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Volunteer and Dummy Head Kinematics in Low-Speed Lateral Sled Tests

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Understanding human head kinematics prior to the safety countermeasure activation is important to help minimize potential for injury in side impact and rollover situations. The objective of this study was to compare three volunteers and the Hybrid III responses in three low-to-moderate lateral crash pulses. The parameters evaluated were lateral pulses and belt usage. A total of 24 tests were carried out in a side impact sled. The subjects consisted of two 50th percentile males (Volunteers 1 and 2), one 5th percentile female (Volunteer 3) and a Hybrid III 50th percentile male. All subjects were in near-side impacts. The pulses consisted of two 4 g pulses (6 and 8 kph) and a 4 g/8 kph followed by a −2.5 g pulse to simulate a low curb impact. In the 6 and 8 kph pulses, the antropometric test devices' head trajectory is somewhat similar to the volunteers'. For near-sided/belted occupants, the peak lateral excursion was 327 ± 53 mm for the volunteers, and 269 mm for the Hybrid III in the 6 kph pulse, while it was 321 ± 35 mm respectively in the 8 kph pulse. It was also observed that, in the first phase of the motion, the Hybrid III vertical displacement remained positive while the volunteers' vertical displacement was initially negative. This is probably due to the rigidity of the Hybrid III spine and the lack of flexibility in its torso compared to humans. In the 4 g/8 kph followed by a −2.5 g pulse, the lateral head excursion was higher with a Hybrid III than with volunteers. For near-sided/belted occupants, the lateral excursion was 155 ± 10 mm for the volunteers and 291 mm for the Hybrid III. The results suggest that the Hybrid III is a useful tool to evaluate head kinematics in slow-speed lateral impacts at 6 and 8 kph. For the 4 g/8 kph pulse followed by a −2.5 g pulse acceleration, a better correlation between the Hybrid III and volunteer head excursion may be needed to improve the biofidelity of the Hybrid III kinematics.

Keywords Hybrid III; Kinematics; Lateral Impacts; Volunteer

The development of safety countermeasure technologies to help protect occupants in side impact and rollover crashes is of significant interest to the safety community. Various countermeasures have already been developed such as the side-window airbag. To evaluate the benefits of the side-window airbag, anthropometric test devices (ATD) or dummies are generally used. ATDs were originally developed for frontal crashes, but improvements have been made to allow ATDs to be used to study side and rear-end impacts.

To evaluate countermeasures, it is important to understand the correlation between an ATD and a human. At this time, there is limited information in the slow-speed side deceleration environment. Understanding the head trajectory in low-speed side deceleration is somewhat critical in rollover where lateral motion generally precedes the roll. The head kinematics must first be evaluated to understand and improve the next generation countermeasures for out-of-position situations.

The objective of this study was to identify the head/neck response in various slow to moderate speed lateral environments and to compare the results with ATDs.

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METHOD

Test Subjects

Volunteers

Three adult volunteers participated in this study. The anthropometric data of each subject is given in Table I. All tests were carried out at Dr. Steffan Datentechnik (DSD) in Linz,

Table I Volunteer anthropometric data

	Height (cm)	Weight (kg)	Age (yr)
Volunteer 1 50th percentile male	175	72	32
Volunteer 1 50th percentile male	183	78	31
Volunteer 3 5th percentile female	158	48	25

Austria, and followed a protocol from Graz University on volunteer tests.

ATD

A Hybrid III dummy was used in this study. Though this test was a lateral impact, a Hybrid III was used instead of a BioSID since one of the goals of this study was to use the results in a rollover environment.

Test Set-Up

The set-up consisted of a rigid buck mounted laterally on a sled test for lateral deceleration.

Buck

The buck consisted of the front compartment of a small car. The steering wheel and instrument panel were removed to minimize interference with the camera views. A three-point seat belt restraint system was available for both the inboard and outboard front passenger.

Sitting Positions

The subjects were seated in a normal initial posture, on the near side. Near side is the leading side which corresponded to the driver side.

Pulse

Three pulses were simulated in this test series:

- Peak 4 g and velocity change (delta-V) of 6 kph
- Peak 4 g/8 kph followed by a −2.5 g pulse
- Peak 4 g and velocity change (delta-V) of 8 kph

The pulses are shown in Figure 1. Note that though the pulses are below injury thresholds; padding on the side structures was added as an extra precaution.

