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Booster-seated children in reclined seating configurations.

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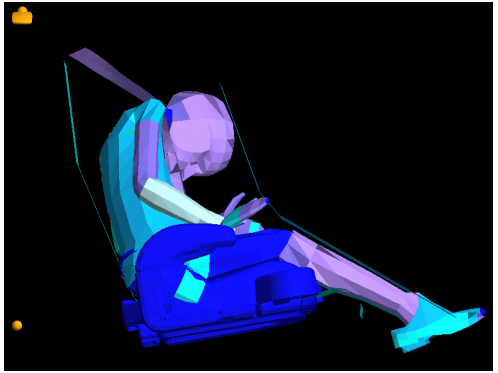
CHILD OCCUPANTS IN RECLINED CONFIGURATIONS

- Children seated behind a reclined occupant:
  - Head impact occurs in Automated Emergency Braking (AEB) events when the front seat is reclined and on mid-rearward track positions (Patton et al 2022).
  - **Head impact** changes based on the **AEB type**?



- Reclined children:
  - Submarining may be prevented by the presence of a BPB, rearward D-ring, and pretensioner (Graci et al 2022, Bohman et al 2022) in frontal crashes
  - What are the **child volunteers' responses** in reclined seats during lateral oblique pre-crash events?

With BPB

no BPB

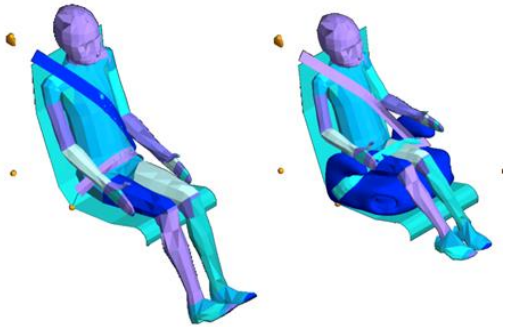
AIMS

1. **Child behind a reclined seat.** To identify how the likelihood and impact velocity of head contact changes with different AEB pulses.
2. **Child in a reclined seat.** To examine reclined child volunteers' responses during lateral-oblique low acceleration events

LIKELIHOOD OF HEAD CONTACT IN AEB

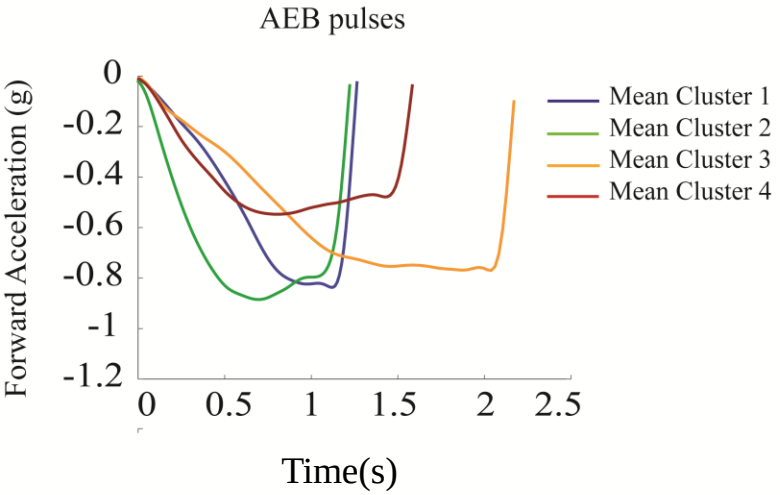
MADYMO CHILD MODELS AND AEB TYPES

- MADYMO child models
  - 6yo (low-back booster)
  - 10yo (no booster)
- AEB pulses based on Graci et al 2021



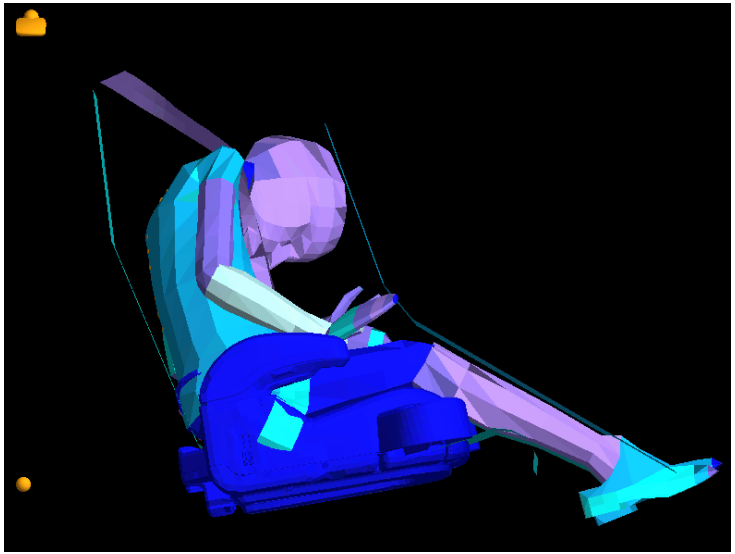
Recline seatback angles:
25°, 45°, 60°

Track positions: Start at aft most position (0 mm) and then move forward by 50 mm increments (25 mm in case of head contact found) up to 250 mm.

