Comparisons of Q10 original and different Q10 Euro NCAP 2020 update dummies in frontal and side impact sled tests

Katarina Bohman1), Isabelle Stockman1), Lotta Jakobsson1), Maria Wimmerstedt1), Dion Kruse2), Håkan Sundmark3).

1) Volvo Cars Safety Centre, Volvo Cars, Göteborg, Sweden.
2) Autoliv Research, Vårgårda, Sweden.
3) Autoliv Sverige, Vårgårda Sweden.

Main author: email Katarina.bohman@volvocars.com. Phone: + 46 72 8870567

ABSTRACT

The Q10original has been criticized for unstable shoulder belt interaction in frontal impacts. Several design changes, with focus on shoulders and torso, have been made resulting in a prototype Q10 (Q10update) and in a second step, some design changes were removed resulting in a second prototype Q10 (Q10light). The aim of this study was to compare kinematics, shoulder belt interaction and dummy loadings to the Q10update and Q10light with the current Q10original in frontal impacts. Q10original and Q10update were also compared and evaluated in side impacts.

The three crash test dummies; Q10original, Q10update and Q10light, were compared in frontal sled tests in a midsize SUV, in two different crash pulses; full frontal and Euro NCAP Offset Deformable Barrier (ODB) crash test pulses. Three different belt geometries were tested, with focus on shoulder belt position on shoulder and lower torso. Dummy kinematics and loadings were analysed. The dummies were positioned on booster cushions and restrained by seatbelt with pretensioner and load limiter.

In addition, the Q10original and Q10update were included in a of total eight side impact sled tests simulating a Euro NCAP 2020 Side Advanced European Mobile Deformable Barrier (AE-MDB) impact, using a midsize passenger car. The dummies were positioned on booster cushions and restrained by seatbelt and combinations of thorax side airbag (SAB) and inflatable curtain (IC), in addition to a reference test without SAB and IC. All tests included a retractor with pretensioner and load limiter.

In the frontal sled tests, the Q10update was less sensitive to initial shoulder belt position far out on the shoulder than the Q10original. The shoulder belt had a tendency to move inboard on the Q10update during the crash, even if the shoulder belt was initially positioned far out on the shoulder. The Q10light had a similar shoulder belt interaction as the Q10original. Both update dummies showed a greater forward excursion of the head and a larger tilt of the upper torso than the Q10original. Both update dummies had increased chest deflection, decreased chest acceleration and decreased neck tension as compared to the Q10original, in similar loading conditions.

The larger upper torso tilt of the update dummies in the frontal sled tests, is potentially due to the mass redistribution from pelvis to upper body. The shoulder belt interaction of the Q10update was influenced by the soft tissue at upper chest and forward shift of the shoulder joint, which likely contributed to the more stable shoulder belt interaction and reduced sensitivity to changes in shoulder belt geometry. These two design features were removed in Q10light, being more similar to the Q10original.

In the side impact sled tests, the Q10update had decreased chest acceleration, but increased chest deflection, as compared to the Q10original in the following test setups: reference, IC only and IC combined with SAB. Furthermore, the shoulder force was increased for the Q10update as compared to the Q10original. This was seen for the combinations: IC only, SAB only and IC combined with SAB. In the reference test without IC or SAB, the Q10update sustained a head impact to the vehicle interior, resulting in increased head acceleration values. The differences in dummy response in the side impact sled tests are mainly due to mass redistribution, resulting in decreased chest acceleration, but increased chest deflection, for the Q10update, especially when no SAB was activated.

Due to its improved kinematics and sensitivity to changes in seatbelt geometry, the Q10light was preferred of the three tested dummies for frontal impact testing. This version was not tested in side impacts in this study. The tested version, Q10update, was not considered providing substantial enhanced information in side impact tests as compared to the Q10original in this study.

BACKGROUND

During the 90s, the development of the Q dummies was initiated in order to replace the P Dummies (EEVC, 2008). The Q10 crash test dummy was developed in the European project EPOCh (Enabling Protection for Older Children). In 2015, Euro NCAP revised the protocol for rear seat evaluation, by replacing the Q1.5 and Q3 dummies with the Q6 and the Q10, in both frontal Offset Deformable Barrier (ODB) and side impact test. The Q10 was positioned behind the passenger in the ODB, resulting in an inboard movement during the crash. In the side impact test, the Q10 was positioned behind the driver, meaning the near side.

The Q10 has been criticized for an unstable shoulder belt interaction in frontal impacts, but also of a pronounced shoulder belt slippage towards the neck. Bohman and Sunnevang (2011) showed that the chest deflection of the Q10 was more sensitive to belt geometry than to any other countermeasure. Arbogast et al (2013) compared shoulder belt interaction of child volunteers with the HIII10 year-old crash test dummy and Q10 in low speed sled tests. They found that the shoulder belt moved to greater extent towards the neck on the Q10 compared with the child volunteers, resulting in an underestimate of chest deflection in the Q10.

In order to improve the Q10 behaviour in frontal impacts, Humanetics updated the dummy to a second version, referred to as Q10update in this paper. Five changes were implemented including shoulder joint movement of 20mm forward, head and neck shifted 20mm forward and 5.3° nose up, soft tissues representation at nipples, continuous shoulder liner and mass redistribution change, by moving 1.7 kg from the pelvis to the torso (Waagmeester et al. 2017). In a CAE comparison of Q10originial, Q10update and Thums v4 10 year-old Human Body Model (HBM), it was found that the Q10update was not sensitive to an outboard shoulder belt geometry; the shoulder belt stayed on the shoulder while the other two dummies showed shoulder belt slipping off (Schnottale et al. 2017). In order to make the Q10update a bit more sensitive to various shoulder belt geometries, only three of the changes from the Humanetics Q10 was included in a third version of Q10, referred to in this study as Q10light. This version included the following design changes; the head and neck shift 20mm forward and 5.3° nose up, continuous shoulder liner and mass redistribution change, by moving 1.4 kg from the pelvis to the torso. This Q10light update kit was supplied by Cellbond. Recently, Euro NCAP has decided to include the Q10light in the rating program in 2020.

The aim of this study was to compare kinematics, shoulder belt interaction and dummy loadings of the Q10update and Q10light with the current Q10original in frontal impacts, and evaluate the Q10update compared with Q10original in side impacts.

METHOD

This study included both frontal and side impact sled testing. Three versions of the Q10 child crash test dummy were compared: Humanetics Q10original, Humanetics Q10update with full update kit including five updates and Humanetics Q10 with update kit light from Cellbond, Q10light, including three updates, see Table 1.

