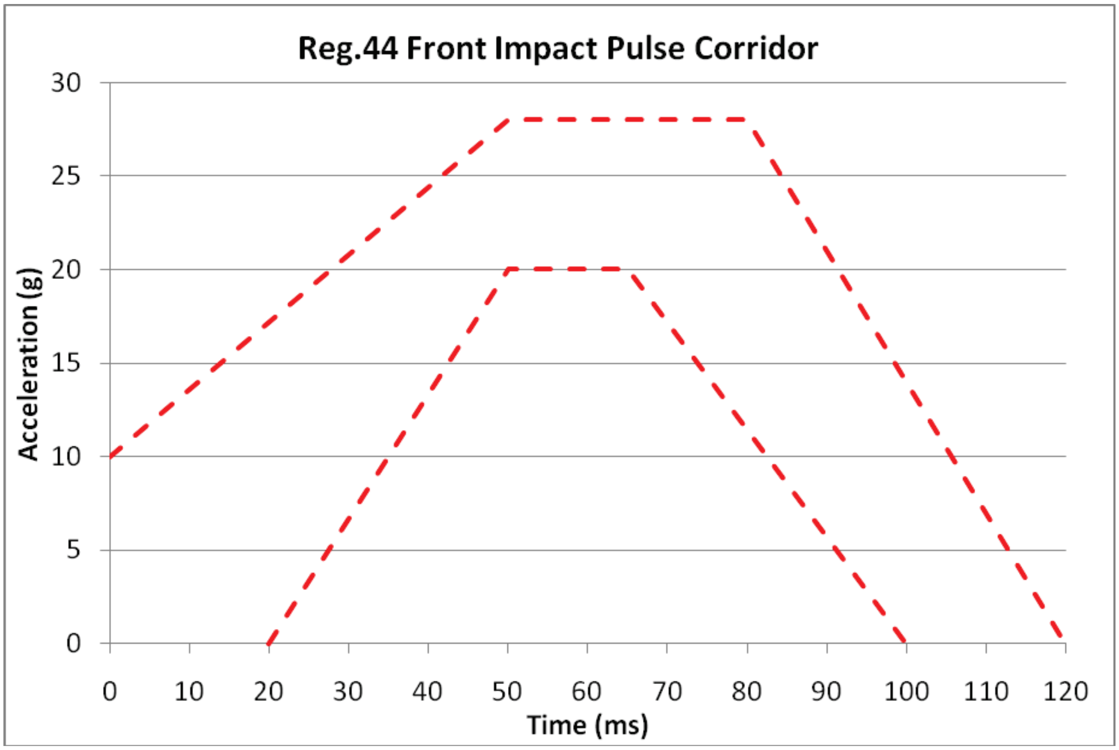

Figure 1: Front impact pulse corridor requirement – Reg.44

An example of the front impact test installation is shown in Figure 2.

Figure 2: Reg.44 testing apparatus

3.2 Dummy instrumentation

The Q10 dummy has the potential to measure 71 channels, if all instrumentation is installed on the dummy. Due to the current regulation requirements, it is expected that only a selection of these will be used, if the dummy is used in Reg.44 testing. A full list of the available Q10 dummy instrumentation used in the testing during this task is shown in Table 2. The full list of instrumentation used in the P10 dummy is shown in Table 3.

Table 2: Q10 instrumentation[2]

Body part	Description	Channels	No. of channels	Dummy 1 (TRL)	Dummy 2 (DOREL)
Head	Accelerometers at CG	A_x, A_y, A_z	3	Y	Y
Head	Angular Rate Sensors	ω_x, ω_y, ω_z,	3		ω_y
Neck	Upper Neck Load Cell	F_x, F_y, F_z, M_x, M_y, M_z	6	Y	F_x, F_z, M_y
Neck	Lower Neck Load Cell	F_x, F_y, F_z, M_x, M_y, M_z	6	Y	F_x, F_z, M_y
Thorax	Accelerometers at T4	A_x, A_y, A_z	3	Y	Y
Thorax	Accelerometers on ribcage near IR-TRACC	2 x A_x or 2 x A_y	2	Y	
Thorax	Angular Rate Sensors	ω_x, ω_y, ω_z,	3	Y	ω_y, ω_z
Thorax	Rib Deflection through 2D IR-TRACC (2 off)	2 x D and ψ	4	Y	Y
Lumbar Spine	Accelerometers at T12	A_x, A_y	2	Y	
Lumbar Spine	Angular Rate Sensors at T12	ω_x, ω_y	2		
Pelvis	Accelerometers at CG	A_x, A_y, A_z	3	Y	Y
Pelvis	Angular Rate Sensors	ω_x, ω_y, ω_z	3	Y	ω_y, ω_z
Pelvis	Lower Lumbar Spine Load Cell	F_x, F_y, F_z, M_x, M_y, M_z	6	Y	F_x, F_z, M_y, M_z
Pelvis	Sacro-Iliac Load Cells (x2)	F_x, F_y, F_z, M_x, M_y, M_z	12		
Pelvis	Pubic Symphysis Load Cell	F_y	1		
Upper legs	Upper Femur Load Cells (x2)	F_x, F_y, F_z, M_x, M_y, M_z	12		
Total number of channels to be recorded during the test			71	41	28

[2] Channels that were available, but were not recorded by TRL or Dorel are highlighted in grey

Table 3: P10 instrumentation

Body part	Description	Channels	No. of channels	Dummy (TRL)
Head	Accelerometers at CG	A_x, A_y, A_z	3	Y
Thorax	Accelerometers at CG	A_x, A_y, A_z	3	Y
Abdomen	Clay insert	Visual Inspection	-	Y
Total number of channels to be recorded during the test			6	6

3.3 Child restraint and dummy installation

Pretesting installation trials with the child restraints were conducted to ensure that the height of the head pad and other adjustable functions of the child restraints were documented. These settings were then shared with all testing laboratories to improve consistency in child restraint set up and installation.

Target markers were placed on the dummies and child restraints to aid the submarining analysis of the test videos (for further information on submarining, D2.4). These are shown in Figure 3 and Figure 4. The exact positioning of these markers is documented in Appendix B.

Unless otherwise stated, the method prescribed in Reg.44 was used to install the child restraint and dummy to the test bench. The force load cells were placed in locations prescribed by Reg.44.

Measurements of the dummy position when installed in the child restraint were made prior to conducting each test to ensure the dummy installation was consistent for subsequent tests.

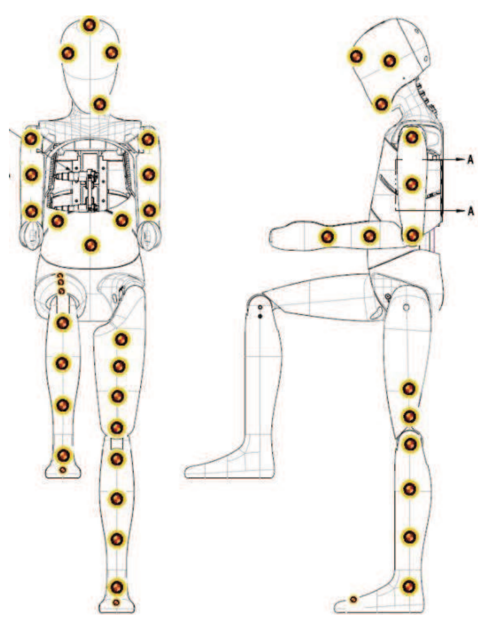

Figure 3: Targets placed on the dummies

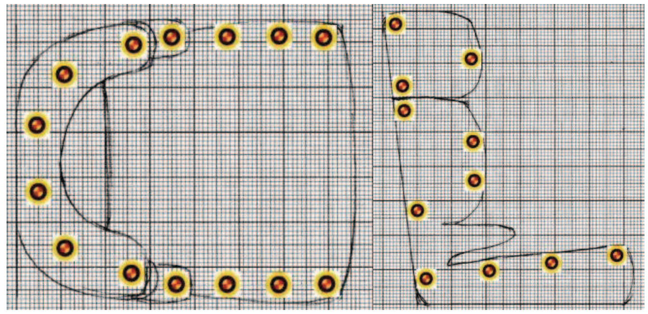

Figure 4: Targets placed on the child restraint system (CRS)

4 Test matrices

4.1 Sensitivity to Restraint Loading

12 tests were conducted to assess how the dummy would cope with the different loading conditions as a result of differences in setup of the dummy in the CRS. The CRS used was selected based on experience of its good reproducibility in Frontal R44 impact testing. These were tests numbered LSP10-5006 to LSP10-5017.

The setup of the dummy differed in the 3 factors;

1. with additional slack behind the Q10 (2 R44 spacers used)
2. with a 100 N force (instead of 50 N) on the vehicle belt
3. with the arms in a 45 degree downward angle.

During the restraint loading testing at Dorel the following behaviour was noted:

- The abdomen foam pops out of the chest cavity during the standard test.
- The lap belt section snags in the hip joint

These observations will be detailed and supported with measurements and time history diagrams in Section 5.2.

This information will be used to answer whether the Q10 dummy is capable of detecting differences in loading when tested to the controlled non standard installation of the Q10 dummy.

Table 4: Restraint loading test matrix

Series identifier	Test order			Set-up	Total No. of tests
1	5006	5009	5014	Baseline, Standard R44 installation, (50N belt tension , without spacer)	3
2	5007	5010	5014	Installation with additional spacer (50N belt tension)	3
3	5008	5011	5016	Installation with 100N belt tension (without spacer)	3
4	5013	5012	5017	Installation with different arm position	3
Total					**12**

All tests to be carried out using Seat 1

4.2 Sensitivity to different child restraint designs

12 tests have been conducted to assess if the dummy could distinguish the different loading conditions as a result of the different CRSs used. The child restraint systems were selected based on their ability to generate different dummy loadings. These were tests numbered LSP10-5018 to LSP10-5030. No other failure of dummy parts occurred during these tests.

During the testing the following behaviour was encountered;

- The diagonal belt was caught in the slit in the chest.
- The abdomen foam popped out of the chest cavity.
- The dummy suit tore at the armpits.

All three of these behaviour issues have been examined further in Section 5.1. This Section also discusses the design improvements that have been made to prevent this behaviour from occurring.

These observations will be detailed and supported with measurements, video analysis and time history diagrams in Section 5.3.

This information will be used to answer whether the Q10 dummy is capable of detecting differences in loading when tested in different child restraint designs.

Table 5: Test Matrix – Sensitivity to child restraint design

Series Identifier	**Test order**			**Set-up**	**Total No. of tests**
5	5018	5022	5026	Seat 7 Booster seat with head pad, side wings and additional attachments that connect to the ISOFix anchorages in a vehicle	3
6	5019	5023	5027	Seat 1 Booster seat with side wings and head pad	3
7	5024	5028	5030	Seat 4 Booster seat with small side wings and flexible head pad	3
8	5021	5025	5029	Cushion 1 Booster cushion	3
Total					**12**

Test LSP10-5020 was deemed not successful, as the installation of the child proved to be incorrect during the post test inspection. The test was been repeated and is shot number LSP11-5030.

4.3 Testing to explore Q10 Durability

A major factor in assessing the Q10 dummy was to establish whether the dummy was capable of performing in place of the P10 during a routine "Technical Service's" Reg.44 assessment.

Due to the nature of dynamic testing, a dummy is required to undergo a number of impacts. Over time, impact testing can therefore cause significant damage to the dummy, or result in the dummy requiring maintenance or recalibration. During regular use, as a test house tool, a dummy is expected to last for at least 70 to 100 Regulatory type tests before parts may need replacing.