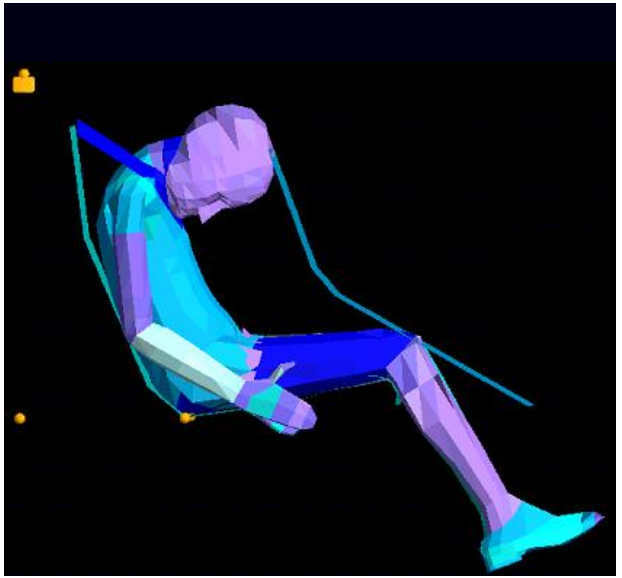


AEB Clusters	Jerk (g/s)	Ramp time (s)	Steady-state acc (g)	Steady state time (s)	Time of Deceleration (s)	Max Dec (g)
1	1.08	0.88	0.91	0.62	1.09	0.94
2	2.24	0.45	0.91	0.13	0.98	0.98
3	0.75	1.21	0.84	0.37	1.97	0.93
4	1.04	0.64	0.58	0.43	1.23	0.66

HEAD CONTACTS WITH A RECLINED FRONT SEAT



Front seat recline = 60 deg
Track position = 50 mm



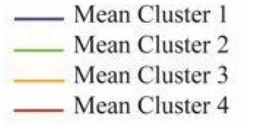
Front seat recline = 60 deg
Track position = 100mm

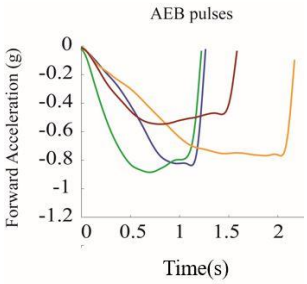
AEB TYPES AND HEAD IMPACT VELOCITY

Position not achievable

Head contact

No head contact





AEB 1 6yo

Recline angle	0	25	50	75	100	125	150	175	200	225	250
60					1.10		0.73		0.08		
45	0.48		0.10		0.5						
25											

(m/s)

Track position

AEB 1 10yo

Recline angle	0	25	50	75	100	125	150	175	200	225	250
60			0.5		0.78		0.29				
45	0.59										
25											

Track position

AEB 2 6yo

Recline angle	0	25	50	75	100	125	150	175	200	225	250
60					1.50		1.08		0.22	0.3	
45	0.99		0.09	0							
25											

Track position

AEB 2 10yo

Recline angle	0	25	50	75	100	125	150	175	200	225	250
60			0.55		1.36		1.17	0.55			
45	1.13		0.30								
25											

Track position

AEB 3 6yo

Recline angle	0	25	50	75	100	125	150	175	200	225	250
60					0.99		0.48		0.22	0.1	
45	0.12		0.09								
25											

Track position

AEB 3 10yo

Recline angle	0	25	50	75	100	125	150	175	200	225	250
60			0.17		0.74		0.22	0.29			
45	0.42		0.12								
25											

Track position

AEB 4 6yo

Recline angle	0	25	50	75	100	125	150	175	200	225	250
60					1.17		0.81		0.12		
45	0.76		0.04								
25											

AEB 4 10yo

Recline angle	0	25	50	75	100	125	150	175	200	225	250
60			0.51		0.88		0.38				
45	0.68										
25											

DISCUSSION

- Head contacts happened in all AEBs, in severe reclined also in more forward track positions
    - Milder AEBs (lower peak acceleration, longer ramp time) showed smaller impact velocity and no head impacts in some reclined/forward track configurations
- “Egg crate” effect with greater recline angle (60 deg), 0-50 mm track position, and the AEB pulse with greater jerk (AEB cluster 2)
- 6 y.o model showed greater impact velocity and more head contacts than the 10 y.o
    - Shoulder slippage in the 6 y.o.→ no active musculature

RECLINED CHILDREN IN PRE-CRASH

PARTICIPANTS

Subject	Age	Gender	Standing Height (cm)	Weight (kg)
1	8	Male	139	30.8
2	6	Female	126	23.1
3	7	Female	131	25.0
4	8	Female	124	24.3
5	7	Male	130	26.3
6	6	Male	122	21.8
		Mean (SD)	**128.7 (6.1)**	**25.2 (3.2)**

- 6 children from 6-8 years old
- 3 females, 3 males
- BMI within 5th and 95th percentile