Test Matrix

A total of 24 tests were carried out: 18 with volunteers and 6 with an ATD. Table II shows the test matrix used.

Film Analysis

Targets

Targets were used for film analysis of the subject with respect to vehicle interior. Targets were placed as shown in Figure 2.

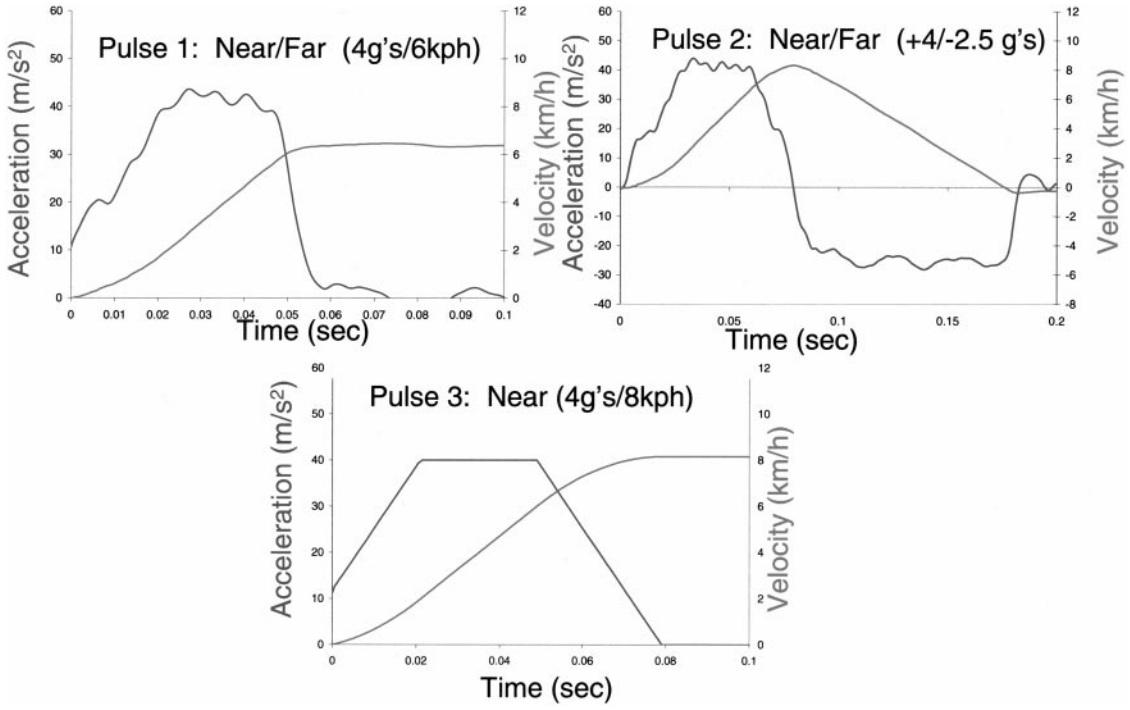

Figure 1 Acceleration and velocity characteristics as a function of time for pulse 1, 2, and 3.

Table II Test matrix

Occupant	Pulse	Belt	Test no.
Volunteer			
Volunteer 1 50th percentile	4 g/6 kph	Yes	2
	4 g/6 kph	No	1
	4 g to −2.5 g/8 kph	Yes	13
	4 g to −2.5 g/8 kph	No	12
	4 g/8 kph	Yes	9
	4 g/8 kph	No	10
Volunteer 2 50th percentile	4 g/6 kph	Yes	22
	4 g/6 kph	No	23
	4 g to −2.5 g/8 kph	Yes	18
	4 g to −2.5 g/8 kph	No	19
	4 g/8 kph	Yes	21
	4 g/8 kph	No	20
Volunteer 3 5th percentile	4 g/6 kph	Yes	32
	4 g/6 kph	No	33
	4 g to −2.5 g/8 kph	Yes	36
	4 g to −2.5 g/8 kph	No	37
	4 g/8 kph	Yes	35
	4 g/8 kph	No	34
Antropometric test device			
Dummy hybrid III 50th percentile	4 g/6 kph	Yes	43
	4 g/6 kph	No	40
	4 g to −2.5 g/8 kph	Yes	38
	4 g to −2.5 g/8 kph	No	39
	4 g/8 kph	Yes	42
	4 g/8 kph	No	41

Locations were:

- on the head band, at the upper head location;
- on the side extension of the head band, representing the side of the head (this target was used if the upper head target became covered);
- on chin of the subjects;
- on the left shoulder;
- on the right shoulder;
- on the chest.

