Lower Extremity Injury Risk in a 6 year-old Hybrid III ATD during Frontal Impacts

Jared C. Seidel, Yun Seok-Kang, John H. Bolte IV, Laura C. Boucher

Abstract OBJECTIVE: During a frontal vehicle crash, for children seated in the rear seat, the first points of contact with the vehicle interior are often the foot, ankle, or tibia. The objective of this study was to evaluate leg interaction with the front seatback during a frontal collision using a prototype Hybrid III 6 year-old anthropomorphic test device with more biofidelic lower extremity (ATD-LE). METHODS: Eight frontal sled tests were conducted using a 48 km/h pulse. The front seatback properties were altered to simulate a rigid versus a soft front seatback condition. Four sled tests were conducted in each condition and within each condition, the ATD's legs were either relaxed or extended and the front seat was either positioned forward or backward. RESULTS: The rigid front seatback condition recorded higher tibia forces, moments, and tibia indices. The seat in the back position with toes touching, resulted in the highest tibia bending moment and tibia index, 91.5 Nm and 1.4, respectively, both above injury threshold. Tibia moment injury threshold was also exceeded due to leg interaction with the front seat frame. DISCUSSION: These data suggest that front seatback material and rear compartment space are important determinants of anatomical and biomechanical interaction. These data provide evidence of potential sources of injurious loading, which may help determine areas in need of added protections in the future.

Keywords Anthropomorphic test device, car crash, children, lower extremity, rear seat safety

I. INTRODUCTION

From 1975 to 2011, motor vehicle crash (MVC) fatality rates in children under the age of 10 have decreased from 7.21 per 100,000 people in to 2.69 per 100,000 people, respectively [1]. The decrease in observed fatalities from MVCs may be attributed to updates to traffic safety laws, improved vehicle safety and car seat designs. It is estimated that there are 39 billion automotive person-trips per year in the rear seat, where 79% of occupants in the rear row were children under the age of twelve [2]. Research has found that children in seatbelts alone have a higher risk of injury in MVCs compared to children of similar age secured in forward facing child restraint system and belt positioning boosters (booster) [3-4]. Children aged 4-8 who used booster seats were 45% less likely to sustain injuries than similar aged children who were using a seat belt [3]. Despite the rear seat being the safest place for children [5] and the overall reduction of injuries for children in forward facing child restraint systems and boosters, they still are at risk for clinically significant injuries to the lower extremity [2][6][7]. MVC injuries below the knee, such as distal tibia fractures can result in premature closure of the epiphysis (growth palate) and result in arrested tibial growth. Before improvements can be made to decrease the risk of exposure to lower extremity injury, there needs to be a better understanding of the biomechanics of this body segment during high velocity impact crashes to gain insight into potential injury mechanisms.

The current United States Federal Motor Vehicle Safety Standard (FMVSS) 213 calls for a sled test intended to represent a 48 km/h (30 mph) frontal impact. Questions have been raised about the applicability of the FMVSS 213 test standard and its translation to real risk for children [8]. For a frontal impact sled test, FMVSS 213 specifies maximum excursion limits for the head and knee, as well as a limit for head injury criterion (HIC). Even though the knee excursion limit does provide a metric to limit contact between the knee and the front seat, this may not be sufficient clearance for the extremities. It has been suggested that realistic injury mechanisms can be better understood if full scale tests utilized a biofidelic ATD and a more realistic test

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environment, such as a front seat [4].

Currently, there is no instrumentation below the knee in any child ATD, which would be necessary to provide direct benchmark metrics for clinically significant injuries to the lower limb. If the biomechanics of the lower extremity are to be considered, the crash standards also need to be updated or altered to better represent a realistic crash environment, alterations such as incorporating a front seat in the test setup. Additionally, the properties of the front seatback can vary between each car manufacturer; the front seatback can be partially filled, hollow, or made of a rigid polymer material. While it may not be realistic to entirely eliminate the interaction with the front seatback, more attention can be focused on the interaction between the lower extremity and the front seatback.

To our knowledge, there is insufficient research investigating mechanisms causing injury to rear-seated child passengers and a lack of understanding of the impact points between the lower extremity and vehicle interior. Considering the limitations of the current Hybrid III 6YO ATD, for this study we sought to explore the lower extremity interaction with the front seatback by using a prototype HIII 6YO ATD with a distal tibia load cell and improved ankle motion and stiffness (ATD-LE) [9-10].

