Comparison of the THORAX Demonstrator and HIII sensitivity to crash severity and occupant restraint variation

Cecilia Sunnevång, David Hynd, Jolyon Carroll, Mikael Dahlgren

Abstract The thorax is the most frequently injured body region in frontal impacts. This study aimed to compare the THORAX Demonstrator THOR and HIII injury risk predictions in relation to expected injury risk reductions based on trends observed in real life data.

Sled tests were performed in a body-in-white representing a mid-sized family car. To relate the test results to real life, the AIS3+ thoracic injury risks measured by the THOR and HIII were compared for different test configurations. For the driver position a 6 kN belt was compared to a 4 kN belt plus airbag and a 3 kN belt plus airbag (same pulse). On the passenger side the same restraint in EuroNCAP ODB (64 km/h) and FMVSS 208 ODB (40 km/h) tests were evaluated. Injury criteria compared were Cd and DEQ(Lin) for the HIII and Dmax, Dc-THOR and strain for the THOR.

The level of thoracic injury risk needs further investigation, but the expected injury risk reduction from a predicted high to a low risk was demonstrated by THOR, contrary to the HIII. The large variations in injury risk as well as the sensitivity to crash severity indicate that the THOR dummy should be the preferred tool for evaluation of frontal impact occupant protection.

Keywords Frontal Impact, Injury risk, Sled tests, THOR, Hybrid III

I. INTRODUCTION

European real life data have shown that the thorax is the most frequently injured body region when it comes to serious and fatal injuries in modern cars. Frequently occurring thoracic injuries are fractures to the ribs and sternum. The lungs are the most frequently injured of the visceral organs [1].

Exposed to a frontal impact, the injury risk for occupants is dependent on vehicle and crash parameters such as impact velocity and angle, change of velocity (delta-v), the mass and structural behavior of the vehicle (intrusion and acceleration levels), etc. As more cars are equipped with electronic data recorders (EDR), these data provide an overview of injury outcome in relation to the crash pulse. Stigson et al. presented injury risk functions based on real life crash pulses where a low level of risk was associated with a low delta-v and low acceleration [2]. However, the occupant injury risk is also dependent on occupant characteristics such as age and gender [3-4], and utilization of the restraint system [5].

Previous studies have evaluated the benefit of existing restraint systems for frontal impacts. It has been shown that a driver (steering wheel) airbag, which distributes thoracic loading, in combination with a force-limiting seat belt, resulted in a lower risk of injury than if the restraint was provided by the belt alone [6]. It has also been shown that thoracic injuries would be further reduced with lowered belt forces, especially for frail and fragile senior occupants [7-8].

In current legal and consumer tests the Hybrid III (HIII) 50th percentile male is used to evaluate the risk of injury for front seat occupants. This includes the risk of sustaining an AIS3+ thoracic injury. Several studies have pointed out the limitations of this dummy for addressing injuries and detecting injury mechanisms observed in real life, as well as limitations of the current injury criteria and corresponding risk functions [9]. To assess AIS2+ injuries, and hence restraint system development to benefit senior occupants, an improved frontal crash test dummy is needed.

C. Sunnevång is a research engineer at Autoliv Research, and a PhD student at the Department of Surgical and Perioperative Science, Umeå University, Sweden (email: cecilia.sunnevang@autoliv.com, phone: +46 322 667488, fax: +46 322 620118). D. Hynd and J. Carroll are at TRL (Transport Research Laboratory), UK. M. Dahlgren is at Autoliv Sverige AB, Sweden.

Within the EC Seventh Framework project THORAX, the THOR-NT dummy was upgraded with a new thorax and shoulder [10-11]. The demonstrator THOR dummy developed within the THORAX project is comparable to the NHTSA THOR Mod Kit dummy with an SD3 shoulder. A biofidelity evaluation performed by NHTSA has shown that the blunt thoracic impact biofidelity of the THOR Mod Kit with an SD3 shoulder (Mod-Kit_SD3) was improved compared to the HIII and previous versions of the THOR dummy [12]. As the thorax and shoulder were upgraded, new injury criteria and corresponding injury risk curves (IRCs) were also derived within the THORAX project [13].

The aim of this study was to compare the THORAX Demonstrator THOR and HIII injury risk predictions in relation to expected injury risk reductions based on trends observed in real life data.

II. METHODS

In addition to the standard biofidelity evaluations it is important to know if an improved dummy can detect differences in restraint system designs, and that the measured response is in accordance with what is obtainable from the field data. To relate the THORAX Demonstrator THOR's (subsequently denoted THOR) response to real life trends regarding injury risk, different restraint systems and two levels of crash severity were evaluated.

ATD thoracic injury risk prediction

To compare the THOR and HIII dummy response in terms of injury risk, AIS3+ IRCs for a 45-year-old occupant were used for both dummies. For THOR the Dmax, DC-THOR and strain NFR (number of fractured ribs) were compared to the standard (currently used) chest deflection criteria (Cd) as well as the proposed DEQ(lin) [14-15]. Dmax is based on the x-deflection component from any of the four 3D Infra-Red Telescoping Rods for the Assessment of Chest Compression (IR-Traccs). The DC-THOR, combined deflection, is calculated using the x-deflection component from all four 3D IR-Traccs according to:

$$DcTHOR = Dm + dDup + dDlw$$

where Dm is the average of the four 3D IR-Tracc x-deflections, calculated according to Eq 1, and dDup and dDlw represent differences in deflection from side to side of the upper and lower rib cage, calculated according to Eq 2 and Eq 3, where ULX, URX, LLX and LRX are the IRTRACC X-component time histories, in local coordinate systems (mm).

