SENSITIVITY TO DIFFERENT SEATING POSITIONS OF THOR-NT AND HYBRID III IN SLED TESTING

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ABSTRACT

In this study, the sensitivity to different seating positions of the THOR-NT and the Hybrid III in sled testing were evaluated. In the tests, the THOR-NT or the Hybrid III was installed on the driver seat of a vehicle body fixed on the sled, and a frontal impact of 15.6 m/s (56 km/h) was given to the sled. Dummy installation was subject to FMVSS 208 and UMTRI seating procedures. Furthermore, based on the FMVSS 208 procedure, the seat slide was adjusted forward 30 mm (MP-30).

In testing of the three seating positions of the THOR-NT, different responses in the head acceleration was shown. The head accelerations in FMVSS 208 and UMTRI exhibited a sharp high wave of about 110 ms, but that in the MP-30 did not exhibit such a wave. Applying the dummy injury values to provisional injury assessment reference values (IARVs) for THOR used in the research of the NHTSA, kinematic rotational brain injury criterion (BRIC) of the MP-30 was lower than FMVSS 208 and UMTRI. For the acetabulum force, it was large, in the order of the UMTRI, FMVSS 208, and MP-30. For inversion/eversion of the right ankle of the accelerator pedal side, it showed large angles, in the order of the FMVSS 208, MP-30, and UMTRI. Other injury values of the ankles showed large angles, in the order of the UMTRI, FMVSS 208, and MP-30.

The difference in the responses to the different seating positions was mainly observed in the head acceleration and lower extremity force responses for both the THOR-NT and the Hybrid III. However, comparing responses of the THOR-NT and the Hybrid III with the same conditions, the upper body of the THOR-NT moved forward more, compared to the Hybrid III, and the torsion about the z-axis was also larger than the Hybrid III. As a result, the head acceleration of the THOR-NT and the Hybrid III exhibited different responses.

INTRODUCTION

Currently, though the Hybrid III frontal crash test dummy is used worldwide, there is a neeed for a more advanced dummy with more biofidelity and higher measurement performance to more sensitively evaluate the advanced restraint devices, so as to further improve safety performance. Under these circumstances, in 2001 an advanced frontal crash test dummy THOR (Test Device for Human Occupant Restraint) - alpha version was developed in the United States [1]. In 2005, the THOR-NT version which exhibited improvement in durability and usability from the THOR-alpha was released [2]. In order to further improve the biofidelity and measurement performance of the THOR-NT, development of a new version THOR (THOR Mod Kit), under collaboration of NHTSA, EU THORAX, and other organizations came in progress [3]. In this study, it evaluates the sensitivity to different seating positions of the THOR-NT and the Hybrid III in sled testing. The objective is to obtain base data which is a comparative target for evaluating the THOR Mod Kit in the near future.

SLED TESTING

Test Condition

The THOR-NT or the Hybrid III was installed on the driver seat of a vehicle body fixed on the sled, and a frontal impact of 56 km/h was given to the sled. The vehicle body used in the sled tests was a four-door sedan passenger car (Figure 1). For the restraint system, the air bag, and a seatbelt with force limiter and a double pretensioner at the retractor and outer lap belt anchorage were used in this series of tests. Figure 2 shows the acceleration and the velocity curves of the sled.

Figure 1. Vehicle body of four-door sedan passenger car

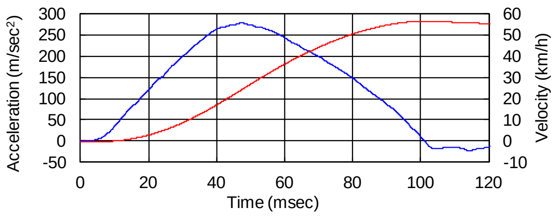


Figure 2. Sled pulse (acceleration and velocity)

Measurements

For the electrical measurements, the accelerations, deflections and forces of the dummies and the acceleration of the sled were recorded by a data acquisition system, and they were filtered in compliance to SAE J211 [4]. The detailed information of the instrumentation of the THOR-NT and Hybrid III is shown in the Appendix (Table A1). For the photogrammetry, two high-speed video cameras were used to take the kinematics of the dummy during the impact. Kinematics of the dummies were observed as follows: The motions of the markers attached to some parts on the dummy were recorded by the video camera, then these were converted into the displacements using a video analyzer.

Dummy Positioning

Dummy installation was subject to the following three seating procedures:

(1) FMVSS 208; specified for Hybrid III [5],

(2) UMTRI (University of Michigan Transportation Research Institute); the seat position depends on the driver occupant size, dimensions of steering wheel and accelerator pedal, and seat adjustment range [6],

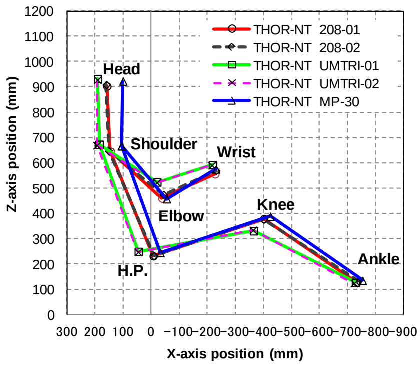
(3) MP-30; based on FMVSS 208 procedure, the seat slide was adjusted forward 30 mm.