II. METHODS

Eight frontal impact tests were conducted on an acceleration sled at Honda R&D Americas, Inc. (Marysville, OH). A 2017 Honda Pilot body in white with standard mass production front and rear passenger seats were used during testing (Figure 1a, b). The front seatback was modified to either a cushioned (soft) or a stiff (hard) front seatback. For the soft scenario, the front seatback was filled with 7.6 cm thick 4.22x10^{-8} kg/mm^3 polyurethane foam used in automotive seats (Lear Corp., Southfield, MI) (Appendix 1). A new sample of foam was used for each test and was secured inside the front seatback cavity, ensuring that no more than one inch of foam protruded past the metal seat frame (Figure 1c). The outer front seatback leather cover was then closed and zipped secure prior to testing. For the hard front seatback condition, 1.6 cm plywood was mounted to the front seatback to simulate impacting a stiff structure anywhere on the front seatback. The plywood measured approximately 36.8 cm x 40.0 cm and was secured on each side of the seat frame as tightly as possible with zip-ties (Figure 1d). The outer leather front seatback cover was pulled over the wood and zipped secure prior to testing.

1a. Front seatback covered | 1b. Front seatback Uncovered | 1c. Front seatback with foam inserted | 1d. Front seatback with wood inserted

Figure 1: (a, b) Standard Honda Pilot front seat, (c) soft modification, (d) hard modification

The ATD-LE was seated in an Evenflo Amp high back, belt-positioning booster seat (Evenflo, Miamisburg, OH) and positioned based on the manufacturer's recommendations and NHTSA's seating procedures for FMVSS 213. A new booster was used for each sled test. The sled test matrix includes two seatback materials (hard or soft), two seat positions (rear of mid-track or forward of mid-track), and two leg positions (legs relaxed over the seat or toes touching the front seatback). The seat forward position was selected to provide the most rear compartment space that still permitted the toes to touch the front seat back. The seat was positioned 9 mm forward of mid-track. The seat back condition was selected to minimize compartment space as well as maintain axial loading with the ATD-LE. The seat was positioned 69 mm rear of mid-track.

The legs relaxed position was chosen to replicate the most common leg position for pediatric passengers. The second leg position was intended to replicate a worst case scenario based on previous work [10], positioning the legs out-stretched with the toes touching the front seatback. The test matrix for all eight scenarios can be found in Table 1.

Table 1. Test matrix

Pulse	Front Seatback Material	Front Seatback Position	ATD-LE Leg Position	Legs relaxed vs. Toes Touching
FMVSS 213 Pulse	Hard	Rear of mid-track (seat backward)	Legs relaxed	
			Toes touching front seatback	
		Forward of mid-track (seat forward)	Legs relaxed	
			Toes touching front seatback	
	Soft	Rear of mid-track (seat backward)	Legs relaxed	
			Toes touching front seatback	
		Forward of mid-track (seat forward)	Legs relaxed	
			Toes touching front seatback	

A standard 213 barrier pulse was used to achieve a change in velocity (ΔV) of 48 km/h (30 mph). High-speed cameras were mounted at three different positions: driver side, passenger side, and passenger side oblique, capturing each sled test at 1000 fps. The test setup can be found in Appendix 2. Additional instrumentation in the test environment was used to record sled kinematics and seatbelt loads. Acceleration of the sled platform was captured using accelerometers mounted to the sled. Seatbelt loads for the shoulder and lap belts were collected using seat belt load cells. All data was collected at 20,000 Hz.

Data were filtered according to the SAE standard J211 [11] channel frequency class (CFC) as a low-pass for the respective cut-off frequencies for each data set. Excursion values were obtained using TEMA Motion analysis software (Image Systems, AB, Linköping, Sweden). The coordinate system defined for the ATD-LE was in accordance with the J211 standard [11]. The main values of interest were tibia and femur loads in the z-axis and tibia moments about the y-axis. Additionally, the coefficient of variance (CV) was calculated at each time point from 5 ms to 75 ms for all 8 sled pulses. For all tests, maximum axial forces, bending moments, and tibia indices were compared against dynamic injury threshold values [12-14] (Appendix 3).Key outcome measures included: tibia forces, tibia bending moments, femur forces, tibia indices, seat belt forces, head injury criterion (HIC), and excursion values of the head, knee, ankle, and booster. The tibia index for each test was calculated [14] to evaluate the risk from the combined effects of bending and axial force on the tibia. The tibia index was calculated using Equation 1.

$$TI = \frac{M}{Mc} + \frac{F}{Fc} \qquad \text{(Equation 1)}$$

M: Resultant Bending Moment

M_c: Critical bending moment to cause pure bending failure of the shaft (74.2 Nm) [12]