In the frontal impact tests, all three versions of the Q10 dummy were compared. In the side impact tests, the Q10original and Q10update were compared and both dummies were instrumented with the original side impact kit as well (EEVC, 2015). When the Q10 dummy is rebuild with a side impact kit the scapula and arms are changed from front to side versions and sensors are moved to measure lateral chest deflection. It also includes shoulder force sensor.

Dummy	**Supplier dummy**	**Supplier update kit**	**Shoulder joint shift**	**Head and neck shift**	**Soft tissue at upper chest**	**Cont. shoulder liner**	**Mass re-distribution**
Q10 original	Humanetics	N/A	N/A	N/A	N/A	N/A	N/A
Q10 update	Humanetics	Humanetics	X	X	X	X	X
Q10 light	Humanetics	Cellbond		X		X	X

Table 1. Q10 versions and details on included updates.

Frontal Impacts

A series of frontal sled tests were performed in a reinforced sled body of a midsize SUV mounted on an acceleration sled. Two different crash test pulses were used (Figure 1): 35mph full frontal and Euro NCAP 64km/h ODB with the sled body rotated 18 degrees. Acceleration in x direction only was input to the sled.

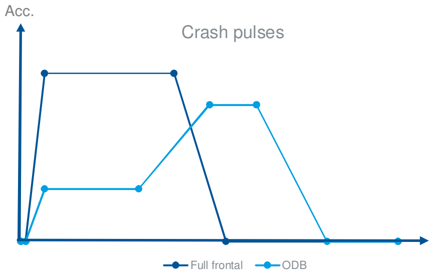
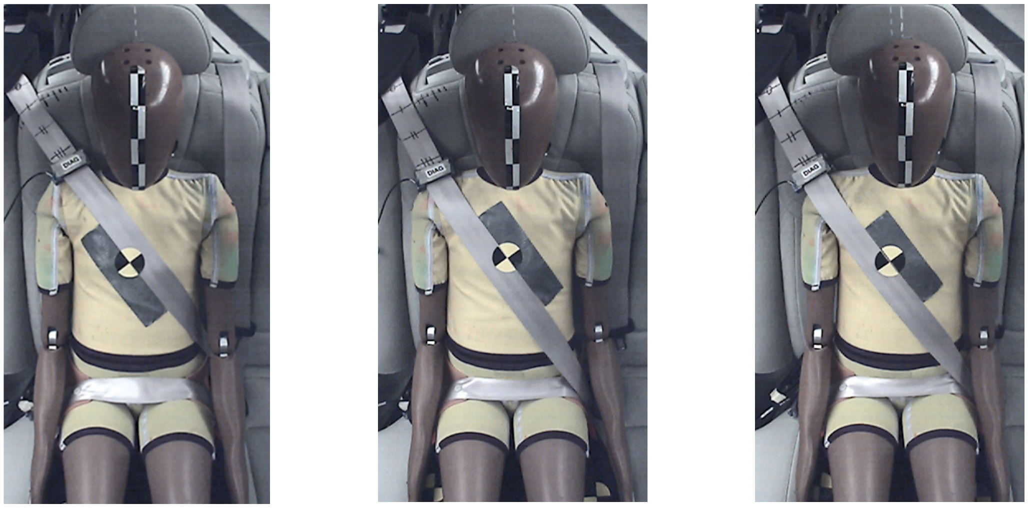


Figure 1. Frontal impact crash test pulses used in the study; a full frontal pulse and an ODB pulse.

The crash test dummies were restrained with a three point seatbelt with pretensioner and load limiter, and seated on Volvo Booster Cushion (BC) without backrest. In all tests except two, the booster cushion was positioned centralised in the seat and the dummy was centred on the booster cushion. Hip shields and spacer in lumbar spine were used. Load cells were placed on the diagonal belt above the dummy shoulder level and on the outer part of the lap belt. Three different belt geometries were tested, as illustrated in Figure 2. The left and mid belt geometries were achieved by routing the diagonal belt above and under the inner guiding loop of the BC, resulting in belt geometries closer to the neck and further out on the shoulder, respectively. The third belt geometry shown to the right in Figure 2, resulting in a belt position far out on the shoulder, was achieved by routing the diagonal belt under the inner guiding loop of the BC and move the dummy and BC 15mm inboard. This geometry was tested in one full frontal test and in one ODB.



Diagonal belt above inboard guiding loop of booster cushion

Diagonal belt under inboard guiding loop of booster cushion

Diagonal belt under inboard guiding loop, and dummy/booster cushion moved 15mm inboard

Figure 2. The three seatbelt geometries included in test setup.

In the full frontal sled tests, the Q10original and Q10update were tested simultaneously, Q10original seated on the left hand side (LHS) of the vehicle and Q10update seated on the right hand side (RHS). In the ODB tests, the Q10original, Q10update and Q10light were all tested on the RHS, resulting in an inboard motion of the dummy relative to the sled body during the test. The test matrix is shown in Table 2.

Test number	Pulse	LHS	RHS	Belt geometry
1	35mph FF	Q10 original	Q10 update	Diagonal belt above guiding loop
2	35mph FF	Q10 original	Q10 update	Diagonal belt above guiding loop
3	35mph FF	Q10 original	Q10 update	Diagonal belt under guiding loop
4	35mph FF	Q10 original	Q10 update	Diag. belt under guiding loop, BC moved 15mm inboard
5	ODB		Q10 original	Diagonal belt above guiding loop
6	ODB		Q10 original	Diagonal belt above guiding loop
7	ODB		Q10 update	Diagonal belt above guiding loop
8	ODB		Q10 light	Diagonal belt above guiding loop
9	ODB		Q10 original	Diagonal belt under guiding loop
10	ODB		Q10 original	Diagonal belt under guiding loop
11	ODB		Q10 update	Diagonal belt under guiding loop
12	ODB		Q10 update	Diagonal belt under guiding loop
13	ODB		Q10 light	Diagonal belt under guiding loop
14	ODB		Q10 update	Diag. belt under guiding loop, BC moved 15mm inboard

Table 2. Test matrix with overview of pulse, dummy and belt geometries.

High speed cameras captured a front view, LHS and RHS views and a top view of the dummy. Dummy kinematics, loadings and seatbelt-to-body interactions during the forward motion of the dummy were analysed and compared. The position of the shoulder belt during the event was categorised as on the shoulder, moved outboard on the shoulder from initial position during the event, and off the shoulder. In Q10original, where the continuous shoulder liner is not included, shoulder belt slip-off was defined as shoulder belt in the gap between the torso and the arm. Head accelerations, neck forces, chest accelerations, chest deflections and diagonal belt and lap belt forces were captured and used in the analysis.