The P-series dummy needs minimal maintenance. It is recommended that the neck is recertified after 10 tests; however recalibration only tends to be required at every other recertification. These adjustments follow a very simple procedure and can be made through adjustment of the neck cables (locally). All these factors must be a consideration when looking at the possibility of changing the main measuring instrument of a Reg.44 certification test.

During these tests, the retainer of the dummy clavicle partly broke. This was noted between tests 0211 and 0219. The part still functioned well enough to transmit pushing forces and shearing forces from the chest to the collar bone. The material of this part was found to have insufficient strength. Therefore the part was remade using a stronger material. This new material was used in all subsequent tests and no further failures of this part occurred.

Dorel conducted 40 dynamic tests with the specific aim of assessing durability of the Q10 dummy. Whilst carrying out this assessment, some smaller studies were carried out for interest. The durability test programme was split into three different studies of tests. These were as follows:

- Study 1; tests 0204 to 0222 = durability across a range of child restraints.
- Study 2; tests 0223 to 0234 = time taken for Q dummy to recover between tests
- Study 3; tests 0236 to 0243 = further assessment of dummy sensitivity to positioning

Study 1; the durability tests with different child restraints were conducted to assess how the dummy would cope with the different loading conditions as a result of the different CRSs used. The child restraint systems were selected across the range available in the market.

Study 2; the time dependency testing was conducted to assess if care should be taken when running tests quickly after one another. In some labs the turnaround time between tests is as short as 20 to 30 minutes. Verification is needed to see if a drift in results occurs when the dummy is not given enough time to recover itself.

The analysis will include looking at the effects of reducing the recovery time of the Q10 between tests. It is expected that the variation in results may increase as the time between test decreases.

Study 3; the dummy positioning tests were conducted to assess if the dummy was sensitive to differences in dummy positioning. A test from the previous series was substituted into series 18, to compensate for an invalid test.

Table 6: Test Matrix – Durability

Series Identifier	Test order				Set-up	Total No. of tests
Study 1- Durability with different seats						
9	204	209	214	219	Seat 1 Booster seat, with side wings and head pad	4
10	205	210	215	231	Seat 2 Booster seat, flexible head pad	3
11	206	211	216	220	Seat 4 Booster seat, small side wings and flexible head pad	4
12	207	212	217	221	Cushion 1 Booster cushion, no side wings or head pad	4
13	208	213	218	222	Cushion 2 Booster cushion, no side wings or head pad	4
Study 2 - Durability time dependency testing						
14	223	227	231		Seat 2	3
15	224	228	232		Seat 2 Test conducted 45 minutes after previous test	3
16	225	229	233		Seat 2 Test conducted 30 minutes after previous test	3
17	226	230	234		Seat 2 Test conducted 15 minutes after previous test	3
Study 3 - Durability dummy positioning						
18	236	239	5024		Seat 4 Baseline	3
19	237	240	242		Seat 4 Slouched dummy	3
20	238	241	243		Seat 4 Extra belt slack	3
Total						**40**

For the Study 3 testing, a slouching spacer element was used to create a consistent slouching position of the Q10 dummy. This is shown in Figure 5. It is dimensioned at a thickness of 65 mm, close to twice the spacer described in R44 for regulatory testing. It has the ability to hinge in the middle to which allows removal sideways from behind the dummy once installed.

Figure 5: Seat with the slouching spacer in position

These observations will be detailed and supported with measurements, video analysis and time history diagrams in Section 5.4.

This information will be used to answer whether the Q10 dummy is durable enough to withstand repeated testing. The recovery time of the dummy will be analysed along with its sensitivity to installation in child restraints.

4.4 Comparison of P10 and Q10

Table 7 shows the matrix for the testing. Five booster seats and four booster cushions were used for the assessment. These child restraints were chosen to represent a cross-section of the current market, in terms of dynamic performance. They were also all child restraints that have been on the market for some time. This means that any real deficiencies in design would have been identified in real world accidents.

Three of the booster seats were assessed three times each, with the P10 and the Q10 dummies. Two of the booster seats were assessed twice each, with the P10, Q10 and Hybrid III 10 year old dummies.

Two of the booster cushions were tested twice each with the P10 and Q10 dummies. The other two booster cushions were tested three times with both the P10 dummy and the Q10 dummy.

Table 7: Comparison of P10 and Q10 test matrix

Series Identifier	Test Matrix Number			CRS	Dummy	Total No. of tests
Booster Seats						
1	1	2		**Seat 1**	P10	2
	3	4			Q10	2
	5	6			Hybrid III	2
2	13	14		**Seat 2**	P10	2
	15	16			Q10	2
	17	18			Hybrid III	2
3	7	8	9	**Seat 3**	P10	3
	10	11	12		Q10	3
4	19	20	21	**Seat 4**	P10	3
	22	23	24		Q10	3
5	25	26	27	**Seat 5**	P10	3
	28	29	30		Q10	3
Booster Cushions						
6	31	32		**Cushion 1**	P10	2
	33	34			Q10	2
7	35	36		**Cushion 2**	P10	2
	37	38			Q10	2
8	39	40	41	**Cushion 3**	P10	3
	42	43	44		Q10	3
9	45	46	47	**Cushion 4**	P10	3
	48	49	50		Q10	3

5 Q10 results discussion

5.1 General Observations

This section describes the general observations that were recorded during the testing with the Q10 dummy. Further explanation of these observations can be found in Appendix F.

5.1.1 Abdomen foam

During the restraint loading testing, the abdomen foam popped out from the thorax in a number of tests. This behaviour seemed to be sensitive to the relative angle of the chest to the pelvis. If this angle becomes too small, the abdomen will pop out (Figure 6).

In a later stage of the testing, it was noticed that the abdomen foam, during testing, was moving into and up in the thorax. Whereas in previous tests the abdomen foam was actually popping out of the thorax. Post test, the foam was found close to the lower IR-TRACC. It is possible that there was contact during the dynamic phase of the test. This could have led to artificial loading of the sensor.

Humanetics have examined this problem and believe it may be due to air inside the PVC skin bulging and pushing the abdomen out. To mitigate this event, the design of the abdomen insert will be refined to include air vents in the skin. It is expected that this will also prevent the abdomen insert from getting stuck under the thorax.

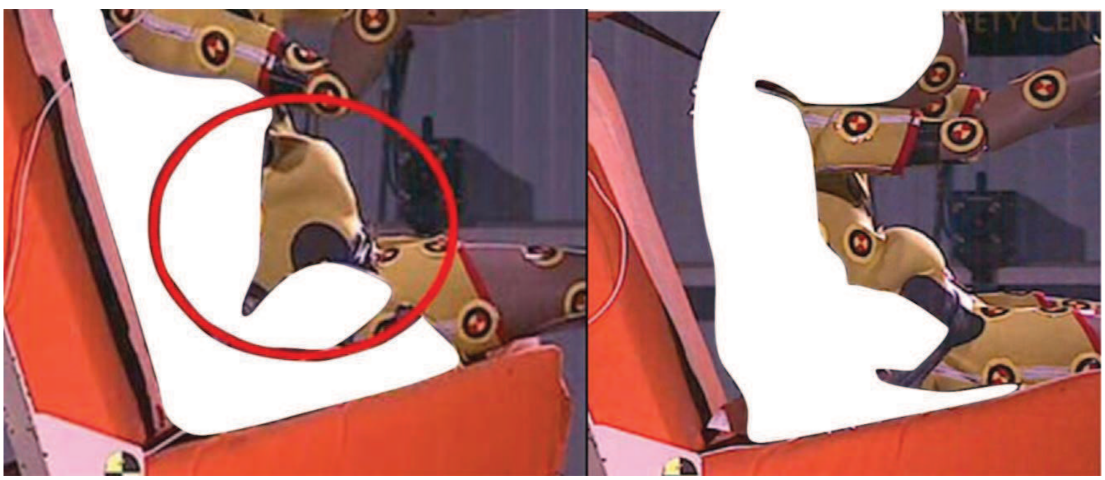

Figure 6: Example (left) showing the foam popping slightly out of the thorax and (right) showing the foam popping entirely out of the thorax

5.1.2 Suit moving up / into the hip joint

During the restraint loading testing, post test analysis showed that the suit is pulled upwards over the dummy's leg. This sometimes resulted in the lap section of the seat belt becoming trapped in a gap between the pelvis and the upper leg (Figure 7).

Figure 7: Belt entrapment

In some of the tests the lap belt is pulled into the gap during the loading phase of the test, and in some of tests the lap section becomes trapped in the gap during the rebound phase of the test.

Belt entrapment in the rebound phase is not considered to be important for the use of the dummy. However belt entrapment during the loading phase of the test could prevent the Q10 from submarining.

Patches were introduced on the suit during the testing at TRL (Section 6.1) to mitigate this issue. The introduction of patches on the dummy suit has reduced the severity of this belt trapping. Humanetics are currently investigating how to improve the situation further. One suggestion is to improve the fit of the suit. The suit is currently quite baggy around the hip area when the dummy is seated. The use of a stiff velcro patch is also being considered.

5.1.3 Belt entrapment in the chest

During the durability testing it became apparent, in some tests, that the diagonal belt became caught in the slit of the chest separating the upper and lower rib segments.

Figure 8: Belt entrapment in the chest

In tests where there was entrapment of the belt in the chest, the interaction of the diagonal belt and the upper torso of the Q10 dummy was unrealistic and damaged the dummy suit.

The design of the ribcage has since been updated to remove the slot. This means that belt entrapment in the chest will no longer occur with the revised thorax.

5.1.4 Suit

The suit was found to have torn under the arms of the Q10 after a number of tests had been conducted. It was discovered that this had occurred because the durable material used in the suit under the arms was not folded when stitched. Therefore all future versions of the suit will include folded material double stitched in this area.

5.1.5 Feet

During the testing it was noticed that the feet were very flexible. The toes were able to bend enough to contact the shin of the dummy. Although this issue does not affect the biofidelity of the Q10, it is not visually pleasing. This could also lead to overstretching of the material and subsequent material failures after prolonged testing. This will be improved with the addition of a skeleton structure to the foot to improve the ridgity, whilst still keeping some flexibility.

5.2 Sensitivity to restraint loading

The research aims of restraint loading were to evaluate the response of the Q10 dummy to different test set-up conditions. It is also important that the dummy can detect differences in loading when the test set-up is varied. This includes the kinematics of the dummy as well as the recorded loading.

This also included evaluating whether the Q10 is measuring as expected for a front impact test. This was done by comparing the results to previous front impact testing knowledge. It was expected that the major load direction for the accelerations would be in the X direction. It was also expected that the largest neck force in the upper and lower neck load cell would be in the Z direction and the largest neck moment in the Y direction.

The output from the Q10 sensors have been analysed for distinctive patterns showing differences in the parameters tested, compared to the standard "baseline" test. The baseline test was where the Q10 was set-up and tested to the requirments for the P10 specified in Reg.44. This means there was no 25mm spacer behind the dummy when the 3-point belt was tensioned to 50N.

5.2.1 Comparing tests conducted with a spacer

It was expected that the use of the Reg.44 spacer behind the dummy during the tensioning of the 3-point belt, would then create slack in the seat belt when the spacer was removed, compared to the baseline tests.

Based on previous knowledge it was then expected that this should mean that the 3-point belt was slightly less effective at restraining the dummy compared to the baseline tests. This belt slack should mean the 3-point seat belt is less affective at restraining the Q10, leading to increased head excursions.

However comparing the results from the tests conducted with a spacer to the baseline tests did not show any clear distinctions between the test set-ups.

