PEDIATRIC OCCUPANT HUMAN BODY MODEL KINEMATIC AND KINETIC RESPONSE VARIATION TO CHANGES IN SEATING POSTURE IN SIMULATED FRONTAL IMPACTS – WITH AND WITHOUT AUTOMATIC EMERGENCY BRAKING

RCCADS Public Workshop

26th May 2021

Jalaj Maheshwari, MSE[1] (maheshwarj@email.chop.edu)

Shreyas Sarfare, MSE[1]

Clayton Falciani[1,2]

Aditya Belwadi, MS, PhD[1]

[1]Center for Injury Research and Prevention (CIRP), Children's Hospital of Philadelphia

[2]Drexel University, School of Computing and Informatics, Drexel University

Children's Hospital of Philadelphia®

BACKGROUND

- All child restraint systems (CRS) sold in the U.S. need to pass regulations as outlined per the Federal Motor Vehicle Safety Standards (FMVSS) No. 213
  - Traditionally, restraint performance is evaluated using optimally positioned ATDs

- However, previous literature documents that restrained children assume a variety of positions during a trip
  - Children spent less than 10% of the time correctly restrained (Meissner et al. 1994)
  - Older children had a greater tendency to be out of position
  - Children spent about 70% of the time in non-standard positions (part of the body out of the CRS protective zone) (Charlton et al. 2010)

BACKGROUND

- Charlton et al. (2013) conducted a comprehensive naturalistic driving study of child passengers to collect quantitative data on occupant positions during a trip

- Arbogast et al. (2016) quantified the head position of naturalistically seated child occupants

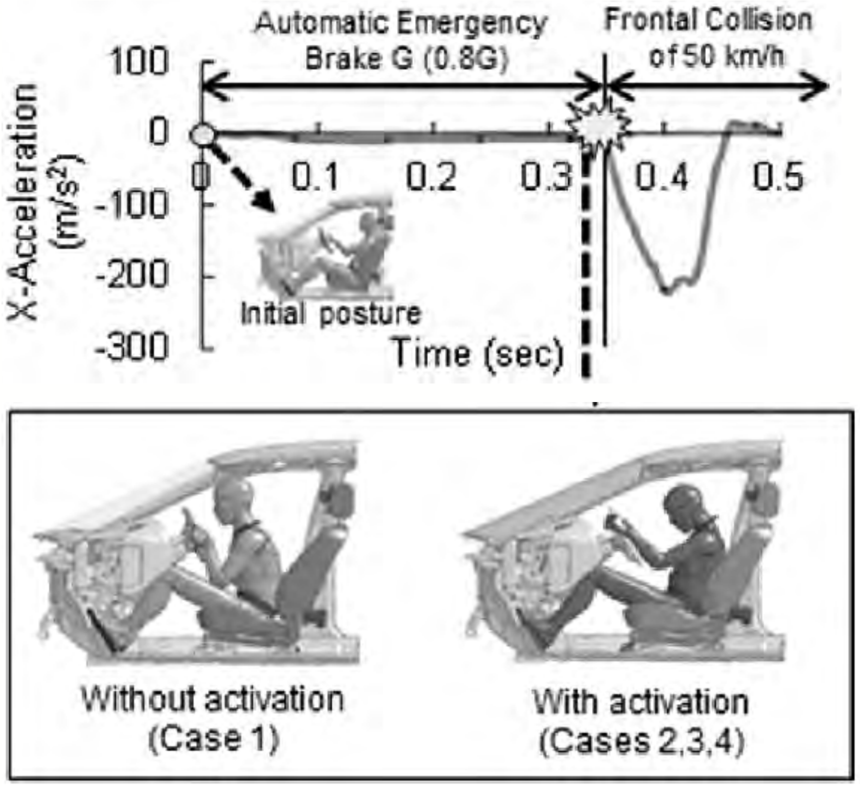
- Bohman et al. (2018) identified the most common and extreme seating postures
  - Conducted sled tests with HIII-6YO ATD to analyze effect of seating posture on kinematics and kinetics
  - Greater excursion observed for forward-leaning postures
  - Accelerations and neck loads were reduced

Naturalistic seating sled testing with HIII 6YO ATD (Bohman at al. 2018)

Children's Hospital of Philadelphia®

BACKGROUND

- Initial seating postures can be more pronounced under application of a pre-crash maneuver (Stockman et al. 2013; Gras et al., 2017; Graci et al., 2019)
- Most studies on pre-crash phase followed by a crash phase have largely focused on adult occupants (Iwamoto et al., 2015; Östmann et al., 2016, Yamada et al., 2016)
- However, the responses of a pediatric human body model in these crash conditions also need to be explored



Occupant posture after braking event (Iwamoto et al. 2015)

AIM

To assess kinematics and kinetics of the 6YO and 10YO naturalistically-seated pediatric occupants in booster seats

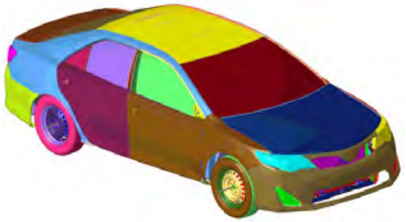
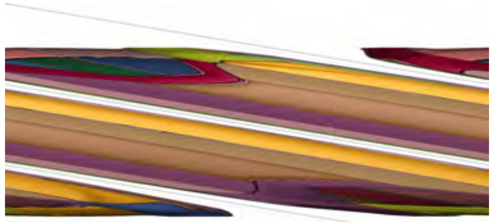
exposed to a full-frontal impact

in a vehicle environment

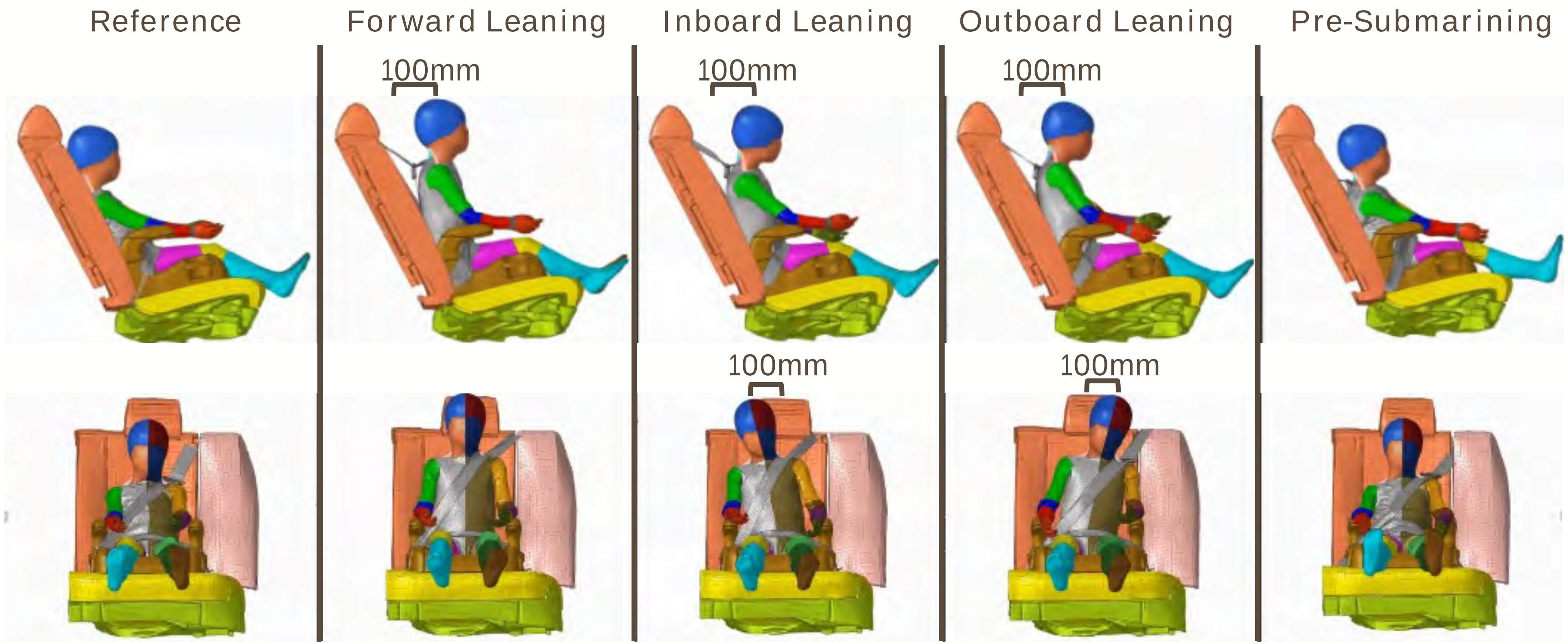
with and without pre-crash automatic emergency braking (AEB) event

