U.S. ARMY TANK AUTOMOTIVE RESEARCH, DEVELOPMENT AND ENGINEERING CENTER

Blast Mitigation Seat Analysis – Assessment of the Effect of Personal Protective Equipment on the 5th Percentile Female Anthropomorphic Test Devices Performance in Drop Tower Evaluations

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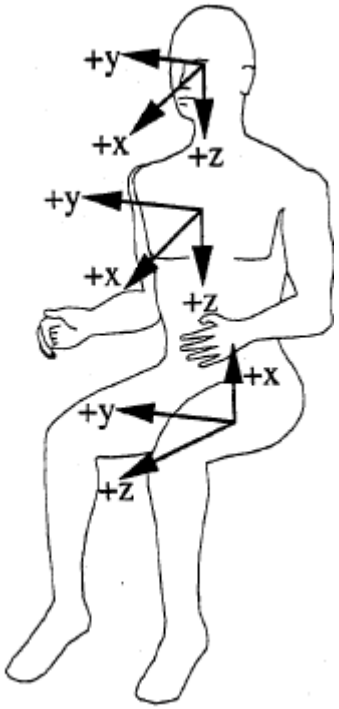
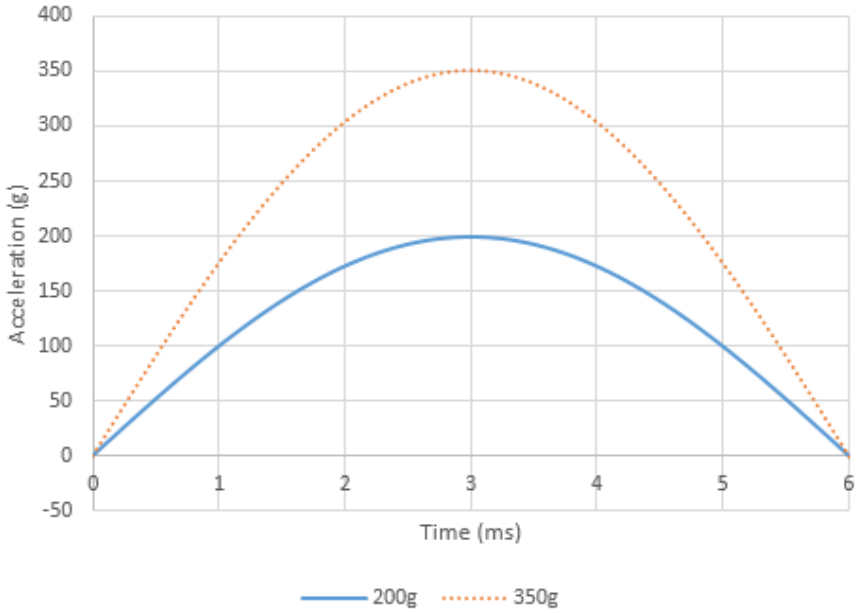
Testing Background

- 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
- ATD data quality-checked and preliminary comparisons conducted
- Testing completed with:
  - 5th percentile Female ATDs
  - With or without personal protective equipment (PPE)
  - 200 g or 350 g pulse
- ATD injury assessment values compared to Occupant Centric Protection (OCP) Injury Assessment Reference Values (IARVs)
- ATD data channels recorded includes:
  - Accelerations
    - Head (Resultant, HIC15, HIC36)
    - Chest (Resultant)
    - Pelvis (DRI)
  - Forces/Moments
    - Upper Neck
    - Lumbar
    - Femur
    - Upper Tibia
    - Lower Tibia