This is not as expected. However the expectation was based on testing with the P-series dummies. The testing conducted at TRL found a difference between the kinematics of the Q10 and the P10 dummies (Section 6.3). During frontal impacts the Q10 dummy remains more upright in tests compared to what we are used to with the P10 dummy. The more biofidelic shoulder of the Q10 is more effectively restrained by the 3-point belt, which therefore results in shorter head excursion measurements.

Therefore as the head excursions of the Q10 dummy are generally smaller than with the P10, then it follows that a less significant difference may be seen. As the effect of using the spacer compared to the overall excursion is reduced.

5.2.2 Comparing the 100N belt tension tests

The standard Reg.44 set-up with the P dummy requires 50N tension in the lap section and the shoulder section of the seat belt. However in these tests the 3-point belt was tensioned to 100N, twice the usual installation tension.

It was expected that this extra tensioning of the seat belt should result in the seat belt restraining the dummy earlier in the test. This will mean the dummy should begin to measure loading earlier than the baseline tests. It was also expected that the head excursions would also be reduced as a result of the increase in belt tension.

The Q10 exhibited a clear difference in behaviour between the tests with 100N in the seat belts compared to the baseline tests. This is demonstrated in the following four areas:

5.2.2.1 Head excursion

As mentioned previously it was expected that there would be a noticable difference in the horizontal head excursions of the Q10 dummy when extra tension was introduced into the belt.

Comparison of the means shows that the mean from the 100N belt tension tests (340mm) was 22mm shorter than the mean of the baseline tests (362mm). All three horizontal measurements were lower than those measured in the baseline tests. This shows that there was a general reduction in head excursion measurements as expected. The vertical head excursion measurements were very similar between the two different set-ups. This means the kinematics of the Q10 resulting from the extra belt tension were as expected. This shows sensitivity to the change in set-up.

5.2.2.2 Chest X acceleration

Figure 9 shows a comparison of the chest X accelerations from the tests with 100N in the belts compared to the baseline tests. This shows that from 35 to 45 ms there is a difference between the baseline and 100N tests. The Q10 dummy begins to measure loading earlier in the tests with extra tension in the seat belt. This is as expected, as the tighter belt begins to restrain the Q10 dummy earlier than in the baseline tests.

The baseline tests all show smaller acceleration values than the 100N belt tension tests. This is expected as they had higher head excursions and it follows that the maximum negative values in the baseline tests also occur later than the tests with the extra belt tension.

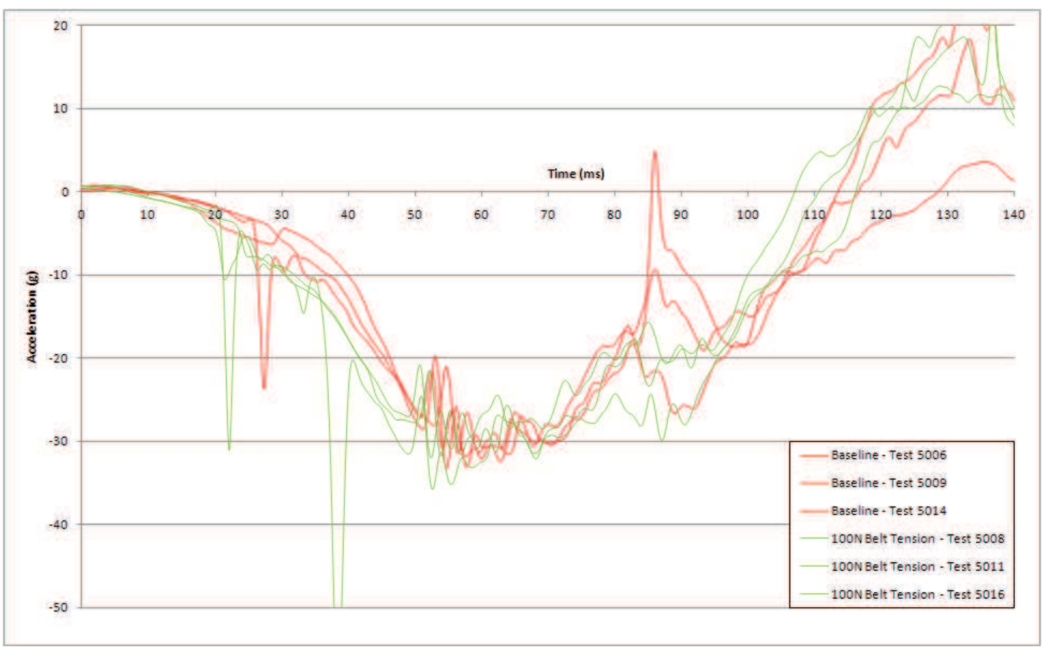

Figure 9: Comparing the tests with 100N belt tensioned and the baseline tests – Chest X acceleration

5.2.2.3 Pelvis X acceleration

Figure 10 shows a comparison of the pelvis X accelerations from the tests with 100N in the belts compared to the baseline tests. This shows that all three baseline tests show peaks at ≈98 ms.

Similarly to the chest X, the Q10 dummy begins to measure loading earlier in the tests with extra tension in the seat belt. This is as expected, as the tighter belt begins to restrain the Q10 dummy earlier than in the baseline tests. This is as expected based on the fact the tighter seat begins to restrain the Q10 earlier compared to the baseline tests.

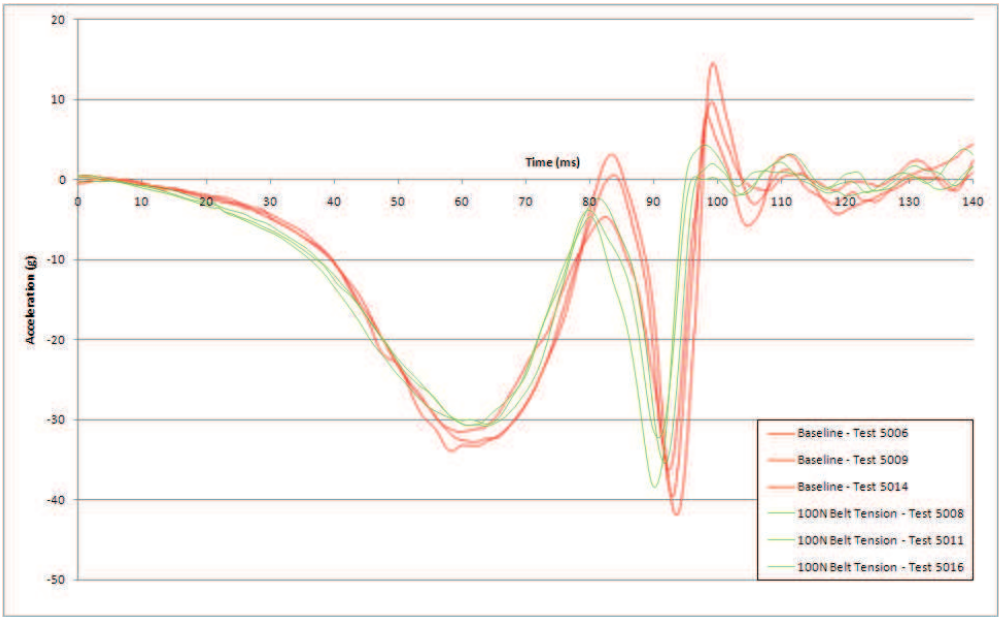

Figure 10: Comparing the tests with 100N belt tensioned and the baseline tests – Pelvis X acceleration

5.2.2.4 Upper neck moment, My

Figure 11 shows a comparison of the upper neck moment My from the tests with 100N belt tension compared to the baseline tests. This shows that from 55 ms to 70 ms there is a clear difference between the baseline tests and the 100N belt tension tests.

Experience of neck loading in older child dummies is limited, so it is unclear whether this is expected. However there is a clear difference between the two set-ups and therefore it can be concluded that the Q10 is capable of detecting a difference in this body region as a result of the increased force in the seat belt.

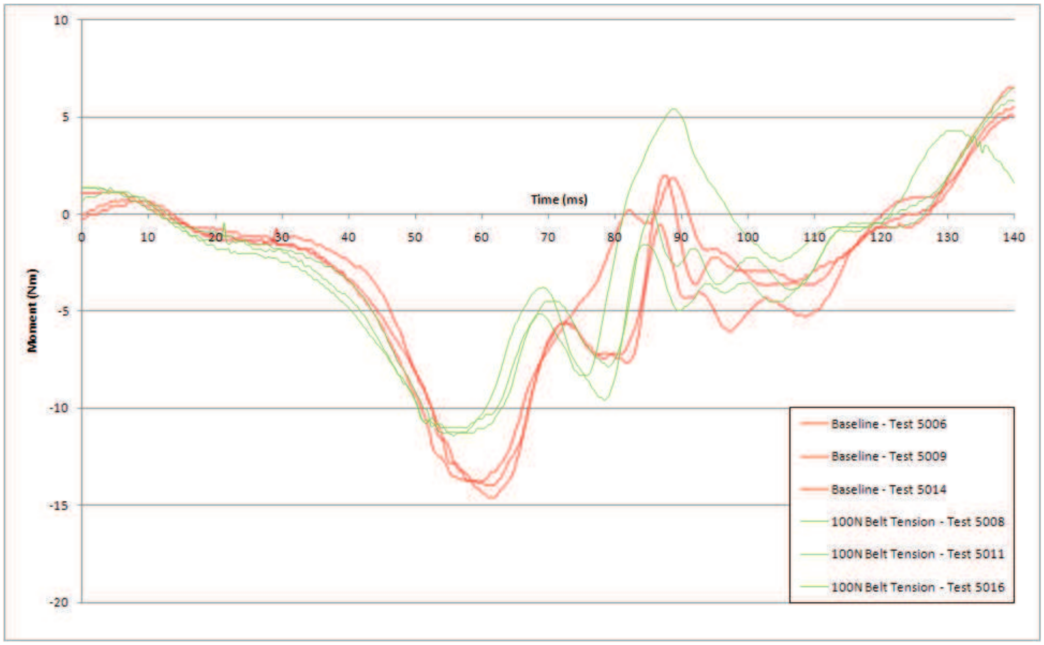

Figure 11: Comparing the 100N belt tension tests to the baseline tests – Upper neck moment M_y

5.2.3 Comparing the different arm position tests

The results from the baseline tests have been compared to those from the tests where the arms were set-up in a different position. The baseline tests were where the child restraint was installed as per Reg.44.

Both arms of the Q10 dummy were placed in a different position for the test (Figure 12). Two different positions were evaluated. In Test 5012 the arms were placed at a 45° angle pointing upwards and pushed together. In tests 5013 and 5017 the arms were extended to the end of the knees.

It was anticipated that this set-up may result in a difference in loading measured by the Q10. The arms may change the kinematics of the Q10 dummy during the loading phase of the test. This would then result in the Q10 recording a difference in loading.

Figure 12: Different arm position set-up

Analysis of the results found that the Q10 only measured a significant difference in the chest X acceleration loading (Figure 13). This shows that at ≈72 ms there was a difference in the loading of the baseline and different arm position tests. This shows that the Q10 was sensitive to the change and able to measure a difference in the loading between the two different test set-ups.

