APPENDIX A – Supplemental Material

Table A1. Offsets (mm) between the KB or KBAB and the proximal and distal lower extremity for each test.

Test ID	Proximal		Distal		Average
	Left	Right	Left	Right	
HIII-KB-1	84	81	55	55	69
HIII-KB-2	81	92	52	55	70
HIII-KB/SWAB-1	80	76	55	55	67
HIII-KB/SWAB-2	80	75	55	52	66
HIII-KBAB/SWAB-1	11	15	8	10	11
HIII-KBAB/SWAB-2	14	13	9	10	12
THOR-KB-1	76	70	57	53	64
THOR-KB-2	77	74	56	55	66
THOR-KB/SWAB-1	93*	87*	59	56	74*
THOR-KB/SWAB-2	77	71	54	54	64
THOR-KBAB/SWAB-1	16	15	8	13	13
THOR-KBAB/SWAB-2	12	12	10	11.5	11
PMHS-KB-1	84	82	61	58	71
PMHS-KB-2	72	73	39	40	56
PMHS-KB/SWAB-1	85	85	60	57	72
PMHS-KB/SWAB-2	73	74	55	57	65
PMHS-KB/SWAB-3	74	71	53	45	61
PMHS-KBAB/SWAB-1	12	10	10	11	11
PMHS-KBAB/SWAB-2	11	13	14	14	13
PMHS-KBAB/SWAB-3	9	9	9	9	9

*Note: The proximal offsets for THOR-KB/SWAB-1 were measured at a different location on the shank compared to the other tests.

Table A2. Average offsets (mm) between the KB or KBAB and the lower extremity for each surrogate.

Surrogate	KB	KBAB
HIII	68	11
THOR	67	12
PMHS	65	11
Average	**66**	**11**

Table A3. Sensor information for all surrogates.

Signal Type	Surrogate		
	HIII	THOR-M	PMHS
Upper Neck Load Cell	1716A, Denton Rochester Hills, MI	10380JI4, Humanetics Plymouth, MI	-
Lower Neck Load Cell	1794A, Denton Rochester Hills, MI	10381JI4, Humanetics Plymouth, MI	-
Head Accelerometers	7264B-2000, Endevco San Juan Capistrano, CA	7264C-2000, Endevco San Juan Capistrano, CA	6DX PRO, DTS Seal Beach, CA
Head Angular Rate Sensors	ARS PRO-18K, DTS Seal Beach, CA	ARS PRO-8K, DTS Seal Beach, CA	6DX PRO, DTS Seal Beach, CA

Table A4. CFCs used to filter each signal type for all surrogates.

Signal Type	Surrogate		
	HIII	THOR-M	PMHS
Upper Neck Forces	1000	1000	-
Upper Neck Moments	600	600	-
Lower Neck Forces	1000	1000	-
Lower Neck Moments	600	600	-
Head Linear Accelerations	600	600	180
Head Angular Velocities	100	100	60
Neck Spring Forces	-	180	-
OC Joint Angle	-	180	-

Table A5. Surrogate movements associated with positive signals.

Signal Type	Direction	Surrogate Movement	Polarity
Upper and Lower Neck Load Cells	Fx	Head rearward, chest forward	Positive
	Fy	Head leftward, chest rightward	Positive
	Fz	Head upward, chest downward	Positive
	Mx	Left ear toward left shoulder	Positive
	My	Chin toward sternum	Positive
	Mz	Chin toward left shoulder	Positive
Front Neck Spring Load Cell	Fz	Chin upward	Positive
Rear Neck Spring Load Cell	Fz	Chin downward	Positive
OC Joint Angle	θy	Chin upward	Positive

Table A6. N_{ij} critical values for the HIII and THOR-M.

Surrogate	$F_{Compression}$ (N)	$F_{Tension}$ (N)	$M_{Flexion}$ (Nm)	$M_{Extension}$ (Nm)
HIII	6160	6806	310	135
THOR-M	3640	2520	48	72

Table A7. cN_{ij} critical values for the THOR-M.

Surrogate	$F_{Compression}$ (N)	$F_{Tension}$ (N)	$M_{Flexion}$ (Nm)	$M_{Extension}$ (Nm)
THOR-M	4227	3216	67	94

Table A8. Initial head contact times (s) for all surrogates.

Test ID	Surrogate		
	HIII	THOR-M	PMHS
KB-1	0.078	0.078	0.078
KB-2	0.078	0.078	0.074
KB/SWAB-1	0.039	0.041	0.033
KB/SWAB-2	0.040	0.040	0.031
KB/SWAB-3	-	-	0.040
KBAB/SWAB-1	0.040	0.042	0.033
KBAB/SWAB-2	0.040	0.042	0.031
KBAB/SWAB-3	-	-	0.028

Table A9. Observed PMHS cervical spine injuries and associated AIS scores.

Test ID	Injury Description	AIS Score
PMHS-KB-1	1) Dislocation/Disc Separation: C6/C7 2) Loose Joint C5/C6	1) AIS2 2) AIS2
PMHS-KB-2	No Injuries Observed	N/A
PMHS-KB/SWAB-1	1) Dislocation/Disc Separation: C3/C4	1) AIS2
PMHS-KB/SWAB-2	1) Dislocation/Disc Separation: C6/C7	1) AIS2
PMHS-KB/SWAB-3	1) Dislocation/Disc Separation: C4/C5 2) Dislocation/Disc Separation: C6/C7 3) Anterior End Plate Fracture: C6 (cortical bone only)	1) AIS2 2) AIS2 3) AIS2
PMHS-KBAB/SWAB-1	No Injuries Observed	N/A
PMHS-KBAB/SWAB-2	1) Osteophyte Fracture: Superior Aspect of C6 (no damage to vertebral body/disc)	N/A
PMHS-KBAB/SWAB-3	1) Dislocation/Disc Separation: C6/C7 2) Anterior End Plate Fracture C6 (cortical bone only)	1) AIS2 2) AIS2

Table A10. Predicted risks of AIS3+ and AIS2+ injuries for each ATD and observed PMHS injuries.

Test ID	N_{ij}	P(AIS3+)	P(AIS2+)	PMHS Observed Injury
HIII-KB-1	1.0062	0.2234	0.2991	PMHS-KB-1: AIS2 PMHS-KB-2: None
HIII-KB-2	1.1822	0.2982	0.3450	
HIII-KB/SWAB-1	0.4748	0.0918	0.1844	PMHS-KB/SWAB-1: AIS2 PMHS-KB/SWAB-2: AIS2 PMHS-KB/SWAB-3: AIS2
HIII-KB/SWAB-2	0.4200	0.0832	0.1748	
HIII-KBAB/SWAB-3	0.5558	0.1060	0.1995	PMHS-KBAB/SWAB-1: None PMHS-KBAB/SWAB-2: None PMHS-KBAB/SWAB-3: AIS2
HIII-KBAB/SWAB-3	0.4947	0.0951	0.1880	
THOR-KB-1	0.9153	0.1939	0.2768	PMHS-KB-1: AIS2 PMHS-KB-2: None
THOR-KB-2	0.7823	0.1562	0.2462	
THOR-KB/SWAB-1	0.4549	0.0886	0.1809	PMHS-KB/SWAB-1: AIS2 PMHS-KB/SWAB-2: AIS2 PMHS-KB/SWAB-3: AIS2
THOR-KB/SWAB-2	0.4180	0.0829	0.1744	
THOR-KBAB/SWAB-1	0.4286	0.0845	0.1763	PMHS-KBAB/SWAB-1: None PMHS-KBAB/SWAB-2: None PMHS-KBAB/SWAB-3: AIS2
THOR-KBAB/SWAB-2	0.4972	0.0955	0.1885	