F: Axial compressive force

F: Critical axial compressive force to cause pure compressive failure (7480 N) [12]

Head injury criterion (HIC) was calculated for each test using the linear acceleration values measured from the center of gravity inside the ATD head form. Excursion limits were measured relative to the LATCH position [15]. Ankle motion (°) was measured using ImageJ software (National Institute of Health Rockville, MD) at the maximum point of plantarflexion or dorsiflexion for each test. Initial starting angle of the ankle and angle at maximum dorsiflexion or plantarflexion, dependent upon the test condition, was measured. Since the ATD-LE does not have bony landmarks similar to humans, measurements were made to replicate a typical ankle motion test; lines were traced parallel to the mid-line of the leg and parallel to the lateral foot, with the fulcrum at the level of ankle rotation. The motion of left ankle of the ATD-LE was measured for each test, given that the left ankle was visible from the driver's side camera view.

III. RESULTS

The sled pulse for the eight frontal acceleration tests fell within the required FMVSS 213 sled pulse corridor. The coefficient of variance between the sled pulses was 2.74% between the 5 ms and 75 ms time points. The results presented will focus on the key outcome variables for the tibia, including compressive force (N), bending moment (Nm), and tibia index. Ankle kinematics (°) and excursion limits (mm) will also be expanded on. A comprehensive table of all data is located in Appendix 4. Results will also indicate that when a value reached 70% of the peak value for tibia compressive force, bending moment, and femur force, the variable of interest was considered to be "approaching" the injury threshold value. Screen shots of each condition are located in Appendix 5.

Tibia Compressive Force

The maximum tibia compressive force was recorded with the front seat in the forward position and the toes touching a hard front seatback. The tibia compressive force for the left leg was 2263 N, approaching the injury threshold value of 2410 N. After a post-test inspection, it was found that the wood used for the hard seatback modification fractured from the load applied by the ATD-LE during the event for this test condition. For the remaining tests when the feet were touching or relaxed with a hard front seatback, the peak tibia force did not approach nor exceed the injury threshold value. Additionally, all conditions with a soft front seatback, toes touching or legs relaxed, the peak tibia force also did not approach nor exceed the injury threshold value (Figure 2).

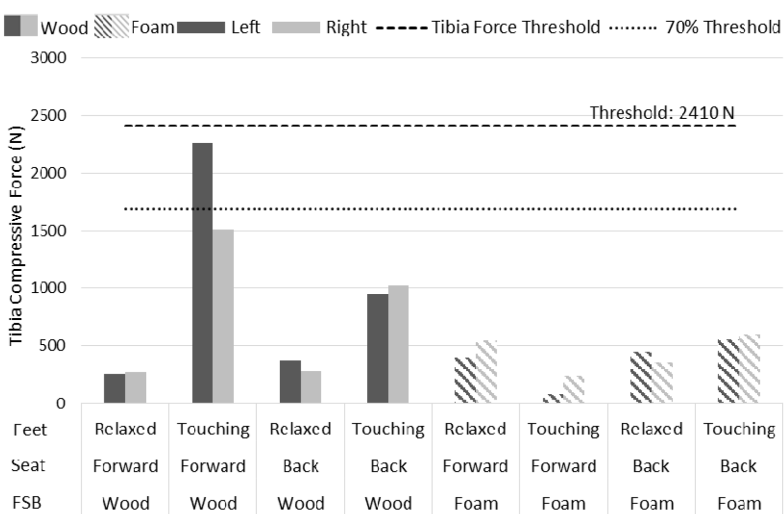

Figure 2. Tibia compressive force for each trial

Tibia Bending Moment

The tibia bending moment injury threshold (± 57.6 Nm) was exceeded in three trials. The greatest tibia bending moment was recorded with the front seat in the back position with the toes touching a hard front seatback (left tibia = 86 Nm, right tibia = 92 Nm). The second highest bending moments occurred with the front seat in the back position with the legs relaxed and a soft front seatback (left tibia = -58 Nm, right tibia = -53 Nm). Lastly, threshold was also exceeded with the front seat in the forward position with the legs relaxed and a hard front seatback (left tibia = -58 Nm, right tibia = -47 Nm. The tibia bending moment approached the injury threshold for two trails. In the first condition, the front seat was in the back position with the legs relaxed and a hard front seatback (left tibia = -52 Nm, right tibia = -47 Nm). In the second, the front seat was in the forward position with the legs relaxed and soft front seatback (left tibia = -38 Nm, right tibia = -49 Nm). Results from each trial can be found in Figure 3. Video analysis revealed the booster seat translated and rotated anteriorly during impact, compressing the rear seat-pan foam, which allowed the ATD's legs to impact the front seatback below the area of foam (soft) modification, resulting in contact with the seat frame.