For FMVSS 208, the seat slide is in the mid position, and the seat lifter is in the lowest position. For UMTRI, the seat slide is rearward 49 mm relative to FMVSS 208, and the seat lifter is upward 14 mm. For MP-30, it is as described above.

Figures 3 and 4 show the comparison of the positioning in the X-Z coordinate system for the THOR-NT and the Hybrid III in each seating position according to three seating procedures. The x-axis is posterior and anterior direction, and the z-axis is superior and inferior direction. Figures 5 and 6 show the posture and the clearance between the instrument-panel and each body region, for the THOR-NT and the Hybrid III in each seating position. For both the dummies, depending on the difference in the seat position, dummy positioning differed in three conditions.

Kinematic Responses

Figures 7 and 8 illustrate the trajectories of the markers on each body region for the THOR-NT and the Hybrid III in three seating positions. Time of trajectories shown in these figures is when the dummies' head has reached to the maximum displacement with the x-direction. Table 1 shows the maximum displacement of each body region. For both the dummies, the trajectory in three seating positions was mostly similar. However, in reviewing the details, the forward movement of the upper body was larger as the dummy position was more in the rear position (UMTRI > 208 > MP-30) (see comparison of the values in the red-bordered boxes in Table 1). For the ankle, the



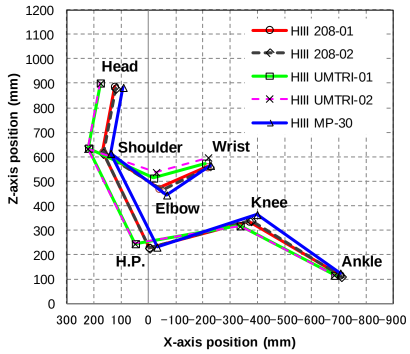
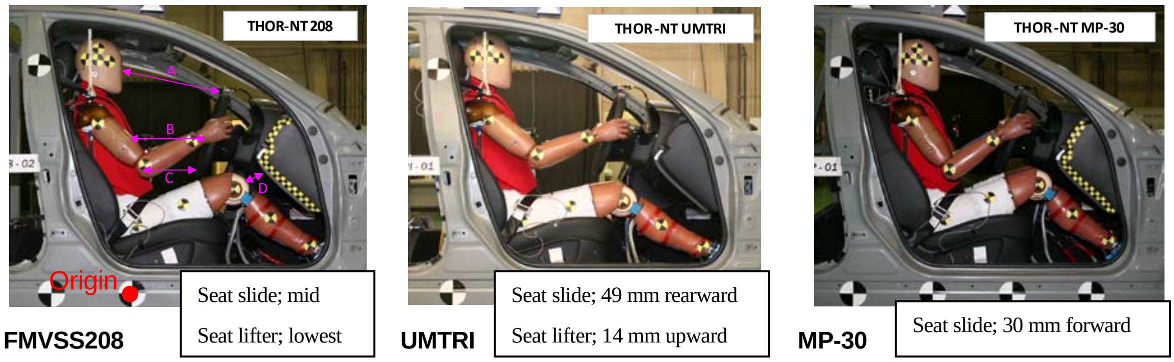


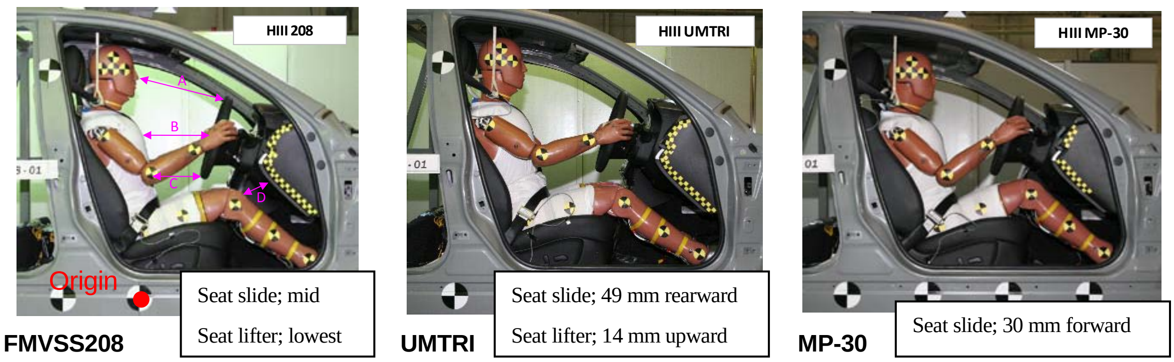
Figure 3. Comparison of the positioning in the X-Z coordinate system for the THOR-NT

Figure 4. Comparison of the positioning in the X-Z coordinate system for the Hybrid III