Side Impacts

A generic pulse replication of the Euro NCAP 2020 Side Advanced European Mobile Deformable Barrier (AE-MDB) test for a midsize passenger vehicle was defined for a deceleration sled system. The 2020 side AE-MDB test method includes an increased barrier weight of 100kg and barrier speed of 60km/h compared with previous speed of 50km/h. The increase of barrier weight and velocity relative the existing Euro NCAP side impact test resulted in higher intrusion velocity and greater deformation characteristics.

The Autoliv sled system comprises three sleds. One vehicle sled carrying the rear seat, a rigid-door-side sled where the interior (pre-tilted door and trim panel) are mounted and a load carrier sled. The vehicle and door sleds, set in their starting positions are accelerated by, the load carrier sled, to mimic a door sled intrusion velocity (peak approximately at 10m/s) and a vehicle sled response velocity, shown in Figure 3). A feed-back system provides a realistic drop of the door sled intrusion velocity to meet the vehicle sled velocity at an almost unified velocity level (approximately 8m/s) before final braking.

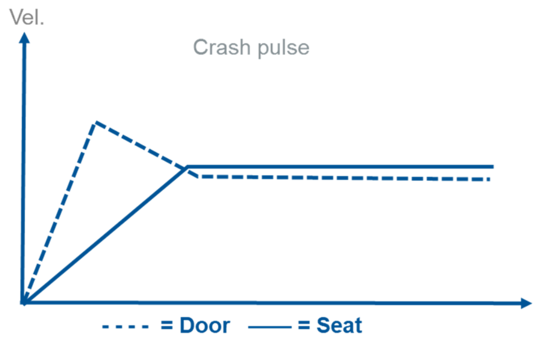


Figure 3. Door and seat velocities during side impact.

The initial position of the door interior in relation to the child dummy was replicated from an estimated average door performance, based on accelerometer signals at different heights and from different types of tested midsized cars, using a pre-tilted door (approximately 10 degrees, lower inboards) at a mid-point door position. The door panel was cut just above the seat bench, in order not to deform the rear seat bench. The side structure rear of the door panel on the door sled was simulated by a foam block to support the side airbag when deployed and preventing the arm to slide off the door panel.

In all tests the child dummy was positioned on the Volvo Booster Cushion without backrest, as shown in Figure 4. In each test the child dummy was restrained with a three point seatbelt including a load limiter function and the pretensioner was activated at 7ms (Reference test). The diagonal belt was routed above the inner guiding loop of the BC. A combination of activation of thorax side airbag (SAB) and inflatable curtain (IC) was used, as shown in Table 3. The IC was inflated with pressurized air to a representative pressure, while the SAB was inflated with a standard inflator. None of the restraint components were tuned prior to the tests. In total 8 tests were performed. The four test setups described in Table 3 were conducted for each dummy.

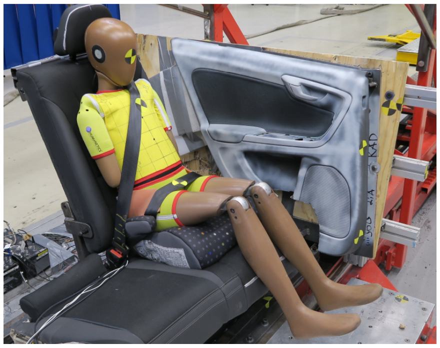


Figure 4. Side impact test set-up.

Test Setup	Seatbelt	Inflatable Curtain	Side Airbag
Reference	Yes	No	No
IC	Yes	Yes	No
SAB	Yes	No	Yes
IC/SAB	Yes	Yes	Yes

Table 3. Side impact test matrix for each dummy.

High speed cameras captured front, side, top and an oblique views. The following measurements were captured and analysed in the tests: x, y, z acceleration of the head, chest and pelvis, upper neck forces, upper and lower chest deflection, left shoulder forces, pubic force, accelerations of door and seat sled.

RESULTS

Frontal Impacts

In total 14 sled tests were performed; four 35mph full frontal impacts and 10 Euro NCAP 64km/h ODB. Repetitions of tests (see Table 2: test 1 and 2, 5 and 6, 9 and 10, 11 and 12) with Q10original and Q10update showed repeatable dummy behaviour. Q10original and Q10update were compared in full frontal tests and Q10original, Q10update and Q10light were compared in ODB tests.

The dummy responses were affected by the dummies' kinematics and their seatbelt-to-body interaction. The dynamic interaction with the seatbelt was greatly influenced by the initial seatbelt geometry and by the dummy designs. When the seatbelt was initially positioned close to the neck by routing the diagonal belt above the inboard guiding loop, a more similar seatbelt-to-body interaction between dummy designs were seen. However, when the seatbelt was routed under the inboard guiding loop resulting in an initial position further out on the shoulder, belt slip-off occurred more frequently in the Q10original and Q10light compared to the Q10update (Table 4).

In full frontal tests the Q10original had decreased head acceleration, neck tension, chest acceleration and lap belt force as the initial seatbelt position was moved outboard relative to the dummy's shoulder. Chest deflection was increased and the diagonal belt force remained the same (Figure 5). Q10update showed a small increase in head and chest accelerations and chest deflection as the initial seatbelt position on shoulder was moved outboard, while neck tension and lap belt force were decreased and the diagonal belt force remained the same (Figure 5). When the initial seatbelt geometry was close to the neck, the upper neck tension and chest acceleration were higher in Q10original compared with Q10update, while Q10update showed higher upper chest deflection. When the initial seatbelt geometry was further out on the shoulder, neck tensions and upper chest deflections were similar while

Q10update had higher chest acceleration. In full frontal tests the lap belt forces were always higher in Q10original while diagonal belt forces were similar between the dummies. When comparing full frontal tests with ODB, the pulse peak acceleration was higher in the full frontal test, i.e. a higher crash severity as compared to the ODB situation. In general, this resulted in increased dummy neck tension, and head and chest accelerations in the full frontal tests, regardless of dummy.

In ODB tests there was a wider spread in dummy-to-seatbelt-interaction between the three Q10 versions, which influenced the dummies' responses to a greater extent compared to full front tests. With the seatbelt initially positioned close to the neck similar seatbelt-to-body interactions were seen between dummy designs. When comparing the results, Q10original had greater neck tension and lap belt force compared to the update dummies, while the chest deflection was lower.