Testing Background

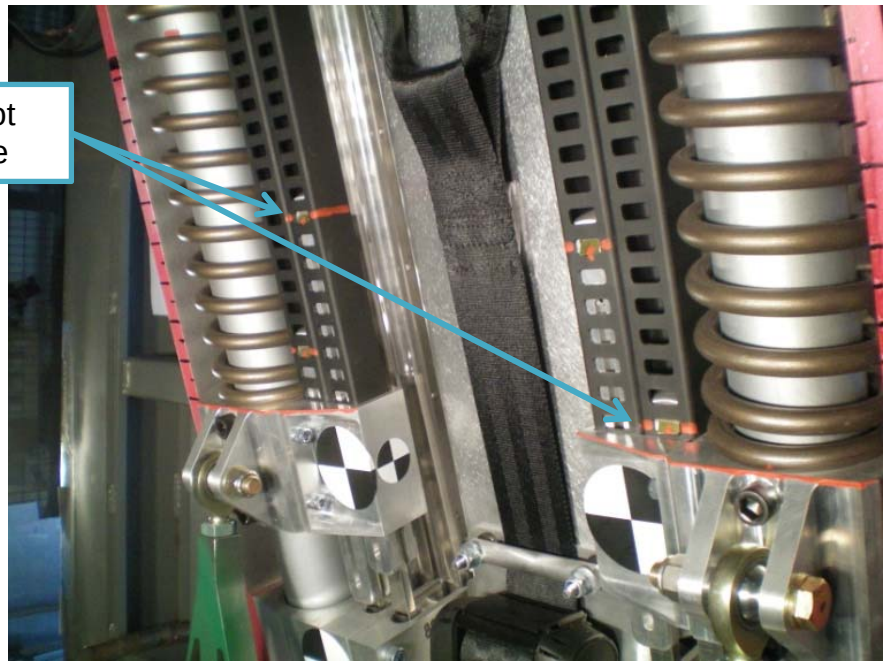
- Drop tower located at TARDEC Occupant Protection (OP) Laboratory
- Testing simulated the initial vertical loading event during an underbody blast
- Pulse profile variables include:
  - Maximum acceleration
  - Time to peak
  - Delta velocity
- Pulse profile tuning is achieved by changing:
  - Drop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



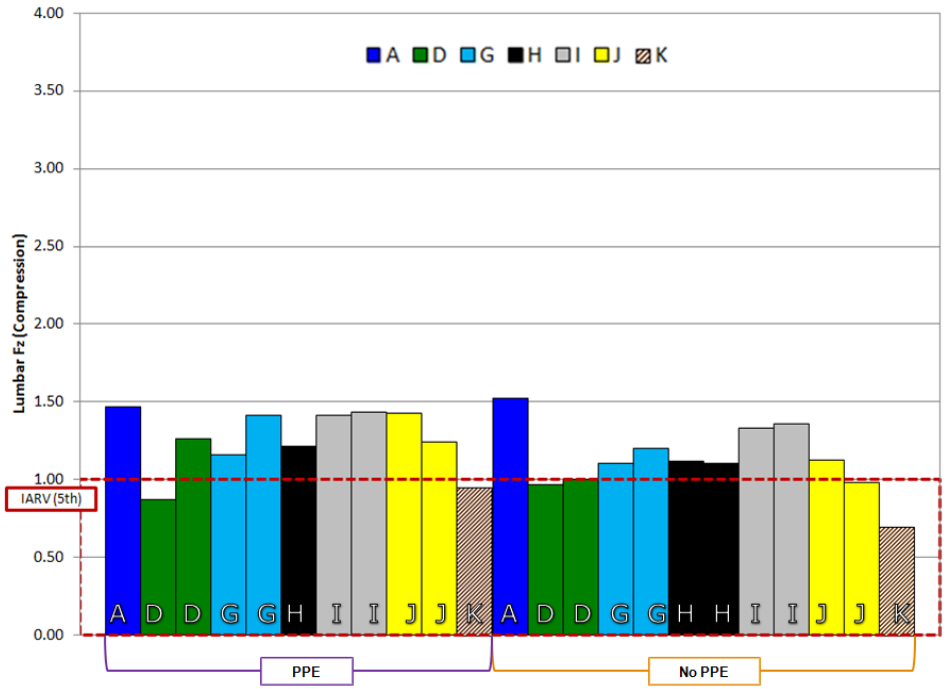
	200 g		350 g		
	PPE	No PPE	PPE	No PPE	Total
A	1	1	1	1	4
B	2				2
C			2	2	4
D	2	2	2	2	8
E	1		1		2
F		4		2	6
G	2	2	2	2	8
H	2	2			4
I	2	2			4
J	2	2		1	5
K	1	1			2
L			6		6
Total	15	16	14	10	**55**

Data Caveats

- Caution should be used in directly comparing test results to each other based on differences in:
  - Test setup (ATD positioning, reusing seats)
  - Energy absorption devices
  - Suitability of each seat based on occupant size and impulse
- Seats were reused in multiple tests, so some seats experienced issues that may have affected results
  - Energy absorption malfunctions
  - Deformation to seat frames
- Limited data sets pose challenges in drawing concrete conclusions such as the effects of PPE
- Lab HVAC temperature was variable; unknown effects on data
- Impact velocity not recorded
- Rebound of platform resulted in higher delta velocity than impact velocity
- All caveats have not yet been identified