	Measurements	THOR-NT 208-01	THOR-NT 208-02	THOR-NT UMTRI-01	THOR-NT UMTRI-02	THOR-NT MP-30
A	Face to Steering Wheel Rim (Top) (mm)	442	442	471	469	380
B	Chest to Steering Wheel (Center) (mm)	337	338	365	361	278
C	Abdomen to Steering Wheel Rim (Bottom) (mm)	213	215	254	260	187
D	Knee to Dash Panel (mm)	60	63	122	123	40

Figure 5. Posture in each seating position and clearance between instrument panel and each body region for the THOR-NT



	Measurements	HIII 208-01	HIII 208-02	HIII UMTRI-01	HIII UMTRI-02	HIII MP-30
A	Face to Steering Wheel Rim (Top) (mm)	382	378	425	428	350
B	Chest to Steering Wheel (Center) (mm)	293	293	333	337	266
C	Abdomen to Steering Wheel Rim (Bottom) (mm)	217	212	264	268	185
D	Knee to Dash Panel (mm)	104	102	150	153	73

Figure 6. Posture in each seating position and clearance between instrument panel and each body region for the Hybrid III

difference in upward movement was remarkable (see comparison of the values in the blue-bordered boxes in Table 1). Figure 9 shows the comparisons of the trajectories of each body region for the THOR-NT and the Hybrid III in FMVSS 208 seating position. The upper body of the THOR-NT moved forward more, compared to the Hybrid III. Figure 10 shows forward displacement versus time curves for the right and left shoulders of the dummies based on the video analysis. With the THOR-NT, the left shoulder was still moving forward even when the right shoulder has rebounded. For the Hybrid III, the left shoulder also started moving rearward when the right shoulder has rebounded. These results showed that the torsion about the z-axis of the upper body of the THOR-NT was larger than that of the Hybrid III.

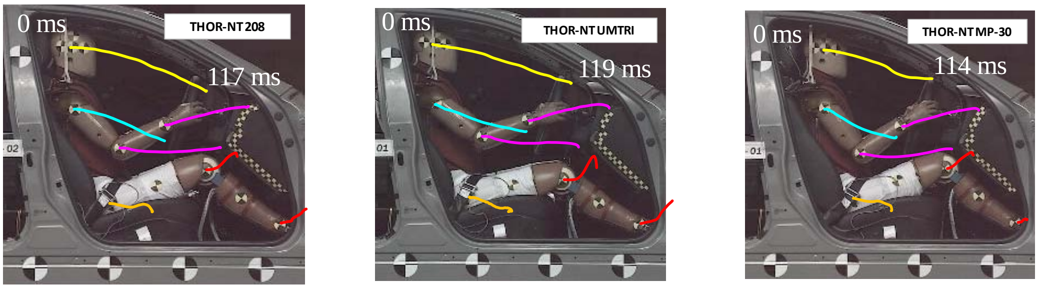


Figure 7. Trajectories of each body region of THOR-NT in three seating positions

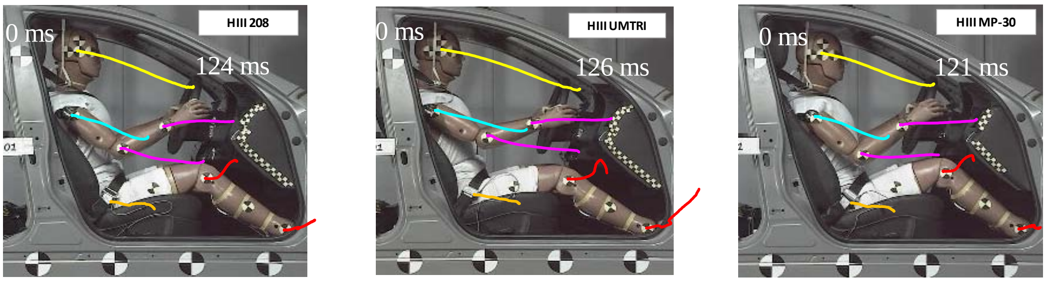


Figure 8. Trajectories of each body region of Hybrid III in three seating positions

Table 1. Maximum displacement of each body region

	THOR-NT						Hybrid III					
	THOR-NT 208		THOR-NT UMTRI		THOR-NT MP-30		HIII 208		HIII UMTRI		HIII MP-30	
	X	Z	X	Z	X	Z	X	Z	X	Z	X	Z
Head	568	-188	594	-171	467	-131	487	-160	592	-180	467	-141
Shoulder	376	-134	392	-120	310	-131	322	-107	390	-90	306	-95
Elbow	417	-20	413	-47	393	23	347	-64	391	-75	346	-19
Wrist	345	82	344	72	332	83	291	25	339	26	318	26
H.P.	177	-36	183	-65	166	-53	179	-33	192	-41	179	-37
Knee	125	73	141	102	112	70	135	77	168	86	128	72
Ankle	103	62	133	103	38	20	128	43	226	175	88	15
+ Direction	Forward	Upward										mm