Children's Hospital of Philadelphia®

METHODS

Seating Setup 2012 Toyota Camry FE Model	From the National Crash Analysis Center (NCAC) archives 
Child restraints Lowback Booster (LBB) Highback Booster (HBB)	CRS model developed from digitization techniques (Belwadi et al., 2015) 
Occupants PIPER 6YO (default) PIPER 10YO (morphed from 6YO using PIPER Positioning Tool Scaling Module)	PIPER Consortium open source model (Beillas et al., 2016) 
Crash Impact Full Frontal Rigid Barrier Impact (35MPH)	

METHODS – SEATING POSTURES



- Reference seating as per FMVSS 213
- Forward leaning, inboard leaning as per head position of most common postures observed in real world (Arbogast et al., 2016)
- Outboard leaning posture similar to inboard leaning – reflected about the sagittal plane
- Pre-submarining position determined by routing the seatbelt such that lap belt falls 5-10mm above the ASIS

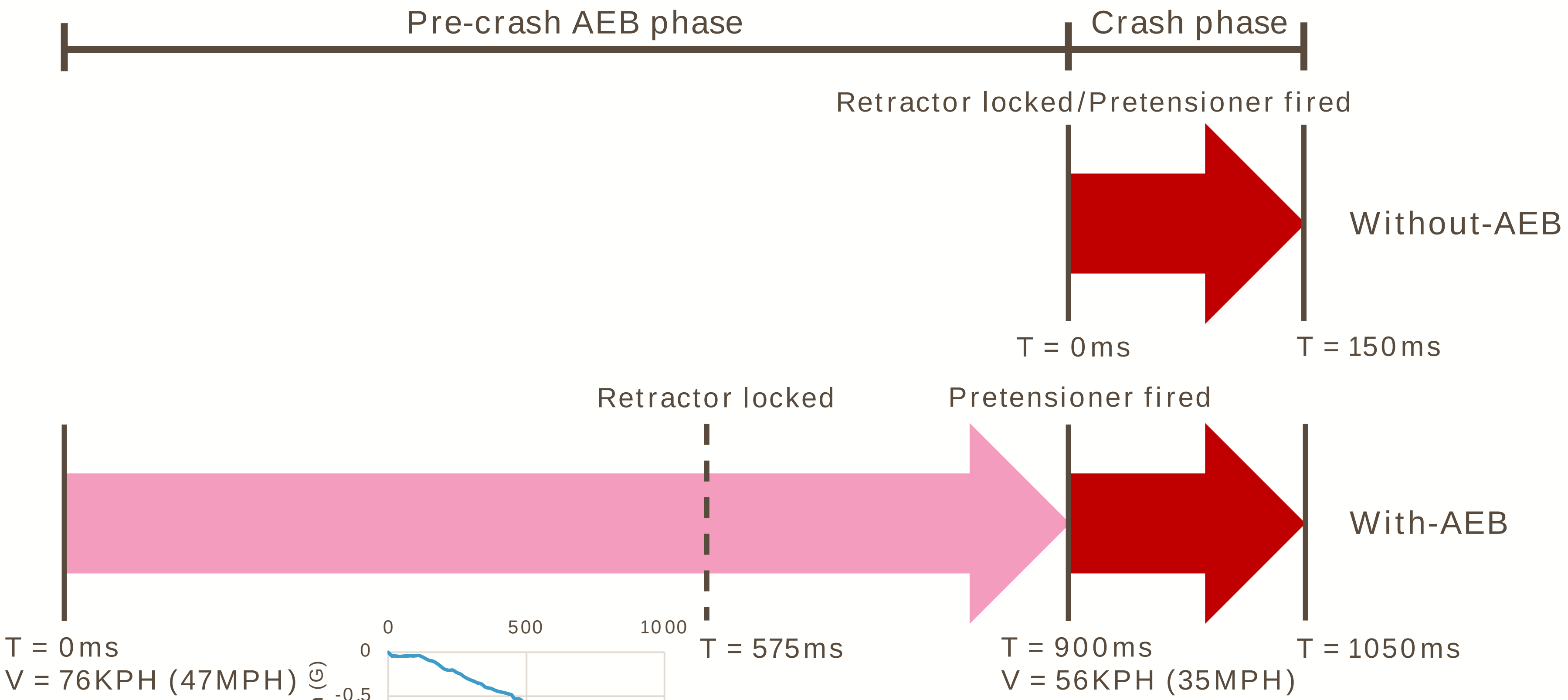
METHODS – TEST MATRIX

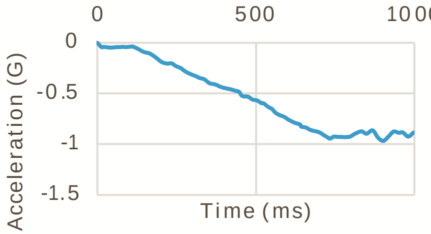
Age	AEB Conditions	Restraint	Impact Conditions	Seating Postures
PIPER 6YO	With AEB Without AEB	Lowback Booster Highback Booster	Full frontal barrier impact (35 MPH)	Reference Seating Forward Leaning Inboard Leaning Outboard Leaning Pre-Submarining
PIPER 10YO		No CRS Lowback Booster		

- A 3-point lap-shoulder belt with a retractor, pretensioner, and a 4kN load-limiter was used
  - According to FMVSS No. 209, retractor was locked when vehicle acceleration was 0.7G for with-AEB conditions
  - Pretensioner fired only in the crash phase for both with and without AEB conditions

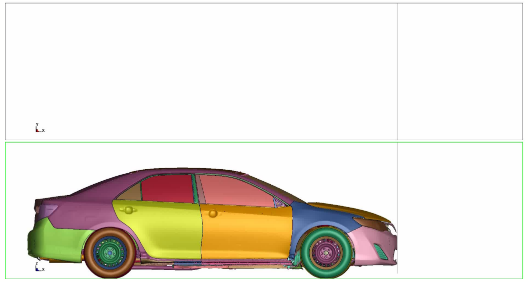
Children's Hospital of Philadelphia

METHODS





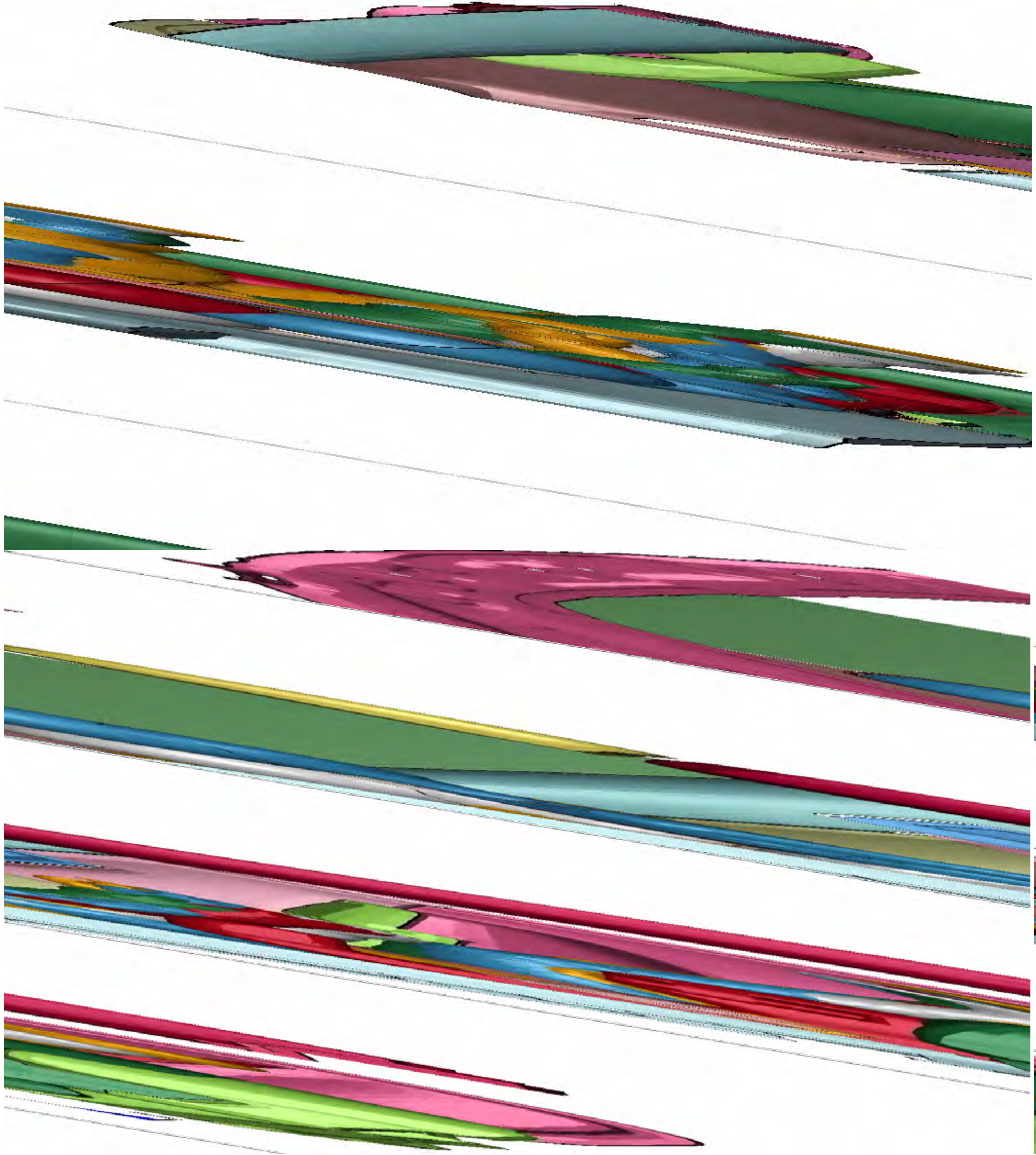
(Yamada et al. 2016)



