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EUROPEAN ENHANCED VEHICLE-SAFETY COMMITTEE

Q10 dummy in Lateral Impact Report

Advanced Child Dummies and Injury Criteria for Lateral impact

Working Group 12 Report,
Document No. 646
November 24, 2015





EUROPEAN ENHANCED VEHICLE-SAFETY COMMITTEE

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kit is improved for the thorax and shoulder region compared to the regular frontal dummy, suggesting that the kit shall be used. The Q10 dummy is currently the best 10yo child dummy suitable for lateral impact test conditions. Further research is needed to improve the biofidelity of the upper leg, pelvis and the abdomen regions of the Q10 in lateral impacts.

It is proposed to implement initially 3 injury criteria for regulatory purposes: for the head (head acc 3ms), chest (lateral deflection) and shoulder (force). The proposed injury thresholds for the chest and shoulder should be evaluated in actual test conditions using various types of restraint systems.

Although the work in the report concerns the Q10 dummy, implications of the findings for the application of other Q-series dummies for side impact testing are given as well. Based on the experience with Q10 a development of a special side impact kit for the Q3 and Q6 might be considered, but before starting such a development EEVC WG 12 should evaluate the performance of the Q3s and Q6s, which were developed specifically for side impact for the North American market.

1 INTRODUCTION

This report is a follow-up of the EEVC report “Q10 Dummy Report - Advanced Child Dummies and Injury Criteria for Frontal Impacts” published in January 2015 [1]. The Q10 dummy is the tallest member of a family of 6 new child crash test dummies for child safety (Q dummies). Objective of the January 2015 report was to advise on the use of the Q10 dummy for frontal impacts in the new UNECE regulations on “Enhanced child restraint systems” (update of R44). The new UN Regulation 129 introduces also a side impact test procedure for child restraint systems and specifies the use of the Q-Series dummy. At its phase 1 redaction, the proposed test procedure assesses head containment and acceleration only. No limits are applied to other body regions in the side impact test procedure.

The Q dummies were designed for both front and side impact test procedures but the main priority and focus in the development has been on frontal impacts. The work described in this report will be on the use of the Q10 dummy in side impacts and will be based largely on work done in the EPOCH project (Enabling Protection for Older Children, 2009-2011 [2]) and third party testing with the baseline Q10 dummy as used for frontal impacts as well as the use of a special designed side impact kit for the Q10 dummy.

Regardless of impact direction, it is essential that the measurement capabilities of a new dummy reflect the injuries that are observed in the field among casualties of the same size, restrained in the same way. This enables the dummy to be used reliably in test procedures that target specific priorities for injury reduction. A broad range of accident data sources have been examined in the EPOCH and the CREST [3] projects to look for side impact injury trends for children. The results of this study are summarized in Chapter 2.

The evaluation of the Q10 for side impact described here includes among others: biofidelity, instrumentation and injury assessment options, repeatability and reproducibility, sensitivity, durability and injury criteria.

In Chapter 3, a description of the development and evaluation of the Q10 in lateral impact is given. For the biofidelity assessment pendulum tests and sled tests are presented. For sensitive, repeatability and reproducibility lateral impact certification type testing are used here.

Chapter 4 deals with experiences gained in testing the Q10 dummy within the EPOCH project, as well as during testing by third parties.

Chapter 5 deals with proposed child dummy injury criteria and injury risk functions for the Q10, which are defined based on scaling from the smaller Q-dummies and scaling on the basis of adult data.

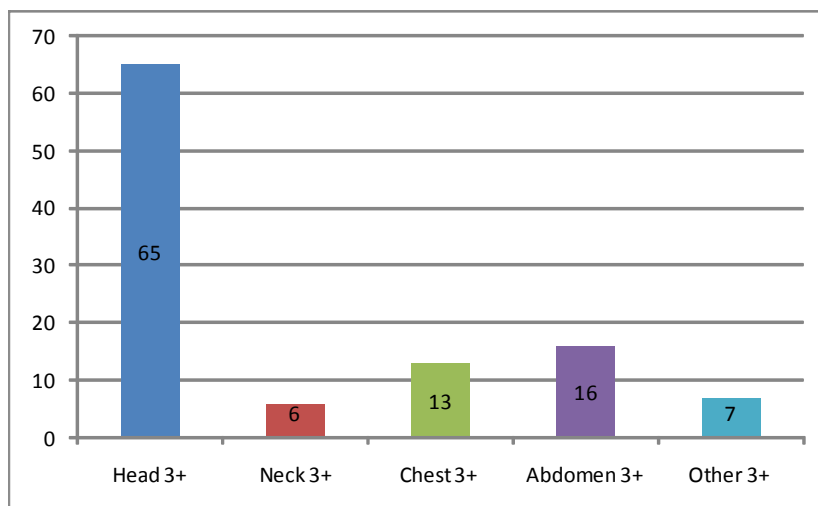
Chapter 6 concludes this report with a discussion and conclusion section including recommendations for further work. Although the work in the report concerns the Q10 dummy, implications of the findings for the application of other Q-series dummies for side impact testing are discussed as well.

2 CHILD INJURY CAUSATION STUDY

The EPOCH project has investigated the injuries received by older children in collisions as part of the process for specifying the measurement capabilities of the Q10 dummy. Therefore these activities are a good basis for establishing the causes of injuries to older children or the priorities for injury prevention. The EPOCH injury investigation work was described by Visvikis et al. (2009) [4] and was published on the project web-site (see www.EPOCHfp7.org). The intention of the work was to draw information primarily from previous large-scale European collision studies, such as those analysed by EEVC Working Groups 12 and 18 for their Q-dummies report (see Wismans et al., 2008 [5]), to support the injury information review. However, while these studies highlighted overall trends and priorities for the protection of children in general, it was impossible to separate the experiences of older children. These studies do, however, provide background information that defines, as well as possible, the injury situation for children in side impacts.

2.1 Europe wide information

Based on analysis of the CREST (Child Restraint STandard, a European collaborative research project) database, the distribution of serious injuries according to different body regions was deduced, as shown in figure 1.



**Figure 1: Side impact AIS 3+ injuries from CREST accident database (N=107)
 (reproduced from EEVC, 2006 [6])**

Head injuries accounted for 61% of all the serious injuries recorded in all restraint types. It was concluded that the current level of protection provided to prevent the occupant's head contacting rigid parts inside the vehicle or an intruding object is at present not sufficient. However, it should be noted that the restraint systems in this dataset may be considered as old (perhaps, out-of-date) compared with modern child restraint system designs and construction and that vehicles have also changed.

Serious injuries also frequently occur in the chest and abdomen body regions. These injuries were mainly observed when the child was sitting on a booster cushion or just using the adult belt and not in CRSs that have side wings for protection. For systems without side wing protection, the chest accounted for 22% of the injuries and the abdomen for 16% of the

injuries. This implies that the presence of side wings on a CRS is protective for the chest and abdomen, but less effective in preventing head injuries. Subsequently, there are proportionally more head injuries for CRS with side wings. However, whilst this is the implication, it may also reflect that the cohorts of children in CRS with and without side wings could be different. Also the types and severities of the side impact accidents causing the AIS ≥ 3 injuries could also be different. For instance, the side wings could be protective for the head, neck and torso, but that in very severe incidents, it will be the head that is most likely to be injured; though this could be at a severity much greater than would have caused an equivalent head injury if the side wings were not present.

2.2 French information

Previously, the EEVC (2006) [6] also analysed the CSFC database, where side impact collisions represented 16% of the total accidents. The CSFC database is a record of children of all ages involved in accidents in rural regions in France 1995-96. 206 children were involved in these accidents, of which 37% of children were uninjured, 43% sustained minor injuries and 20% were severely injured. Again, a limitation of these data is the age of the child restraint systems included within the accident cases.

Further analysis looked at the breakdown of injuries for only the struck side of the vehicle. Considering ‘moderate (AIS 2)’ injuries, this showed that the body area most often injured was the head with 42%, with upper limb injuries at 29% and abdominal injuries representing 19% (figure 2).

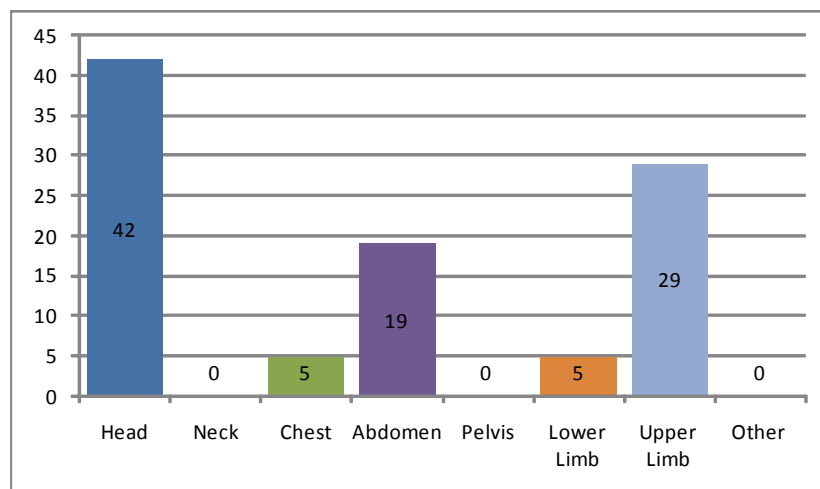


Figure 2: Side impact struck side occupant injury (AIS 2) frequency in percentage (reproduced from EEVC, 2006 [6])

It was concluded that there were not enough cases to draw a strong conclusion for severe injuries suffered by children during side impact collisions. However injuries to the head were very frequent and seemed to account for around 75% of the total body area injured for children involved in side impacts, who were restrained in forward facing child seats on the struck side. For children using booster type restraints head injuries only account for around 50% of the injured body regions and 40% for children only using the adult seat belt. This difference is not only due to the type of restraint system but also to the difference in height of the children and the corresponding impact areas with the interior of the vehicle. The study

was carried out before older children were using child restraint systems so those children restrained are likely to be aged up to 6 years.

Lesire et al. (2006) [7] concluded that in side impact the injury causations for children on the struck side of the vehicle were:

- Head injuries are the most frequent injuries and occur due to head contact with rigid parts of the vehicle interior.
- Chest and abdomen injuries are the next most frequently injured body regions and occur due to compression through door panel contact.
- Upper limb injuries are more frequent for children using booster type restraints and are also usually caused by door panel contact.
- Pelvis and lower limb injuries become more frequent for children only restrained by the adult seat belt as there is no protection from intrusion.

2.3 UK information

In an effort to gain more detailed information on older children, the EPOCH partners performed a new analysis of the United Kingdom Cooperative Crash Injury Study (for the period 1998-2008). This work was outside of the original scope of the project and hence a Europe-wide analysis of representative data was not feasible. Nevertheless, these UK data provided a useful insight into the types of injuries and mechanisms experienced by older children (aged 6 to 12 years).

Five restrained children (aged 6 to 12 years) received AIS \geq 2 injuries in side impacts. Details of the sample are shown in table 1. The average age of the injured children was 7.8 \pm 2.2 years. Where reported, the average velocity change (Δv) was 26 km/h. One child was seated in the front passenger seat and four children were seated in the rear outboard seats.

Table 1: Cases of AIS \geq 2 injury in restrained children aged 6 to 12 years involved in a side impact collision

Case	Age	Restraint type	Seating position	MAIS (Body region)	PDOF/ Δv (km/h)	Object hit
1	11	Adult seat belt	Rear nearside	2 (Head)	1/Unknown	HGV or PSV
2	6	Adult seat belt	Front seat	2 (Head)	11/25	MPV or LGV
3	6	Adult seat belt	Rear offside	4 (Head)	3/17	Car
4	9	Adult seat belt	Rear nearside	3 (Thorax)	10/27	Car
5	7	Adult seat belt	Rear nearside	2 (Lower extremity – left and right)	10/34	Car

There were 8 AIS \geq 2 injuries among the 5 children. The distribution of injuries is shown in figure 3. Half of the injuries occurred in the head (n=4). There were too few cases with AIS \geq 2 injuries to identify any trends associated with the likelihood or severity of injury for older children in side impact. However, in general, the proximity of the child to the intruding side structures, and the level of intrusion into the passenger compartment are important.

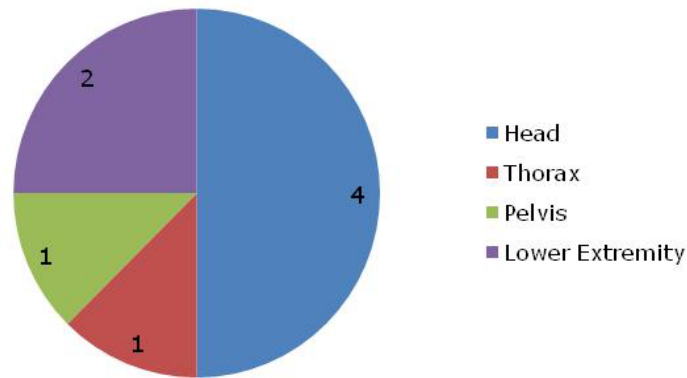


Figure 3: Distribution of AIS \geq 2 injuries (n=5) among restrained children

The CCIS sample consisted of 127 children aged 6 to 12 years and including all restraint types and injury levels. Eight of these children were known to be using a child restraint system: 2 were in a booster seat, while 6 were in a booster cushion. Table 1 reveals that none of the children on booster cushions and booster seats received AIS \geq 2 injuries. It was impossible, therefore, to make any meaningful comments on the performance of the child restraint systems in side impact.

2.4 Conclusions

There are few severe injuries to correctly restrained older children recorded in the accident databases maintained around Europe. This indicates that restraint systems for older children are able to provide good protection for children. However, when severe injuries occur, consistent trends were found among the various sources of data documented for the EPOCH review.

Head injuries accounted for the majority of all the serious injuries recorded in all restraint types. It was concluded that the current level of protection provided to prevent the occupant's head contacting rigid parts inside the vehicle or an intruding object is at present not sufficient. However, it should be noted that with retrospective accident analyses and this information being taken from a review of accident analyses, the restraint systems used in the accidents may be considered as old (perhaps, out-of-date) compared with modern child restraint system designs and construction. Also, vehicles will also have changed in the period from these accidents occurring to this review of the information available.

Other than the head, serious injuries were also frequently found to occur in the chest and abdomen body regions. These injuries occur due to compression through door panel contact. They were mainly observed when the child was sitting on a booster cushion or just using the adult belt and not in CRSs that have side wings for protection. It was noted from the CREST database of accident cases that CRS with side wings were more effective at preventing chest and abdomen injuries than in protecting the head, when compared with systems without side wing protection.

Upper limb injuries were also prevalent in the French accident data and should not be neglected from consideration of injury priorities for prevention in the future.

3 DUMMY DEVELOPMENT AND EVALUATION IN CERTIFICATION TYPE TESTING

3.1 Dummy Description

Specific design features of the Q-dummies are: the anatomical representation of body regions, the modular design, the dummy-interchangeable instrumentation, the multi-directional use (frontal & side impact) and the easy handling properties (limited component count, easy assembly/disassembly and simple calibration). The initial goal was to develop dummies for multi directional use, however, priority has been given to reach compliance with frontal impact performance targets. As a result, the side impact performance is not as good as for frontal impact. This is the reason why for the Q10 a side impact kit was developed. This kit comprises a modified shoulder joint with load cell and a new upper arm with flexible bone structure. In this report the focus is on lateral performance.

The dummy layout of the Q10 is rather similar to that of the other Q-dummy family members except for the pelvis structure, which is similar to the design of the WordSID dummies.

The Q10 dummy for frontal impact is extensively described in the EEVC WG12 document 642, published January 2015 [1]. The following sections on anthropometry, biofidelity, repeatability and reproducibility, sensitivity, durability and handling provide specific side impact related information. Where it is applicable reference will be made to the Q10 frontal report [1].

3.2 Side Impact Kit Anthropometry

The Q10 anthropometry is described in [1]. For side impact a dedicated half arm is designed. This half arm is based on the arm design of the WorldSID 50th dummy. This paragraph describes the anthropometry details of the half arm.

The Q10 side impact arm design uses the same shoulder joint location as the Q10 full arm for frontal impact, the outer contour of the half arm is almost identical to that of the upper arm of the frontal full arm configuration. In figure 4 the Q10 side impact half arm (grey) is compared with frontal full arm.

The following anthropometry details highlight the differences of the side impact half arm with respect to the frontal full arm:

- Arm is made symmetrical so that it can be used at both sides.
- Main dimensions are:
 - Length 268 mm (top of shoulder to bottom elbow).
Compared to full upper arm length 292 mm (slightly shortened to improve repeatability and reproducibility by preventing interaction of the elbow with pelvis bone in case of lateral flexion of lumbar spine).
 - Width 80 mm (back to front).
Compared to full upper arm width 74 mm (consequence of making the arm symmetrical).
 - Depth 50 mm (outside to inside).
Compared to full upper arm depth 57 mm (arm circumference maintained to fit with the suit sleeve).