$$Dm \ = \ (|ULX|max + |URX|max + |LLX|max + |LRX|\mathrm{max})/4 \tag{1}$$

$$dDup = |ULX - URX|max - 20; \ = 0 \ if \ |ULX - URX| \leq 20 \ or \ min(|ULX|max, |URX|max) \leq 5 \tag{2}$$

$$dDlw = |LLX - LRX|max - 20; \ = 0 \ if \ |LLX - LRX| \leq 20 \ or \ min(|LLX|max, |LRX|max) \leq 5 \tag{3}$$

The THOR was equipped with uniaxial strain gauges on ribs 2-7, aligned with the long axis of the ribs . As the ribs are loaded, the gauges measure tensile and compressive strain throughout the event. The signals were post processed to identify each peak value and determine peak strain for each rib. For the strain criteria, a THOR specific strain threshold, representing "dummy rib fracture", was determined as being 1.6 mstrain. The strain threshold was determined by correlating the predicted number of fractured ribs with the THOR, which is a function of the strain threshold used, and the number of fractured ribs in the original PMHS tests for all tests included. If the threshold of 1.6 mstrain was reached from one or more of the gauges, the rib was determined as fractured (dummy fractured rib). The number of dummy fractured ribs was then related to a prediction for human fractured ribs via the risk function [13].

Within the THORAX Project, injury risk functions were developed for the occurrence of either 'at least five' (NFR5+) or 'at least seven' (NFR7+) fractured ribs. These outcomes were determined to be broadly equivalent with AIS2+ or 3+ severity levels. It should be noted that this approximate relationship is based on consideration of skeletal chest injuries only and hence could underestimate the risk for all injury types. It is also most applicable to revisions of the AIS from 1998 onwards, where the coding was changed so that severity followed the number of fractured ribs more accurately than in earlier revisions of the Scale. Due to the dataset used for that work, the AIS2+ curves had tighter confidence intervals than the AIS3+ curves. It was also noted that the two severity predictions overlapped at very low risk levels (low compression), although this behaviour (with 7+ fractured ribs occurring at lower compression than 5+) is not realistic from a practical point of view, and furthermore, was not a statistically robust finding at the confidence levels considered [13].

Experimental Testing

The THOR and Hybrid III (HIII) were seated in a body-in-white representing a mid-sized sedan with a five star rating in EuroNCAP. Vehicle specific pulses were used for each load case. The steering column, seat and restraints were changed for each test. A piece of the seat back was cut to allow measurement of chest forward excursion using a string potentiometer. The instrument panel was used in repeated tests, but changed according to a carefully controlled order to make sure each loading condition was run with panel components having undergone the same number of previous tests for comparable tests. The passenger airbag (PAB) lid was closed as much as possible for each repetition.

Fig. 1. Sled setup.

The HIII was positioned according to the EuroNCAP protocol. The THOR was positioned according to the draft seating procedure from SAE [15]. In comparison to the HIII the THOR head centre of gravity (CoG) and shoulder were 25 mm higher (z-direction) and 25 mm more rearward (x-direction).

Both the THOR and Hybrid III were equipped with sensors in the head, thorax and pelvis. Common channels for the two dummies were head Centre of Gravity (CoG) acceleration, thorax and pelvis acceleration, and femoral force. For the thoracic injury prediction the HIII was measuring sternum deflection via the rodpot. The THOR measured deflections at four locations (upper left, upper right, lower left and lower right) using four 3D IR-Traccs. Each rib was also equipped with 6x2 (left and right side of sternum and spine) strain gauges that recorded the strain profile during impact.

In addition to dummy measurements, sled acceleration was measured at the body-in-white CoG as well as on the front door sills. Steering column displacement, chest forward excursion, belt forces (diagonal and lap), belt pay out, airbag pressure (DAB and PAB) and trigger times for sled and restraints were also measured. Each test was captured by five high-speed cameras. The rear view captured the interaction between dummy and airbag (for both occupants), and on each left- and right-hand side one camera captured the pure lateral view of the test, and an additional oblique view on each side was added to capture the belt position on the thorax as far into the event as possible.

Restraint variation

For the driver the EuroNCAP load case was chosen for all tests, and the restraint configuration was varied based on findings from real life data. Previous studies have suggested that a reduction of belt force (level of load limiter) in combination with the addition of an airbag reduces the risk of thoracic injury [6]. Based on these real life findings it was assumed that the 6 kN belt-only condition represented the most severe impact condition in terms of occupant protection, followed by the 4 kN belt and driver airbag system. Furthermore, it was assumed that lowering the belt force even more would result in less thoracic loading and hence a reduced injury risk. In the third test the vehicle standard restraint system, a 3 kN belt and driver airbag, was used. The driver test matrix is presented in TABLE I.