- AEB pulse corresponding to initial velocity of 76kmph (47 MPH) (Yamada et al. 2016)
- Vehicle velocity prior to barrier impact is 35 MPH

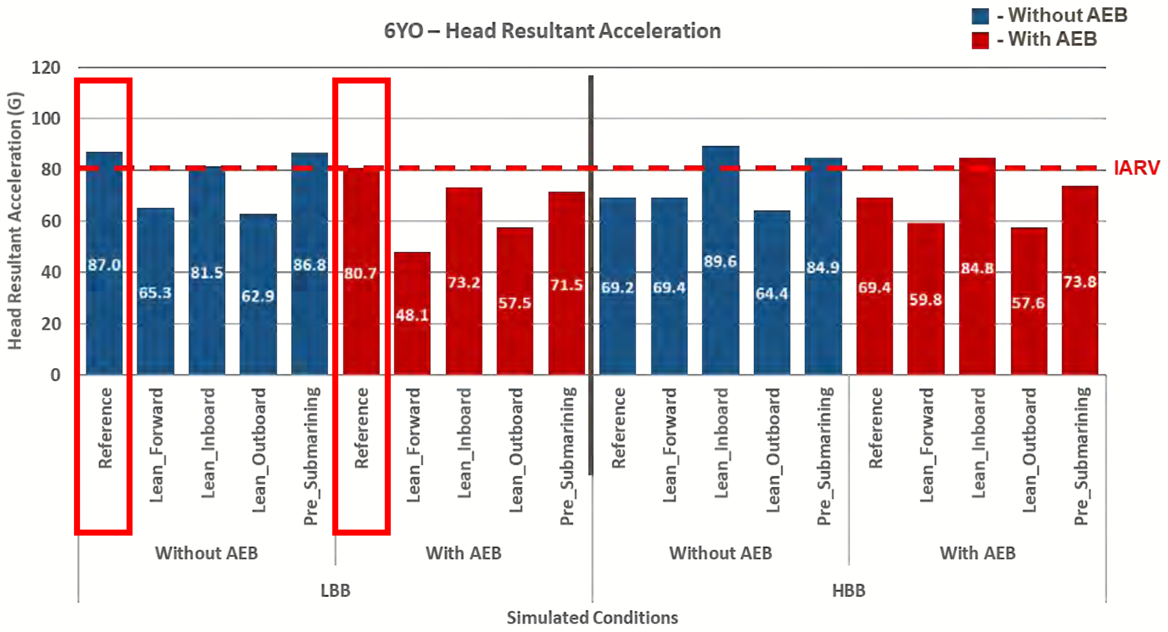
METHODS

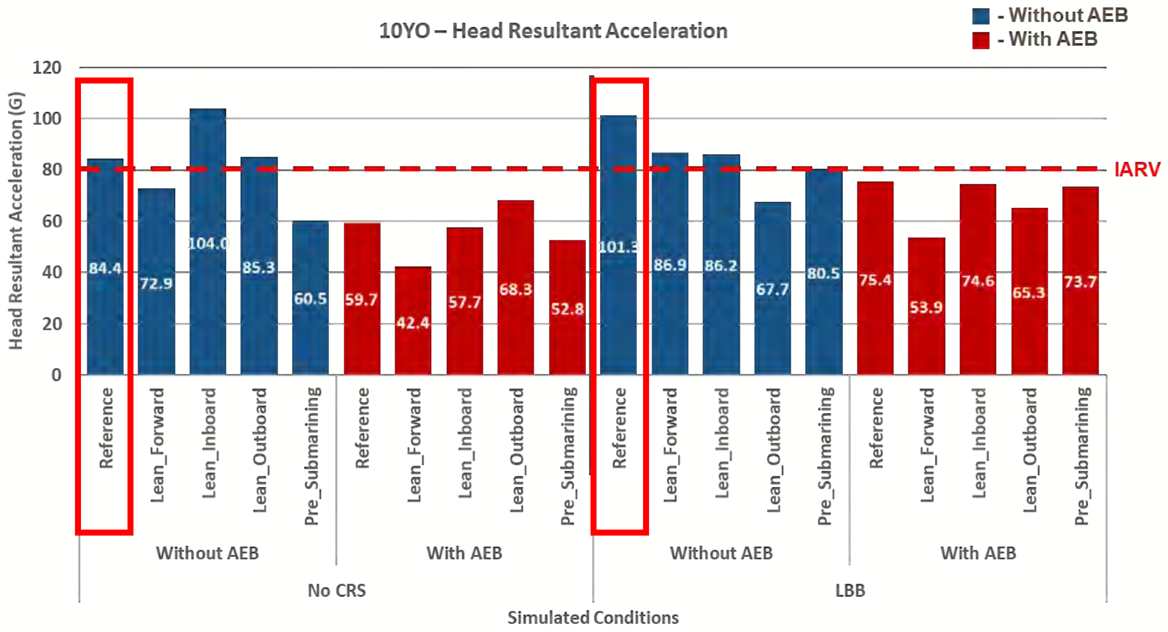
- Front driver seat was positioned in its mid-track position
- Seatbelt loads and stresses carried over from pre-crash phase to crash phase for conditions with AEB
- *Total of 40 simulations* were carried out and models setup in LS-DYNA R10.1.0 (LSTC Inc., CA) explicit dynamic solver.
- Kinematic and kinetic measures of the PIPER child model including head, chest, and pelvis acceleration, chest deflection, neck loads and moments were extracted



- Reference
- Leaning Forward
- Leaning Inboard
- Leaning Outboard
- Pre-Submarining

RESULTS – VARIATION ACROSS SEATING POSTURES

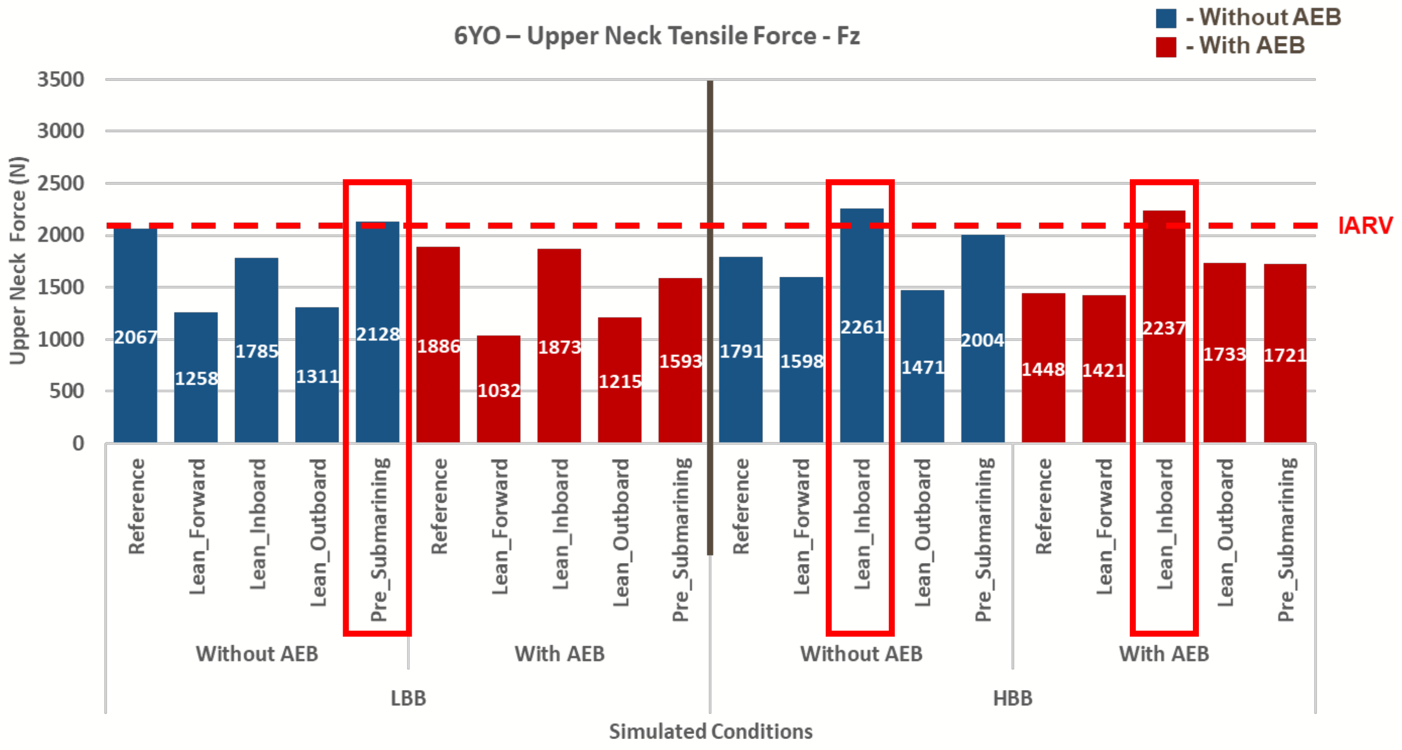




- However, reference posture seems to capture most responses exhibited by other seating postures