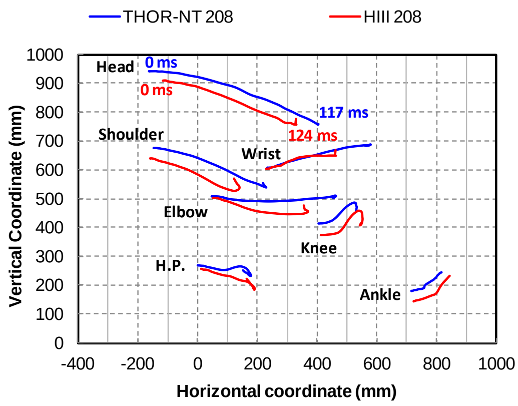


Figure 9. Trajectories of each body region of THOR-NT and Hybrid III in FMVSS 208 seating position

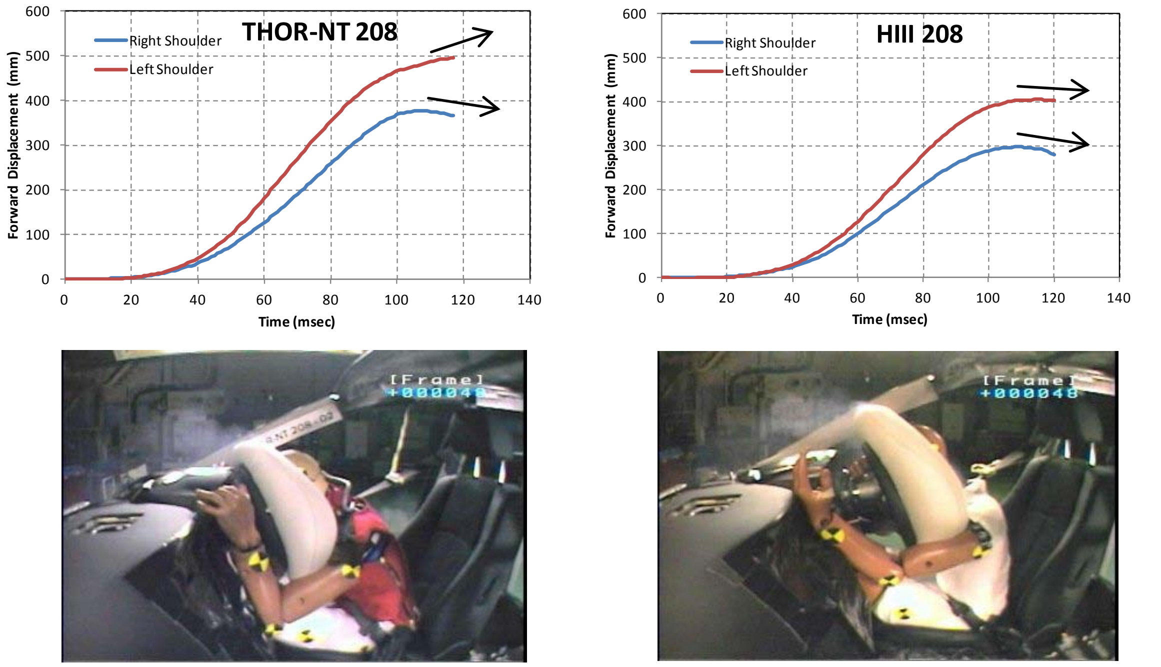


Figure 10. Forward displacement versus time curves for the right and left shoulders of THOR-NT and Hybrid III

Dynamic Responses

<u>Responses of THOR-NT</u>

Figures 11 to 16 show the comparison of dummy responses of the different seating positions for each body region. The head accelerations in FMVSS 208 and UMTRI exhibited sharp high wave of about 110 ms, but that in the MP-30 did not exhibit such wave (Figure 11). The response of chest deflection was similar in three seating positions (Figure 12). Acetabulum force between FMVSS 208 and MP-30 was similar, but the time of the maximum in UMTRI was later and the maximum value was larger than the others (Figure 13). For femur axial force, UMTRI exhibited stronger force than others in both compression and tension (Figure 14). Tibia axial force exhibited different responses between the three seating positions. The initial response of UMTRI was later than others but the force increase was the sharpest and the value was the largest. The initial response of MP-30 was earlier than others, exhibiting a flat curve between 40 ms and 80 ms, and the value was the lowest (Figure 15). For inversion/eversion of the right ankle of the accelerator pedal side, it showed large angles, in order of FMVSS 208, MP-30, and UMTRI (Figure 16).

Responses of Hybrid III

Figures 17 to 20 show the comparison of responses of the different seating positions for each body region.The head acceleration in UMTRI exhibited sharp high wave of about 110 ms, but the others did not exhibit such wave (Figure 17). The response of chest deflection was similar in the three seating positions (Figure 18). With the femur axial force, slight compression force was generated between 40 ms and 60 ms in all three seating positions, and the time of the maximum of UMTRI was later than the others (Figure 19). The tibia axial forces of FMVSS 208 and MP-30 exhibited one sharp wave while that of UMTRI exhibited two peaks (Figure 20).