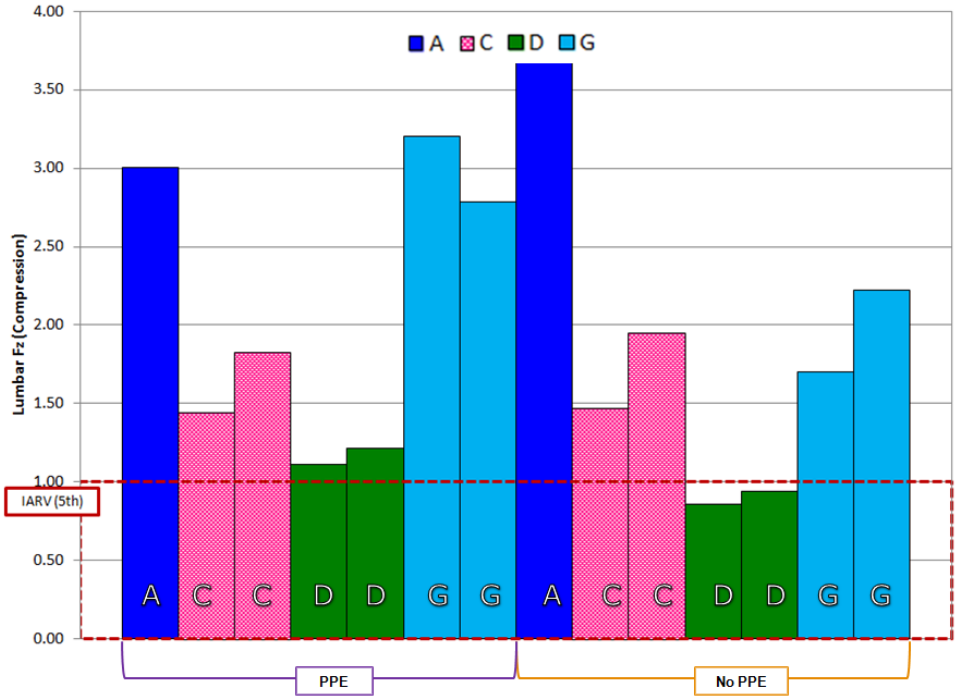
Lumbar FZ Compression Normalized – 200 g



- Data normalized against 5th percentile female ATD OCP IARVs
- Addition of PPE at 200 g for all but one seat model caused an increase in lumbar compression

Seat ID	Test Number	Configuration	Lumbar Peak Compression Load [Normalized]	Change in Lumbar Peak Compression Load due to PPE
A	3	PPE	1.47	-4%
A	5	No PPE	1.53	
D	8	PPE	0.87	+8%
D	9	PPE	1.26	
D	4	No PPE	0.97	
D	5	No PPE	1.01	
G	5	PPE	1.16	+12%
G	6	PPE	1.41	
G	1	No PPE	1.10	
G	2	No PPE	1.20	
H	3	PPE	1.21	+9%
H	5	No PPE	1.12	
H	6	No PPE	1.10	
I	3	PPE	1.42	+6%
I	4	PPE	1.43	
I	5	No PPE	1.33	
I	6	No PPE	1.36	
J	4	PPE	1.43	+27%
J	5	PPE	1.24	
J	1	No PPE	1.12	
J	2	No PPE	0.98	
K	2	PPE	0.95	+36%
K	1	No PPE	0.70	

Lumbar FZ Compression Normalized – 350 g



Seat ID	Test Number	Configuration	Lumbar Peak Compression Load [Normalized]	Change in Lumbar Peak Compression Load due to PPE
A	13	PPE	3.00	-22%
A	15	No PPE	3.86	
C	7	PPE	1.44	-4%
C	8	PPE	1.83	
C	9	No PPE	1.47	
C	10	No PPE	1.95	
D	10	PPE	1.11	+30%
D	11	PPE	1.22	
D	6	No PPE	0.86	
D	7	No PPE	0.94	
G	7	PPE	3.20	+52%
G	7a	PPE	2.78	
G	3	No PPE	1.70	
G	4	No PPE	2.23	

- Half of the seats tested resulted in increases of 30% to 52% in lumbar compression load
- Other two seats evaluated produced decreases of lumbar compression of -4% and -22%

