Sensitivity of Rear-Seated Hybrid III 5th and THOR 5th to Load Limiting and Crash Pulse

Amanda Hederskog, Stefan Schilling, Dion Kruse, Nils Lubbe

I. INTRODUCTION

For over 50 years, the Hybrid family of anthropomorphic test devices (ATDs) have been the industry standard for crash testing. However, the Hybrid III (HIII) family discriminates insufficiently between the differences in modern restraint designs [1]. The newer THOR family has higher biofidelity compared to the HIII family [2-3] and the THOR 50th male ATD has been shown to be more sensitive to variations in the belt system, compared to the HIII 50th male [4]. Carroll *et al*. [5] compared the female ATDs, the THOR 5th and the HIII 5th, in a front seat environment, with a semi-rigid seat with and without airbag, and found both ATDs to be sensitive to restraint design. Clear differences in the ATD responses were observed with, for example, much higher chest deflections of the THOR 5th, indicating substantially higher thoracic injury risk [5]. Tang *et al*. [6] ran full scale crash tests with one HIII 5th ATD and one THOR 5th ATD in the rear seat and found kinematic and kinetic differences, consistent with those observed by Carroll *et al.* [5]. No conclusions on sensitivity to restraint design were made and additional matched pair testing with the THOR 5th and HIII 5th was recommended [6]. To supplement the findings from [5] with knowledge on sensitivity in other environments, the objective of this study was to compare the ability of THOR 5th and HIII 5th to discriminate between different load-limiting levels and crash pulses in a rear-seat environment, in terms of chest deflection and forward excursion.

II. METHODS

The testing was conducted as a matched pair sled test with the THOR 5th and the HIII 5th (side-by-side) in the rear-seat Body-in-White environment of a mid-sized European sedan. In total, five different tests were conducted. Three tests (tests 1–3) were performed with a delta-v of 50 km/h (maximum acceleration of 35 g, occupant loading criterion (OLC) 27 g) and two tests (tests 4–5) were performed with a delta-v of 32 km/h (maximum acceleration of 24 g, OLC 17 g). A three-point belt with pretensioner (activated at 15 ms for tests 1–3 and at 17 ms for tests 4–5) and "off-the-shelf" retractors were used in all tests. Two different load limiters, with different characteristics, were used, one with a constant force level of approximately 4 kN and one with a degressive characteristic, decreasing from approximately 3.5 kN to 2 kN. The former was used in tests 1–4 and the latter was used in test 5. In test 3, a crash locking tongue was used, whereas a conventional sliding tongue was present in the other four tests. The ATDs were positioned after using the SAE mannequin to determine the H-point. Due to the short legs and lower amount of soft material in the pelvic area of the HIII 5th, it was positioned 30 mm more forward and 40 mm lower than the THOR 5th. The chest deflection was assessed using the four IR-TRACCs for THOR 5th and using the rod potentiometer for HIII 5th. An external string potentiometer was mounted at the T8 level to measure chest excursion in x-direction for both ATDs. The pelvis excursion, in sled x-direction, was computed using measured pelvis angle and acceleration. The shoulder-belt force was measured between the shoulder of the ATD and the upper belt anchorage point.

III. INITIAL FINDINGS

In all five tests, the THOR 5th experienced larger forward excursions than the HIII 5th but the effect of the variations in pulse and load limiting were similar for both ATDs. The change in pulse affected both the pelvis excursion and the chest excursion while the load limiter with a lower force limit only affected the chest excursion. The amount of extra forward excursion for the THOR 5th chest compared with the HIII 5th chest was approximately the same for every test set up, except for test 1, where the belt slipped off the THOR 5th shoulder resulting in even larger forward chest excursion.

The chest deflection of the HIII 5th was unaffected by delta-v but decreased by 5.4 mm when changing load limiter, from 4 kN to 3.5 kN peak load. For the THOR 5th, the chest deflection differed little between the tests; all chest deflections were between 53.7 mm and 56.6 mm in R_{max}. Table I and Fig. 1 shows the relation between peak chest deflection and chest excursion. IR-TRACC rotation was also recorded (but is not depicted). Maximum rotation around the z-axis was recorded at 50–65 ms and plateaued for about 70 ms in tests 1–3 and 50 ms in tests 4–5.