Responses of THOR-NT versus Hybrid III

Figures 21 to 24 show the comparison of the responses of each body region for the THOR-NT and the Hybrid III in FMVSS 208 seating position. The head acceleration of the THOR-NT exhibited sharp wave of about 110 ms, but that of the Hybrid III did not exhibit such wave (Figure 21). The chest deflection in the left side (upper and lower) of the THOR-NT was similar to the Hybrid III (on the chest center) (Figure 22). The axial force to the femur of the THOR-NT was not significantly strong. For Hybrid III, tension force was larger than compression force (Figure 23). The tibia axial force of the Hybrid III exhibited sharp wave and value was larger than that of the THOR-NT (Figure 24).

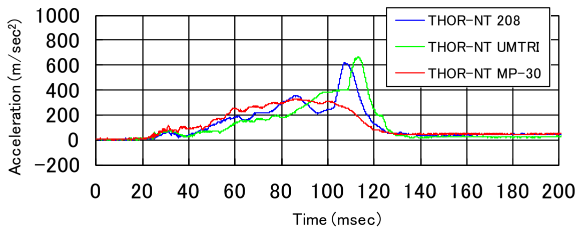


Figure 11. Head resultant acceleration of THOR-NT

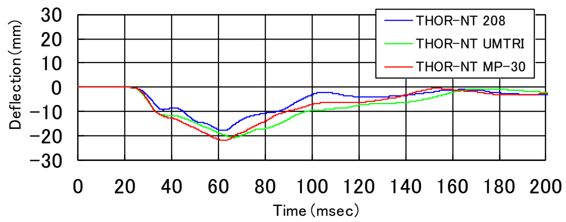


Figure 12. Chest deflection (upper right) of THOR-NT

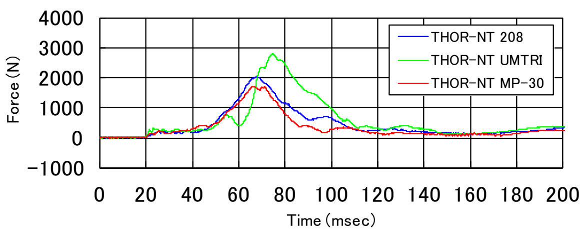


Figure 13. Right acetabular resultant force of THOR-NT

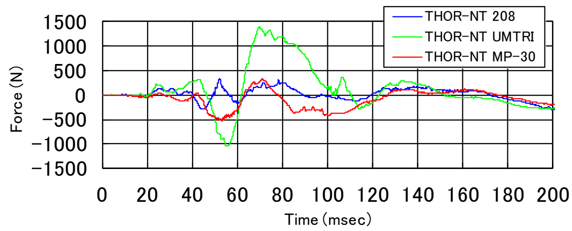


Figure 14. Right femur axial force of THOR-NT

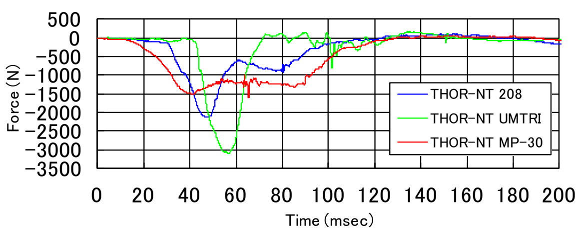


Figure 15. Right tibia axial force (lower) of THOR-NT

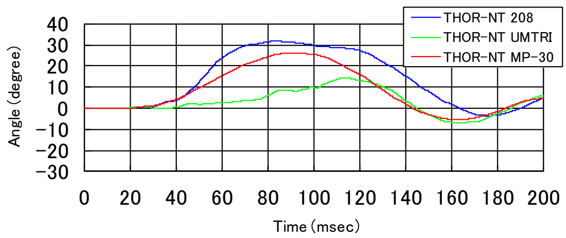


Figure 16. Right ankle rotation (inversion/eversion) of THOR-NT

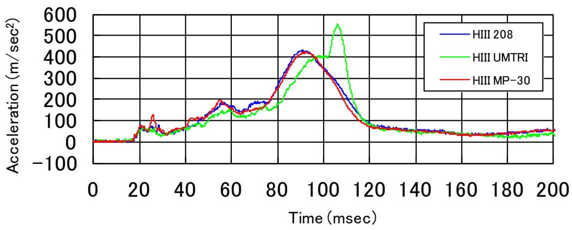


Figure 17. Head resultant acceleration of Hybrid III

