SHORT COMMUNICATION: STAPP CAR CRASH CONFERENCE

Comparison of Hybrid III, THOR, and PMHS Forward Excursions in the Rear Seat during Frontal Sled Tests

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ABSTRACT – The purpose of this study was to compare the forward excursions of the Hybrid III and THOR 50th-percentile male ATDs to PMHS in the rear seat when advanced or conventional restraints are equipped. A total of 16 frontal sled tests were performed with either PMHS or ATDs seated in the rear seat of four production vehicle bucks: two with advanced restraints and two with conventional restraints. Peak forward excursions of the head, shoulders, hips, and knees were quantified for all surrogates. All surrogates followed the same trends across vehicles. The vehicles with advanced restraints resulted in the lowest excursions for the lower body. The vehicles with conventional restraints produced the greatest forward excursions for the lower body. Comparing between surrogates, the Hybrid III forward excursions better matched the PMHS response for the upper body, while the THOR better matched the PMHS response for the lower body.

INTRODUCTION

Recent studies have reported that the safety of adult occupants in the rear seat is lagging behind that of the front seat for newer vehicles (Jermakian et al., 2019; Tatem & Gabler, 2019). Incorporation of advanced restraints, such as pretensioners and load limiters, into the front seat is a likely contributor to this discrepancy. Previous studies evaluating the effects of advanced restraints on occupant response in postmortem human surrogates (PMHS) and anthropomorphic test devices (ATDs) have shown different effects on the kinematics of these surrogates (Forman et al., 2008; Forman et al., 2009). For the PMHS tests, it was reported that head and shoulder excursions were greater when advanced restraints were equipped, but advanced restraints had minimal effects on lower extremity excursions. For the ATD tests, pelvis forward excursions were greater when conventional restraints were used. At the head, they reported no appreciable difference in forward excursion between restraint types except for the THOR-NT, which experienced greater head excursions for the advanced restraints. How well the ATD excursions matched the PMHS results was not evaluated.

It is important to evaluate whether ATDs have biofidelic kinematics in the rear seat since contact with the front seat and other forward structures can greatly influence injury outcomes. The use of advanced restraints can affect surrogate kinematics, altering injury risk. Therefore, the purpose of this study was to compare the forward excursions of the Hybrid III and THOR 50th-percentile male ATDs to PMHS in the rear seat when advanced or conventional restraints are equipped. The effect of advanced restraints on forward excursions was also evaluated.

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METHODS

Twelve frontal sled tests were conducted using 12 approximately 50th-percentile male PMHS, and four matched sled tests were conducted using the Hybrid III and THOR 50th-percentile male ATDs. All tests were conducted in the rear seat of four production vehicle bucks (Table 1) as part of a larger study focused on investigating rear seat occupant safety (Bianco et al., 2022; Guettler et al., 2023). The bucks consisted of two compact sport utility vehicles (CUVs) and two sedans. Two of the vehicles were equipped with conventional 3-point seatbelts with a retractor. The other two vehicles were equipped with advanced restraints, i.e., 3-point seatbelts with a retractor, pretensioner, and load limiter. Three PMHS tests were conducted per vehicle with the PMHS seated in the left second-row seat. One ATD test was conducted per vehicle with the THOR seated in the left second-row seat and the Hybrid III seated in the right second row seat. The sled tests were conducted using the NCAP acceleration pulse for each vehicle scaled by 85% to generate a consistent ΔV of 56 kph across all vehicles.

Surrogate motion data were collected at 1000-fps using a Vicon motion capture system (Vicon Motion Systems, Oxford, UK). The surrogates were instrumented with retroreflective markers at key anatomical landmarks including the head center of gravity, outboard shoulder, outboard hip, and outboard knee. The trajectories of each of these markers were converted to the reference frame of the sled and to the SAE J211 sign convention. Then, the trajectories were converted into excursions by subtracting the initial location of each marker at the beginning of the test from the marker's location throughout the duration of the test. The peak forward (X) excursions were calculated for each location of interest, and compared between restraint types and surrogates. Sight lines were lost before peak excursion for some body regions during some tests. The locations of these markers were reconstructed using rigid body dynamics using other markers on the same body segment as the location of interest. In some cases, sightlines to the auxiliary markers were also insufficient to reconstruct the marker of interest. These instances represent a minimum estimate of peak forward excursion.