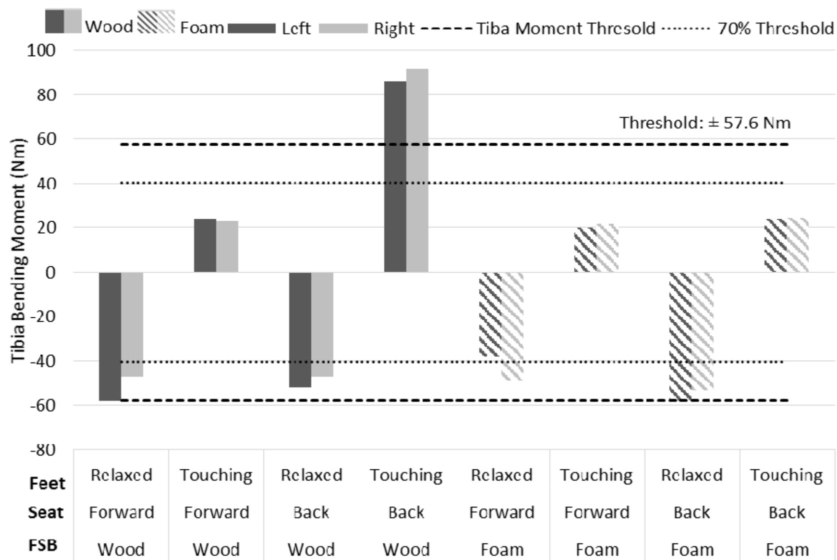

Figure 3. Tibia bending moment for each trial

Tibia Index

The tibia index exceeded the threshold value (1.1) when the front seat was in the back position and the feet were initially touching a hard front seatback (left tibia = 1.1, right tibia = 1.4). The tibia index approached the injury threshold (.77-1.1) for three trials. The first condition was when the front seat was in the forward position with the legs relaxed and a hard front seatback (left tibia = 0.85, right tibia = 0.69), the second condition was when the front seat was in the forward position with the toes touching the soft front seatback (left tibia = 0.59, right tibia = 0.79). In the third condition, the front seat was in the back position with the legs relaxed with a soft front seatback (left tibia= 0.82, right tibia= 0.77).

Ankle Kinematics

In both the hard and soft seatback conditions when the legs were initially relaxed, the ankle was always forced into plantarflexion upon interaction with the front seatback, with the greatest plantarflexion motion measuring approximately 60°. Conversely, when the toes were initially touching the front seatback, the ankle was forced into dorsiflexion upon impact, with maximum loading resulting in upwards of 50° of motion. More extreme dorsiflexion measures were observed in the seat backward conditions for both the hard and soft front seatback modifications. Initial and maximum ankle motion values can be found in Table 2.

Excursion Limits

The excursion values of the ATD-LE knee, ankle, head, and booster are reported in Table 2. None of the parameters required for FMVSS 213 exceeded excursion limits, relative to the LATCH point. Additionally, HIC values did not exceed the injury threshold and belt loads did not differ drastically per condition, thus will not be reported.

Table 2. Ankle motion and excursion values for each trial

Test Condition			Initial Ankle Position		Maximum Ankle Position		Max Excursion, From LATCH (mm)[b]			
Seat Back	Seat Position	Leg/Feet Positon	PF / DF[a]	Angle (deg)	PF / DF[a]	Angle (deg)	Knee	Ankle	Head	Booster Base
Hard	Forward	Relaxed	PF	29	PF	60	552	733	384	462
		Touching	PF	11	DF	35	538	746	416	460
	Back	Relaxed	PF	32	PF	58	576	714	402	474
		Touching	DF	20	DF	50	423	677	415	464
Soft	Forward	Relaxed	PF	19	PF	60	574	760	385	468
		Touching	PF	15	DF	34	583	794	402	478
	Back	Relaxed	PF	31	PF	62	561	706	378	457
		Touching	DF	23	DF	43	571	756	411	468

[a] PF = Plantarflexion / DF = Dorsiflexion

[b] Excursion limit from LATCH (mm) (which was 102 mm ahead of Point-Z in the x-direction): Head = 711 mm, Knee = 813 mm

IV. DISCUSSION

This study is the first experimental assessment of leg interaction of a rear-seated HIII 6YO ATD equipped with more biofidelic legs during a frontal collision using a front seatback. Some key findings include that in the conditions when the ATD-LE was initially touching a hard front seatback, values either approached or exceed injury threshold. The most injurious scenario involved the seat in the back position and toes touching a hard front seatback. In this scenario, both tibia moment and tibia index injury threshold were exceeded. Interestingly, across all tests, the tibia and femur force did not exceed the injury threshold values.

