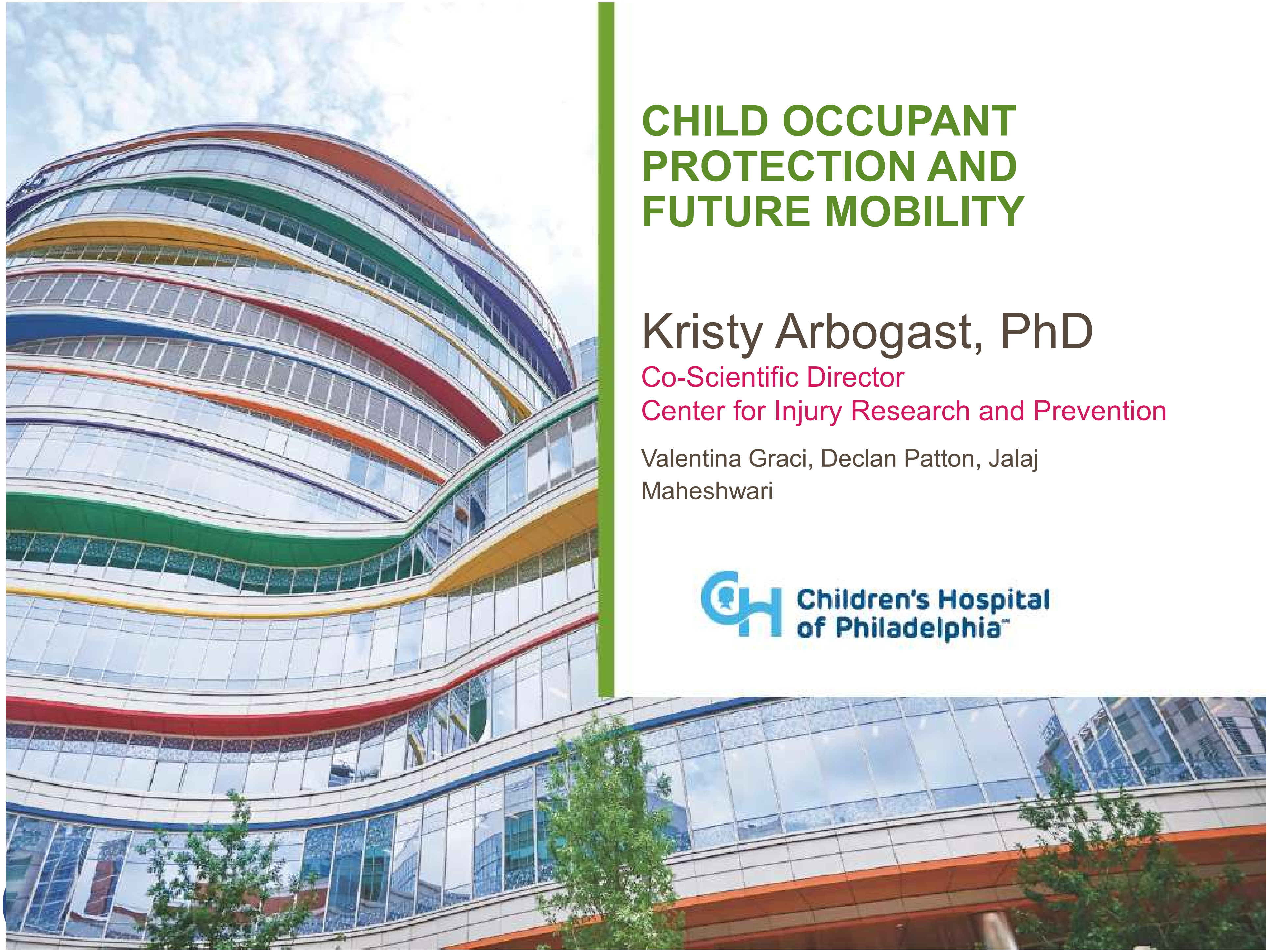


CHILD OCCUPANT PROTECTION AND FUTURE MOBILITY

Kristy Arbogast, PhD

Co-Scientific Director

Center for Injury Research and Prevention

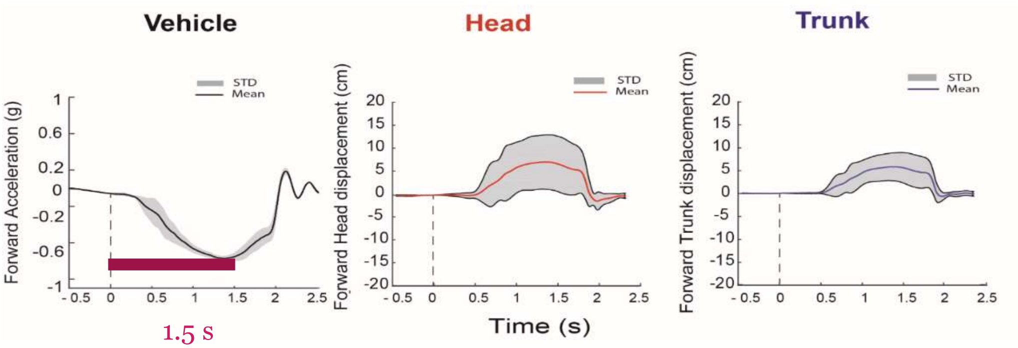
Valentina Graci, Declan Patton, Jalaj Maheshwari