RECLINED CHILDREN IN PRE-CRASH

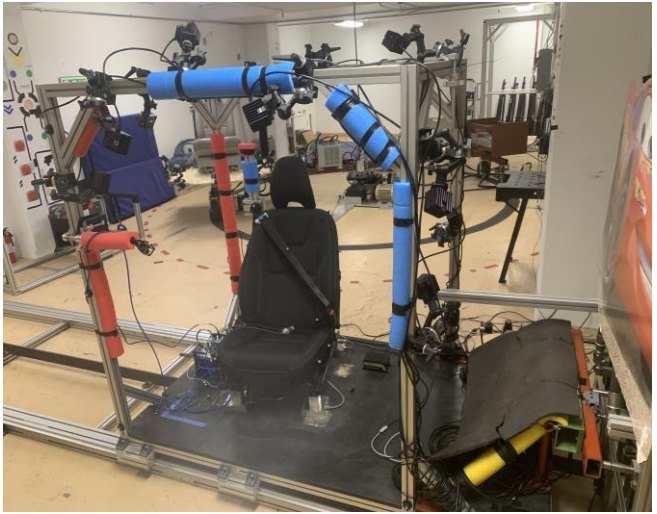
BOOSTER SEATS

- Standard BPB
- 2.3 kg, 21.59 cm height

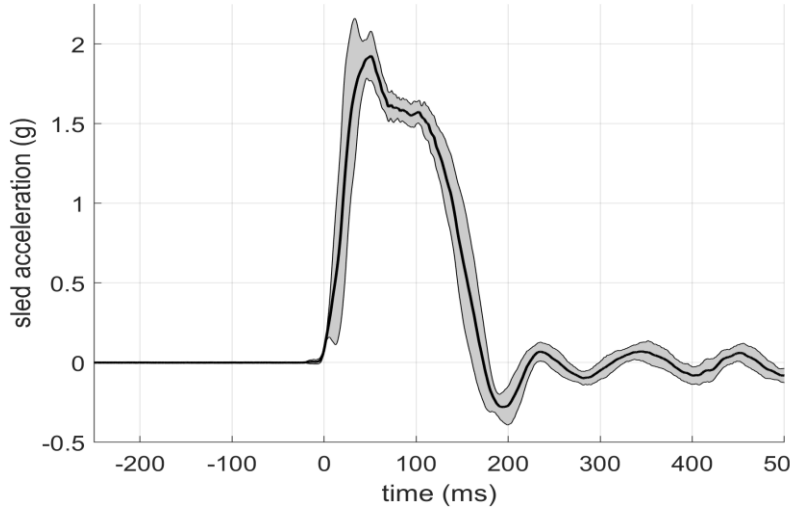
- Lightweight BPB
- 0.91 kg, 16.51 cm height

RECLINED CHILDREN IN PRE-CRASH

LATERAL OBLIQUE 80° FROM FRONTAL LOW ACCELERATION SLED PULSE



Mean max acceleration: 1.9 g
Mean duration: 173 ms



RECLINED CHILDREN IN PRE-CRASH

TEST MATRIX

Booster Type	Recline Angles (°)	Repetitions
Lightweight	25	2
Lightweight	45	2
Lightweight	60	2
Standard	25	2
Standard	45	2
Standard	60	2

Outcome measure:

1. Peak displacement (mm)
   - Head & trunk
   - Lateral & forward
   - Knee-head forward distance
2. Belt peak loads
3. Muscle activation (left and right sternocleidomastoid, trapezii, deltoids, biceps, rectus femoris, tibialis anteriori, rectus abdominus)