The tibia force approached injury threshold value when initially in contact with a hard front seatback in the forward position. The increase in tibia force is most likely a result of the front seat being positioned further from ATD-LE, allowing the lower extremity to engage the front seatback mostly in the x-direction of the lower limb, axially loading and forcing the ankle into dorsiflexion With little knee flexion after impact. The wood (hard seatback modification) broke as a result of the impact of the ATD-LE legs, consequentially the tibia may have underestimated the force of impacting a rigid structure in this seating position. Interestingly, the tibia force in the other hard front seatback condition with the toes touching, but with the seat in the backward position, the tibia force was approximately half of the force recorded compared to the seat in the forward position. When evaluating the video, the initial position of the ankle was much more dorsiflexed and the knees were more flexed. Upon impact the ankles were able to continue to move into dorsiflexion and the knees were able to flex, likely accounting for much of the force reduction. In both conditions where the feet were initially touching the soft, foam-filled front seatback, no injurious values were observed. When comparing a soft front seatback to a hard front seatback in the forward position, the tibia forces were reduced by 96% and 84% for the left and right limbs, respectively. The reduction of forces can be credited to the padding of the foam material, indicating that this insert may help reduce observed forces on the tibia.

The tibia moment did exceed the threshold value when the feet were initially in contact with a hard front seatback in the back position. The large bending moment can be attributed to the initial position of the ATD-LE, with the ankle beginning in 20° of dorsiflexion and the smaller rear compartment space, due to the position of the front seatback. The increased bending moment was a result of the foot being forced further into dorsiflexion, creating a large positive bending moment. The scenarios with the feet initially relaxed resulted in contact between the lower extremity and the lower portion of the front seat frame, independent of the front seat initial positioning. This unexpected result happened due to the compression of the rear seat-pan foam. The compression of the rear seat-pan foam influenced the trajectory of the lower limb during the acceleration pulse, causing the legs to hit much lower on the seatback then expected. In all cases, the feet swung forward and hit the lower metal frame of the front seat, resulting in a high tibia moment that either exceeded or approached 70% of the injury threshold value in at least one of the limbs.

To evaluate the combined effects of tibia force and bending moment, the tibia index was calculated. Across all sled tests, the tibia index exceeded threshold once and passed 70% of the threshold value three times. For the toes touching conditions, a hard front seatback in the back position did result in the tibia index threshold value to be exceeded. The bending moment, in addition to the large axial force from the hard front seatback modification pushed the tibia index past the threshold value. The limited amount of rear compartment space appeared to play an important role in the results. Conversely, when the front seat was positioned in the forward position with a hard front seatback, the tibia index did not exceed or approach the threshold value. The front seatback wooden modification did fracture in this scenario, likely underestimating the true tibia index. In the three tests when the tibia index did exceed 70% of the threshold value, this was mostly due to high bending moments, caused by the interaction with the lower frame of the front seat. The interaction between the legs and the lower seat frame two do identify an interesting point of focus, revealing that the lower limb does not necessarily swing into the middle front seatback region, but rather translate inferiorly and anteriorly, due to seat-pan foam compression, allowing contact with the rigid lower portion of the front seat frame.

The observed ROM for the left and right ankles were 12° and 5° beyond the reported ROM of the modified ATD-LE ankle [9]. The observed increase in dorsiflexion can most likely be attributed to the fact that this test was a high speed acceleration pulse, simulating a 48 km/h (13 m/s) impact. Boucher et al. was limited to comparing ROM data at low speeds due to comparing against child volunteer data. In all seating positions when the feet were in the relaxed position, the feet made contact with the lower portion of the front seat frame, forcing the ankle into plantarflexion, which approached 58° to 62°.

Additionally, the influence of the initial positioning of the front seat was investigated. The forward seat position (106 mm rear of the fully forward position) was selected to provide the most rear compartment space that still permitted the toes to initially touch the front seatback. The back position (69 mm rear of mid-track) was selected to minimize compartment space as well as maintain axial loading with the ATD-LE. Reference [16] found that small females sit about 42 mm rear of the fully forward position, mid-size males sit 46 mm rear of the mid-track position, and large males sit in the rear-most front seat position. In relation to the findings of [3], the forward position would correspond between the small female and midsize male position, and the back position would fall between the average male and large male seating positon.

