Investigation of Potential Q-Series Dummy Modifications to Mitigate Chin-to-Chest Contact Effects

Costandinos Visvikis, Thomas Müller

Abstract Chin-to-chest contact increases Q-Series dummy neck force and chest deflection, limiting the value of these parameters in regulatory and consumer tests of child restraints. This study aimed to investigate the effect of potential Q-Series modifications on chin-to-chest contact. Baseline sled tests were carried out with standard dummies in different child restraints and under different regulatory and consumer test conditions. These were supplemented with matching tests with three prototype parts (i.e., modified heads and/or softer abdomen). Chin-to-chest contact was observed in all tests with standard dummies, regardless of the test procedure or dummy size and orientation. This contact generated peaks in the tension component of the neck axial force and in the chest deflection over the period of contact. Softening the chin of the dummy reduced the effect of chin-to-chest contact on neck tension force, with one of the prototype solutions being more successful. This might offer a simple, short-term way of improving the dummy response in regulatory and consumer tests of child restraints. However, softening the chin did not reduce the effect of chin-to-chest contact on chest deflection. Although the softer abdomen achieved only moderate reduction in the chin-to-chest interaction, addressing spine flexion more comprehensively by tuning the lumbar spine response might be a worthwhile longer-term solution.

Keywords Child dummies and instrumentation, child occupant protection, child restraint systems.

I. INTRODUCTION

United Nations (UN) Regulation No. 129 (R129) specifies Q-Series dummies for dynamic testing of child restraint systems in front, rear and side impact. For a given impact direction, each child restraint is typically tested several times to cover different dummy sizes, child restraint orientations and seating and/or support leg adjustments (where applicable). Fifty-five countries in Africa, Asia and Europe have adopted UN R129 officially under the 1958 Agreement [1]. The Q-Series is also used by the European Test Consortium (ETC) for dynamic testing of child restraints in front and side impact as part of their wider assessment of child restraints for European consumers.

The Q-Series comprises a *family* of six child anthropomorphic test devices from a 6-week old infant (Q0) through to a 10.5-year-old child (Q10)[1]. The Q-Series complies with comprehensive biofidelity requirements established by the European Enhanced Vehicle safety Committee (EEVC) [2]. These requirements take the form of measurement response corridors assessed with simple drop tests or pendulum tests. The tests focus primarily on individual components, comprising the head, neck, chest and abdomen. Although the Q-Series displays generally acceptable performance against the corridors, experience with the dummies has found unfavourable interaction with seat belts, or between body parts, that might not be biofidelic [3]. These issues can often be traced to parts that are not assessed for biofidelity (such as the thoracic spine), which in turn influences the whole-body kinematics [4]. For example, the Q-Series chin often impacts the upper torso, influencing head, neck and chest loads [5-7]. Such chin-to-chest contact in anthropomorphic test devices has been variously attributed to a lack of thoracic spine flexibility or limited elongation and a lack of anterior-posterior translation in the cervical spine [8-9].

Chin-to-chest contact was highlighted by EEVC as a potential limitation in the value of chest deflection measurement in the Q-Series [5]. Specifically, EEVC concluded that chin-to-chest contact is not biofidelic in the Q-Series because it would fall further down the body in real children (due to their lower spine stiffness in comparison with the dummies). For this reason, chest deflection was specified for monitoring purposes only in

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[1] The complete Q-Series family comprises a Q0, Q1, Q1.5, Q3, Q6 and Q10 dummies.

UN R129 and is not a significant part of the assessment and scoring of child restraint performance by ETC. Chin-to-chest contact has also been found to increase the neck tension force measured by the Q-Series in UN R129 tests [6]. Typically, the tension component of the neck axial force displays a peak far beyond the level it would reach under purely inertial loading from the head [7]. A proposal to introduce neck tension thresholds in UN R129 was suspended by the UN Working Party on Passive Safety (GRSP) for this reason, since preventing chin-to-chest contact would be incentivised as a means of reducing dummy neck force measurements without meaningful consideration of the true inertial loading to the cervical spine. [10]. Chin-to-chest contact also increases neck force measurements in child restraint consumer tests carried out by ETC [11]. The neck resultant force forms an important part of the ETC assessment criteria, suggesting that forward-facing child restraints are being penalised by chin-to-chest contact.

Modified dummy parts (with the chin removed entirely) mitigated chin-to-chest contact and its effect on neck force with the Q3 (3-year old) and Q6 (6-year old) dummies [12]. However, these previous prototypes did not comply with the Q-Series design and anthropometry targets, such as the menton (chin) to vertex (top of head) distance, and they influenced other key measurements in the dummy. A soft abdomen, as a means of reducing lumbar spine stiffness, had more marginal effects, but was not evaluated in combination with a modified head [13]. This study aims to investigate whether improved prototype heads that maintain the original shape and appearance of the Q-Series head can mitigate chin-to-chest contact and its effects, either alone or in combination with a soft abdomen.

II. METHODS

Experiment Overview

Twenty impact experiments were carried out on an acceleration sled at the CYBEX Safety Centre in Germany. The experiments are summarised in Table I. No experiments were repeated. Six front impact and eight rear impact experiments followed the dynamic test procedure in the 03 series of amendments to UN R129. The regulatory front impact test conditions comprise a sled velocity change of 52^{+2}_{-0} km/h and an acceleration corridor that peaks between 20 g and 28 g. The regulatory rear impact test conditions comprise a sled velocity change of 32^{+0}_{-2} km/h and an acceleration corridor that peaks between 14 g and 21 g. A further six front impact experiments followed the dynamic test procedure used by ETC. This procedure is not publicly available, but was summarised by [11]. It comprises a velocity change of 72 km/h and an acceleration profile that peaks between 32 g and 38 g. A vehicle body-in-white (five-door VW Polo VI) is mounted on the sled and the acceleration pulse is derived from the European New Car Assessment Programme (Euro NCAP) frontal offset deformable barrier test of the same vehicle and is a longer, more back-loaded pulse than that of UN R129. The ETC child restraint and dummy installation procedures follow those of UN R129, with some differences. Notably, ETC uses a real Polo seat belt system including an emergency locking retractor.

Dummies and Modified Parts

Two instrumented Q-Series dummies were used: a Q0 and a Q3. The dummies were manufactured by Humanetics, Germany, and certified and prepared for testing in line with their user manual. These dummies were chosen due to previous susceptibility to chin-to-chest contact effects [14]. The two principal Q-Series dummy manufacturers in Europe (Cellbond, UK, and Humanetics, Germany) provided prototype parts to reduce chin-to-chest interaction. These comprised two alternative solutions to soften the chin, herein named the *Cellbond head* and the *Humanetics head*, as well as a softer abdomen provided by Cellbond, herein named *soft abdomen*.

The Cellbond head was developed for the Q3 dummy and featured a soft foam chin that replaced the standard flesh and plastic skull in this region (Fig. 1). The head was prepared by cutting the chin away from a standard head. A foam chin element was then bonded to the head with epoxy glue applied to the head surface. The shape of the chin was moulded so as to keep the same external dimensions and profile as the standard head (Fig. 2). The Humanetics heads were developed for the Q3 (Fig. 3) and the Q0 (Fig.4) and maintained the existing flesh in the chin, but part of the internal plastic skull was cut away, as illustrated in Fig. 3 for the Q3 head.

TABLE I
EXPERIMENT MATRIX

Test Protocol	Dummy	Child restraint system	Abdomen	Head
UN R129: Front impact	Q3	Booster seat	Standard	Standard
				Cellbond
				Humanetics
			Soft	Standard
				Cellbond
				Humanetics
UN R129: Rear impact	Q0	RF integral harness CRS 1	Standard	Standard
				Humanetics
		RF integral harness CRS 2 (infant carrier)		Standard
				Humanetics
	Q3	RF integral harness CRS 1	Standard	Standard
				Cellbond
			Soft	Standard
				Cellbond
ETC: Front impact	Q3	Booster seat	Standard	Standard
				Cellbond
				Humanetics
			Soft	Standard
				Cellbond
				Humanetics

Fig. 1. Cellbond head with soft foam chin element (Q3).

