



Influence of vehicle seat recline on child belt fit and posture

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Child Occupant Protection Seminar | 16 September 2026



BACKGROUND

- Children adopt a range of postures and belt fit scenarios even when using belt-positioning boosters
- Slouched postures observed in nominal seat configurations

[Reed 2009, Jones 2020, Baker 2021]

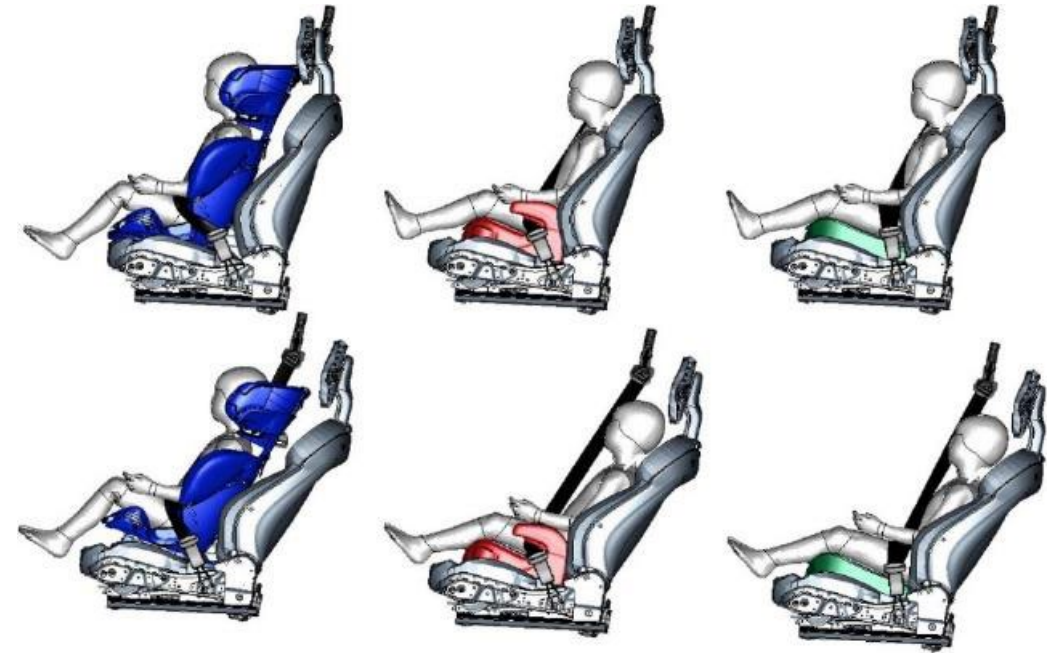


[Images from Baker 2021, 2023]

- Reed et al. (2009). *Accident Analysis & Prevention*, 41(3), 598-607.
- Jones et al. (2020). *International journal of environmental research and public health*, 17(3), 810.
- Baker et al. (2021). *Traffic Injury Prevention*, 22(sup1), S87-S92.

BACKGROUND

- Increased occupant desire and possibilities for reclined seating [Jorlöv 2017]
- Dynamic assessment of reclined child volunteers, ATDs, and HBMs [Bohman 2022; Graci 2022, 2023]
- Adult reclined posture and belt fit has been assessed [Reed 2019]
- **Still needed:** evaluation of static **child posture and belt fit** in reclined seatback configurations



[Image from Bohman 2022]