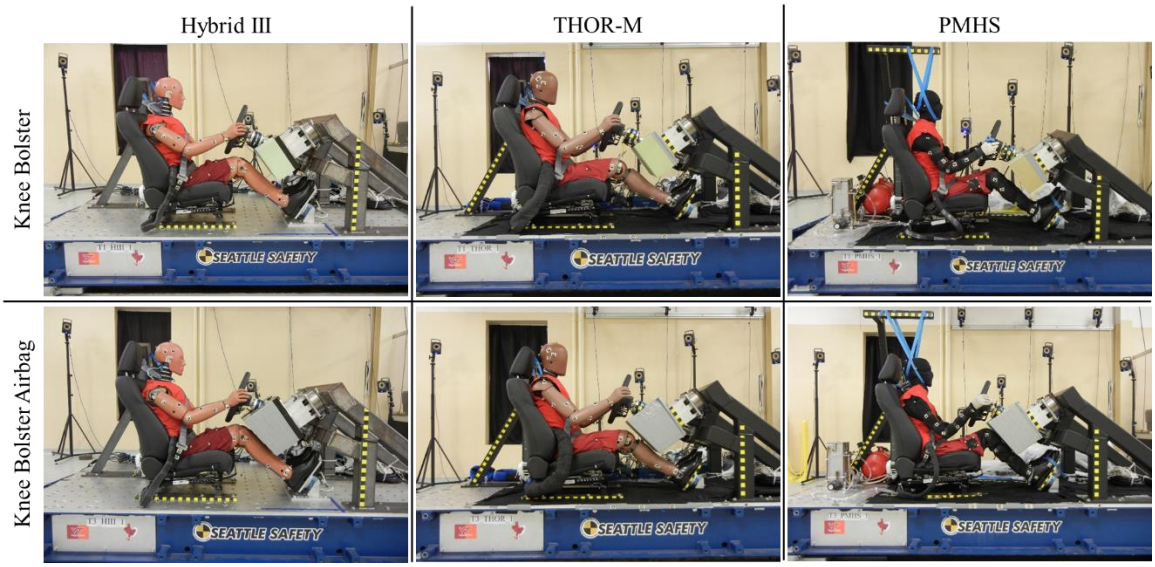

Figure A1. The sled test setup for the KB and KBAB conditions for all surrogates.
Figure originally published in Albert et al. (2018). Reprinted by permission of the publisher Taylor & Francis Ltd, http://www.tandfonline.com.

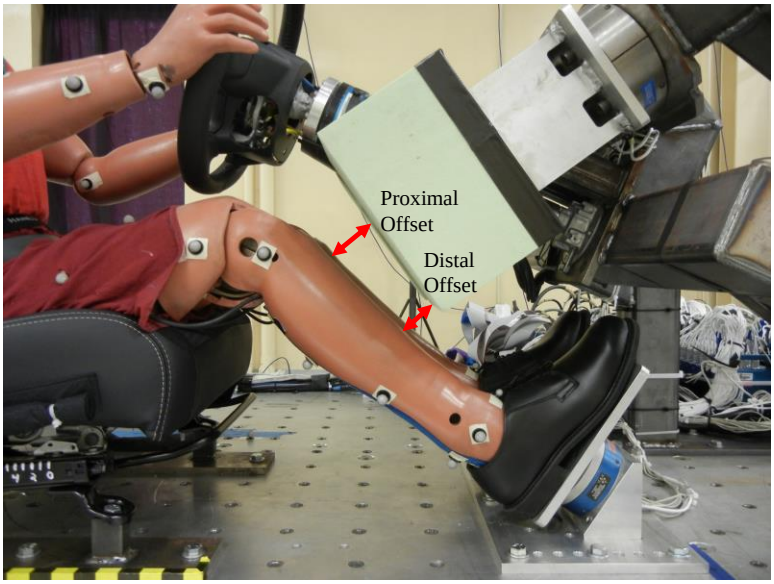

Figure A2. Picture of proximal and distal offsets for KB condition.

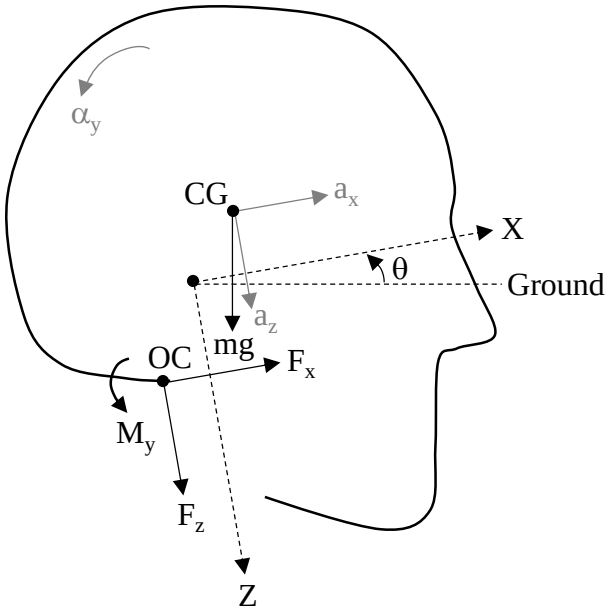

Figure A3. Force body diagram for calculation of upper neck forces and moments.