The targets were tracked from the video using the Target Tracking software, a software developed internally by DSD. Initially, the electronic targets were manually superimposed on the targets seen on the avi files. The initial overlap between the electronic and the targets seen on the avi was then optimized by the software. For tracking, a minimum increment of 0.5 pixels was used. The maximum measurement error is thus estimated to be ± 1 mm.

Reference Boards

A checkered reference board was placed behind the front occupant seats.

Cameras

Three cameras were used:

- Camera 1 is a high-speed color camera mounted on the buck, focusing on the front view of the subject.
- Camera 2 is a high-speed color camera mounted on the buck, also focusing on the front view of the subject, but laterally offset from camera 1. This camera was used when the subjects became out of camera 1 view.
- Camera 3 is an off-board color video camera focusing on the overall view of subject in the vehicle. The view is oblique and was used to get gross occupant motion.

RESULTS

Near-Side Occupants in Pulse 1: 6 kph

Belted

Figure 3 shows the head trajectory of the two 50th percentile males (Vol. 1 and 2), the 5th percentile female (Vol. 3) and the ATD (dummy). For volunteer 1, the head traveled laterally to a

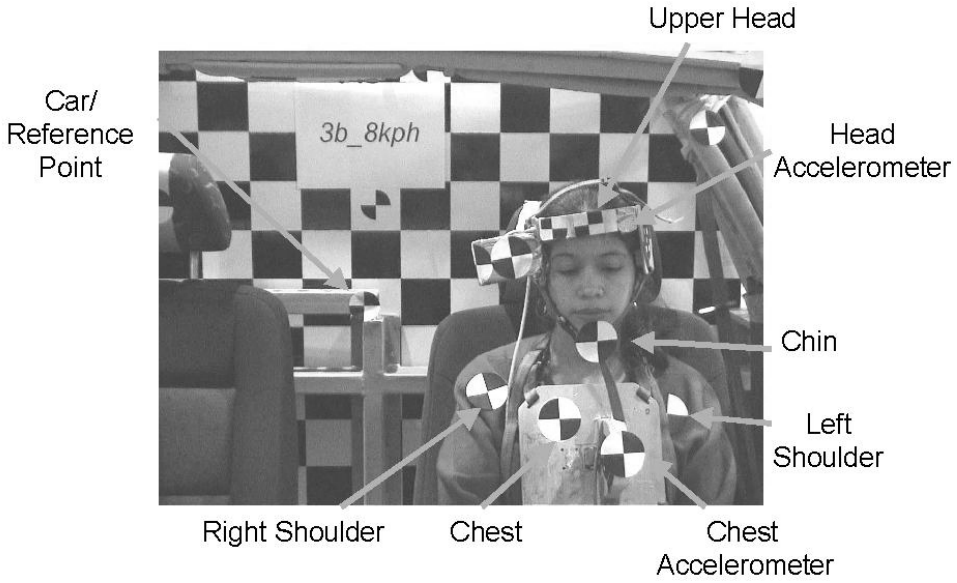

Figure 2 Target locations.

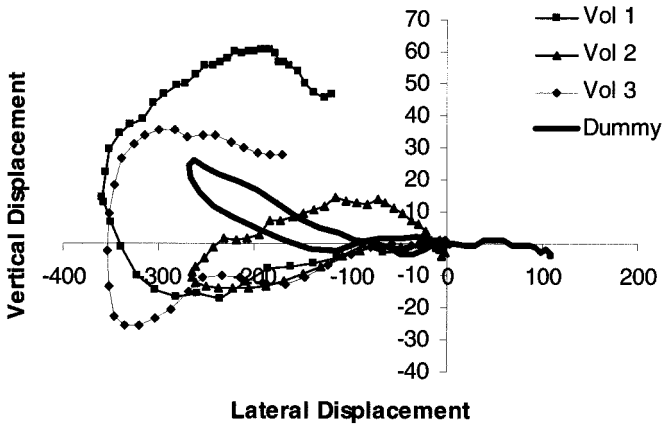

Figure 3 Near-side/belted occupant head trajectory in 6 kph pulse.

maximum of −359 mm with a 13 mm vertical displacement; for volunteer 2, the head traveled −266 mm laterally with a −11 mm vertical displacement; for volunteer 3, the peak lateral motion was −355 mm with −2 mm vertical motion; while, for the ATD, the lateral displacement of the head was at a peak of −269 mm with 24 mm vertical motion (Appendix A). Comparing the head trajectories for each subject, the vertical head displacement of the ATD remained positive, while it was initially negative in all three volunteers.