Fig. 2. Standard head, without modification (Q3).

Fig. 3. Humanetics head with skull material removed from the chin (Q3) (left) vs. standard head without modification.

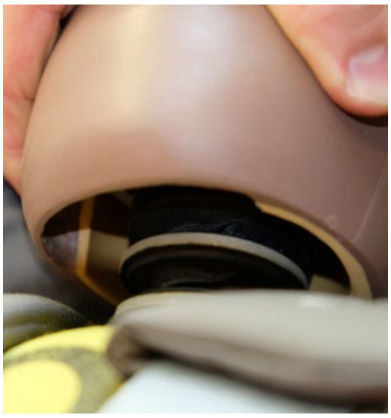

Fig.4. Humanetics head with skull material removed from the chin (Q0).

The soft abdomen was moulded from a flexible polyurethane foam and included cavities for the abdominal pressure twin sensors. The precise material specification was confidential to Cellbond at the time of the study, but more precise material information, or the abdomen itself, are available on request to Cellbond. The soft abdomen was primarily used as a pragmatic tool to increase lumbar spine flexion and was unlikely to meet the abdomen certification requirements.

Child Restraint Systems and Their Use in the Matrix

All child restraint systems were type-approved to UN R129 and were selected from CYBEX's product range. The test matrix (Table I) focused on child restraint types that were known to experience chin-to-chest contact with the Q0 and/or Q3 dummies in the R129 and ETC test protocols. For example, the UN R129 front impact experiments were carried out with the Q3 restrained in a booster seat (i.e., a booster with a backrest), based on the findings of [14]. The matrix included all possible combinations of the standard and modified abdomen and heads for the Q3 in this child restraint. The UN R129 rear impact experiments were carried out with the Q0 and the Q3. The Q0 was restrained in two rear-facing integral harness child restraints, one of which was an infant carrier with a more prone seated position. The Humanetics head was the only modified part applicable to this dummy. The Q3 was restrained in a rear-facing integral harness child restraint. Although both the Cellbond and Humanetics heads were available for this dummy, only the Cellbond head was investigated, primarily for pragmatic reasons. The ETC front impact experiments were carried out with the Q3 restrained in a booster seat. The matrix included all possible combinations of the standard and modified abdomen and heads for this dummy.

Data Analysis and Chin-to-chest Contact Assessment Measures

All measurement and data analysis conformed to ISO 6487. The UN R129 assessment criteria were calculated for each experiment. These comprise head excursion, resultant head acceleration (cumulative 3ms value), resultant chest acceleration (cumulative 3ms value) and abdomen pressure. Neck tension force and flexion moment and chest deflection are specified in UN R129 for monitoring purposes and were measured in this study. Head excursion was measured relative to the fixed Cr point on the test bench, as specified in UN R129. The Cr point marks the intersection of the surface planes of the seat cushion and backrest of the test bench. The head excursion was determined by video analysis (FalCon eXtra, Falkner Consulting für Messtechnologie GmbH, Germany) using a 2D coordinate system with automatic parallax correction. The excursion of the leading edge of the head from the Cr point was tracked by hand for each frame.

The timing and duration of chin-to-chest contact were identified from the resultant external head contact force, as calculated using the procedure in SAE J2052. Previous research had highlighted the value of this approach [15]. The procedure uses the head mass (above the neutral axis of the upper neck load cell), the head acceleration components (a_x, a_y, a_z), and the neck force components (F_x, F_y, F_z) in a root sum square calculation. SAE J2052 assumes a contact has occurred when the external head contact force has reached 500 N. However, as this threshold was likely established for adult dummies, it was used as an indicative guide only for the child dummies used in this study. The inertial neck force was calculated to determine the level of neck force that might have been measured, if the contact had not occurred or had been mitigated. The calculation followed the principle and method proposed in [6], as set out in Eq. 1 below:

$$\vec{F} = m\vec{a} \tag{1}$$

Where *F* is the inertial neck force (N), *m* is the applicable dummy head mass (kg) and *a* is the head vertical acceleration (ms^{-2}).

III. RESULTS

Some degree of chin-to-chest contact was observed in all experiments, including those with modified dummy parts. In each case, the dummy displayed significant cervical spine flexion with the chin striking the chest in the sternum area. This occurred in the UN R129 and ETC front impact tests with the forward-facing child restraints and in the UN R129 rear impact tests with the rear-facing child restraints. Indicative dummy kinematics are shown in Fig. A1 (UN R129 front impact) and Fig. A2 (UN R129 rear impact) in the Appendix. Selected peak dummy measurements are provided in Table AI in the Appendix.

UN R129: Front Impact

Chin-to-chest contact had a substantial effect on the upper neck axial force of the standard Q3 dummy in the booster seat under UN R129 front impact conditions (Fig. 5). This was characterised by an initial tensile peak prior to chin-to-chest contact, followed by a second peak during the period of contact. The onset of this second peak corresponded with the time of engagement between the chin and chest, identified from the external head contact force. This was further illustrated in comparison with the calculated inertial neck force which diverged from the measured force over the period of contact. The soft abdomen alone (i.e., in combination with the standard head) had limited influence on the severity of chin-to-chest contact and its effect on the neck axial force (Fig. 6). A substantial peak was observed that was similar in magnitude to that with the standard abdomen.

The Cellbond head reduced the magnitude and duration of the external head contact force and delayed the onset (Fig. 7). This appeared to influence the neck axial force, which displayed a lower second peak, that was similar in magnitude to the initial inertial peak and to the calculated force. The soft abdomen further improved the response of the Cellbond head such that the second peak in the neck force due to contact was almost eliminated (Fig. 8). The Humanetics head also reduced the magnitude of the external head contact force, but not to the same extent as the Cellbond head (Fig. 9). Nor did it reduce the duration of contact or delay the onset. This likely explains why the Humanetics head did not reduce the neck axial force sufficiently to remove the effect of chin-to-chest contact. The Humanetics head in combination with the soft abdomen was more effective in this regard and led to a reduction in the external head contact force that was more in line with that of the Cellbond head (Fig. 10).

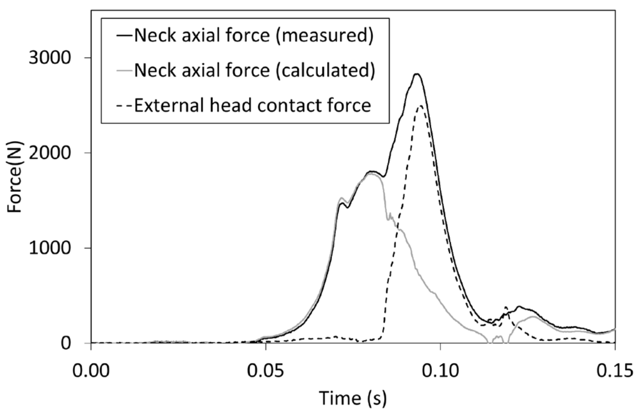

Fig. 5. UN R129 Front impact. Q3 Upper neck axial force and external head contact force: Standard head with standard abdomen.

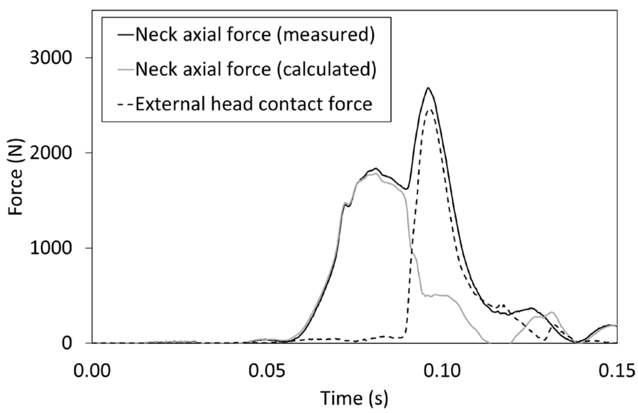

Fig. 6. UN R129 Front impact. Q3 Upper neck axial force and external head contact force: Standard head with soft abdomen.