TABLE I
DRIVER TEST MATRIX

Pulse	Seat belt load limiter	Driver Airbag
EuroNCAP ODB 64 km/h	6 kN	No
EuroNCAP ODB 64 km/h	4 kN	Yes
EuroNCAP ODB 64 km/h	3 kN	Yes

Pulse variation

For the passenger, crash severity in terms of impact speed was evaluated, while the restraint system remained unchanged. The passenger test matrix is shown in TABLE II. Pulses from existing legal and consumer rating tests were available for the particular test vehicle. Since the characteristics for these pulses are generally known, it was decided to use these pulses rather than creating specific pulses. The EuroNCAP pulse was chosen as the reference pulse and was compared to the FMVSS 208 ODB (offset deformable barrier) at 25 mph (40 km/h), which represents a low speed pulse. The pulses are shown in the Appendix, Fig. A1. The EuroNCAP peak acceleration and delta-v was 25g and 65km/h, representing a range of a 25 to 85% risk of MAIS2+ injury according to Stigson et al. [2]. The low speed pulse, with a peak acceleration of 15g and a delta-v of 40 km/h, represented 10% to 30% risk of MAIS2+. For the passenger the same (vehicle standard) restraint configuration was used (3 kN belt + passenger airbag) in all tests.

TABLE II
PASSENGER TEST MATRIX

Pulse	Seat belt load limiter	Airbag
EuroNCAP ODB 64 km/h	3 kN	Yes
Low Speed (FMVSS 208 ODB 25 mph)	3 kN	Yes

III. RESULTS

ATD Measurements

In all tests the THOR head and chest moved more forward compared to the HIII (for comparison see table III and IV in Appendix). When restrained by the belt only the head of both dummies impacted the steering wheel. Fig. 2 shows a comparison of the HIC. Reducing the belt load limiter to 4 kN and introducing a driver (steering wheel) airbag prevented head to steering wheel interaction for the HIII, but there was a slight strikethrough (where the head strike penetrates the airbag "bottoming out" with a hard contact against the steering wheel) for the THOR. For the lowest load limiter both dummies bottomed out the driver airbag. On the passenger side, when varying the crash pulse, no strikethrough was observed for either dummy.

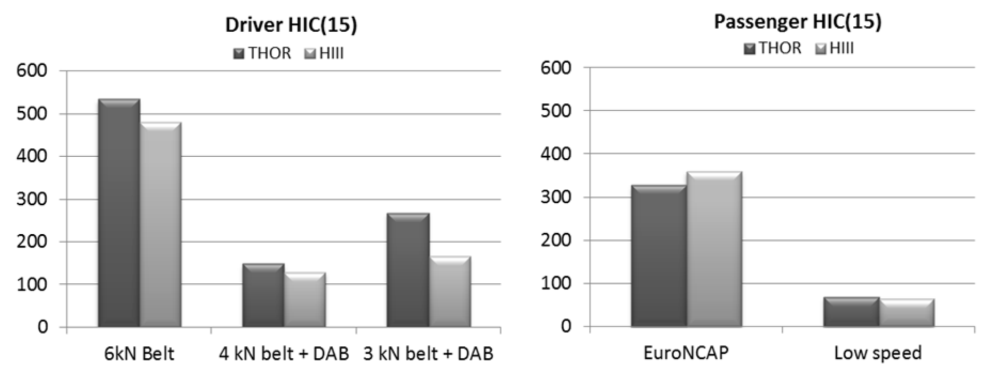

Fig. 2. HIC(15) comparison for THOR and HIII as driver (left) and passenger (right)

Dummy deflections (by rodpot and IR-Traccs in the x-direction) for the driver position are shown in Fig. 3. The deflection measured by the HIII as driver was 27 mm for the 6 kN belt-only restraint configuration (circle). For the 4 kN and 3 kN belt in combination with a driver airbag, HIII deflection was 28 mm and 22 mm, respectively. For the THOR in the driver's seat, maximum deflection was measured at the lower right (LR) IR-Tracc in all three tests. For the 6 kN belt only, the maximum deflection (in x-direction) was 58 mm. For the 4 kN and 3 kN belt in combination with an airbag, the maximum x-deflection was 40 mm and 30 mm, respectively. Dc-THOR was calculated to 85 mm for the test using a 6 kN belt only, and 51 mm and 17 mm for a 4 kN and 3 kN belt and driver airbag, respectively.

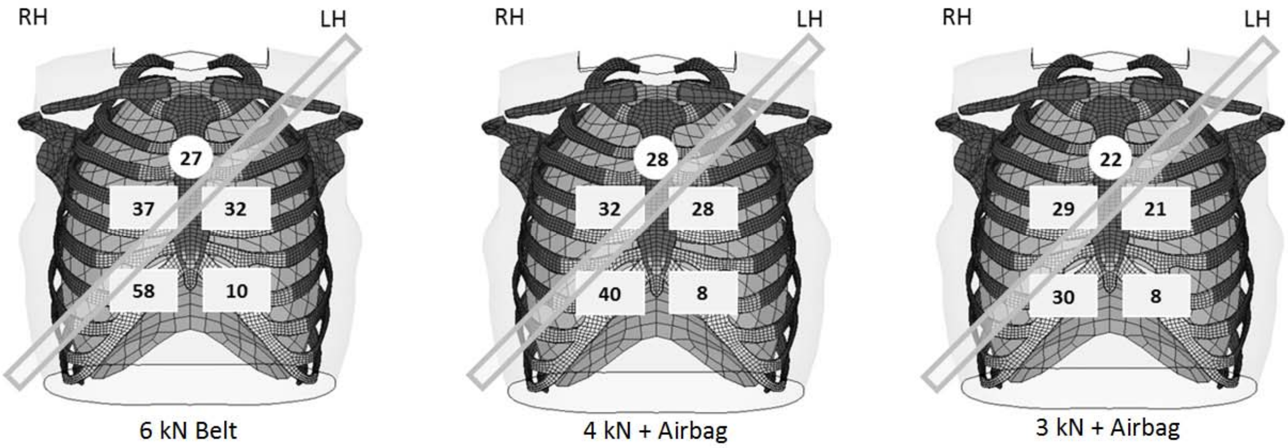

Fig. 3. Maximum deflections for THOR (in x-direction) in the squared text box and HIII (rodpot) in the circle for 6 kN belt only (left), 4 kN + Airbag (mid) and 3 kN + Airbag (right).

