Blast Mitigation Seat Analysis – Evaluation of Lumbar Compression Data Trends in 5th Percentile Female Anthropomorphic Test Device Performance Compared to 50th Percentile Male Anthropomorphic Test Device in Drop Tower Testing

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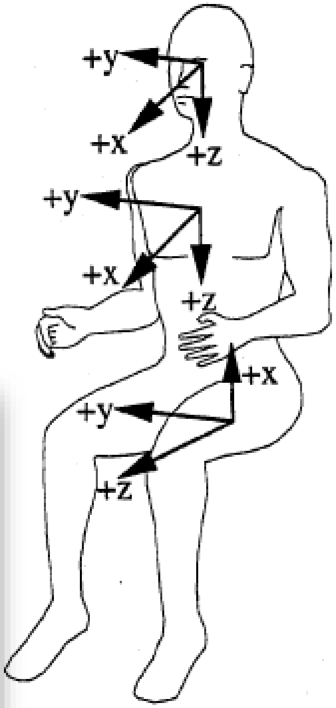
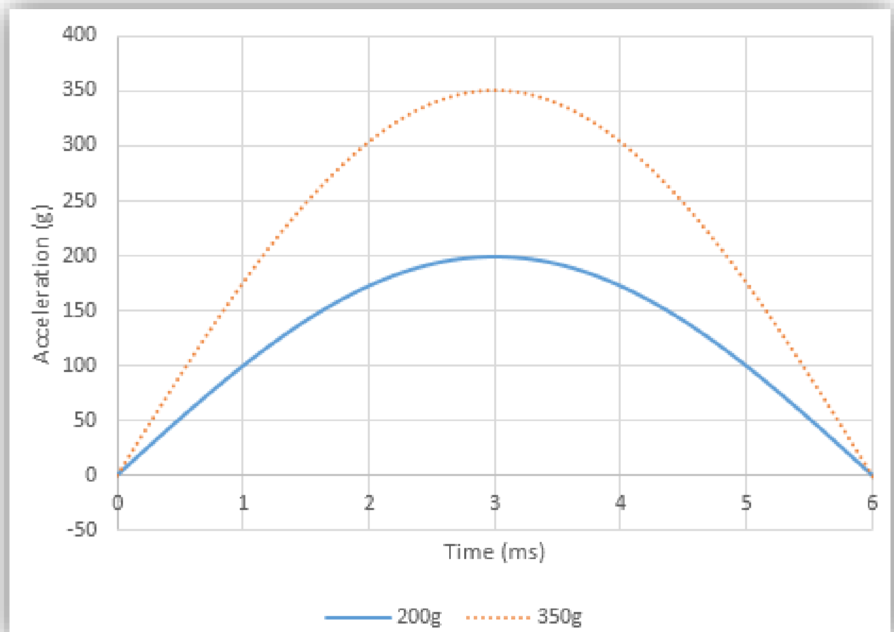
Testing Background

- Baseline drop tower data collected from Anthropomorphic Test Devices (ATDs) seated in 12 models of Commercial Off-The-Shelf (COTS) and prototype blast energy-attenuating (EA) seats in various phases of engineering design development
- Testing completed with:
  - 5th Percentile Female ATDs and 50th Percentile Male Hybrid III ATDs
  - 200 g or 350 g pulse
- ATD data quality-checked and preliminary comparisons conducted
- ATD injury assessment values compared to Occupant Centric Protection (OCP) Injury Assessment Reference Values (IARVs)
- ATD data channels recorded include:
  - Accelerations
    - Head (Resultant, HIC15, HIC36)
    - Chest (Resultant)
    - Pelvis (DRI)
  - Forces/Moments
    - Upper Neck
    - Lumbar
    - Femur
    - Upper Tibia
    - Lower Tibia



Testing Background

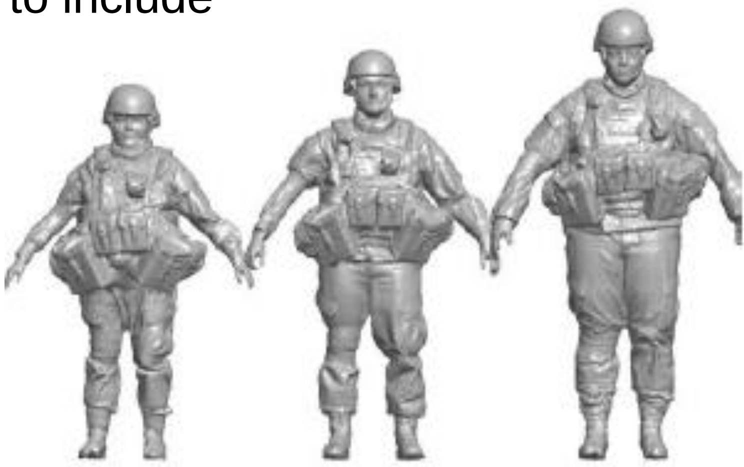
- Drop tower located at TARDEC Occupant Protection (OP) Laboratory
- Testing simulated the initial vertical loading event during an underbody blast
- Pulse profile variables include:
  - Maximum acceleration
  - Time to peak
  - Delta velocity
- Pulse profile tuning is achieved by changing:
  - Drop height
  - Platform payload
  - Energy absorbing medium
- Test matrix designed to maximize information gained
  - Focus of this study is to evaluate the overall accelerative loading trends of the 5th percentile female ATD when compared to the 50th percentile male ATD



Seat ID	200 g 5th PPE	200 g 5th No PPE	200 g 50th PPE	200 g 50th No PPE	350 g 5th PPE	350 g 5th No PPE	350 g 50th PPE	350 g 50th No PPE	Total
A	1	1	1		1	1	1		6
B	2		4						6
C					2	2	2		6
D	2	2	2		2	2	2		12
E	1		1		1		1		4
F		4	2	2		2	6		16
G	2	2			2	2			8
H	2	2	2						6
I	2	2	2						6
J	2	2	2			1			7
K	1	1	3	1					6
L					6		1		7
Total	15	16	19	3	14	10	13	0	90

Testing Background

- Most EA seats are designed for the average-sized male:
  - ATD dimensions:
    - 5’9”
    - 171 lbs
- US Army is expanding occupant protection focus to include small females:
  - ATD dimensions:
    - 4’11”
    - 108 lbs
- Matched pair testing conducted in multiple EA seats to assess differences in energy absorption due to occupant size
- Focus on pelvis acceleration (Az) and lumbar compressive force (Fz)
- Results
  - Some seats able to maintain same loading profiles and protection regardless of occupant size
  - Some seats show marked differences
  - Continued research and engineering development is needed to improve seat energy absorption properties and EA mechanisms to ensure all Soldiers, regardless of size and weight, are provided with equivalent protection