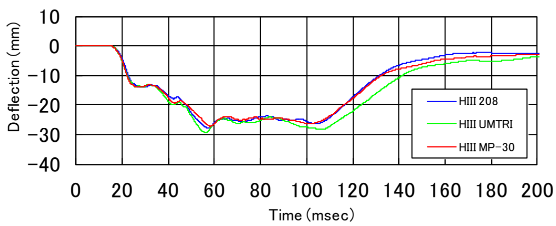


Figure 18. Chest deflection of Hybrid III

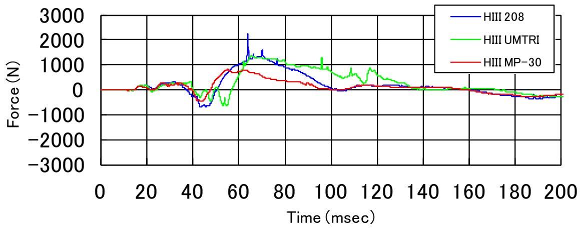


Figure 19. Right femur axial force of Hybrid III

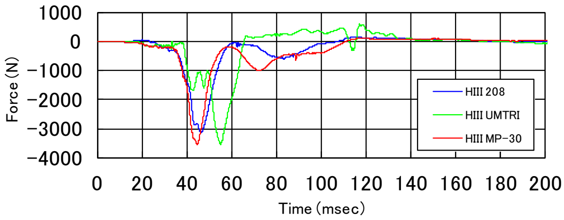


Figure 20. Right tibia axial force (lower) of Hybrid III

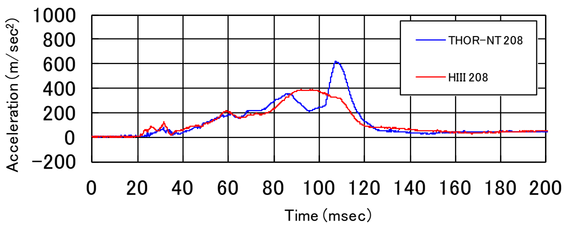


Figure 21. Head resultant acceleration of THOR-NT and Hybrid III

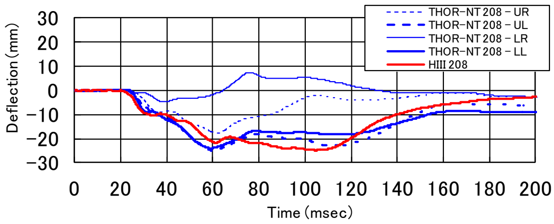


Figure 22. Chest deflection of THOR-NT and Hybrid III

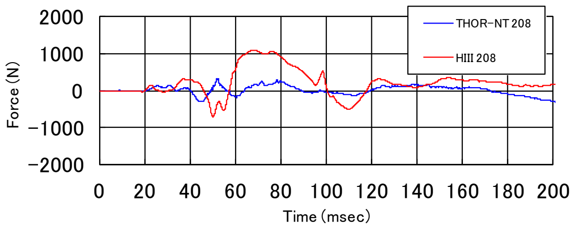


Figure 23. Right femur axial force of THOR-NT and Hybrid III

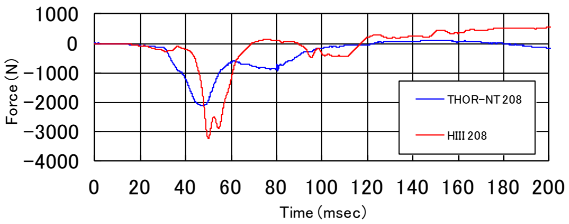


Figure 24. Right tibia axial force (lower) of THOR-NT and Hybrid III

Dummy Injury Values

Table 2 shows the injury values of THOR-NT in three seating positions. It also shows provisional injury assessment reference values (IARVs) for THOR used in the research of the NHTSA [7].

Applying the dummy injury values to IARVs for THOR, kinematic rotational brain injury criterion (BRIC) of MP-30 was lower than FMVSS 208 and UMTRI. For the acetabulum force, it was large, in the order of the UMTRI, FMVSS 208, and MP-30. For inversion/eversion of the right ankle of the accelerator pedal side, it showed large angles, in the order of the FMVSS 208, MP-30, and UMTRI. Other injury values of the ankles showed large angles, in the order of the UMTRI, FMVSS 208, and MP-30.