Upper Neck FZ Compression Normalized – 200 g

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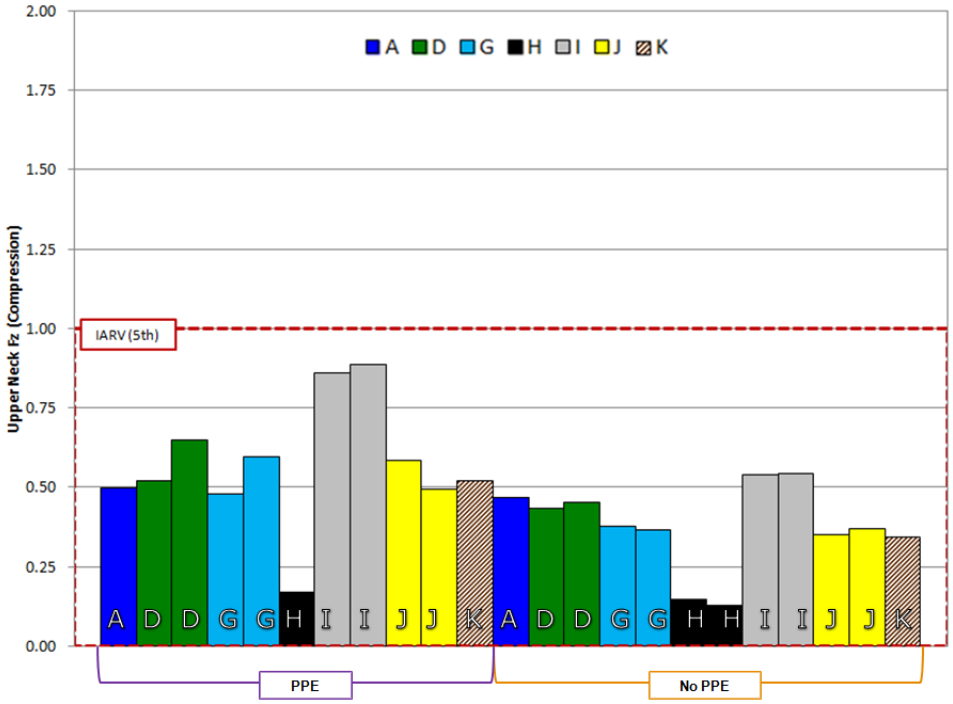
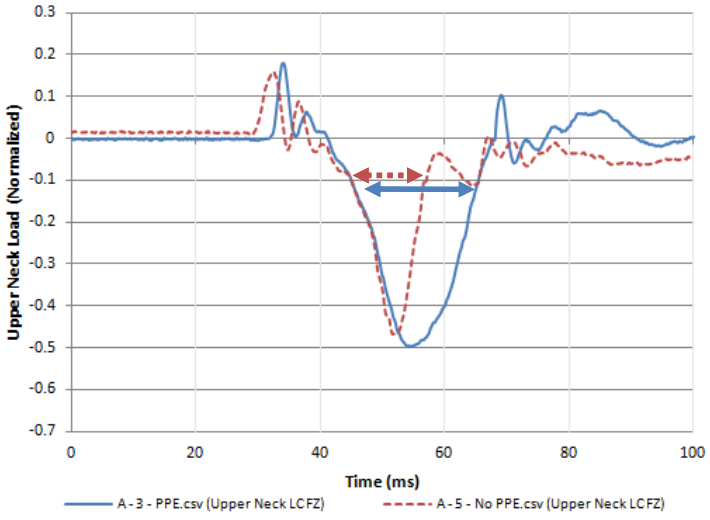
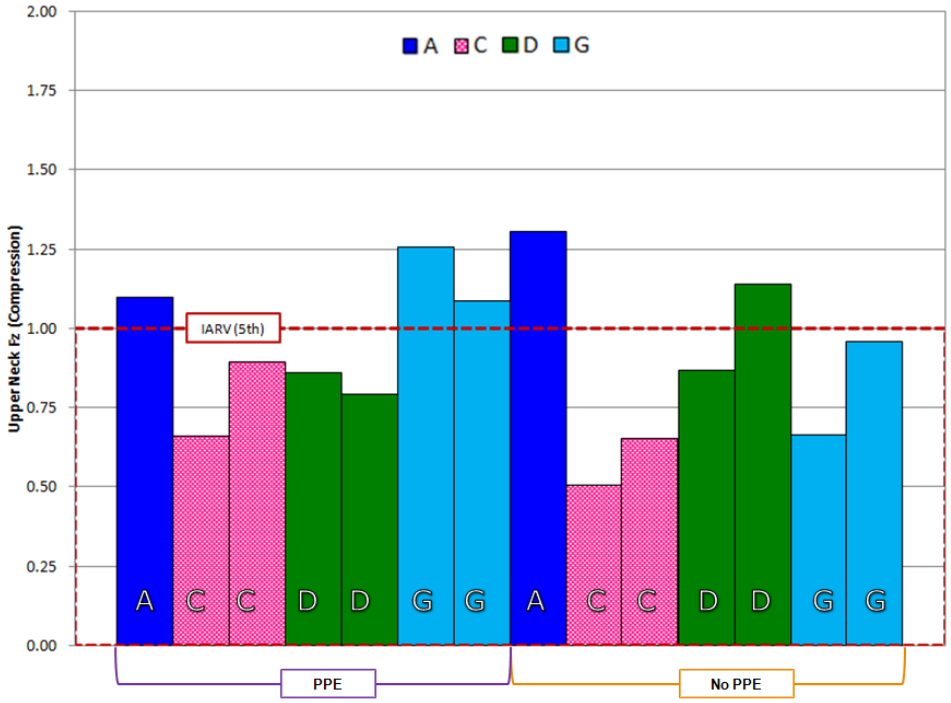