- Flat inside face with increased gap with the rib cage at the arm pit.
- Instead of a ball joint a joint with two rotational axis of freedom is used. The joint allows rotation about the X-axis (abduction and adduction) and about the Y-axis (flexion and extension) the rotational freedom about the upper arm bone longitudinal axis is eliminated.
- Mass of half arm tuned with ballast in the flesh simulating soft plastic material to match with frontal upper arm. The mass of the omitted lower arm is not compensated.

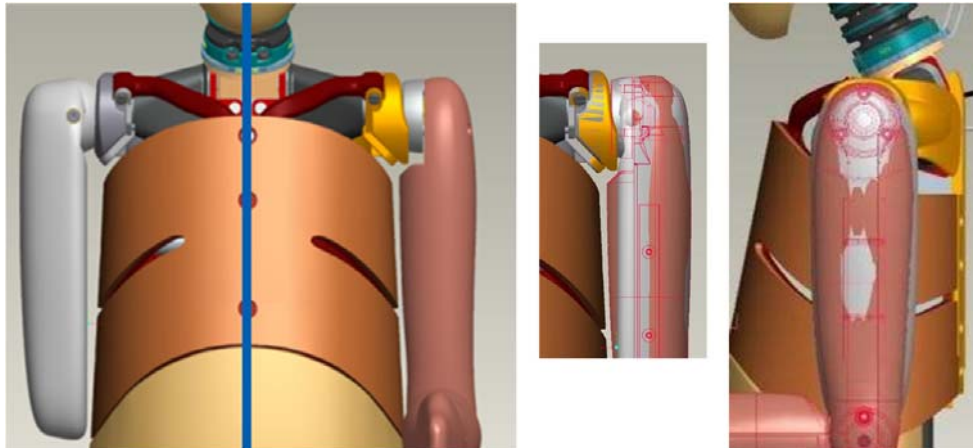


Figure 4: Q10 side impact half arm (grey) compared with frontal full arm

The dimensions of the side impact half arm generally complies with the anthropometry of the 10.5 year old child (ref. [1] Annex C). The adaptations to the outer contour of the Q10 were applied to promote stable impact performance.

3.2.1 Measurement Capabilities

The Q10 dummy facilitates a large number of instrumentation options and the side impact kit includes enhanced measurement option in the shoulder region. In figure 5, an overview of the available instrumentation options is given. In ANNEX A: Q10 MEASUREMENT CAPABILITIES a more extensive description of the possible instrumentation channels is given.

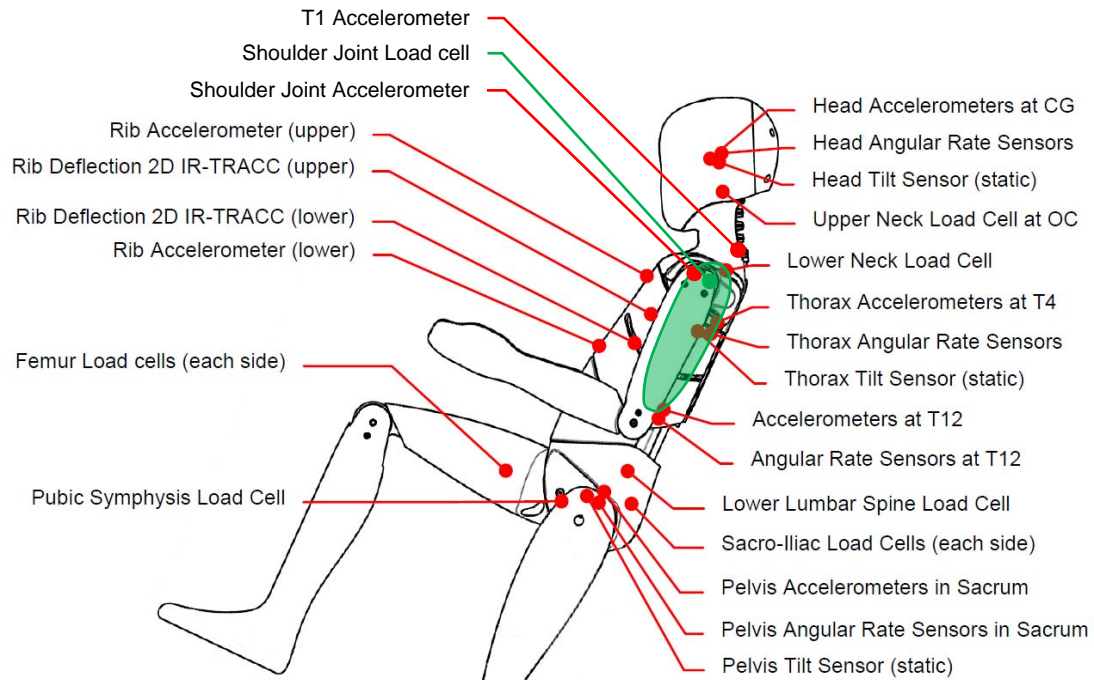


Figure 5: Q10 Overview of instrumentation options (with side impact kit in green)

3.3 Biofidelity

In this section the Q dummy biofidelity performance information for lateral impact is presented per body region based on component and full body pendulum tests. Moreover the Q10 side impact performance in sled tests conducted at BAST and reported by TRL at the IRCOBI conference 2014 [8] are summarised.

3.3.1 **Biofidelity in Component and Full Body Pendulum Tests**

Head

For the head biofidelity, two criteria for head drops on a rigid plate have been evaluated:

- 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.
- Lateral 200 mm drop height: Biofidelity corridor limits based on ISO TR9790 scaling are: 107 – 161 g;
 - The average measured value is 179.5 g (out of the corridor see statement below).

The ISO acceleration corridor is lower than the EEVC one although the drop height is larger, because the EEVC does not consider skull fracture while ISO includes data with and without skull fracture.

The head drops were performed with a half upper neck load cell replacement attached to the head base plate. In figure 6 the resultant head accelerations versus time are shown together with the corridors specified above (Note: the corridor is an acceleration range and not timing requirements).

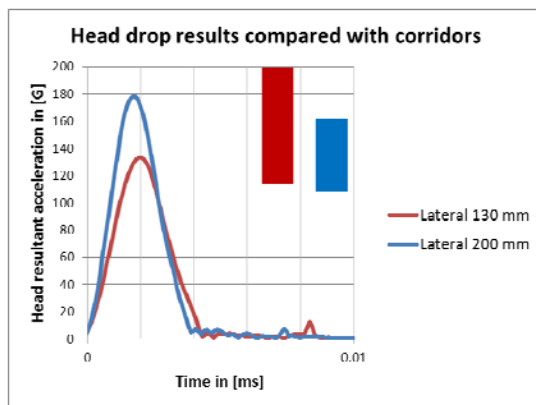
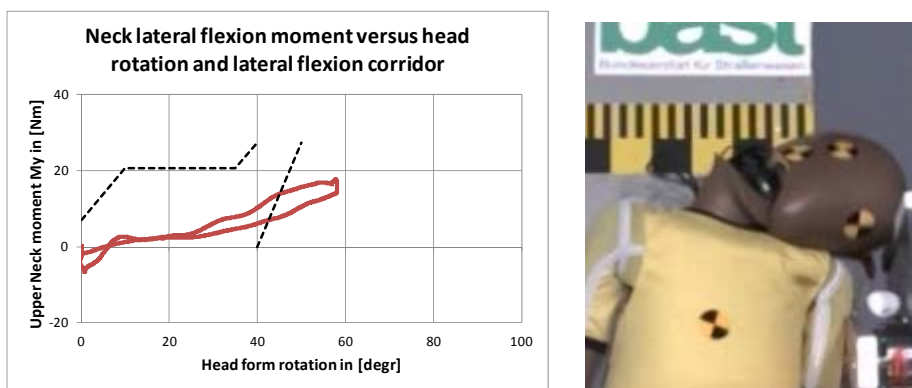


Figure 6: Head drop biofidelity results (Q10 prototype)

It can be observed that the head meets the lateral (130 mm) requirements low in the EEVC corridors and the results for the lateral 200 mm ISO based test exceeds the corridor significantly. It was concluded that simultaneous compliance with EEVC and ISO lateral requirements was not possible with the current design and that for an improved compliance with the EEVC requirement a stiffness increase was desired. Based on experience with other dummies, it seems likely that head stiffness will increase when the product ages. Therefore, it was decided to slightly increase the stiffness of the production dummy heads such that its performance will become closer to the middle of the biofidelity corridor. For the Q10 production version the head performs in the lateral impact certification corridor between 128.7 and 157.3 (see paragraph on Certification in this Chapter).

Neck

Figure 7 (left) shows the neck lateral flexion bending performance in a Part 572 neck pendulum test, in comparison with the lateral flexion biofidelity corridor. It can be concluded that up to 45 degrees of head lateral flexion the response is within the corridor, and above 45 degrees, it is below the corridor. Based on head kinematics observed in the biofidelity sled tests at BAST (figure 7 (right)) it can be concluded that the head to shoulder contact occurs at a lateral head flexion of 70 to 80 degrees.



**Figure 7: Left: Neck lateral flexion moment versus head rotation
 Right: Maximum head rotation in the MCW sled test**

Shoulder

For the shoulder 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 = 8.76kg, diameter = 112 mm, six wire suspended). In figure 8 the test setup is shown for the Q10 in full arm and half arm configuration.

Figure 9 shows the pendulum force versus time in comparison with and scaled biofidelity corridor as presented in the IRCOBI conference 2014 [8]. The scaled impact conditions replicating PMHS tests from the literature were provided through an 8.76 kg pendulum with a speed of 4.5 m/s. Findings from these tests were that:

- The peak pendulum force are almost double as high as the average values of the corridor.
- There is a negligible difference between test results with the Q10 prototype [5] and the Q10 production version.
- The two tests with the Q10 side impact shoulder kit show a better response resulting in a 500 N (17%) reduction in maximum pendulum force with respect the Q10 full arm results.
- The duration of the pendulum force signal for the side impact shoulder kit increased by about 5 ms with respect to the Q10 frontal arm results, bringing it closer to the biomechanical corridor.

In figure 10 the WorldSID 5th (Rev. 1) performance data with respect to the corridor relevant for WorldSID 5th are given for comparison. It should be noted that there are scaling differences between Q10 and WorldSID 5th: This can be attributed to anthropometry differences as well as difference in impactor mass (Q10: 8.76 kg, WS5: 14.0 kg). It is obvious that the Q10 shows a higher overshoot and a smaller time base than the WorldSID 5th that comes close to the scaled corridor. The Q10, that is not specifically designed as a side impact dummy, is less compliant than the WorldSID 5th which is designed to comply with the lateral impact requirements.



Figure 8: Q10 dummy in shoulder impact pendulum test setup
Left: Q10 with full arm Right: Q10 with half arm

It can be observed that the initial response of the shoulder overestimates the force whereas the response at later times gives lower force. This can be related to the more elastic and earlier rebound behaviour of the dummy relative to the PMHS.

In the pendulum test evaluation, though peak shoulder forces do come down with the side kit modification, they have not been reduced sufficiently to fit within the corridors (either the EEVC corridor used as a design target or the scaled ISO 9790 corridor). Also, the equivalent test results for the WorldSID-5F Revision 1 dummy [9] are closer to the respective fifth female corridor than the Q10 is to its corridor. The peak impactor force for the WorldSID 5th

is only 15 to 20 % higher than the upper boundary of the corridor, rather than 40 to 50 % as with the Q10 fitted with the side impact kit.

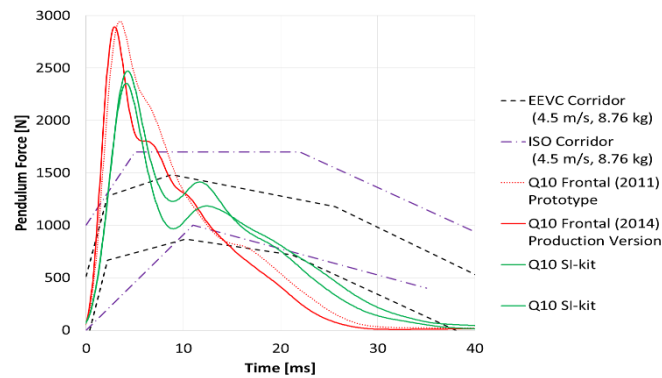


Figure 9: Q10 Lateral Shoulder impact force versus time [8]

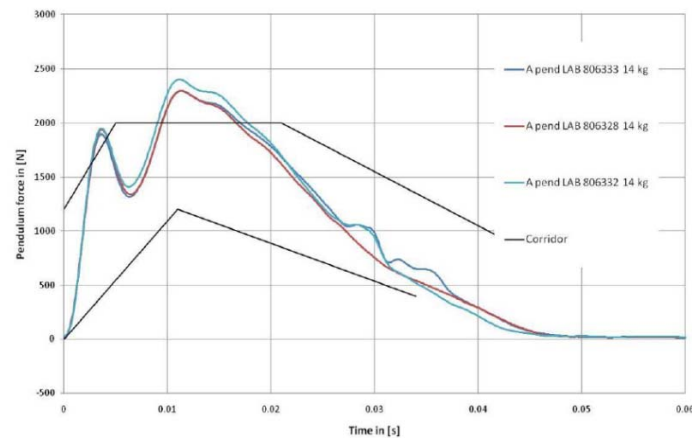


Figure 10: WorldSID 5th (Rev. 1): Shoulder impact pendulum response (4.5 m/s, 14 kg) [10]

Thorax

For the lateral biofidelity two pendulum test impact speeds with an 8.76 kg pendulum 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 time. The results are compared with the biofidelity corridors. The “Q10 corridor” is EEVC recommended corridor for adults scaled according to the Q-series methodology [1] (Annex C - Q10 Design Brief) and the “ISO 10yo” is the corridor specified in ISO/TR9790 [11].

In figure 13 and figure 14 the WorldSID 5th (Rev. 1) performance data with respect to the corridors relevant for WorldSID 5th are given for comparison. It should be noted that there are scaling differences between Q10 and WorldSID 5th: This can be attributed to anthropometry differences as well as differences in impactor mass and speed (Q10: 8.76 kg at 4.3 and 6.7 m/s, ISO corridor 10yo: 6.9 kg at 4.3 and 6.0 m/s and WS5: 14.0 kg at 4.3 and 6.0 m/s). The Q10 shows a steeper loading curve a similar overshoot and a smaller time base than the WorldSID 5th. The Q10 is less compliant than the WorldSID 5th.

As for the shoulder the initial response of the thorax overestimates the force whereas the response at later times gives lower force. This can be related to stiffness or to more elastic

and earlier rebound behaviour of the dummy relative to the PMHS. This is true for both impact speeds.

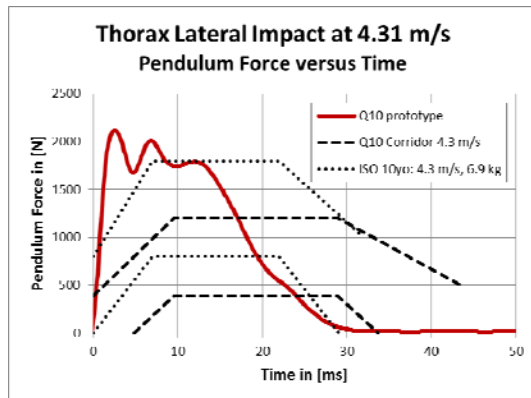


Figure 11: Thorax lateral pendulum impact (4.31 m/s, 8.76kg)

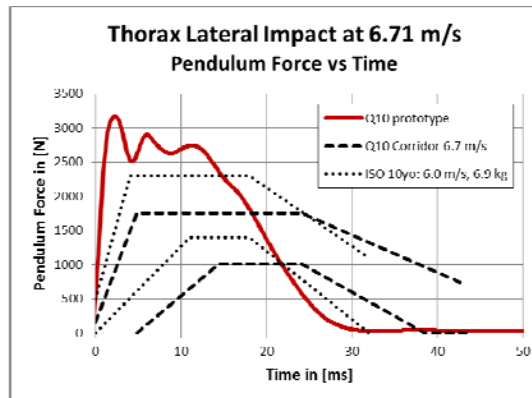


Figure 12: Thorax lateral pendulum impact (6.71 m/s, 8.76 kg)

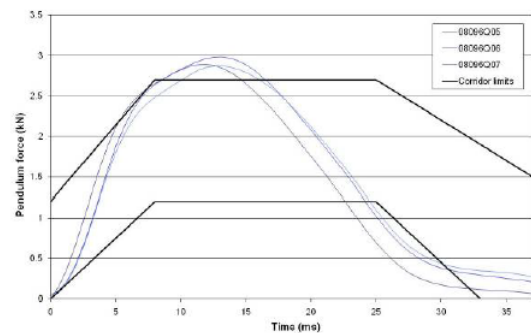


Figure 13: WorldSID 5th (Rev. 1) Thorax lateral pendulum impact (4.3 m/s, 14 kg) [10]

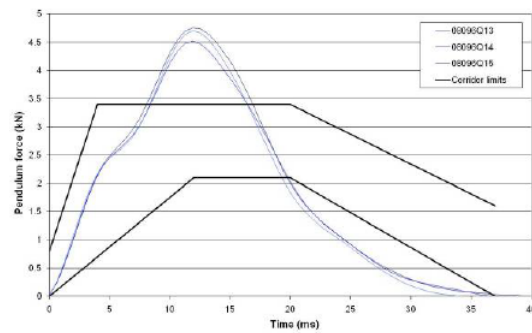


Figure 14: WorldSID 5th (Rev. 1) Thorax lateral pendulum impact (6.0 m/s, 14 kg) [10]

Lumbar Spine

The lateral bending and shear performance of the lumbar spine, which is a cylindrical column, is equivalent to that for frontal as reported in [1]. There are no biofidelity targets specified for the lumbar spine.