Occupant Size Difference

5th Percentile Female
(4’11”)

50th Percentile Male
(5’9”)

Accelerative Loading Profiles

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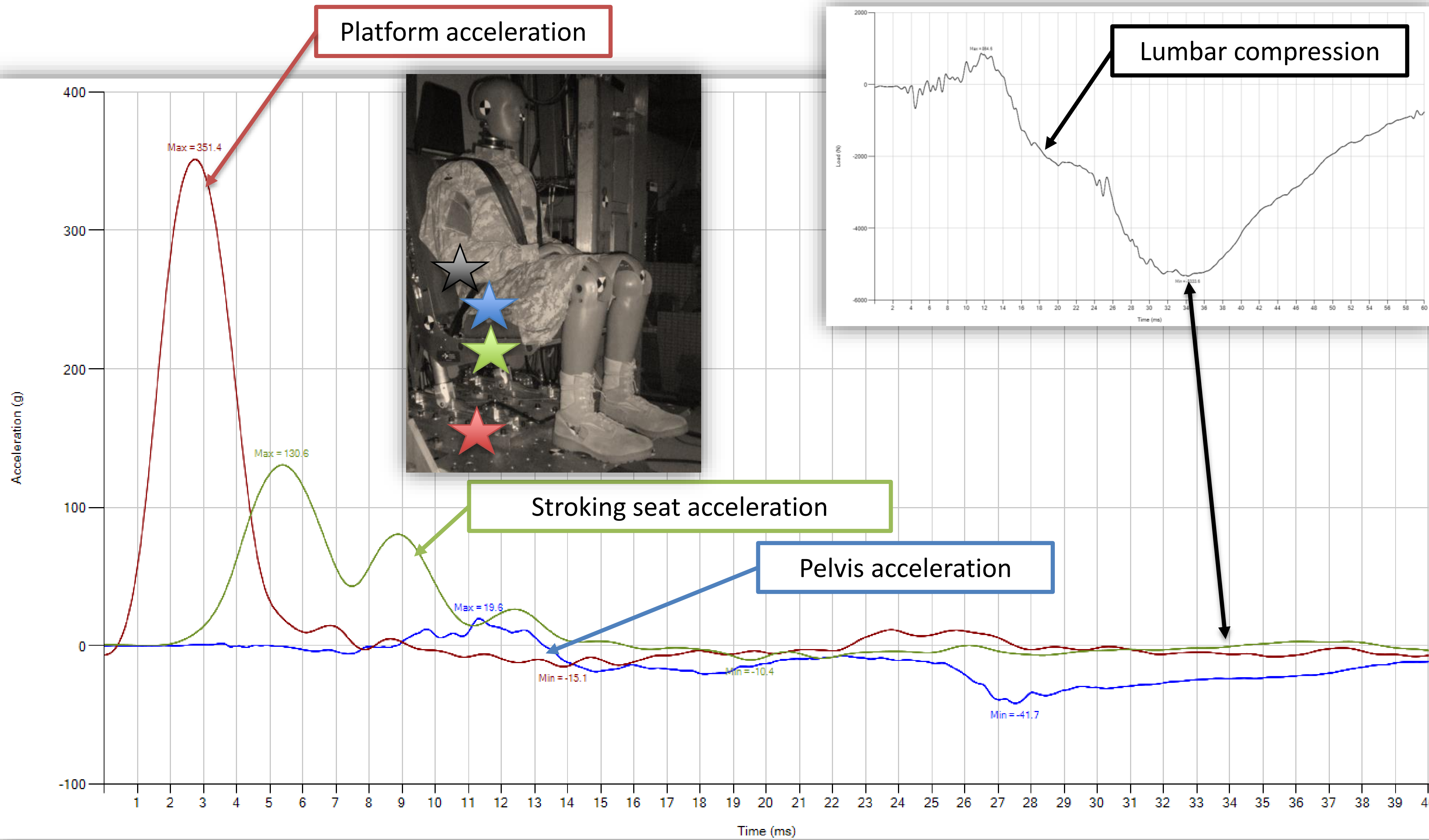