Table 1. Vehicle and PMHS characteristics.

ID	Vehicle Type	Restraint Type	Avg. Age (years)	Avg. Mass (kg)
V13	CUV	Conventional	75.7	76.3
V14	CUV	Advanced	67.0	78.7
V15	Sedan	Conventional	55.0	78.0
V19	Sedan	Advanced	59.0	75.3

RESULTS

Peak forward excursions for all tests and body regions are presented in Table 2.

Table 2. Peak forward excursions (cm) for all vehicles and surrogates at the head, shoulder, hip, and knee.

ID	Test	Sur.	Head	Sho.	Hip	Knee
V13	2	HIII	47.5	29.8	28.9	29.8
	2†	THOR	57.1	47.0*	55.2	47.3
	4†	PMHS	43.9	23.4	42.1	39.4
	5†	PMHS	41.0	38.4	49.1	47.6
	6†	PMHS	43.5	42.5	53.1	54.9
V14	4	HIII	43.3	22.7	16.8	18.2
	4	THOR	51.3	42.6	25.2	28.4
	5‡	PMHS	38.7	25.3	25.0	31.7
	6†	PMHS	32.8	21.0	32.0	35.5
	7†	PMHS	38.0	24.8	37.2	37.2
V15	4	HIII	49.4	31.1	23.5	29.1
	4†	THOR	58.9	51.3*	46.3*	42.2
	5‡	PMHS	44.3*	32.5	37.2	37.0
	6	PMHS	45.0	32.6	38.2	39.9
	7‡	PMHS	45.6	31.2	35.4	38.4
V19	4	HIII	60.4	40.7	17.3	18.8
	4†	THOR	68.9*	60.9	30.4*	34.8
	5‡	PMHS	56.5	44.0	26.9	31.1
	6	PMHS	45.8	33.8*	34.2	37.7
	7	PMHS	49.7	40.6	30.5	33.4

†Indicates a test where the surrogate submarined.
‡Indicates a test where pelvis fracture occurred.
*Indicates a test where sightlines were lost before peak excursion.

Comparisons between Restraints and Vehicles

ATDs. Similar trends were observed for both the Hybrid III and THOR when analyzing peak excursions between vehicles and restraint conditions. Trends between vehicles were more apparent than trends between restraint conditions. Both ATDs exhibited the greatest peak forward excursions at the head and shoulder in V19. V13 resulted in the greatest peak forward excursions for the hip and knee. V14 resulted in the lowest peak excursions across all body regions for both ATDs.

PMHS. The PMHS peak forward excursions, on average, followed similar trends between vehicles as the ATDs. For the PMHS, V19 resulted in the greatest head and shoulder excursions, while V13 resulted in the greatest hip and knee excursions. V14 had the lowest head and shoulder excursions. V19 and V14 had similar lower extremity excursions, which were lower than all other vehicles.

Comparisons between Surrogates

As noted above, the ATDs followed the same trends as the PMHS when comparing excursions between vehicles. However, the magnitude of the excursions differed between the ATDs and PMHS for some body regions. For the upper body, the THOR moved farther forward than the other two surrogates, while the Hybrid III head and shoulder forward excursions were either greater than or within the range of PMHS responses. At the head in particular, both ATDs followed the PMHS response. However, the THOR continued moving several cm forward and downward beyond the PMHS response (Figure 1).

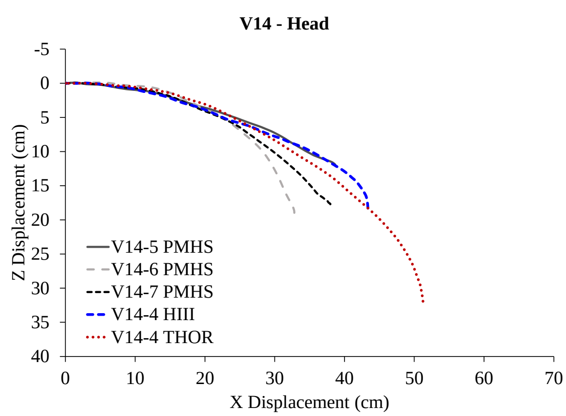

Figure 1. Exemplar head excursions for all surrogates in V14. Excursions are truncated to the time of peak forward excursion.