Abdomen

There is no lateral impact related performance data available for the abdomen.

Pelvis

The Q10 pelvis lateral impact biofidelity target corridor is based on Viano 1989 [12]. The impactor force versus time corridor for adults is scaled in accordance with the method given in the Q6 Design Brief [13]. Moreover the impactor force versus impact speed corridor, scaled from Irwin 2002 [14], is used for comparison with WordSID 5th performance.

The pelvis lateral full body biofidelity test should be done with a pendulum mass of 8.76 kg 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 peak pendulum force is found to be about linear with the impact speed in this interval (see figure 16). In figure 15 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 15 is based on scaling factors estimated by interpolation using the pelvis impact corridor specified in the Q6 design brief and the corridor for adults.

In figure 16 the pendulum force versus impact speed is shown together with the relevant corridor scaled for Q10 (impactor mass 8.76 kg). In figure 17 the WorldSID 5th (Rev. 1) performance data with respect to the corridors relevant for WorldSID 5th are given for comparison. It should be noted that there are scaling differences between Q10 and WorldSID 5th: This can be attributed to anthropometry differences as well as differences in impactor mass and speed (Q10: 8.76 kg and WS5: 14.0 kg scaled down to 10.1 kg). It is obvious that the Q10 shows a curve that is overall far above its corridor whereas the WorldSID 5th performance is crossing its corridor between 6 and 8 m/s. The Q10 dummy is less compliant than the WorldSID 5th which is designed to comply with the lateral impact requirements.

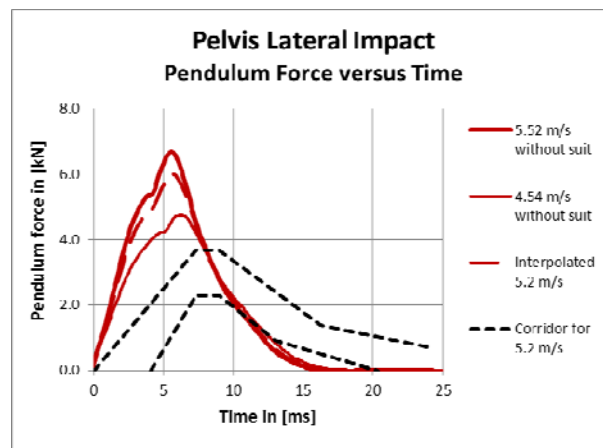


Figure 15: Pelvis lateral pendulum impact at 5.2 m/s (prototype)

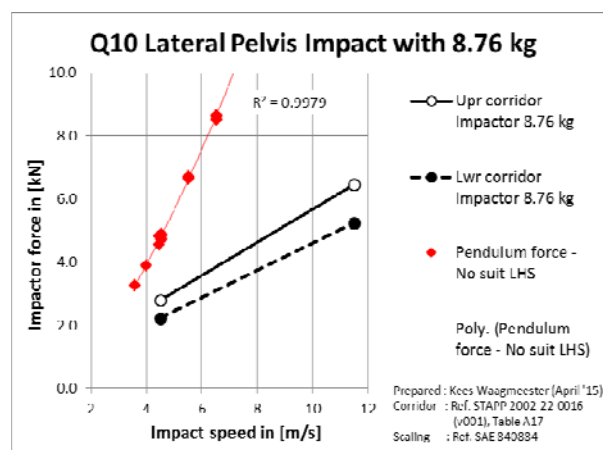


Figure 16: Q10 Pelvis lateral pendulum impact force versus impact speed (prototype)

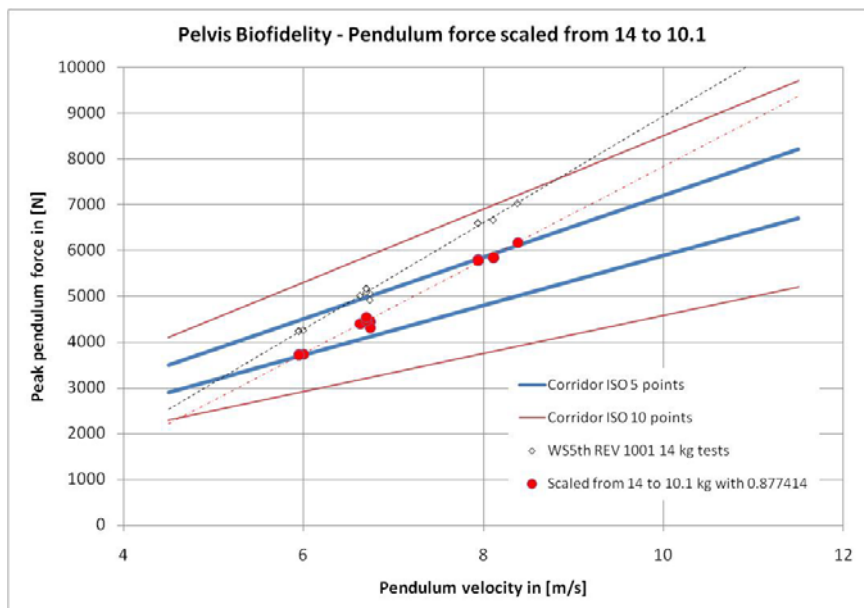


Figure 17: WorldSID 5th (Rev. 1) pelvis lateral pendulum impact force versus impact speed (results scaled for impactor mass from 14 kg to 10.1 kg) [9]

3.3.2 Biofidelity in Sled Tests

The Q10 dummy with full arm and half arm (side impact kit) was tested in a rigid wall side impact sled test setups according to the Heidelberg, Medical Centre Wisconsin (MCU) and Wayne State University (WSU) sled configurations. The study compared the baseline dummy against a dummy equipped with the side impact kit. The work included the definition of size-appropriate whole-body side impact biofidelity requirements for the Q10 dummy; scaling of test procedures for the evaluation of the Q10 against these requirements; and running the biofidelity performance tests. Details of the test configurations, scaling applied etc. as well as results are described in [8].

Heidelberg sled tests

The thorax plate force responses from the 6.8 m/s tests into the rigid Heidelberg force plates are shown in figure 18. The peak dummy acceleration measurements from the pelvis are shown in figure 19. From figure 18 it can be observed that upper plate forces are within the ISO corridor both for the original parts and the side impact kit. Repeats of tests with the side impact kit demonstrate a good level of repeatability. It can also be noted that the responses with the side impact kit are similar to those with the original parts. Although detailed kinematic analyses were not conducted on the test videos, no substantial difference in behaviour or head motion was observed between the two configurations. Peak pelvis accelerations from figure 19 indicate that values are higher than the upper limit of the ISO biofidelity requirement. On closer investigation of the pelvis acceleration responses (as shown in figure 21) and the time-histories, two things were determined; firstly that the acceleration would have been slightly higher than the biofidelity requirement due to the exerted force being too high or the effective mass being too low, secondly that a hard contact occurred within the pelvis. This hard contact manifests itself in the response as a spike in the pelvis acceleration which makes the peak value much higher than the ISO requirement. It also presents a design issue if the contact offers an un-instrumented load path for the transmission of force through the pelvis which could be used to offset loading to other instrumented regions. For reference purposes the thorax performance of the WorldSID 5th is

shown in figure 20 with respect to the Heidelberg biofidelity corridor. The WorldSID 5th performance is within in or close to the corridor, but it can be seen that the Q10 response is closer to the centre of the corridor, so more biofidelic than the response of the WorldSID.

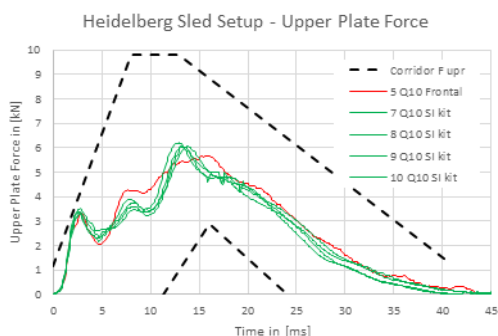


Figure 18: Upper (thorax) plate forces from Heidelberg sled test at 6.8 m/s into the rigid load cell wall (Q10 Frontal signal not compensated for sled acceleration)

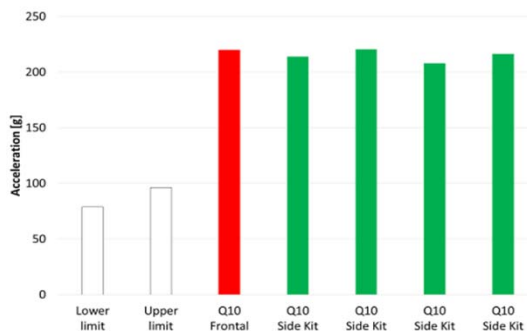


Figure 19: Peak pelvis accelerations from Heidelberg sled test at 6.8 m/s into the rigid load cell wall

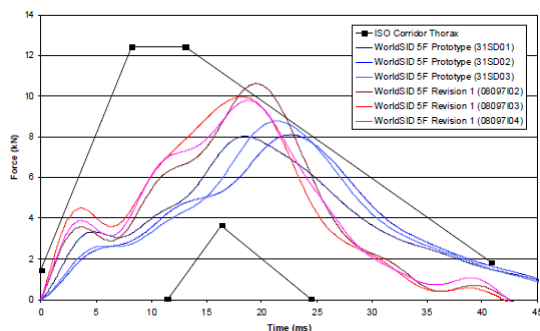


Figure 20: WorldSID 5th (Prototype, blue lines; Rev. 1, red lines) Upper (thorax) plate forces from Heidelberg sled test at 6.8 m/s into the rigid load cell wall [10]

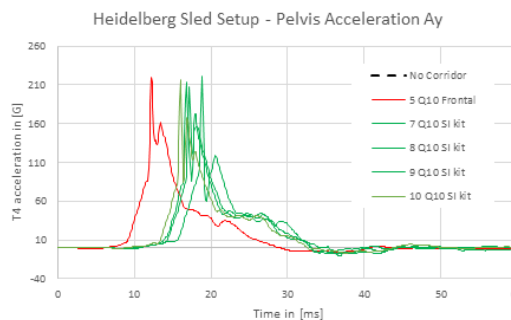


Figure 21: Pelvis acceleration time histories from the Heidelberg sled test at 6.8 m/s into the rigid load cell wall

Wayne State University (WSU) sled tests

The abdomen and pelvis plate force responses from the 6.8 m/s tests into the rigid WSU force plates are shown in figure 24 and figure 25. Unfortunately, there is no biofidelity requirement for the shoulder and the thorax plate force for this WSU condition, though results from these force plates are shown in figure 22 and figure 23.

Also in this condition too much force is transferred through the pelvis, while the abdomen plate force is below the corridor. Whilst the peak value of shoulder plate force is similar between the two configurations tested, the side impact shoulder kit offers a lower inertial peak in the first 5 ms and a shorter overall duration of shoulder plate force. Whilst this is evident in the transducer data, no clear kinematic differences were observed in the test videos; noting that quantitative analyses were not undertaken by the original authors. It is felt that the more compliant shoulder allows slightly more work to be done by the pelvis and that this small change gives a big difference in force once the pelvis to sacrum contact occurs, which is likely in these severe sled test condition. However, the force on the pelvis plate was well above the upper limit of the biofidelity requirement. This was true before any notable change in the force-time history due to testing with or without the side impact kit.

It should be noted that the responses from the dummy are synchronised on the first rigid wall contact, therefore the delay in the abdomen and pelvis response represents the time between the first contact between the thorax plate and the shoulder and the application of substantial force through the lower body regions. For simplicity and consistency of approach with other dummies and the original PMHS tests, the pelvis plate wasn't offset towards the dummy to give a simultaneous loading between shoulder and pelvis. Therefore the result is dependent on the anthropometry of the dummy as well as its dynamic response. The Abdomen and Pelvis plate force results figure 24 and figure 25 could be time-shifted to align the peak response with the peak in the corridor target. However, this would not help the dummy meet the requirements in this instance, it also removes some of the interesting information offered regarding the sequence of contacts (implicit in these synchronous data).

In figure 26 and figure 27 the WorldSID 5th (Rev. 1) performance data with respect to the corridors relevant for WorldSID 5th are given for comparison. It should be noted that in the WorldSID 5th graphs time shifts are applied to position the loading curves in the start of the corridor.

- Abdominal plate forces for Q10 are rather low, for WorldSID 5th close to the upper corridor. The time base of these signals are comparable but a little too short (Q10: 15ms, WorldSID 5th: 20ms) relative to the corridor time base (40 ms).
- Pelvis plate forces for Q10 are way too high (overshoot factor 2.9), for WorldSID 5th exceeding the upper corridor (overshoot factor 1.4). The time base of these signals is comparable and matching with the corridor time base.

The Q10 is less compliant than the WorldSID 5th which is designed to comply with the lateral impact requirements.

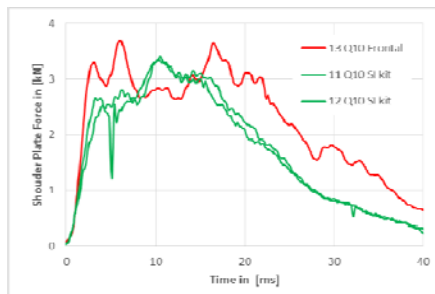


Figure 22: Shoulder plate forces, WSU sled test at 6.8 m/s

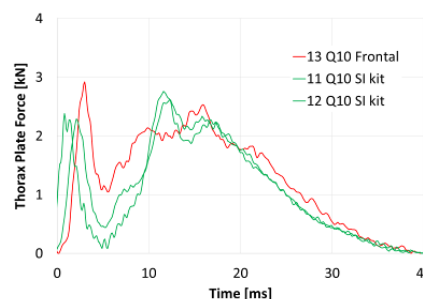


Figure 23: Thorax plate forces, WSU sled test at 6.8 m/s

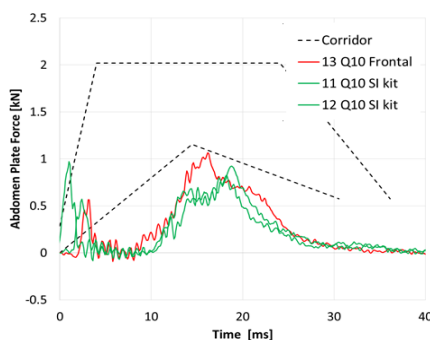


Figure 24: Abdomen plate forces, WSU sled test at 6.8 m/s

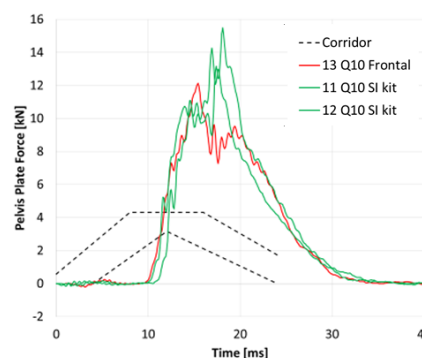


Figure 25: Pelvis plate forces, WSU sled test at 6.8 m/s

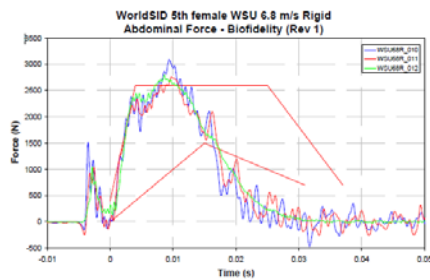


Figure 26: WorldSID 5th (Rev. 1) Abdomen plate forces, WSU sled test at 6.8 m/s [10]

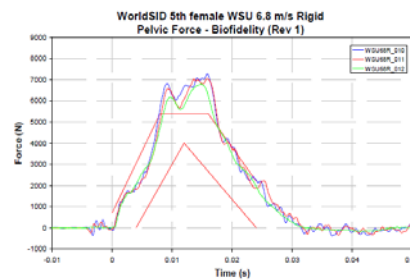


Figure 27: WorldSID 5th (Rev. 1) Pelvis plate forces, WSU sled test at 6.8 m/s [10]

Medical Centre Wisconsin (MCW) sled tests

The thorax, abdomen and pelvis plate force responses from the 6.8 m/s tests into the rigid MCW force plates are shown in figure 28, figure 29 and figure 30. None of the dummy responses fits within the biofidelity corridors. The duration of the loading seems reasonable for all three load cell plates and the general shapes (modality) of the abdomen and pelvis plate responses show similarities with that of the corridor. However the amplitudes and time of peak differ from the reference corridors. In this configuration a hard contact was again evident in the pelvis acceleration responses, starting at about 90 G. The pelvis plate load at this point was about 9.5 to 10.5 kN and already above the upper limit of the biofidelity requirement.