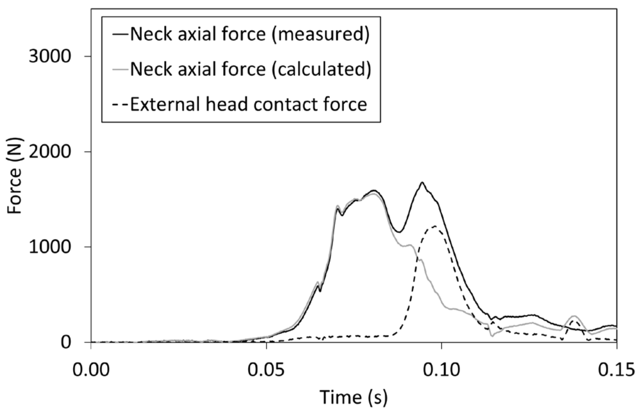

Fig. 7. UN R129 Front impact. Q3 Upper neck axial force and external head contact force: Cellbond head with standard abdomen.

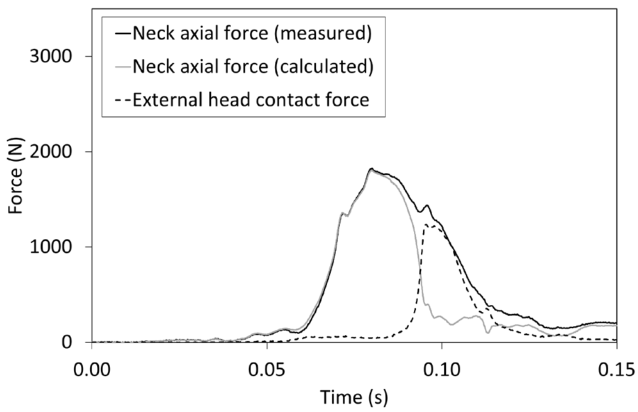

Fig. 8. UN R129 Front impact. Q3 Upper neck axial force and external head contact force: Cellbond head with soft abdomen.

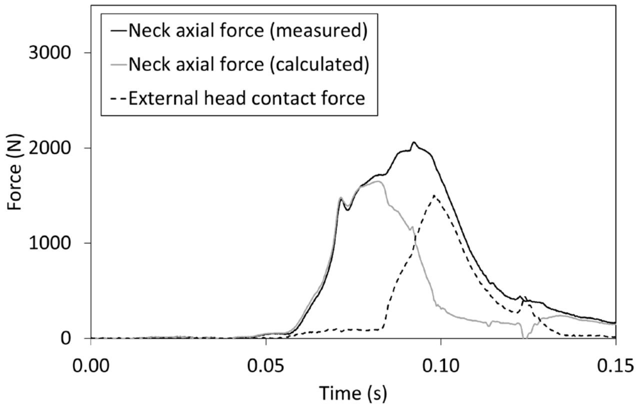

Fig. 9. UN R129 Front impact. Q3 Upper neck axial force and external head contact force: Humanetics head with standard abdomen.

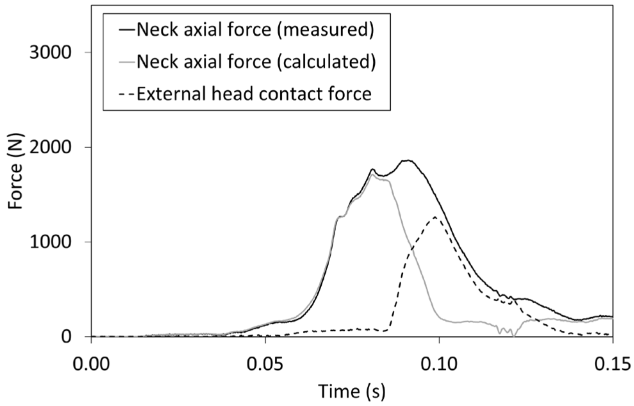

Fig. 10. UN R129 Front impact. Q3 Upper neck axial force and external head contact force: Humanetics head with soft abdomen.

Chin-to-chest contact had a substantial effect on the chest deflection of the Q3 dummy in the booster seat (Fig. 11). This was characterised by an initial peak prior to chin-to-chest contact, followed by a second peak during the period of contact. The onset of this second peak corresponded with the time of engagement between the chin and chest, identified from the external head contact force. None of the modified parts, either alone or in combination, were capable of reducing the deflection peak due to contact. The soft abdomen led to moderate increases in deflection for all dummy heads.

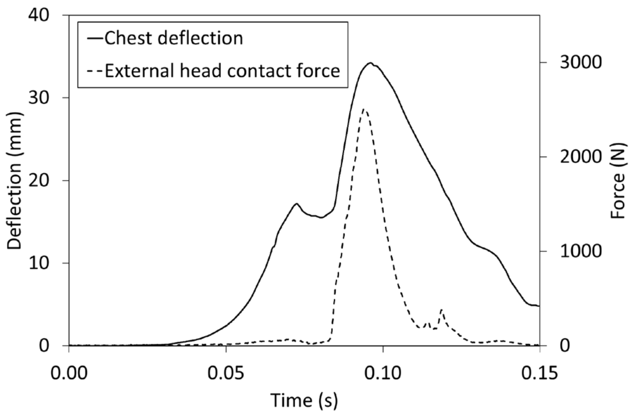

Fig. 11. UN R129 Front impact. Q3 Chest deflection and external head contact force: Standard head with standard abdomen.

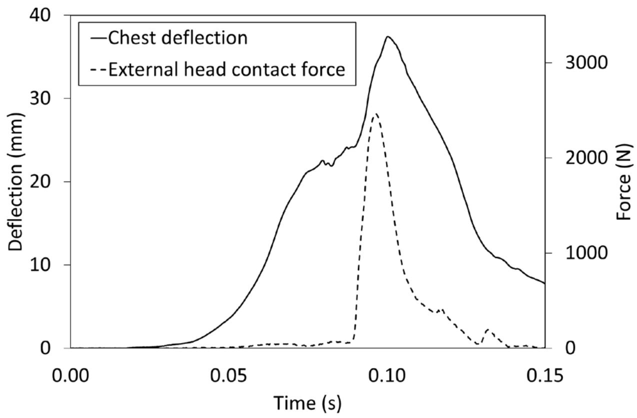

Fig. 12. UN R129 Front impact. Q3 Chest deflection and external head contact force: Standard head with soft abdomen.

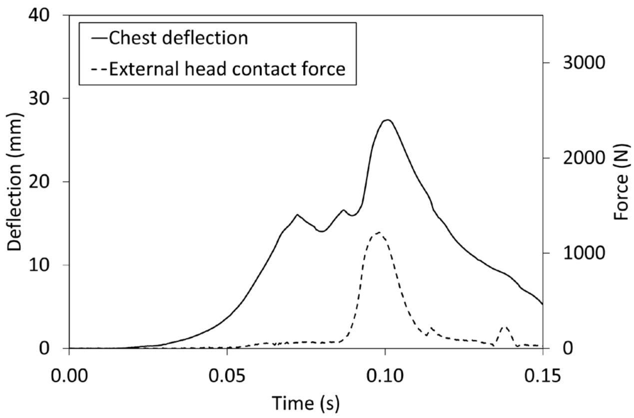

Fig. 13. UN R129 Front impact. Q3 Chest deflection and external head contact force: Cellbond head with standard abdomen.