Children's Hospital of Philadelphia™

AUTOMATED EMERGENCY BRAKING

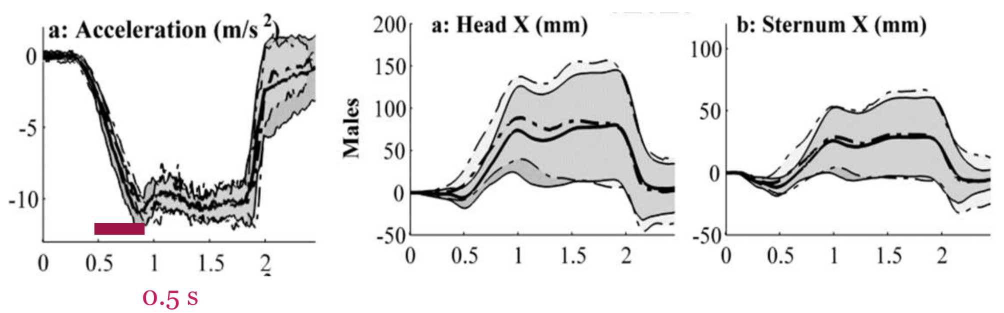
- Most research focused on crash avoidance
  - Are there particular crash scenarios where AEB is most effective?
- What about the influence of AEB on occupant positioning?
  - If crash is avoided…
  - If subsequent crash occurs…
- Future mobility modes where front seat is reclined may present unique challenges for rear seat occupants

DIFFERENT AEB PULSES EXIST IN THE MODERN FLEET



Mean displacement:
11 cm (head) & **6** cm (trunk)

Graci et al 2019



Mean displacement:
15 cm (head) & **8** cm (trunk)

Osth et al 2013

- How the AEB is achieved varies by vehicle make & model
- Results in different pre-crash occupant motion

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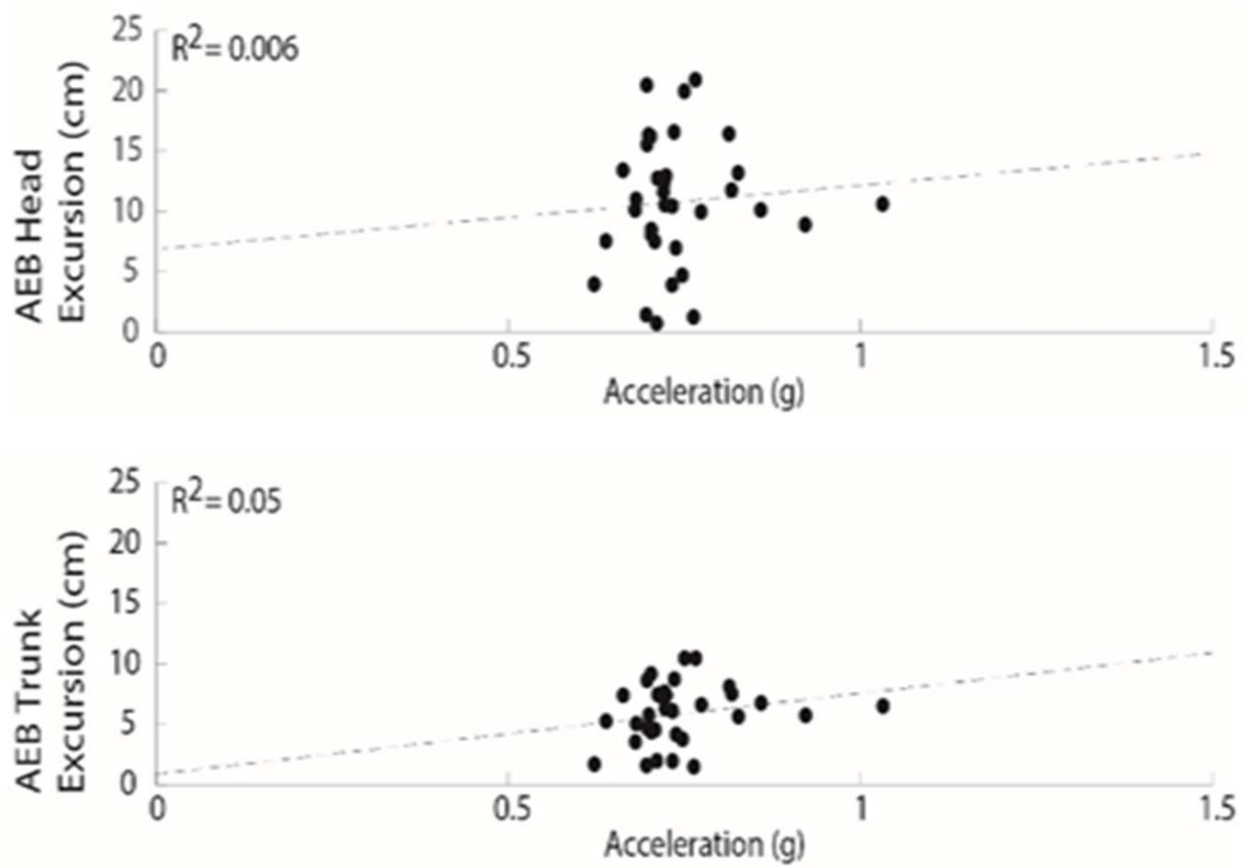
AEB PULSE CHARACTERISTICS



Maximum deceleration → **not the only factor** determining the head and trunk excursion of an occupant during AEB.