With the thorax plate, the initial peak in force is not a characteristic seen in the PMHS behaviour. The side impact kit helps to reduce this feature, bringing the shape of the response closer to that of the corridor.

In figure 31, figure 32 and figure 33 the WorldSID 5th (Rev. 1) performance data with respect to the corridors relevant for WorldSID 5th are given for comparison:

- Thorax plate forces for Q10 are too high (overshoot factor 1.43), for WorldSID 5th close to the middle of the corridor. The time base of these signals is comparable but a little too short relative to the corridor time base and the Q10 shows a more rapid start.
- Abdomen plate forces for Q10 are rather low, for WorldSID 5th generally within the corridor. The time base of these signals is comparable and matching with the corridor time base.
- Pelvis plate forces for Q10 are much too high (overshoot factor 2.00), for WorldSID 5th close to the middle of the corridor. The time base of these signals for Q10 and WorldSID 5th are comparable but a little too short relative to the corridor time base.

The Q10 is less compliant than the WorldSID 5th which is designed to comply with the lateral impact requirements.

Figure 34 and figure 35 show upper and lower chest deflections compared to corridors. For the frontal dummy (full arm) the deflections are already close to the expected peak values. Although the Q10 side impact kit responses still do not meet corridors it is evident that the side impact kit improves the peak deflection values measured, making them both laying closer to each other and within the range of expected peak values from the biofidelity corridors, though the timing of the dummy response means the peak occurs too early. The pelvis acceleration responses in figure 36 again demonstrate that forces in the Q10 dummy are too high in these tests.

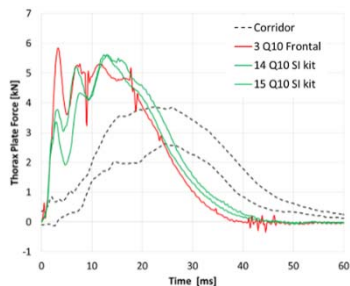


Figure 28: Thorax plate forces, MCW sled test at 6.8 m/s

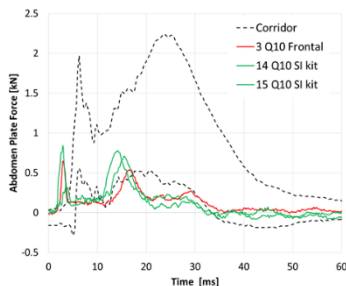


Figure 29: Abdomen plate forces, MCW sled test at 6.8 m/s

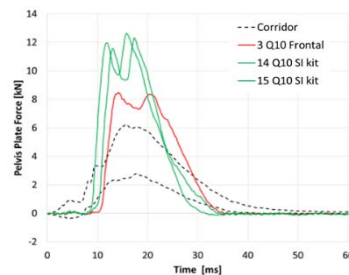


Figure 30: Pelvis plate forces, MCW sled test at 6.8 m/s

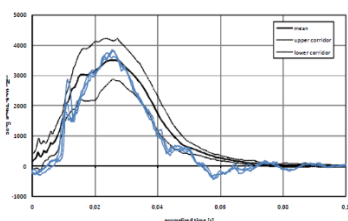


Figure 31: WorldSID 5th (Rev. 1) Thorax plate forces, MCW sled test at 6.7 m/s [10]

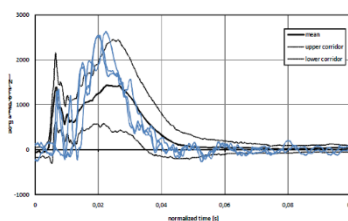


Figure 32: WorldSID 5th (Rev. 1) Abdomen plate forces, MCW sled test at 6.7 m/s [10]

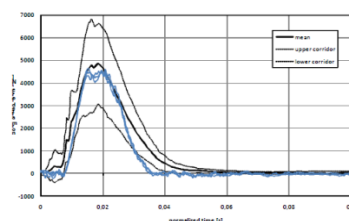


Figure 33: WorldSID 5th (Rev. 1) Pelvis plate forces, MCW sled test at 6.7 m/s [10]

In figure 37, figure 38 and figure 39 the WorldSID 5th (Rev. 1) performance data with respect to the corridors relevant for WorldSID 5th are given for comparison:

- Chest deflection upper for Q10 and WorldSID 5th are comparable in the lower part of the corridor. The time base of these signals is also comparable. The signal for Q10 starts relatively too early and for WorldSID 5th too late.
- Chest deflection lower for Q10 and WorldSID 5th are comparable in the lower part of the corridor. The time base of these signals is also comparable. The signal for Q10 starts relatively too early and for WorldSID 5th too late.
- Pelvis acceleration for Q10 and WorldSID 5th are comparable (apart from the strange Q10 peaking). The time base of these signals is also comparable. The signal for Q10 starts relatively late.

The Q10 is less compliant than the WorldSID 5th which is designed to comply with the lateral impact requirements.

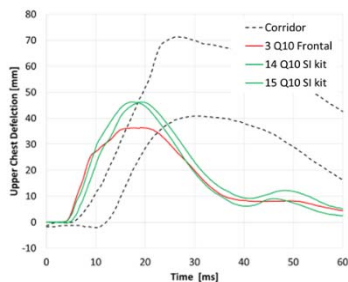


Figure 34: Chest deflections (upper), MCW sled test at 6.8 m/s

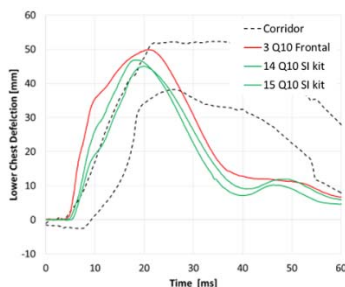


Figure 35: Chest deflections (lower), MCW sled test at 6.8 m/s

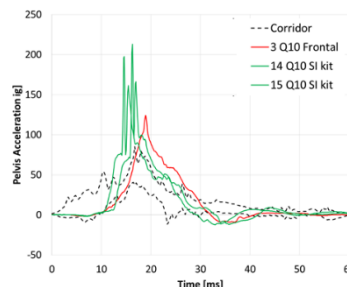


Figure 36: Pelvis accelerations, MCW sled test at 6.8 m/s

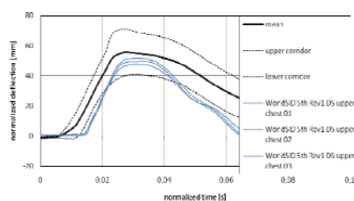


Figure 37: WorldSID 5th (Rev. 1) Chest deflections (upper), MCW sled test at 6.7 m/s [10]

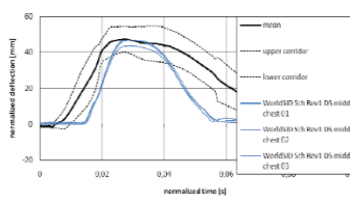


Figure 38: WorldSID 5th (Rev. 1) Chest deflections (lower), MCW sled test at 6.7 m/s [10]

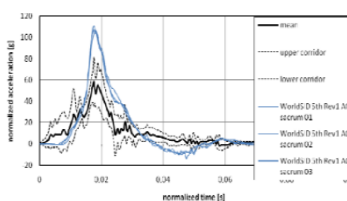


Figure 39: WorldSID 5th (Rev. 1) Pelvis accelerations, MCW sled test at 6.7 m/s [10]

Discussion and conclusions

Shoulder region – No specific requirements could be defined nor assessed from any of the tests considered. Related to the side impact kit, the results for upper plate forces show a minor influence only in the upper plate responses, which indicates that the response is driven more by the dummy mass rather than by the local stiffness. Initial peak values are reduced though.

Thorax region – The Q10 thorax responses with or without the side impact shoulder kit are in the centre of the scaled corridor for the Heidelberg configuration. This is similar or even better than the performance shown by WorldSID 5th. For the MCW tests on the other hand, the thorax plate responses are higher than the corridor whereas WorldSID 5th shows thorax plate loads that are in or close to the corridor. In contrast to side impact dummies, the Q10 does not have an abdomen designed to control deformation in lateral loading in the region of the soft tissue and the floating and false ribs. The lumping of false and floating ribs in the ribcage in the Q10 may contribute to the higher force responses in the thorax region. The soft upper arm bone of the side impact shoulder kit, results in a more compliant interaction in the thorax region with regards to upper and lower chest deflection. The metal bone of the original arm shielded the upper part of the thorax while bridging between the shoulder and the lower torso. Due to the flexible bone the shielding is reduced and the loading is distributed more evenly over the impacted area, bringing chest deflection results closer to the MCW biofidelity corridors with a relatively early start. The WorldSID 5th results show a relative late start of the ribs response, however the rebound is not so fast due more damping in the ribs. The WorldSID 5th shows a better compliance than the Q10.

Abdomen region – In the abdomen region, the Q10 dummy responses, with and without the kit, follow trends as observed in the PMHS tests but loadings are well below the corridors

defined. This may be explained by the fact that the Q10 does not have a separate representation of the abdomen and floating and false ribs region in two rib units as in WorldSID. In the Q10 the floating and false ribs are lumped in the integral rib cage. The WorldSID 5th results show a better compliance due to better, separated, abdomen representation.

Pelvis region – In the pelvis region higher forces and accelerations are observed both with and without the side impact kit. Although the trends of the signals matches those of the response requirements quite well, values are too high which may be explained by the lumping of the lower torso mass in the rigid sacrum block, increasing the effective mass in this region. Also the pelvis and upper leg representation in the Q10 are likely to be more rigid than the PMHS used to define the requirements for side impact as the dummy design focus was on frontal impact. This could also contribute to the forces and accelerations being higher than the requirements. Moreover the Q10 pelvis suffers in the sled tests from bottoming out of the iliac wing and hip joint hardware against the sacrum block, whereas the WorldSID 5th is free of bottoming out in all three sled test configurations. The Q10 production version is free of bottoming out up to the impact severity of the certification pendulum test at 4.3 m/s, but bottoming out may still occur at higher impact severities. This may present an issue in applications where the severity of loading to the Q10 pelvis may be comparable to the sled tests reported above. If a hard contact was to occur, it would be expected to change the biofidelity of the dummy response beyond that point. It may also offer an un-instrumented load path for transmission of force to the dummy, depending on the instrumentation specified for use and monitoring in the application. This would be of concern if the pelvis could be used to off-load other body regions where injury criteria are being assessed critically against thresholds or performance requirements.

3.4 Sensitivity

In this section the Q10 dummy sensitivity performance for the head, shoulder, thorax and pelvis in lateral impacts is presented. The background to this testing is that a dummy should be sensitive to parameters that relate directly to injury mechanisms (e.g. impact speed), but should not be sensitive to parameters that do not correlate to injuries, such as temperature or small angle variations.

3.4.1 Head

For the head, the sensitivity to impact angle variation was investigated. In lateral impact conditions, the impact angle was varied ± 10 degrees. In figure 40, the result is 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 completed.

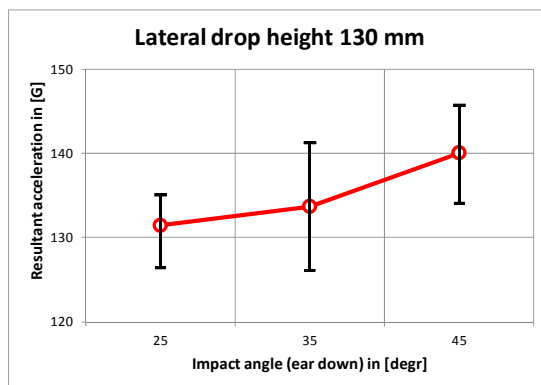


Figure 40: Lateral angle variation, 130 mm drop height

From figure 40 it can be observed that the sensitivity found for ± 10 degrees variation of impacts angle is in the same order as the variation that can be expected for repeated impact tests in a single test conditions. Compared to the variation that can be expected between two different dummies $143\text{G} \pm 10\%$ (see paragraph on Certification in this Chapter), the sensitivity is not large and is not considered to be significant. It can be concluded that the head response is not sensitive to small variations in the impact location.

3.4.2 Shoulder

Q10 with full arm (frontal impact configuration)

For the lateral shoulder impact with the full arm the sensitivity for speed, impact angular offset and impact alignment offset variation was investigated with the Q10 prototype, considering the peak pendulum force and T1 peak acceleration. Figure 41 shows the sensitivity for the impact speed. Figure 42 and figure 44 give the sensitivity for the angular offsets ± 10 degrees from pure lateral impact in the horizontal plane. In figure 43 and figure 45 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.

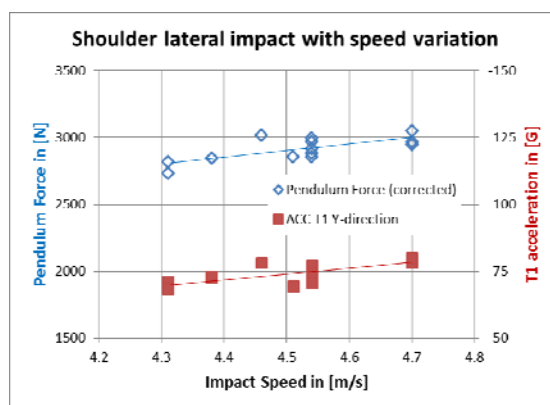


Figure 41: Shoulder lateral impact results versus speed (full arm)

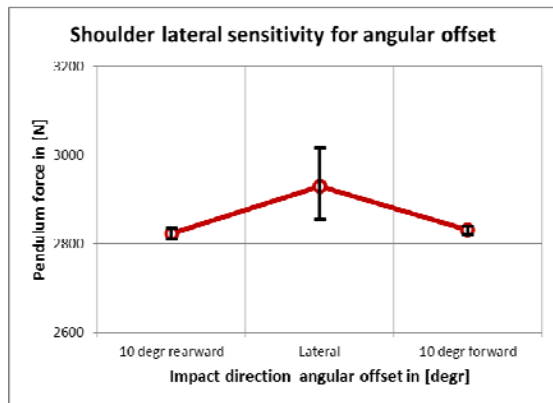


Figure 42: Impact force sensitivity for angular offset (full arm)

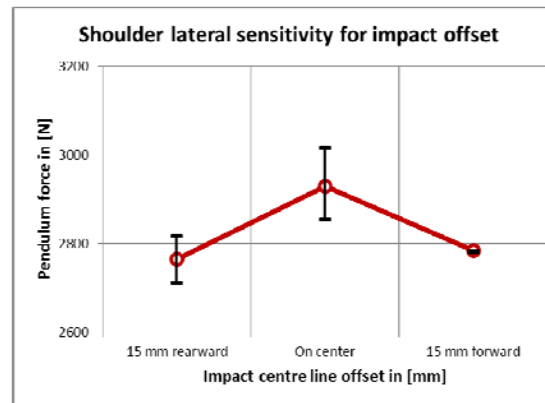


Figure 43: Impact force sensitivity for alignment offset (full arm)

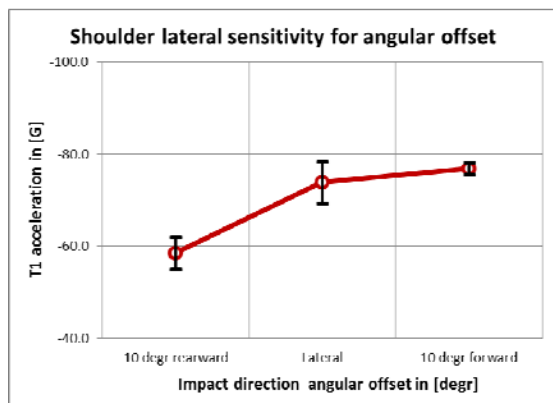


Figure 44: T1 acceleration sensitivity for angular offset (full arm)

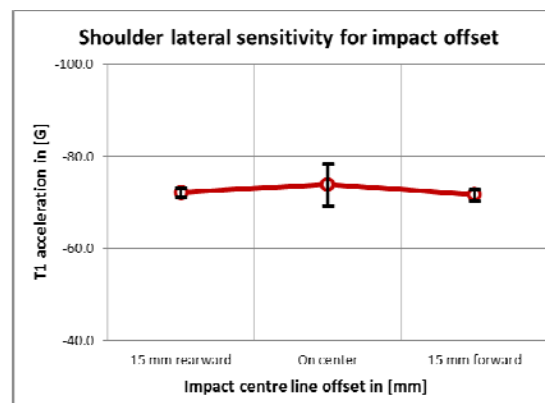


Figure 45: T1 acceleration sensitivity for alignment offset (full arm)

As can be seen from figure 41 both pendulum force and T1 lateral acceleration increase with impact speed as one might expect. The results for variations in impact angle are compared to results for pure lateral impacts and the results for variations of impact location are compared to results for impacts at shoulder joint centre line. Both variations result in a decrease of the pendulum force (see figure 42 and figure 43). This can be attributed 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 45) while showing a large sensitivity to impact angle (figure 44). 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.