OBJECTIVE

- Evaluate child posture and belt fit in reclined seatback configurations



METHODS

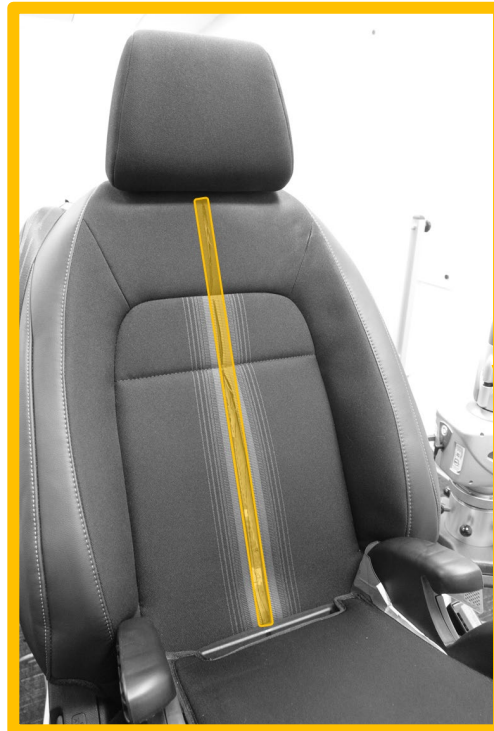
- N=43 children evaluated in all conditions
 - Grouped by booster or no-booster (randomized order), recline angle order randomized

Volunteer inclusion criteria

- 4–12 years
- 18.1–54.4 kg (40–120 lbs)
- 112–145 cm (44–57")



METHODS



Entertainment



METHODS

FARO 3D Coordinates (instantaneous)

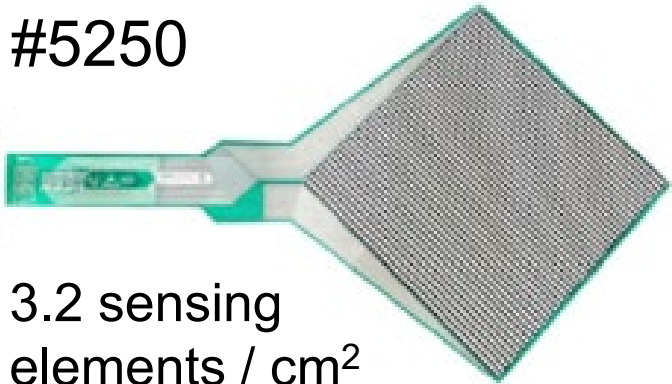
- Position of anatomic landmarks
- Position of shoulder and lap belt



XSENS Inertial Measurement Units (60 Hz)

- Body segment orientations
- Joint angles

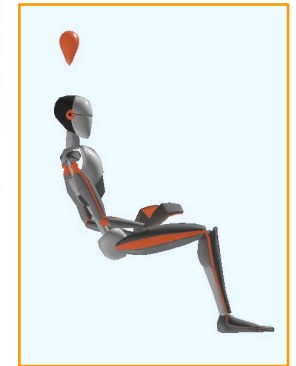
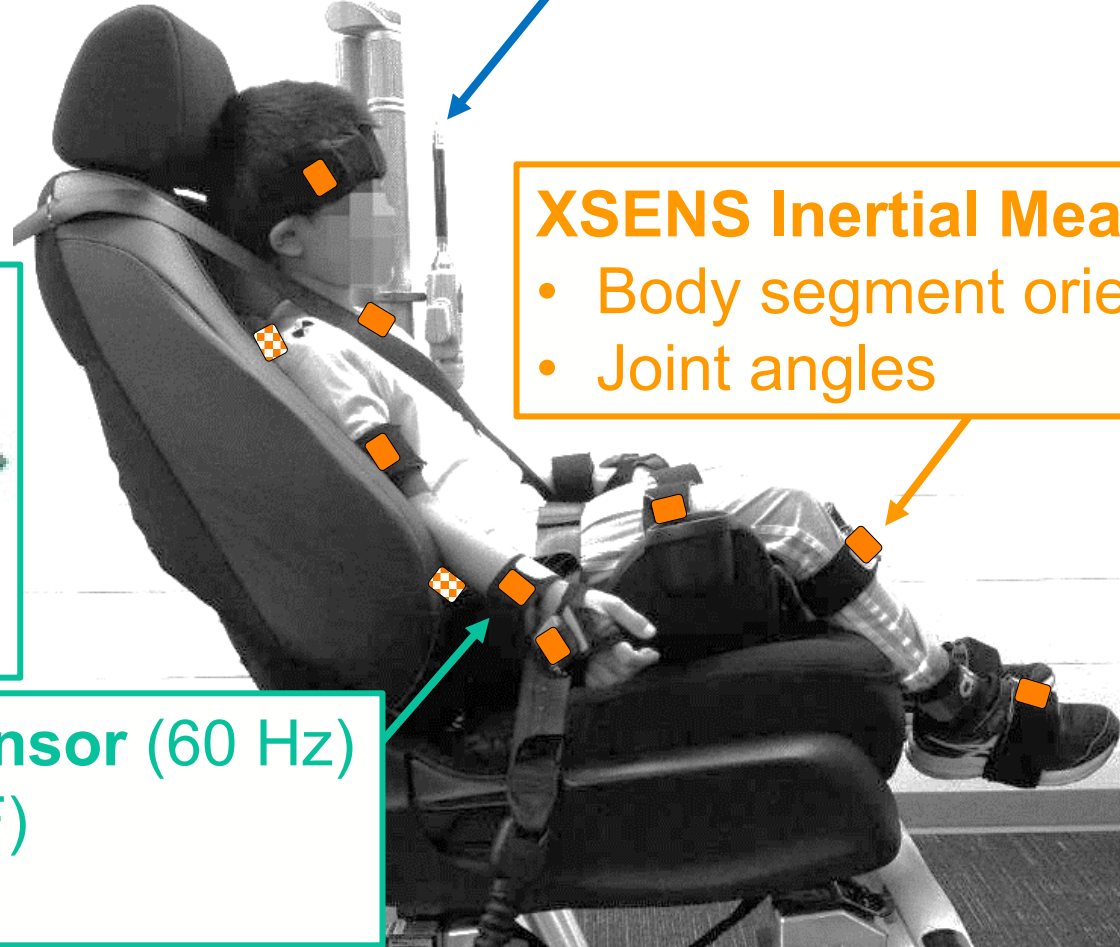
#5250