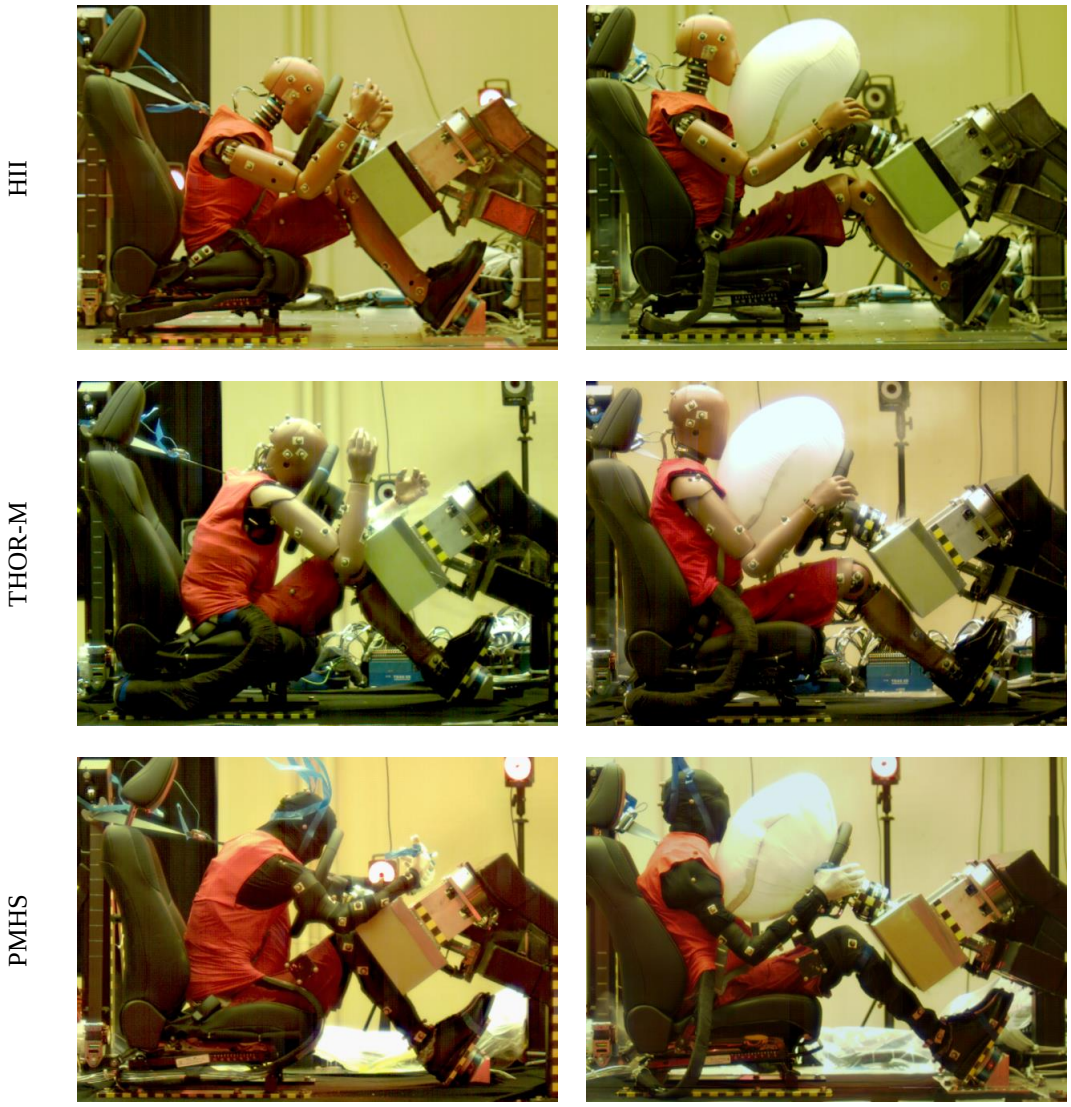

Figure A4. Exemplar initial head contact stills for each surrogate for the no SWAB (KB) and SWAB (KB/SWAB or KBAB/SWAB) conditions.

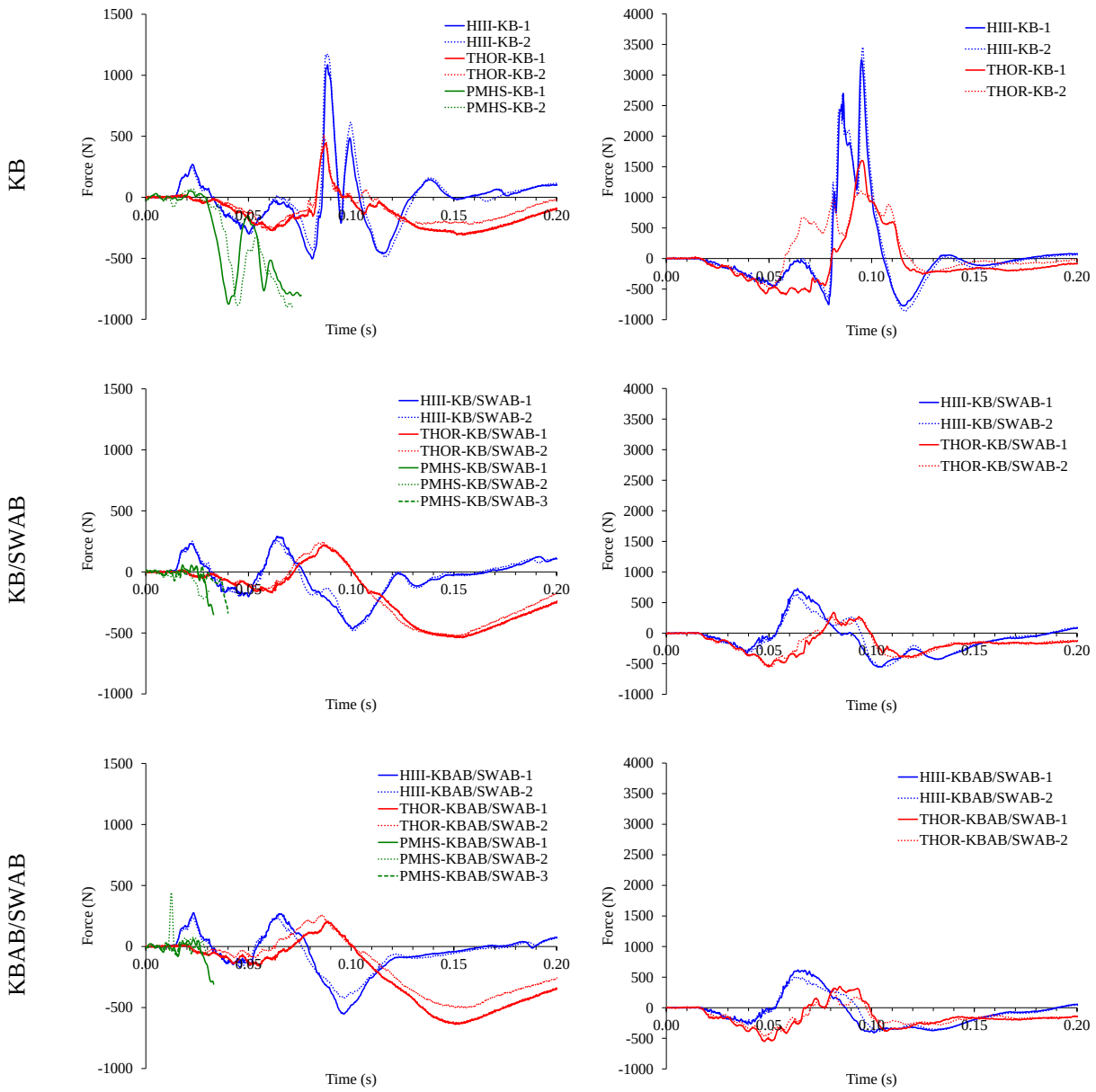

Figure A5. Upper neck (left) and lower neck (right) AP shear forces (Fx) for all conditions.
Note: Y-axis scales are different between the upper and lower neck. Rearward head motion relative to the chest is positive.