Q10 with half arm (side impact configuration)

For the lateral shoulder impact with the half arm the sensitivity for speed, impact angular offset and impact alignment offset variation was investigated with the Q10 prototype dummy equipped with the side impact kit, considering the peak pendulum force and T1 peak acceleration. These test results are not extensively reported and published before. Figure 46 shows the sensitivity for the impact speed. Figure 47 and figure 49 give the sensitivity for the angular offsets ± 10 degrees from pure lateral impact in the horizontal plane. In figure 48 and figure 50 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.

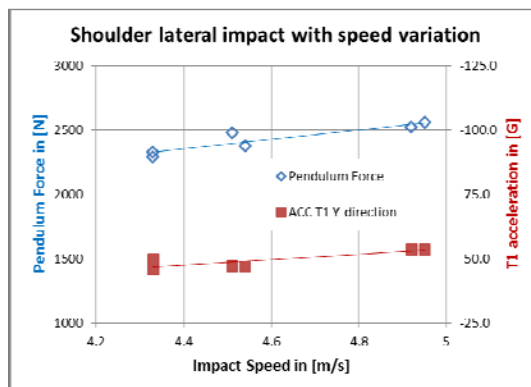


Figure 46: Shoulder lateral impact results versus speed (half arm)

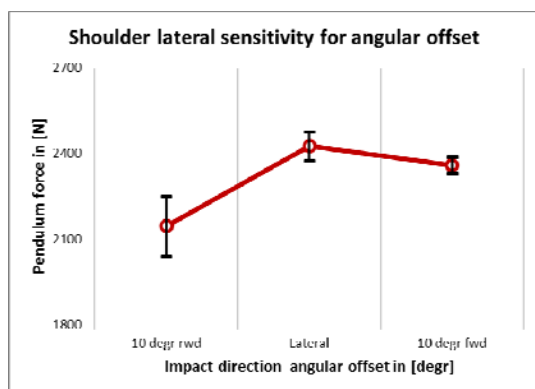


Figure 47: Impact force sensitivity for angular offset (half arm)

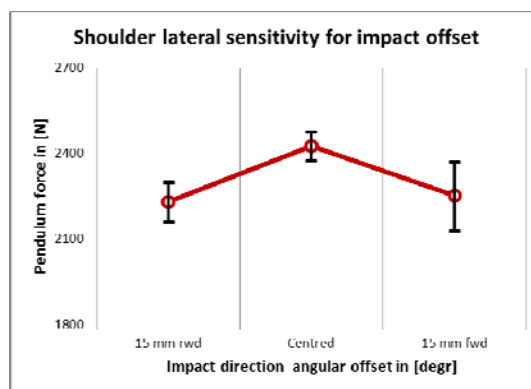


Figure 48: Impact force sensitivity for alignment offset (half arm)

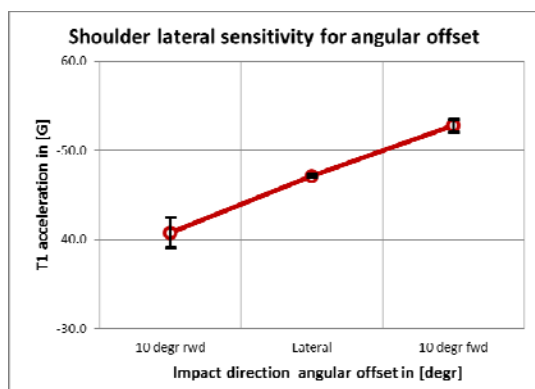


Figure 49: T1 acceleration sensitivity for angular offset (half arm)

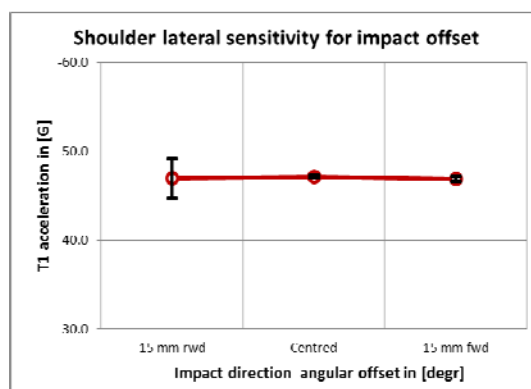


Figure 50: T1 acceleration sensitivity for alignment offset (half arm)

As can be seen from figure 46 both pendulum force and T1 lateral acceleration increase with impact speed as one might expect. The results for variations in impact angle are compared to results for pure lateral impacts and the results for variations of impact location are compared to results for impacts at shoulder joint centre line. Both variations result in a decrease of the pendulum force (see figure 47 and figure 48). This can be attributed 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 50) while showing a large sensitivity to impact angle (figure 49). 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.

Compigne et al. (2004) [15] found that the shoulder response of adult PMHS at low impact speeds (1.5 m/s) was sensitive to the direction of the impact, with the highest impact forces obtained for angles of +15 degrees (around 0.8 kN in average), followed by 0 degrees (around 0.7 kN) and -15 degrees (around 0.6 kN).

These variations were attributed to the alignment of the load with the clavicle at +15 degrees. While the test speeds, subject ages and angle increment differ for the Q10, this effect of clavicle loading is not visible in the current study for which the highest load is obtained in pure lateral loading (0 degree). Moreover the Q10 has a rubber column between the shoulder joint and the thoracic spine whereas in a human, in this region, the scapula is floating on a package of muscles that support it.

The shoulder sensitivities for full arm and the half arm show similar character, however the pendulum force and T1 acceleration magnitude are significant lower for the half arm configuration. Considering the limitations of an omni-directional design, that does not represent the human scapula being supported by a muscle package, the dummy shows to be sensitive to variations in impact speeds, impact direction and alignments as desired.

3.4.3 Thorax

For the thorax lateral impact the sensitivity for impact speed and angular offset from the pure lateral impact was investigated. In figure 51 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 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 (two tests for each offset direction). In figure 51 the results for the pendulum force are shown and in figure 52 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 graph of figure 53 the displacement in lateral directions (Dy) has been used. In figure 54 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.

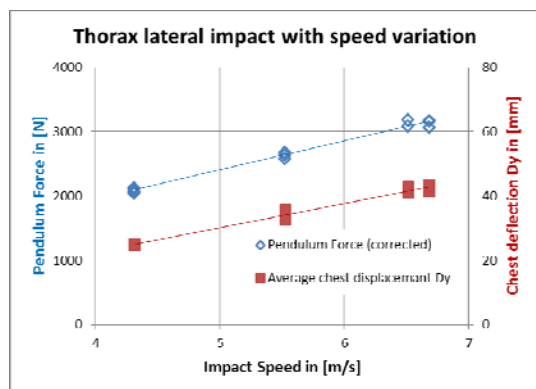


Figure 51: Thorax lateral impact results versus speed

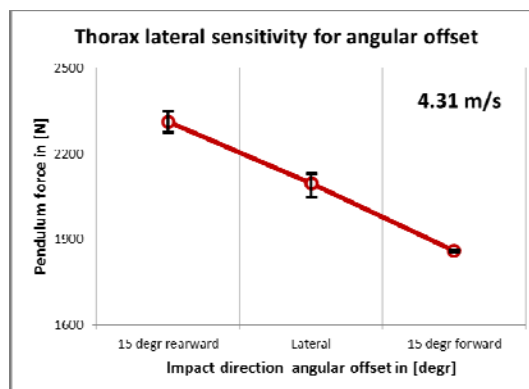


Figure 52: Pendulum force sensitivity for angular offset

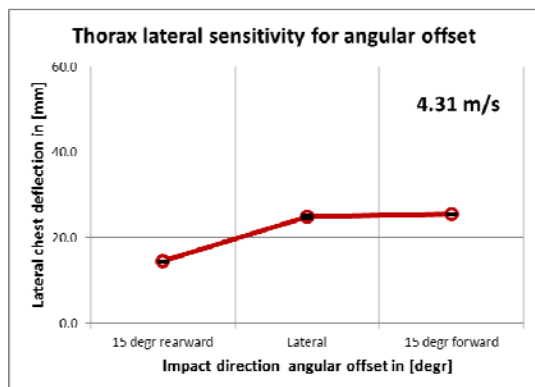


Figure 53: Chest deflection sensitivity for angular offset

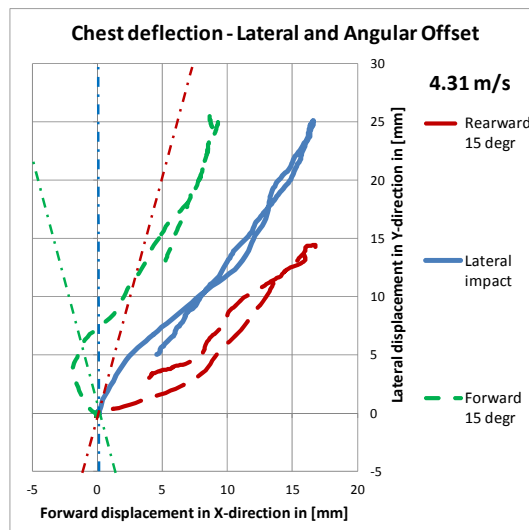


Figure 54: Chest deflections lateral and angular offset (+/- 15 degrees) (Thin lines are impact directions, thick lines dummy X-Y responses)

The pendulum force and chest deflection (D_y) in figure 51 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 52). The chest deflection in lateral direction (D_y) decreases more in case of rearward angular offset: 42% relative to pure lateral at 4.3 m/s impact speed (figure 53). 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 attributed to the attachment of the rib cage to the thoracic spine.

The X-Y displacement plots given in figure 54 (4.31 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 2D-IRTRACC's in the WorldSID dummies (for the small female WorldSID see ref. [16]). 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 (D_y) 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 as the directional dependence of the tolerance is not known.

The thorax sensitivities for full arm and the half arm are equivalent. Considering the limitations of an omni-directional design, the dummy shows to be sensitive to variations in impact speeds, impact direction and alignments. In the light of the pronounced 2-D response

sensitivity of the chest deflection it is recommended to always assess the X-Y displacement to get the best possible insight in the chest deformation.

3.4.4 Pelvis

For the pelvis lateral impact the sensitivity for impact speed and alignment offset (30 mm above and 30 mm forward of the H-point) was investigated. Figure 55 shows results for the pendulum force and pubic symphysis loads as function of impact speed. Figure 56 and figure 57 show sensitivities of parameters to the impactor alignment. The impact speed is 4.5 m/s in all these offset sensitivity cases. In the graphs the maximum minimum deviation for the aligned impact seems to be much larger than in the tests with angle and offset variation. This is not typical, it should be anticipated that with larger numbers of tests equivalent max-min deviations will be observed. For the nominal impact direction, five (5) tests were completed and for the 30 mm offset impacts three (3) tests were completed.

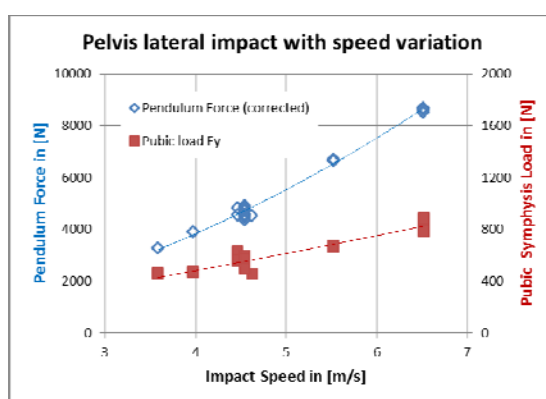


Figure 55: Pelvis impact results versus impact speed

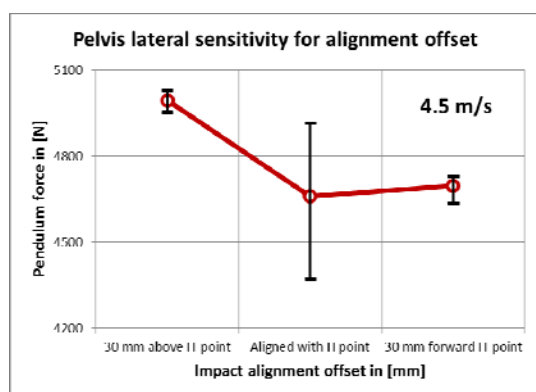


Figure 56: Impact force sensitivity for alignment offset

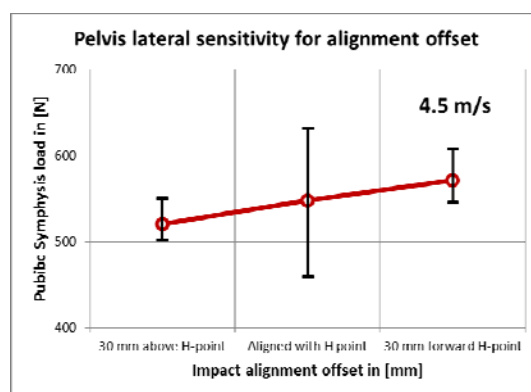


Figure 57: Pubic load sensitivity for alignment offset

In figure 55 the pendulum force and pubic symphysis force show sensitivity for the impact speed as expected. Quadratic trend lines could be used to represent peak force as a function of the impact speed. When impacted 30 mm above the H-point the pendulum force increases about 7% (figure 56) and the pubic symphysis load drops with about 5% (figure 57). 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 30 mm forward of the H-point the pendulum force is the same as in an impact aligned with the H-point (figure 56). In that case the pubic symphysis load rises

with 4% (figure 57). It should be noted that the pubic symphysis loads most likely are influenced by the bottoming out of the hip joint hardware against the sacrum block. This occurred in the prototype dummy at pendulum impact speeds larger than 4.0 m/s. This bottoming out is addressed in the pelvis redesign for the Q10 production version that provides more clearance between the iliac wings and the sacrum block (now 12 mm instead of 10 mm before), more stiffness in the iliac wings and less lumped mass in the sacrum block. Due to this redesign bottoming out is observed only at higher impact speeds (rigid wall sled tests at 6.8 m/s).

The pelvis sensitivities for full arm and the half arm are equivalent. The dummy shows to be sensitive to variations in impact speeds, impact direction and alignments.

3.5 Durability

During the evaluation and validation testing, only a few tests in lateral impact were performed. Later the dummy with the full arm and with the half arm (side impact kit) was exposed to severe sled tests. There are no issues reported from this test series.

3.6 Certification

The purpose of dummy certification is to safeguard consistent dummy performance in production and during operation of the dummy. Certification tests are often based on biofidelity tests. In October 2011, provisional certification procedures and corridors, based on the prototype performance, were set for internal use by Humanetics. The first production batches were tested to comply with this internal requirement. After collecting data from 18 production version dummies delivered to the market, final procedures and corridors were proposed in February 2014. There are no significant differences between the prototype performance and the production corridors. In this chapter, the final certification procedures and corridors are summarised. The frontal certification tests on head, neck, thorax, abdomen and lumbar spine are not mentioned here because these covered in the EEVC report on Q10 frontal [1]. The corridors are according to engineering judgment proposed as: average value $\pm 10\%$, which for the tests concerns generally appears to be about 2.4 times the Standard Deviation of the measured values. Using the 18 data sets, the repeatability and reproducibility of the production version dummy is assessed and reported.

3.6.1 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 tests are related to lateral impact:

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), the corridors are:

- Maximum resultant acceleration shall be between 128.7 and 157.3 g.
- Maximum frontal acceleration (A_x) shall be between +20 and -20 g.

The Side Impact kit does not have any influence on this certification test.

3.6.2 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 M_x (lateral bending) and M_y (forward bending) (CFC600) should be recorded. Six inch honeycomb is used for the deceleration of the pendulum. The certification tests are related to lateral impact: 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
 - @ 10 ms: 0.7 – 1.7 m/s;
 - @ 20 ms: 1.7 – 2.8 m/s; and
 - @ 30 ms: 2.8 – 4.0 m/s.

The pulse corridor and the pulses of the tests performed are shown in figure 58.

The corridors are:

- Maximum upper neck moment (M_x) shall be between 14.85 and 18.15 Nm.
- Maximum head form rotation shall be between 45.9 and 56.1 degrees.