Children's Hospital of Philadelphia®

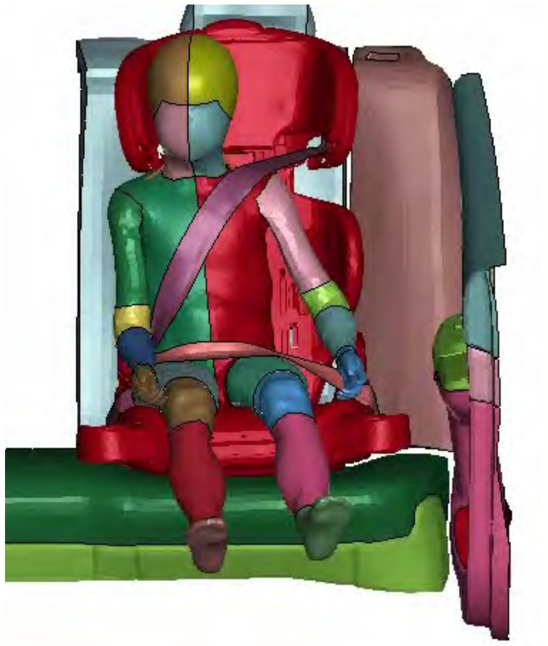
RESULTS –
VARIATION ACROSS SEATING POSTURES



- In some cases, injury values were higher for naturalistic postures than the reference posture
  - Crossed the IARV threshold where the reference posture did not

RESULTS AND DISCUSSION – VARIATION ACROSS SEATING POSTURES

- Shoulder belt slippage observed for the 6YO on HBB in the inboard leaning posture
  - Observed for both with and without AEB conditions
  - Resulted in greater HIC15, head acceleration, head excursion, neck tensile force and flexion moment compared to other postures
  - Similar kinematics in other studies with pediatric ATDs (Bohman et al. 2018)
  - Behavior due to the shoulder belt held in place on the routing guides of the HBB during impact



Shoulder belt slippage for 6YO on HBB, without AEB conditions

Children's Hospital of Philadelphia

RESULTS AND DISCUSSION – VARIATION ACROSS SEATING POSTURES

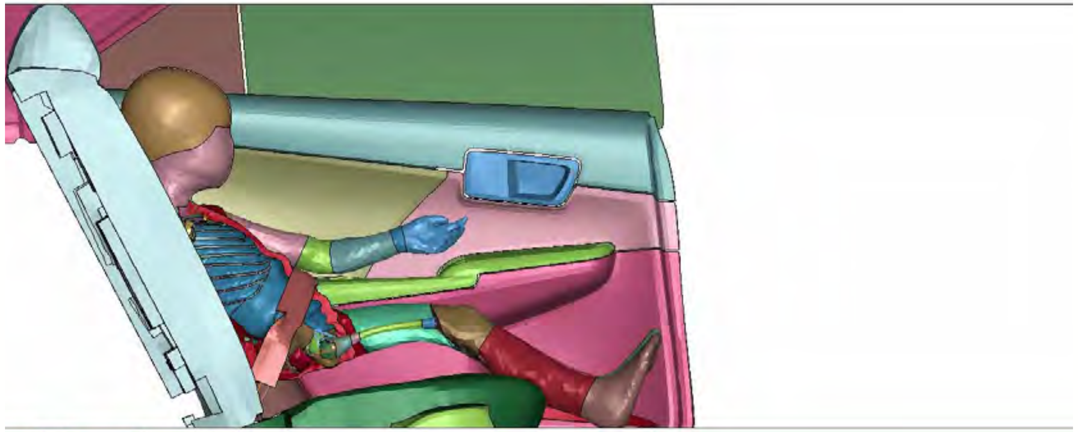
- Apart from the case with the belt slippage, forward leaning postures (forward leaning, inboard leaning, outboard leaning) had relatively lower HIC15 and neck tension than the reference posture
  - Can be attributed to reduced space available for travel before the occupant reached its most flexed position
  - Similar observations reported in literature (Bohman et al. 2018)

Children's Hospital of Philadelphia®

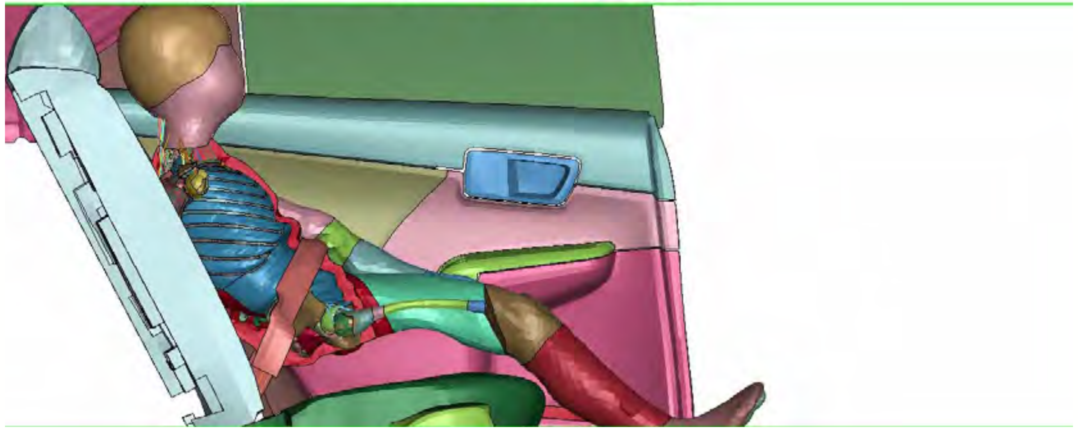
RESULTS AND DISCUSSION – VARIATION ACROSS SEATING POSTURES

- Pre-Submarining posture
  - Lap belt rode over the ASIS, thereby loading the abdomen for both the 6YO and 10YO
  - Effects of such a response need additional analysis