Lumbar Compression

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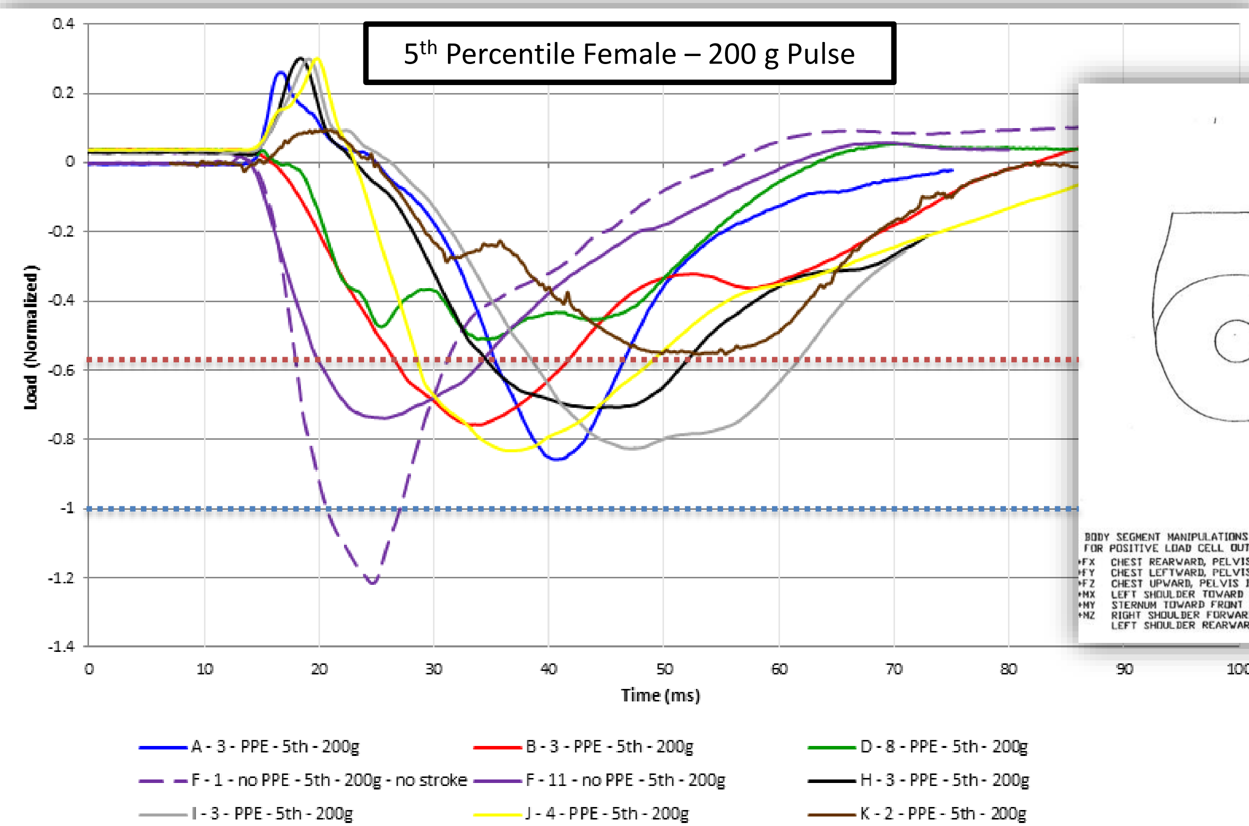
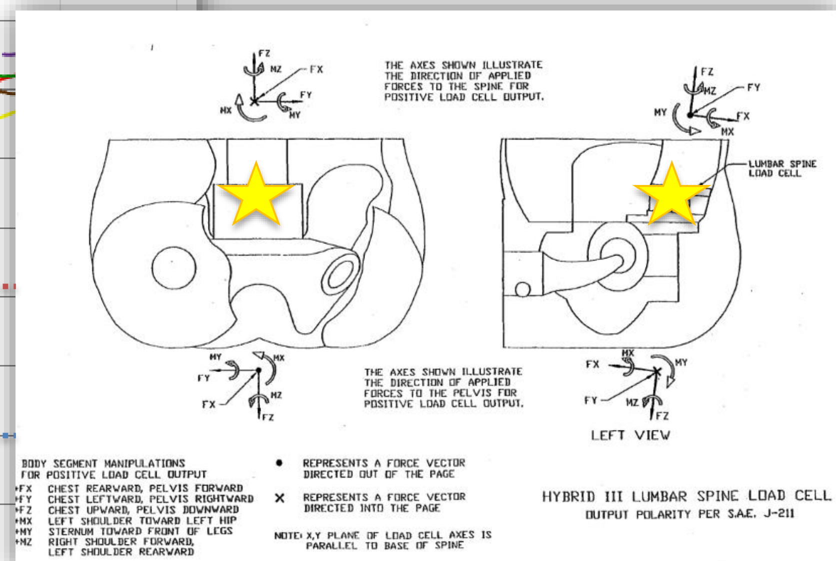
- Lumbar compression is considered the "go/no-go" gage for seat performance
- Clearest and most consistent data signal in lower body – measured with load cell
- Compression data normalized
  - >1.0 → exceeds IARV for 50th percentile male (blue dotted line)
  - >0.58 → exceeds IARV for 5th percentile female (red dotted line)
- Large variation in ATD lumbar response when subjected to the same floor impulse but with different seat types, including a non-stroking trace from Seat F (purple dashed line)
- Properties of seat design and EA mechanism dictate the amplitude and duration of the force imparted on the occupant
- Ideal EA device would reduce peak load and duration to reduce injury probability





Lumbar Compression – 200 g

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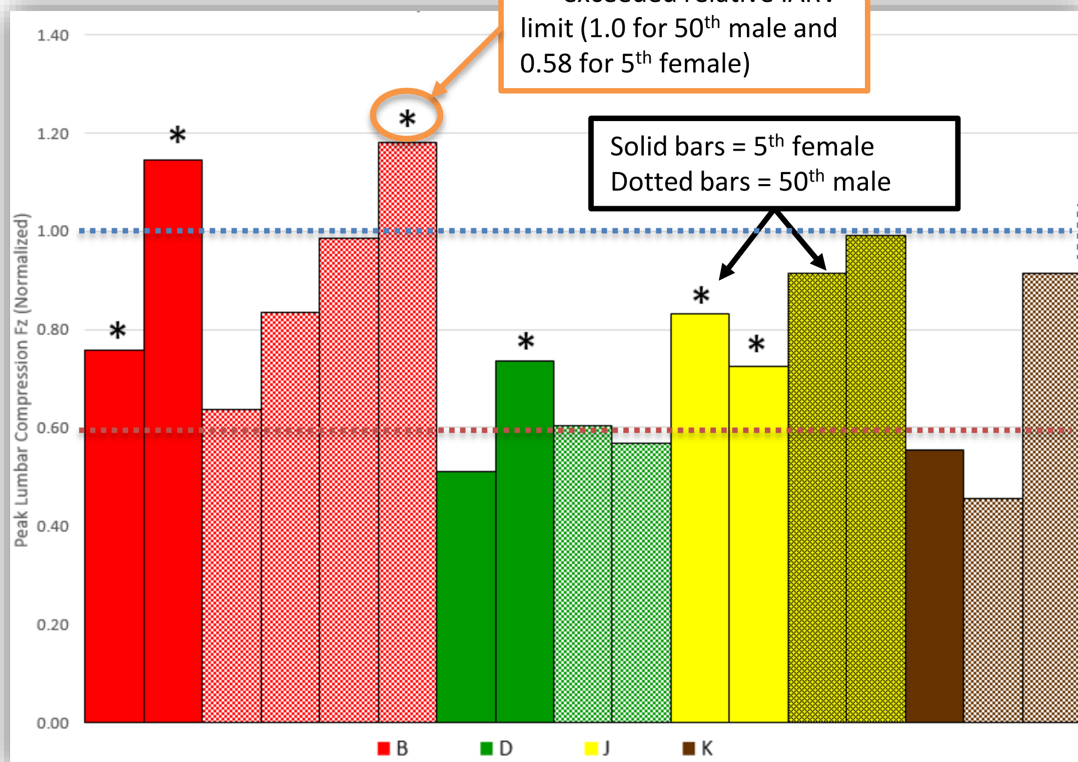
- No distinct trend at 200 g for peak lumbar compression based on occupant size
- Several tests at 200 g had lumbar compression below the IARV threshold



* = exceeded relative IARV limit (1.0 for 50th male and 0.58 for 5th female)

Solid bars = 5th female
Dotted bars = 50th male

50th IARV

5th IARV

Seat ID	Test Number	ATD	Lumbar Fz Peak Compression [Normalized]	Difference in Average Peak Lumbar Compression*
A	3	5th	0.86	+27%
A	1	50th	0.67	
B	3	5th	0.76	+5%
B	4	5th	1.15	
B	1	50th	0.64	
B	2	50th	0.83	
B	11	50th	0.99	
B	12	50th	1.18	
D	8	5th	0.51	+6%
D	9	5th	0.74	
D	1	50th	0.60	
D	2	50th	0.57	
H	3	5th	0.71	-11%
H	1	50th	0.80	
I	3	5th	0.83	+12%
I	4	5th	0.84	
I	1	50th	0.72	
I	2	50th	0.76	
J	4	5th	0.83	-18%
J	5	5th	0.73	
J	6	50th	0.91	
J	7	50th	0.99	
K	2	5th	0.55	-27%
K	10	50th	0.46	
K	26	50th	0.91	
K	27	50th	0.91	