The Side Impact kit does not have any influence on this certification test.

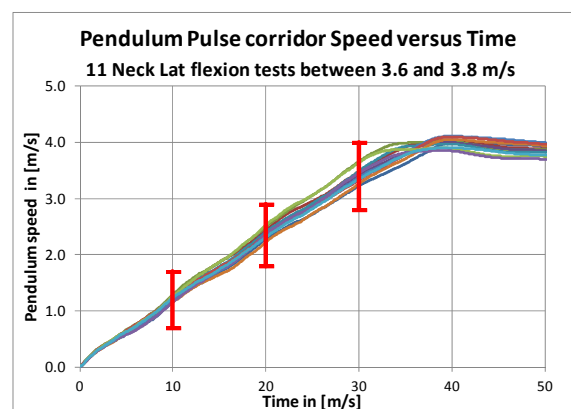


Figure 58: Pendulum pulse for neck lateral flexion test

3.6.3 Shoulder

For the shoulder certification, a full body lateral impact test should be performed with a six wire suspended pendulum (mass of 8.76 kg and an impact plate diameter of 112 mm). The pendulum speed should be between 4.2 and 4.4 m/s. The impact should be purely lateral with the pendulum centreline aligned with the shoulder joint centre. The dummy should be sitting with the thoracic spine vertical and the legs stretched forward on two sheets of PTFE (Teflon) to minimise the friction. In the lateral test the upper arms should be along the thorax sides. The pendulum acceleration (CFC600) and T1 A_y acceleration at (CFC600) should be recorded.

The lateral impact corridors are:

Lateral for full arm

- Maximum pendulum force shall be between 2385 and 2915 N.

- Maximum T1 Ay acceleration shall be between 48.0 and 68.0 g.
(The T1 Ay corridor is provisionally established as a wide corridor (average $\pm 17.2\%$) because the T1 Ay results, initially obtained with a double sided tape mounted sensor, showed large variations. The T1 accelerometer mount provisions were introduced with the Side Impact kit. After collection of a significant number of certification test results with a properly mounted sensor, this corridor may be updated in the future and the results will be included in the User Manual of the dummy).

Lateral for half arm

For the half arm only provisional corridors are established based on the performance of the prototype. After the production and testing of a significant number of side impact kits final corridors will be established and published in the user's manual.

- Maximum pendulum force shall be between 2199 and 2688 N.
- Maximum T1 Ay acceleration shall be between 47.7 and 58.3 g.

3.6.4 Thorax

For the thorax certification, a full body lateral impact test should be performed with a six wire suspended pendulum (mass of 8.76 kg and an impact plate diameter of 112 mm). The pendulum speed should be between 4.2 and 4.4 m/s. The impact should be purely lateral with the pendulum centreline in the middle between the two IR-TRACCs 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 minimise the friction. In the lateral test the upper arms should be along the thorax sides. The pendulum acceleration (CFC600) and chest deflection from both 2D IR-TRACCs (IR-TRACCs and potentiometers at (CFC600) should be recorded.

The lateral impact corridor is:

- Maximum pendulum force shall be between 2025 and 2475 N.
- Maximum average IR-TRACC deflection shall be between 24.39 and 29.81 mm.

The Side Impact kit does not have any influence on this certification test.

3.6.5 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:

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
 - @ 10 ms: 0.9 – 1.9 m/s;
 - @ 20 ms: 2.3 – 3.4 m/s; and
 - @ 30 ms: 3.4 – 4.6 m/s.

The pulse corridor and the pulses of 11 lateral flexion tests performed are shown figure 59.

The corridors for both flexion and lateral flexion are:

- Maximum head form rotation shall be between 45.9 and 56.1 degrees.
- Time of maximum head form rotation shall be between 60.30 and 73.70 ms.

The Side Impact kit does not have any influence on this certification test.

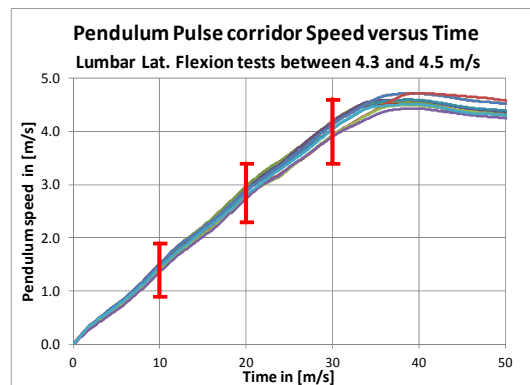


Figure 59: Pendulum pulse for lumbar lateral flexion

3.6.6 Pelvis

For the pelvis certification, a full body lateral impact test should be performed with a six wire suspended pendulum (mass of 8.76 kg and an impact plate diameter of 112 mm). The pendulum speed should be between 4.2 and 4.4 m/s. The impact should be purely lateral with the pendulum centreline aligned with the hip joint centre (H-point). The dummy should be sitting with the thoracic spine vertical and the legs stretched forward on two sheets of PTFE (Teflon), to minimise the friction. In the lateral test the upper arms should be along the thorax sides. The pendulum acceleration (CFC600) and pubic symphysis load at (CFC600) should be recorded.

The lateral impact corridor is:

- Maximum pendulum force shall be between 3755 and 4565 N.
- Maximum pubic symphysis load shall be between TBD and TBD N.
(The pubic symphysis corridor is still under development because initially the data from this sensor was not collected. As soon as the corridor is available it will be included in the User's Manual of the dummy).

3.7 Repeatability and reproducibility

Based on data sets obtained from the certifications of the 18 production version dummies, the repeatability and reproducibility of the Q10 dummy is assessed. The CoV values obtained for each composed group are provided in table 2. The composed groups are detailed below. Between brackets the associated number of tests in the (composed) group is given. In general, there are two tests (one repeated test) per test mode per dummy available (2 tests * 18 dummies = 36 tests). For lateral tests, LHS and RHS can be combined and 72 tests are available.

For the Repeatability:

- The two tests per test mode per dummy are grouped (18 groups of 2 tests).
- The results are normalized with the average of the group.
- The standard deviation of the normalized results is the coefficient of variation for repeatability.

For the Reproducibility:

- All first tests per test mode are grouped and the second tests are grouped (frontal: 2 groups of 18 tests or lateral: 4 groups of 18 tests).
- The results are normalized with the average of the group.

- The standard deviation of the normalized results is the coefficient of variation for reproducibility.

Table 2: Repeatability and Reproducibility of production version in certification tests

Test configuration		Repeatability	Reproducibility
Mode	Parameter	CoV = StDev / Mean	CoV = StDev / Mean
Head impact			
Lateral	Max Resultant acceleration	1.39% (72)	3.76% (72)
Neck pendulum test			
Lat. flexion	Max D-Plane Rotation	1.45% (72)	2.49% (72)
	Max Occipital Moment	0.91% (72)	1.72% (72)
Shoulder pendulum impact (full body)			
Lateral	Max Pendulum Force	2.06% (72)	4.24% (50, see note)
	Max T1 Acceleration (y)	3.46% (72)	6.39% (50, see note)
Thorax pendulum impact (full body)			
Lateral	Max Pendulum Force	1.25% (36)	3.51% (36)
	Max Sternum Deflection	1.61% (36)	4.34% (36)
Lumbar pendulum test			
Lat. Flexion	Max D-Plane Rotation	1.48% (72)	3.58% (72)
	Time at Max Rotation	1.58% (72)	2.67% (72)
Pelvis pendulum impact (full body)			
Lateral	Max Pendulum Force	1.65% (72)	3.00% (72)
	Max Pubic Symphysis Load	No data available	No data available
All modes together		1.83% (648)	3.57% (604)

Note: Tests only considered when the part involved passed certification.

All the coefficients of variation are well within the required 5% for repeatability and 10% for reproducibility. Overall it is concluded that the Q10 production version dummy can be used as a repeatable and reproducible tool.

Also for the prototype dummy a repeatability analysis was carried out which is presented in ANNEX B: Q10 PROTOTYPE REPEATABILITY. Both the prototype and production version repeatability tests showed comparable results.

3.8 Summary and conclusions

The Q dummies initially were developed for multi directional use, but in the development phase priority has been given to frontal impact performance targets. For the Q10 there is a side impact kit developed. This kit comprises a modified shoulder joint with load cell and a half arm which is based on the arm design of the WorldSID 50th dummy.

3.8.1 Biofidelity

Head

The head is evaluated in 130 mm (EEVC) and 200 mm (ISO) lateral drop tests. EEVC requirements were met, but ISO requirements are exceeded (acceleration too high). It was concluded that simultaneous compliance with EEVC and ISO lateral requirements is not physically possible. Note that the Q dummy certification requirement is based on a 130 mm drop test.

Neck

The neck lateral flexion is evaluated in Part 572 lateral pendulum tests. The neck performance is within the wide Mertz corridor up to 45 degrees and for higher rotations the neck is too soft compared to this corridor. However the Mertz corridor is too stiff compared

to volunteer tests, so the dummy neck response is considered acceptable. Note that the head to shoulder contact occurs at a higher lateral head flexion of about 70 to 80 degrees.

Shoulder

The shoulder is evaluated in shoulder full body biofidelity impactor (8.76 kg) tests at a speed of 4.5 m/s both with full and half arm (side impact kit) and compared with EEVC and ISO corridors. The pendulum force for the full arm dummy (without SIK), is almost double the average corridors values, so the Q10 dummy with full arm is too stiff. Performance for the half arm dummy is improved, but still the side impact performance is too stiff. In contrast: the performance of the 5th WorldSID dummy which has a slightly different anthropometry and which was evaluated under slightly different pendulum conditions appears to perform much more biofidelic than the Q10 dummy in this type of tests.

Thorax

The thorax is evaluated in tests at 4.31 and 6.71 m/s with an 8.76 kg pendulum and compared with ISO and EPOCH corridors. Like in the shoulder impacts the initial peak is too high but to a much less extent than in the shoulder impacts. The 5th WorldSID dummy evaluated under slightly different pendulum conditions appears to perform slightly more biofidelic than the Q10 dummy in this type of tests. In the biofidelity sled tests the Q10 thorax responses with or without the side impact shoulder kit are in the centre of the scaled corridor for the Heidelberg configuration while for the MCW tests the thorax plate responses are higher than the corridor for these tests. The soft upper arm bone of the side impact shoulder kit causes the loading to be distributed more evenly over the impacted area, bringing results closer to the MCW biofidelity corridors. Compared to WorldSID 5th that complies closely with the target corridors, the Q10 shows in general too high plate loads and a faster rebound.

Abdomen region

In the abdomen region, the Q10 dummy responses in the biofidelity sled tests, with and without the kit, follow trends as observed in the PMHS tests but forces are well below the corridors defined. Compared to WorldSID 5th, that comply closely with the target corridors, the Q10 under estimated the loads in this region. This can be attributed to the fact that the floating and false ribs are lumped in the ribcage in the Q10 whereas they are separately represented in the WorldSID 5th.

Lumbar region

No biofidelity assessment made.

Pelvis

The pelvis is evaluated in 5.2 m/s pendulum tests with an impactor mass of 8.76 kg. Performance requirements are based on Viano [12] adopted by EEVC as pelvis lateral impact performance target. Moreover an impact force versus impact speed relation is evaluated with a corridor proposed by Irwin and Mertz [14]. Like for the shoulder also here the peak impact force exceeds the corridor almost with a factor 2. Also here the WorldSID 5th percentile performs much more realistically in comparable test conditions. It should be noted that the bottoming out observed in the prototype lateral impact tests at 4.0 m/s is shifted in the production version dummy beyond the certification test severity (4.3 m/s).

In spite of this in the Q10 production version dummy biofidelity sled tests still higher forces and accelerations are observed both with and without the side impact kit. So this region of the

dummy is too stiff. This is attributed to the fact that in the Q10 the lower torso mass is largely lumped in the sacrum block and the bottoming out of the iliac wing and hip joint hardware against the sacrum block is still present for higher impact speeds. The WorldSID 5th that complies closely with the target corridors embodies a more distributed mass representation and is free of bottoming out even in the severe biofidelity sled tests.

3.8.2 Sensitivity

Head sensitivity tests show that the head response is not sensitive to small variations in the impact location. The shoulder with full and half arm is found to be similar sensitive to impact speed and impact angle. This can be explained by the fact that the shoulder rubber is flexible when impacted with a rear angle, whereas in a forward angle impacts the shoulder rubber is loaded in the relatively stiff compression mode. The thorax lateral impact is found to be sensitive to impact speed and impact angle. This can be explained by the fact that in rear angled impact the impact point is closer to the rigid ribcage attachment to the thoracic spine than in a forward angled impact that involves a larger (more flexible) part of the ribcage.

The pelvis lateral impact is found to be sensitive to impact speed. Regarding impact offsets the dummy is found to be sensitive for impacts 30 mm above the H-point. This can be explained by the fact that than besides the H-point also the iliac wing upper edge is exposed. In general the sensitivity studies show that the Q10 dummy in lateral impact is sensitive to variations in impact speeds, impact direction and alignments as desired with regards to injury risk assessment.

3.8.3 Durability

The durability of the Q10 seems to be rather promising since the dummy with full and half arm (side impact kit) was exposed to various severe sled tests without durability issues reported from this test series.

3.8.4 Certification

After collecting data from 18 production version dummies delivered to the market final certification procedures and corridors were developed for the lateral response of the head, neck, shoulder, thorax, lumbar spine and pelvis. The certification corridors are proposed as: average value $\pm 10\%$, which for the concerned tests generally appears to be about 2.4 times the Standard Deviation of the measured values.

3.8.5 Repeatability and reproducibility

Using the data sets resulting from the tests with the 18 production version dummies, the repeatability and reproducibility of the production version dummy was assessed. All coefficients of variation were found to be within the required 5% for repeatability and 10% for reproducibility. Overall it can be concluded that the Q10 production version dummy can be used as a repeatable and reproducible tool.

4 THIRD PARTY EVALUATION

Within the EPOCH project [2], sled tests according to the New Programme for the Assessment of Child-restraint Systems (NPACS)-protocol [17] (task 3.1) were performed to assess the ability of the Q10 dummy as a measurement tool. After the EC-EPOCH project, the two prototype dummies (equipped with full arms) were used in a third party evaluation test program. In this chapter the results of these test series as far as relevant for lateral impact are summarised.

4.1 Test program

4.1.1 EC-EPOCH sled test according NPACS Protocol

Both prototype Q10 dummies (equipped with full arms) were used in lateral impact tests at TRL (UK):

- TRL performed 88 side impact tests (in general three repeats) to investigate:
 - Q10 sensitivity to restraint loading from variation in test setup.
 - Q10 sensitivity to differences in child restraint system (CRS) design.
 - Q10 durability.

4.1.2 Third party evaluation test program

After completion of the EPOCH project evaluation testing in September 2011, the two prototype dummies entered a third party evaluation program. A number of parties from Japan, America and Europe borrowed the dummies to examine a large variety of operational aspects such as belt and airbag interaction, comparison with other dummy types, repeatability and reproducibility, robustness and sensitivity to restraint system features, including pre-tensioners and load-limiters. The results of the third party tests are summarized here.

4.2 Results

4.2.1 EC-EPOCH sled test according NPACS Protocol

The following summary was derived from EC-EPOCH testing according to the NPACS-protocol (for detailed results, see the EPOCH Project Dissemination (POCC 2011) [18]):

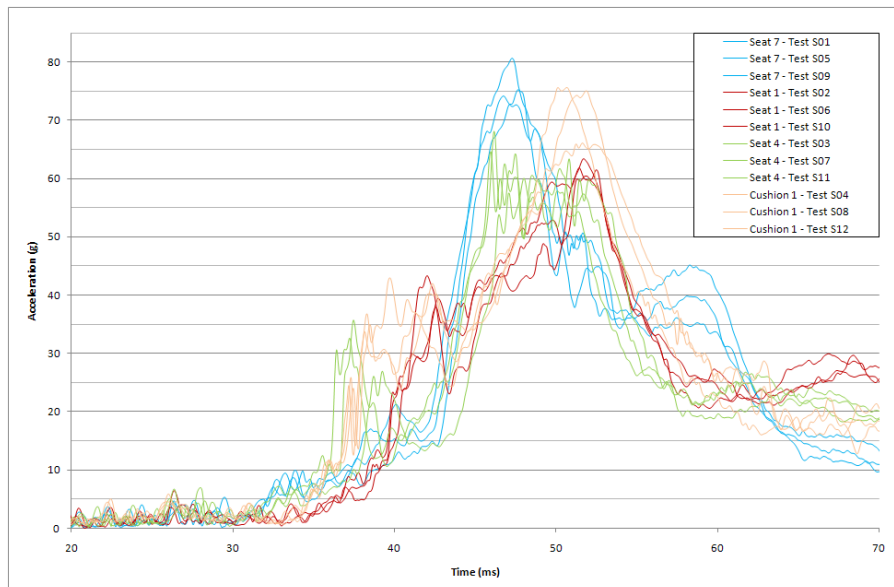
- The main objective of the sensitivity to test setup variations was to assess whether the Q10 dummy was capable of picking up differences between child restraints. The baseline configuration was with spacer, lower arm on lap and moving door. The variation applied was no spacer, raised arm and fixed door. In table 3 the average value as well as the coefficient of variation over the three tests per test configuration is given. The values show that without spacer the results are not significant different from the baseline test. The raised arm tests show significant different values for head acceleration, neck loads and lower chest compression. Finally the fixed door tests show significant different values for all the parameters assessed. These differences demonstrate that the Q10 dummy was sensitive to test setup variations. The results of these side impact sled tests show a good overall repeatability (CoV \leq 6.0%).
- The main objective of the sensitivity to child restraint design testing was to assess whether the Q10 dummy was capable of picking up differences between child restraints. From the analysis of the results, it was concluded that the dummy produced different results, depending on the particular child restraint tested. Figure

60 highlights differences seen in the head accelerations measured by the Q10 in lateral impact tests to investigate sensitivity of the Q10 to child restraint design. These differences, which are also shown in Table 4, demonstrate that the Q10 dummy was sensitive to child restraint design.