6YO

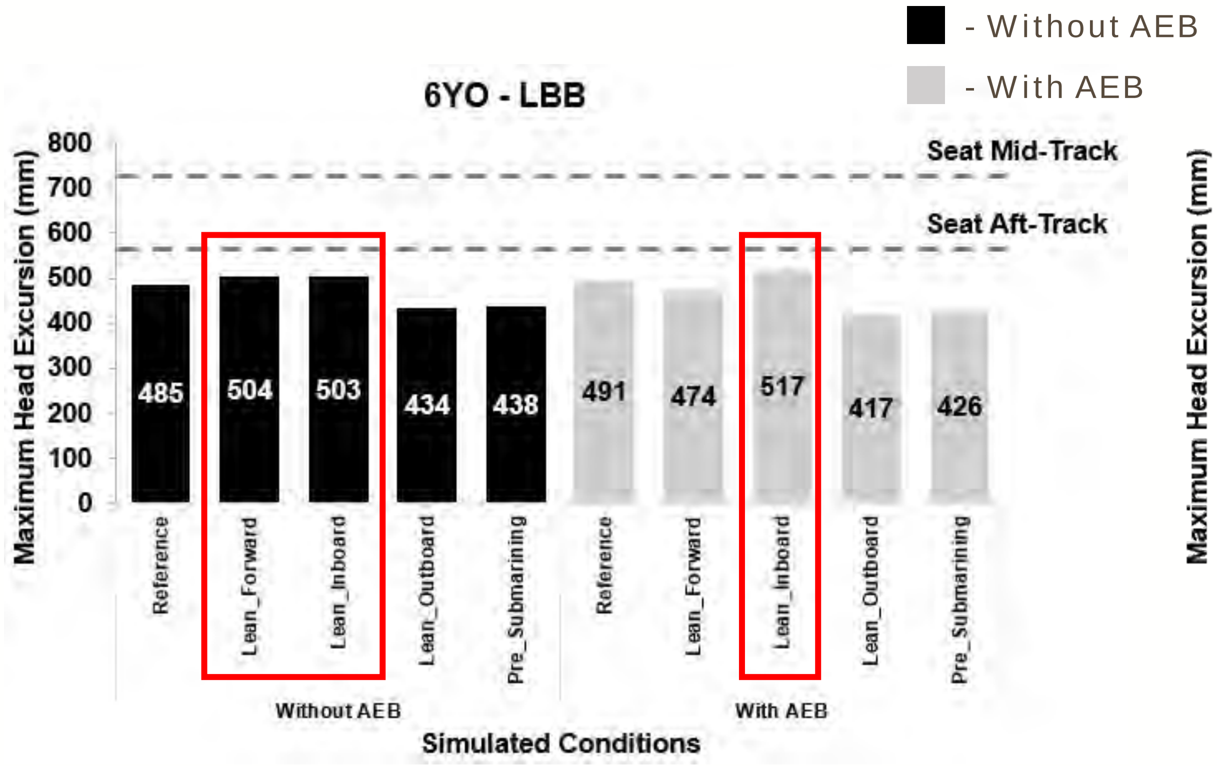


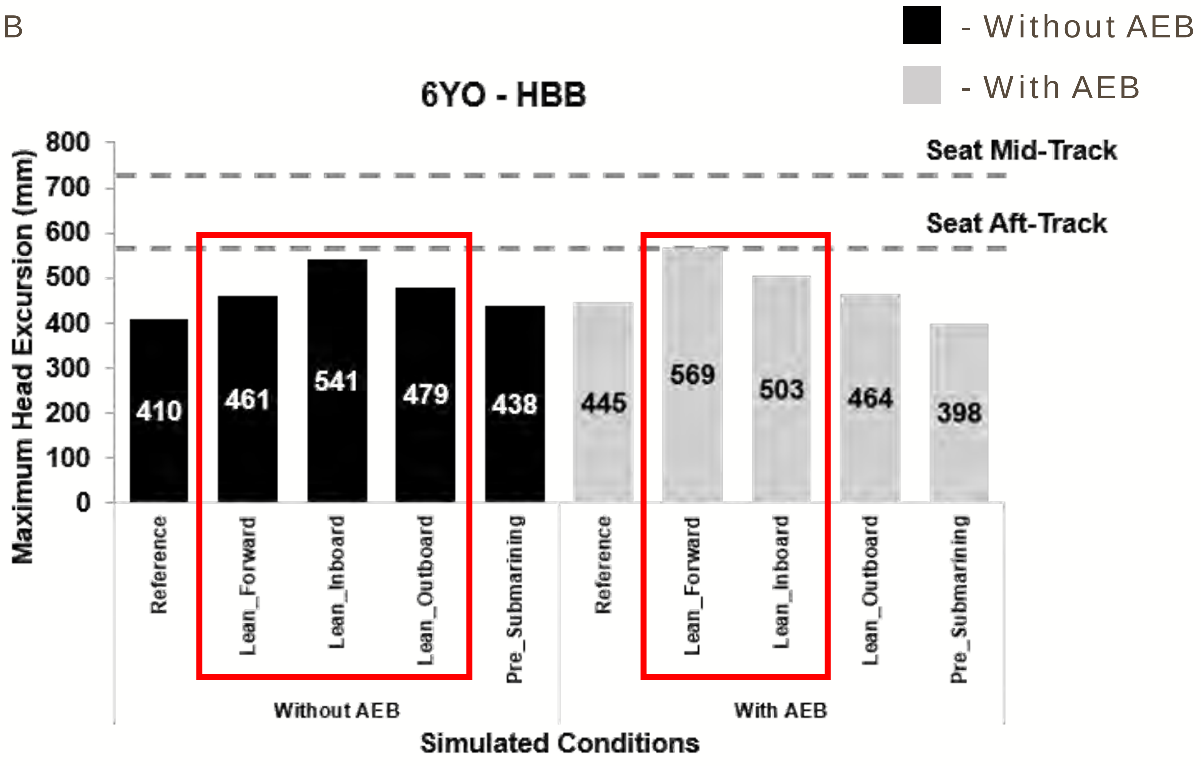
10YO



Pre-submarining seating posture
lap belt loading the abdomen

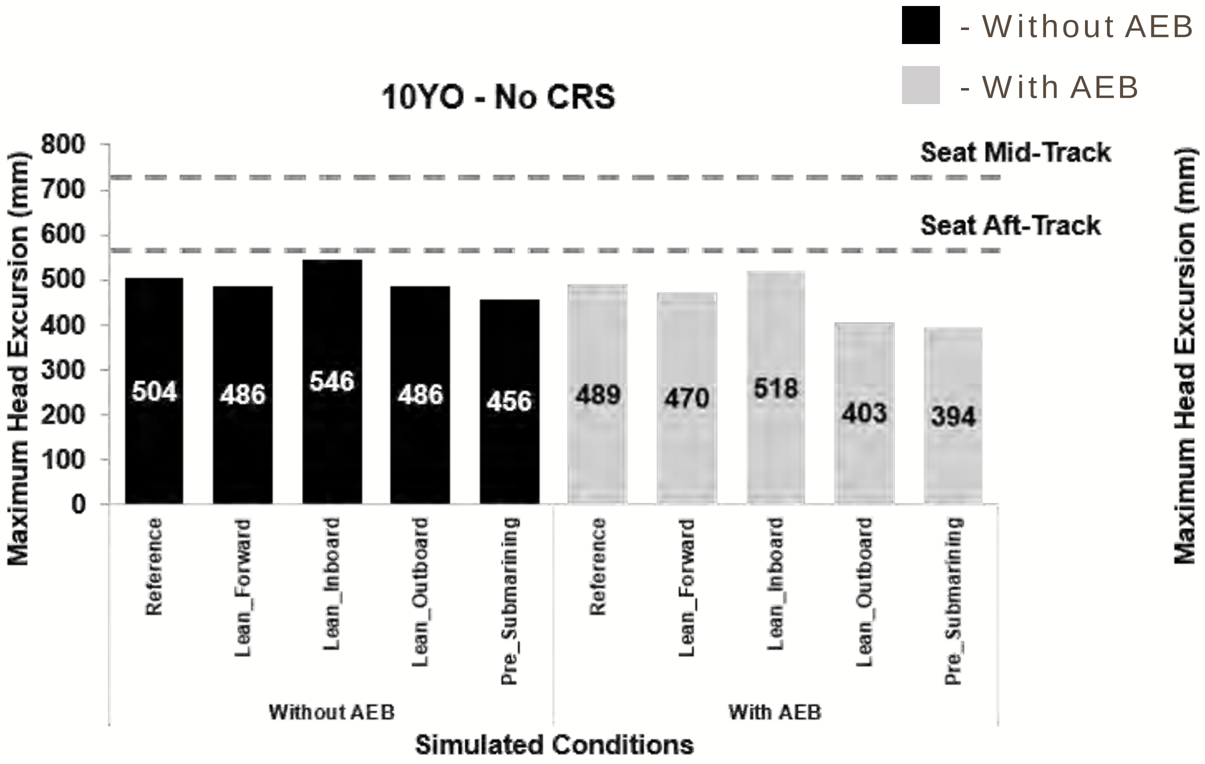
RESULTS AND DISCUSSION – HEAD EXCURSION ACROSS SEATING POSTURES

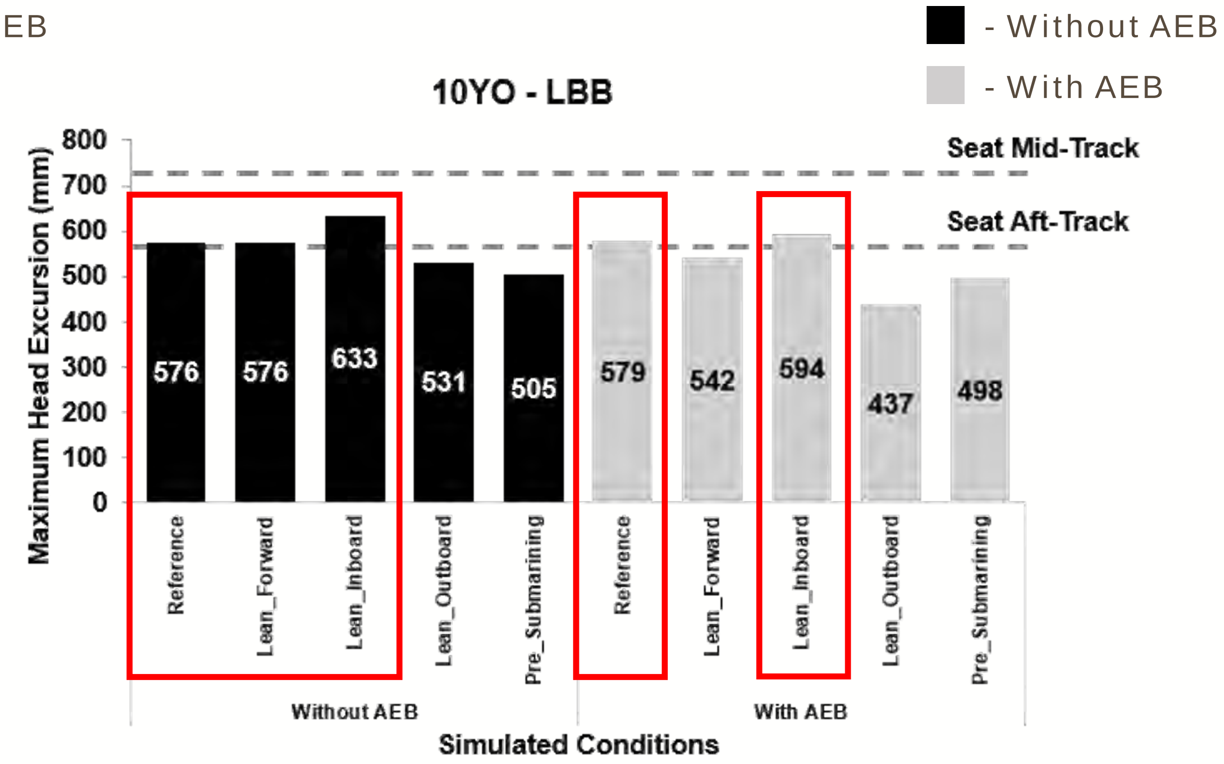




- Possibility of head contact if front seat is in aft-most track position
  - Increased likelihood of head contact in smaller vehicles