THOR strain profiles are shown in Fig. 4 where the THOR-specific fracture limit of 1.6 mstrain is marked by a line. The 6 kN belt-only configuration resulted in nine dummy fractured ribs; a 4 kN and 3 kN belt in combination with a driver airbag resulted in eight and five dummy fractured ribs, respectively. Peak strain values were found in the upper left and lower right in all tests.

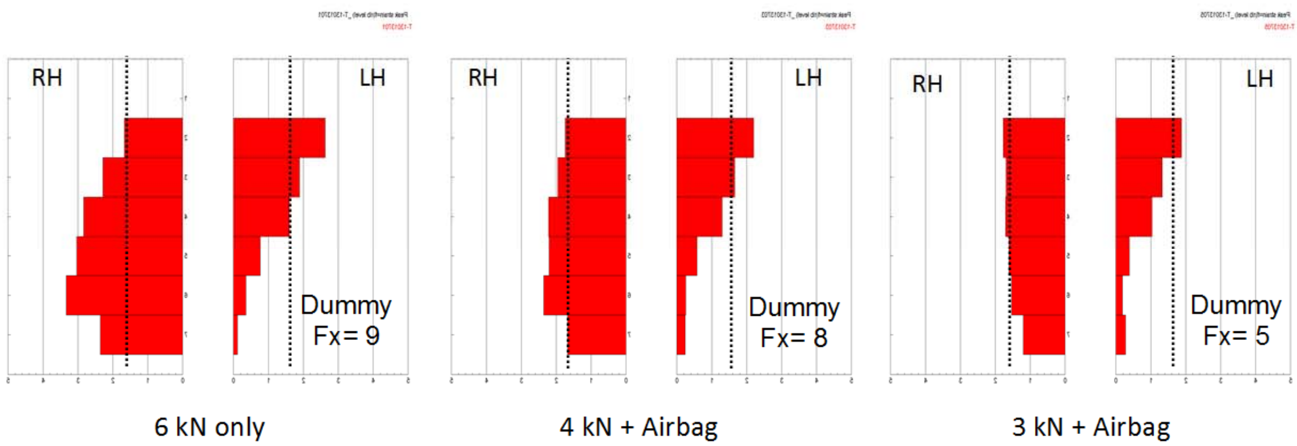

Fig. 4. Driver THOR strain peak value distributions. Vertical lines at 1.6 mstrain represent the THOR specific limit for fracture.

Dummy deflections (determined by rodpot and IR-Traccs in x-direction) for the passenger position, in the two crash severities, are shown in Fig. 5. The peak HIII deflection was measured to 20 mm and 15 mm for the EuroNCAP and low speed conditions, respectively. Peak deflection for THOR was found at the upper right (UR) and lower left (LL) IR-Tracc. Dmax was 35 mm for the EuroNCAP and 27 mm for low speed severity, and Dc-THOR was calculated to 14 mm and 4 mm for the two tests. THOR peak strain distributions for the tests are shown in Fig. 6.

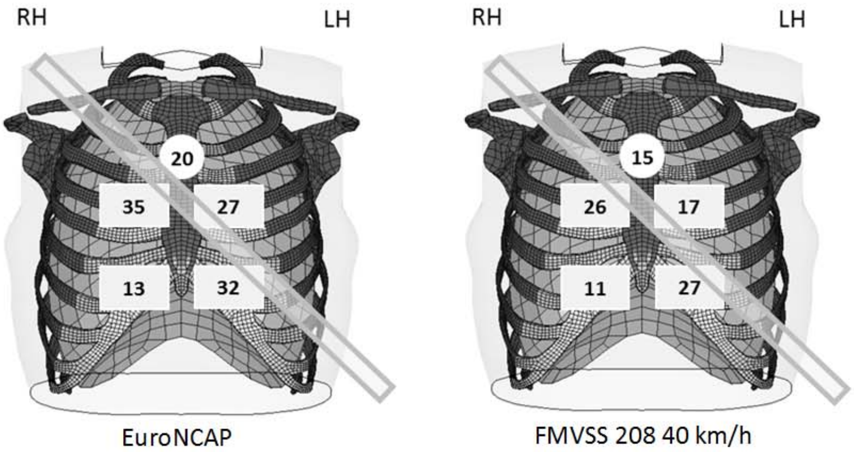

Fig. 5. Maximum deflections for THOR (in x-direction) in the squared text box and HIII (rodpot) in the circle for the EuroNCAP pulse (left) and FMVSS 208 low speed 40 km/h (right).

The standard EuroNCAP test severity for the passenger THOR resulted in six dummy fractured ribs and the lower severity resulted in a single dummy fractured rib. The highest peak strain values were found in the upper right and lower left part of the thorax.