Since only one test was performed for each condition, conclusions cannot be made in regards to a specific recommendation, but these tests do provide valuable insight into the effects of a potentially hard or soft front seatback. Since two injury threshold values were exceeded, these results do draw attention to the need for further testing with a rigid production front seatback. Conversely, when the feet were initially touching a foam front seatback, the absence of injurious values demonstrate that a softer front seatback reduces the forces and bending moments on the lower limb. Additional testing is recommended for both conditions, to further understand the interaction between the lower extremity and the front seatback. While it is unrealistic to entirely eliminate contact between the lower extremity and the front seatback, changes can be made to improve the interaction by focusing on modifications that would reduce peak force and moments, such as adding additional padding around the frame of the rear seatback. Additionally, these data can be used as a resource to help create standards to improve the interaction between the lower extremity and the front seatback in a manner similar to the FMVSS 201 standard for head impact to the front seatback.

Although a prototype ATD-LE was used as a new tool to understand lower extremity biomechanics and interaction with the front seatback, there were still limitations to this study that can be addressed in future work. In this study design, only one pulse was used for each condition, which was at a relatively low speed, 48 kph (30 mph), however injuries to the lower extremity are more likely to occur at high speed [4]. Moving forward, a secondary high speed pulse should be considered for future test design. Additionally, this study only performed one test at each condition. The lack of repeated tests does not permit statistical significance to be determined when comparing across the other scenarios. However, each test can be used as a tool for reference moving forward for future study designs.

V. CONCLUSIONS

Data from eight frontal impact sled tests reveal valuable information about contact between the lower extremity of a HII6YO ATD-LE and geometry of the front seatback. If the lower extremity was initially touching a hard front seatback, the values recorded either approached or exceeded injury threshold. When the lower extremity was initially touching a soft front seatback, no injurious values were observed. In all four tests when the lower extremity was initially relaxed, independent of front seat positon, the lower extremity contacted the lower rigid portion of the front seat frame resulting in values that either approached or exceeded injury threshold. These data suggest that the front seatback material does make a difference in injury potential. The amount of space between the front and rear seat is also an important determinant of anatomical and biomechanical interaction during impact. Improved protections should be considered to the seatback and frame to improve safety for the lower extremity of the rear-seated occupant. These data provide evidence of potential sources of injurious loading, which may help determine areas in need of added protections in the future.

VI. Acknowledgement

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VII. References

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VIII. APPENDIX

Appendix 1

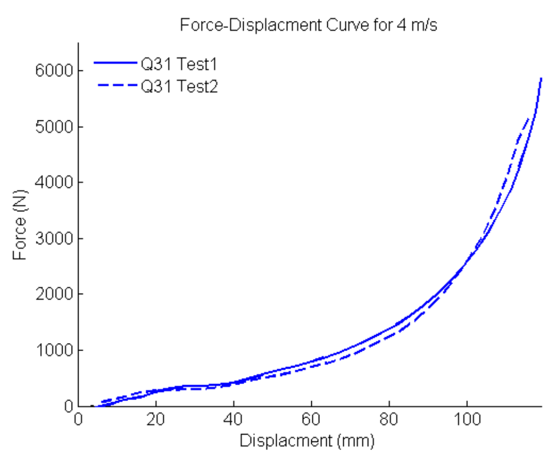


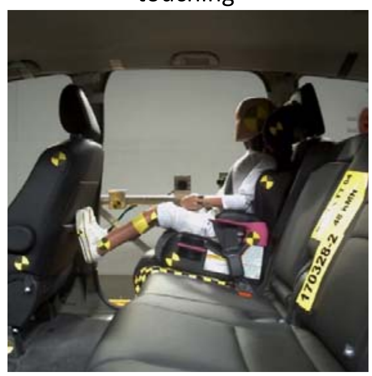
Figure A1. Force displacement curve of foam at 4 m/s compression determined from drop tower testing. The calculated stiffness = 3.5 N/mm.

Appendix 2

A2a. Seat forward, legs relaxed

A2b. Seat forward, toes touching

A2c. Seat back, legs relaxed



A2d. Seat back, toes touching

Figure A2. Seat positions for all test set-ups. Each position tested with conducted with both a soft and hard front seatback modification.