  - Greater likelihood of head contact in leaning inboard posture

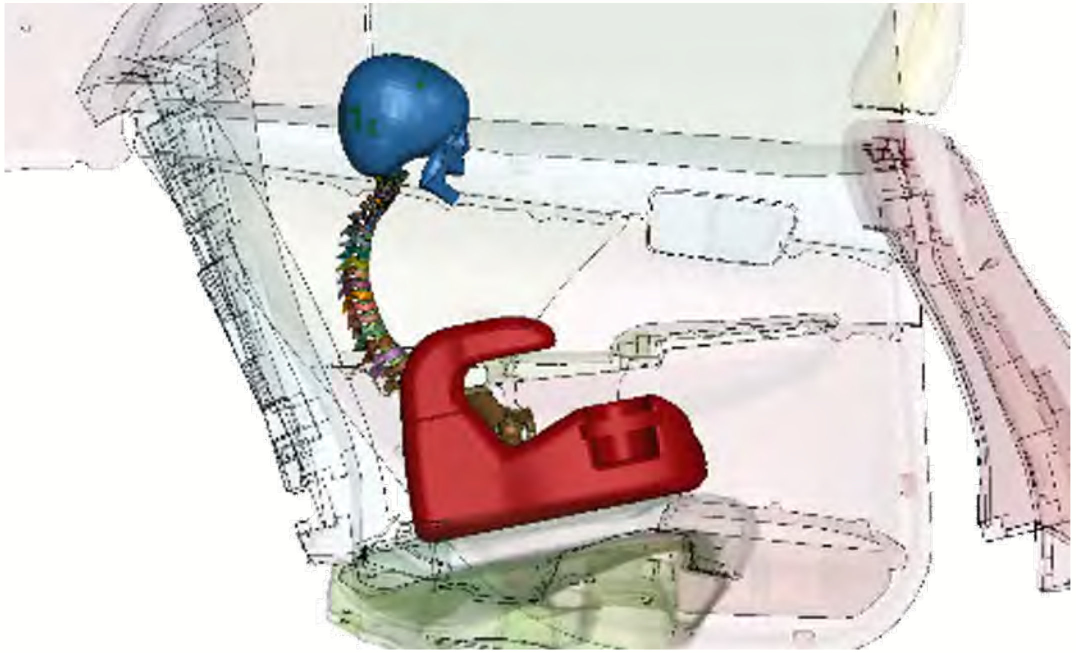
RESULTS AND DISCUSSION – HEAD EXCURSION ACROSS SEATING POSTURES



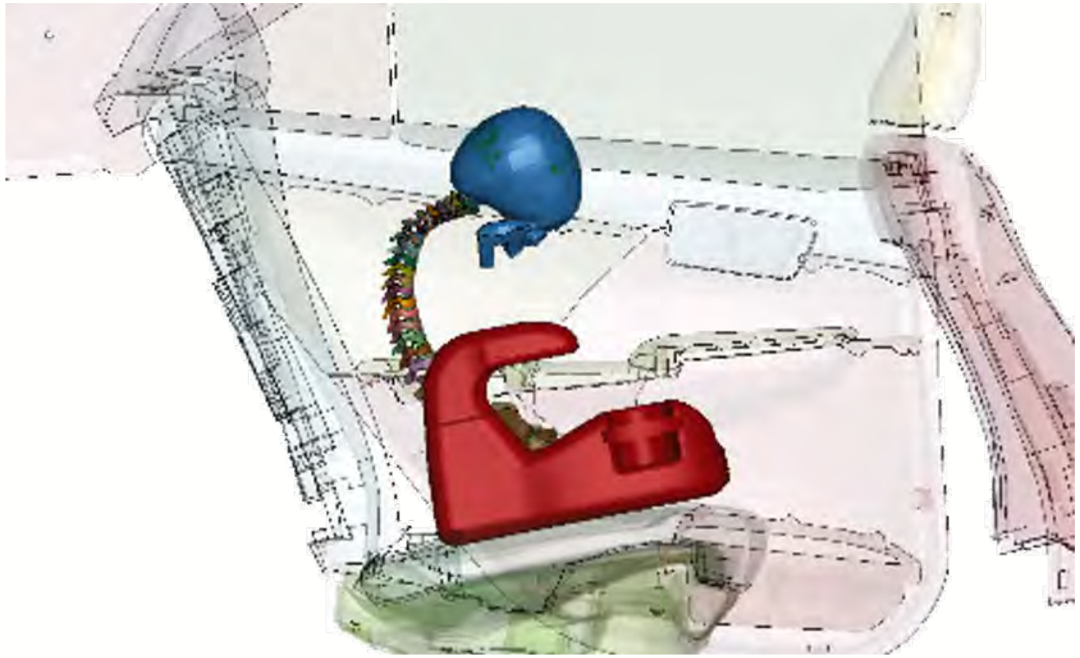


- Possibility of head contact if front seat is in aft-most track position
  - Increased likelihood of head contact in smaller vehicles
  - Greater likelihood of head contact in leaning inboard posture