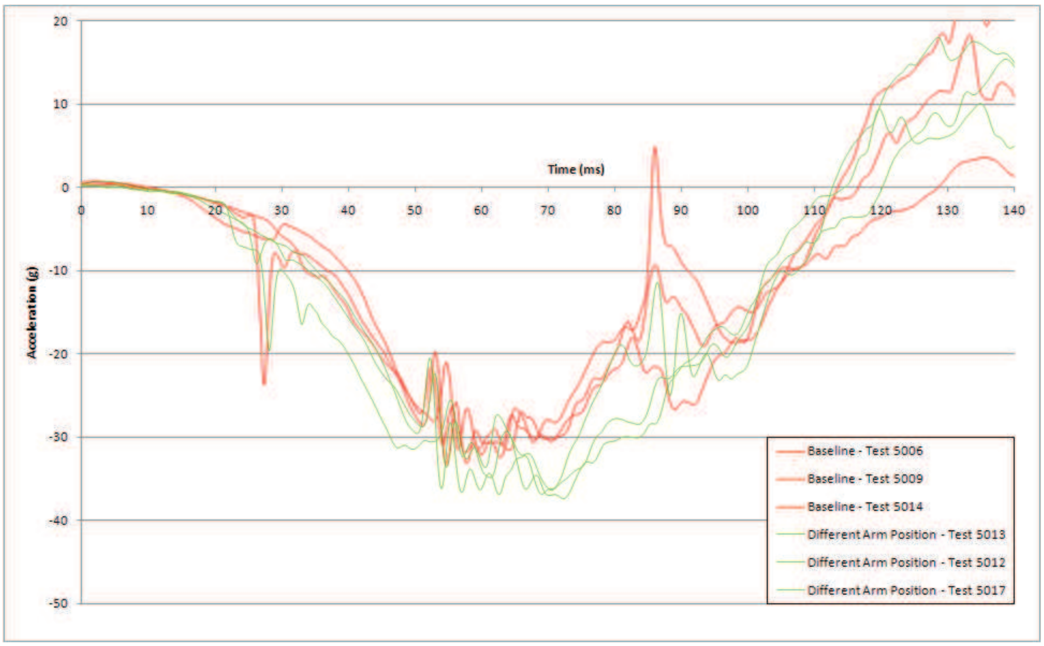

Figure 13: Comparing the tests different arm position tests and the baseline tests – Chest X acceleration

5.2.4 Summary

The main aim of this restraint loading testing was to evaluate the response of the Q10 dummy to different test set-up conditions. It is important that the dummy can detect differences in loading when the test set-up is varied. This includes the kinematics of the dummy as well as the recorded loading.

From the analysis of the sensitivity to restraint loading testing it can be concluded that the Q10 dummy is sensitive to the test set-up. The Q10 was able to detect differences in kinematics and loading in different set-ups.

The Q10 was able to display a difference in horizontal head excursion when expected to. The Q10 was also able to show a difference in the acceleration loading as a result of differing kinematics. These differences between the measured loading were as expected, base on variation in test set-up conditions.

These differences demonstrate that the Q10 dummy is sensitive to changes in test set-up that affects its kinematics and loading.

5.3 Sensitivity to child restraint design

The research aims of the sensitivity to child restraint design testing were to evaluate the response of the Q10 dummy to different child restraint designs. The main aims of these tests were to evaluate whether the Q10 dummy is capable of picking up difference in child restraint design. This includes the kinematics of the dummy as well as the measured loading. It is essential that the Q10 is able to differentiate between different child restraint designs, especially in the important body regions.

For this assesment four types of child restraint systems have been tested using the Q10 dummy. The design of these four different child restraints differ in terms of structure and weight.

The output from the Q10 sensors has been analysed for distinctive patterns that show differences in the seat types used. Analysis of the results showed that the Q10 dummy was able to pick up the following differences across the different seats.

5.3.1 Head excursion

The tests from Seat 1 and Seat 4 show a very close grouping. This means that the kinematics of the Q10 are repeatable when the dummy is consistently well restrained. Figure 14 shows the horizontal head excursion plotted against the vertical head excursion. This shows that there are clear grouping of tests results relating to each seat.

Seat 7 is a less repeatable product, with greater vertical excursion. All three tests produced the largest three vertical head excursion measurements. This is as expected as Seat 7 has the tallest base-pan and the Q10 sitting height is the highest in this seat.

Cushion 1 had more variable horizontal excursion, which was expected with this product, and produced similar vertical head excursions in all three tests. The vertical excursions were among the lowest vertical measurements across the products tested, as were those of Seat 4. This is as expected as Cushion 1 and Seat 4 have the slimmest seat-pans, so the Q10 sitting height is relatively low, compared to the other two seats.

However in general the grouping of the head excursions means each seat could be identified from the excursion results. Therefore the Q10 has demonstrated sensitivity to the different designs of child restraint.

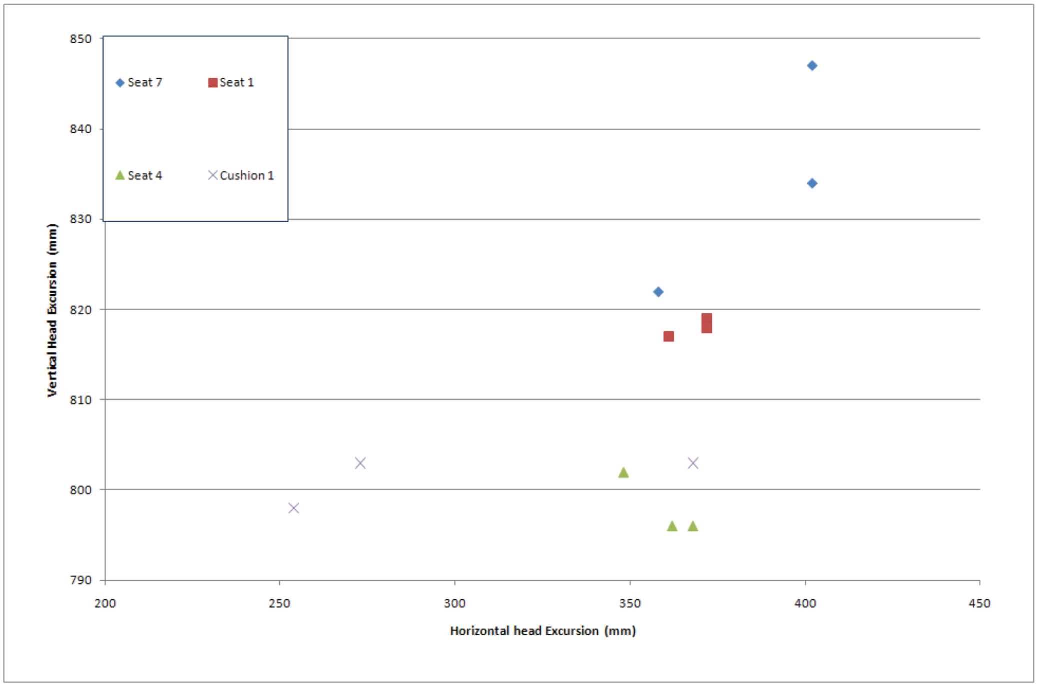

Figure 14: Sensitivity to child restraint design - Head excursion

5.3.2 Head acceleration

The head X acceleration loading measured by the Q10 in the sensitivity to child restraint design testing is shown in Figure 15. This shows that the Q10 was sensitive to the different designs, measuring unique patterns in the time histories of the loading.

Between 65ms and 85ms a plateau appears in the loading of the Q10 in Seat 7. This is not seen in the time histories of the other Q10 in the other child restraints.

The time histories of Seat 7 also peak later relative to the other two child seats and especially the booster cushion. The peaks measured are also quite broad compared to those of the other products. Based on the head excursion measurements it was expected that the peaks should occur later. As the excursion of the Q10 in Seat 7 were generally the largest horizontal head excursions. Therefore it should take longer in time for the head to come to a stop (in the X-direction), which is when the maximum head accelerations occur.

The time histories of the Q10 in Seat 7 also show that the dummy starts to measure positive head acceleration in this restraint before it does in the other three products. This is a result of contact with the side of the head pad as the Q10 begins to rebound.

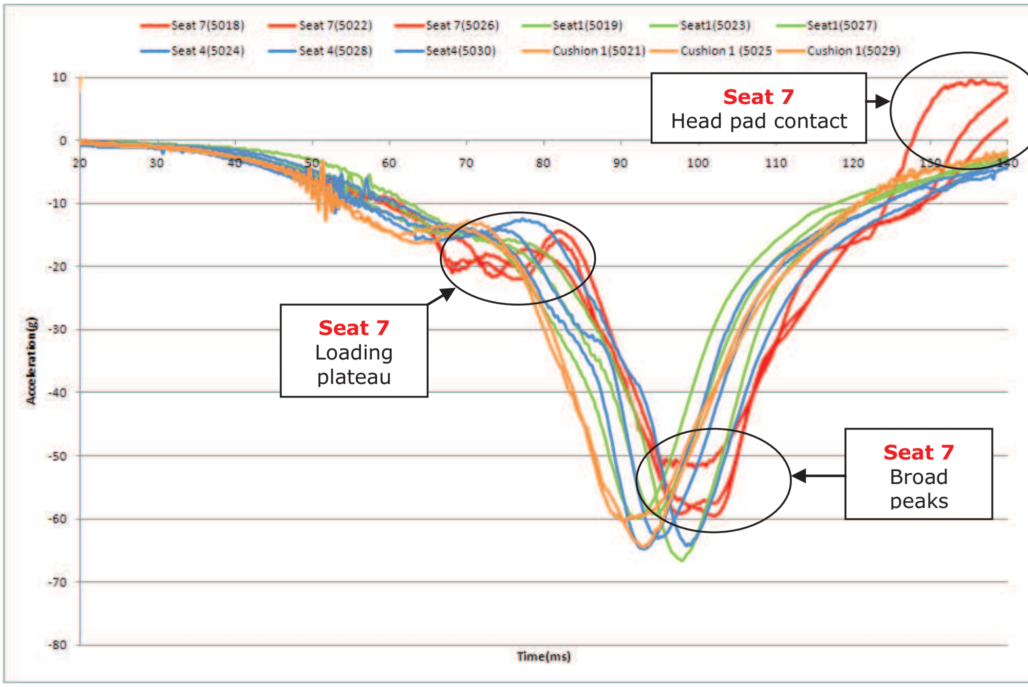

Figure 15: Sensitivity to child restraint design - Head X acceleration

The head Z acceleration loading measured by the Q10 in the sensitivity to child restraint design testing is shown in Figure 16. This shows that the Q10 was able to measure some unique patterns in the time histories of the loading.

Response to product is obvious, the graph shows that the loading measured by the Q10 in Cushion 1 peaks first, compared to the other three child restraints.

The maximums of Seat 1 and Seat 4 occur later in time and are generally larger in severity, than the other two child restraints. Similar to the head X results the loading of Seat 1 and Seat 4 are similar.