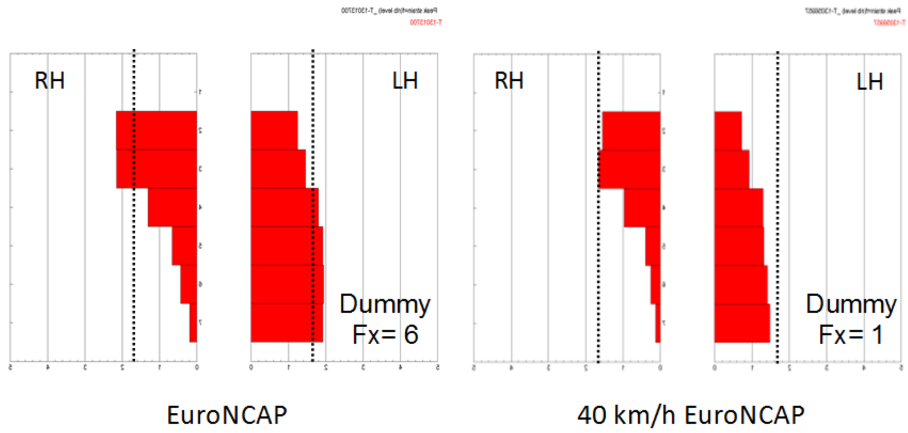

Fig. 6. Passenger THOR strain peak value distributions. Vertical lines represent the THOR specific limit for dummy rib fracture.

Head, chest and pelvis acceleration resultants were similar for both dummies, except that THOR head acceleration showed higher peak values in the cases of strikethrough in the test with a 3 kN belt and driver airbag. Femur forces were low and similar for both dummies.

ATD Injury risk comparison

Thoracic injury risks for the HIII compared to the THOR are shown in Fig. 7 and Fig. 8. The HIII rodpot deflections for a 6 kN belt only, a 4 kN belt + airbag and a 3 kN belt + airbag correspond to an 8%, 9% and 4% risk of AIS3+ thoracic injury. The DEQ(Lin) for each test was calculated at 46, 42 and 29 corresponding to a 19%, 14% and 3% risk of AIS3+ thoracic injury. For THOR, the AIS3+ thoracic injury risk using a 6 kN belt only was 58%, 59% and 89% for Dmax, Dc-THOR and strain. For the 4 kN belt and driver airbag, thoracic risk was 32%, 51% and 55%. For the 3 kN belt and driver airbag Dmax, Dc-THOR and strain resulted in a 17%, 17% and 37% risk of AIS3+ thoracic injury.

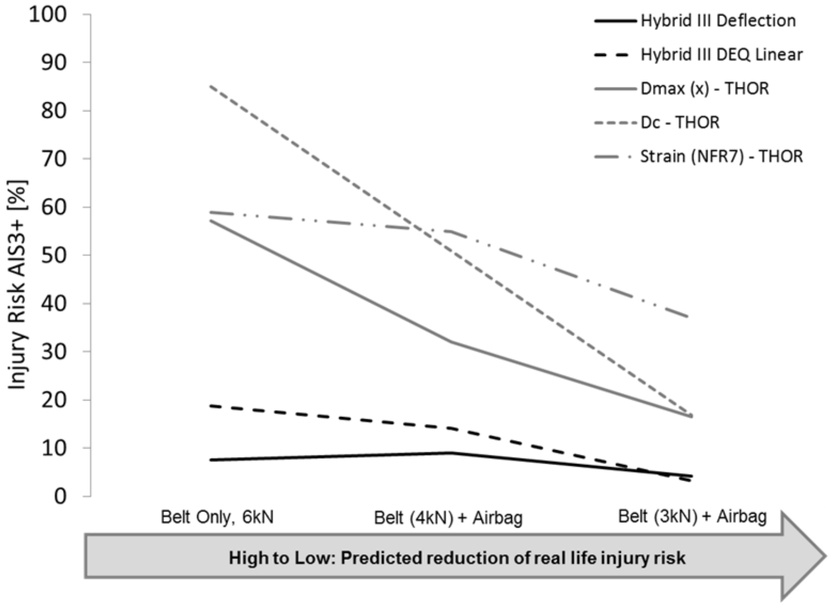

Fig. 7. Driver THOR and HIII trend of AIS3+ thoracic injury risk prediction based on different restraint systems (EuroNCAP pulse).

On the passenger side, HIII rodpot deflection and DEQ(Lin) both resulted in 3% AIS3+ thoracic risk for the EuroNCAP pulse, and 2% and 1% in the low speed pulse. For THOR Dmax, Dc-THOR and strain resulted in 23%, 14% and 44% AIS3+ thoracic risk while at the low speed the risk was 11%, 4% and 5% for the respective criteria.

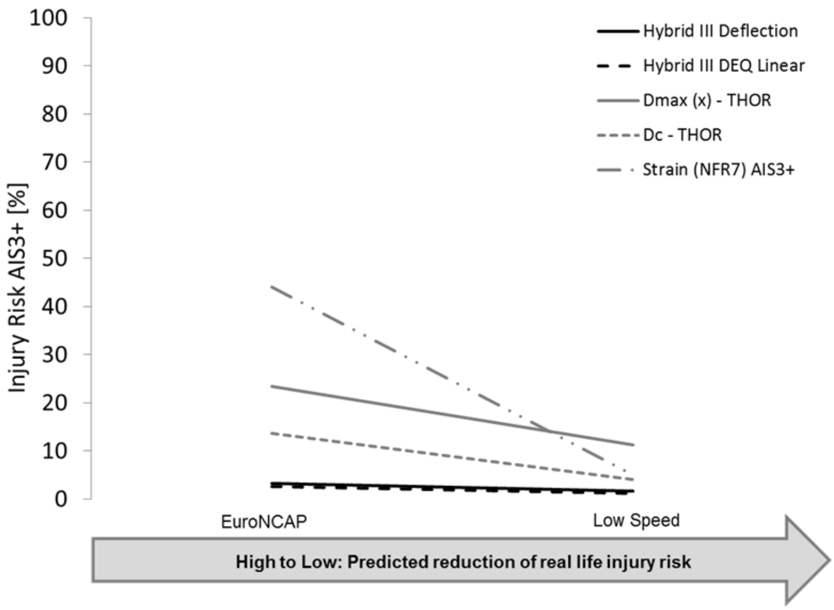

Fig. 8. Passenger THOR and HIII trends of AIS3+ thoracic injury risk prediction based on crash severity (3 kN and passenger airbag)