RECLINED CHILDREN IN PRE-CRASH

CHILD VOLUNTEERS' RESPONSES

25°

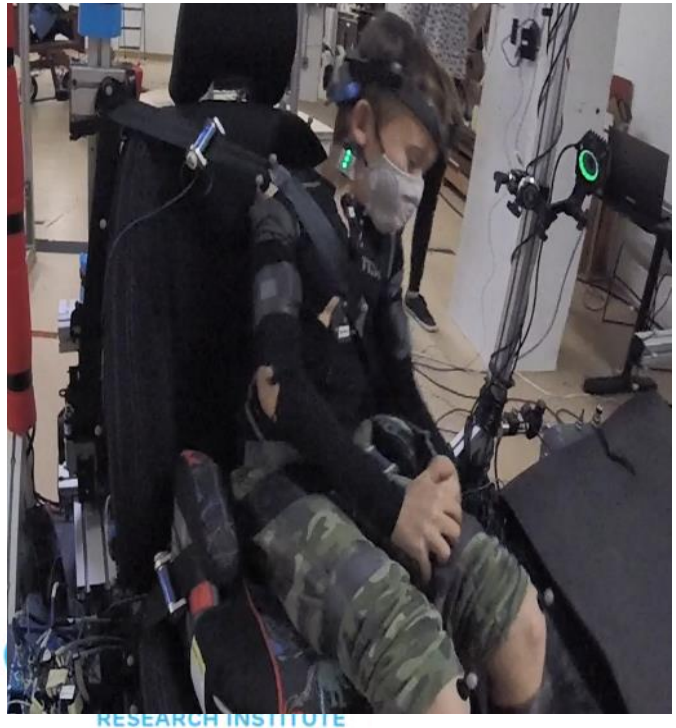
45°

60 °

RECLINED CHILDREN IN PRE-CRASH

CHILD VOLUNTEERS' RESPONSES

25°



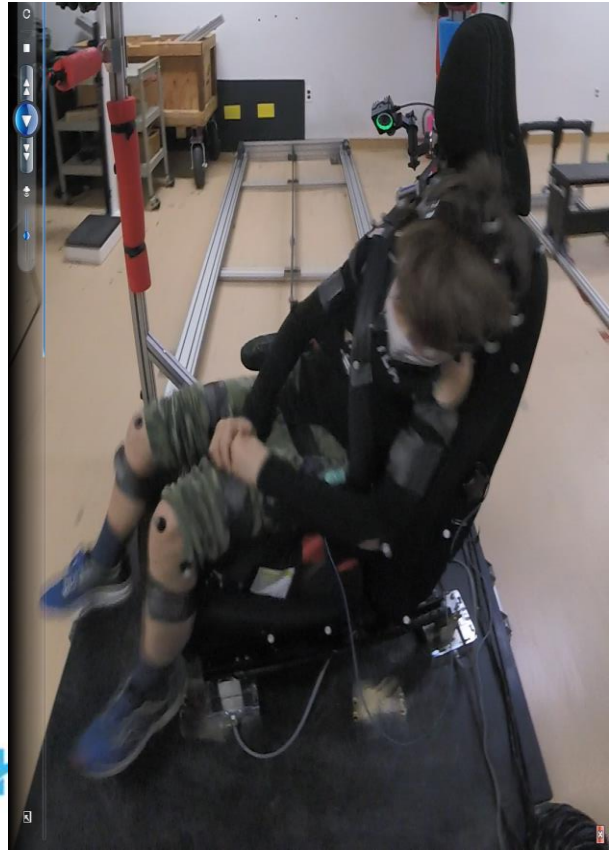
45°

60°

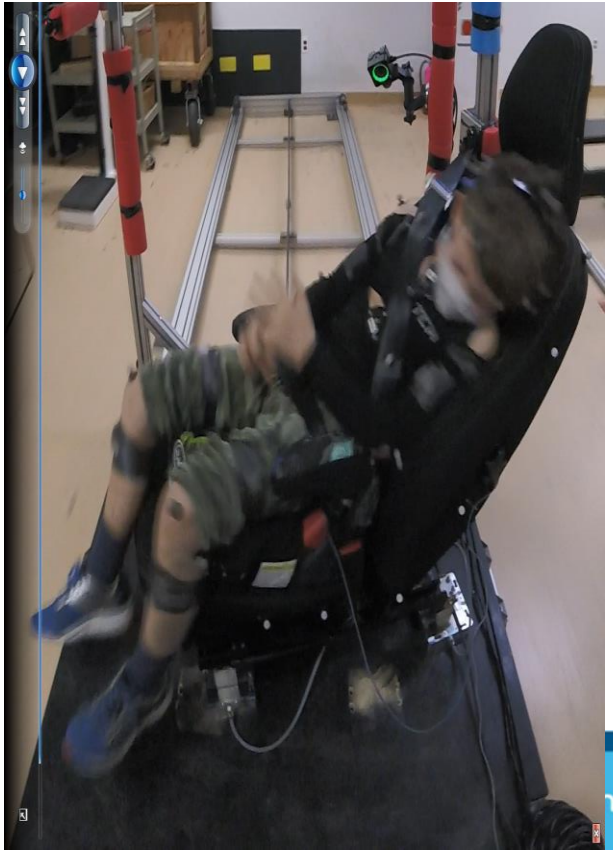
RECLINED CHILDREN IN PRE-CRASH

CHILD VOLUNTEERS' RESPONSES

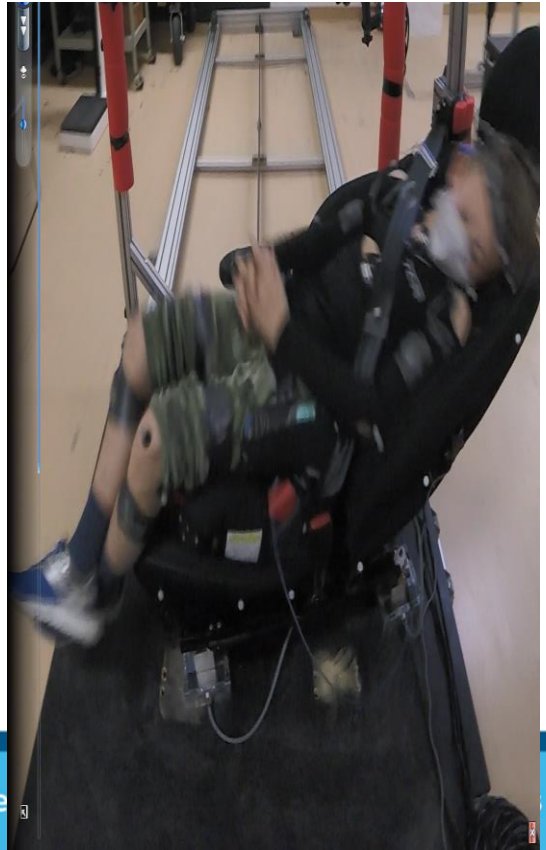
25°



45°

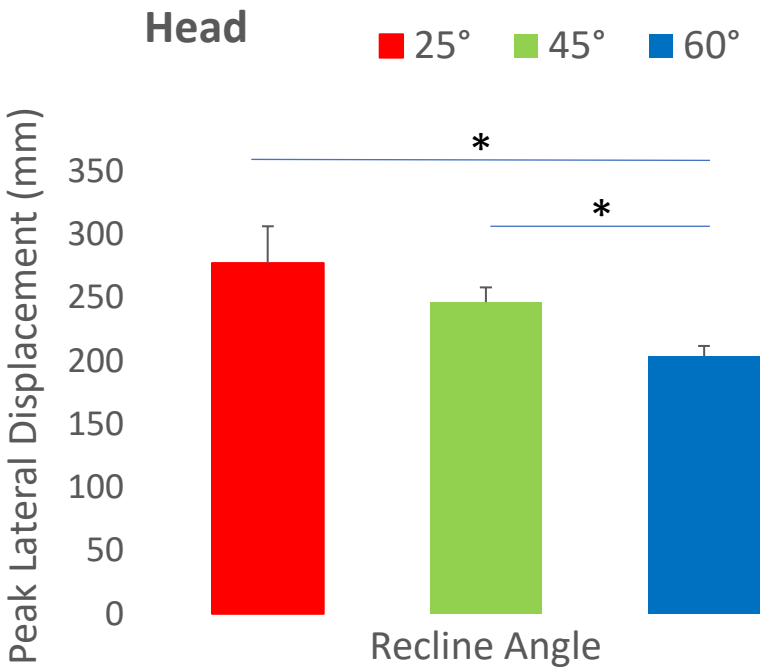


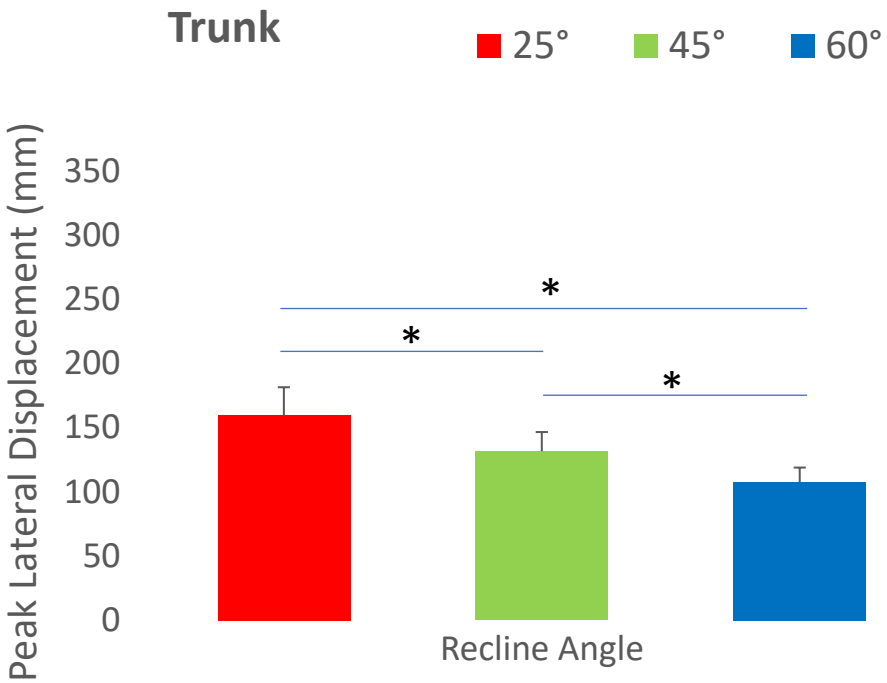
60°



RECLINED CHILDREN IN PRE-CRASH

PEAK LATERAL DISPLACEMENT