Table 3: Results of sensitivity tests with test and dummy setup variation (12 tests, 3 tests per setup, Average value over three tests and Coefficient of variation, Full arm configuration)

Test	Resultant acceleration 3ms			Upper Neck resultant		Chest compression	
	Head	Chest	Pelvis	Force	Moment	Upper	Lower
Baseline	55.0 7.9%	65.7 6.3%	101.3 4.1%	2319 6.5%	34.0 7.8%	35.3 8.2%	40.7 7.9%
No spacer	55.3 5.5%	63.7 3.3%	98.7 4.6%	2436.7 4.0%	35.7 1.6%	34.3 6.1%	39.0 2.6%
Raised arm	45.7 4.6%	64.7 3.2%	97.7 1.6%	1675.3 6.8%	31.0 3.2%	33.3 1.7%	47.0 3.7%
Fixed door	39.7 6.3%	48.3 4.3%	52.7 5.5%	1391.7 4.5%	25.7 6.0%	21.0 9.5%	26.7 9.4%
Overall CoV (12 tests)	5.3%	3.8%	3.6%	4.8%	4.5%	6.0%	5.6%

Note: Shading: *Blue* : Baseline tests,
Green : Difference is limited w.r.t. baseline test (within coefficient of variation),
Orange : Difference is larger w.r.t. baseline test (larger than coefficient of variation).



**Figure 60: Head resultant acceleration in NPACS tests with five CRS types
Seat 1: Red, Seat 4: green, Seat 7: blue and Cushion 1: purple**

**Table 4: Results of sensitivity tests with CRS type variation
(12 tests, 3 tests per setup, Average value over three tests and Coefficient of variation, Full arm configuration)**

Test	Resultant acceleration 3ms			Upper Neck resultant		Chest compression	
	Head	Chest	Pelvis	Force	Moment	Upper	Lower
Seat 7	67.0 1.5%	51.0 11.9%	106.7 0.5%	1850.7 3.4%	27.0 3.7%	37.7 5.5%	41.3 7.8%
Seat 1	53.0 8.6%	63.3 1.8%	102.3 2.0%	2171.3 3.8%	33.3 4.6%	34.3 7.3%	41.7 3.7%
Seat 4	57.0 1.8%	65.0 8.1%	95.0 5.6%	2001.0 2.8%	37.0 5.4%	40.7 1.4%	45.3 1.3%
Cushion 1	71.0 9.9%	84.3 1.8%	99.7 3.2%	2344.0 8.1%	56.0 8.9%	46.3 1.2%	52.7 1.1%
Overall CoV (12 tests)	5.7%	6.3%	2.9%	4.2%	5.1%	4.0%	3.7%

Note: Shading: Green : Minimum value (best performance).

Orange : Maximum value (worst performance).

Table 5: Results of durability tests (24 tests, 4 tests per setup, Average value over three tests and Coefficient of variation, Full arm configuration)

Test	Resultant acceleration 3ms			Upper Neck resultant		Chest compression	
	Head	Chest	Pelvis	Force	Moment	Upper	Lower
Seat 1	56.3 5.1%	66.3 4.3%	101.0 1.8%	2204.3 6.3%	35.8 4.8%	36.3 4.7%	43.8 2.2%
Seat 3	41.0 3.4%	56.3 4.7%	98.5 3.0%	1359.0 5.1%	25.5 8.2%	39.0 4.7%	43.0 4.2%
Seat 4	60.0 6.8%	67.5 5.1%	96.0 2.9%	2231.3 8.2%	38.8 13.7%	44.8 5.0%	50.5 5.2%
Seat 6	80.3 5.7%	62.8 5.1%	104.3 3.2%	2614.8 5.3%	58.8 8.4%	47.8 2.6%	54.3 3.1%
Slouched	64.8 4.3%	79.5 6.4%	88.5 3.5%	2514.5 5.3%	51.5 3.7%	45.3 3.3%	48.0 5.9%
Extra slack	66.8 6.0%	66.0 6.4%	92.8 3.2%	2575.0 8.7%	40.3 13.8%	48.0 2.4%	53.0 1.5%
Overall CoV (24 tests)	4.7%	4.8%	2.7%	5.9%	8.5%	3.5%	3.6%
Overall CoV (48 tests)	5.0%	4.9%	2.9%	5.1%	6.8%	4.2%	4.1%

Note: Shading: Green : Minimum value (best performance).

Orange : Maximum value (worst performance).

- The results from the NPACS durability side impact testing (Table 5) generally showed good repeatability. This was consistent with the repeatability found in the restraint loading and sensitivity to CRS design frontal impact testing. Overall, the durability of the Q10 dummy was good in the lateral impact testing. There were a

few parts that required improved durability and reduced maintenance. The complete overview of updated is given in Annex F of the EEVC report on Q10 frontal [1].

- Based on test series with test intervals of 45, 30 and 15 minutes, it is recommended to maintain a minimum 30 minutes time interval between subsequent tests that loads the same area.

4.2.2 Third party evaluation test program

Following the EPOCH evaluations, two instrumented Q10 prototype dummies were made available to third parties for further evaluation testing. A wide variety of tests were performed by research labs, restraint manufacturers, OEMs and consumer organisations world-wide to investigate the dummy performance in a range of conditions. The tests included sled tests on a body-in-white as well as full-scale crash tests. In two meetings (May and September 2012) third party testing participants presented the results of their testing. The results were discussed and recommendations and feedback were compiled and taken on board in the definition of the production version dummy. In figure 61 two cross plots of maximum prototype dummy results from EPOCH project and third party testing up to September 2012 are given:

- Maximum Head resultant A3ms versus Maximum Chest resultant A3ms.
- Maximum Head resultant A3ms versus Maximum Pelvis resultant A3ms.

The data points are distinguished by type of testing:

1. TRL NPACS sled testing with setup variation.
2. TRL NPACS sled testing with CRS type variation.
3. TRL NPACS sled testing with interval variation and for durability.
4. TRW BIW sled testing with CRS variation.
5. ADAC BIW sled tests with CRS type variation.
6. Dorel BIW sled tests with door distance variation.

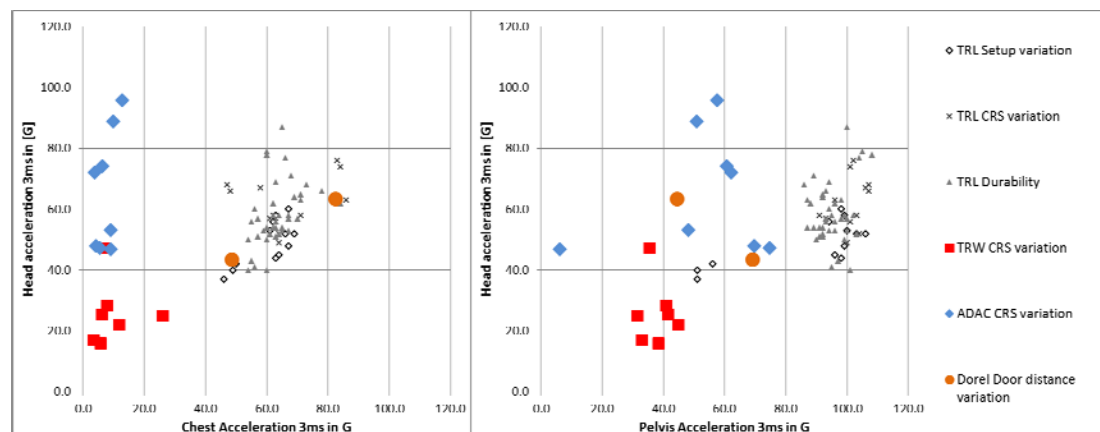


Figure 61: Cross plots of prototype dummy test results (up to September 2012)

One study by TRW not reported in conferences is briefly summarised here. TRW reported their feedback based on seven BIW lateral impact sled tests with a Q10 prototype dummy in the third party evaluation participants meeting in May 2012:

- The dummy lower leg did not have proper contact with the door panel and flied under the door panel lower edge. The door panel did not have an extension in that area. (door representation on the sled to be adapted).

- There is bottoming out contact between the hip joint hardware in the iliac wing and the sacrum block.
- The M6 shoulder joint attachment gets loosened.
- Thorax tilt sensor interferes with the IRTRACC hardware.

The dummy hardware related issues are all covered by the improvement implemented in the Q10 production dummy.

4.3 Discussion and conclusions

The lateral impact tests performed in the EPOCH project show that the Q10 (in full arm configuration) is sensitive to dummy positioning parameters and CRS type variation. Regarding repeatability good Coefficients of Variation (CoV's) of 5% or smaller are found. Only the upper neck moment shows a larger CoV of 6.8% which is still judged to be acceptable for CRS lateral sled tests. Moreover it was concluded that the dummy is found to be sufficiently durable for lateral impact. Based on the tests it is recommended to maintain a minimum 30 minutes time interval between subsequent tests that loads the same area.

From the third party test program some durability issues were reported. These issues were all addresses in improvement program that lead to the production version dummy (Annex F in [1]). The severe biofidelity sled test carried out with the production version dummy did not show any durability issue.

5 INJURY CRITERIA

Unlike the adult situation, there is very little biomechanical data from which specific injury risk functions for children can be derived. Within the EPOCH project, adult injury risk functions were scaled in an attempt to make them relevant for the Q10. Scaling was applied to generate risk curves or injury threshold values for the following parameters in lateral impacts:

- Linear head acceleration.
- Neck tension, anterior-posterior bending, and shear force.
- Chest compression.

Some recommendations were made on the use of injury criteria in side impact testing but mainly for the head.

5.1 Head

The EPOCH project authors noted a limitation of the scaling of head injury risk for children in that the adult risk functions for HIC and head acceleration are based on head contact impacts of a very short duration. These impacts may not be very relevant to the conditions under which the Q10 dummy will be used. Therefore it was recommended within the EPOCH project that alternative, additional data sources are found which are more relevant to the conditions expected for children in CRSs during accidents.

Subsequently, Johannsen et al. (2012) [19] used the CASPER Project accident reconstruction database to look at potential injury risk functions for the Q-dummies. Regarding head acceleration, they presented survival analysis of the head AIS as a function of head acceleration from the reconstructions and the data points scaled to a 3 year old are plotted in figure 62 together with the injury risk curve. For lateral impacts, Johannsen et al. provided the examples of 55 g and 85 g relating to a 20 % and 50 % risk of AIS ≥ 3 head injury. Those authors provided scaling coefficients to relate different head acceleration measurements from one dummy size to another. These coefficients had a length scaling parameter and another parameter for tissue failure properties. Using an equivalent approach, scaling can be undertaken to convert the Q3 measurements to make the injury risk more appropriate for application with the Q10 dummy. If this is applied, with a factor of 1.078, then the acceleration values associated with a 20 and 50 % risk of injury would be 59 and 92 g, respectively.

The same process was done with the HIC₃₆ and HIC₁₅. However, the sizes of the confidence intervals were higher, leading to unacceptable curves. It was then recommended to use the linear acceleration 3ms and not the HIC.

It is suggested that adult tolerance values for rotational inertial loading could be used with the Q10 to give a conservative threshold. However, this assumption would benefit from further validation. Also, the appropriate tolerance value would need to be selected for the injury or injuries against which protection is being encouraged (e.g. diffuse axonal injury, traumatic brain injury, or mild traumatic brain injury). This selection may be far from trivial, particularly where different authors have proposed different limits or assessment methods for the same injury group.

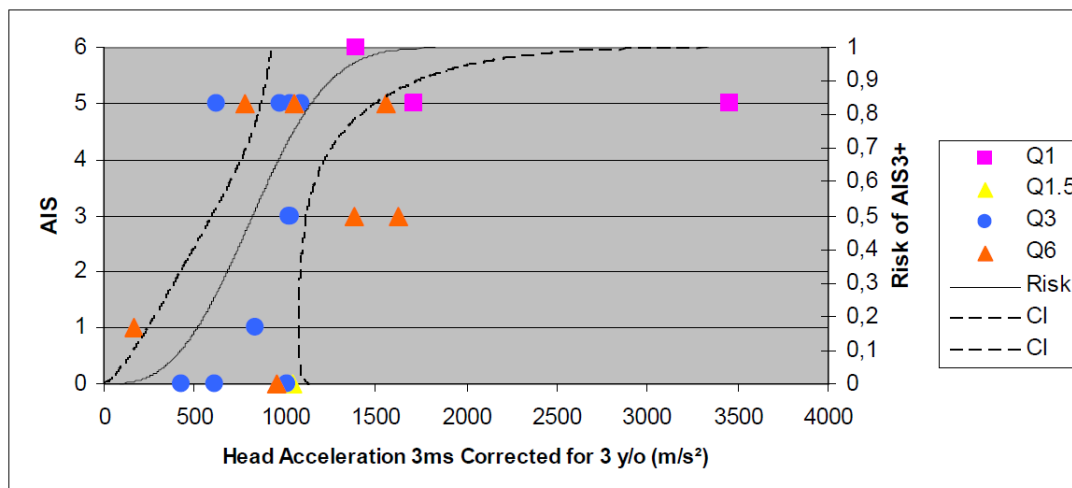


Figure 62: Head injury risk curve as a function of head acceleration 3ms for 3 year old (Reproduced from Johannsen et al., 2012 [19])

5.2 Thorax

When Johannsen et al. [19] plotted chest AIS values as a function of chest accelerations, they found that the number of reconstructed accident cases with severe chest injuries in side impact was too small to allow for the definition of thresholds.

In the absence of an injury risk function for the chest from accident reconstructions, scaling down of injury risk functions from adults becomes the only option. However there should be concerns over the assumption of geometric similitude. That is, that the bodies of the people represented by the scaling are the same apart from their external size. Noting this limitation the adult thoracic injury risk functions for the WorldSID 50th percentile, mid-sized, male dummy were sought for scaling. These are provided by Petitjean et al. (2012) [20].

For the WorldSID 50M it is proposed that skeletal thoracic injury at the level of AIS ≥ 3 is represented by maximum thoracic rib deflection (in mm). With a threshold for a 45 year old of 48.4 mm for a 25 % risk of injury and 55.4 for a 50 % risk of injury. Given the assumption that injury risk is related to the compression of the chest as a proportion of the chest depth, then scaling to make these values appropriate for the Q10 relies on the ratio of lateral chest depth for the two dummies. The chest depth for the 50th percentile male is 394 mm. For a 10.5 year old child this value is 217.4. Therefore the rib deflection thresholds for the Q10 are approximately, 26.7 mm for a 25 % risk of injury and 30.6 mm for a 50 % risk of AIS ≥ 3 skeletal thoracic injuries; based on geometry alone.

Previously, scaling ratios have been modified to incorporate a proxy for the changing strength of biological material, e.g. changes in bones with age. The ultimate tensile strength of the calcaneal tendon was used by Wismans et al. (2008) for this purpose. Based on the extrapolation by Carroll and Pitcher (2009), the failure strength for a 10.5 year old is 53.4 MPa and for an adult it is 54.9 MPa. Additionally, changing bone modulus with age is modelled by considering the skull bone with values for the 10.5 year old of 8.45 GPa and 9.7 GPa for the adult. Adding these factors to the scaling (one has the effect of decreasing the tolerable deflection and the other to increase it) means that the rib deflection thresholds for the Q10 are approximately, 29.7 mm for a 25 % risk of injury and 34.2 mm for a 50 % risk of AIS ≥ 3 skeletal thoracic injuries.