The THOR AIS2+ injury risk comparison is shown in Fig. 9 for the driver and Fig. 10 for the passenger. For the driver a 6 kN belt only resulted in a 70% to 100% risk of AIS2+ injury, which was reduced to 36% and 63% for the 4 kN belt in combination with a driver airbag. The 3 kN belt with a driver airbag resulted in 7% to 39% AIS2+ injury risks. The injury risk levels followed the same trend as for AIS3+; however, the very high levels were higher and the low levels were lower. This was also true for the THOR in the passenger position comparing the low severity to the standard EuroNCAP. For the passenger, the EuroNCAP severity resulted in 20% to 50% AIS2+ thoracic injury risk and at the lower severity 1% to 5%.

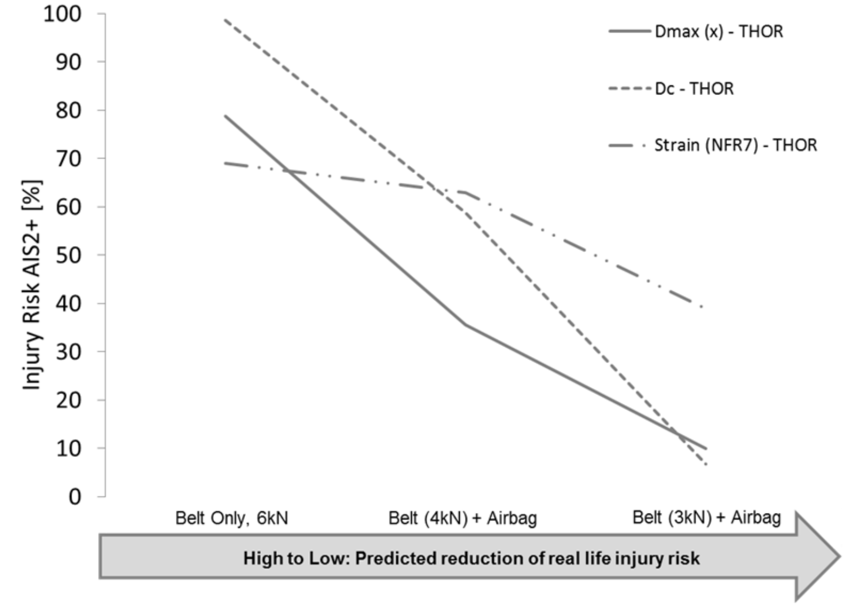

Fig. 9. Driver THOR trend of AIS2+ thoracic injury risk prediction based on different restraint system (EuroNCAP pulse).

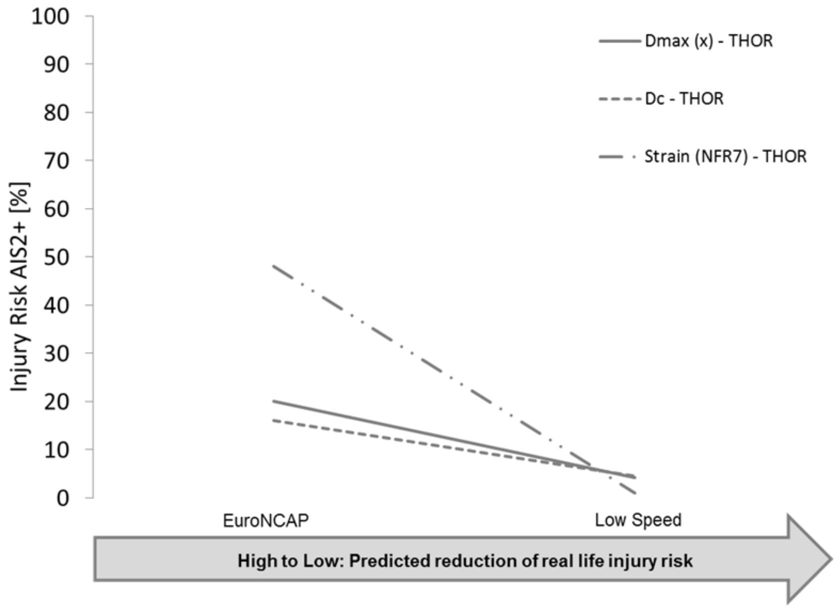

Fig. 10. Passenger THOR trend of AIS2+ thoracic injury risk prediction based on different restraint system (3 kN and passenger airbag).