Seat ID	Test Number	Configuration	Upper Neck Fz Peak Compression [Normalized]	Change in Upper Neck Peak Compression due to PPE
A	3	PPE	0.50	+7%
A	5	No PPE	0.47	
D	8	PPE	0.52	+32%
D	9	PPE	0.65	
D	4	No PPE	0.43	
D	5	No PPE	0.45	
G	5	PPE	0.48	+47%
G	6	PPE	0.60	
G	1	No PPE	--	
G	2	No PPE	0.37	
H	3	PPE	0.65	+44%
H	5	No PPE	0.47	
H	6	No PPE	0.44	
I	3	PPE	0.86	+61%
I	4	PPE	0.89	
I	5	No PPE	0.54	
I	6	No PPE	0.54	
J	4	PPE	0.58	+50%
J	5	PPE	0.50	
J	1	No PPE	0.35	
J	2	No PPE	0.37	
K	2	PPE	0.52	+51%
K	1	No PPE	0.34	

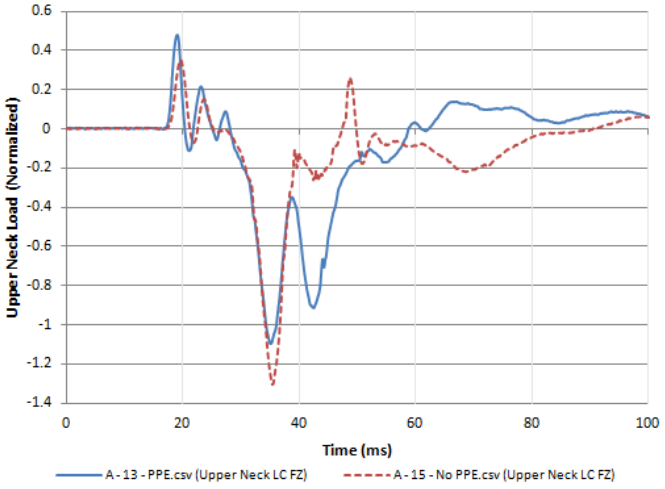
- ACH (helmet) adds more than 50% to weight sustained by ATD above upper neck load cell
- Addition of the helmet at the lower drop height resulted in increases ranging from 7% to 61% across seat models
- ACH weight (blue curve) tends to increase the duration of the load sustained by the upper neck due to mass recruitment effects

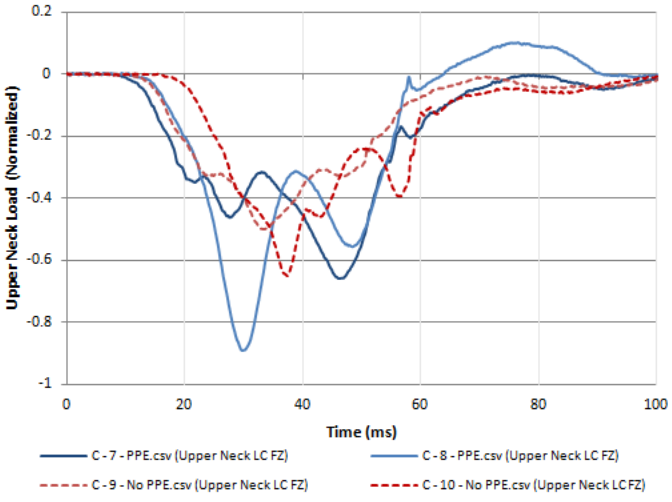
Upper Neck FZ Compression Normalized – 350 g