Graci et al 2019

QUANTITATIVE CHARACTERIZATION OF AEB PULSES ACROSS THE MODERN FLEET

OBJECTIVES

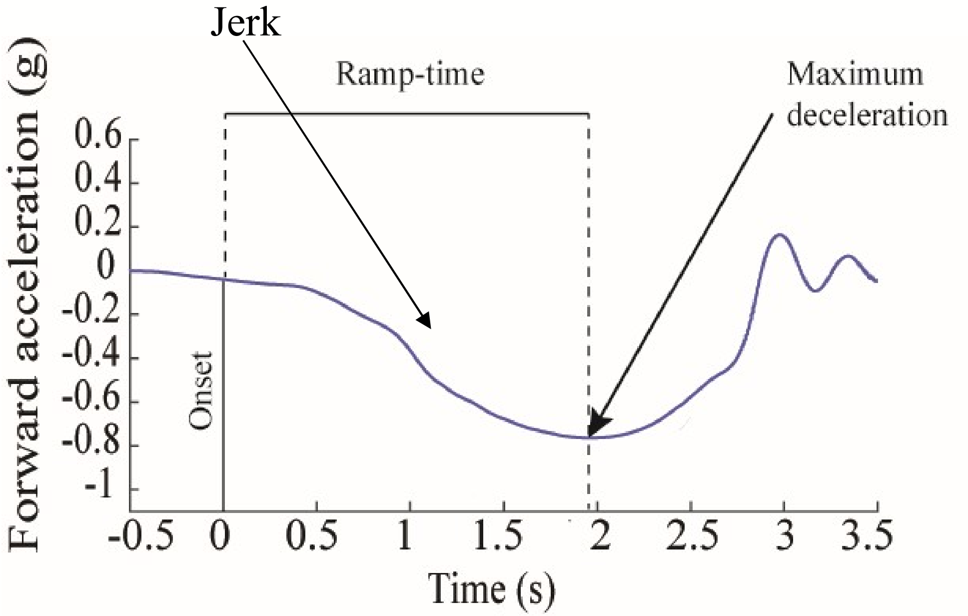
1. **Characterize the different AEB pulses** currently on the road based on their pulse characteristics (e.g. Maximum Deceleration, Jerk, Ramp-time, etc.)

2. **Categorize the AEB pulses** based on their pulse characteristics, so that future physical testing can be optimized by using representative AEB pulse categories.

CHARACTERIZING AEB PULSES

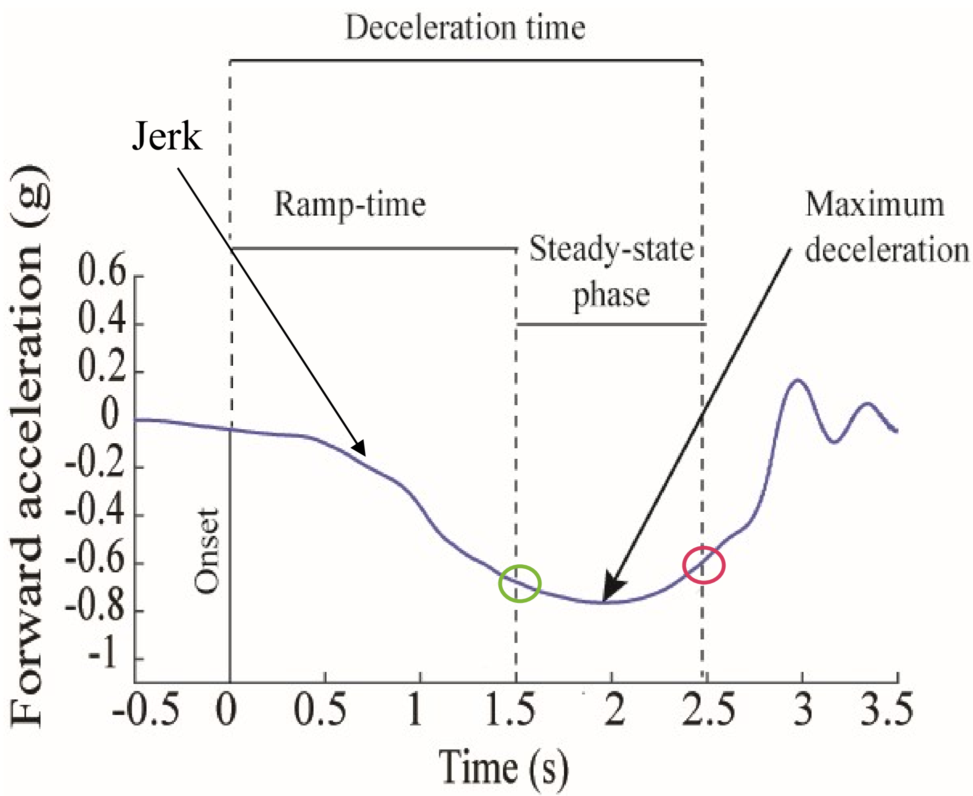
- AEB data/videos of 210 vehicles (2013-2019 model year) from Insurance Institute for Highway Safety (both 20 km/h and 40 km/h)
  - 2278 AEB tests were reviewed:
    →1665 without contact with the target
    →613 with contact with the target

AEB PULSE CHARACTERISTICS



Other characteristics: Mass, Model Year, Contact, Speed

NON-CONTACT AEB PULSE CHARACTERISTICS



- *Steady-state deceleration start*- defined as the first point where the vehicle deceleration was above 85% of the peak deceleration

- *Steady-state deceleration end* - defined as the last point where the vehicle deceleration was above 85% of the peak deceleration