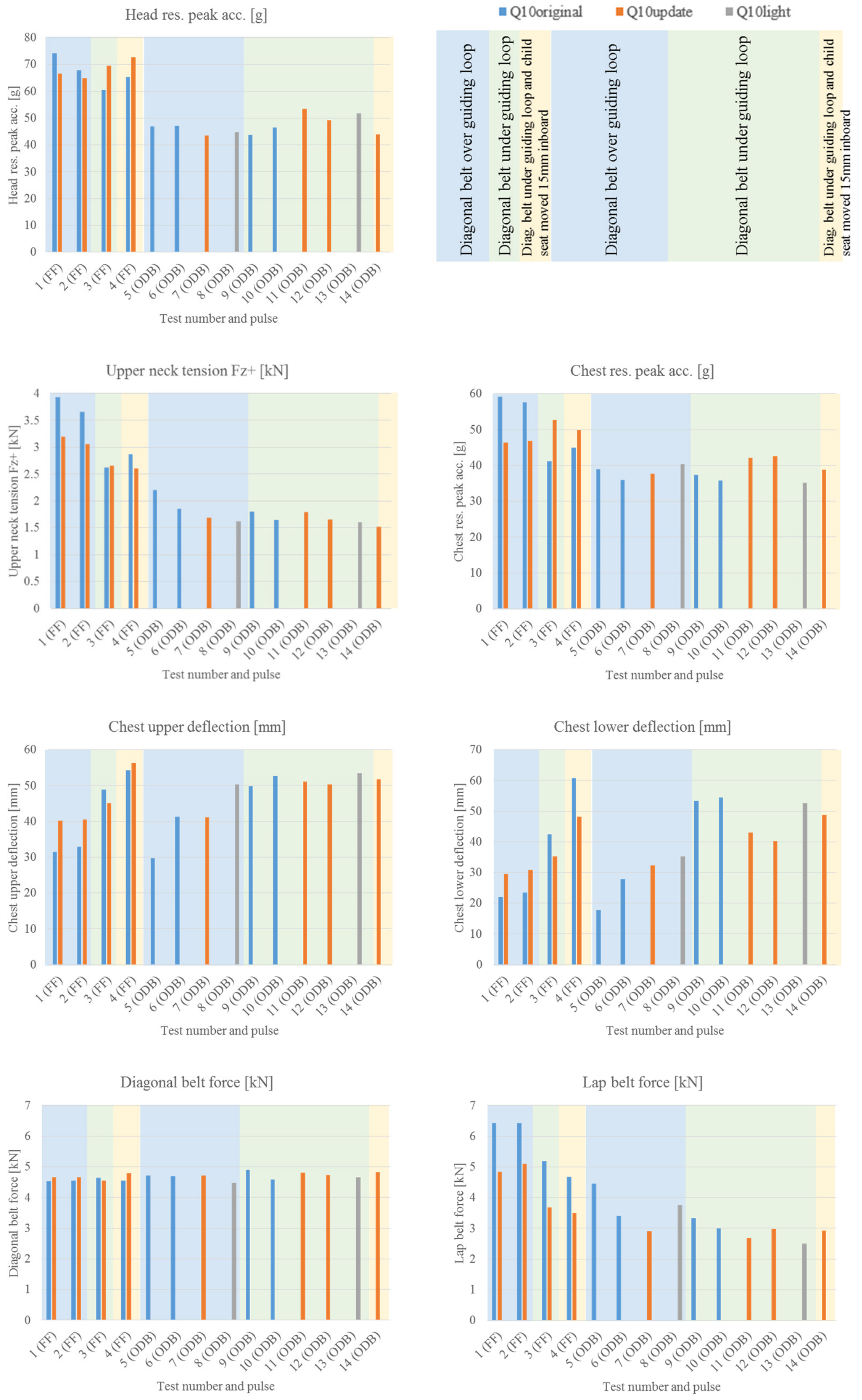


Figure 5. Head, neck, chest and seat belt loading to the three dummies. The shoulder belt geometries are shown by the background colour of the graph, see figure at the bottom right for colour coding.

Kinematics:

Initial position of the dummies differed due to the changes made to the Q10update and Q10light compared with the Q10original. The initial head positions of the Q10update and the Q10light were more perpendicular to the horizontal plane, compared to the Q10original, where the head had a greater forward rotation.

In the full frontal tests, the Q10update showed greater head excursion and upper body tilt, as well as more pronounced shoulder excursion as compared to the Q10original, regardless of initial seatbelt geometry. The pelvis excursion of the Q10update showed less forward excursion as compared to the Q10original (see Figure 6).

In the ODB tests with diagonal belt guided above the inboard guiding loop of the booster cushion the seatbelt remained on the shoulder for all three dummy versions. The Q10update and Q10light showed more head excursion and upper body tilt compared to the Q10original. The Q10update had the most forward excursion of the head followed by the Q10light and the Q10original (see Figure 7).

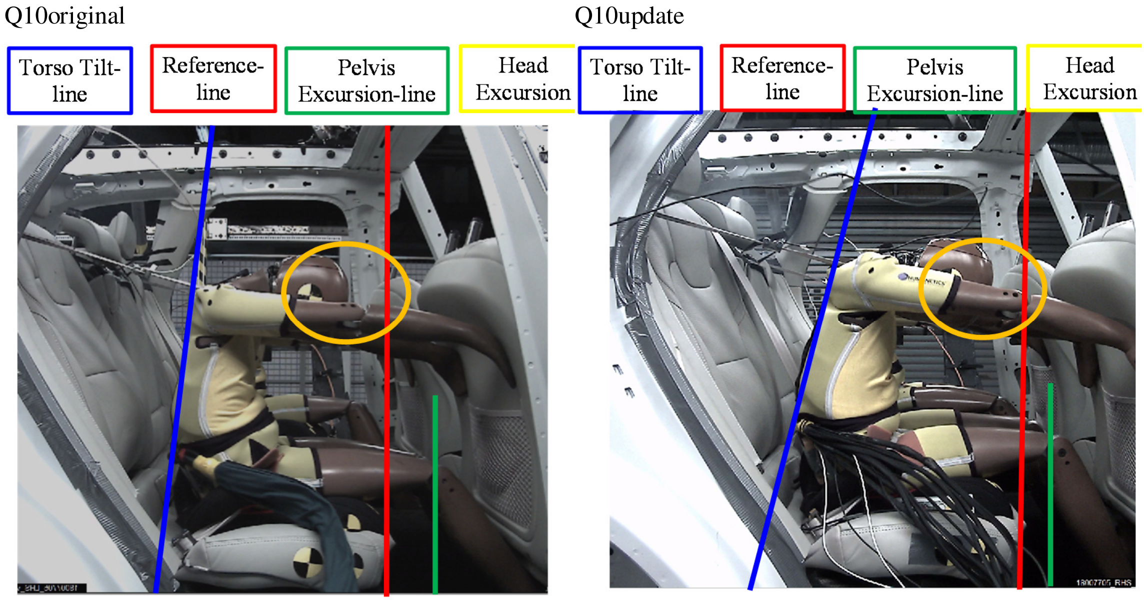


Figure 6. The kinematics of the Q10orginial and Q10update in full frontal test at the time of max head excursion.