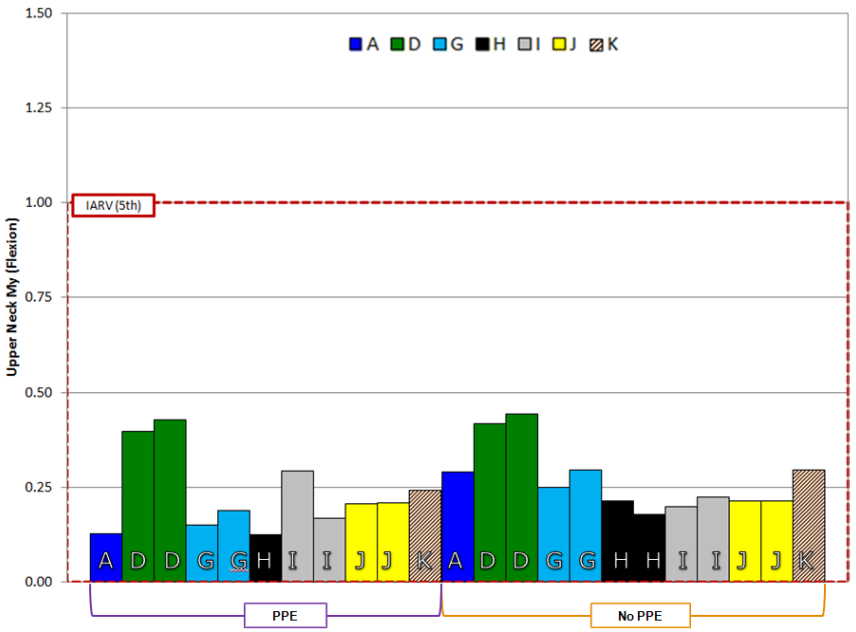
Seat ID	Test Number	Configuration	Upper Neck Fz Peak Compression [N]	Change in Upper Neck Peak Compression due to PPE
A	13	PPE	1.10	-16%
A	15	No PPE	1.30	
C	7	PPE	0.66	+35%
C	8	PPE	0.89	
C	9	No PPE	0.50	
C	10	No PPE	0.65	
D	10	PPE	0.86	-18%
D	11	PPE	0.79	
D	6	No PPE	0.87	
D	7	No PPE	1.14	
G	7	PPE	1.26	+45%
G	7a	PPE	1.09	
G	3	No PPE	0.66	
G	4	No PPE	0.96	

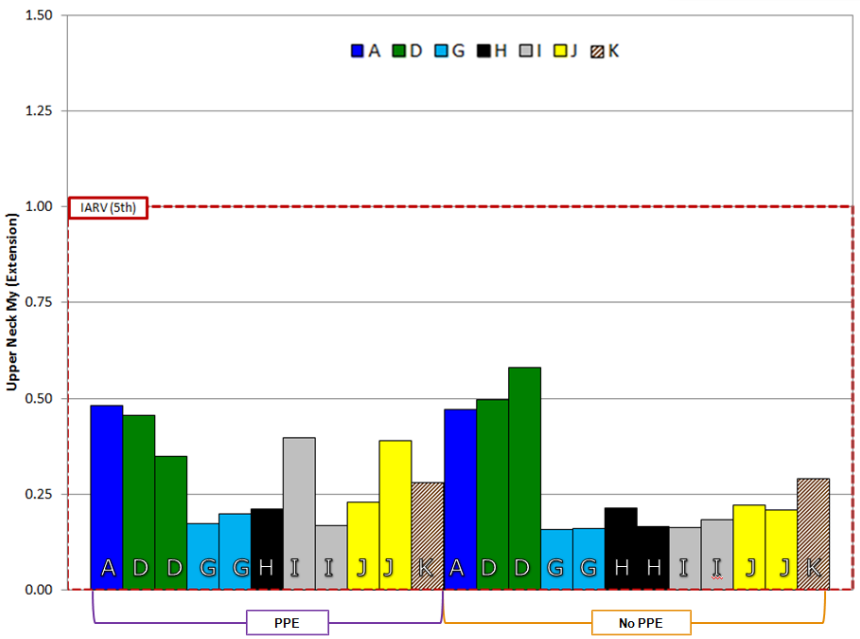
- Half of the seats tested at 350 g resulted in increases of in upper neck compression load, similar to lumbar
- Trends in loading duration are not as consistent at 350 g with addition of PPE (blue)