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Figure 2 shows the shoulder-belt force as a function of chest deflection, including only those measurements from the pretensioning peak until the time of the z-axis rotation plateau. For the included measurements, belt force and chest deflection appear to follow a relationship, independent of crash pulse.

TABLE I

PEAK PELVIS- AND CHEST EXCURSION AND CHEST DEFLECTION FOR HIII 5TH AND THOR 5TH

Test No	Speed	Load limiter peak force	CLT	Pelvis excursion [mm]		Chest excursion [mm]		Chest deflection [mm]	
				HIII 5th	THOR 5th	HIII 5th	THOR 5th	HIII 5th	THOR 5th
1	50 km/h	4 kN	No	147.8	211.1	241.8	381.6	26.1	56.5
2	50 km/h	4 kN	No	126.5	205.7	236.2	322.0	25.2	56.6
3	50 km/h	4 kN	Yes	137.3	223.6	238.3	316.9	23.4	55.4
4	32 km/h	4 kN	No	103.8	157.1	124.5	165.4	22.8	53.7
5	32 km/h	3.5 kN	No	105.3	149.9	170.0	211.4	17.4	53.9

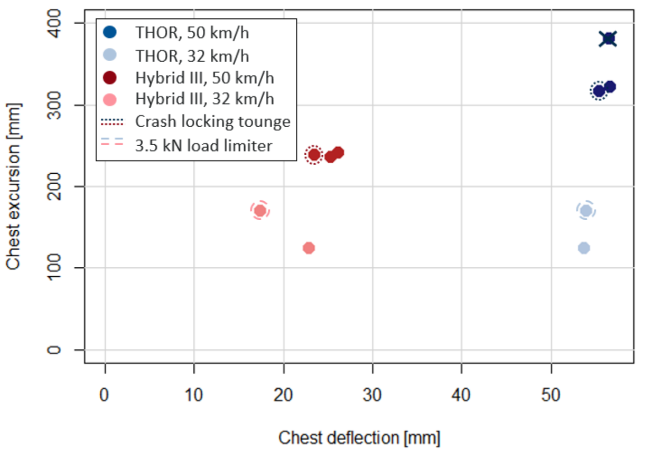

Fig. 1. The points illustrate chest deflection vs chest excursion for each test: red for HIII 5th, blue for THOR 5th. The lighter colours mark the lower delta-v, dashed lines mark the lower load limiter, and the dotted lines mark the test with CLT. The crossed-out data point marks the test with off belt slip off the shoulder.

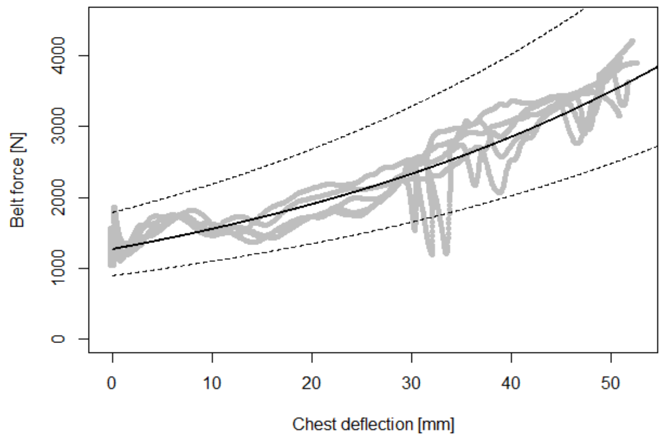

Figure 2. The gray lines show the measured shoulder belt force as a function of chest deflection for THOR 5th in all five tests (from pretensioning peak to rotation plateau). The black lines show an exponential regression of the measurements, together with the 99 % prediction intervals.

IV. DISCUSSION

For the given test setup – with two different delta-v, and acceleration levels of 24 g and 35 g – the THOR 5th was not able to discriminate between the different load limiters in terms of chest deflection. The HIII 5th chest captured the variation in belt force better, showing a decrease in chest deflection when lowering the load limiter force. Both ATDs responded similarly to variations in delta-v, with an effect on the forward excursion but almost no effect on the chest deflection.