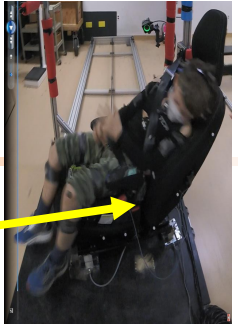
RECLINED CHILDREN IN PRE-CRASH

PEAK FORWARD DISPLACEMENT

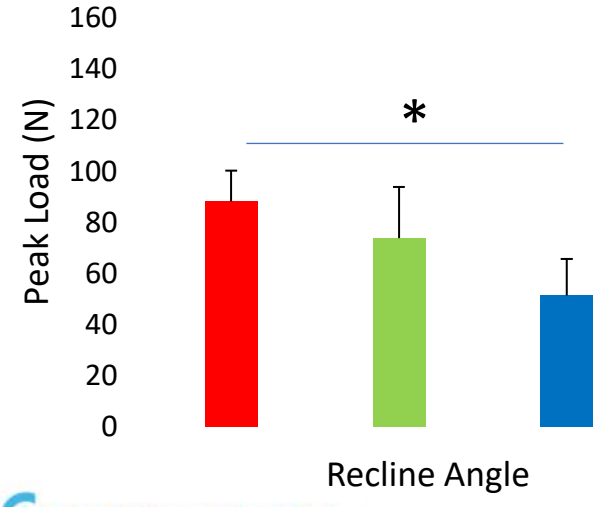
	BPB types	Lightweight			Standard		
		25°	45°	60°	25°	45°	60°
Peak head displacement (mm)	Forward	58 (32)	73 (47)	75 (29)	65 (43)	60 (25)	86 (38)
	Lateral	273 (33)	236 (16)	200 (19)	280 (27)	256 (16)	206 (12)
Peak trunk displacement (mm)	Forward	44 (20)	44 (17)	42 (14)	53 (20)	41 (17)	47 (12)
	Lateral	155 (22)	124 (17)	101 (11)	165 (23)	139 (15)	113 (14)
Knee-head distance (mm)	Forward	41 (30)	52 (44)	49 (17)	38 (45)	23 (17)	43 (31)