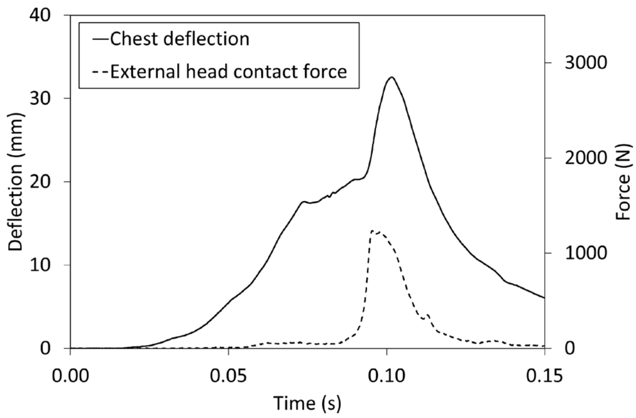

Fig. 14. UN R129 Front impact. Q3 Chest deflection and external head contact force: Cellbond head with soft abdomen.

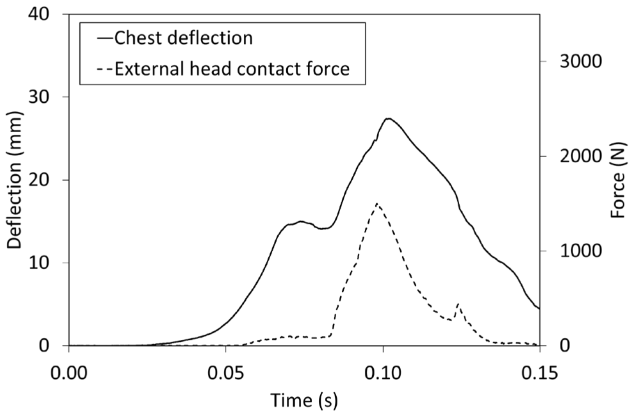

Fig. 15. UN R129 Front impact. Q3 Chest deflection and external head contact force: Humanetics head with standard abdomen.

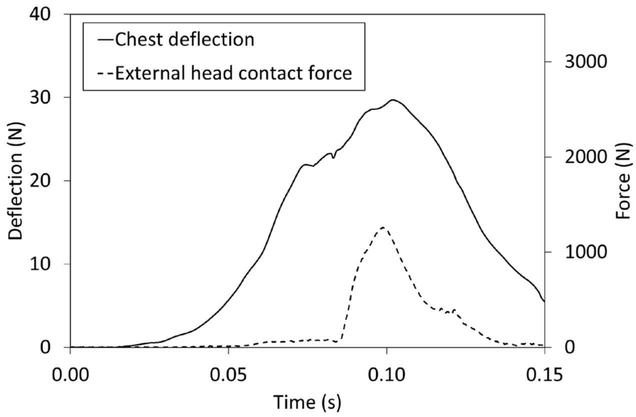

Fig. 16. UN R129 Front impact. Q3 Chest deflection and external head contact force: Humanetics head with soft abdomen.

UN R129: Rear Impact

Chin-to-chest contact appeared to have a substantial effect on the neck axial force of the Q0 dummy in both rear-facing child restraints under UN R129 rear impact conditions (Fig. 17 and Fig. 19). This was characterised by a large discrepancy between the measured and the calculated neck force over the period of contact. In contrast with the forward-facing child restraint in front impact (Fig. 5), chin-to-chest contact occurred relatively early in these rear-facing child restraints in rear impact and before a peak in the tensile force had been reached. This meant that the measured and the calculated force diverged very early and through the entire period of tensile loading. That said, the calculated force should be viewed with caution in the Q0 because the head accelerometer is located below the upper neck load cell, not at the centre of gravity of the head. The Humanetics head had little influence on chin-to-chest contact and the neck force in CRS 1 (Fig. 18) and only marginal effect in CRS 2 (Fig. 20).

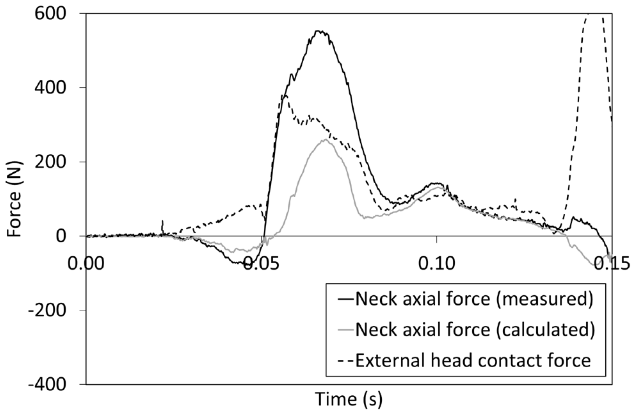

Fig. 17. UN R129 Rear impact. Q0 Upper neck axial force and external head contact force: Standard head (CRS 1).

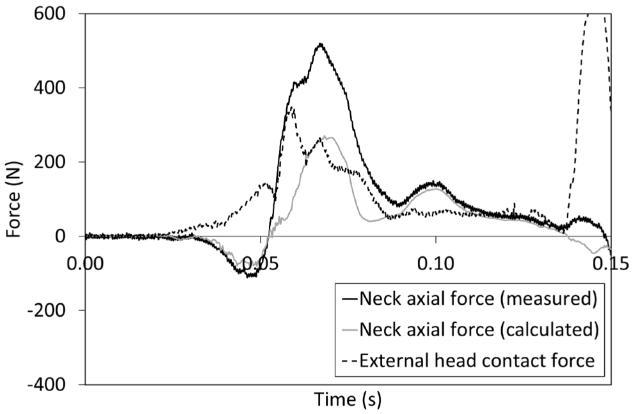

Fig. 18. UN R129 Rear impact. Q0 Upper neck axial force and external head contact force: Humanetics head (CRS 1).

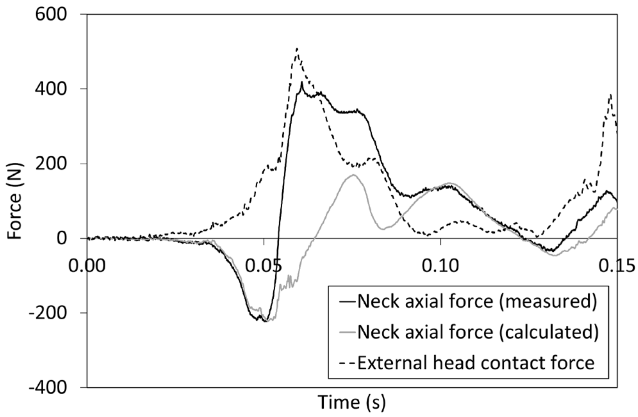

Fig. 19. UN R129 Rear impact. Q0 Upper neck axial force and external head contact force: Standard head (CRS 2).

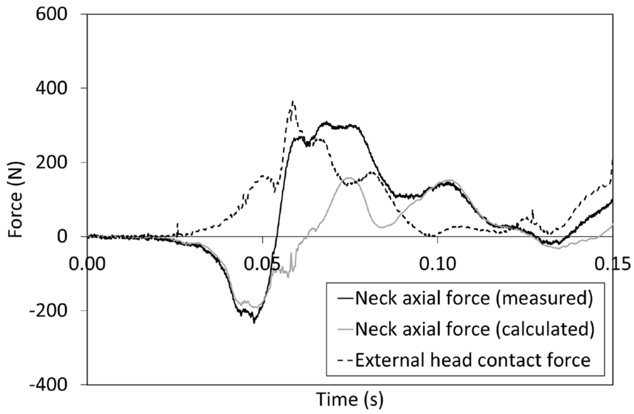

Fig. 20. UN R129 Rear impact. Q0 Upper neck axial force and external head contact force: Humanetics head (CRS 2).

Chin-to-chest contact was somewhat marginal with the standard Q3 in the rear-facing integral child restraint under UN R129 rear impact conditions (Fig. 21). The external head contact force did not reach the 500 N threshold at which a significant contact is assumed to have occurred in SAE J2052. Nevertheless, an external force was measured that peaked at around 300 N and the measured axial neck force and the calculated force began to diverge during the period of chin-to-chest contact, identified from the external head contact force. This was suggestive of contact influence on the neck force, although the discrepancy between the measured and calculated force was moderate. In contrast, the head contact force was reduced to a negligible level with the soft abdomen (Fig. 22) and with the Cellbond head regardless of which abdomen was used (Fig. 23 and Fig. 24). In each of these tests, the measured and calculated forces were very similar suggesting the modified parts had prevented contact and its influence on neck axial force.