5.3 Shoulder (Side Impact Kit)

A similar approach can be followed with the shoulder force requirements for the 50th percentile WorldSID. Representing a 45 year old person and the risk of an AIS ≥ 2 shoulder injury, the maximum shoulder rib (y-axis) force is 1799 N, 2270 N and 2556 N for a 5, 25 and 50% risk of injury respectively (Petitjean, 2012) [20]. For the scaling of these values it is assumed that the shoulder width for the Q10 is about 338 mm and an equivalent measurement for the adult is 406 mm. Using these values and the strength and modulus factors described in the previous paragraph yields corresponding lateral force values for the Q10 shoulder of 1665 N, 2101 N and 2366 N at the 5, 25 and 50 % risk of AIS ≥ 2 injury level.

5.4 Conclusions

For the head the only risk function that is available is the 3ms head acceleration exceedance, scaled up to the Q10 from the CASPER accident reconstruction experiments (see figure 62). For the chest scaling adult lateral impact requirements resulted in rib deflection thresholds for the Q10 of 29.7 mm for a 25 % risk of injury and 34.2 mm for a 50 % risk of AIS ≥ 3 skeletal thoracic injuries. For the Q10 shoulder scaling from adults resulted in forces of 1665 N, 2101 N and 2366 N resp. at the 5, 25 and 50 % risk of AIS ≥ 2 injury levels. It is not certain that the assumptions made in the simple scaling process will provide appropriate and equivalent values for the Q10. Therefore it is recommended that these thresholds are evaluated in the particular testing application before being adopted.

6 CONCLUSIONS AND RECOMMENDATIONS

6.1 Conclusions

This report is a follow-up of the EEVC report “Q10 Dummy Report - Advanced Child Dummies and Injury Criteria for Frontal Impacts” published in January 2015 [1]. The Q10 dummy is the tallest member of a family of 6 new child crash test dummies for child safety (Q dummies). The new UN Regulation 129 introduces also a side impact test procedure for child restraint systems and specifies the use of the Q-Series dummy. The Q dummies were designed for both front and side impact test procedures but the main priority and focus in the development has been on frontal impacts. The work described in this report is on the use of the Q10 dummy in side impacts.

Accident causation for children in cars was briefly discussed in this report. There are few severe injuries to correctly restrained older children recorded in the accident databases maintained around Europe. This indicates that restraint systems for older children are able to provide good protection for children. Head injuries accounted for the majority of serious injuries recorded in all restraint types. Other than the head, serious injuries were also frequently found to occur in the chest and abdomen body regions. These injuries occur due to compression through door panel contact. They were mainly observed when the child was sitting on a booster cushion or just using the adult belt and may not be as frequent in CRSs that have side wings for protection. Upper limb injuries were also prevalent in French accident data and should not be neglected from consideration of injury priorities for prevention in the future.

For use in lateral impacts a *special side impact kit* has been developed for the Q10 dummy consisting of a halve arm and modified shoulder. Test carried out described in this report include tests with and without this special side impact kit. The evaluation of the Q10 for side impact includes biofidelity in impactor and sled test conditions, repeatability and reproducibility, sensitivity and durability.

For lateral impactor *biofidelity* tests it can be concluded that all three important body regions (shoulder, thorax and pelvis) show initially an overestimated force (approximately 40% to even 100% depending on the region) with a relative lower force at later times. The WorldSID 5th percentile dummy in this respect is much closer to the target corridors. The fact that the overestimation affects all involved regions (except perhaps abdomen for which there was no assessment) may lead to a relative balance of the regional loads in the case of distributed loading. Also in sled test the pelvis shows too high forces indicating that the pelvis of the Q10 is too stiff. For the thorax force (with and without side impact kit) the response is within the corridor for the Heidelberg test condition but the forces are initially too high for the MCW (Medical College of Wisconsin) tests. In sled tests, the response does not appear to be significantly improved by the presence of the side impact kit. There was however an improvement in shoulder pendulum tests, where, while still above the corridor, the peak force was reduced by the kit. In the abdominal region the forces are below the corridors. This can be attributed to the floating and false ribs which are lumped in the ribcage in the Q10 whereas they are separately represented in the WorldSID 5th. For the abdomen and pelvis region modifications to the Q10 should be considered to improve the dummy performance.

The response of the Q10 dummy with the side impact kit could lead to the question whether this side impact kit should not be integrated standard in the Q10 dummy, so replacing the current Q10 dummy version. The disadvantage however is the absence of the lower arm in the side impact kit, which as a consequence would lead to a different kinematical behaviour and particular also a different shoulder-belt interaction. Due to this at the moment such an integration of the side impact kit cannot be recommended.

In general the *sensitivity* studies show that the Q10 dummy in lateral impact is sensitive to variations in impact speeds, impact direction and alignments. In the EPOCH and 3rd party testing the Q10 dummy was also shown to be sensitive to dummy installation and CRS type variations.

Initially some *durability* issues were reported for the prototype dummy but they were addressed in the Q10 production version dummy. The durability of the Q10 production version dummy seems to be rather promising since the dummy with full and half arm (side impact kit) was exposed to various severe sled tests without any durability issues reported from both the internal and third party test series.

Tests with 18 production version dummies showed that all coefficients of variation were within 5% for *repeatability* and 10% for *reproducibility*. In the EPOCH and 3rd party testing the test to test repeatability was found to be good while Coefficients of Variation (CoV's) in repeatability tests were found to be 5% or smaller except for the upper neck moment showing a larger CoV of 6.8%, which however is still judged to be adequate for CRS lateral sled tests. So a main conclusion is that the Q10 production version dummy can be used as a repeatable and reproducible tool.

For the head a 3ms head acceleration limit is proposed based on scaling up to the Q10 from the CASPER accident reconstruction experiments (see figure 62). For the chest scaling of adult lateral impact requirements resulted in rib deflection thresholds for the Q10 of 29.7 mm for a 25 % risk of injury and 34.2 mm for a 50 % risk of AIS ≥ 3 skeletal thoracic injuries. For the Q10 shoulder scaling from adults resulted in forces of 1665 N, 2101 N and 2366 N resp. at the 5, 25 and 50 % risk of AIS ≥ 2 injury levels. Due to the assumptions made in the simple scaling process it is recommended that these thresholds are evaluated in the particular testing application before being adopted.

6.2 Recommendations

1. EEVC considers the current Q10 production version dummy based on its observed sensitivity, repeatability, reproducibility and durability in the extensive evaluation described in this report as sufficiently adequate and, in the absence of a better alternative for a 10YO dummy, therefore recommends the dummy to be used for the future evaluation of the protection of children in restraint systems in lateral impacts, including R129 and full scale crash tests.
2. Concerning biofidelity, the performance of the Q10 with the special side impact kit is better in the thoracic area than the regular dummy in shoulder pendulum tests. The side impact response in sled tests is however showing issues in all regions, and a biofidelity which is lower than the WorldSID 5th Female. The presence of the kit does not solve these issues but does not degrade the response either. So the use of this side impact kit is recommended by EEVC.

3. The Q10 dummy with side impact kit is currently the best dummy for representing children of this size in side impacts. In spite of this, for the pelvis and the abdomen region modifications in the Q10 could be considered to improve the dummy biofidelity performance in lateral impacts.
4. It is proposed to implement initially 3 injury criteria: for the head (head acc 3ms), chest (deflection) and shoulder (force). The proposed injury thresholds for the chest and shoulder should be evaluated in actual test conditions using various types of restraint systems.

6.3 Implications of the findings for other Q-series dummies in side impact testing

In the United States of America, a biofidelic lateral impact version of the Q3 called Q3s is developed ([21], [22], [23], [24], [25], [26] and [27]) and specified in regulation FMVSS 213 [28]. Along the same lines a Q6s version of Q6 is developed [22], [25] and [26]. The Q3s and Q6s dummy are largely different from Q3 and Q6, The difference are: glass fibre skull (to prevent ringing in case of airbag contact), new neck similar to Hybrid III 3YO neck (including tuned Mz stiffness), flexible shoulder, softer ribcage and flexible pelvis (floating hip cups and softer thigh flesh). These side impact child dummies showed, according to the various studies mentioned above, a good biofidelity performance in a number of different side impact test conditions. Qualitatively speaking, the biofidelity performance of these dummies approximates the lateral biofidelity requirements similar to the WorldSID 5th in side impact biofidelity tests. The effect of the side impact kit developed for the Q10 brings improvement concerning the side impact response of the Q10, but as mentioned earlier, in the abdominal and pelvic regions, the biofidelity is subject for further improvement. One possibility is a special side impact kit replacing some of the current dummy parts in the abdomen/pelvis area. Alternatively also the Q3s and Q6s could be considered in the UN regulations. Therefore it is recommended that EEVC performs an evaluation of these dummies.

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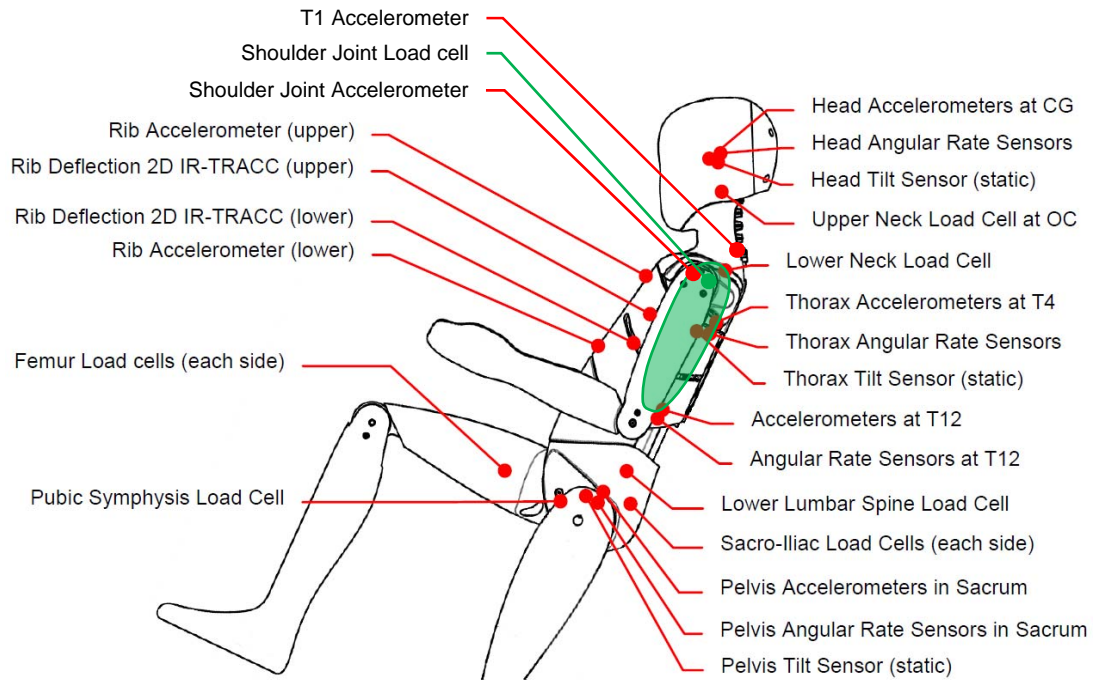
ANNEX A: Q10 MEASUREMENT CAPABILITIES

This Annex gives an overview of the set of instrumentation and measurement channels per body segment for 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 6. The specification per type of sensor is shown in figure 63 and table 7. Special mounts are available to mount the instrumentation on the dummy.

Table 6: Q10 dummy instrumentation and measurement channels per body segment.

Body segment	Instrumentation	Direction	# of channels
Q10 dummy			Total 70 + (12)
Head	Accelerometers	Ax, Ay, Az	3
	Angular velocity sensors	Wx, Wy, Wz	3
Neck	Load cell (upper neck)	Fx, Fy, Fz, Mx, My, Mz	6
	Load cell (lower neck)	Fx, Fy, Fz, Mx, My, Mz	6
Shoulder	T1 accelerometer	Ay	1
	Shoulder joint load cells	Fx, Fy, Fz (SI-kit only)	2 x 3
	Shoulder joint accelerometers	Ay	2 x 1
Thorax	T4 accelerometers	Ax, Ay, Az	3
	T4 angular velocity sensors	Wx, Wy, Wz	3
	T12 accelerometers	Ax, Ay	2
	2D-IR-TRACC (upper)	Dx and φ_z	2
	2D-IR-TRACC (lower)	Dx and φ_z	2
Lumbar spine	load cell	Fx, Fy, Fz, Mx, My, Mz	6
Pelvis	Accelerometers	Ax, Ay, Az	3
	Angular velocity sensors	Wx, Wy, Wz	3
	Pubic symphysis load cell	Fy (side impact)	1
	Sacro-iliac load cells	Fx, Fy, Fz, Mx, My, Mz	2 x 6
	ASIS load cells	Fx, My	2 x 2
Abdomen	Twin pressure	p left and p right	2
Upper leg	Femur load cell (to be designed, provisions only)	Fx, Fy, Fz, Mx, My, Mz	(2 x 6)

Note: The number of channels between brackets means that provisions are available in the dummy but the sensors are not yet developed.



**Figure 63: Q10 Overview of instrumentation options
(Side Impact Kit indicated green, ASIS load cells not indicated)**

Table 7: 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 Neck and Lumbar spine Shoulder joint Sacro-Iliac Pubic symphysis ASIS Upper femur	Humanetics	IF-217-HC (350 Ohm) IH-10980JI4 (LH), -10970JI4 (RH) IH-11380JI4 (LH), -11390JI4 (RH) W50-71051S3 IH-11570JI4 (LH), -11580JI4 (RH) (to be designed)

ANNEX B: Q10 PROTOTYPE REPEATABILITY

The analysis in this annex is performed on prototype version test data. The level of repeatability of dummy responses is often expressed as 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 [29]. For a proper statistically valid CoV, the minimum number of tests is six (6). The test series performed in this dummy validation exercise comprises, in general, a maximum of five (5) and a minimum of two (2) tests of the same test configuration, so the validity of the repeatability assessment would be limited. To overcome this limitation, an alternative approach is used: for each test configuration the results are normalised to the average result of the group. For any parameter, the CoV can be determined by calculating the standard deviation of all of the normalised results for that parameter. Below, per body region tables are presented that show the test configuration considered and the CoV values obtained per composed group. The associated number of tests in the (composed) group is given between brackets. If the number of tests is smaller than six (6), the CoV value is not statistically reliable. For an assessment of the Q10 production version dummy repeatability and reproducibility performance, see the paragraph on Certification at the end of this chapter.

For the lateral tests, as shown in the tables below, only two parameters in two test configuration (T1 Ay in shoulder tests 10 degrees rearward and Sternum deflection in thorax tests 6.7 m/s 15 degrees rearward) are considered to be outliers (CoV >7%). This result is excluded from the assessment. The results presented in table 8 to table 13 show good repeatability of the dummy (prototype). Nearly all combined CoV values remain below 3.5%. One parameter shows an increase level of repeatability in the prototype tests pubic symphysis load in the pelvis tests (CoV = 4.62%). This may be attributed to the bottoming out of the iliac wings to the sacrum block. In the production version of the Q10 gap between these parts is increased. All of the coefficients of variation but four are within the required 5% (this concerns a limited amount of tests). Overall, it is concluded that the Q10 dummy can be used as a repeatable tool.

Table 8: Head lateral impact repeatability

Test configuration	Head accel
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% (5)
35 degrees LH- and RH- side	2.24% (10)
45 degrees LH- and RH- side	4.21% (5)
All tests together	2.54 % (44)

Table 9: Neck lateral bending repeatability

Test configuration	Upper neck moment	Head form rotation
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	1.59% (11)	1.10% (11)

Table 10: Shoulder lateral impact repeatability

Test configuration	Pendulum force	T1 Y - accel
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 rwd	2.66% (2)	2.01% (2)
4.5 m/s, 15 mm fwd	0.18% (2)	2.36% (2)
4.5 m/s, 10 degr rwd	0.17% (2)	<i>Excluded</i> >7% (2)
4.5 m/s, 10 degr fwd	0.14% (2)	2.47% (2)
All tests together	1.97% (21)	3.23% (19)

Table 11: Lumbar spine lateral bending repeatability

Test configuration	Lower lumbar moment	Head form rotation
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	1.68% (11)	1.69% (11)

Table 12: Thorax lateral impact repeatability

Test configuration	Pendulum force	Sternum deflection (X-direction)
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, rwd 15 degr	2.18% (2)	0.60% (2)
6.7 m/s, rwd 15 degr	3.28% (2)	<i>Excluded</i> >7% (2)
4.3 m/s, fwd 15 degr	0.17% (2)	0.35% (2)
6.7 m/s, fwd 15 degr	0.14% (2)	1.04% (2)
All tests together	1.49% (21)	2.16% (19)

Table 13: Pelvis lateral impact repeatability

Test configuration	Pendulum force	Pubic symphysis load
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	1.51% (25)	4.62% (20)

29 ISO document, Calculation Methods & Acceptance Levels for Assessing Repeatability and Reproducibility, ISO/TC22/SC12/WG5 Document N751