Table 2. Injury values of THOR-NT in three seating positions

		IARV	THOR-NT 208-01	THOR-NT 208-02	THOR UMTRI-01	THOR UMTRI-02	THOR-NT MP-30
Head	BRIC	1	0.55	0.52	0.55	0.49	0.44
	HIC 15ms	700	317.2	200.3	270.7	147.5	87.1
	3ms clip G	80	68.9	59.6	64.0	42.2	32.8
Upper Neck	Tension Force (N)	2520	867.4	892.3	864.4	874.7	1154.9
	Compression Force (N)	3600	281.4	274.2	173.7	219.5	260.0
	Flexion at OC (Nm)	48	5.0	6.5	9.5	14.4	1.9
	Extension at OC (Nm)	72	7.5	7.3	6.8	6.1	8.4
Chest	Deflection(Upper Right) (mm)	N/A	15.7	17.7	20.7	18.9	21.9
	Deflection(Upper Left) (mm)		25.6	24.8	21.0	18.8	24.8
	Deflection(Lower Right) (mm)		-8.4	-7.5	6.8	7.4	5.9
	Deflection(Lower Left) (mm)		25.6	23.9	25.4	22.7	25.5
	3ms clip G	60	34.2	32.7	28.6	29.1	31.0
Abdomen	Deflection (mm)	111	39.3	29.1	17.4	17.3	29.9
Acetabulum	Right Resultant Force (N)	3500	3118.8	2024.1	2789.5	2693.0	1712.9
	Left Resultant Force (N)		1731.5	1640.3	2173.6	2184.9	1567.6
Femur	Right Femur Force (N)	10000	330.9	294.9	1047.3	1045.5	524.3
	Left Femur Force (N)		1163.1	378.5	313.4	328.9	720.8
Tibia	Right Upper Tibia Index	1.16	0.41	0.38	0.32	0.34	0.39
	Left Upper Tibia Index		0.45	0.55	0.48	0.54	0.47
	Right Lower Tibia Index		0.33	0.34	0.34	0.35	0.31
	Left Lower Tibia Index		0.33	0.44	0.40	0.44	0.39
Ankle	Right Inversion/Eversion	35/35	33.9	32.0	14.4	8.4	26.1
	Right Dorsiflexion/Plantarflexion		21.8	23.0	23.4	27.3	14.5
	Left Inversion/Eversion		31.9	28.4	34.3	34.0	27.5
	Left Dorsiflexion/Plantarflexion		25.2	29.3	29.5	31.6	23.1

DISCUSSION

Difference in Dynamic Responses of THOR-NT

With regard to some differences of injury values among the three seating positions, the cause of the difference is considered.

Head Acceleration Response

As shown in Figure 11, the head accelerations in FMVSS 208 and UMTRI exhibited sharp high wave of about 110 ms, but that of the MP-30 did not exhibit such wave. With the high speed video analysis, the incline of the dummy upper body during impact in MP-30 was smaller than in FMVSS 208 (Figure 25). Thus, it was presumed that the contact force between head and airbag in MP-30 became lower than others, and the head acceleration was lower. As a result, it was presumed that BRIC in MP-30 was also lower than others (Table 2).

KTH and Lower Extremity Responses

As shown in Figures 13 to 15, the acetabulum, femur and tibia forces in UMTRI seating position differed from others. The cause of the difference is considered the following: The initial gap between the floor and lower extremity was wider as the H-point of the dummy was more in the rear position, and the peak values increased. In addition, the load path to the knee-thigh-hip and lower extremity differed with the difference in the angle of the knee during the load against the tibia from the accelerator pedal (Figure 26).