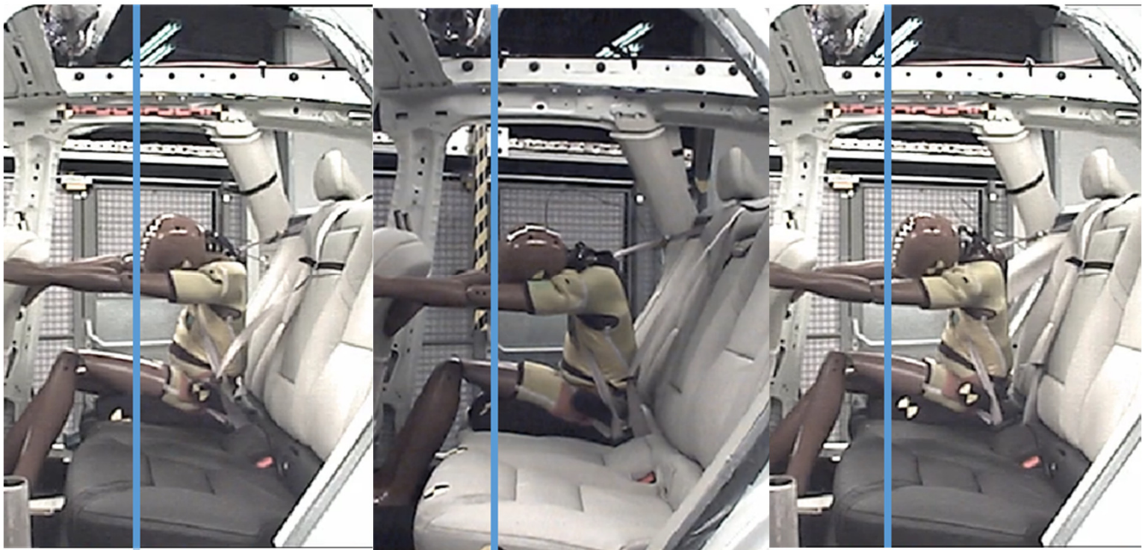


Figure 7. The kinematics of the Q10orginial (left), Q10update (mid) and Q10light (right) in ODB test at the time of max head excursion (vertical line).

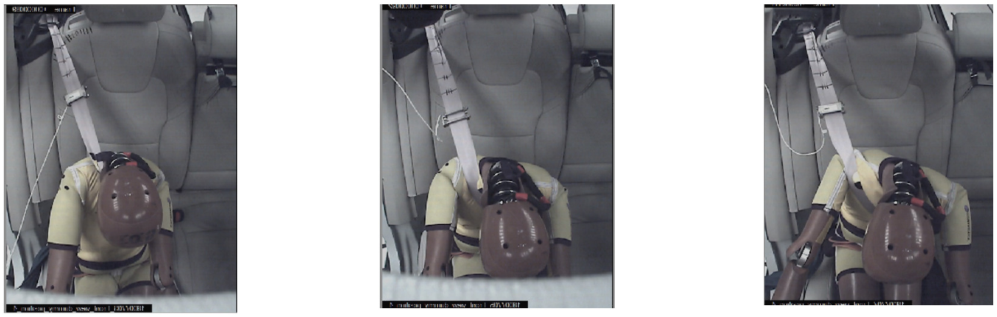
Seatbelt-to-body interaction:

The overall results of diagonal belt position relative to the shoulder can be found in Table 4. In the full frontal test, the diagonal belt slipped off the shoulder of the Q10original in the belt geometry where the diagonal belt was initially furthest out on the shoulder, i.e. when the BC was moved 15mm inboards. For the Q10update in this belt geometry (BC moved 15mm inboard), the diagonal belt was moved further out on the shoulder but it did not slip off (see Figure 8).

In the ODB, the diagonal belt stayed on the shoulder for all the three dummies in the belt geometry where the diagonal belt was routed above the guiding loop, hence, the starting position was closer to the neck. When the diagonal belt was routed under the guiding loop, the diagonal belt slipped of the shoulder for both the Q10original and Q10light, while it stayed on the shoulder for the Q10update. In the belt geometry with BC moved 15mm inboards, the diagonal belt slipped off the shoulder on the Q10update as well (see Figure 9).

	Full front			**ODB**		
Dummy	**Diagonal belt above guiding loop**	**Diagonal belt under guiding loop**	**Diag. belt under guiding loop BC moved inboard**	**Diagonal belt above guiding loop**	**Diagonal belt under guiding loop**	**Diag. belt under guiding loop BC moved inboard**
Q10 original	on shoulder	outboard motion	off shoulder	on shoulder	off shoulder	
Q10 update	on shoulder	on shoulder	outboard motion	on shoulder	outboard motion	off shoulder
Q10 light				on shoulder	off shoulder	

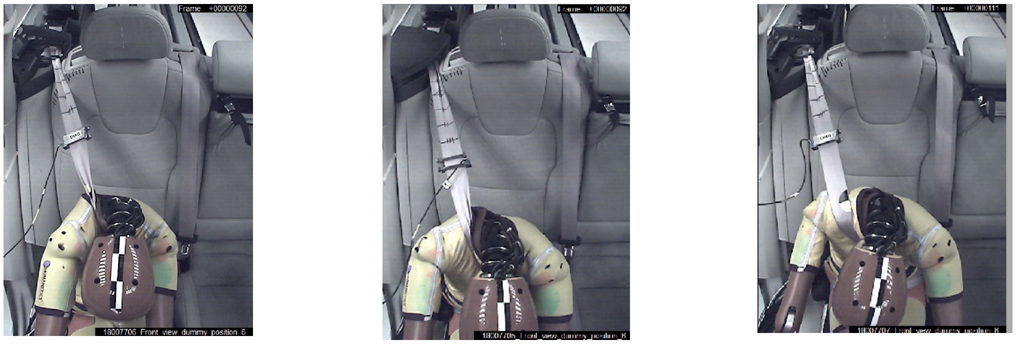
Table 4. The diagonal belt position relative the shoulder at maximum head excursion of the dummy in the various seat belt geometries for the three dummies.