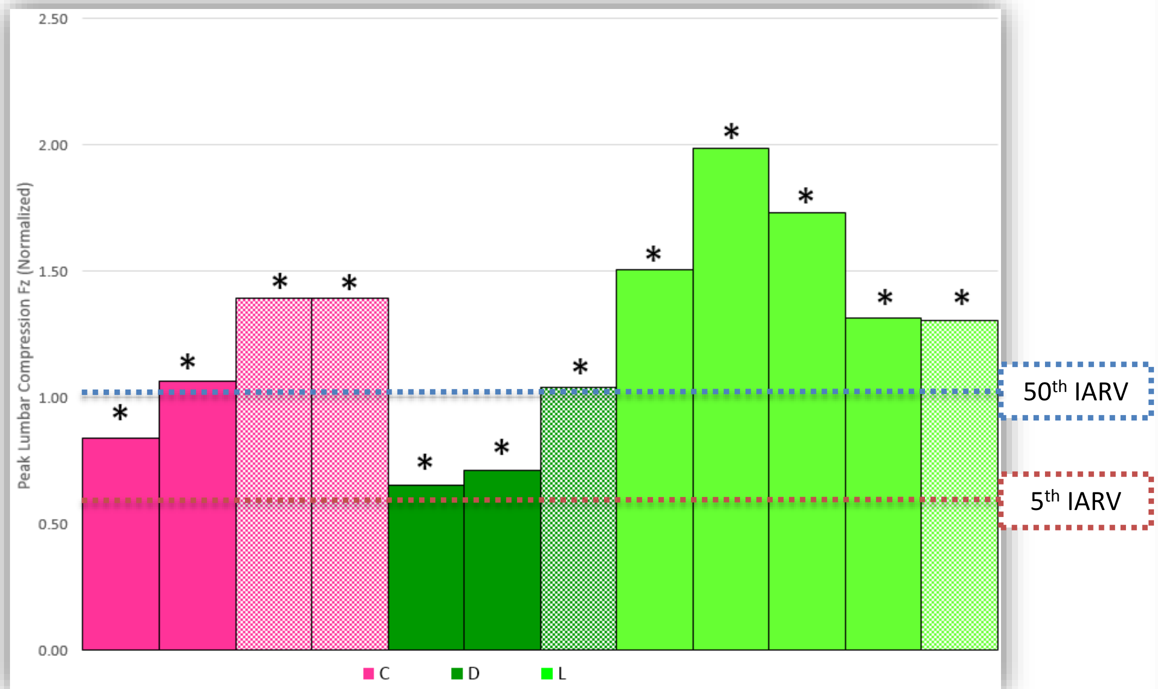
* '+' denotes 5th percentile female lumbar load is greater than 50th percentile male

Red = 5th female lumbar compression higher than 50th male

Yellow = 5th female compression within 10% of 50th male

Green = 5th female lumbar compression lower than 50th male

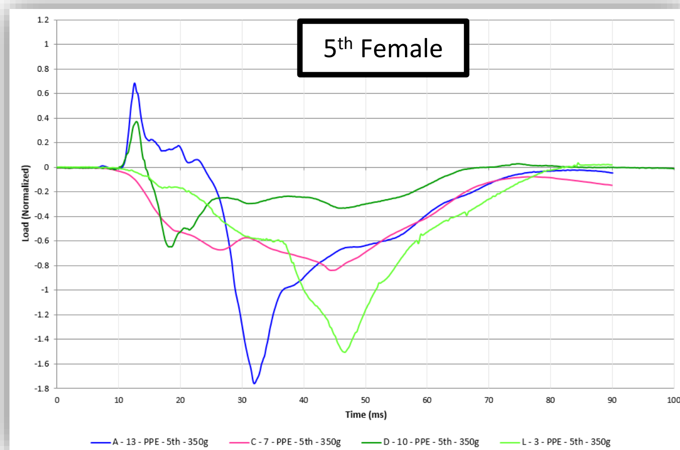
Lumbar Compression – 350 g

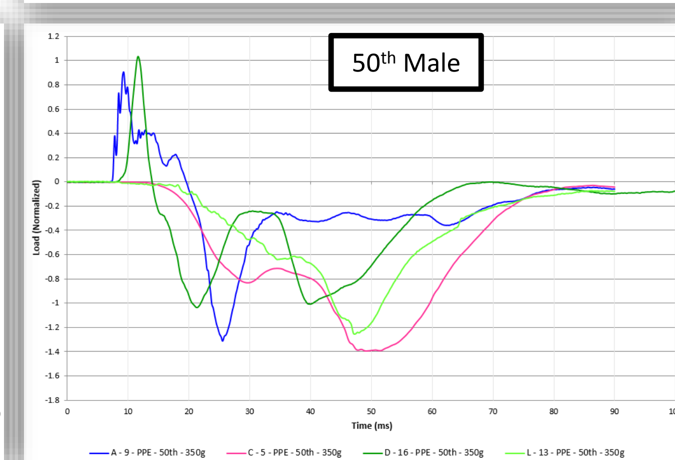


Seat ID	Test Number	ATD	Lumbar Fz Peak Compression [Normalized]	Difference in Average Peak Lumbar Compression*
A	13	5th	1.76	+35%
A	9	50th	1.30	
C	7	5th	0.84	-32%
C	8	5th	1.07	
C	5	50th	1.39	
C	6	50th	1.39	
D	10	5th	0.65	-34%
D	11	5th	0.71	
D	3	50th	N/A	
D	16	50th	1.04	
L	3	5th	1.50	+31%
L	8	5th	1.99	
L	9	5th	1.73	
L	24	5th	1.31	
L	25	5th	2.02	
L	13	50th	1.31	