Unbelted

Figure 4 shows the head trajectory of the two 50th percentile males (Vol. 1 and 2), the 5th percentile female (Vol. 3) and the ATD when unbelted in the 6 kph pulse. The peak vertical displacement was highest for the ATD, at 104 mm. The volunteers' displacements were 88 mm for Vol. 1 and 36 mm for both Vol. 2 and Vol. 3. The peak lateral displacment was highest for the 5th percentile female (Vol. 3) at −405 mm, while it was −370 mm for Vol. 1, −266 for Vol. 2 and −384 for the ATD.

Near Occupants in Pulse 2: 4 g to −2.5 g/8 kph

Belted

Under the influence of this pulse, the lateral head trajectory was highest for the ATD than the volunteers, at −291 mm for the ATD, −157 mm for Vol. 1, −163 mm for Vol. 2 and −154 mm for Vol. 3 (Figure 5). The vertical displacement was also highest for the ATD at 51 mm, while it was 18 mm for Vol. 1, 40 mm for Vol. 2 and 26 mm for Vol. 3. It should also be noted that at peak lateral displacement, the vertical displacement was smaller for the volunteers at −10 mm for Vol. 1, −8 mm for Vol. 2, and 2 mm for Vol. 3, than for the ATD at 31 mm.

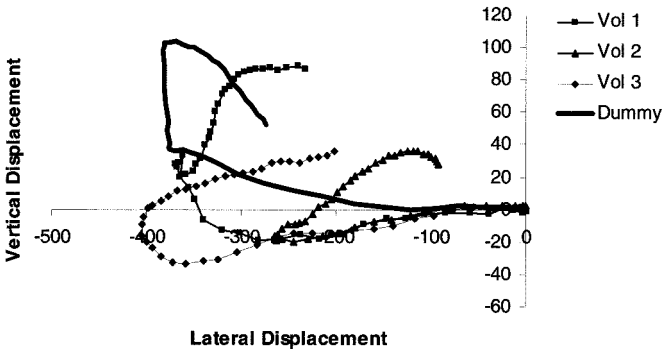

Figure 4 Near-side/unbelted occupant head trajectory in 6 kph pulse.

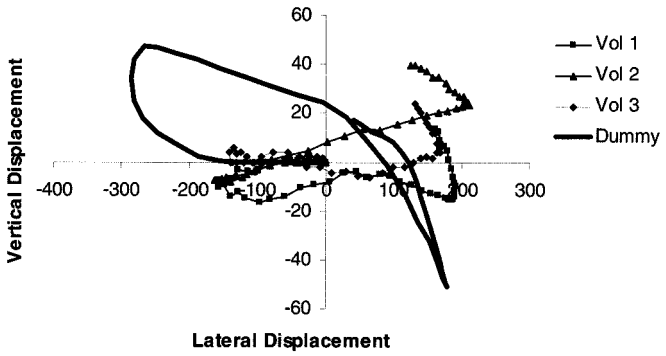

Figure 5 Near-side/belted occupant head trajectory in 4 g to −2.5 g/8 kph pulse.

Unbelted

For the unbelted occupants, the peak vertical displacement was also highest for the ATD, at 93 mm (Figure 6). The peak lateral displacement was almost two times higher for the ATD than the volunteers, at −312 mm for ATD, −160 mm for Vol. 1, −161 mm for Vol. 2, and −175 mm for Vol. 3.

Near-Sided Occupants in Pulse 3: 8 kph

Belted

In this pulse, the peak lateral displacement for the ATD and volunteers was similar, at −319 mm for Vol. 1, −287 for Vol. 2, −356 mm for Vol. 3, and −304 mm for the ATD (Figure 7). The peak vertical displacement varied from 29 mm (dummy) to 62 mm (Vol. 3).