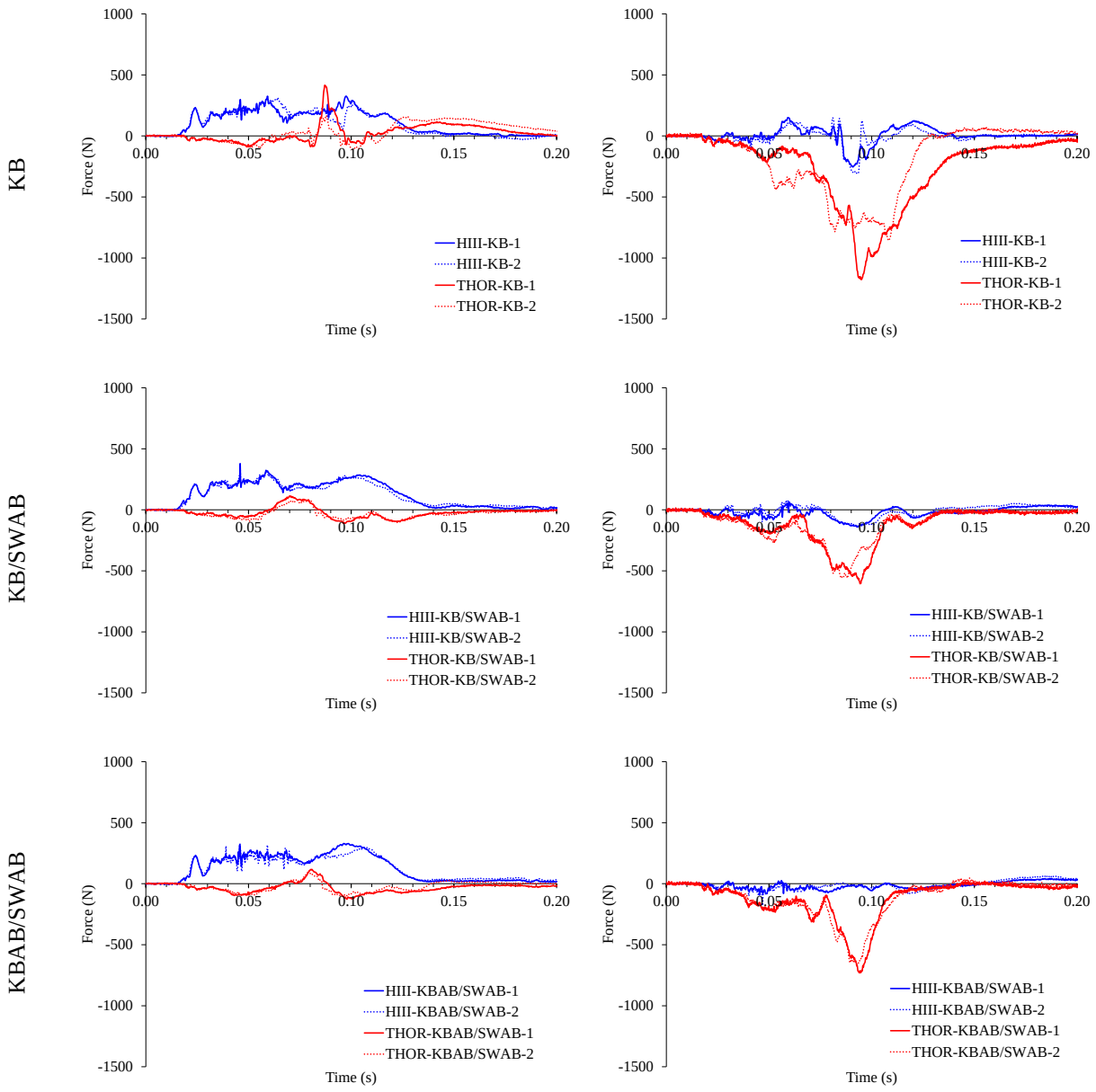

Figure A6. Upper neck (left) and lower neck (right) ML shear forces (Fy) for all conditions.
Note: Leftward head motion relative to the chest is positive.

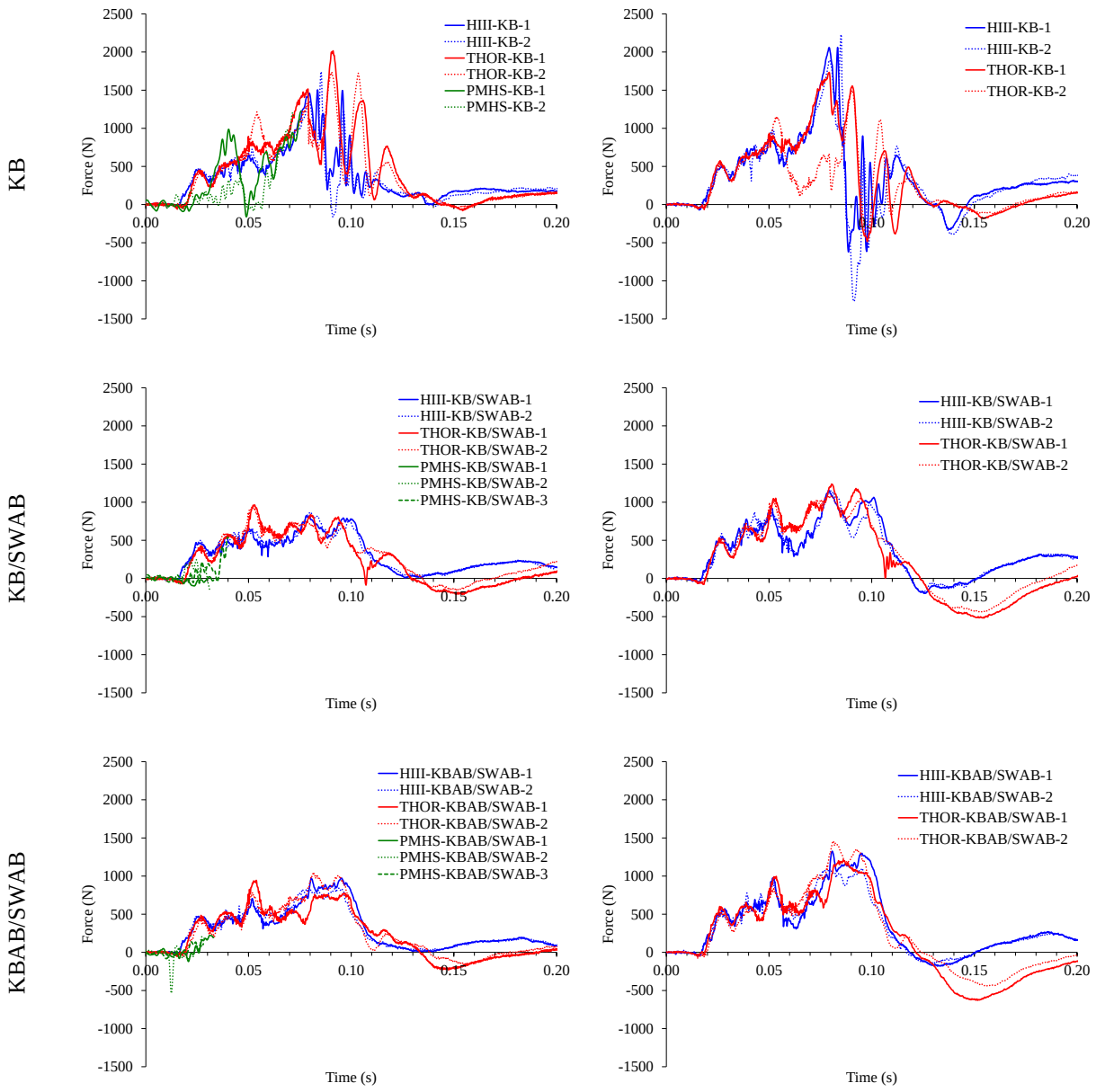

Figure A7. Upper neck (left) and lower neck (right) axial forces (Fz) for all conditions.
Note: Tension is positive.