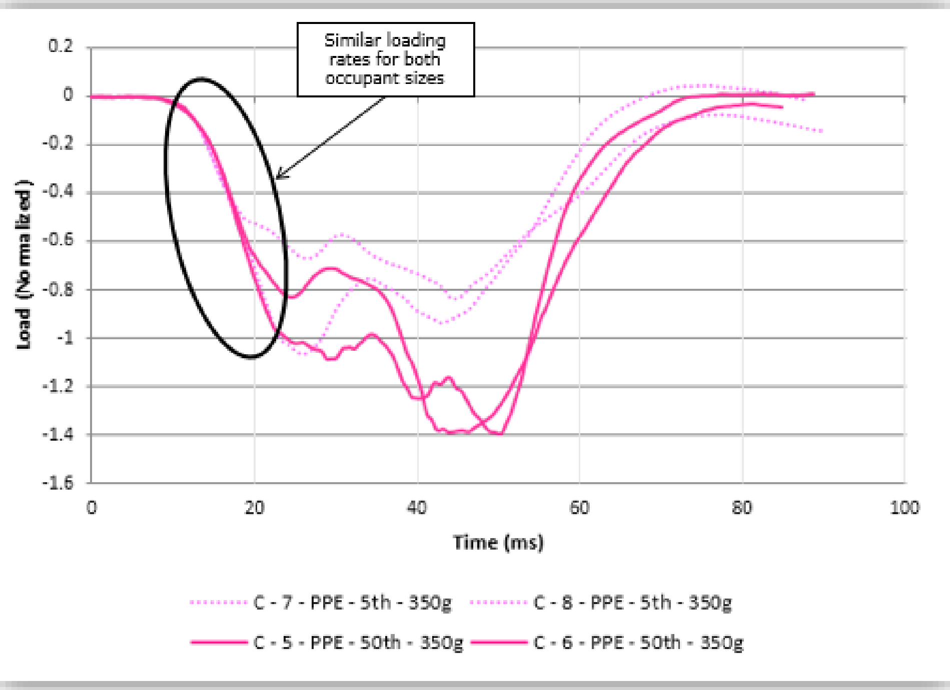
* '+' denotes 5th percentile female lumbar load is greater than 50th percentile male

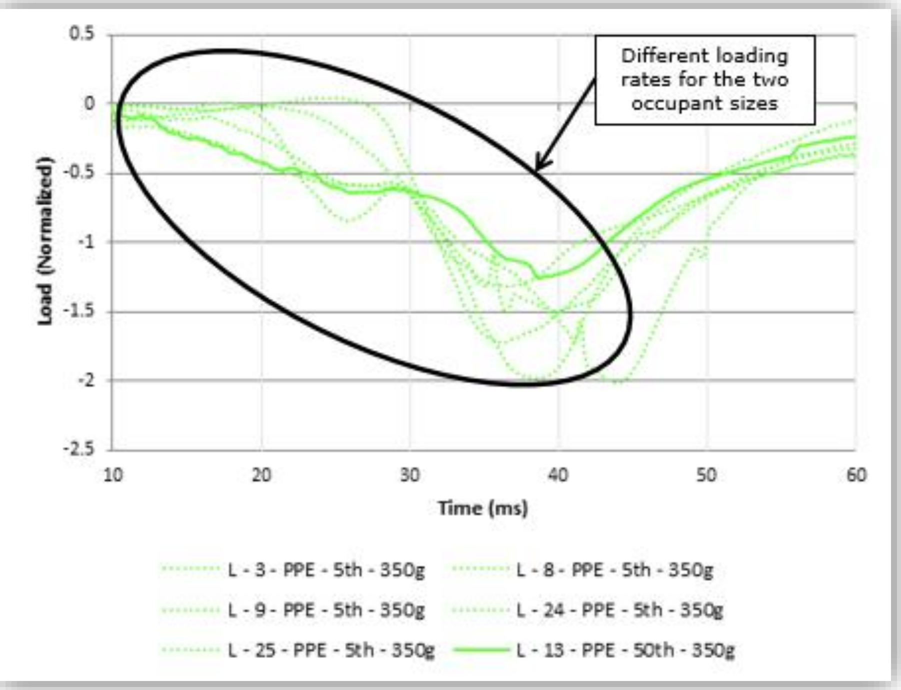
- No distinct trend at 350 g for peak lumbar compression based on occupant size
- All tests at 350 g had lumbar compression below the IARV threshold
- Lumbar traces show large variations in seat response (similar to 200 g)





Lumbar Compression

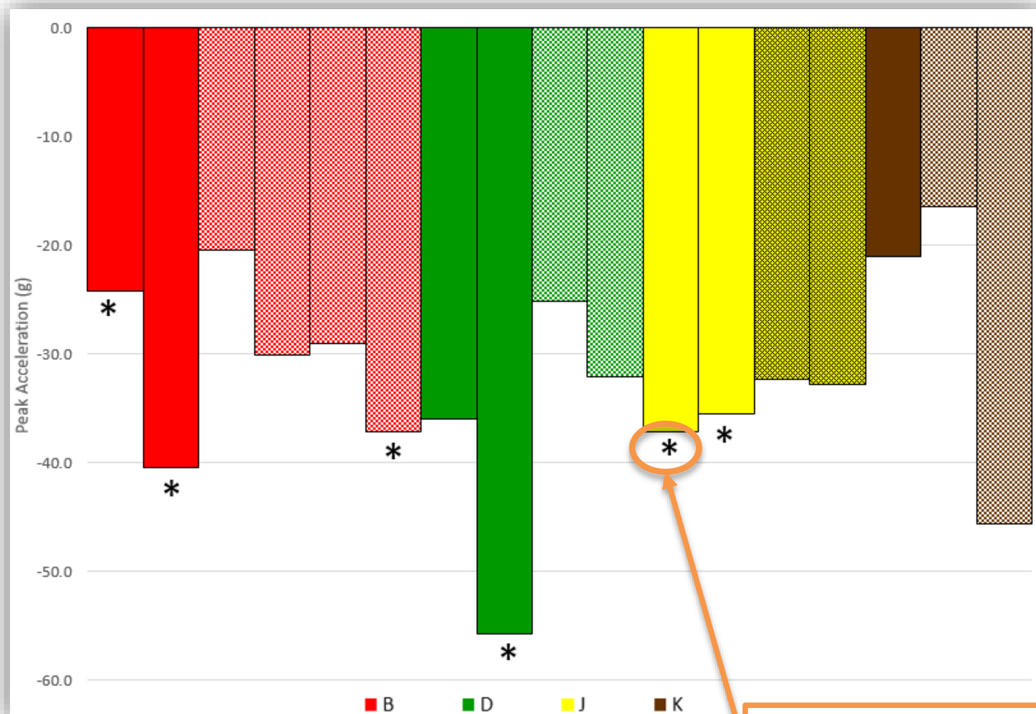




- Slope of initial onset compression loading was also compared for the two occupants
- Majority of tests showed that initial compression rate was very similar between the 5th female and 50th male ATD across almost all seat models
- Seat C features initial loading rates for both occupant sizes that are almost identical during the initial ramping period
- Seats L and K, which are variations of the same seat model, featured the most varied loading rates with a less distinct trend between the two occupant sizes