Q10original: Diagonal belt above inboard guiding loop of booster cushion

Q10original: Diagonal belt under inboard guiding loop of booster cushion

Q10original: Diagonal belt under inboard guiding loop, and dummy/booster cushion moved 15mm inboard



Q10update: Diagonal belt above inboard guiding loop of booster cushion

Q10update: Diagonal belt under inboard guiding loop of booster cushion

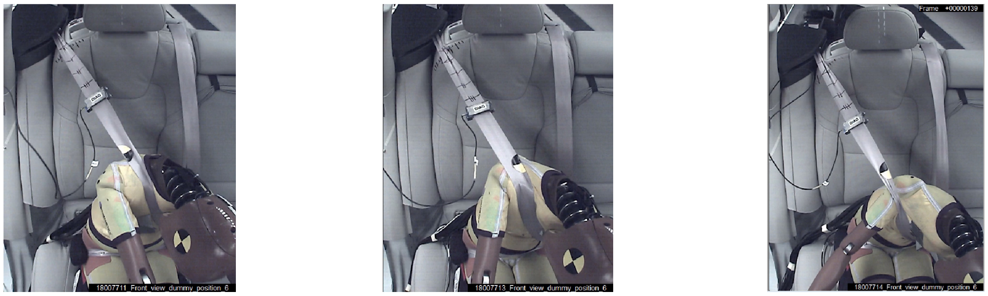
Q10update: Diagonal belt under inboard guiding loop, and dummy/booster cushion moved 15mm inboard

Figure 8. The pictures are taken at the time of maximum head excursion in the full frontal pulse with Q10original and Q10update.

Q10original: Diagonal belt above inboard guiding loop of booster cushion

Q10original: Diagonal belt under inboard guiding loop of booster cushion

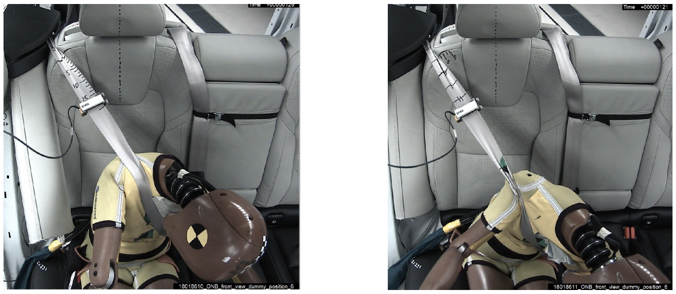
N/A



Q10update: Diagonal belt above inboard guiding loop of booster cushion

Q10update: Diagonal belt under inboard guiding loop of booster cushion

Q10update: Diagonal belt under inboard guiding loop, and dummy/booster cushion moved 15mm inboard



Q10light: Diagonal belt above inboard guiding loop of booster cushion

Q10light: Diagonal belt under inboard guiding loop of booster cushion

N/A

Figure 9. The pictures are taken at the time of maximum head excursion in the ODB pulse with the Q10original, Q10update and Q10light.

In the Q10original, the diagonal belt was stuck in the gap between the arm and the shoulder, as the belt slips of the shoulder. This is prevented by the shoulder liner in Q10update and Q10light (see Figures 7 and 8).

Side Impacts

The difference between the Q10update and the Q10original results, shown in Table 5, in the reference as well as in the IC/SAB setups are noticed in an increase in head accelerations (10-25%) and pelvis accelerations (35-45%) and a decrease in chest accelerations (10-20%). The chest deflections are increased in the Q10update (5-20%) while the chest accelerations are decreased in both the reference and the IC/SAB tests (see Table 5).

Test	Head acc.	Chest acc.	Pelvis acc.	Chest def. up	Chest def. low.
Reference test					
Q10original	58,4	69,1	70,2	20,2	28,2
Q10update	73,1*	54,1	102,3	24,5	31,5
Update vs. Original	(+26%)	-22%	46%	21%	12%
IC/SAB test					
Q10original	54,3	40,1	45	21	26,8
Q10update	59,1	37,3	60,8	22,1	28,5
Update vs. Original	9%	-7%	35%	5%	6%

*) Head-to-door contact

Table 5. Comparison between Q10update and Q10original in reference and IC/SAB tests.

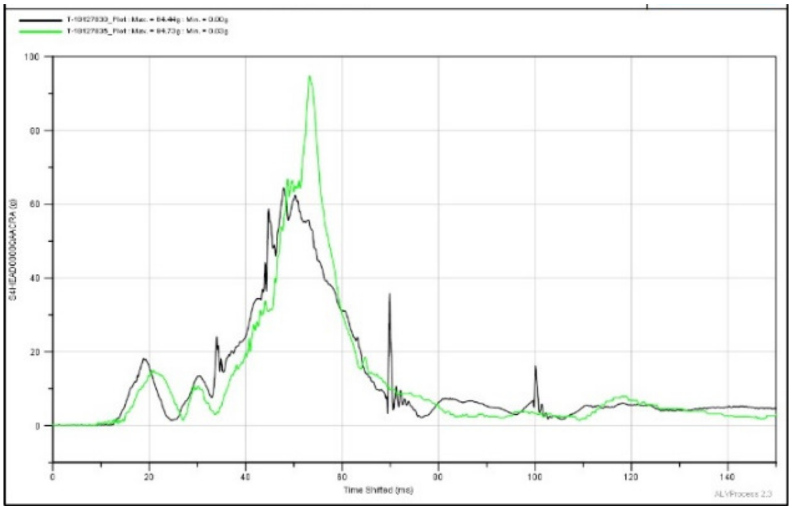


Figure 10. Head accelerations Q10original (black) and Q10update (green) in reference tests.

In the reference test head-to-door contact occurred at 50ms for the Q10update shown in figure 10. In the test with IC only head-to-door contact was did not occur. A relative lower head acceleration and upper neck force was seen, while the chest acceleration increased slightly (Figures 11), as compared to the reference test for Q10update. In the test with SAB only head-to-door contact for the Q10update did not occur. Compared to the reference tests, both dummies were exposed to a decrease of chest acceleration, pelvis acceleration and pubic force, while the head acceleration increased slightly if not considering the head-to-door contact case (Figures 11).Compared to the reference tests, the combination of IC and SAB decreased head, chest and pelvis accelerations, in addition to upper neck, shoulder and pubic forces and the lower chest deflections decreased for both dummies (Figures 11 and 12).