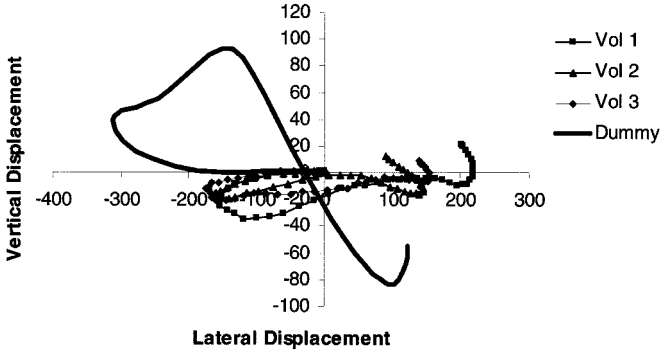

Figure 6 Near-side/unbelted occupant head trajectory in 4 g to −2.5 g/8 kph pulse.

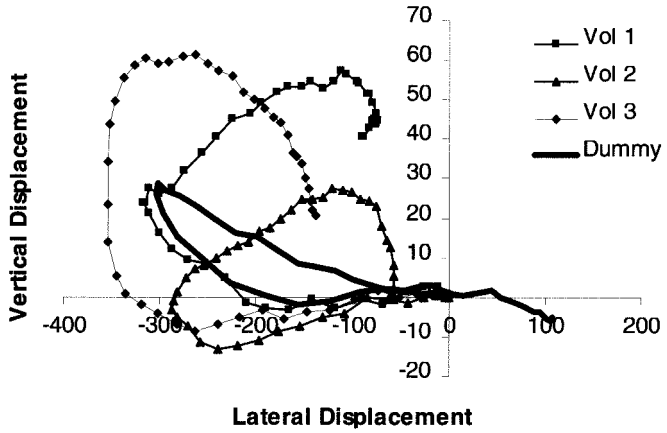

Figure 7 Near-side/belted occupant head trajectory in 8 kph pulse.

Unbelted

The head trajectory for Vol. 1 and Vol. 2 was similar (Figure 8). The lateral peak displacement of the head was similar for the dummy and Vol. 3, at −408 mm and −428 mm respectively. However, the corresponding vertical displacements were 67 mm for the dummy and −32 mm for Vol. 3.

Overall Kinematics

To compare the head kinematics between volunteers and the Hybrid III ATD, it not only is important to evaluate head trajectories but also to look at the displacement as a function of time. Tables III and IV summarize the lateral and vertical displacement as a function of time, respectively, for all test conditions tested. Time is given for a 50 ms increment. Data is not tabulated at higher than 250 ms, since occupant-vehicle contact is likely to occur beyond this time.

For the belted cases in a controlled lateral pulse, either 6 or 8 kph, the ATD seems to reach peak lateral excursion earlier than the volunteers (Appendixes B and C). As for the vertical displacement, the ATD upward motion was initially larger than the volunteers.

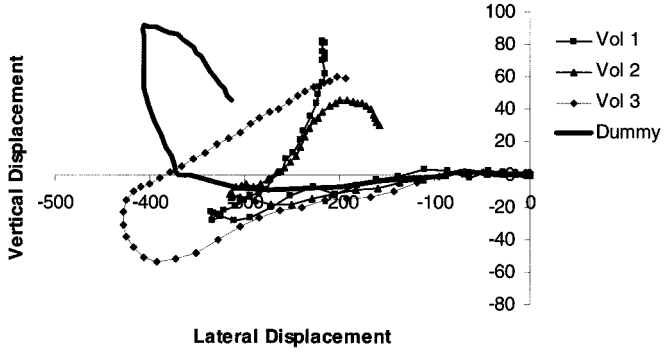

Figure 8 Near-side/unbelted occupant head trajectory in 8 kph pulse.