Other characteristics: Mass, Model Year, Speed

ANALYSIS

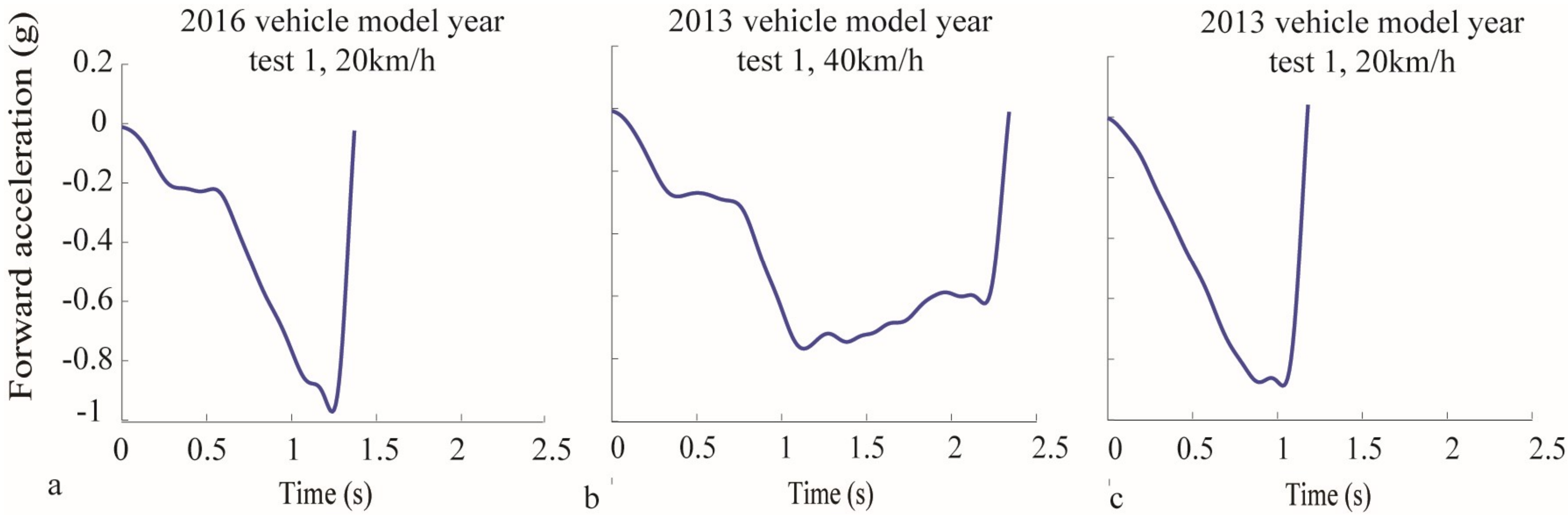
- Quantify the rate of contact in the AEB tests per Vehicle Model Year
- AEB pulses were categorized using machine learning clustering methodology (pamk and k-mean unsupervised learning methods):
  - All pulses
  - Non-contact AEB pulses only

RATE OF CONTACT IN AEB TESTS

Vehicle Model Year	N of tests	N of tests with contact	Rate of contact
2013	128	77	60.2%
2014	325	217	66.8%
2015	287	117	40.8%
2016	432	108	24.9%
2017	489	67	13.7%
2018	275	21	7.6%
2019	342	6	1.8%

Increased crash avoidance, increased aggressivity of braking pulse.

VARIETY OF AEB PULSES



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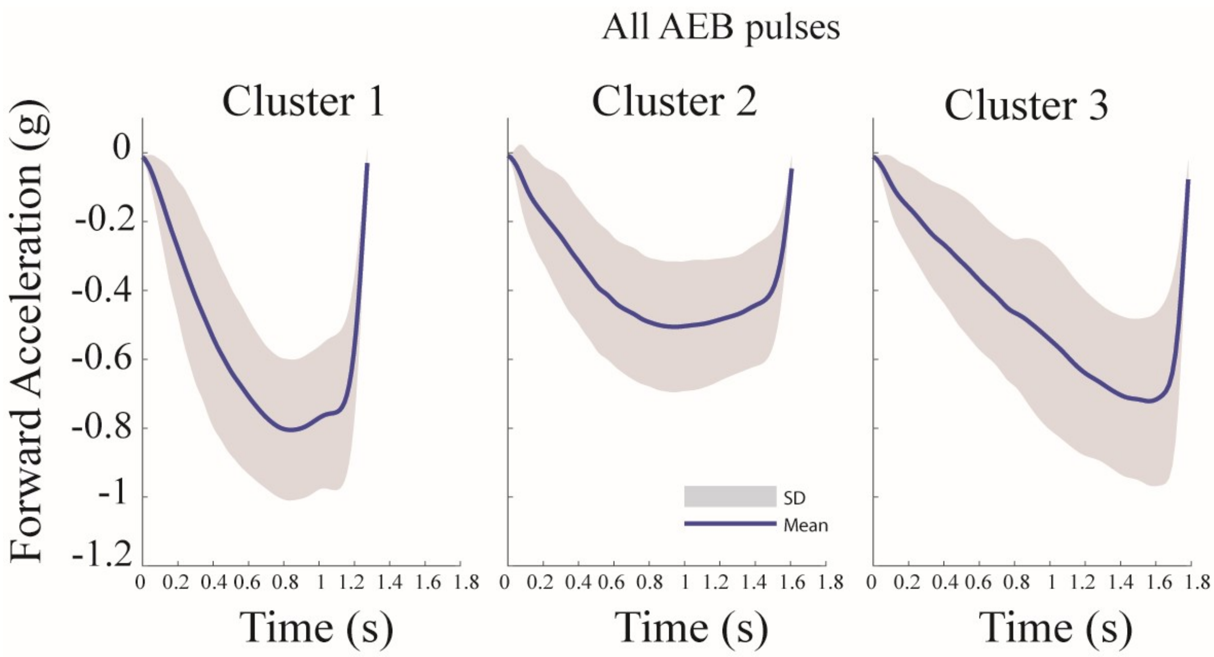
CATEGORIES AEB PULSES



Short ramp, highest decel

Generally low dynamics

Long ramp, low jerk

Unsupervised clustering method (k-means)