Appendix 3

Table A3. Tabulated injury thresholds for 6 year olds

Parameter	Published Values	Average
Femur Axial Force	2290 N (Ivarsson et al. 2004) 2250 N (Mertz et al. 2016)	2270 N
Femur bending moment	73.3 Nm (Ivarsson et al. 2004)	73.3 Nm
Tibia axial force	2100 N (Mertz et al. 2016) 2720 N (Ivarsson et al. 2004)	2410 N
Tibia bending moment	57.6 Nm (Ivarsson et al. 2004)	57.6 Nm
Tibia Index	1.1 (Ivarsson et al. 2004)	1.1

These values were obtained from Ivarsson et al. (2004), and Mertz et al., (2016), Table A2, shows published injury threshold and the average injury thresholds, which was the value used for comparison with these data.

Appendix 4

Table A4. Tabulated values from each sled test. Red = above injury threshold, Yellow = “approaching” injury threshold. SFD = seat forward, LRx = legs relaxed, TT = toes touching, SBK = seat back

		Test Condition															
		Hard (Wood)								Soft (Foam)							
		Test 1: SFD, LRx		Test 2: SFD, TT		Test 3: SBK, LRx		Test 4: SBK, TT		Test 5: SFD, LRx		Test 6: SFD, TT		Test 7: SBK, LRx		Test 8: SBK, TT	
Parameter	Injury Threshold	Left	Right	Left	Right	Left	Right	Left	Right	Left	Right	Left	Right	Left	Right	Left	Right
Tibia Force	-2410 N	-255.0	-270.2	-2263.4	-1505.1	-376.3	-278.1	-950.9	-1025.3	-400.0	-545.9	-87.7	-237.3	-444.6	-356.0	-561.2	-601.7
Tibia Moment	± 57.6 Nm	-57.8	-47.0	24.2	23.0	-52.0	-47.0	86.3	91.5	-38.1	-49.3	20.1	21.7	-58.2	-53.2	24.4	24.6
Femur Force	2270 N	959.6	879.7	-1448.5	-918.7	714.5	806.5	-499.9	-746.8	1106.8	1004.0	711.6	509.9	764.7	804.8	335.8	222.6
Tibia Index	1.1	0.85	0.69	0.62	0.61	0.72	0.66	1.13	1.42	0.59	0.79	0.28	0.34	0.82	0.77	0.45	0.49
HIC	732	407		334		434		397		485		471		447		415	

Appendix 5

0.00 sec 0.02 sec 0.04 sec 0.06 sec*[1, 2]

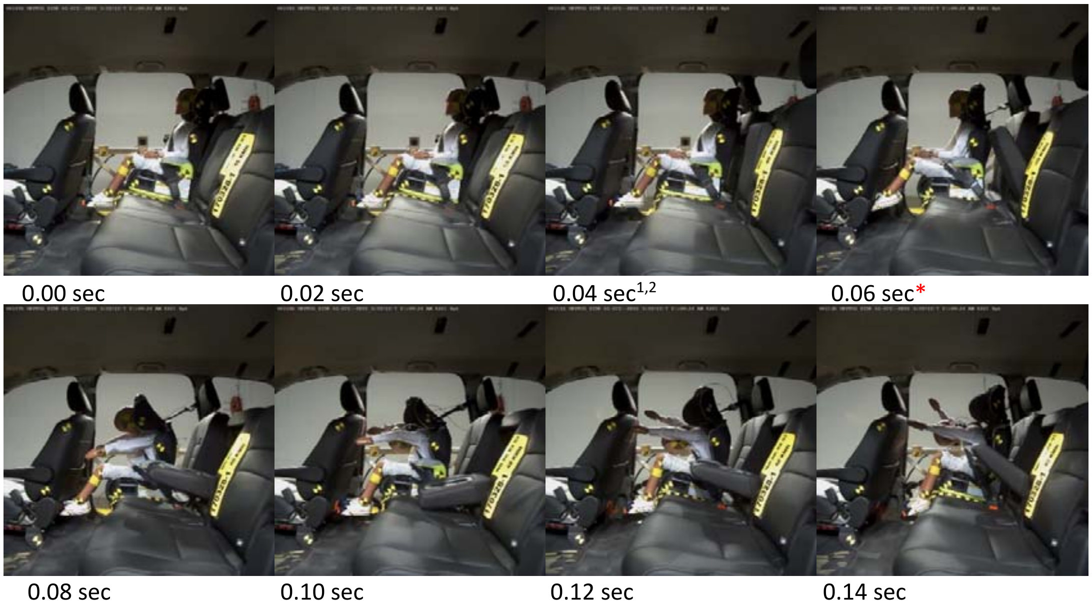
0.08 sec 0.10 sec 0.12 sec 0.14 sec

A5a. Test 1: Seat forward, legs relaxed, with the hard seatback. Asterisk indicates initial contact with the front seat (*). [1] Max force @ 0.060 m/s = 255 N. [2] Max moment @ 0.060 m/s = 57.8 Nm.