Table III Head lateral displacement for near-side occupants

Time (sec)	Vol. 1 (mm)	Vol. 2 (mm)	Vol. 3 (mm)	Dummy (mm)
		6 kph/belted		
0.05	−66	−48	−56	−47
0.10	−185	−149	−168	−169
0.15	−303	−237	−269	−266
0.20	−359	−261	−346	−217
0.25	−317	−208	−339	−112
		6 kph/unbelted		
0.05	−59	−42	−55	−47
0.10	−171	−141	−160	−180
0.15	−282	−230	−264	−326
0.20	−355	−265	−359	−376
0.25	−362	−238	−405	−377
		8 kph/belted		
0.05	−43	−43	−51	−46
0.10	−165	−154	−171	−189
0.15	−271	−258	−283	−304
0.20	−316	−281	−353	−242
0.25	−255	−230	−337	−136
		8 kph/unbelted		
0.05	−43	−45	−49	−45
0.10	−162	−160	−168	−199
0.15	−273	−273	−284	−346
0.20	−336	−314	−392	−372
0.25	−300	−283	−428	−396
		4/−2.5 g/belted		
0.05	−40	−40	−38	−59
0.10	−129	−131	−120	−221
0.15	−155	−159	−141	−281
0.20	−97	−80	−106	−156
0.25	8	56	−28	31
		4/−2.5 g/unbelted		
0.05	−43	−43	−45	−57
0.10	−131	−133	−143	−220
0.15	−157	−156	−171	−312
0.20	−99	−96	−144	−263
0.25	6	5	−69	−171

CONCLUSIONS

In this study, 24 tests were carried out to compare the head trajectory of various volunteers and of the Hybrid III in low-speed side impacts. For this purpose, three different pulses were chosen. The occupants were sitting on the front near side of a sled buck with and without their seat belts.

Although the ATD seems to have overall kinematics similar to the volunteers, differences have been observed. In the controlled lateral pulses (6 and 8 kph), the lateral head displacement of the belted ATD reached its maximum earlier than the volunteers (Table III, Appendixes B and C). For belted and unbelted occupants, there was a trend for higher peak head lateral displacement when the occupant was unbelted than belted (Appendix A) in the 6 and 8 kph pulses.

Based on the results of this study, the Hybrid III seems to be a conservative tool for countermeasure evaluation since its lateral excursion was in general equal or higher than the volunteers'. Furthermore, the Hybrid III tended to reach its maximum

Table IV Head vertical displacement for near-side occupants

Time (sec)	Vol. 1 (mm)	Vol. 2 (mm)	Vol. 3 (mm)	Dummy (mm)
		6 kph/belted		
0.05	−3	−1	0	2
0.10	−8	−9	−13	1
0.15	−15	−14	−15	21
0.20	15	−7	−23	20
0.25	39	1	26	3
		6 kph/unbelted		
0.05	−2	2	1	2
0.10	−9	−6	−12	4
0.15	−19	−19	−17	28
0.20	13	−17	−34	37
0.25	33	−9	−16	54
		8 kph/belted		
0.05	1	−2	0	2
0.10	−3	−7	−6	0
0.15	9	−11	−7	26
0.20	24	1	14	20
0.25	37	12	56	8
		8 kph/unbelted		
0.05	2	1	1	1
0.10	−3	−8	−14	−8
0.15	−21	−19	−27	−2
0.20	−23	−11	−54	1
0.25	−16	−6	−23	33
		4/−2.5 g/belted		
0.05	0	0	2	0
0.10	−3	−6	0	7
0.15	−9	−8	4	42
0.20	−17	1	0	38
0.25	−8	13	−2	19
		4/−2.5 g/unbelted		
0.05	0	−1	1	2
0.10	−8	−9	−5	5
0.15	−19	−19	−13	38
0.20	−34	−14	−21	52
0.25	−17	−2	−16	88

lateral displacement earlier than the volunteers. However, it should be noted that the volunteers used in this study were expecting the sled motion and thus were likely to be tense. Muscle tension probably limited their head/upper torso lateral excursion.

In a different set-up, in a roll cage fixture, Moffat et al. (1997) compared head kinematics of the Hybrid III, volunteers, and postmortem human subjects (PMHS). Though most results in that study were reported on vertical excursion, the authors observed about 80 mm more vertical excursion in the Hybrid III than the PMHS and about 120 mm in lateral excursion. The increase in lateral excursion was attributed to the bending of the neck. For the Hybrid III the lateral movement was limited by shoulder contact with the side panel which resulted in slight neck bending, while for the PMHS lateral motion was limited by significant compression of the lower left portion of the neck with the torso belt. This resulted in higher neck bending than in the Hybrid III. It should be noted, however, that the PMHS lacks muscle tension. Unfortunately, the study did not compare the lateral excursion in volunteers and Hybrid III so it is difficult to compare this study's findings with previous work.