3 categories

Statistically significant differences in jerk, ramp time and max deceleration

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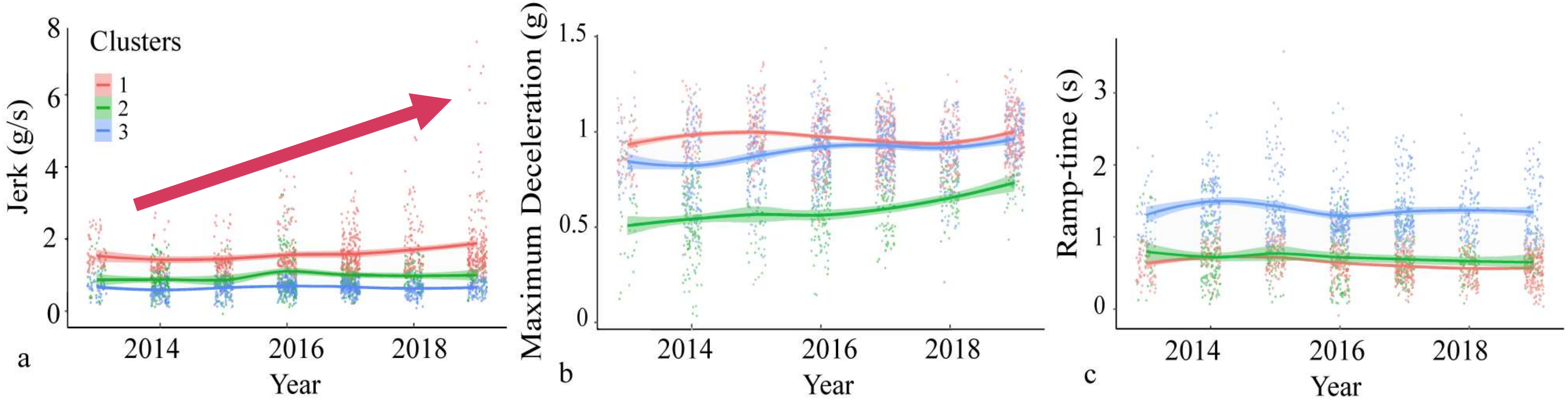
Graci et al 2021

AEB PULSE CHARACTERISTICS



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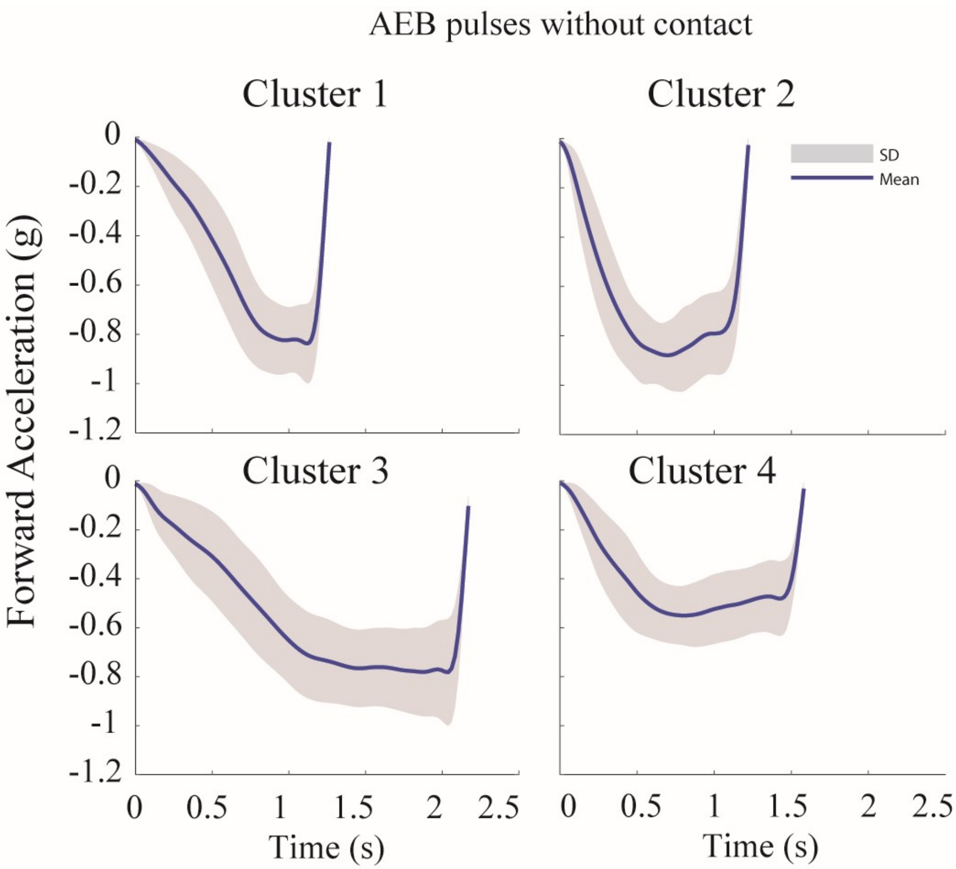
NON-CONTACT AEB PULSES ONLY



Cluster	Jerk (g/s)	Ramp Time (s)	Steady-State Acc (g)	Steady State Time (s)	Time of Dec (s)	Max Dec (g)	Mass (lbs)	Speed (kph)
1	1.08	0.88	0.91	0.62	1.09	0.94	3538.4	20.2
2	2.24	0.45	0.91	0.13	0.98	0.98	3684.3	27.3
3	0.75	1.21	0.84	0.37	1.97	0.93	3656.9	39.9
4	1.04	0.64	0.58	0.43	1.23	0.66	3939.9	22.1

Cluster 1→ shorter pulse, lower speed
Cluster 2→ greatest jerk, shortest Ramp-time*
Cluster 4→ lowest Max Decel
Cluster 3→ longest Ramp-time