RESULTS AND DISCUSSION – EFFECT OF AEB



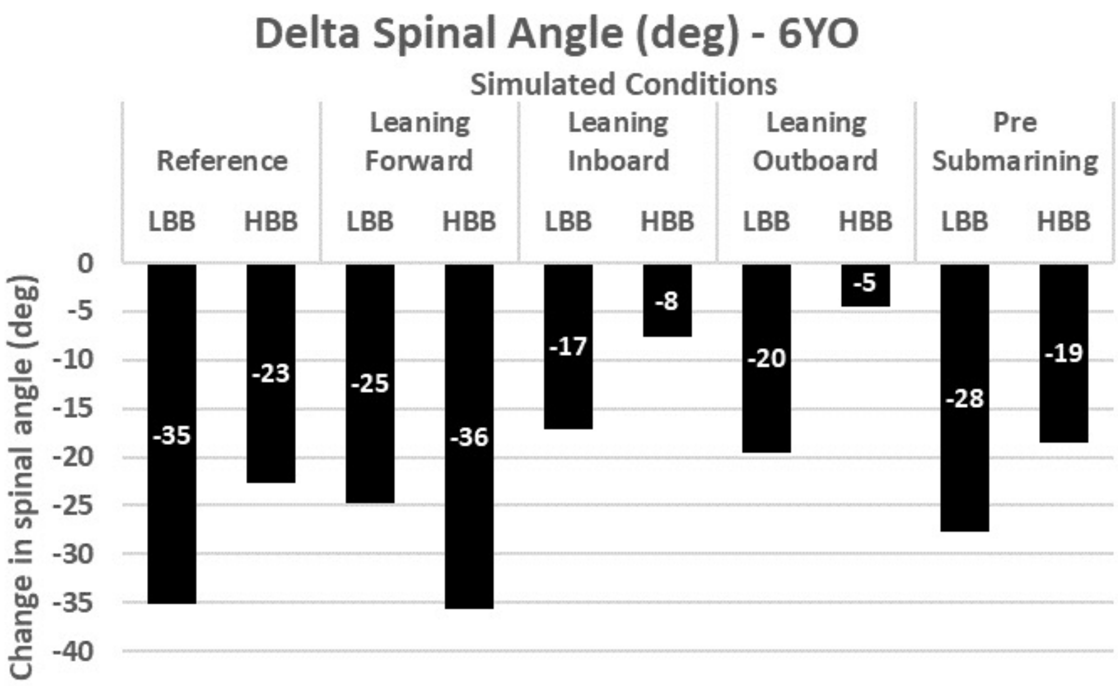
Without AEB

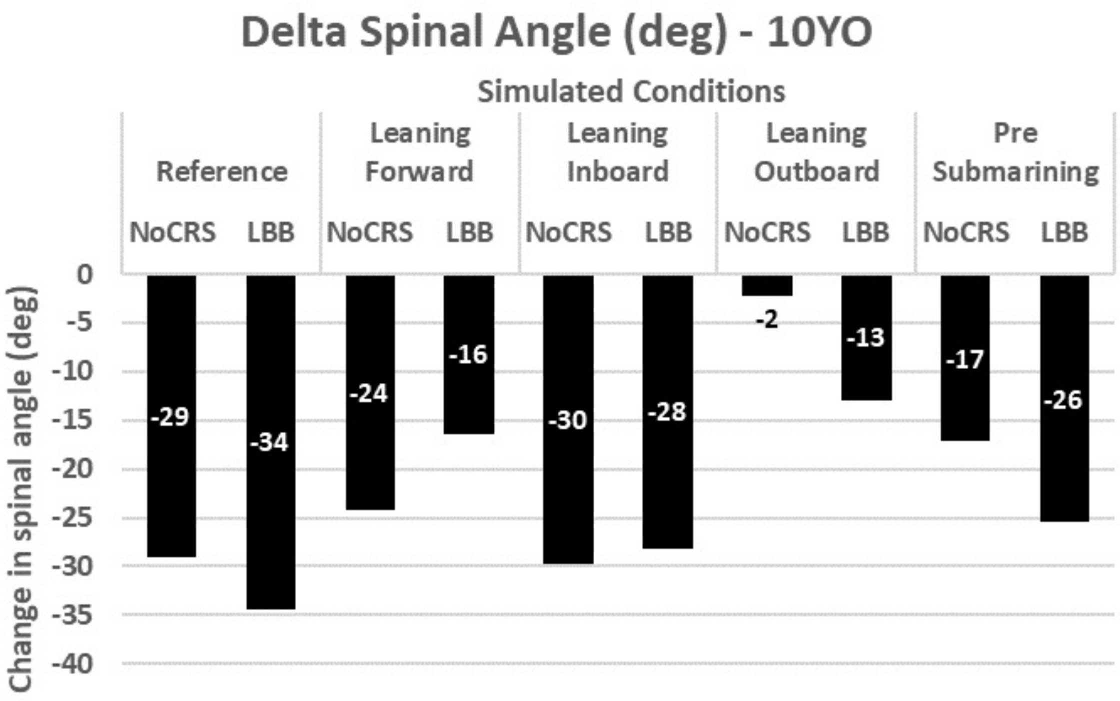


With AEB

- Prior to impact, occupants were more forward flexed in cases with AEB than without AEB across all simulated conditions
- Resulted in relatively lower injury numbers for cases with AEB

RESULTS AND DISCUSSION – EFFECT OF AEB

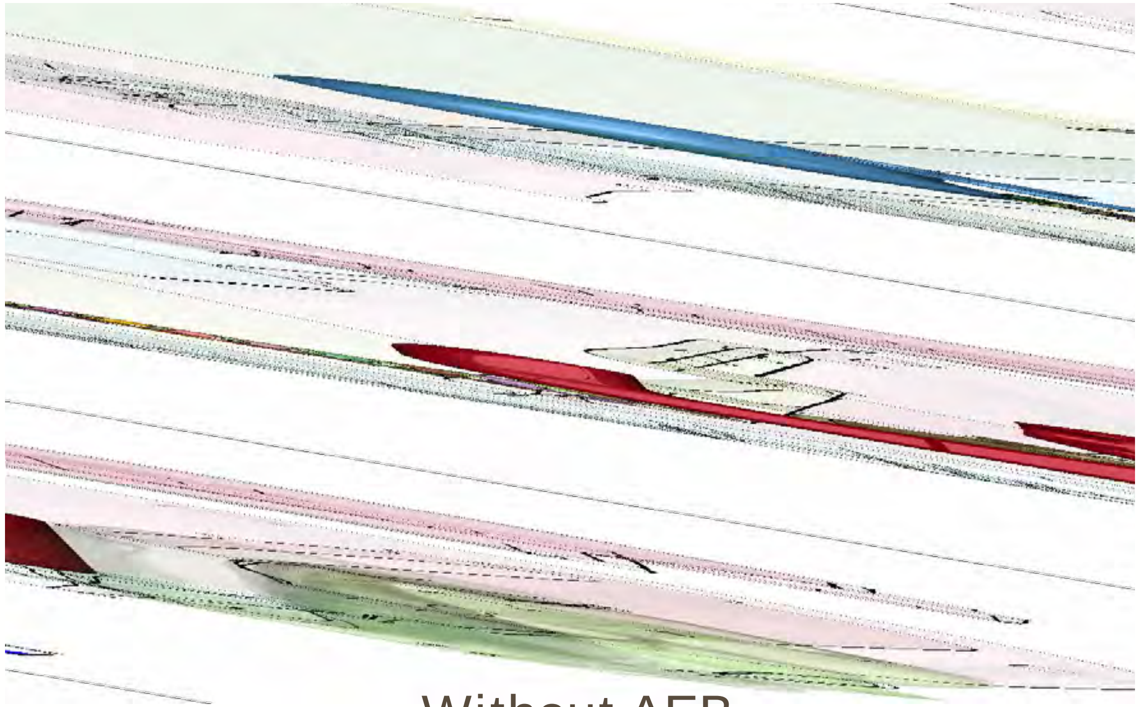




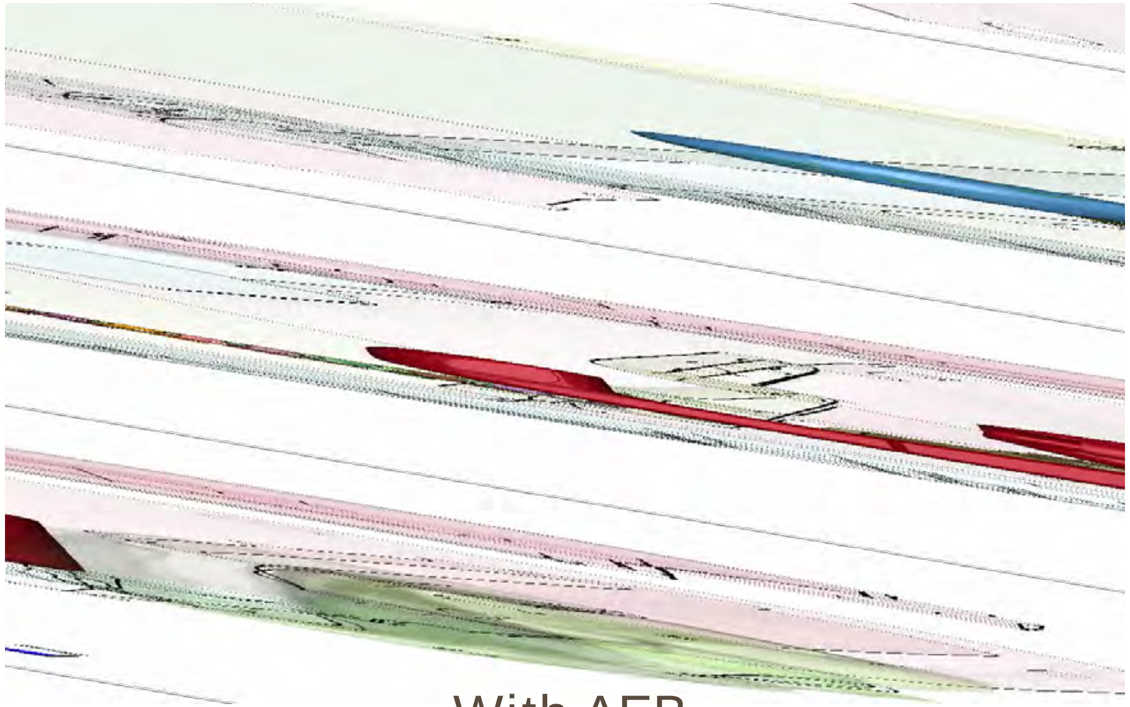
- Spinal angle measured from C1-C7 level of the spine between with-AEB cases and without-AEB cases
- Negative delta spinal angles indicate that the spine at the start of the crash phase was more flexed for the with-AEB cases than the without-AEB cases.