A plateau in the IR-TRACC rotation was observed and was likely caused by an internal contact with the spine box; similar interactions have been observed in earlier work [6]. Without this contact, chest deflection measurements may differ. Although the R_{max} can be questioned after the plateau, there is no uncertainty that the THOR 5th experiences much larger chest deflections than HIII 5th, consistent with previous studies [5-6].

Using the relation between shoulder-belt force and chest deflection (Fig. 2), we can estimate that to maintain, for example, a chest deflection below 30 mm, the shoulder belt force should not exceed 2 kN. While a 2 kN load limiter could be feasible in a low-speed crash, there is a risk that a contact to the back of the front seat or head-to-knee contact would occur at higher speed. This makes the balancing of the chest deflection – forward excursion tradeoff more difficult for the THOR 5th, compared with the HIII 5th, and enhances the importance of an adaptive restraint system.

V. REFERENCES

[1] Kent, *et al.*, AAAM, 2003
[2] Parent, *et al.*, *Stapp Car Crash J*, 2017
[3] Watkins, *et al.*, NHTSA, 2022
[4] Eggers, *et al.*, *IRCOBI*, 2014
[5] Carroll, *et al.*, *IRCOBI*, 2021
[6] Tang, *et al.*, *IRCOBI*, 2022

ERRATUM

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Numbers from Table I were incorrectly depicted in Fig 1. Table I states chest excursion for THOR 5th for test no. 4 and 5 at 165.4 and 211.4 mm. Fig 1 depicts them at 124.5 and 170.0 mm, which are the values for HIII 5th. The light blue coloured dots in figure 1 are incorrect.

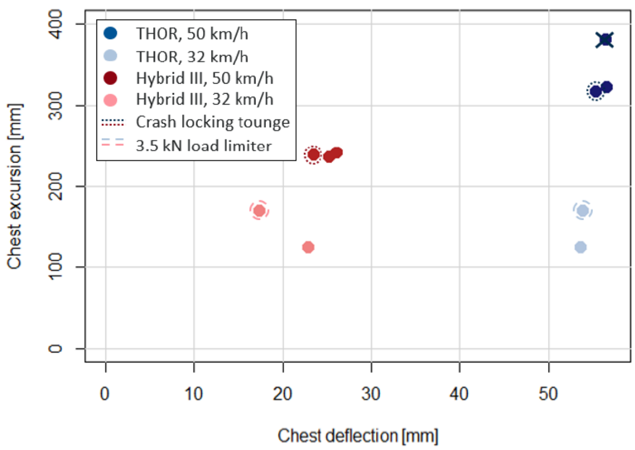

Fig. 1. Incorrect

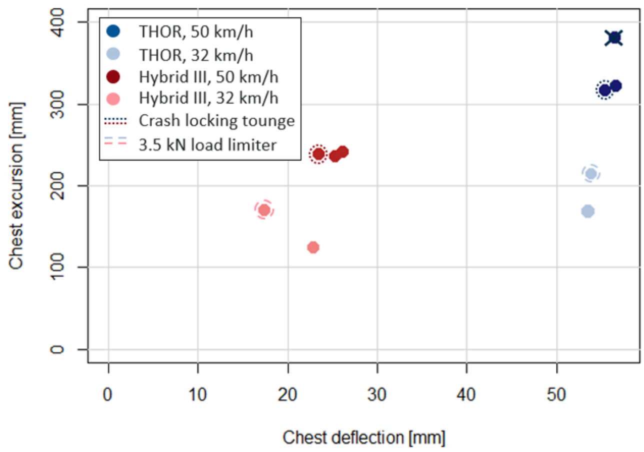

Fig 1 **corrected**. The points illustrate chest deflection vs chest excursion for each test: red for HIII 5th, blue for THOR 5th. The lighter colours mark the lower delta-v, dashed lines mark the lower load limiter, and the dotted lines mark the test with CLT. The crossed-out data point marks the test with off belt slip off the shoulder.