* Recent model year vehicles most represented in cluster 2

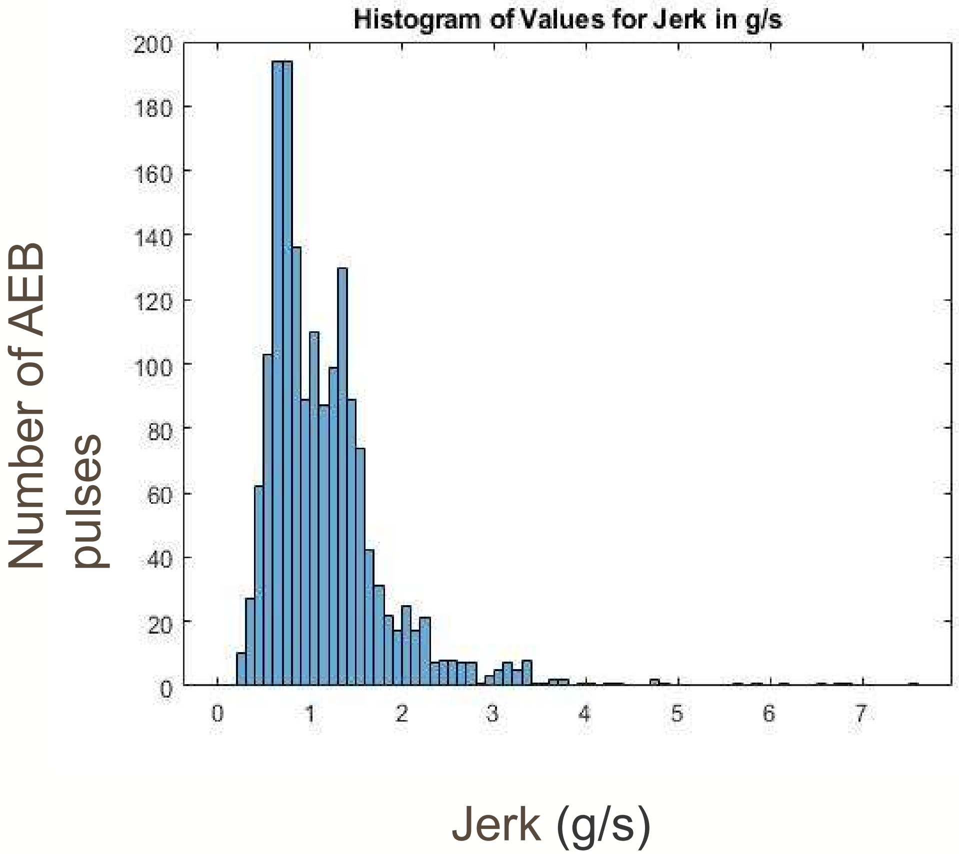
STUDY OF RECLINED PASSENGERS

- Current research efforts are focusing on reclined adult passengers and injury risk in future seating configurations for autonomous scenarios.

- There is a lack of focus on injury risk for rear seat passengers, such as children, seated behind reclined front seat passengers.

AEB PULSE CHARACTERISTICS AND RECLINED PASSENGERS

- In novel future seating configurations (e.g. reclined seats) for autonomous driving, AEB pulses with increased Jerk may lead to occupant head impact even in absence of a crash.



CONTEXT

- 92% front seat occupants position their seat aft of the mid-track position (Reed et al, 2020)
- For 2nd row child occupants, the head is the most frequently injured body region due to contact with vehicle interior structures (Arbogast et al, 2012)
- Most common contact location was the front-row seat back (Bohman et al, 2011)

How does this change with reclined front seat occupants and AEB?

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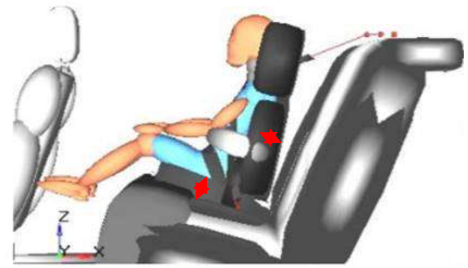
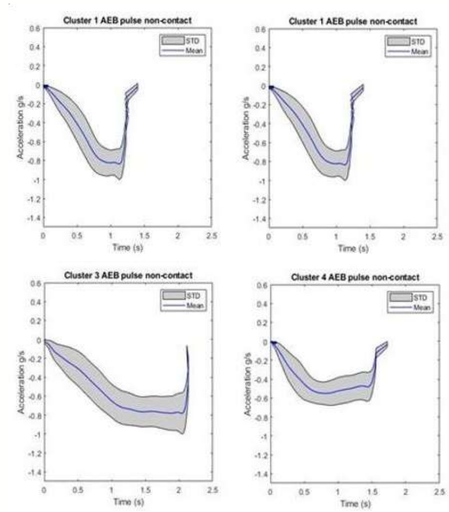
NEXT RESEARCH QUESTION

To identify **the likelihood and characteristics of head contact** for a rear seat child occupant for different combinations of front seat recline and track positions.

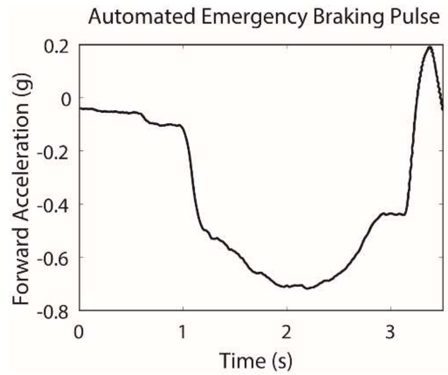


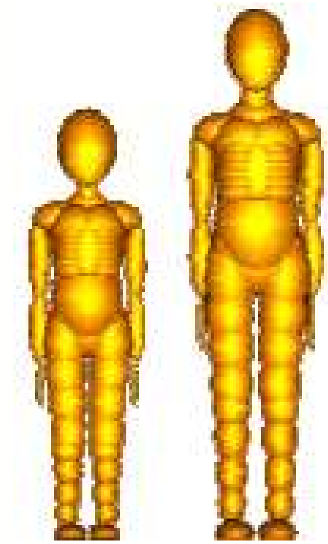
1. How the presence of a booster seat influences the likelihood and characteristics of head contact
2. How exemplar AEB pulses influence the likelihood and characteristics of head contact