Children's Hospital of Philadelphia

RESULTS AND DISCUSSION – EFFECT OF AEB



Without AEB



With AEB

- Prior to impact, occupants were more forward flexed in cases with AEB than without AEB across all simulated conditions
- Resulted in relatively lower injury numbers for cases with AEB

Children's Hospital of Philadelphia®

RESULTS AND DISCUSSION – EFFECT OF AEB

- Occupant maximum head excursion
  - Leaning inboard posture showed greatest excursion (among all postures)
  - Leaning outboard and pre-submarining postures showed lowest excursion
    - This could be due to the interaction of the shoulder and lap belts with the occupant in respective seating postures

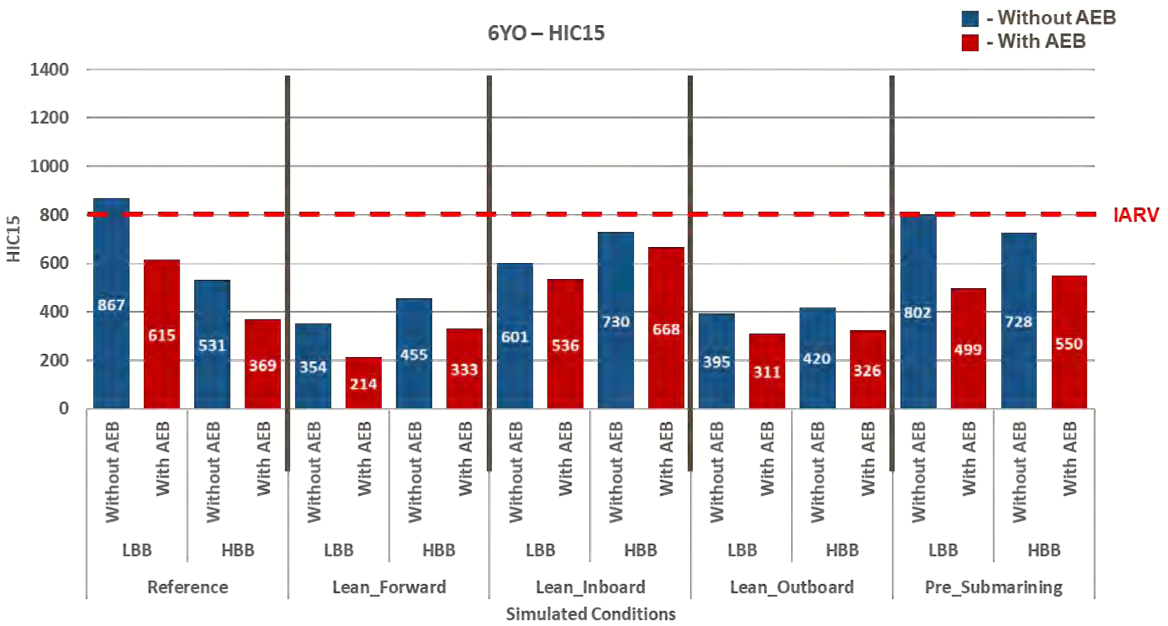
Leaning Inboard

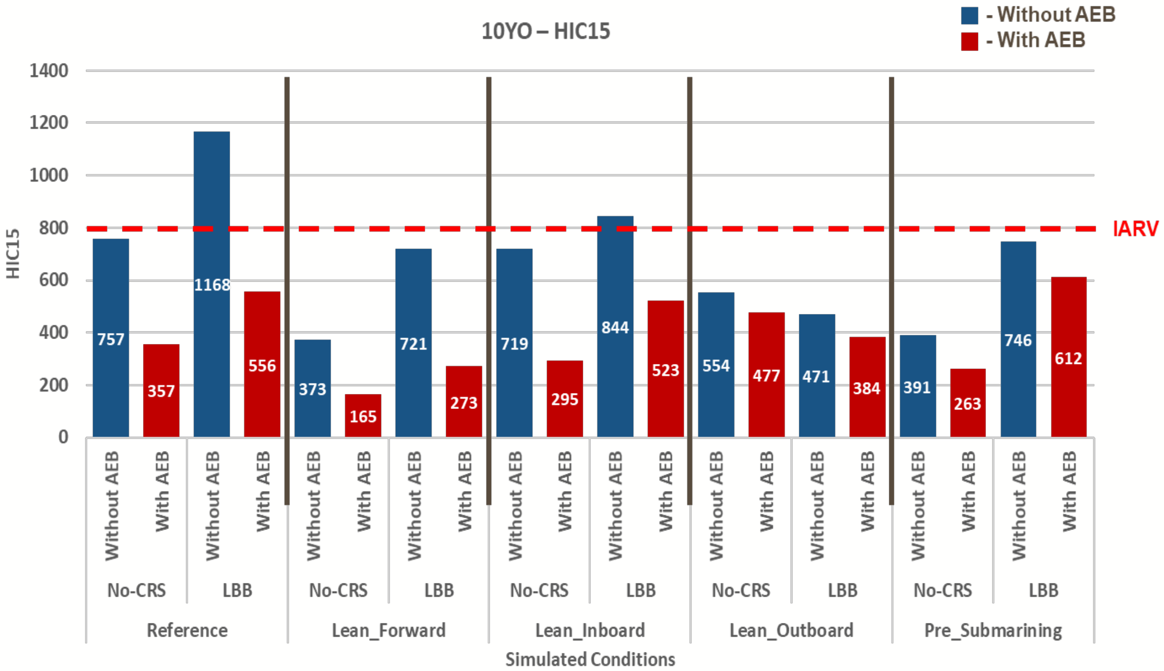
Leaning Outboard

Shoulder belt position after application of AEB

Children's Hospital of Philadelphia®

RESULTS AND DISCUSSION – EFFECT OF AEB





- Lower injury numbers for with-AEB cases
  - Lower HIC36, head acceleration, upper neck tensile force and flexion moment
  - Occupant reaches forward flexed position under effect of AEB, thereby resulting in lower injury numbers than without-AEB cases
  - Greater ride-down effect in with-AEB cases (Yamada et al. 2016)

Children's Hospital of Philadelphia

LIMITATIONS

- AEB Pulse, CRSs, seatbelt characteristics
  - The effect of one variation of each was studied; additional variations need to be explored
- PIPER human body model
  - Modeled with passive musculature
  - Active musculature in PIPER human body model could change kinematics and kinetics
  - Fidelity of the PIPER model
  - Scaling challenges
- Validation
  - Complete environment needs to be validated with physical test data

CONCLUSIONS

- Different initial seating postures result in substantially different kinematics and kinetics that are not necessarily captured by the reference seating posture

- Lower injury numbers do not necessarily reflect better behavior
  - Eg: 10YO in pre-submarining posture in NoCRS had moderate injury metrics but did not measure injury potential due to submarining
  - Lap belt loading the abdomen could lead to internal injuries

- Different initial seating postures should be incorporated in standard vehicle/CRS testing to ensure complete robust pediatric occupant protection
  - Other impact conditions need to be explored before different postures are incorporated into standard testing

- Although AEB may not prevent a crash, it may reduce the effect of the crash on the occupant as opposed to without-AEB conditions, despite the same impact velocity

PEER-REVIEWED LITERATURE

- Maheshwari J, Sarfare S, Falciani C, Belwadi A. Pediatric occupant human body model kinematic and kinetic response variation to changes in seating posture in simulated frontal impacts - with and without automatic emergency braking. Traffic Inj Prev. 2020 Oct 23:1-5. doi: 10.1080/15389588.2020.1825699. Epub ahead of print. PMID: 33095067.

- Maheshwari J, Sarfare S, Falciani C, Belwadi A. Analysis of Kinematic Response of Pediatric Occupants Seated in Naturalistic Positions in Simulated Frontal Small Offset Impacts: With and Without Automatic Emergency Braking. Stapp Car Crash J. 2020 Nov;64:31-59. PMID: 33636002.

Children's Hospital of Philadelphia®

ACKNOWLEDGEMENTS

The authors would like to acknowledge the National Science Foundation (NSF) Center for Child Injury Prevention Studies at The Children's Hospital of Philadelphia (CHOP) and The Ohio State University (OSU) for sponsoring this study and its Industry Advisory Board (IAB) for their support, valuable input and advice. The views presented are those of the authors and not necessarily the views of CHOP, OSU, the NSF or the IAB members.

PEDIATRIC OCCUPANT HUMAN BODY MODEL KINEMATIC AND KINETIC RESPONSE VARIATION TO CHANGES IN SEATING POSTURE IN SIMULATED FRONTAL IMPACTS – WITH AND WITHOUT AUTOMATIC EMERGENCY BRAKING

RCCADS Public Workshop

26th May 2021

Jalaj Maheshwari, MSE[1] (maheshwarj@email.chop.edu)

Shreyas Sarfare, MSE[1]

Clayton Falciani[1,2]

Aditya Belwadi, MS, PhD[1]

[1]Center for Injury Research and Prevention (CIRP), Children's Hospital of Philadelphia

[2]Drexel University, School of Computing and Informatics, Drexel University

Children's Hospital of Philadelphia®