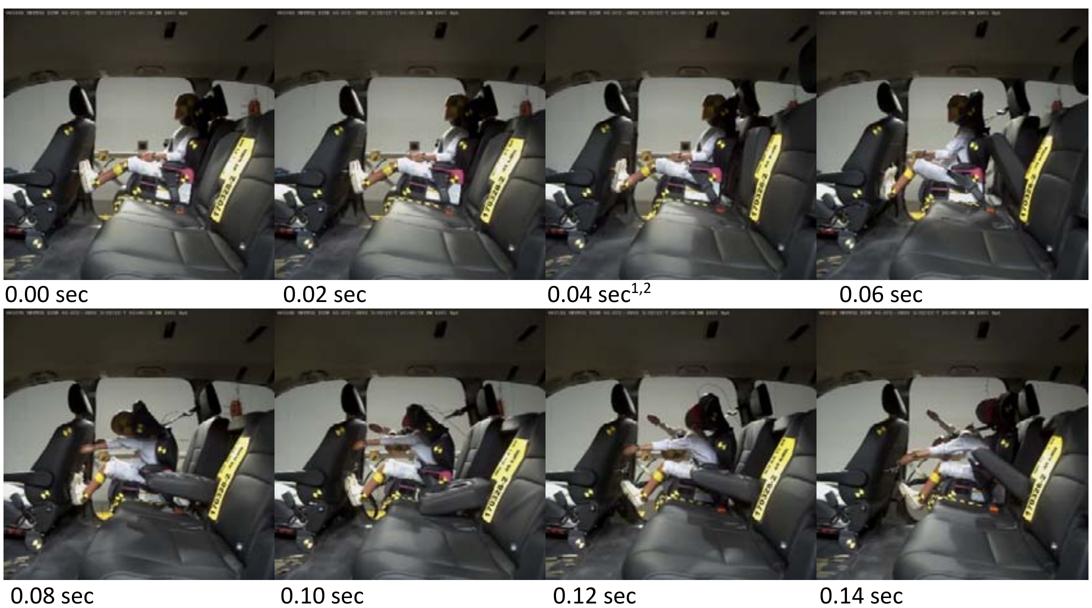
0.00 sec 0.02 sec 0.04 sec[1,2] 0.06 sec

0.08 sec 0.10 sec 0.12 sec 0.14 sec

A5b. Test 2: Seat forward, toes touching, with a hard front seatback. [1] Max force @ 0.044 m/s = 2263 N. [2] Max moment @ 0.053 m/s = 23.0 Nm.



A5c. Test 3: Seat backward, legs relaxed, hard front seatback. Asterisk indicates initial contact with front seat (*).[1] Max force @ 0.053 m/s = 376.3 N. [2] Max moment @ 0.053 m/s = 58.0 Nm.



A5d. Test 4: Seat backward, toes touching, hard front seatback condition. SBK, FT, wood FSB condition. [1] Max force @ 0.047 m/s = 1025.3 N. [2] Max moment @ 0.050 m/s = 91.5 Nm.

0.00 sec 0.02 sec 0.04 sec 0.06 sec*[,1,2]

0.08 sec 0.10 sec 0.12 sec 0.14 sec

A5e. Test 5: Seat backward, legs relaxed, soft front seatback. Asterisk indicates initial contact with front seat (*).[1] Max force @ 0.065 m/s = 545.9 N. [2] Max moment @ 0.067 m/s = 49.3 N/m.

0.00 sec 0.02 sec 0.04 sec 0.06 sec[1,2]

0.08 sec 0.10 sec 0.12 sec 0.14 sec

A5f. Test 6: Seat forward, toes touching, soft front seatback**.** [1] Max force @ 0.062 m/s = 237.2 N. [2] Max moment @ 0.063 m/s = 21.7 N/m.

0.00 sec 0.02 sec 0.04 sec[1,2] 0.06 sec*

0.08 sec 0.10 sec 0.12 sec 0.14 sec

A5g. Test 7: Seat backward, legs relaxed, foam front seatback. Asterisk indicates initial contact with front seat (*).[1] Max force @ 0.052 m/s = 444.6 N. [2] Max moment @ 0.055 m/s = 58.2 N/m.

0.00 sec 0.02 sec 0.04 sec 0.06 sec

0.08 sec 0.10 sec 0.12 sec 0.14 sec

A5h. Test 8: Seat backward, toes touching, soft front seatback**.** [1] Max force @ 0.058 m/s = 601.7 N. [2] Max moment @ 0.059 m/s = 24.6 N/m.