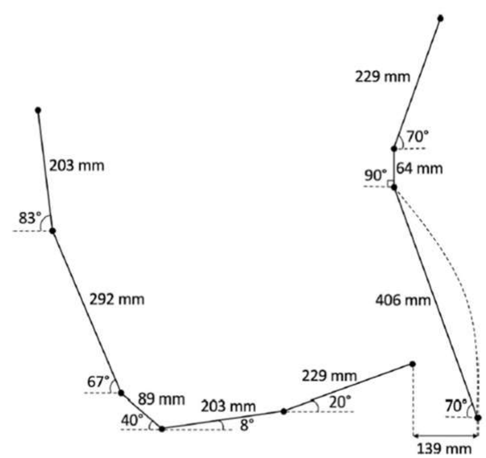


METHODS

- MADYMO child facet models
  - 10yo (no booster)
  - 6yo (low-back and high-back booster)
- 3-point seat belt with retractor
- 2^{nd} row seat from 2017 4-door sedan
  - Chosen to match with previous study of human volunteers (Graci et al, 2019)
- Front seat initially in aft-most position
  - If legs of 2nd row child occupant intersected, the front seat was translated forward 50 mm
  - If head contact occurred in the simulation, the front row was translated 50 mm forward and simulation repeated until no contact occurred
  - Then the front row was translated 25 mm rearward for the final simulation
- AEB pulse from same vehicle

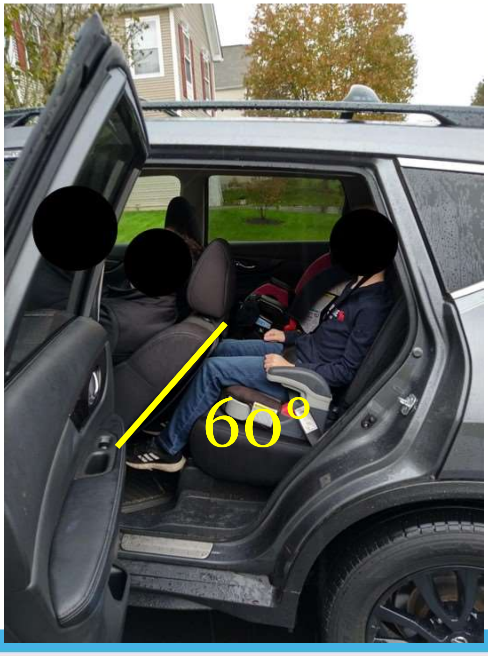






SEAT RECLINE

- Example photos with child in low-back booster
  - Nissan Rogue SUV
  - 7yo (stature, 1.35 m; body mass, 28.2 kg)



OCCUPANTS POSITIONED ON THEIR RESPECTIVE CRS

10-year-old seatbelt-restrained on a rear row vehicle seat

6-year-old on a low-back booster

6-year-old on a high-back booster

RESULTS

Age	CRS	Recline angle (°)	Seat track distance (mm)	Head Contact
10 year old	None	25	0	No
		45	0	Yes
			25	Yes
			50	No
		60	50	Yes
			100	Yes
			125	Yes
			150	No

Age	CRS	Recline angle (°)	Seat track distance (mm)	Head Contact
6 year old	Low-back booster	25	0	No
		45	0	Yes
			50	Yes
			100	Yes
			125	No
			150	No
		60	100	Yes
			150	Yes
			175	Yes
			200	No
	High-back booster	25	0	No
		45	50	No
		60	150	No

HOW DOES THIS VARY BY AEB PULSE?

- Representative AEB pulses based on 4 Clusters

AEB Cluster	Peak jerk [g/s]	Ramp time [s]	Steady-state acceleration [g]	Steady-state duration [s]	Fall time [s]	Peak acceleration [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

- 6yo (low back)
- 10yo (no booster)

- Retractor locking at 0.3g
- Without vs with pre-pretensioner

* Most representative of current vehicles

10 YEAR OLD HEAD CONTACT

Position not achievable
Head contact
No head contact

Without pre-pretensioner

AEB 1 10yo

Recline angle	0	25	50	75	100	125	150	175	200	225	250
60			0.54		0.20		0.28				
45	0.59										
25											

Track position

AEB 2 10yo

Recline angle	0	25	50	75	100	125	150	175	200	225	250
60			0.54		0.27		1.17	0.56			
45	1.13		0.30								
25											

Track position

AEB 3 10yo

Recline angle	0	25	50	75	100	125	150	175	200	225	250
60			0.86		0.15		0.02	0.29			
45	0.42		0.12								
25											

Track position

AEB 4 10yo

Recline angle	0	25	50	75	100	125	150	175	200	225	250
60			0.95		0.28		0.38				
45	0.68										
25											

Track position

With pre-pretensioner

AEB 1 10yo

Recline angle	0	25	50	75	100	125	150	175	200	225	250
60			0.24		0.09	0.49					
45											
25											

Track position

AEB 2 10yo

Recline angle	0	25	50	75	100	125	150	175	200	225	250
60			0.45		1.00	1.29					
45	0.10										
25											

Track position

AEB 3 10yo

Recline angle	0	25	50	75	100	125	150	175	200	225	250
60			0.30		0.03	0.01					
45	0.08										
25											

Track position

AEB 4 10yo

Recline angle	0	25	50	75	100	125	150	175	200	225	250
60			0.43		0.66	0.01					
45											
25											