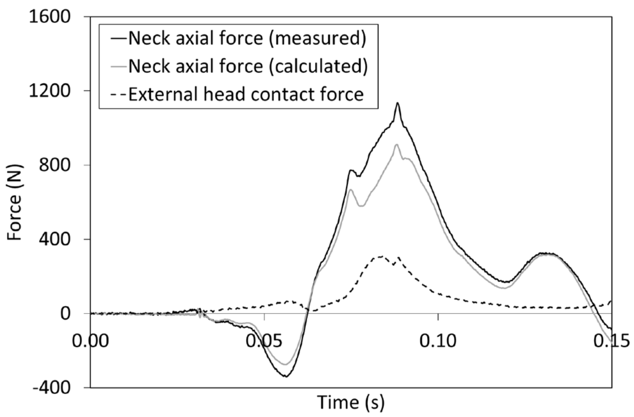

Fig. 21. UN R129 Rear impact. Q3 Upper neck axial force and external head contact force: Standard head and standard abdomen.

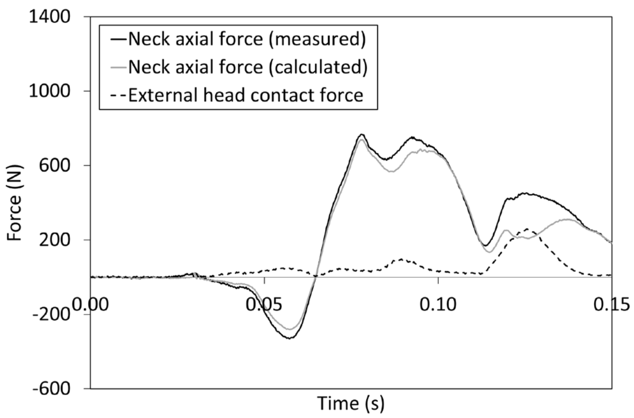

Fig. 22. UN R129 Rear impact. Q3 Upper neck axial force and external head contact force: Standard head with soft abdomen.

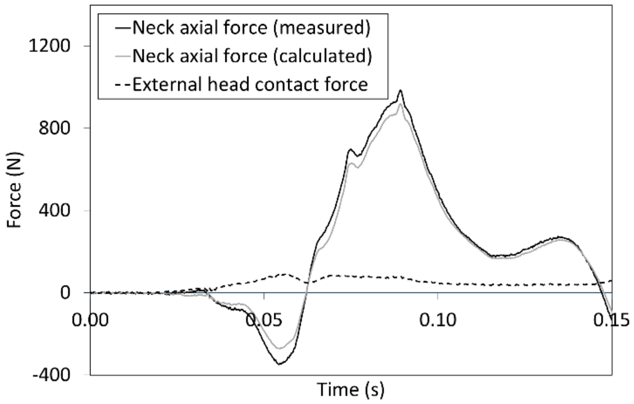

Fig. 23. UN R129 Rear impact. Q3 Upper neck axial force and external head contact force: Cellbond head with standard abdomen.

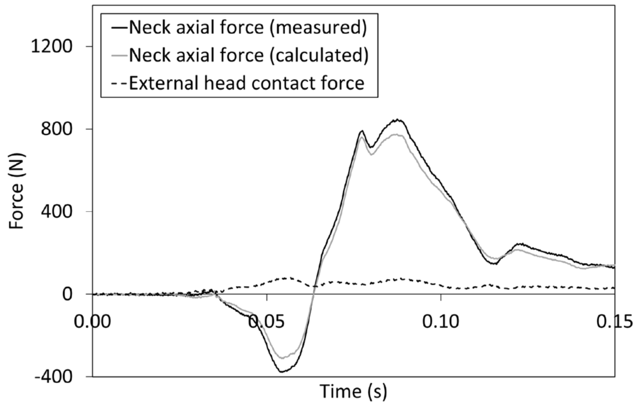

Fig. 24. UN R129 Rear impact. Q3 Upper neck axial force and external head contact force: Cellbond head with soft abdomen.

ETC: Front Impact

Chin-to-chest contact generated a large increase in the neck axial force of the standard Q3 dummy in a booster seat under ETC front impact conditions (Fig. 25). The measured neck force appeared to have reached a peak prior to chin-to-chest contact, which was followed by a marked increase in the measured force over the duration of contact. The calculated neck force diverged from the measured force over the period of contact, but did not fall away as quickly as observed in the corresponding R129 front impact test (i.e., Fig. 5). Instead, the force was maintained for a short period before increasing slightly (albeit far below the level of the measured neck force due to contact). The soft abdomen alone (i.e., in combination with the standard head) had no influence on the severity of chin-to-chest contact and its effect on the axial neck force (Fig. 26). A substantial peak was observed that was similar in magnitude to that with the standard abdomen.

The Cellbond head reduced the influence of chin-to chest contact on the neck axial force (Fig. 27). Although chin-to-chest contact generated a second peak in the neck force, it was similar in magnitude to the initial inertial peak and to the calculated force. The soft abdomen offered no benefit in combination with the Cellbond head and in fact increased the gap between the measured and the calculated force (Fig. 28). Furthermore, the measured force actually increased compared with that of the Cellbond head and the standard abdomen (Fig. 27). The Humanetics head did not reduce the neck axial force sufficiently to remove the effect of chin-to-chest contact. Once again, the soft abdomen offered no benefit in combination with the modified head. These findings under ETC front impact test conditions differ from those under UN R129 front impact conditions in which the soft abdomen improved the performance of both the Cellbond and the Humanetics heads.

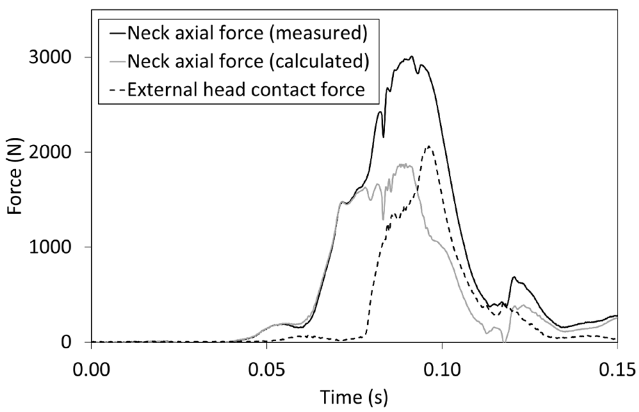

Fig. 25. ETC Front impact. Q3 Upper neck axial force and external head contact force: Standard head with standard abdomen.

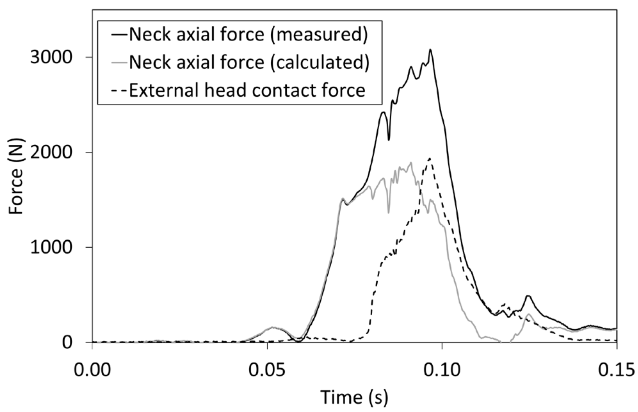

Fig. 26. ETC Front impact. Q3 Upper neck axial force and external head contact force: Standard head with soft abdomen.