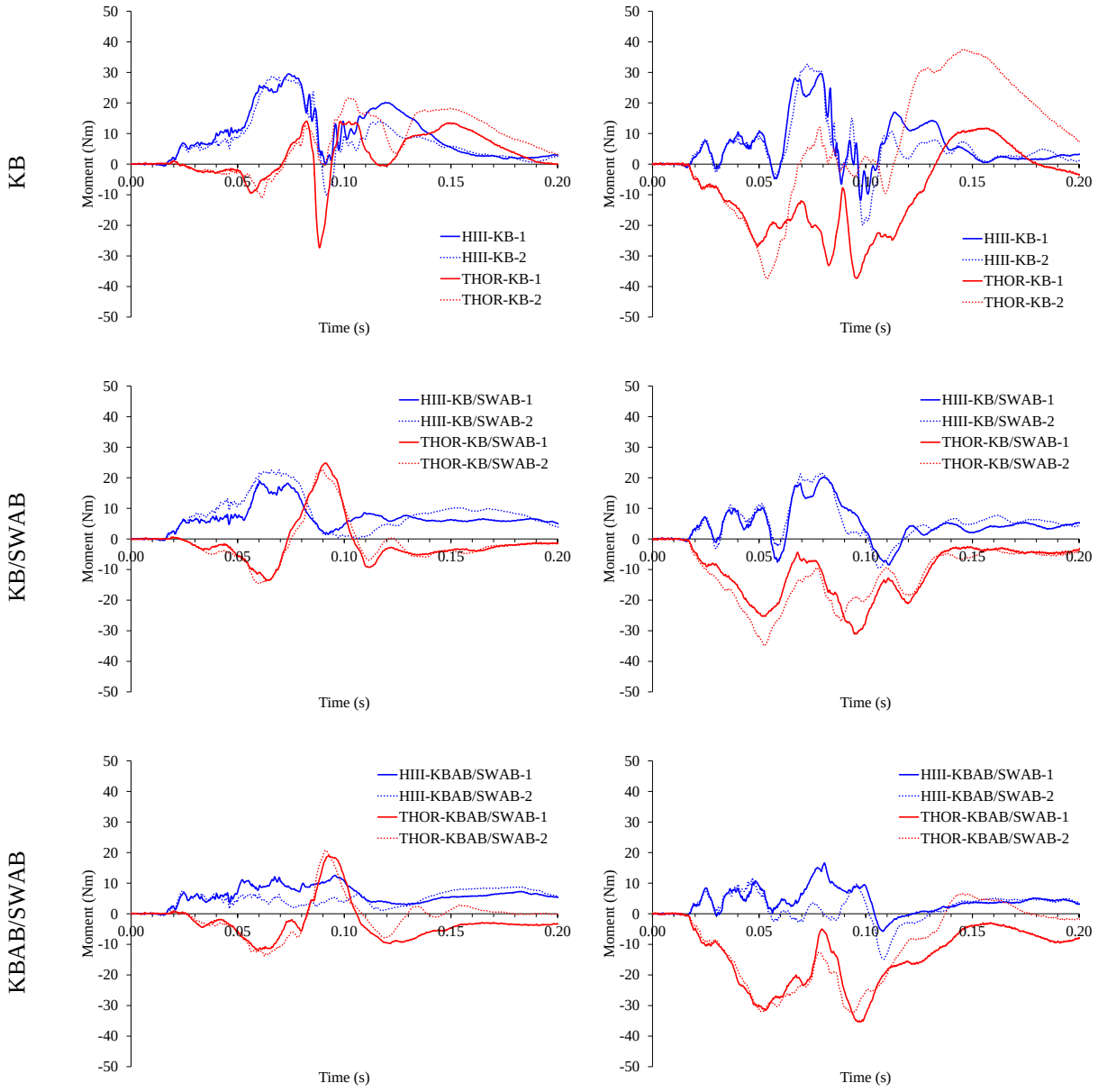

Figure A8. Upper neck (left) and lower neck (right) moments about the x-axis (Mx) for all conditions. Note: Movement of the left ear toward the left shoulder is positive.

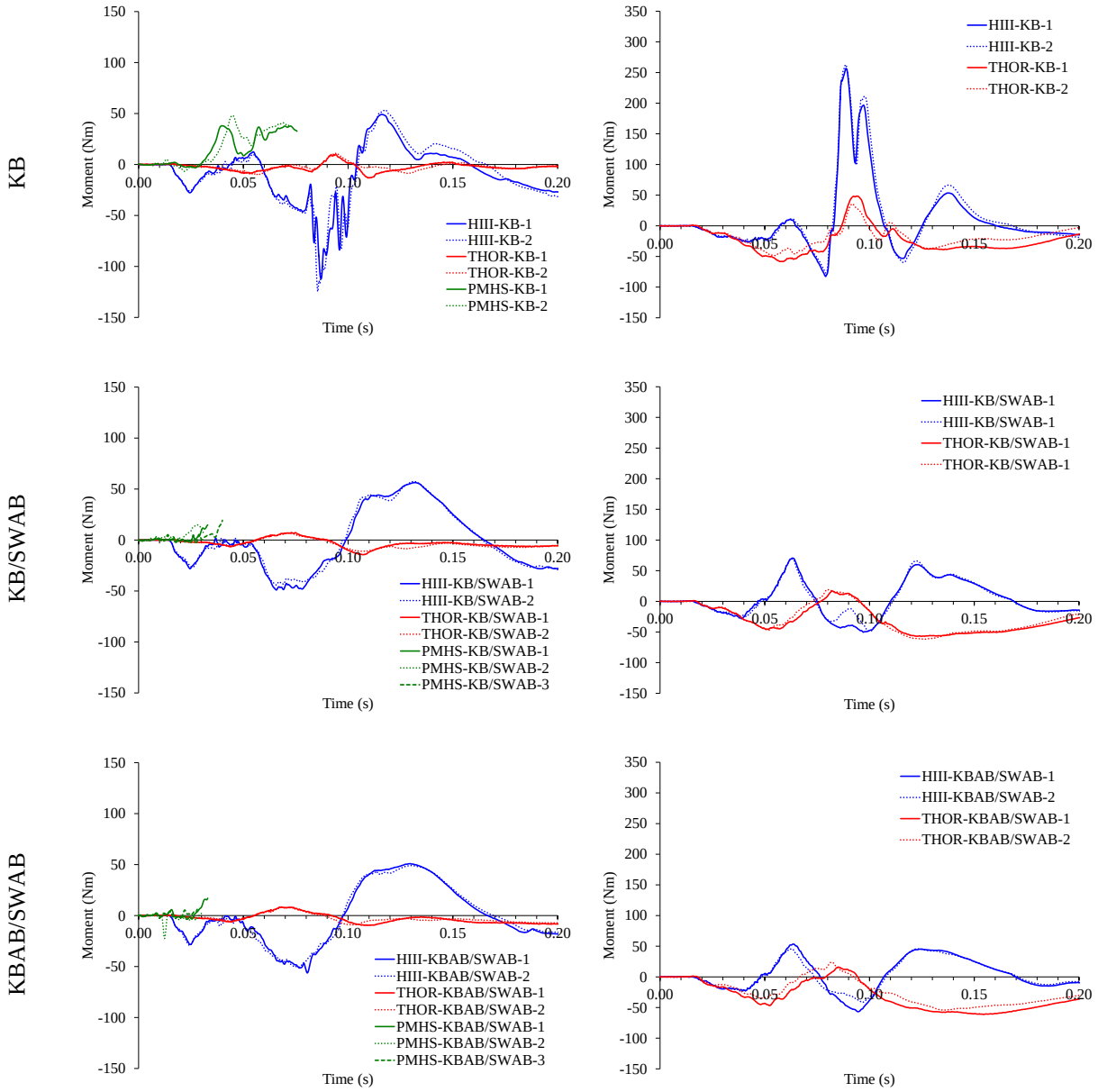

Figure A9. Upper neck (left) and lower neck (right) moments about the y-axis (My) for all conditions. Note: Y-axis scales are different between the upper and lower neck. Flexion is positive.