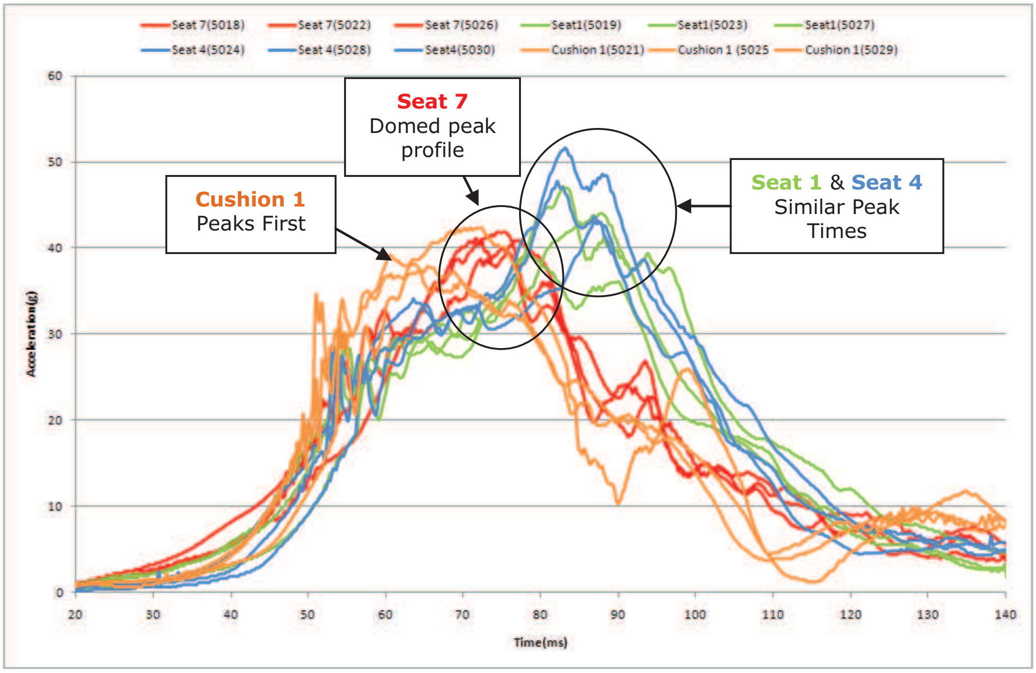

Figure 16: Sensitivity to child restraint design - Head Z acceleration

The Q10 head resultant acceleration loading of all four child restraints reflects the differences noticed in the head X and head Z (Figure 17).

This shows that the peaks from the head Z acceleration measured in Cushion 1 are the first significant feature. There is a large time difference between the first peaks (60-65ms) and the main peak (90-100ms) in the head acceleration resultant loading of the Cushion 1, compared to the other three child restraints. The main peak corresponds to the maximum head X loading measured by the Q10.

It was expected that Cushion 1 would have the highest accelerations in the head based on the head excursion measurements. This is because as the Q10 in Cushion 1 was restrained in a relatively short distance, resulting in a short horizontal head excursion. The kinematics of the Q10 head during these tests, were such that the X-direction acceleration and Z-direction acceleration occurred at different times. This was reflected in the overall resultant.

The head acceleration resultant measured by the Q10 in tests of Seat 7 also shows these distinct two peaks in the loading. The head Z peaks first (70-75ms) before the head X (95-105ms). The fact that the X and Z accelerations do not peak at the same time means the acceleration resultant is relatively low. This is as expected, based on the fact that the Q10 horizontal head excursions were among the largest of the four child restraints.

As shown in the graph, the head Z maximum peaks and the head X maximum peaks occur at similar times (80-90ms for head Z and 90-100ms for head X). This means the acceleration resultants are larger. It was expected that the head accelerations measured by the Q10 in Seat 1 and Seat 4 should be similar, as the head excursions were also similar. This was indeed the case, with the mean of the Seat 1 head acceleration resultant maximum 71g and 72g for Seat 4.

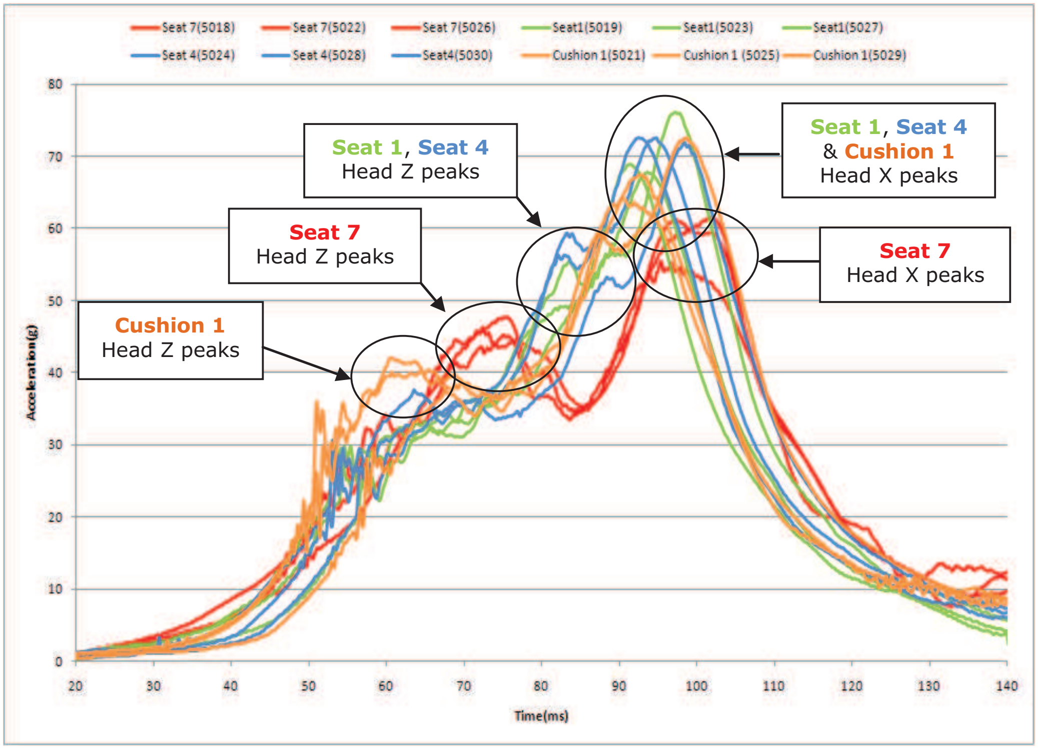

Figure 17: Sensitivity to child restraint design - Head acceleration resultant

5.3.3 Neck force

Figure 18 shows the upper neck Z-direction forces measured by the Q10 during the sensitivity to child restraint design testing. This shows that there is an initial loading that then forms a relatively flat loading plateau. This plateau corresponds to when the maximum upper neck moment M_y occurs in each test. After this point a few distinct trends can be seen. The graph shows that the results from each different child restraint are grouped.

The neck force measured by the Q10 in Cushion 1, in two of the tests peak relatively low, compared to Seat 1 and Seat 4. As mentioned earlier there was a kinematic difference in one of the Cushion 1 tests, which has resulted in a difference in the loading, measured by the Q10 in the head and neck.

The loading measured by the Q10 in Seat 7 shows a delay before the loading increases to peak. This corresponds to the same pattern as seen in the head acceleration loading described earlier. The timing of the peak force corresponds to the timing of the maximum horizontal head excursion.

The upper neck force loading measured by Seat 4 was very consistent, with the peaks occurring at a similar time and with a similar magnitude.

The graph also shows that two of the tests of the Q10 in Seat 1 measured neck force loading similar to Seat 4. This shows the same trends as those seen in the head acceleration graphs. The Seat 1 test which recorded a larger force was the same test that measured a slightly larger loading in the head acceleration.

The distinct grouping of the loading measured by the Q10, shows that the Q10 is sensitive to measuring different neck loading in the different child restraint designs.

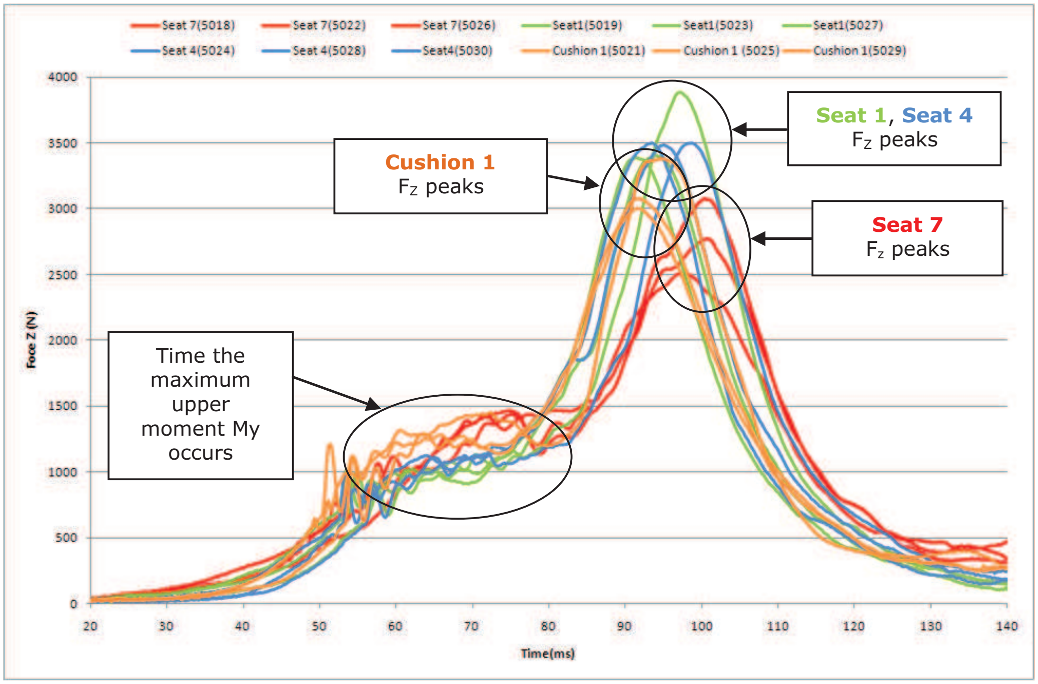

Figure 18: Sensitivity to child restraint design – Upper neck force F_Z

5.3.4 Neck moment

The lower neck M_y loading measured by the Q10 in the sensitivity tests also showed a similar pattern to the upper neck force F_z loading. Figure 19 shows the loading measured by the Q10 in the lower neck M_y.

The results from each different child restraint are grouped in the same patterns. The peaks of Cushion 1 occur first. The peaks of Seat 1 and Seat 4 occur at similar time. Finally the peaks of Seat 7 occur. The maximum peak of the bending moment corresponds to the time of the maximum head excursion occurs.

Therefore the loading results from the Q10 show that the dummy is sensitive to measuring different neck moment loading in different designs of child restraint.

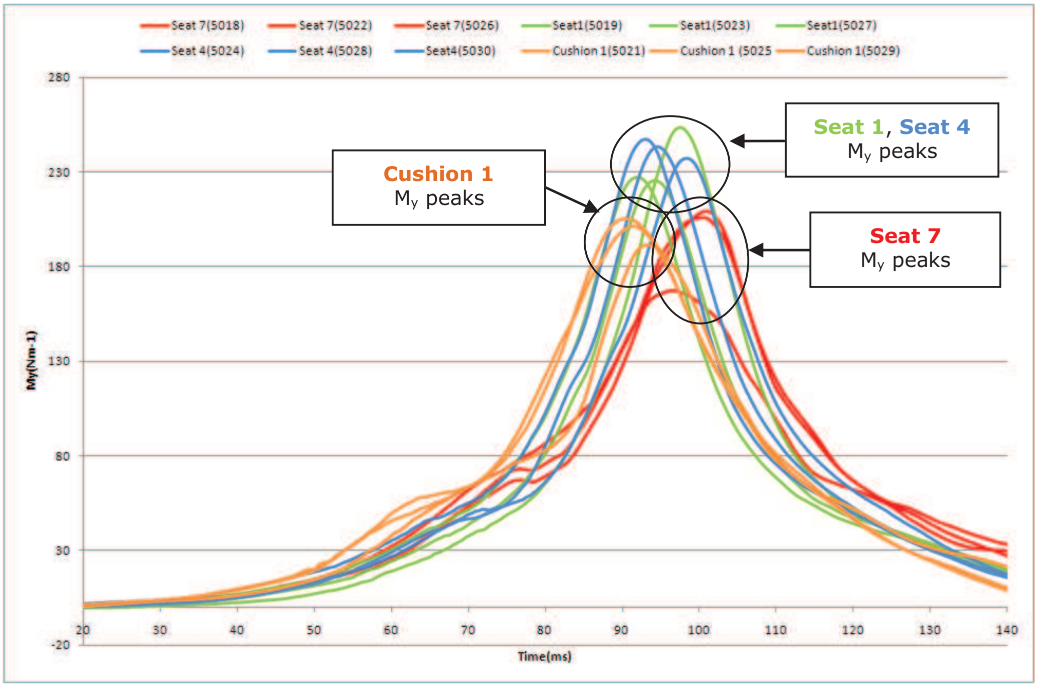

Figure 19: Sensitivity to child restraint design – Lower Neck Moment M_y

5.3.5 Chest acceleration

Figure 20 shows the same grouping of the loading measured by the Q10 in each of the child restraints. This does not seem to show any clear difference or group of the different child restraints. This is a little surprising.