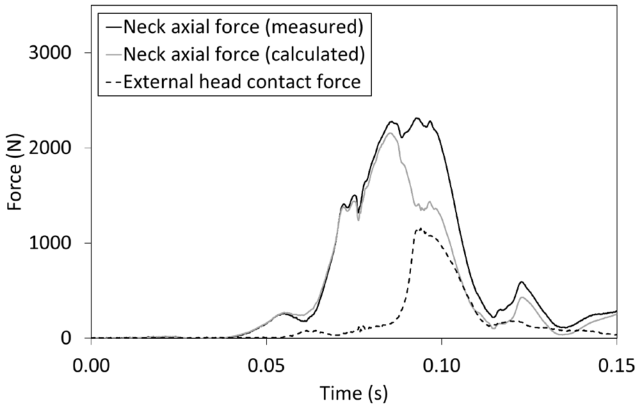

Fig. 27. ETC Front impact. Q3 Upper neck axial force and external head contact force: Cellbond head with standard abdomen.

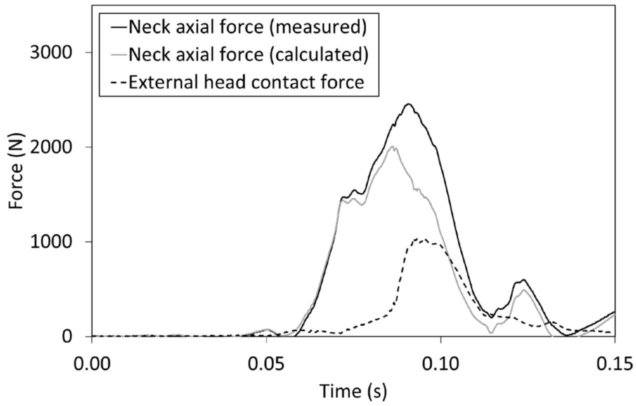

Fig. 28. ETC Front impact. Q3 Upper neck axial force and external head contact force: Cellbond head with soft abdomen.

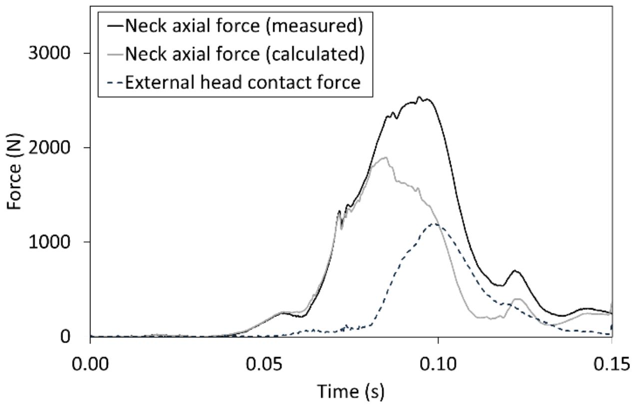

Fig. 29. ETC Front impact. Q3 Upper neck axial force and external head contact force: Humanetics head with standard abdomen.

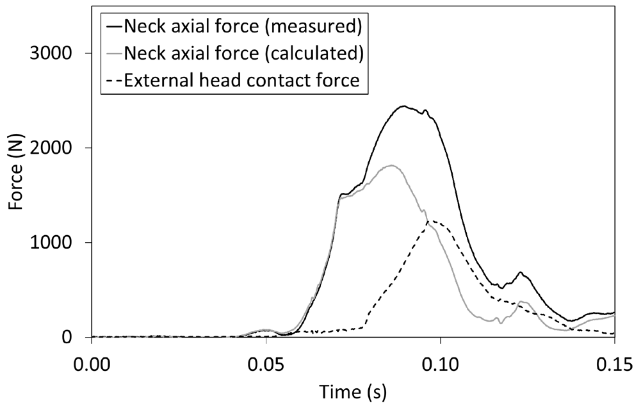

Fig. 30. ETC Front impact. Q3 Upper neck axial force and external head contact force: Humanetics head with soft abdomen.

Chin-to-chest contact had a substantial effect on the chest deflection of the standard Q3 dummy in the booster seat under ETC front inpat conditions. These results are presented in the Appendix (Fig. A3 to Fig. A8) as the trends were practically identical to those under UN R129 front impact conditions. Namely, none of the modified parts, either alone or in combination, offered any benefit in mitigating chin-to-chest contact and its effects on chest deflection.

IV. DISCUSSION

Chin-to-chest contact was observed in all tests with the standard Q-Series dummies, regardless of the test procedure or dummy size and child restraint orientation. In each case, the dummy displayed significant cervical spine flexion with the chin striking the chest in the sternum area. This contact generated peaks in the upper neck axial force and the chest deflection that corresponded with the period of engagement between the chin and chest. In the case of the neck, the tension component of the axial force reached a peak beyond the level it would have reached under purely inertial loading from the head. This was confirmed by the calculated (i.e., purely inertial) neck force derived from the product of the head mass and head vertical acceleration. A similar assessment was impossible for the chest as there was no equivalent way of determining whether the restraint loading may have continued to compress the chest cavity during the period of contact.

Similar findings have been observed in other child dummies, including the P-Series [16] and the Hybrid III [8][15]. The timing of Q-Series chin-to-chest contact and its effects were influenced somewhat by the test procedure and child restraint type. Although our study was very limited in investigating these parameters, it appears to support other findings that dummy posture and child restraint design can influence chin-to-chest contact characteristics [17-18]. Chin-to-chest contact has also been observed in child post-mortem human subjects (PMHSs) [8] and in human body models [4][19]. However, the severity of contact and its effect on neck forces and chest deflection seems to be greater in dummies, primarily due to the stiffness of their parts, such as the skull, rib cage and spine [9]. Unfortunately, the prevalence of chin-to-chest contact in real-world collisions and its effect on child injury potential, if any, does not appear to have been reported.

Reducing the contact stiffness has been shown to reduce peak neck tensile forces in MADYMO simulations of a P3/4 dummy [14]. Furthermore, the Hybrid III 10-year-old dummy chin specifications were tuned to eliminate some of the effects of chin-to-chest contact [20]. Modified Q-Series dummy parts (with the chin removed entirely) mitigated chin-to-chest contact and its effect on neck force with the Q3 and Q6 dummies [12]. Our study, with further developed prototypes to soften (rather than remove) the chin, found they were capable of reducing the neck tension force, but only the Cellbond head reduced the force to a level below that expected under purely inertial loading from the head. The response of the Cellbond head was improved further by the softer abdomen, but the abdomen was not effective on its own (i.e., with the standard head). Softening the chin and/or abdomen did not reduce the effect of chin-to-chest contact on chest deflection significantly.

The modification approach adopted for the Cellbond head (i.e., a soft chin element separate from the main head) might offer a simple, short-term way of improving the response of the dummy in regulatory and consumer tests of child restraints. Chin-to-chest contact still occurred with this modification, often generating an external head contact force above 1000 N (and far above the 500 N contact threshold specified in SAE J2052). However, the modification doesn't necessarily need to eliminate chin-to-chest contact altogether (or even reduce it below 500 N) to be a useful test tool. Pragmatically, it simply needs to reduce the severity of chin-to-chest contact such that its effects on the dummy measurements are minimised. This was achieved for the neck force at least.

The use of a soft chin element in the Cellbond head provides an opportunity for further tuning the response. For example, adjusting the properties of the material, or the position of the transition line between the head and the chin element, might yield further improvements in both the neck force and the chest deflection measurements. That said, removing the effect of chin-to-chest contact on chest deflection seems challenging, given this first attempt provided negligible improvement in that regard. Nevertheless, modifying the dummy such that the neck force measurements become more meaningful might be worthwhile in itself, especially if it removes a potential barrier to the introduction of neck tension thresholds in UN R129.