Track position

Numbers in cells are contact velocity in m/s

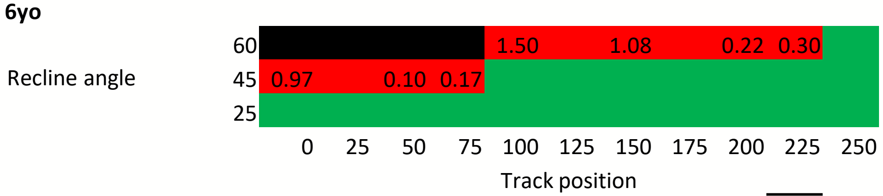
6 YEAR OLD HEAD CONTACT

Position not achievable
Head contact
No head contact

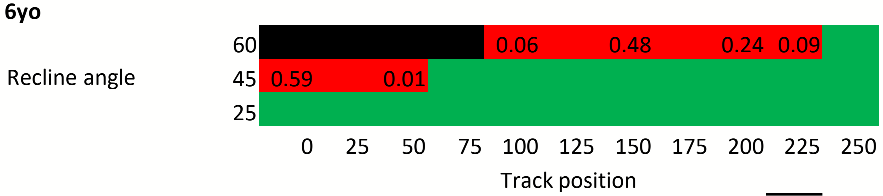
Without pre-pretensioner

AEB 1 6yo

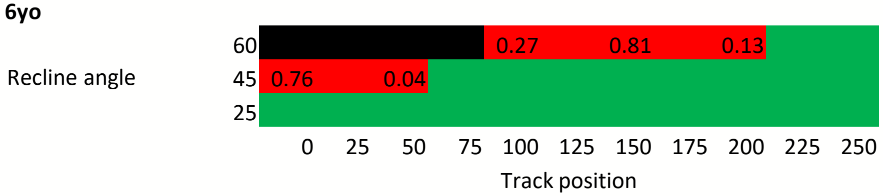
AEB 2 6yo



AEB 3 6yo

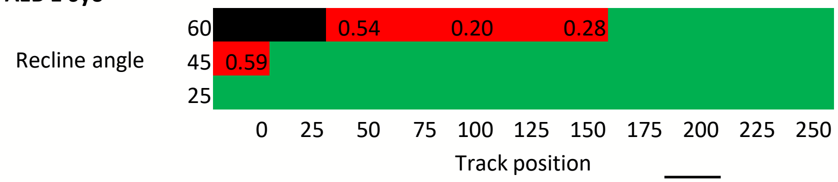


AEB 4 6yo

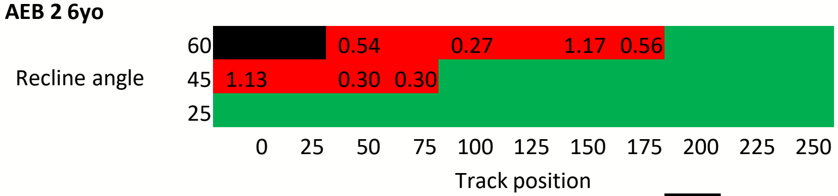


With pre-pretensioner

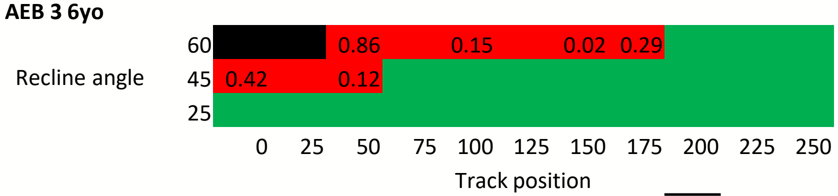
AEB 1 6yo



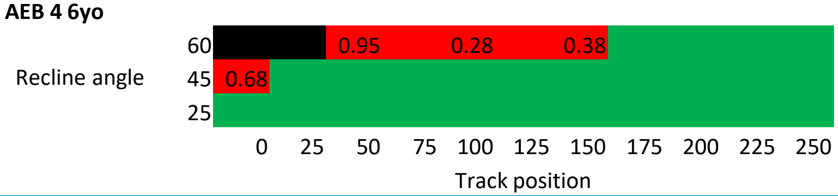
AEB 2 6yo



AEB 3 6yo



AEB 4 6yo



Numbers in cells are contact velocity in m/s

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KEY DISCUSSION POINTS

- AEB pulses vary – and have become more aggressive in recent model years
- Different AEBs→ different head motion.
  - AEB pulse (cluster 2) with greater jerk and shorter ramp-time led to greater impact velocity and more frequent head contact.
- Generally, 60 degree reclined seat back angle showed the highest number of head contacts and greater impact velocity across all AEB pulses.
- Optimal restraint (6 year old in a high back booster) resulted in no head contact – minimized belt slip out
- Lack of muscle response in these models limits its biofidelity
- These studies considered optimally positioned occupants – real child occupants in more naturalistic postures could have increased risk of head contact
- Intervention opportunities – improved restraints (pre-pretensioner showed benefits) and/or improved energy management of front seat backs

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TAKE AWAY MESSAGES

- When designing reclined seating configurations, the effect of the reclined seat back on the rear-seated passengers need to be considered also in non-crash events.
- Pre-pretensioner in the rear-seat has the potential to decrease head impact events, although they can still occur in the most extreme recline angle/track position configurations.
- Data could be used to improve AEB standards for autonomous vehicles.

TRAFFIC INJURY PREVENTION
https://doi.org/10.1080/15389588.2021.1961227

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Check for updates

Quantitative characterization of AEB pulses across the modern fleet

V. Graci[a], M. Maltenfort[b], M. Schneider[a,c], M. Griffith[a], T. Seacrist[a], and K. B. Arbogast[a,d]

COMPUTER METHODS IN BIOMECHANICS AND BIOMEDICAL ENGINEERING
https://doi.org/10.1080/10255842.2022.2032003

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Check for updates

Head contacts in second-row pediatric occupants when the front-seat is reclined during automated emergency braking

Declan A. Patton[a], Jalaj Maheshwari[a], Kristy B. Arbogast[a,b] and Valentina Graci[a,c]

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