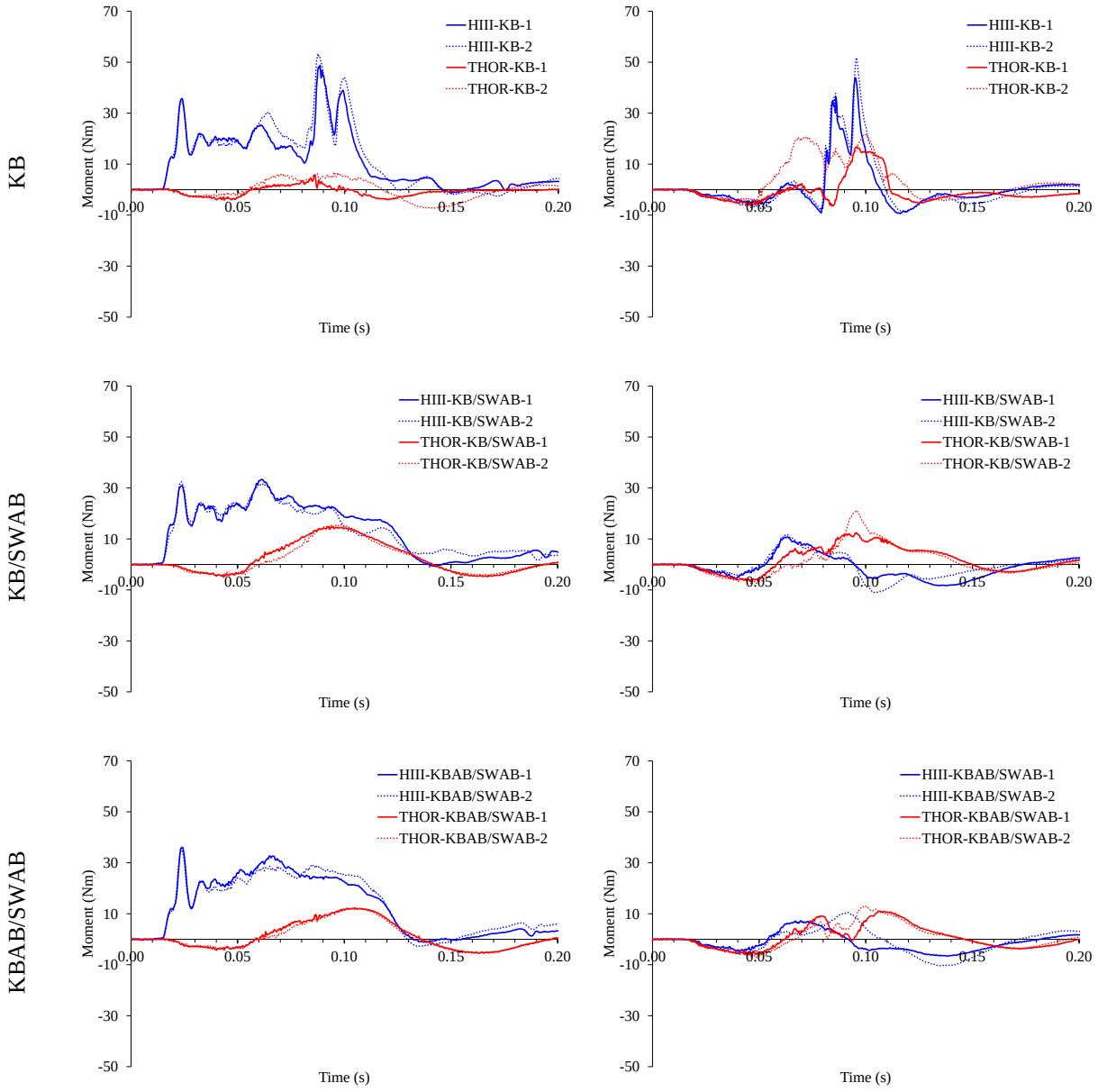

Figure A10. Upper neck (left) and lower neck (right) moments about the z-axis (Mz) for all conditions. Note: Movement of the chin toward the left shoulder is positive.