3.2 sensing
elements / cm²

Tekscan Pressure Sensor (60 Hz)

- Center of force (COF)
- Pressure distribution



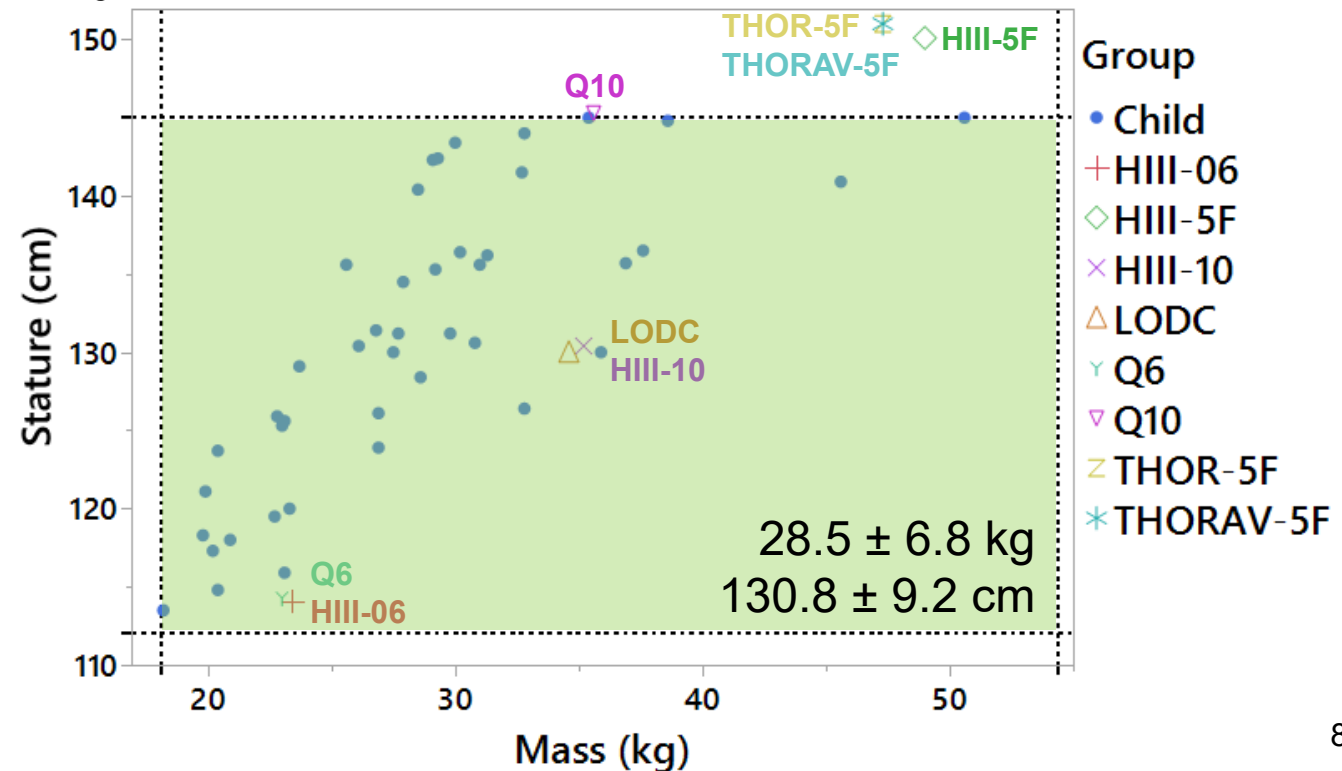
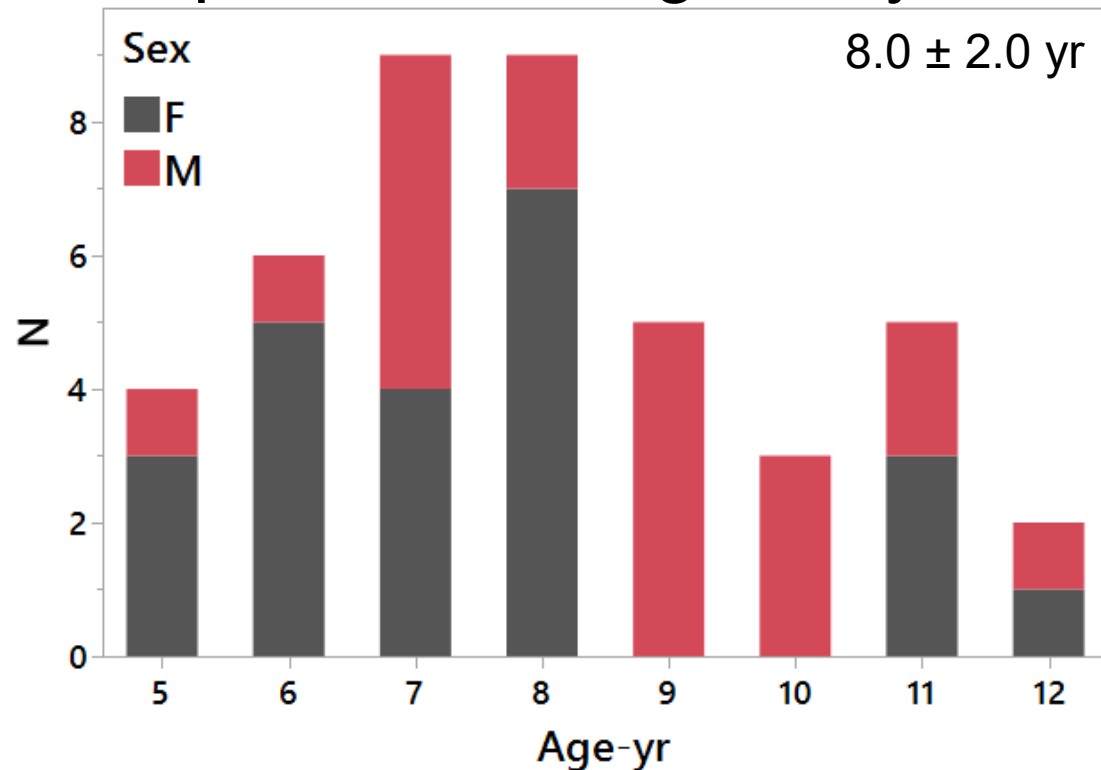
RESULTS

CHILD PARTICIPANTS

- Participants spanned booster manufacturer ranges
- Represented range of 6yo and 10yo ATD sizes

Volunteer inclusion criteria

- 4–12 years
- 18.1–54.4 kg (40–120 lbs)
- 112–145 cm (44–57")