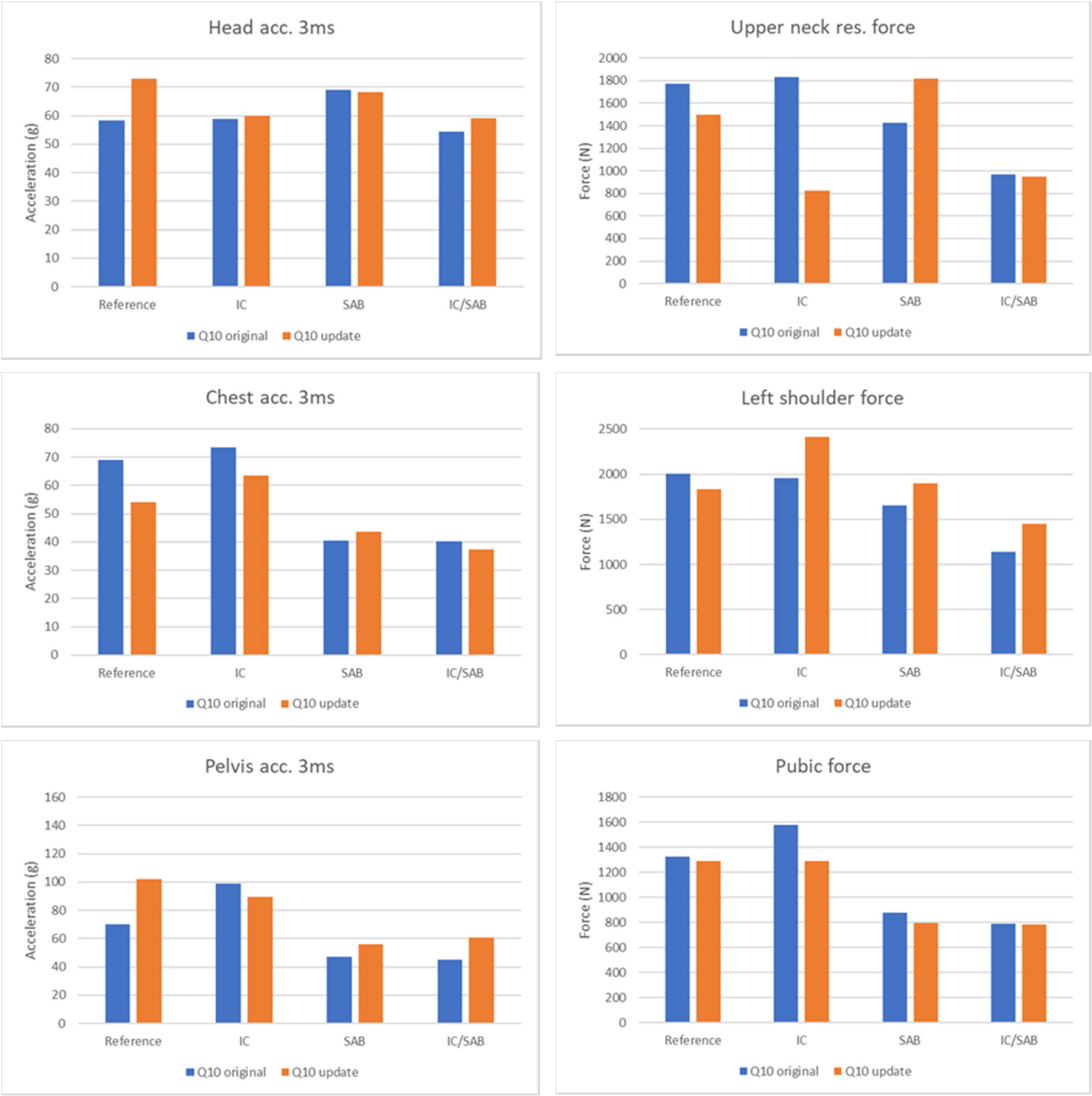


Figure 11. The graphs show resultant acceleration to head, chest and pelvis, force to neck, left shoulder and pubic for the tests defined in the test matrix for the side impact tests.

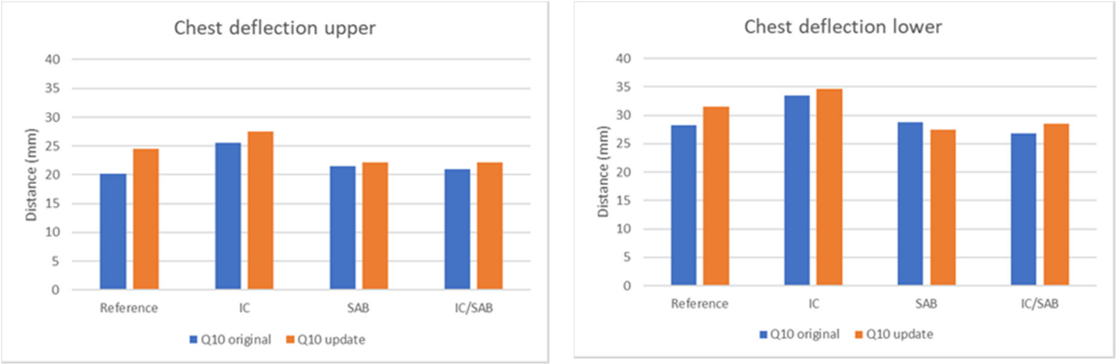


Figure 12. The graphs show chest deflection upper and lower for the tests defined in the test matrix for the side impact tests.

DISCUSSION

The Q10 dummy was introduced in consumer rating procedures and regulatory tests at Euro NCAP, UNECE 129 and ETC (ADAC) and has been used in both frontal and side impact tests. An update of the Q10 was initiated for the introduction of Euro NCAP 2020. The experience gained so far has initiated a request for an update, primarily in frontal but also in side impact load cases. Regarding the Q10 performance at side impact the priority has been lowered in favour for the frontal impact performance.

Frontal impacts

Overall, both update dummies showed a difference in kinematics compared with the Q10original dummy and especially Q10 update showed difference in dummy loading compared to the Q10orginal.

The Q10update showed more head excursion and torso tilt compared to the Q10original in full frontal tests regardless of initial shoulder belt position, even though the Q10original had the diagonal belt further out on the shoulder during the event allowing a more forward motion. The increased mass of the upper body contributed to this change in kinematics. Furthermore, the shoulder joint shifted 20mm forward allowing more forward motion of arms that are clearly stretched forward, which also contribute to the forward motion of thorax. Schnottale et al. (2017) showed that the Q10update had kinematics with an increased upper torso tilt and was more like the kinematic pattern of the Thums v4 10 year-old HBM compared to the Q10original.