IV. Discussion

On the driver's side, the 6 kN belt only, the 4 kN plus airbag and the 3 kN plus airbag were chosen to represent a progression of the real life injury risk ranging from higher to lower. The THOR AIS3+ injury risk predictions clearly show a reduction in thoracic injury risk from a high belt load to a lower, which was not the case for the HIII. The HIII showed a similar trend as THOR using DEQ(lin), but not for the injury risk based on rodpot measurement only. An expected reduction in injury risk when using the same restraint and reducing the crash severity was reflected by THOR (for all criteria) but not for the HIII. The ability to evaluate injury risk in a low speed crash would particularly benefit senior occupants.

In general all AIS3+ risk levels measured by the THOR were larger than for the HIII (as shown in Fig. 7 and Fig. 8). The comparison shows the increased thorax sensitivity of the THOR compared to the HIII and the higher risk range demonstrated by the THOR compared to the HIII, implying that THOR has a higher potential to reflect real life data than HIII. As less severe injuries and injuries to the elderly need to be addressed, the increased sensitivity and measurement range is needed in a crash test dummy.

In all tests the THOR head and chest excursion was greater compared to the HIII. As a result, decreasing the belt force limit from 4 kN to 3 kN while using the same driver airbag resulted in head strikethrough and a higher HIC for THOR compared to HIII (shown in Fig. 2). While not detected by the HIII, which only showed a benefit of decreasing belt forces due to the limited kinematic biofidelity, the use of THOR will require an improved balance of airbag and belt loading to a greater extent than is currently needed. Using the THOR dummy will most likely influence the restraint configurations used in the future. The potential disadvantages of adjusting restraint system behaviour to crash severity without anticipating the full excursion of a human occupant have been considered in a previous case-by-case analysis [17].

The proposed THOR thoracic injury criteria showed different injury risk levels in all tests. Injury risk based on strain was the highest overall. It is also a fairly new criterion, currently associated with a discontinuous (or discrete) risk function since it is based on the number of dummy rib fractures. A dummy rib fracture is counted when one of the gauges on the left or right-hand side exceeds 1.6 mstrain and, as long as that threshold is passed, it does not matter how high the peak strain is. It is therefore important that the current threshold is representative. Dmax showed the lowest risk levels for the driver, compared to Dc-THOR and strain. For the passenger, however, Dc-THOR showed the highest levels. It is difficult to relate the magnitude of the predicted injury risk compared to what might be expected in real life. The AIS3+ injury risk reduction when going from a 6 kN belt only to a 4 kN belt with driver airbag was 40% and 45% for the deflection based criteria Dc-THOR and Dmax, and approximately 10% for the strain criteria. Considering AIS2+ the thoracic risk reduction was 40% for Dc-THOR, 55% for Dmax and 10% for strain. In a real life study using French collision data the risk reduction for the same restraint combinations was 75% at an AIS3+ level and 50% at an AIS2+ level [6]. Comparing the levels of reduction, at least for the deflection based criteria, it seems as though the THOR predicted injury reduction was in a relevant range.

A comparison of NASS/CDS real life injury risk rate and estimated HIII injury risk for USNCAP-like crashes concluded that the level of risk measured by the dummy was comparable, and about 10% risk of thoracic AIS3+ injuries for occupants aged 15-43 years [18]. The MAIS2+ injury risk curves, with respect to EDR acceleration and delta-v, derived by Stigson et al. can be used for comparison of the THOR estimated injury risk level [2]. However, since real life data consists of different vehicles, restraint systems and crashes, it is not possible to compare specific restraint systems. Depending on the injury criteria and restraint system, the AIS2+ thoracic injury risks for the THOR in the driver position ranged from 10% to 99% (Fig. 9). Regardless of the restraint system, the average AIS2+ thoracic injury risk for each injury criteria was 41%, 55% and 57% for Dmax, Dc-THOR and strain, respectively. These levels were within the range (25% to 85%) of MAIS2+ injury risk with respect to acceleration and delta-v for the EuroNCAP pulse used in this study. The large range of risk estimation as well as the large difference, depending on whether acceleration or delta-v is the measure of severity, makes it difficult to conclude if the risk levels are correct. For the THOR in the passenger position, varying the pulse resulted in a range of AIS2+ thoracic injury risk between 1% and 70% (Fig. 10). The average injury risk for each criterion was 18%, 22% and 39% for Dmax, Dc-THOR and strain, respectively. Compared to the MAIS2+ injury risk based on acceleration and delta-v, which was 10% to 30%, the level of THOR injury risk estimation might be close to that expected in the real world, but perhaps a bit too high depending on the precise relationship between the broad range of real world risk and the criterion used.

The standard restraint system in the tested vehicle was the 3 kN belt and driver airbag on the driver side, and the same belt plus passenger airbag on the passenger side. Comparing the AIS3+ injury risks for these configurations shows that the injury risks on the driver side and the passenger side were similar (14%-44%), although they differed somewhat depending on the injury criteria considered. Using the AIS2+ level, the thoracic injury risks on the passenger side were higher (16%-48%) compared to the injury risks for the driver (7%-39%); a trend in line with what research using European real life data has shown [1].

Using only one type of vehicle, a BiW with a limited set of crash pulses, and modern restraints makes the correlation to real life data difficult. Repeatability and reproducibility of the injury risk predictions from the THOR are uncertain. To provide some assurance on the reliability of the injury risk predictions, repeated tests would have been desirable. Unfortunately, time and sled test materials did not allow such a comparison within this study and, hence, remains to be formally determined.

Three thoracic injury criteria proposed within the THORAX Project were used with the THOR dummy to assess the risk of injury. Ideally, the strain-related criterion should be revised to avoid so few discrete levels in the risk function. Apart from this, all three criteria showed similar relationships to changes in the restraint system being tested or the severity of the crash pulse as varied within this study. For this reason no one criterion is proposed for future use with the dummy, but each has some merit based on this testing.