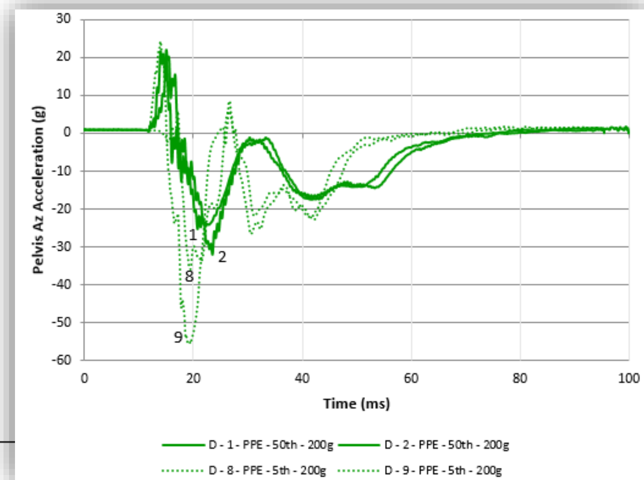
Pelvis Acceleration – 200 g

- Pelvis data was noisy or unusable in several series
- 5th female is more likely to have a higher pelvis acceleration for each seat configuration

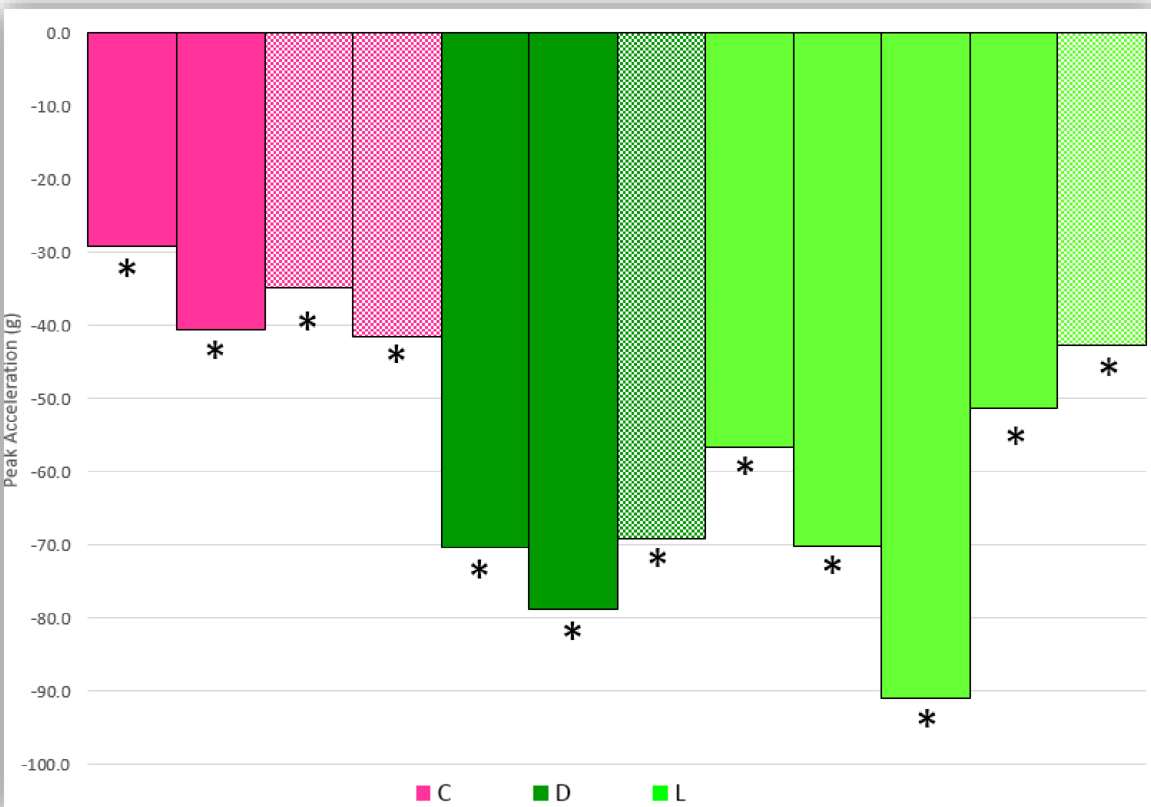


* = exceeded relative IARV limit for lumbar compression

Seat ID	Test Number	ATD	Average Peak Accel (g)	Difference in Average Peak Accel*
B	3	5th	-32.3	+10%
B	4	5th		
B	1	50th	-29.2	
B	2	50th		
B	11	50th		
B	12	50th		
D	8	5th	-45.8	+46%
D	9	5th		
D	1	50th	-28.7	
D	2	50th		
J	4	5th	-36.3	+11%
J	5	5th		
J	6	50th	-32.6	
J	7	50th		
K	2	5th	-21.1	-38%
K	10	50th	-31.1	
K	26	50th		
K	27	50th		