For the lower body, the Hybrid III tended to move forward less than the other two surrogates (Figure 2). The THOR peak forward excursions varied with respect to those of the PMHS, either being less than, greater than, or within the range of the PMHS responses. However, the magnitudes of the PMHS hip and knee forward excursions, on average, were closer to those of the THOR than the Hybrid III.

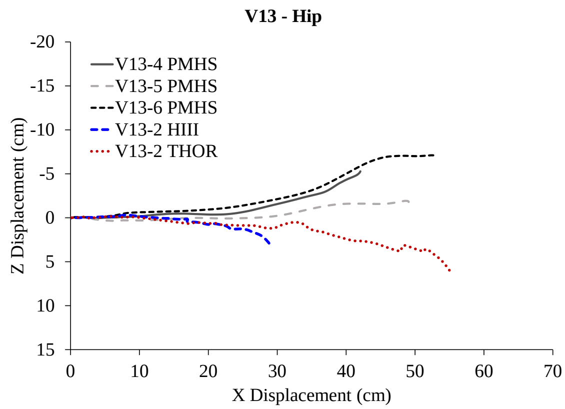

Figure 2. Exemplar hip excursions for all surrogates in V13. Excursions are truncated to the time of peak forward excursion.

DISCUSSION

Comparisons between Restraints and Vehicles

The effect of advanced restraints on peak excursion varied due to differences between vehicles. V14, which had advanced restraints, generally produced the lowest forward excursions for all body regions. However, V19, which was also equipped with advanced restraints, produced the greatest forward excursions for the head and shoulders. The difference in upper body responses observed in these two vehicles is likely a result of the differences in their load limiters. V19 was equipped with a constant force load limiter, which activated at approximately 4 kN (Bianco et al. 2022). V14, on the other hand, had a progressive load limiter that was active between 4 and 6 kN. Therefore, the lower load limit for V19 resulted in greater upper body forward excursions and less severe thoracic damage compared to all other vehicles. V13, which had conventional restraints, produced the greatest forward excursions for the pelvis and knees. Both the THOR and PMHS submarined during the V13 tests, which likely contributed to this finding. However, the Hybrid III did not experience submarining in any vehicle and still followed this trend. Hence, other vehicle characteristics are likely contributing to the greater lower extremity excursions observed in V13, as well.

Comparisons between Surrogates

The THOR peak excursions were more similar to the PMHS response for the hips and knees. This indicates the THOR had more biofidelic pelvis to lap belt engagement compared to the Hybrid III. However, it should be noted that the THOR and PMHS did not always submarine in the same vehicles. The THOR experienced submarining in V15 and V19, while the PMHS did not. Additionally, the PMHS submarined for V14-6 and V14-7, while the THOR did not submarine in V14. Despite this, THOR lower extremity excursions still matched the PMHS response better than the Hybrid III did in these vehicles.

The Hybrid III was generally closer than the THOR to the PMHS response for the head and shoulders. This is consistent with the results of a previous study in the front seat (Albert et al., 2018). For these test conditions, the THOR moved farther forward compared to the PMHS, indicating that it is too compliant. The source of this compliance could come from the spine (lumbar, thoracic, or cervical), rib cage, and/or from the shoulder protraction possible in the THOR design. Analysis of the spine and head accelerations from these tests could elucidate the sources of this compliance and will be performed in the future.

CONCLUSION

The Hybrid III, THOR, and PMHS all exhibited similar trends in forward excursions between vehicles with advanced restraints versus vehicles with conventional restraints. The vehicle with the lowest peak excursions for all body regions had advanced restraints (V14). Interestingly, the vehicle that resulted in the greatest upper body excursions also had advanced restraints (V19). The vehicle with the greatest peak forward excursions for the lower body had conventional restraints (V13). The Hybrid III forward excursions better matched the PMHS response for the upper body, while the THOR better matched the PMHS response for the lower body. Future work will evaluate the surrogate accelerations of different body regions to further explore the different ATD responses so that clearer conclusions can be made.

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