However all four different designs of child restraint do essentially restrain the chest of the occupant in the same way. The 3-point belt is used to restrain the torso of the dummy in all designs of child restraint. Therefore it could be expected that the chest measured similar loading in all the tests.

The only slight difference seems to be that Seat 1 and Seat 4 show slightly broader maximum peaks. Whereas Seat 7 and Cushion 1 seem to have extra peaks, occurring later in time. These occur around the time of maximum head excursion.

Comparison of the mean 3ms peak values also shows similar values. Seat 1 and Seat 4 had a similar value (35g). This is consistent with the loading measured in the other body regions. Both seats recorded similar values in the head, and neck as well as having similar head excursion measurements.

Seat 7 measured a slightly lower mean 3ms chest acceleration resultant maximum (34g). This shows the trend similar to the head that as the dummy travelled further it was decelerated over a larger period and therefore the chest accelerations are lower. However the difference from the other two booster seats is not that significant.

Cushion 1 had a slightly higher mean 3ms chest acceleration resultant maximum (37g). This also follows the trend that as this child restraint had the shortest head excursion that the chest was decelerated over a shorter distance and therefore the accelerations are increased.

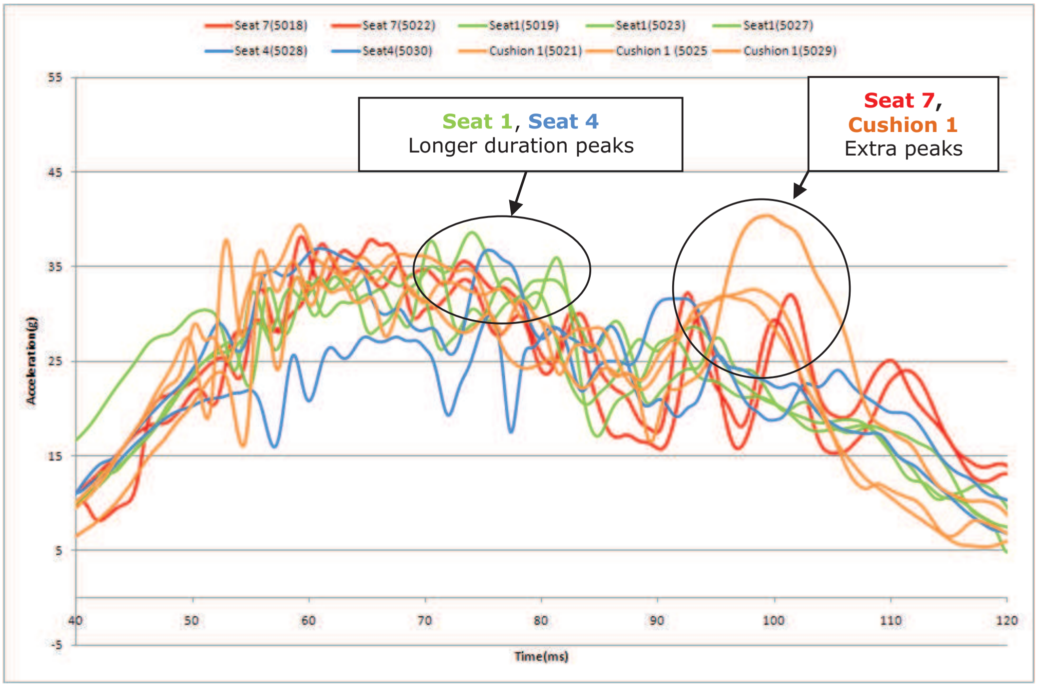

Figure 20: Sensitivity to child restraint design - Chest acceleration resultant

5.3.6 Pelvis acceleration

The Q10 pelvis X acceleration loading of all four child restraints is shown in Figure 21.

This shows that there are distinct groupings of the maximum pelvis X loading measured by the Q10 for Seat 7 and Cushion 1. The maximum peaks for Seat 1 and Seat 4 occur around the same point and with the same magnitude.

The three booster seats then display a secondary peak between 90ms and 105ms. The grouping of these peaks enables each of the booster seats to be identified.

Seat 7 then displays a unique positive peak, which is not measured by the Q10 in the other child restraints.

This shows that the Q10 is sensitive to the design of the child restraint in the pelvis area.

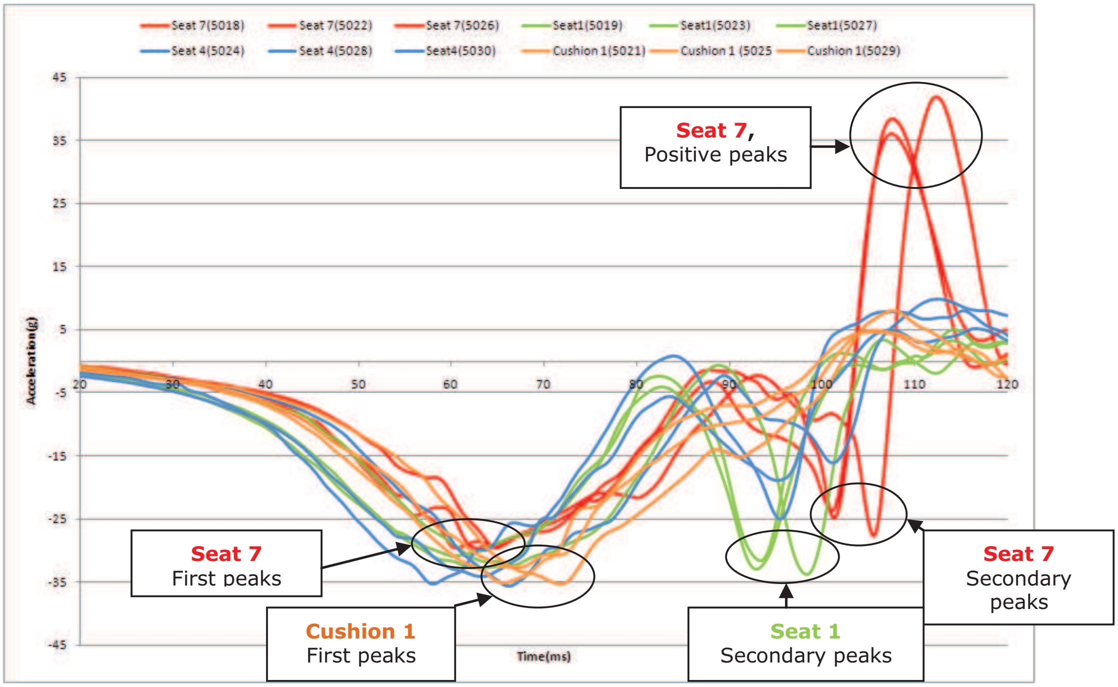

Figure 21: Sensitivity to child restraint design - Pelvis X acceleration

The Q10 pelvis acceleration resultant loading of all four child restraints is shown in Figure 21. This shows the same patterns seen in the Q10 pelvis X loading.

There is a distinct grouping of the maximum pelvis loading measured by the Q10 for in Seat 7 and Cushion 1. The maximum peaks for Seat 1 and Seat 4 occur around the same point and with the same magnitude.

Seat 1 then shows a secondary peak. A secondary peak in the Q10 pelvis loading is also then seen in the Seat 7 time histories.

This all shows that the Q10 is sensitive to the design of the child restraint in the pelvis area.

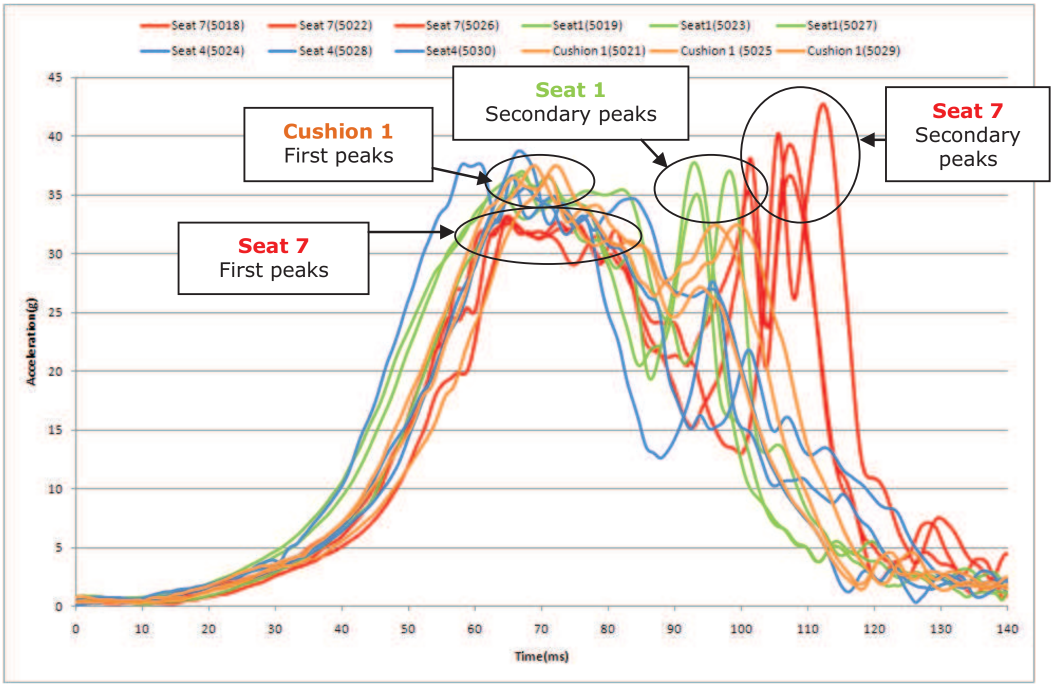

Figure 22: Sensitivity to child restraint design - Pelvis acceleration resultant

5.3.7 Seat belt loading

The seat belt loads were also recorded during the tests. This showed that the seat belt forces were able to distinguish the child restraint.

The diagonal belt force in all three tests of Seat 1 were grouped together and were separate from the other loading from the other three child restraints, from 55ms to 80ms. The diagonal belt force also showed a distinction between all three tests of Seat 4. The loading was grouped together and separate from the other signal data, from 75ms to 95ms.

The lap belt forces in all three tests of Seat 1 begin to load at the same point in time between 20 to 47 ms, before the other three child restraints.

Three distinct groups of belt loading data can be identified from the reel belt force measurements. The reel force of Seat 1 is grouped from 65ms to 80ms; Seat 4 loading is grouped from 78ms to 95ms and Seat 1 and Seat 4 loading is grouped from 95ms to 105ms.

5.3.8 Summary

The research aims of the sensitivity to child restraint design testing were to evaluate the response of the Q10 dummy to different child restraint designs. It is important that the Q10 is able to differentiate between different child restraint designs, especially in the important body regions. The loading of both the important body regions and the additional sensors in the Q10 were analysed. This includes the kinematics of the dummy as well as the measured loading.