Upper Neck Moments Normalized – 200 g



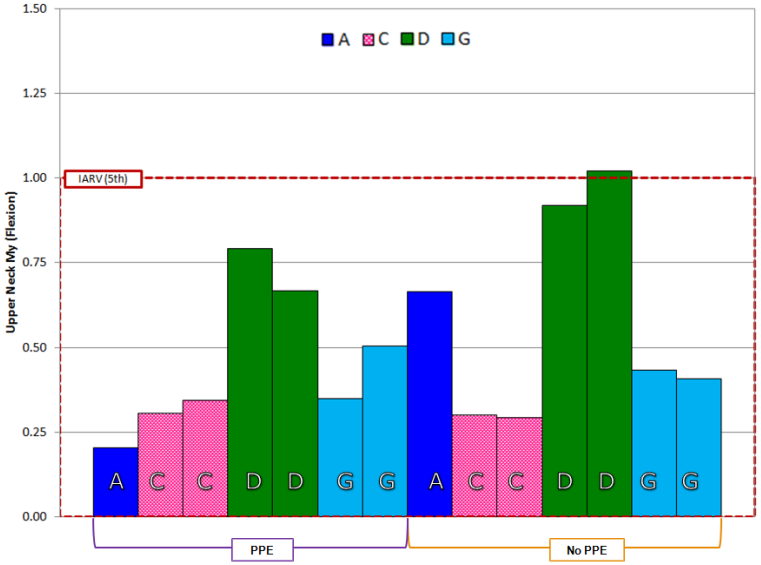


Seat ID	Test Number	Configuration	Upper Neck Peak Flexion [Normalized]	Change in Upper Neck Peak Flexion due to PPE
A	3	PPE	0.13	-56%
A	5	No PPE	0.29	
D	8	PPE	0.40	-4%
D	9	PPE	0.43	
D	4	No PPE	0.42	
D	5	No PPE	0.44	
G	5	PPE	0.15	-38%
G	6	PPE	0.19	
G	1	No PPE	0.25	
G	2	No PPE	0.30	
H	3	PPE	0.12	-37%
H	5	No PPE	0.21	
H	6	No PPE	0.18	
I	3	PPE	0.29	+9%
I	4	PPE	0.17	
I	5	No PPE	0.20	
I	6	No PPE	0.22	
J	4	PPE	0.21	-3%
J	5	PPE	0.21	
J	1	No PPE	0.21	
J	2	No PPE	0.21	
K	2	PPE	0.24	-18%
K	1	No PPE	0.29	

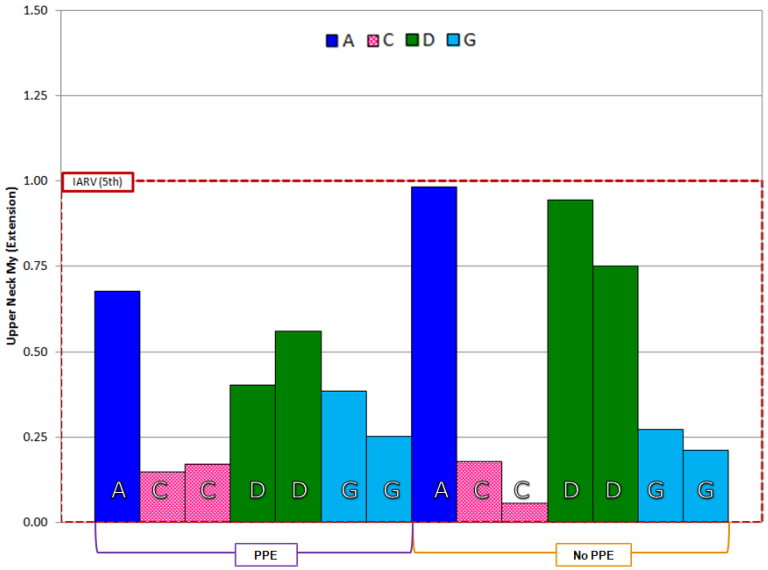
- No definitive trends were noted in upper neck flexion or extension at 200 g
- IARVs were not exceeded for any configuration

Seat ID	Test Number	Configuration	Upper Neck Peak Extension [Normalized]	Change in Upper Neck Peak Extension due to PPE
A	3	PPE	0.48	+2%
A	5	No PPE	0.47	
D	8	PPE	0.46	-25%
D	9	PPE	0.35	
D	4	No PPE	0.50	
D	5	No PPE	0.58	
G	5	PPE	0.17	+17%
G	6	PPE	0.20	
G	1	No PPE	0.16	
G	2	No PPE	0.16	
H	3	PPE	0.21	+10%
H	5	No PPE	0.22	
H	6	No PPE	0.17	
I	3	PPE	0.40	+63%
I	4	PPE	0.17	
I	5	No PPE	0.16	
I	6	No PPE	0.18	
J	4	PPE	0.23	+44%
J	5	PPE	0.39	
J	1	No PPE	0.22	
J	2	No PPE	0.21	
K	2	PPE	0.28	-4%
K	1	No PPE	0.29	