RECLINED CHILDREN IN PRE-CRASH

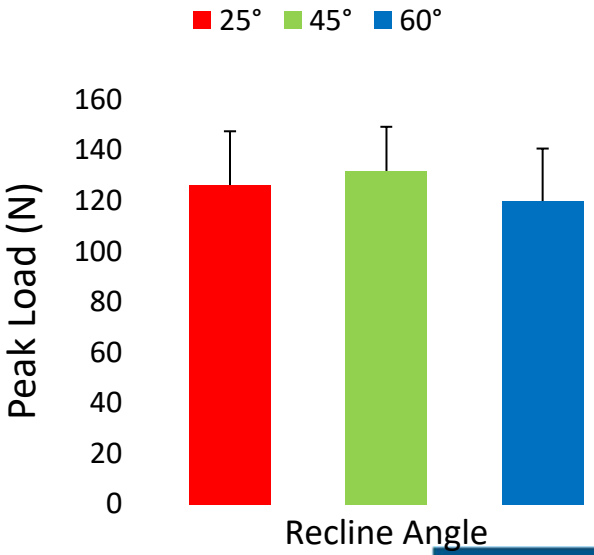
SEAT BELT LOADS



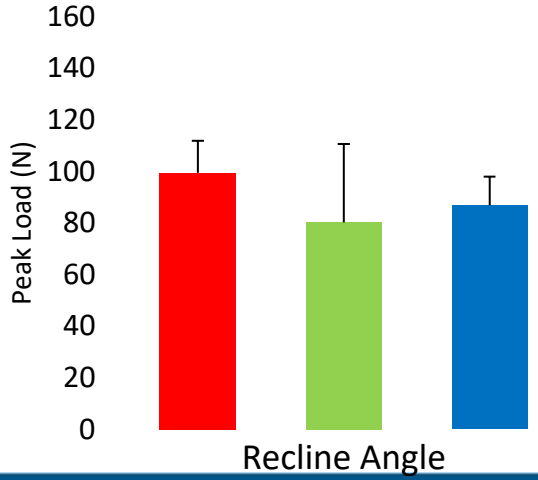
Shoulder Belt Peak Loads



Buckle Lap Belt Peak

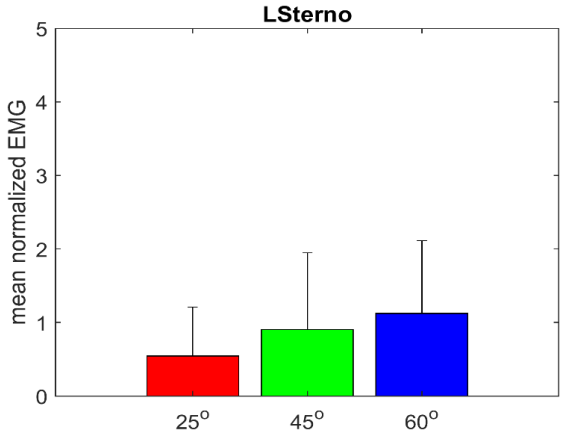


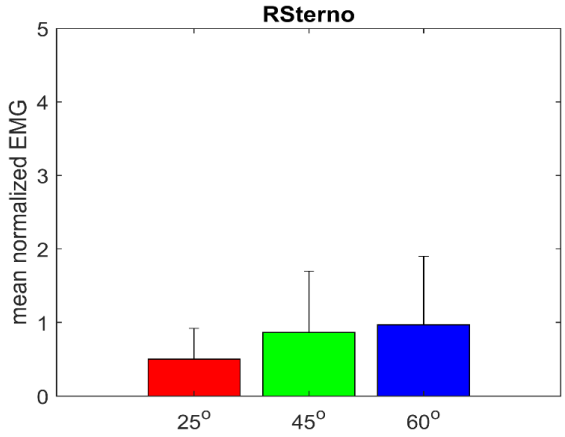
Anchor Lap Belt Peak

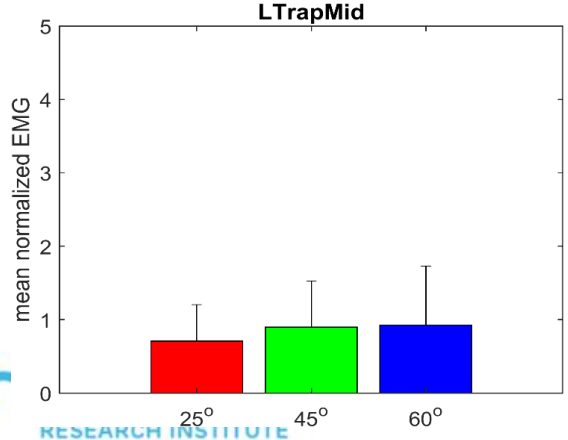


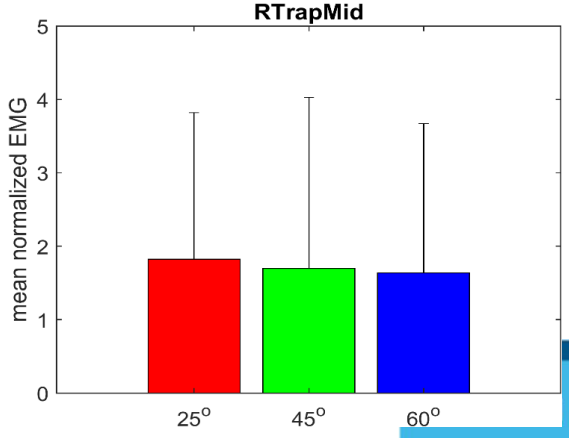