From the analysis of the sensitivity to restraint design testing it can be concluded that the Q10 dummy is sensitive to the design of the different child restraints. The Q10 was able to detect differences in kinematics and loading in different set-ups.

The Q10 was able to display a difference in horizontal head excursion between the different designs of child restraint. The Q10 was also able to show a difference in the acceleration loading as a result of differing kinematics. These differences between the measured loadings were as expected, based on the variation in dummy kinematics.

These differences demonstrate that the Q10 dummy is sensitive to child restraint design.

5.4 Durability

In this section the results of the 40 durability tests will be discussed. As previously mentioned a major factor in assessing the Q10 dummy was to establish whether the dummy was capable of performing in place of the P10 during routine "Technical Service" Reg.44 assessments.

Firstly the durability over the range of 40 tests will be discussed. This includes the observations relating to the durability of the Q10 made during the testing conducted by DOREL and TRL. Further details of these can be found in Appendix E.

After this the findings of each of the three different studies conducted during the 40 tests will be discussed.

5.4.1 Durability of the Q10

It is important that the Q10 is robust and durable enough to be able to undergo a number of impacts without regular breakages. Typically the P-series dummies can be used during regular use, as a test-house tool, at least 70 to 100 Regulatory type tests before parts may need replacing.

The P-series dummy only needs minimal maintenance. It is recommended that the neck is recertified after 10 tests; however recalibration only tends to be required at every other recertification. These adjustments follow a very simple procedure. Due to the advancements of the Q-series dummies, they typically require a few more calibration tests. However this reflects the increase in the number of sensors in the dummies.

5.4.1.1 Q10 durability – failure of parts

5.4.1.1.1 *Clavicle retainer*

The only part showing a breaking failure was the clavicle retainer, and that failure could best be described as a partial failure, as the important functions of the part remained intact. As the part was still able to function this breakage was considered to be of minor importance to the biofidelity of the tests.

The reason for the failure was deemed to be that the material was too weak. A new material for this part was selected and a new retainer was made and used for all subsequent tests. No further failures of this part occurred.

5.4.1.1.2 *Arm pit of the suit tearing out*

As previously mentioned, during the sensitivity testing series, it was noted that the suit of the Q10 became damaged at the armpit.

This was caused by a number of effects:

- The arm was thrown forwards, pulling the material over the shoulder blade.
- The suit became wedged into the chest slit by the diagonal belt, pulling it downwards.
- The stitching of the material under the armpit was made too close to the edge of the material.

A solution has been developed to this problem. The stitching on the suit will be improved and the chest slit on the thorax will be removed.

5.4.1.1.3 *Suit damage due to belt loading and Chest interaction*

The suit also became damaged by the belt pressing on the suit over the edges on the ribcage. In later tests, this fraying of the material increased, up to the point that roughly 3 mm of material thickness was removed from the edge.

This problem will no longer occur as this slit will be removed in the final version of the dummy.

5.4.1.1.4 *Suit wear*

The dummy's suit began to show signs of wear from the 3-point belt rubbing on the suit, after only a few tests. The damage increased as the testing continued and the number of damage sites also increased. This problem was solved by making a new suit with reinforced panels, which was used for later testing. This reduced the wear on the suit in the usual seat belt contact areas.

5.4.1.1.5 *Knee stop wear*

During the first few impacts it was noted that the knees were able to over-extend as the legs swing forward. Mechanical stops were fitted to the dummy to prevent this excessive movement.

There was some wearing of the knee stops over time, which allowed the knee to extend further than it should. This will be solved by increasing the size of the screws and the size of thread engagement.

5.4.1.1.6 *Spine cable protector*

The spine cable protector cover became cracked and eventually broke off the dummy. This has been solved by changing the material of the cover to improve the strength of the protector.

5.4.1.1.7 *Ribcage cracking*

Towards the end of the testing (20 tests) a crack developed at the back of the ribcage, on the side where the lower part of the shoulder belt loads the ribcage. This issue will be solved with the new ribcage, made with reinforced material in the future version of the Q10. This will maintain the same biofidelic properties whilst improving the ribcage strength.

5.4.1.2 Dummy maintenance

During the test series periodic checks of the dummy were carried out to check that it was still functioning correctly. It is important that these checks can be carried out quickly and therefore do not cause delays in test programmes. The maintenance required for the P10 was used as a benchmark for comparison purposes.

5.4.1.2.1 *Lower arm screws*

The lower arms often became loose between tests and had to be retightened. This is a minor issue as this is also a common occurrence for the P10.

5.4.1.2.2 *Upper arm screws*

The stiffness of the shoulder joint needed to be adjusted every so often. The P10 has a much simpler upper arm connecting. However the P10 ball and socket joint has a screw thread in the shoulder which needs to be constantly adjusted between tests. Therefore this adjustment for the Q10 is no more onerous than the current P10.

5.4.1.2.3 *Shoulder-spine readjustment*

The bolt that connects the shoulder to the spine needed to be retightened on a couple of occasions after tests, as it had worked loose. The thread of the bolt will be improved to prevent this happening in the final version of the Q10.

5.4.1.2.4 *Abdomen readjustment*

After several of the tests, mainly of the booster cushions, the abdomen insert was found to have been pushed underneath the ribcage or out to one side. The solution to prevent this from happening in the future will be to have venting holes incorporated in the skin of the abdomen insert.

5.4.2 Durability with different child restraints

The aim of the durability tests with different child restraints were conducted to assess how the dummy would cope with the different loading conditions as a result of the different child restraints used. The child restraints were selected across the range available in the market.

The 20 tests were conducted in a sequence that would help identify whether there was any drift in the results measured by the Q10. If drift was found it would indicate the Q10 may need recalibration. However none of the body region loadings measured by the Q10 showed signs of drift in any of the five child restraints tested.

All time histories were analysed and trends were searched to find if the four time histories from the same type of seats showed patterns such as increase or decrease of the peak values from the first to the last test, with each specific child restraint type. Also, the data was checked for the timings at which the peak values occurred. Cushion 2 was used for the analysis of the time histories, as it was expected to find drift in results earlier in child restraints that are loading the dummy to a higher extent.

Similar to the results found in Section 5.3, several of the body regions were able to show clear groupings of the loading measured by the Q10 in each of the five child restraints. The pelvis X acceleration is one of the best examples of this. As Figure 23 shows, all four data time histories in each child restraint follow very closely to each other.

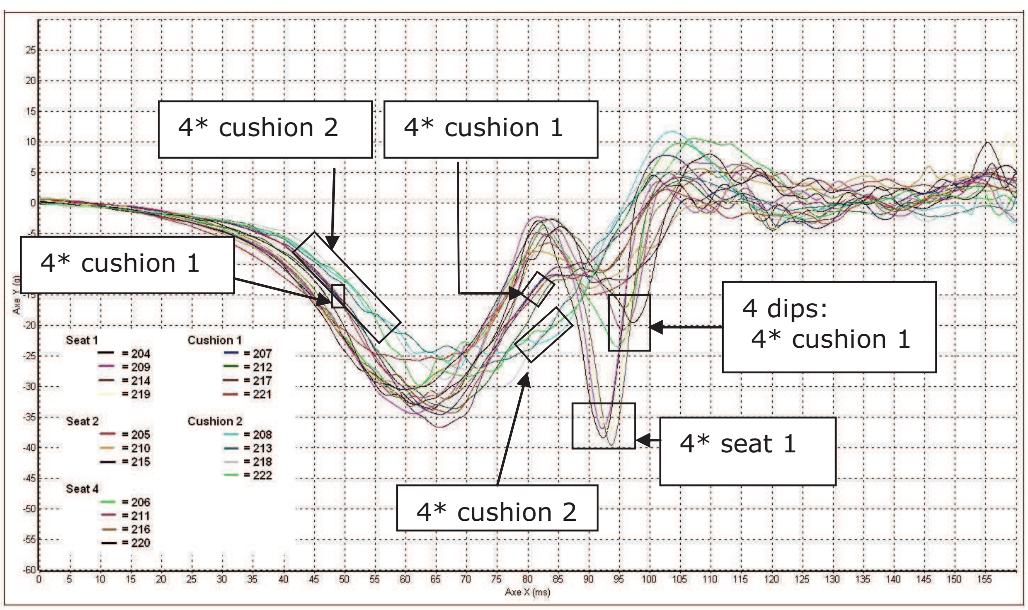

Figure 23: Durability with different child restraints - Pelvis X acceleration

However there were some body regions which showed less repeatability and therefore the grouping of the loading measured in each child restraint was not so clear.

In some cases there are extra peaks leaving the group of time histories. However it was not found that these extra peaks were related to the order of testing. This is demonstrated by the loading data of the upper neck moment M_y (Figure 24). The graph shows that for the loading measured by the Q10 in Cushion 2, the 2nd and 3rd time histories have additional sharp positive peaks. This extra peak is also different to the loading measured in the other four child restraints.

However the fact that the loading was similar from the 1st and 4th tests shows that the difference is not due to drift in results, which would indicate the dummy could require recalibration. This is more likely the result of an unrepeatable product.

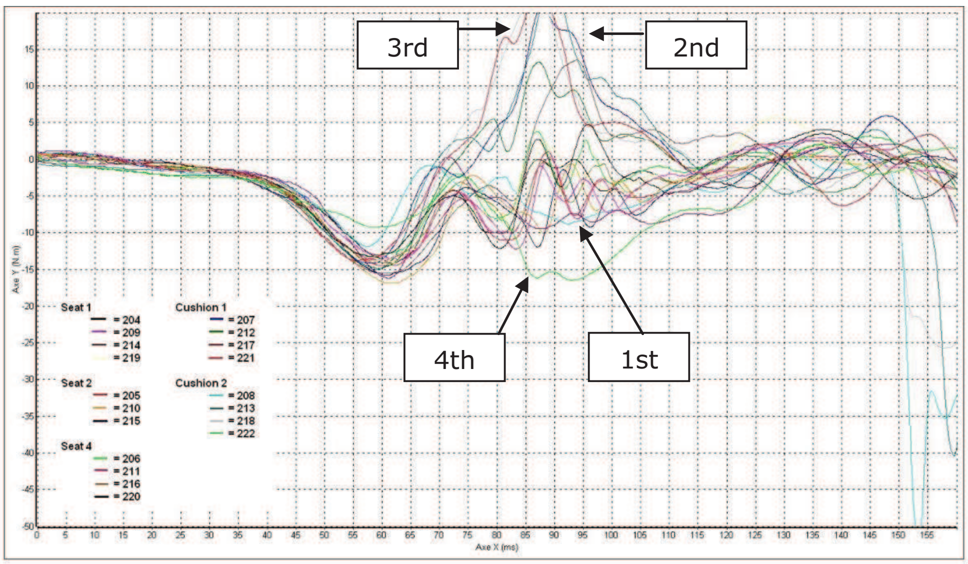

Figure 24: Durability with different child restraints - Upper neck moment M_y

From the above evaluations, it can be concluded that the results are consistent over extended testing (20 shots), without recalibration.

5.4.3 Durability time dependency testing

The aim of the durability time dependency testing was conducted to assess if care should be taken when running tests quickly after one another. In some laboratories the turnaround time between tests is as short as 20 to 30 minutes. Therefore verification is needed to see if a drift in results occurs when the dummy is not given enough time to recover itself. It is expected that the variation in results may increase as the time between tests decreases.

For the analysis of the time dependency tests, two approaches have been taken. In both cases, graphs have been studied that show differences between the four different test times; unlimited set-up time (baseline), 45 minutes recovery time, 30 minutes recovery time and 15 minutes recovery time. Three tests were conducted for each time.