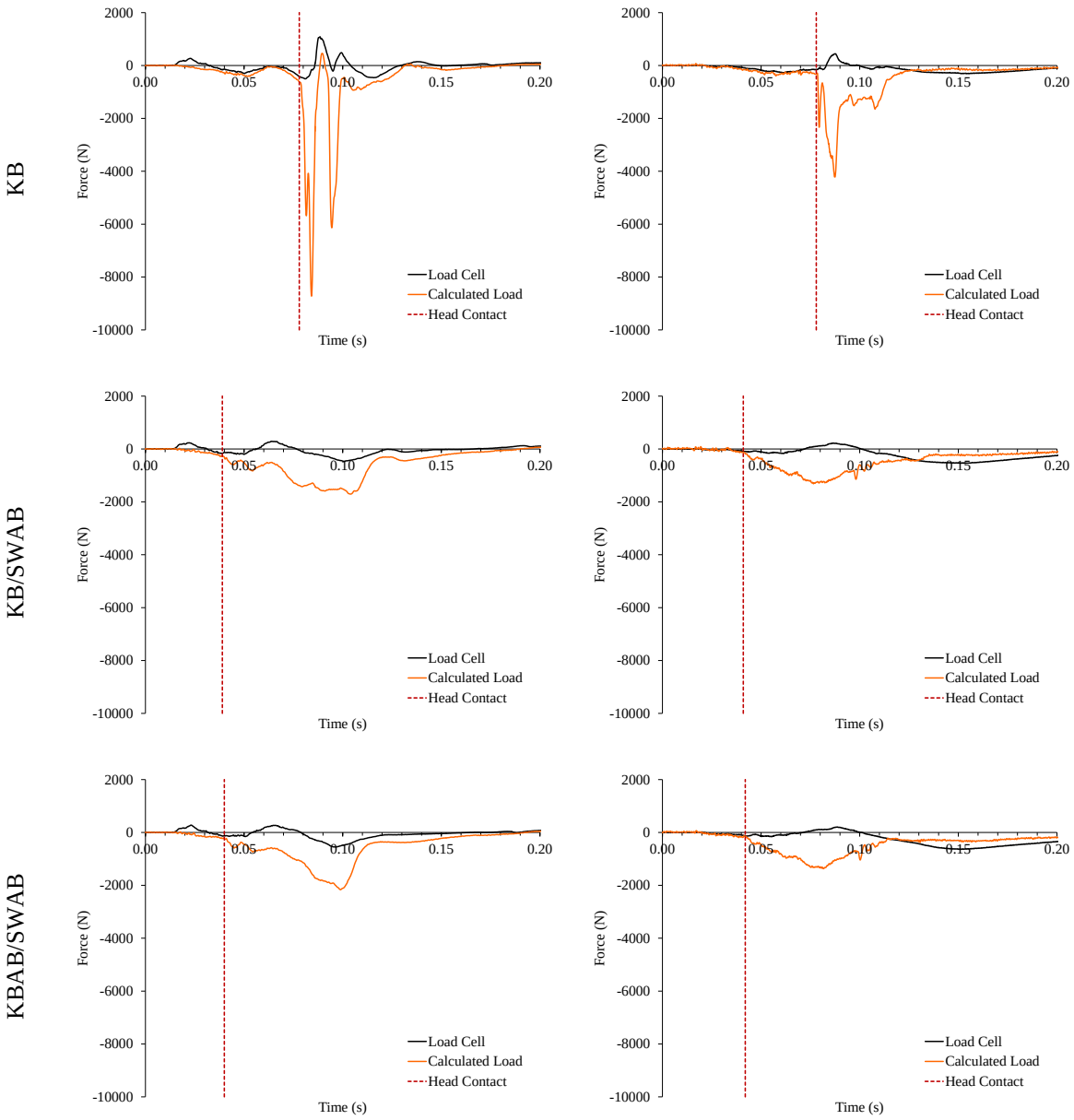

Figure A11. Exemplar HIII (left) and THOR-M (right) upper neck measured (load cell) and calculated (inverse dynamics) AP shear forces (Fx) for all conditions.
Note: Rearward head motion relative to the chest is positive.

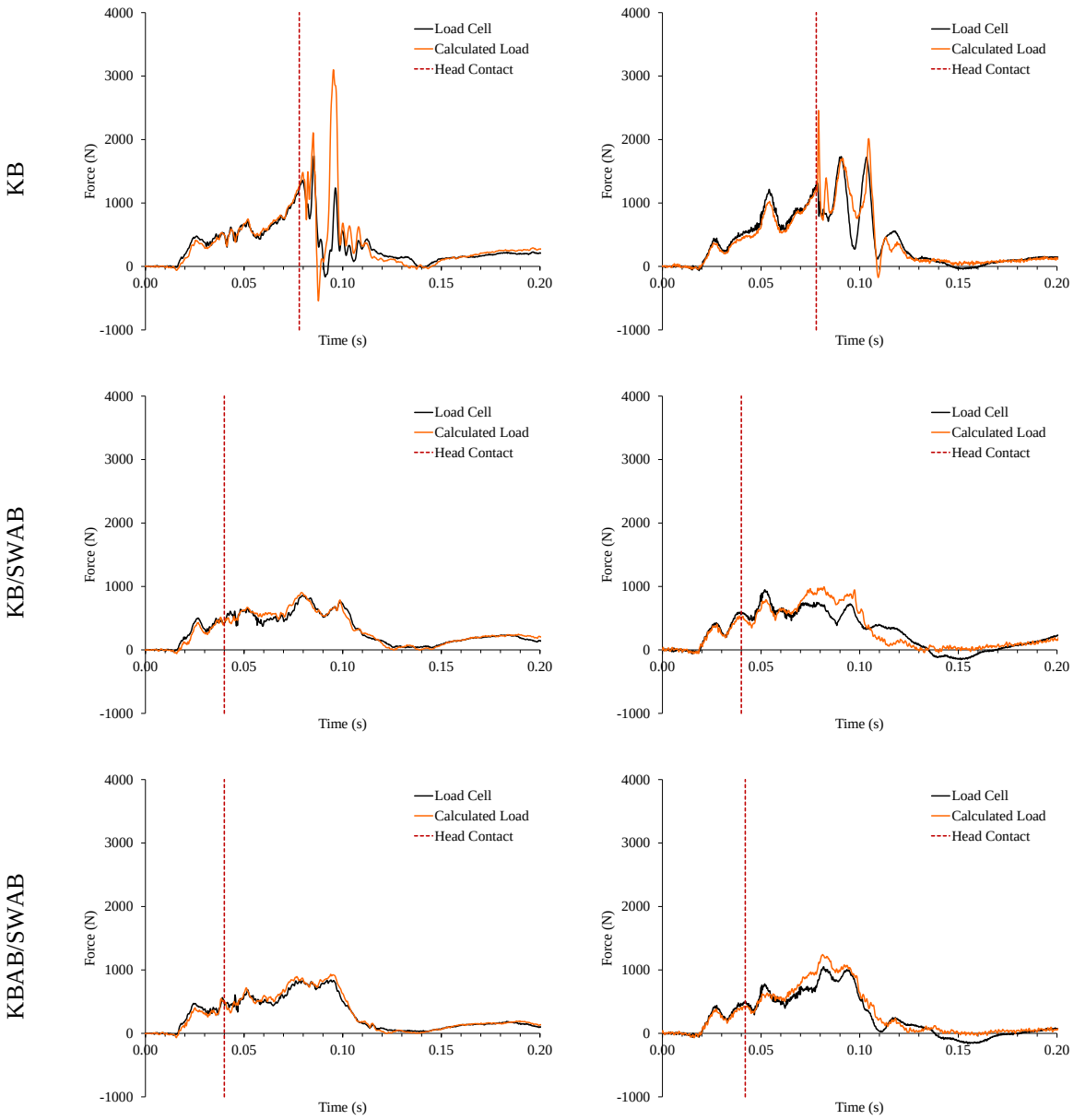

Figure A12. Exemplar HIII (left) and THOR-M (right) upper neck measured (load cell) and calculated (inverse dynamics) axial forces (Fz) for all conditions.
Note: Tension is positive.