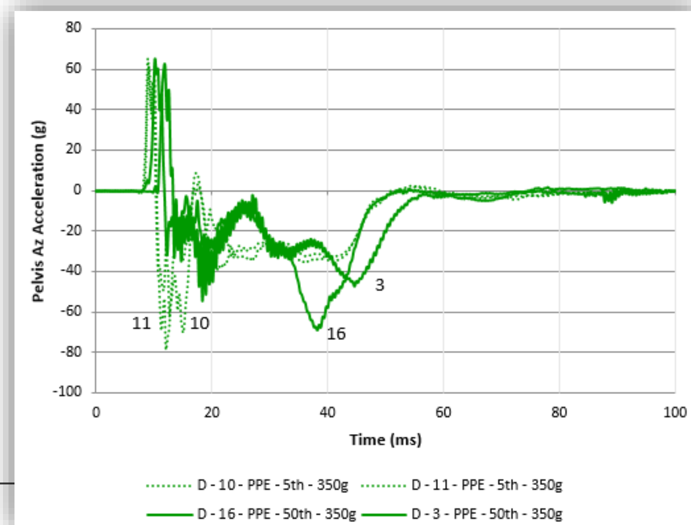


Pelvis Acceleration – 350 g

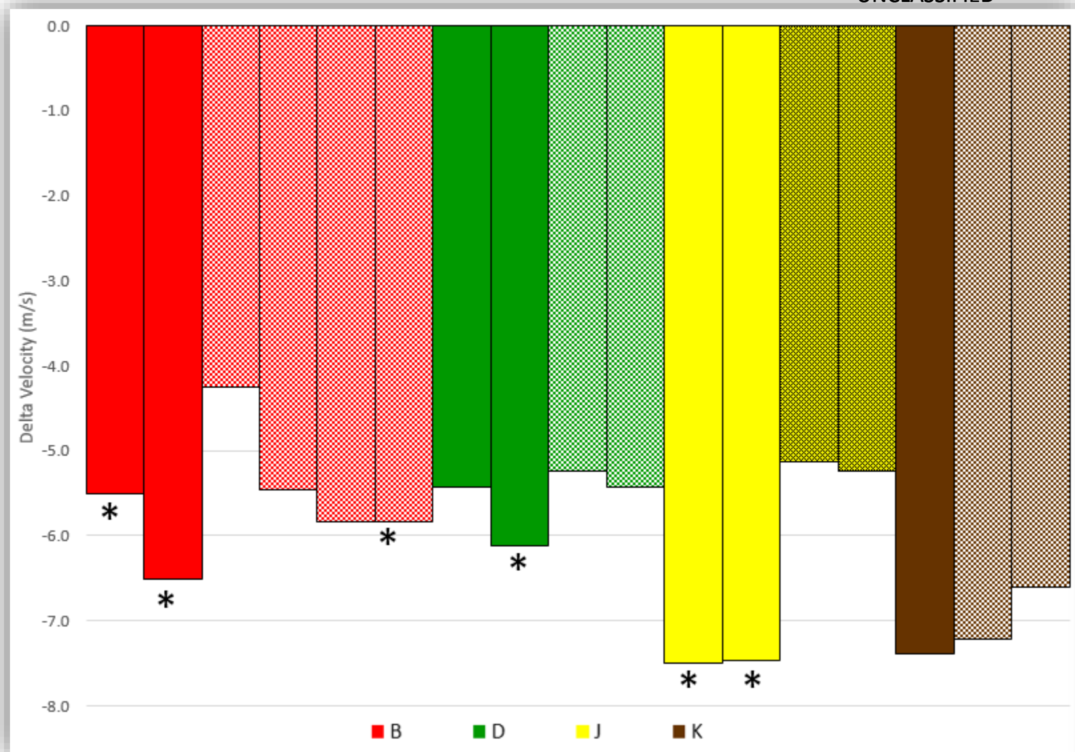


Seat ID	Test Number	ATD	Average Peak Accel (g)	Difference in Average Peak Accel*
C	7	5th	-34.9	-9%
C	8	5th		
C	5	50th	-38.3	
C	6	50th		
D	10	5th	-74.5	+7%
D	11	5th		
D	3	50th	-69.2	
D	16	50th		
L	3	5th	-67.3	+44%
L	8	5th		
L	9	5th		
L	24	5th		
L	25	5th		
L	13	50th	-42.8	

- 5th female is more likely to have a higher pelvis acceleration at 350 g
- Seat design greatly affects peak pelvis acceleration
  - Seat performance is not equal
- Seat D tested at both drop severities
  - Pelvis acceleration reaction differences varied (+46% vs +7%)
  - Seat D is sensitive to occupant size with varying drop heights



Pelvis Velocity – 200 g



Seat ID	Test Number	ATD	Average Velocity (m/s)	Difference in Velocity*
B	3	5th	-6.0	+12%
B	4	5th		
B	1	50th	-5.3	
B	2	50th		
B	11	50th		
B	12	50th		
D	8	5th	-5.8	+8%
D	9	5th		
D	1	50th	-5.3	
D	2	50th		
J	4	5th	-7.5	+36%
J	5	5th		
J	6	50th	-5.2	
J	7	50th		
K	2	5th	-7.4	+7%
K	10	50th	-6.9	
K	26	50th		
K	27	50th		

- Pelvis velocity calculated from integral of pelvis accelerometer
- Peak velocity is higher for 5th female for every seat
- Length of accelerative loading period affected peak velocity
- In general, 5th female usually has a higher peak velocity, but 50th male has a higher lumbar compressive force