The first analysis approach involved analysing the peak values and their time of occurrence have been analysed. The overview from this first analysis is shown in Table 8.

This analysis did not highlight any time histories that showed any relation to the recovery time between the tests. No significant variation in the loading measured by the Q10 was found as the recovery time of the dummy was varied. No significant variation was seen in the timings and magnitude of the peaks.

The second analysis approach involved analysing the graphs where time histories show specific shapes, such as secondary peaks or dips. The graphs have been analysed by hand, looking to specific identifiers of a graph, not being necessarily the highest or lowest peak.

An example of this approach is shown in the graph of the lower neck force F_z (Figure 25). When looking at the peaks of the time histories, it was expected that the peak values around 60 ms did not show any difference. The first analysis confirmed that.

However the differences in the time history after 75ms are quite different. This secondary peak is when the upper neck force is at a maximum, just before maximum head excursion. There are secondary peaks that do not occur at a constant time interval to the first peak. However the time histories are all grouping again from 100ms to 105ms.

Figure 25 does not show any specific variation in the results in time or force level, i.e. the results do not drift. Therefore it can be concluded that the time histories do not have a relation to the recovery time of the dummy between tests.

In both types of analysis, no specific order was found in the results. A short or longer time between tests does not influence the analysed time histories. This shows that the dummy is not sensitive to short recovery time intervals between tests. Therefore a recovery time of 15 minutes between tests is judged to be satisfactory.

Reg.44 sets a minimum time of 20 minutes between tests. This is to allow the test bench cushion foam to recover. Therefore the recovery time of 20 minutes for the Q10 would be consistent with this when used in Reg.44 testing.

Table 8: Durability time dependency testing - Summary of peak values and time of their occurrence

		Head Acceleration		Head Acceleration		Chest Acceleration Resultant			Chest X Acceleration		Upper Neck Fz		Upper Neck My		Lower neck Fz		Lower Neck My	
		peak	X	peak	Z	peak			peak	X	peak		peak		peak		peak	
Batch	test	g	ms	g	ms	g	ms	3ms(g)	G	ms	N	ms	Nm	ms	Nm	ms	Nm	ms
Std	223	-60,3	94	42,8	86	35,6	62	34,7	-35,1	62	3520	94	-14,0	63	1132	61	209,0	95
	227	-57,0	97	41,4	89	36,5	88	33,3	-30,6	70	3375	96	-13,0	68	1178	60	208,0	97
	231					36,1	67	35,0	-35,3	67	3051	97	-14,6	101	1108	62	192,8	97
45 min	224	-56,5	96	66,5	96	33,2	63	32,7	-31,5	66	3382	95	-15,5	98	1170	93	200,0	96
	228					43,9	90	33,2	-31,2	58	3614	97	-14,6	65	1246	60	215,0	98
	232	-54,2	100	38,4	82	34,5	84	32,5	-26,6	84	2594	99	-14,0	65	1198	60	161,0	99
30 min	225	-55,1	97	37,6	89	36,2	88	33,0	-32,4	68	3183	95	-14,6	68	1205	59	196,1	97
	229					33,9	93	30,0	-29,3	70	2760	95	-12,4	63	1082	59	175,5	99
	233	-52,5	93	37,5	78	34,2	92	33,9	-31,5	67	2708	93	-14,8	101	1127	63	162,0	99
15 min	226	-63,8	97	49,5	87	41,5	86	37,6	-37,0	66	3833	95	-14,0	69	1284	94	229,6	96
	230					36,2	67	35,4	-35,7	67	3245	96	-13,0	70	1108	59	202,7	97
	234	-51,5	95	36,2	80	36,6	95	34,2	-27,8	81	2717	96	13,1	65	1142	59	156,1	99

Particular order?

Timeshift		No		No		No			No		No		No		No		No
peak value	No		No		No		No	No		No		No		No		No *	

*= Tests 231/232/233/234 (much) lower, but no relation to std, 45, 30 or 15 minutes.

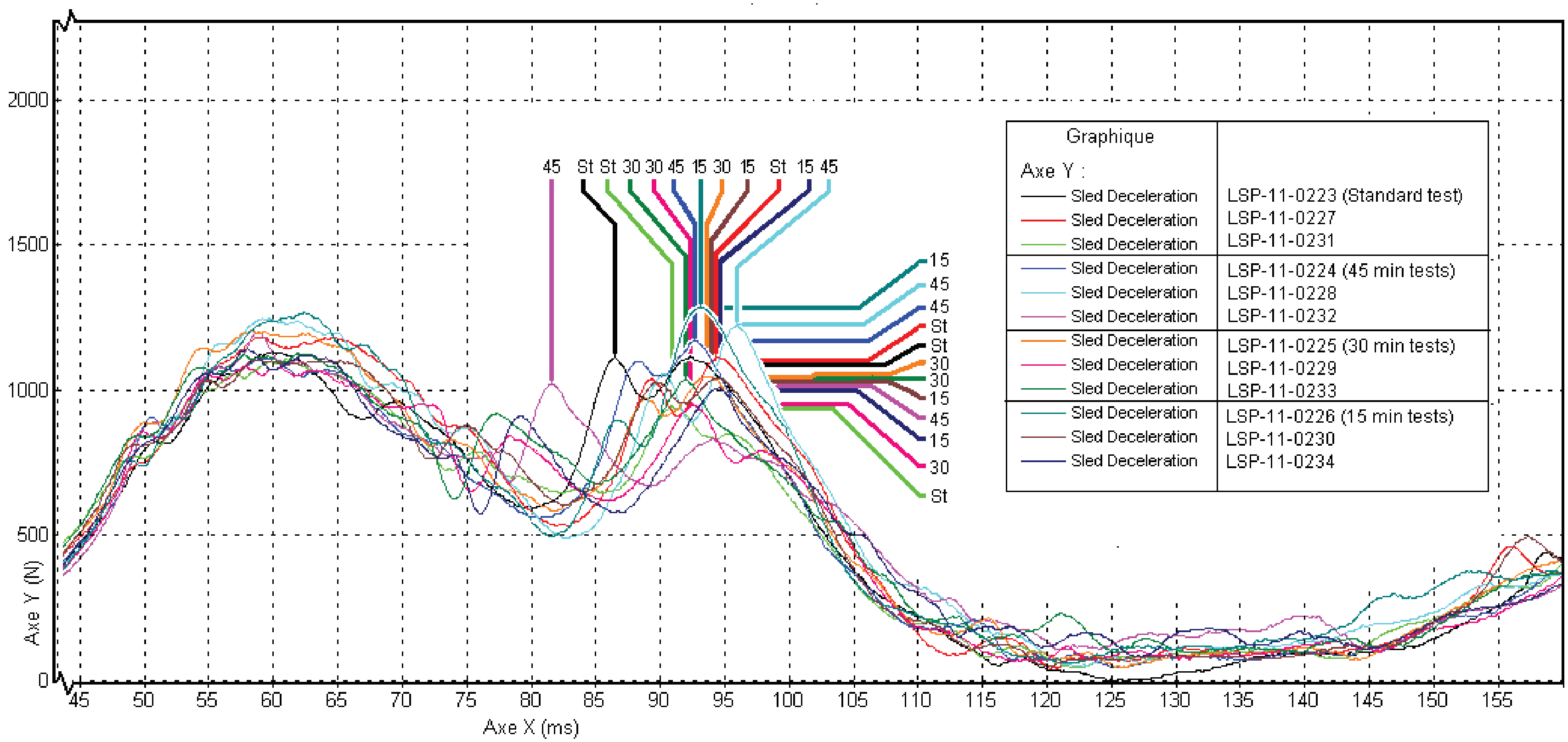

Figure 25: Durability time dependency testing - Lower Neck Force Fz

5.4.4 *Durability dummy positioning*

The aim of the durability to dummy positioning tests was conducted to assess if the dummy was sensitive to differences in dummy positioning. Section 5.2 has already shown that the Q10 is able to distinguish between different methods of installation. However in this testing two additional poor installation set-ups were used.

For this assessment, the time histories from the Q10's sensors have been compared from the baseline tests to the two different methods of installation used; a slouched dummy and a dummy installed with additional belt slack.

Similar to the results found in Section 5.2.1, the tests with extra belt slack did not show any significant differences in measured loading compared to the baseline tests. However comparison of the time histories of the slouched dummy to the baseline tests showed that differences in time histories occur in the following sensors:

5.4.4.1 Head acceleration

A clear difference was seen in the loading of the head X acceleration from 65 to 75 ms and 110ms-125ms. The peak loading was also higher for the dummy in the slouched position.

This resulted in the overall head acceleration resultant being higher for the slouched dummy tests (75g) compared to the baseline tests (70g).

5.4.4.2 Neck force

The upper neck force F_z peaks was much larger for the slouched dummy tests (5000N), compared to the baseline tests (3500N).

The upper neck moment M_y for the slouched dummy shows a positive moment from 85ms-110ms, whereas the baseline tests are still negative.

The lower neck force F_z peaks was much larger for the slouched dummy tests (1300-1500N) and occur later (95ms) compared to the baseline tests 900-1300N, occurring at 86ms.

5.4.4.3 Chest acceleration

The chest Z accelerations for the slouched dummy were showing positive loading between 90ms and 115ms. However in the baseline tests the Q10 dummy was measuring positive loading during the same period.

5.4.4.4 Pelvis acceleration

The pelvis acceleration resultant peak loading (25g-30g) occurs at 107 ms, whereas the baseline peak occurs earlier (95ms) and is smaller in magnitude (22g-25g) was also higher for the dummy in the slouched position.

5.4.4.5 Belt force loading

The belt force loading measured in the 3-point belt also showed a difference between the tests with a slouched dummy and the baseline.

In the slouched dummy tests the diagonal belt is loaded later compared to the baseline tests, with the peaks occurring 15ms-20ms later.

The reel belt also showed a similar trend with the loading in the slouched dummy tests occurring later compared to the baseline tests (15ms-20ms later).

5.4.5 Summary

The main aim of the durability testing was to evaluate the durability of the Q10 dummy. It is important that the Q10 is robust and durable enough to be able to undergo a number of impacts without regular breakages. It is also important that the number of maintenance checks needed between tests is at a minimum; this is to prevent delays between tests, as parts are tightened or inspected.

Only a few breakages were seen during the testing conducted by DOREL and TRL. All of these have since been addressed. The new designs to prevent these breakages from occurring will be implemented in the final version of the Q10. It is therefore envisaged that the Q10 is durable for normal use in Reg.44 testing.

The maintenance checks required between tests of the Q10 have been found to be comparable to those required by the current Reg.44 test dummy the P10.

The findings of the durability with different child restraint testing confirmed the findings of the sensitivity to child restraint design. These findings were that the Q10 is able to produce different loading in different designs of child restraint. Therefore the Q10 is sensitive to child restraint design.

The findings of the durability time dependency testing were that there was no drift in the results was found. This means there did not seem to be a relationship between the loadings measured by the Q10 and the amount of recovery time the dummy had between tests.

The findings of the durability dummy positioning testing confirmed the findings of the sensitivity to restraint loading. The slouched dummy position set-up produced consistent results that were significantly different than the baseline.

There was also no significant overall drift in the results of the same child restraint when tested over a number of tests. Therefore the results from the durability tests show that the Q10 was able to produce consistent repeatable results over extended testing (20 shots), without recalibration. Therefore it can be recommended that recalibration of the Q10 is conducted after every 20 tests. As long as the Q10 does not exceed 150% of the loading levels for each body region specified in D1.2.