RECLINED CHILDREN IN PRE-CRASH

MUSCLE ACTIVATION



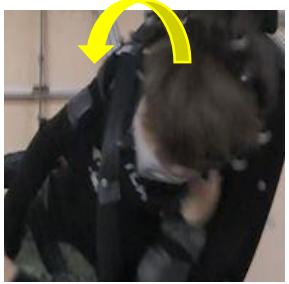






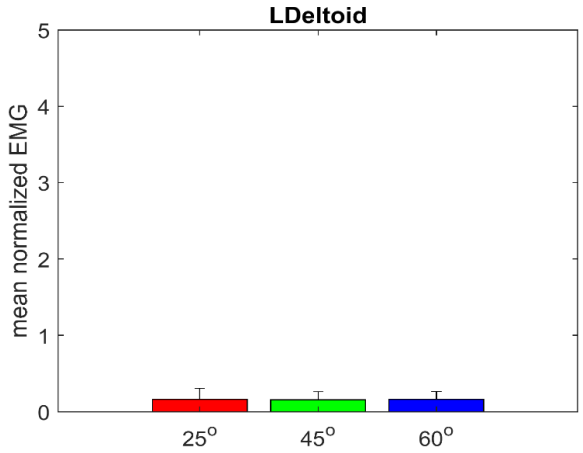
1. Greater bracing with 60→ less head excursion
2. Symmetry in the neck muscle may be sign of startle reflex

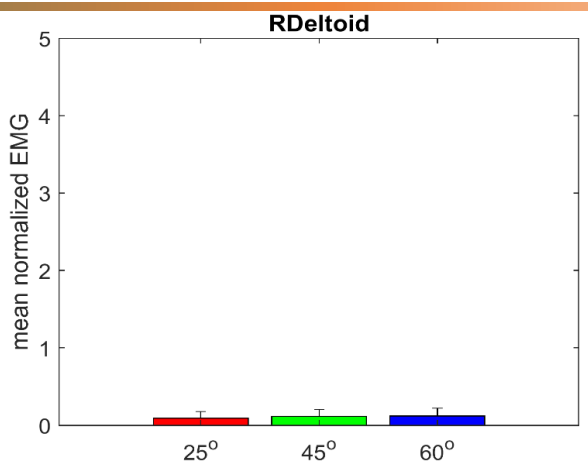
Greater activation on the side of the belt anchor (right)