The results provided in this study provide a good start for the development of human neck mathematical models in a low- to moderate-speed motion, and for possible ATD neck enhancements. Further work, however, should be carried out to evaluate the effect of muscle tension at various loading conditions and to compare human and ATD kinematics in all stages of a rollover event.

ACKNOWLEDGMENTS

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REFERENCES

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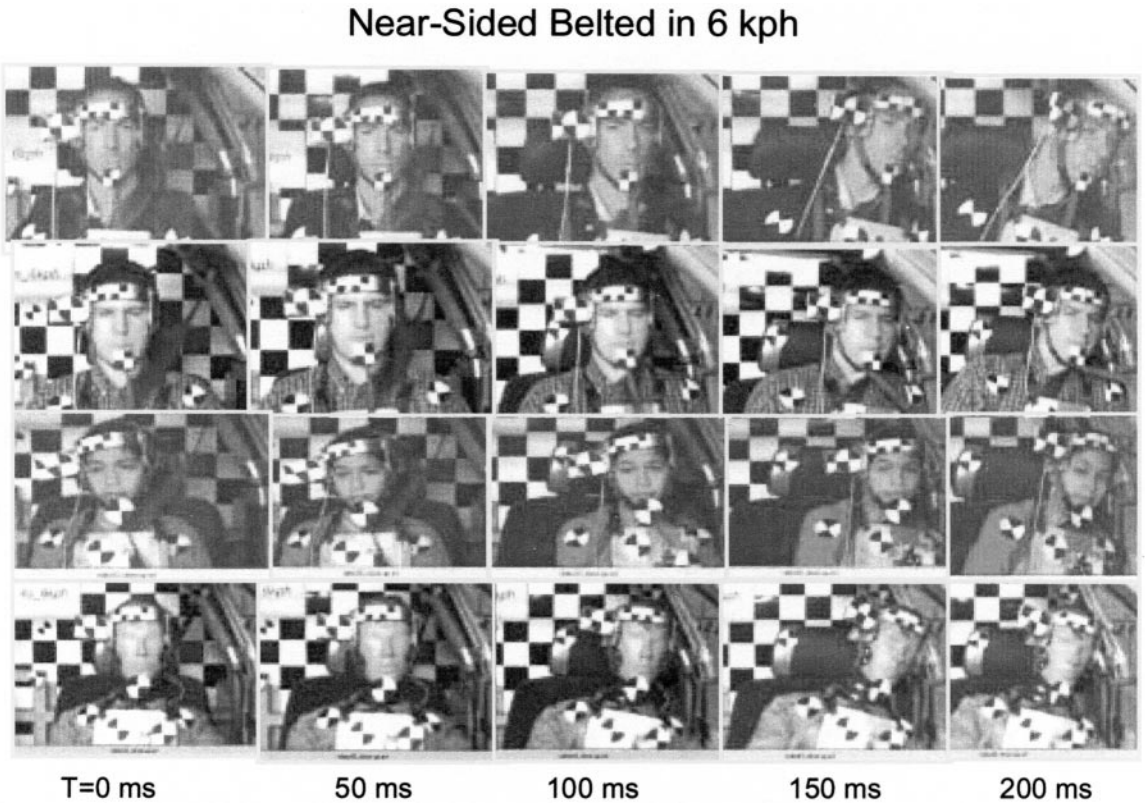
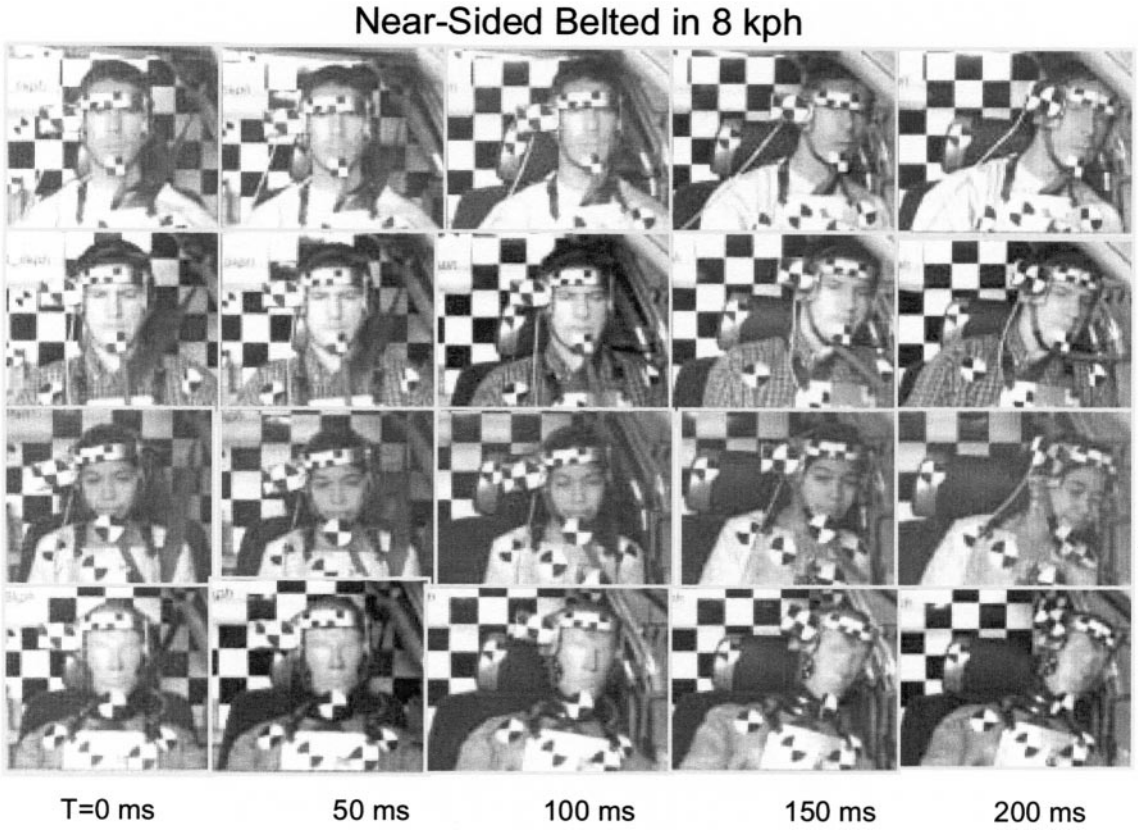
APPENDIX A: PEAK HEAD DISPLACEMENTS