V. CONCLUSIONS

In this study, thoracic injury predictions using the THOR dummy with an upgraded thorax and SD3 shoulder (similar to Mod-Kit_SD3) were compared with those from the HIII in three restraint configurations (in the same severity test) and using the same restraint (in two different severity levels) as well.

Although the precise level of thoracic injury risk needs further investigation, the expected injury risk reduction going from what was predicted as a high to a low risk was obvious for the THOR, but was not demonstrated by the HIII. Contrary to the HIII the THOR predicted a substantially greater reduction in injury risk in changing from the EuroNCAP to the low speed crash condition. The large variations in injury risk as well as the sensitivity to crash severity indicate that the THOR dummy should be the preferred tool for evaluating frontal impact occupant protection. Furthermore, the kinematics of the dummy revealed the potential limitations of a poor balance between restraint from the seat belt and the airbag. This was not evident with the Hybrid III.

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VIII. APPENDIX

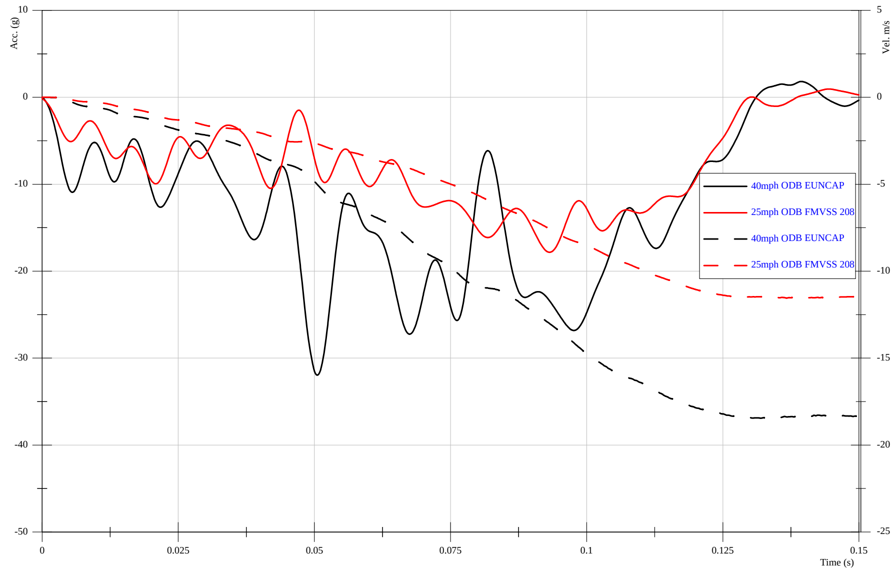

Fig. A1. Acceleration and delta-v comparison for the EuroNCAP pulse and the Low speed pulse.

TABLE III
DRIVER MEASUREMENTS AND INJURY RISKS

Dummy measurement	EUNCAP 6 kN	EUNCAP 4 kN + DAB	EUNCAP 3 kN + DAB
THOR Chest Excursion (mm)	412	340	425
Hybrid III Chest Excursion (mm)	280	275	370
Hybrid III Peak Deflection (mm)	26,8	28,3	21,8
Hybrid III Injury Risk Age (years)	45	45	45
Hybrid III Deflection Injury Risk AIS 3+ (%)	7,6	9,0	4,2
Hybrid III Max DEQ Linear	45,7	42,2	28,9
Hybrid III DEQ Linear Injury Risk M50 AIS3+ (%)	18,8	14,1	3,2
Dmax (x)-THOR Injury Risk AIS3+ (%)	57,2	32,1	16,5
Dmax (resultant)- THOR Injury Risk AIS3+ (%)	53,2	27,5	14,1
Dc-THOR Injury Risk AIS3+ (%)	85,0	51,0	16,9
Strain (NFR7) AIS3+ (%)	59	55	37
Dmax (x)-THOR Injury Risk AIS2+ (%)	78,7	35,6	9,9
Dc-THOR Injury Risk AIS2+ (%)	98,6	58,7	6,8
Strain (NFR7) AIS2+ (%)	69	63	39

TABLE IV
PASSENGER MEASUREMENTS AND INJURY RISKS

Description	EUNCAP 3 kN + PAB	EUNCAP 40 km/h 3 kN + PAB
THOR Chest Excursion (mm)	520	400
Hybrid III Chest Excursion (mm)	440	295
Hybrid III Peak Deflection (mm)	20,0	15,2
Hybrid III Injury Risk Age (years)	45	45
Hybrid III Deflection Injury Risk AIS 3+ (%)	3,3	1,7
Hybrid III Max DEQ Linear	27,3	22,9
Hybrid III DEQ Linear Injury Risk M50 AIS3+ (%)	2,5	1,2
Dmax (x)-THOR Injury Risk AIS3+ (%)	23,4	11,2
Dmax (resultant)- THOR Injury Risk AIS3+ (%)	18,9	9,0
Dc-THOR Injury Risk AIS 3+ (%)	13,6	4,0
Strain (NFR7) AIS3+ (%)	44,0	5,0
Dmax (x)-THOR Injury Risk AIS2+ (%)	30,6	20,1
Dc-THOR Injury Risk AIS2+ (%)	44,1	16,0
Strain (NFR7) AIS2+ (%)	69	48