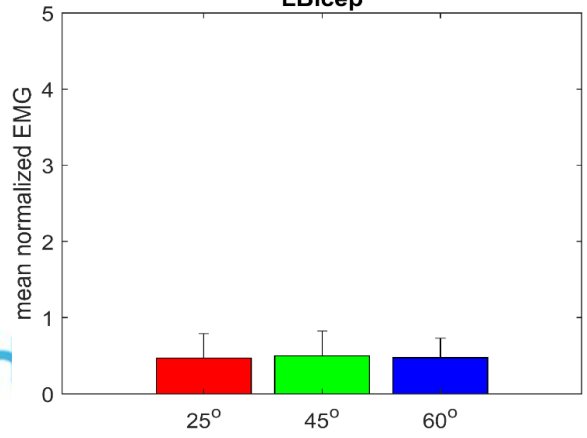


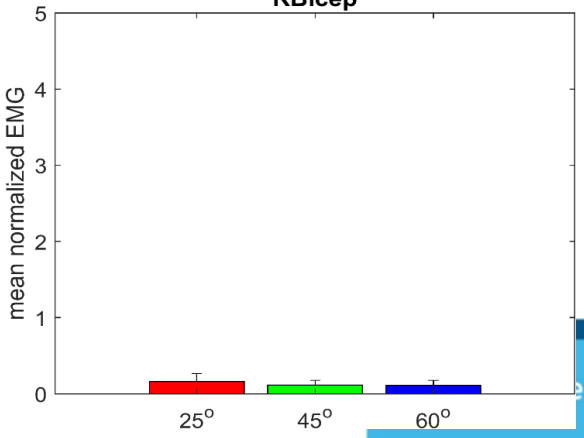
RECLINED CHILDREN IN PRE-CRASH

MUSCLE ACTIVATION





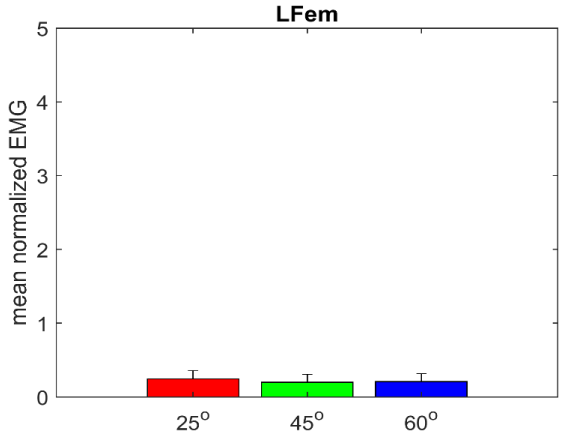


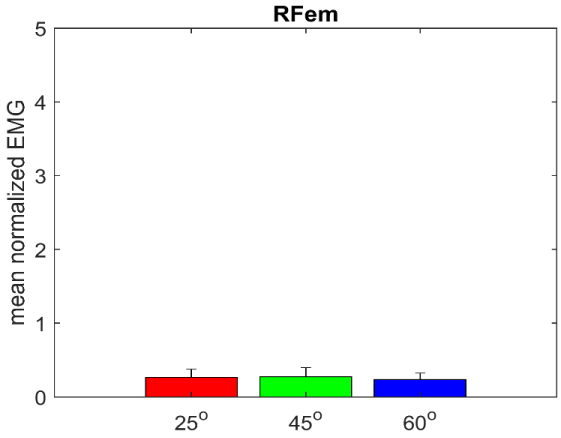


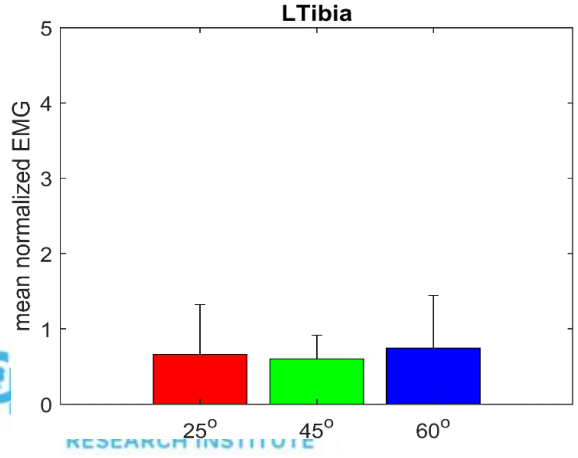
Small arm muscle activation, children did not brace by holding the arm rests.

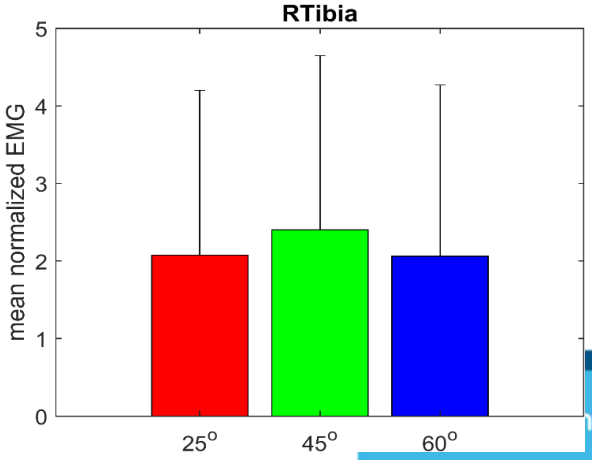
RECLINED CHILDREN IN PRE-CRASH

MUSCLE ACTIVATION

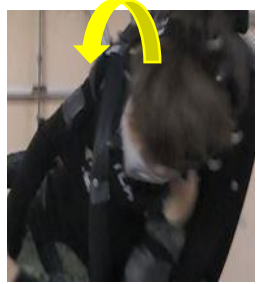








Greater activation on the side of the belt anchor (right)



DISCUSSION

- **Lateral peak head and trunk displacement decreased with increased recline angle in pre-crash**
  - More favorable position within shoulder seatbelt in lateral-oblique pre-crash maneuvers
  - Lower shoulder belt load in reclined conditions, no differences in the lap belt
  - Neck muscles activation increased in reclined→ less lateral motion
  - Subjects tend to roll to the side rather than flex forward with increase recline angle
  - No submarining in pre-crash→ lap belt stayed in place

- **No relevant differences (mm) were found between standard and lightweight BPBs**

TAKE HOME MESSAGE

- Reclined seating configurations in adults will need to consider the effect of these configuration on rear-seated occupants
    - Vehicle interior geometry may need to change
- The effect of different AEB acceleration profiles on occupants in novel seating configurations need to be studied
- Reclined seating configurations in children need further explorations
    - with modern vehicle interiors and seat belt configurations (pre-pretensioner and pretensioner, load limiters etc.)
    - in simulated crashes

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