Pelvis Velocity – 350 g

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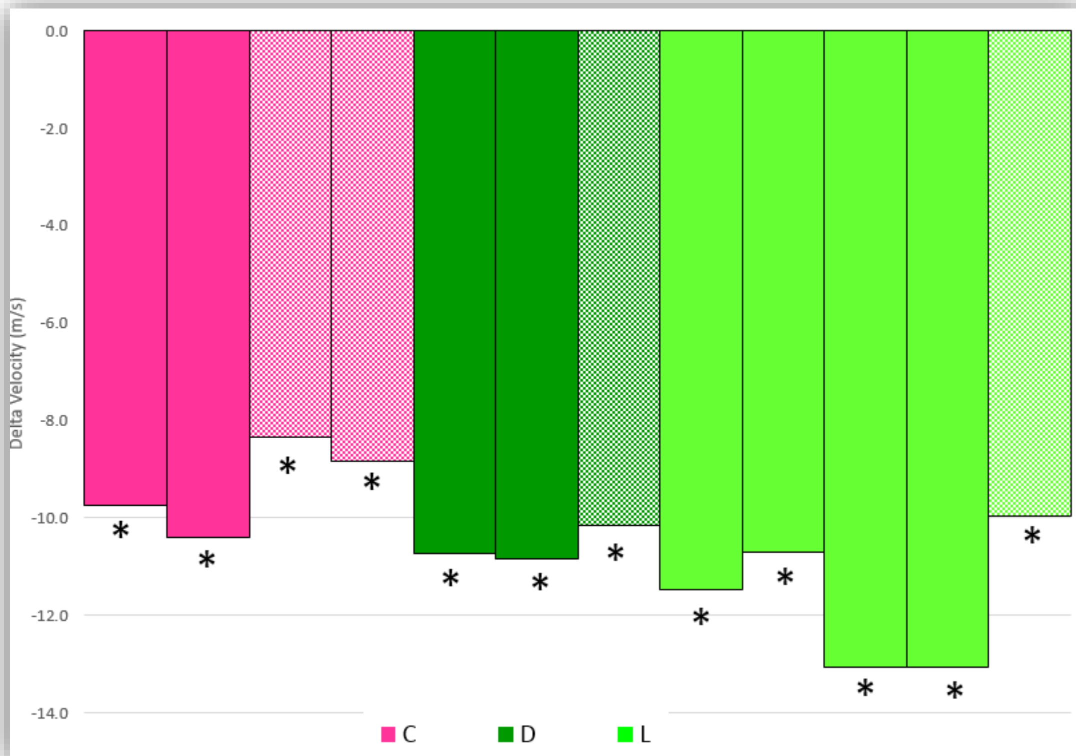
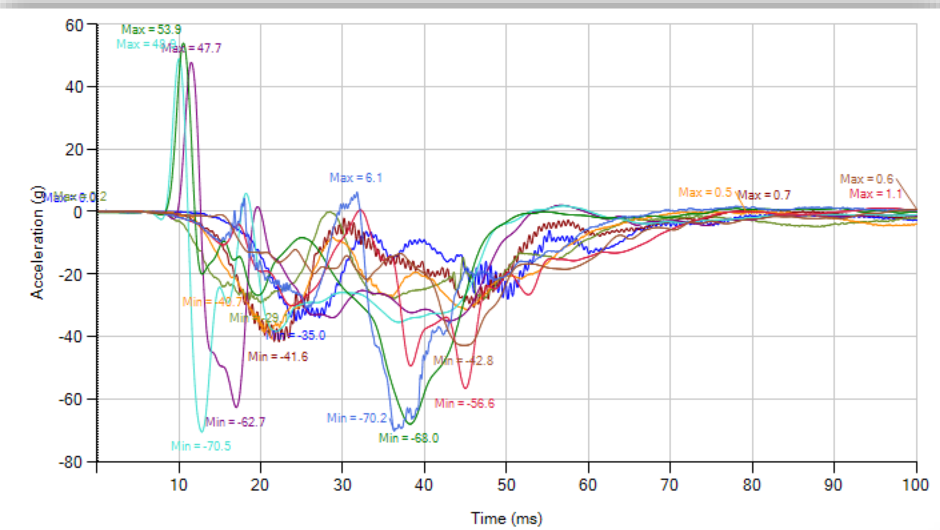
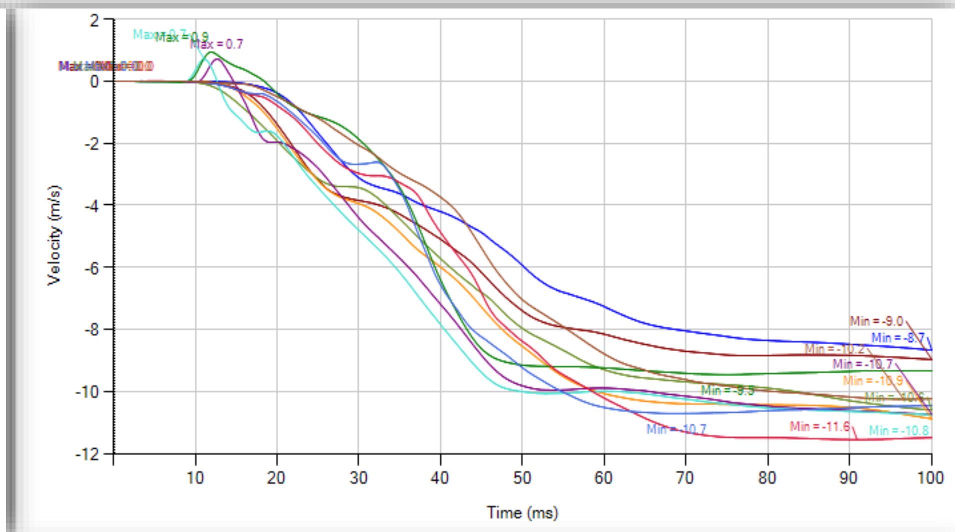


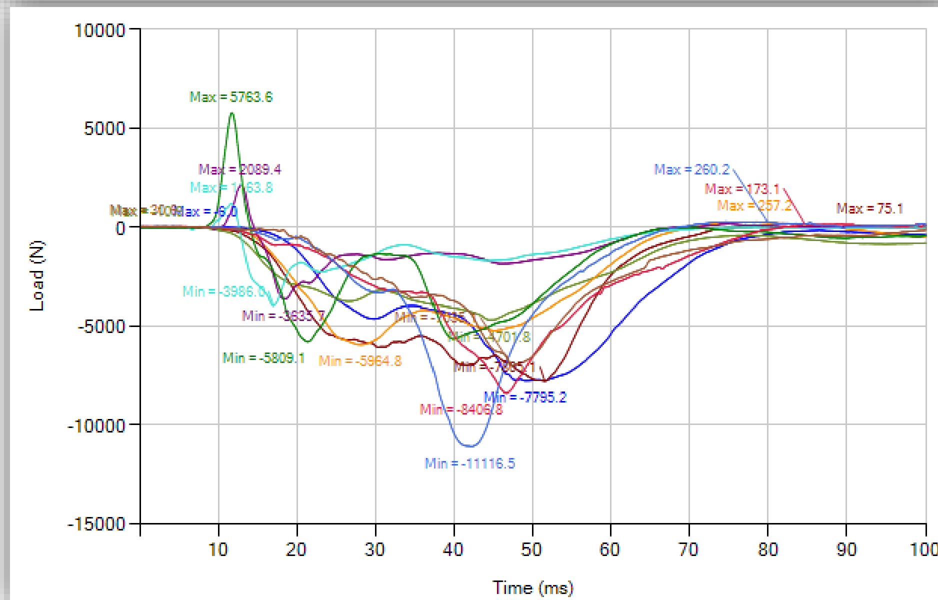
Seat ID	Test Number	ATD	Average Velocity (m/s)	Difference in Velocity*
C	7	5th	-10.1	+16%
C	8	5th		
C	5	50th	-8.6	
C	6	50th		
D	10	5th	-10.8	+6%
D	11	5th		
D	3	50th	-10.2	
D	16	50th		
L	3	5th	-12.1	+19%
L	8	5th		
L	9	5th		
L	24	5th		
L	25	5th		
L	13	50th	-10.0	

- 5th female consistently has higher pelvis velocity at 350 g
- Velocities tend to equal out across seat models at higher drop height
- In general, 5th female usually has a higher peak velocity, but 50th male has a higher lumbar compressive force

Seat Performance Variance







- 350 g runs plotted for pelvis acceleration, velocity, and lumbar compression
- Data shows wide variance in pelvis and lumbar response due to occupant size and seat performance
- Overall effect of seat performance less pronounced for pelvis velocity
- Seat velocity and dynamic displacement not recorded for this test series
  - Would provide key information for effectiveness of seat
  - Displacement/time history data should be recorded for all future test series

Conclusions/Future Work

- Data analysis confirmed assumption that seat design plays a significant role in pelvis and lumbar outputs
- Some of the current seats tested are able to adequately protect both the 50th male and 5th female
- Energy attenuation performance varies as a factor of occupant size
- Effectiveness of EA mechanism determined by lumbar compression
- Future seat designs must account for a wide range of occupant weights
- Further understanding of dynamic stroke properties of EA mechanisms and their effect on lumbar compression are key to improving seat designs

- Future work:
  - Continued interfacing with seat manufacturers to broaden occupant protection range
  - Record dynamic stroke on all drop tower tests to evaluate correlation between displacement rate and lumbar compression


QUESTIONS?