In the ODB tests, the Q10light and Q10update had more head excursion and torso tilt compared to the Q10original. Comparing the Q10light and the Q10update, the Q10light had slightly less head excursion and torso tilt than the Q10update. The Q10light only had a mass distribution change of 1.4kg compared to 1.7kg, also, the shoulder joint shift of 20mm was not included in the Q10light. This difference in update design features, explains the difference in kinematics of the two dummies.

The differences in dummy response between the Q10original and the Q10update were seen in reduced neck tension and increased chest deflection in Q10update. The increased mass to upper torso contributed to increased chest deflection in the updated versions of the dummy in tests when the seatbelt remained on the shoulder. Small differences between the Q10original and the Q10light in dummy responses were seen. They included mainly differences in upper neck tension (greater in the Q10original) and in chest deflection results in the ODB tests with diagonal belt guided above the inboard guiding loop resulting in greater chest deflection in the Q10light. In the ODB tests with guiding loop under the inboard guiding loop, the shoulder belt slipped off the shoulder for both Q10original and Q10light and no distinct difference in dummy responses was seen.

The Q10update showed limited sensitivity to seatbelt geometries with the initial seatbelt position far out on the shoulder, compared to the two other dummies. This is potentially due to the combination of design changes in the Q10update resulting in a shoulder belt motion towards the neck rather than off the shoulder. The shoulder belt interaction with the shoulder in the Q10update was influenced by the soft composition of shoulder liner contributing in stabilising the belt over the jacket. Also, the shoulder rubber design together with the shoulder joint shifted 20mm forward contributed in holding the shoulder belt in position. The Q10light and Q10original showed similar sensitivity to various seatbelt geometries. However, if the diagonal belt slipped off the shoulder, the belt slipped completely off the shoulder due to the shoulder liner on the Q10light, while the belt slipped into the gap between the arm and the torso on the Q10original.

The Q10update was repeatable in both loading and kinematics. There were no repeated tests conducted for the Q10light, so it is not possible to evaluate this. This may be an issue, since this has been one of the drawbacks of the Q10orignal (Bohman and Sunnevang, 2012).

In all three dummies, the lap belt was engaging in the gap of the thighs and the pelvis, despite the hip shields. In the final Q10light version, Cellbond has modified the femurs such that the penetration of the lap belt will not be possible. That new design feature will potentially probably be contributing to further improvement of the Q10 dummy.

Side Impacts

The load paths in a side impact are mainly covered by the pelvis, chest and shoulder interaction with the intruding door or side structure of the car for a near-side impact rear-seated passenger. All these three load paths are possible to control and measure in the proposed and tested Q10update and Q10original. The pelvis (pubic) and shoulder are equipped with load cells, the spine (in the chest area) is equipped with an accelerometer and the chest is equipped with rib deflection measurements. The Q10 dummies have a side impact kit, including a short arm and the shoulder force load cell mentioned above, for side impact testing. The arm is positioned vertically aligned to the thorax. It is believed that the arm has an influence on the chest deflection results. The arm most likely “bridge” the force between the upper part of the arm, the shoulder load path and the lower part of the arm, lower chest, so that the upper chest deflection will be lower than the lower chest deflection in most load cases. The tests in this study were all performed with the same arm position and hence are comparable. The Q10update showed a reduced chest acceleration by 22% compared to the Q10original in the reference test and the reduction could be explained by the mass redistribution of 1.7 kg from the pelvis to the chest. The reduced chest acceleration for the Q10update compared to the Q10original was also noticed in the IC and IC/SAB tests but not in the SAB only test.

The consequence of reduced chest acceleration in similar test setups results in lower displacement of the chest (actual in spine) which will cause a lower neck and head displacement as well. This behaviour reduced the distance between the head and intruding side structure, potentially leading to higher head loadings which could also result in a head-to-side structure impact. This was the case in the Q10update reference test were the head contacted the side structure and the acceleration was increased by 26% as compared to the Q10original where no contact was seen. In the IC/SAB tests the head accelerations were increased by 9% for the Q10update.

The consequence of mass redistribution was also noticed in the response of the pelvis acceleration. The pelvis accelerations increased with 46% and 35% for the reference and the IC/SAB tests respectively. The proposed mass redistribution for the Q10update was referred to a more biofidelic mass distribution (Waagmeester et al. 2017) and is thereby more relevant to consider although the sensitivity of mass distribution is lower in the tests including safety systems such as inflatable curtains and thorax side airbags compared to the reference tests.

The introduction of airbags in side impacts reduced the loadings of the body by distributing the loads on a larger contact area and initiate an earlier movement of the occupant away from the intruding side structure. The result of the safety systems in this study indicates that both the IC and SAB do play a significant part in improved child dummy protection although these systems were not tuned in performance for the tests in this study.

The characteristics of the chest deflections are difficult to evaluate since the performance of the chest deflection in the Q10original does not fully comply with the thorax lateral pendulum force target corridors recommended by EEVC. The Q10update ribcage stiffness has not been changed although the shoulder structure and mass distribution were changed. The proposal of chest deflection threshold for Q-Series dummy, EEVC WG1 Report D661 (2016) with reference to Hynd et al. (2011) regarding the Q10 of 56mm and Wismans et al. (2008), so-called bag loading scaling, resulting in a 32.7mm chest deflection limit based on 50% risk of AIS3+ injury do neither account for dummy stiffness differences within the Q-Series family of dummies nor for the dummy responses that are not completely within the biofidelity corridors and should be taken into account when evaluating the chest deflections.

The side impact kit arm interference with the ribcage influence significantly the chest deflections at the upper and lower IR-TRACC sensors. If chest deflection based criteria will be used or evaluated, then the performance of the ribcage and the arm in combination with a new mass redistribution needs to be evaluated further.

CONLUSIONS

In the frontal tests, the Q10update was less sensitive to seatbelt geometry far out on shoulder compared to the Q10original and Q10light. For the Q10update, the seatbelt moved inboard towards the neck regardless of initial belt geometry. Both update dummies, showed increased head excursion and upper torso tilt, which is considered as a more biofidelic behaviour compared to Q10original. Due to its improved kinematics and sensitivity to seat belt geometry, the Q10light was preferred of the three tested dummies, for the frontal load case.

In the side impact tests, the Q10update showed reduced chest acceleration compared to the Q10original but also led to head-to-structure contact in one test and increased pelvis acceleration. The chest deflections were overall slightly increased for the Q10update compared to the Q10original.The proposed mass redistribution is considered as more biofildelic and the effects will move focus from chest acceleration to chest deflection, pelvis acceleration and head acceleration criteria. The Q10update is not recommended as an improvement for side impact testing. The differences between the Q10update and Q10original do not improve the understanding of chest acceleration and deflection considering chest performance.

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