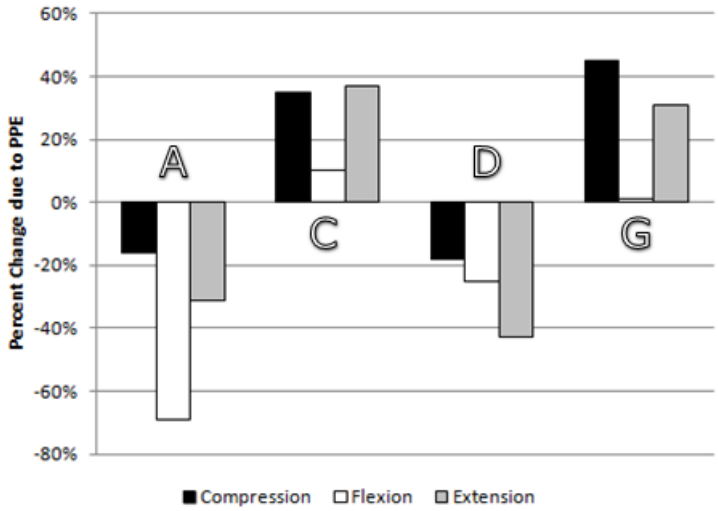
Upper Neck Moments Normalized – 350 g



- No definitive trends were noted in upper neck flexion or extension at 350 g
- ACH effects on flexion and extension followed the same trends as compression at 350 g



Seat ID	Test Number	Configuration	Upper Neck Peak Flexion [Normalized]	Change in Upper Neck Peak Flexion due to PPE
A	13	PPE	0.20	-69%
A	15	No PPE	0.66	
C	7	PPE	0.30	+10%
C	8	PPE	0.34	
C	9	No PPE	0.30	
C	10	No PPE	0.29	
D	10	PPE	0.79	-25%
D	11	PPE	0.67	
D	6	No PPE	0.92	
D	7	No PPE	1.02	
G	7	PPE	0.35	+1%
G	7a	PPE	0.50	
G	3	No PPE	0.43	
G	4	No PPE	0.41	



Seat ID	Test Number	Configuration	Upper Neck Peak Extension [Normalized]	Change in Upper Neck Peak Extension due to PPE
A	13	PPE	0.68	-31%
A	15	No PPE	0.98	
C	7	PPE	0.15	+37%
C	8	PPE	0.17	
C	9	No PPE	0.18	
C	10	No PPE	0.05	
D	10	PPE	0.40	-43%
D	11	PPE	0.56	
D	6	No PPE	0.94	
D	7	No PPE	0.75	
G	7	PPE	0.38	+31%
G	7a	PPE	0.25	
G	3	No PPE	0.27	
G	4	No PPE	0.21	

Conclusions

- The additional mass of PPE on the 5th percentile female is a contributing factor to injury outcomes during drop tower testing in EA seats
  - Advanced Combat Helmet (ACH) [+50% weight above upper neck load cell]
  - Improved Outer Tactical Vest (IOTV) [+55% weight of total ATD]
- Mass recruitment causes higher lumbar compression and upper neck compression forces
  - More pronounced in 200 g testing
  - Less consistent trends at 350 g
- No definitive trends for upper neck flexion or extension due to ACH weight
- The ballistic armor protection of the IOTV and ACH are critical to the safety of the soldier despite the potential for increased injury risk due to the additional weight
- The insight gained during this analysis may be useful for seat manufacturers, as future seat designs need to compensate for the effects of PPE during vertical accelerative loading event





Future Work/Next Steps

- Further detailed analysis of the data is needed to fully comprehend the specific kinetic and kinematic effects of PPE on the small occupant.
- A more detailed timing analysis of the progression of forces and accelerations through the ATD could provide more insight into how the ATD interacts with the seat and PPE
- Future tests to evaluate the effect of PPE on the 5th percentile female ATD could include dynamic seat stroke characterization
- Drop tower data should be compared to live fire data to identify similarities and differences in ATD and seat response
- Further analysis of this data with respect to seat construction may allow an evaluation of seat characteristics to create an optimum seat design
- Repeating this same analysis on the 50th percentile male and 95th percentile male to determine if similar trends occur based on the effect of PPE on larger occupants
- Use lessons learned from data analysis to improve lab procedures and best practices
- Drop tower is currently being moved – lessons learned will be incorporated
- Future test plans can be developed to evaluate seats efficiently