Pulse	Condition	Vol. 1	Vol. 2	Vol. 3	Avg ± *SD*	ATD
			Lateral displacement (mm)			
4 g/6 kph	Near/belted	−359	−266	−355	−327 ± 53	−269
4 g/6 kph	Near/unbelted	−370	−266	−405	−347 ± 72	−384
4 g to −2.5 g/8 kph	Near/belted	−157	−163	−144	−155 ± 10	−291
4 g to −2.5 g/8 kph	Near/unbelted	−160	−161	−175	−165 ± 8	−312
4 g/8 kmph	Near/belted	−319	−287	−356	−321 ± 35	−304
4 g/8 kmph	Near/unbelted	−337	−315	−427	−360 ± 59	−407
			Vertical displacement (mm)			
4 g/6 kph	Near/belted	61/−17	14/−14	36/−27	37/−19 ± 24/−7	26/−4
4 g/6 kph	Near/unbelted	88/−21	36/−21	36/−34	53/−25 ± 30/−8	104/0
4 g to −2.5 g/8 kph	Near/belted	25/−18	40/−9	26/−6	30/−11 ± 8/−6	48/−51
4 g to −2.5 g/8 kph	Near/unbelted	72/−35	17/−20	9/−21	33/−25 ± 34/−8	93/−84
4 g/8 kmph	Near/belted	58/−3	28/−14	62/−9	49/−9 ± 19/−6	29/−6
4 g/8 kmph	Near/unbelted	84/−31	46/−19	61/−55	64/−35 ± 19/−18	92/−10

APPENDIX B: SNAPSHOTS OF BELTED OCCUPANT KINEMATICS AS A FUNCTION OF TIME IN THE 6 kph PULSE



APPENDIX C: SNAPSHOTS OF BELTED OCCUPANT KINEMATICS AS A FUNCTION OF TIME IN THE 8 kph PULSE



APPENDIX D: SNAPSHOTS OF BELTED OCCUPANT KINEMATICS AS A FUNCTION OF TIME IN THE +4/−2.5 g PULSE