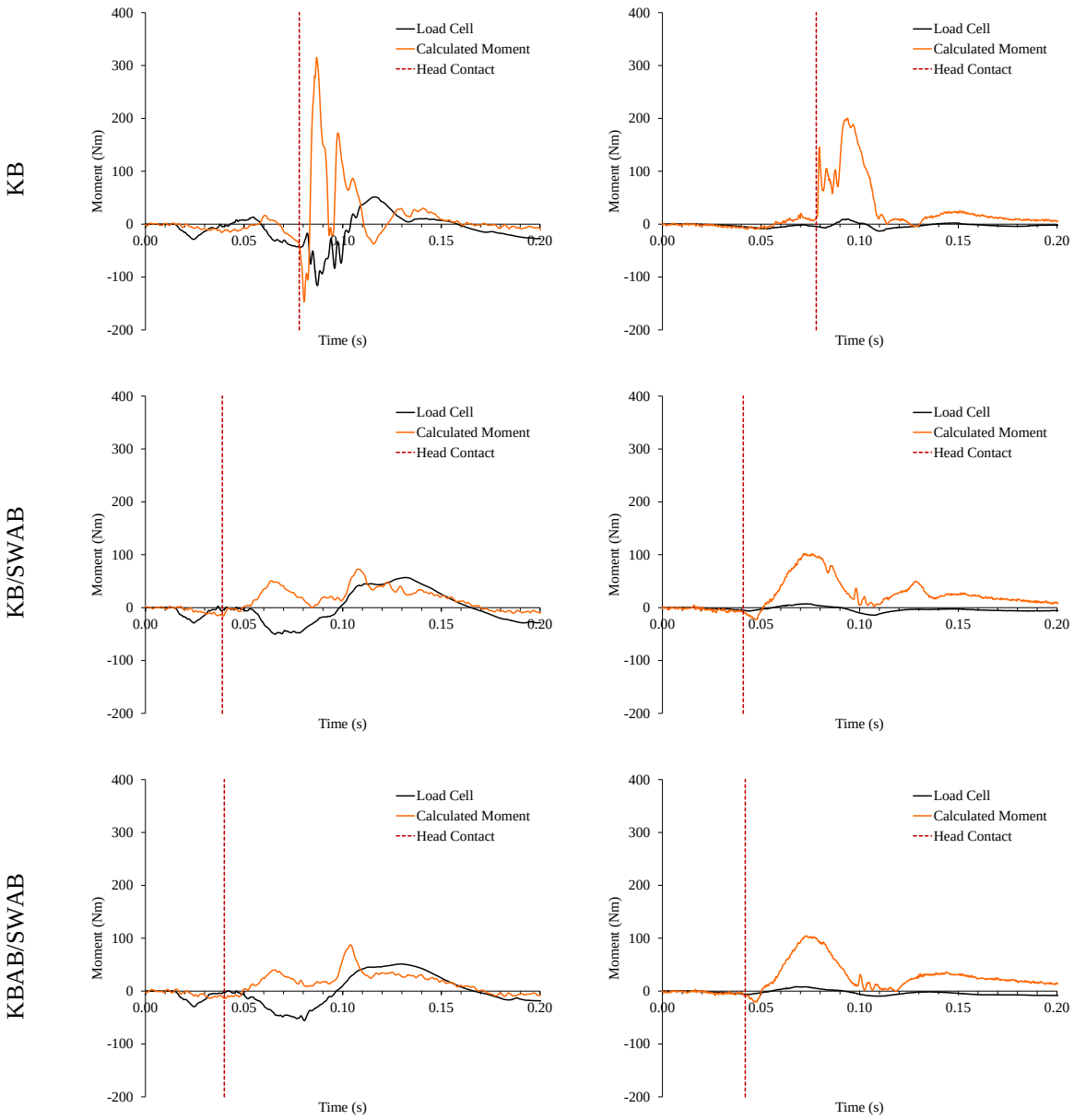

Figure A13. Exemplar HIII (left) and THOR-M (right) upper neck measured (load cell) and calculated (inverse dynamics) bending moments about the y-axis (My) for all conditions.
Note: Flexion is positive.

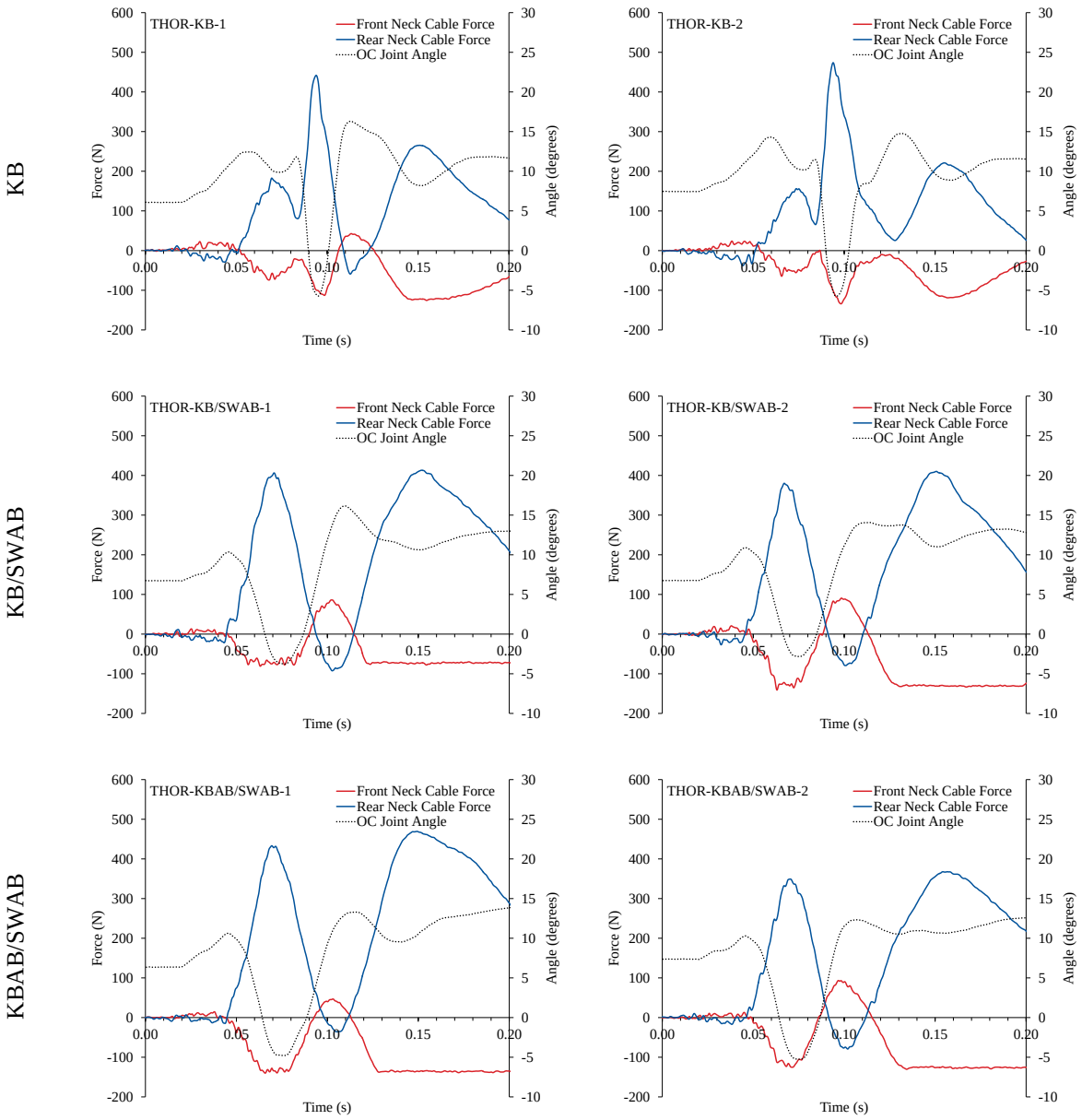

Figure A14. Front and rear neck cable loads (left vertical axis) and OC joint angle (right vertical axis) for the THOR-M for each test.

Note: For the neck cable forces, tension is positive. For the OC joint angle, extension is positive.

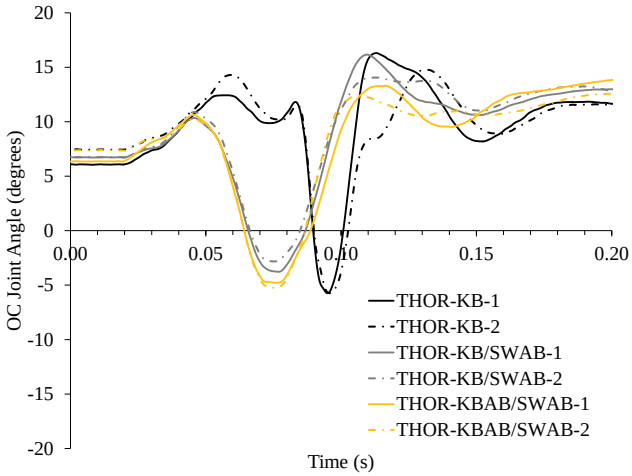

Figure A15. OC joint angle for the THOR-M for each test.
Note: Extension (chin upward) is positive.

References:

1. Albert DL, Beeman SM, Kemper AR. Occupant kinematics of the Hybrid III, THOR-M, and postmortem human surrogates under various restraint conditions in full-scale frontal sled tests. Traffic injury prevention. 2018;19(sup1):S50-S58.