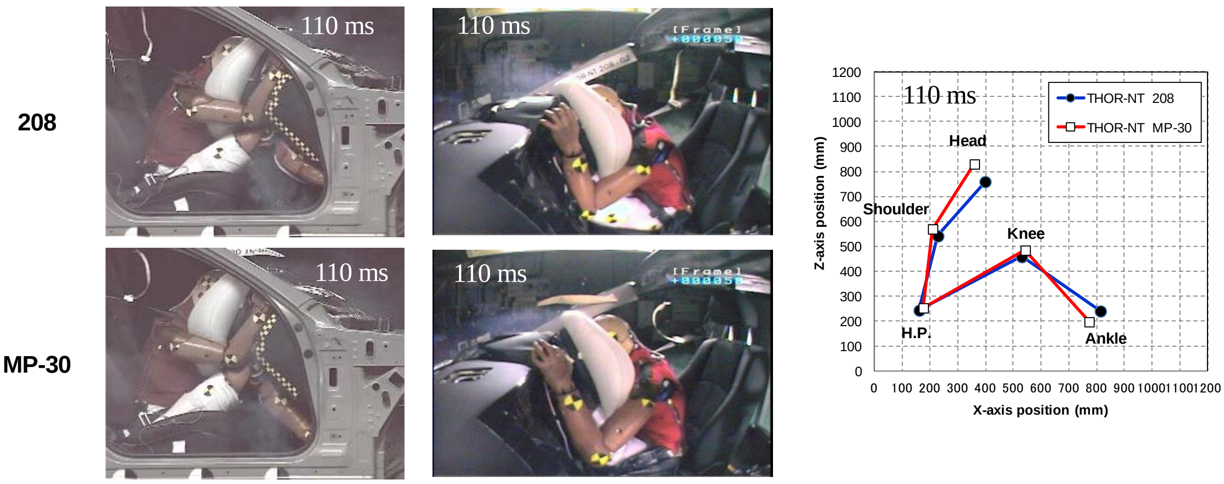


Figure 25. Behavior of upper body of THOR-NT

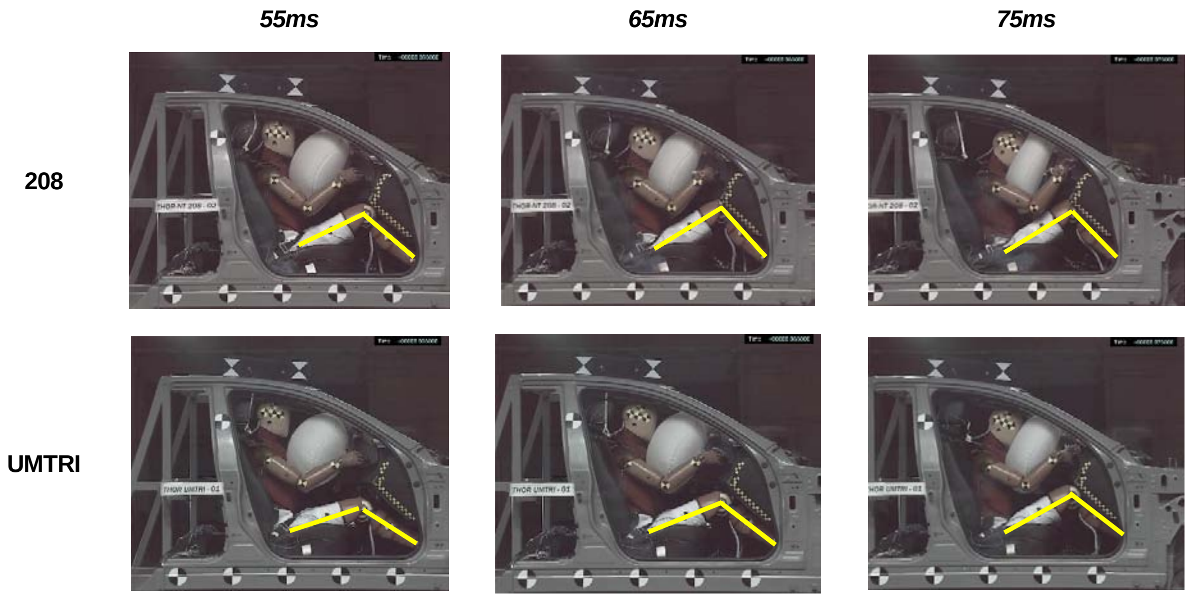


Figure 26. Behavior of KTH and lower extremity of THOR-NT

CONCLUSION

The difference in the responses to the different seating positions was mainly observed in the head acceleration and lower extremity force responses for both the THOR-NT and the Hybrid III. However, comparing responses of the THOR-NT and the Hybrid III with the same conditions, the upper body of the THOR-NT moved forward more, compared to the Hybrid III, and the torsion about the z-axis was also larger than the Hybrid III. As a result, the head acceleration of the THOR-NT and the Hybrid III exhibited different responses.

Development of the THOR seating procedure is in progress under SAE THOR Task Force, etc. Considering such differences in dummy responses as observation in this study, it is necessary that the THOR seating procedure is determined.

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APPENDIX

Table A1. Comparison of the instrumentations of the THOR-NT and the Hybrid-III

	THOR-NT	Hybrid III(Typical Configuration)
Head	9 Uniaxial Accelerometers	**Yes** (1 Triaxial Accelerometer at Head C.G.)
	1 Biaxial Tilt Sensor	No
Face	Five Uniaxial Load Cells	No
Neck	Upper Neck Load Cell (6 channels)	**Yes**
	Lower Neck Load Cell (6 channels)	**Yes**
	Front Neck Cable Load Cell	No
	Rear Neck Cable Load Cell	No
	Head Rotation Potentiometer	No
Thorax	CRUX Deflection Units - 3 Dimensional Displacement at each of Four Locations (UL, UR, LL, LR)- 4 CRUX units @ 3 channels each;	**Yes** (One-directional Displacement String Potentiometer)
	1 Triaxial Accelerometer at the C.G.	**Yes**
Mid Sternum	1 Uniaxial Accelerometer	No
Upper Abdomen	Uni-directional Displacement String Potentiometer	No
	Uniaxial Accelerometer	No
Lower Abdomen	DGSP Deflection Units - 3 Dimensional Displacement at L & R Locations (2 DGSP units @ 3 channels each)	No
Spine	1 Triaxial Accelerometer at T1 location	No
	1 Triaxial Accelerometer at T12 location	No
	T12 Load Cell (5 channels)	**Yes**
	4 Biaxial Tilt Sensors	No
Pelvis	Acetabulum Load Cell (left and right, 3 channels each)	No
	Iliac Crest Load Cells (left and right, 1 channel each)	No
	1 Triaxial Accelerometer at Pelvis C.G.	**Yes**
Femur	Femur Load Cell (left and right, 6 channels each)	**Yes**
Knee	Knee Shear Displacement, L&R	**Yes**
Lower Extremity	Upper Tibia Load Cell (left and right, 4 channels each)	**Yes**
	Lower Tibia Load Cell (left and right, 5 channels each)	**Yes**
	Tibia Acceleration (left and right, 2channels each)	No
	Achilles Tendon Load Cell (left and right, 1 channels each)	No
	Ankle Joint Rotation Potentiometers (left and right, 3channels each)	No
	Foot Acceleration (left and right, 3 channels each)	No