Although the softer abdomen achieved only a moderate reduction in the chin-to-chest interaction, addressing spine flexion more comprehensively by tuning the lumbar spine response might be a better solution in the longer term [4]. Similarly, redesigning the thoracic spine to allow flexion would also be likely to reduce chin-to-chest contact effects, as well as facilitating inertial neck force measurements that are more representative of real-world child injury potential [8]. However, the appetite of regulators to initiate significant child dummy development work so soon after the Q-Series was introduced is unclear. In that context, a pragmatic short-term solution might be more likely to be implemented.

Although the Cellbond head was effective in reducing the severity of chin-to-chest contact sufficiently for the neck force measurement to better reflect the purely initial loading from the head, the calculated neck axial force was just as effective, and arguably more so in some circumstances. Simply adopting this calculation as a performance requirement might be an alternative option to modifying the dummy head. However, one of the reasons for adopting the Q-Series in regulation was that it enabled the direct measurement of neck loading [2]. Simply applying a calculation to the head acceleration might seem a backward step, particularly as the predecessor to the Q-Series, the P-Series, adopted a similar approach by using chest vertical acceleration to assess the risk of neck loading in UN Regulation No. 44. Furthermore, in the context of a type-approval regulation that is adopted across borders, adding a calculation to the regulation might introduce more potential for errors and variation than introducing a new dummy part.

Limitations

The modified parts used in this study were prototypes developed by Cellbond and Humanetics. Modified heads were available for the Q0 and Q3 dummies only. The value of modifying the head to reduce chin-to-chest contact and its influence cannot be verified for the full range of Q-Series dummies until further prototypes are developed. Similarly, investigating the repeatability and reproducibility of any such modification was not part of this study and would need to be investigated before adopting such a head more widely.

No repeat experiments were performed. The UN R129 and ETC protocols deliver consistent results, which is an essential requirement for regulatory or consumer testing. However, to reduce the risk of unexpected or spurious results, our test and analysis team thoroughly reviewed the results. Each child restraint system used in the study has been tested in the same conditions many times in our laboratory during its development, type-approval and ongoing conformity of production assessment. Any unusual result would be recognised immediately. That said, there was no similar base of reference for the tests with the modified parts and, as noted above, a thorough repeatability assessment should be made if any of the modifications become candidates for adoption by UN R129 or ETC.

The investigation of the effect of dummy modified parts was limited to a small convenience sample of child restraints in limited test protocols. These child restraints, dummies and tests were prioritised based on the findings of previous work [14]; nevertheless, other child restraint types might have different chin-to-chest contact behaviour and/or might respond differently to the dummy modifications.

V. CONCLUSION

Softening the chin of the Q-Series dummy reduced the effect of chin-to-chest contact on the neck tension force, with one of the prototype solutions (the Cellbond head) being more successful. This might offer a simple, short-term way of improving the response of the dummy in regulatory and consumer tests of child restraints. However, softening the chin did not reduce the effect of chin-to-chest contact on chest deflection significantly. Although the softer abdomen achieved only moderate reduction in the chin-to-chest interaction addressing spine flexion more comprehensively by tuning the lumbar spine response might be a worthwhile longer-term solution.

VI. ACKNOWLEDGEMENTS

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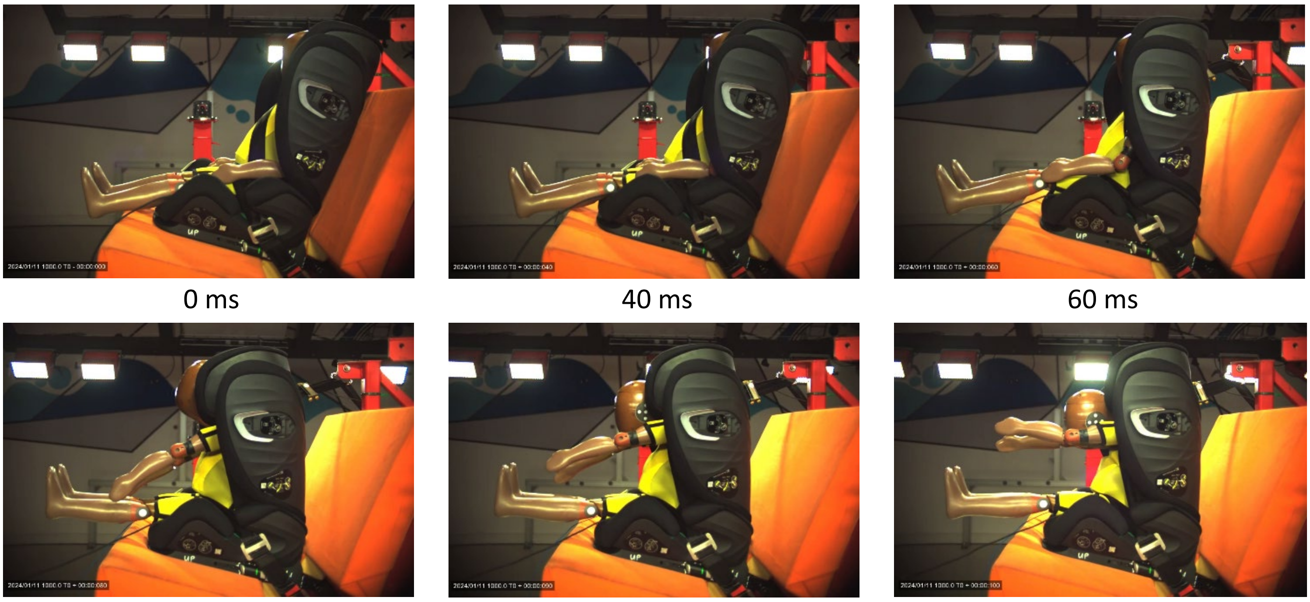
VIII. APPENDIX

TABLE AI

TEST RESULTS: PARAMETERS ASSESSED BY UN R129 AND ETC

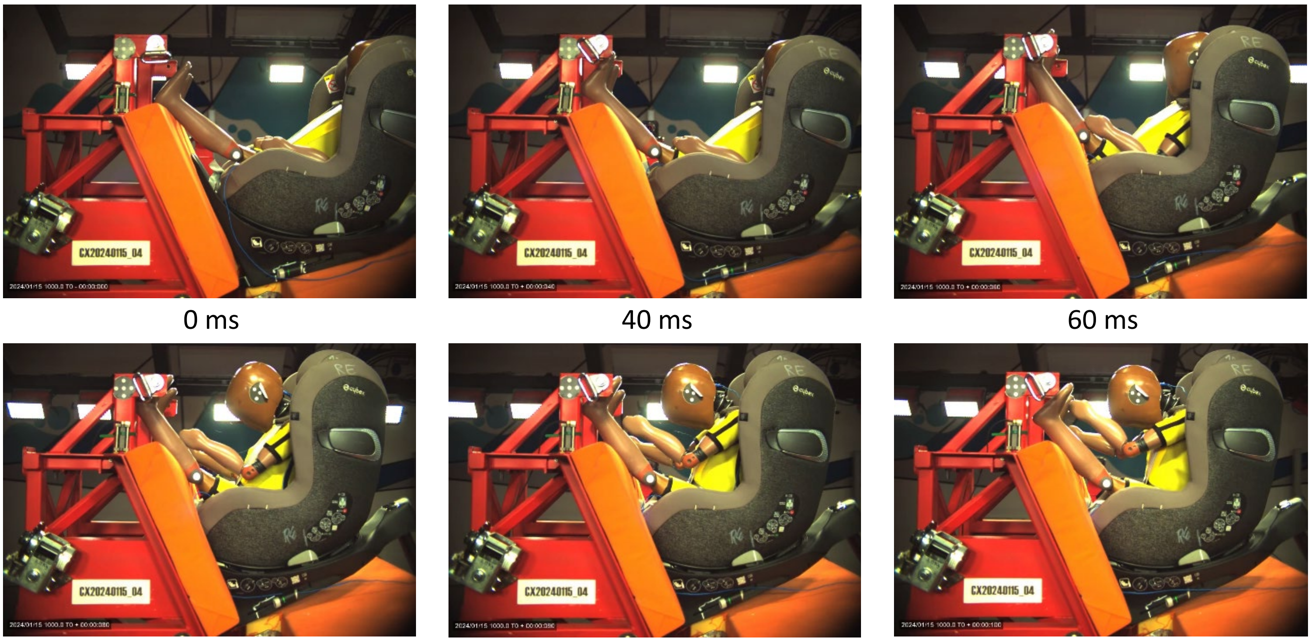
Test Protocol	Dummy	Child restraint system	Abdomen	Dummy head	Head excursion (mm)	Resultant head acc. 3ms (g)	Resultant chest acc. 3ms (g)
UN R129: Front impact	Q3	Booster seat	Standard	Standard	344	65.4	40.0
				Cellbond	331	60.0	41.1
				Humanetics	342	63.7	42.9
			Soft	Standard	360	67.0	40.4
				Cellbond	337	68.7	40.1
				Humanetics	340	64.8	38.0
UN R129: Rear impact	Q0	RF integral harness CRS	Standard	Standard	-	66.0	45.1
				Humanetics	-	65.8	44.4
		RF integral harness CRS (infant carrier)		Standard	-	54.8	39.8
				Humanetics	-	52.2	42.2
	Q3	RF integral harness CRS	Standard	Standard	-	37.8	37.1
				Cellbond	-	36.4	41.7
			Soft	Standard	-	35.8	47.5
				Cellbond	-	34.9	41.6
ETC: Front impact	Q3	Booster seat	Standard	Standard	408	77.8	52.3
				Cellbond	413	84.2	51.1
				Humanetics	416	72.5	49.5
			Soft	Standard	416	74.8	55.2
				Cellbond	408	76.7	51.1
				Humanetics	401	72.3	46.4



0 ms 40 ms 60 ms

80 ms 90 ms 100 ms

Fig. A1. UN R129 Front impact. Q3 dummy kinematics: Standard head with standard abdomen.



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80 ms 90 ms 100 ms

Fig. A2. UN R129 Rear impact. Q3 dummy kinematics: Standard head with standard abdomen.

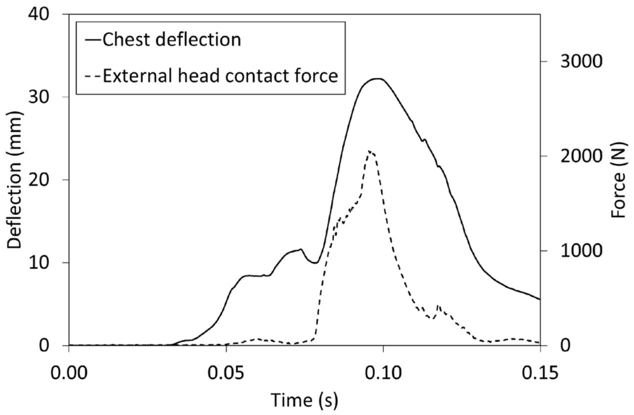

Fig. A3. ETC Front impact. Q3 Chest deflection and external head contact force: Standard head with standard abdomen.

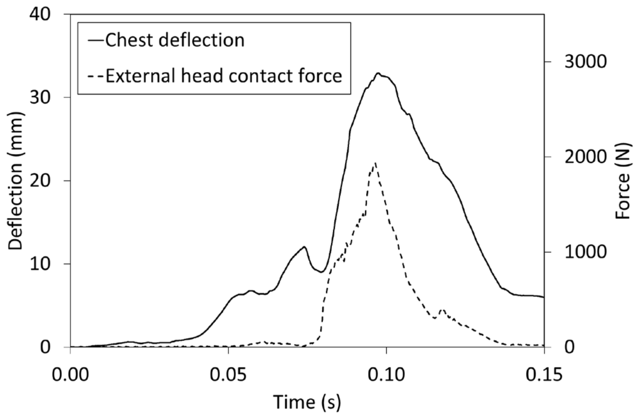

Fig. A4. ETC Front impact. Q3 Chest deflection and external head contact force: Standard head with soft abdomen.

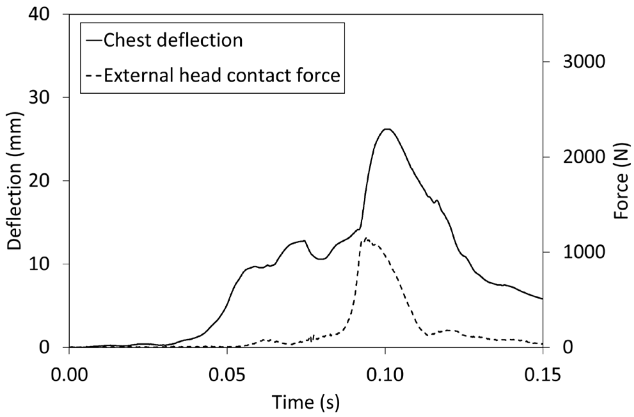

Fig. A5. ETC Front impact. Q3 Chest deflection and external head contact force: Cellbond head with standard abdomen.

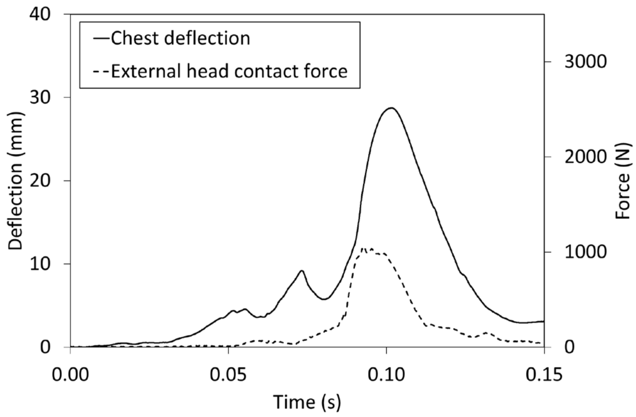

Fig. A6. ETC Front impact. Q3 Chest deflection and external head contact force: Cellbond head with soft abdomen.

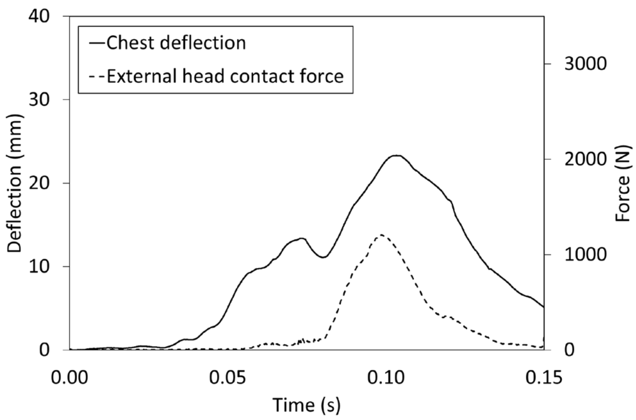

Fig. A7. ETC Front impact. Q3 Chest deflection and external head contact force: Humanetics head with standard abdomen.

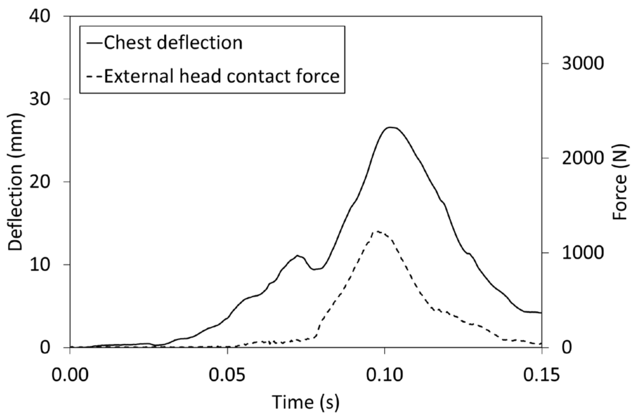

Fig. A8. ETC Front impact. Q3 Chest deflection and external head contact force: Humanetics head with soft abdomen.