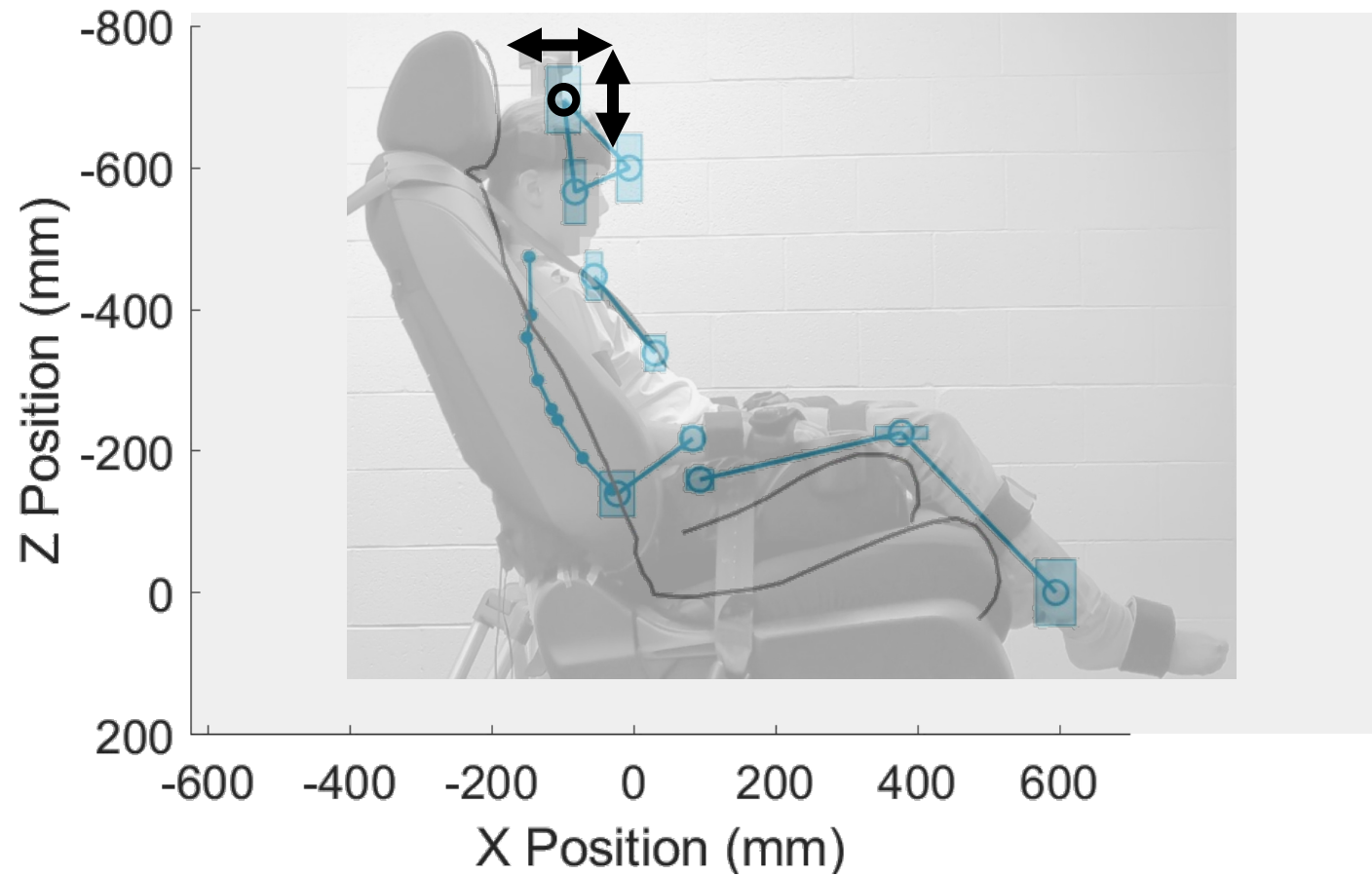


RESULTS POSTURE



RESULTS

POSTURE



*Shaded regions represent $\pm 1SD$



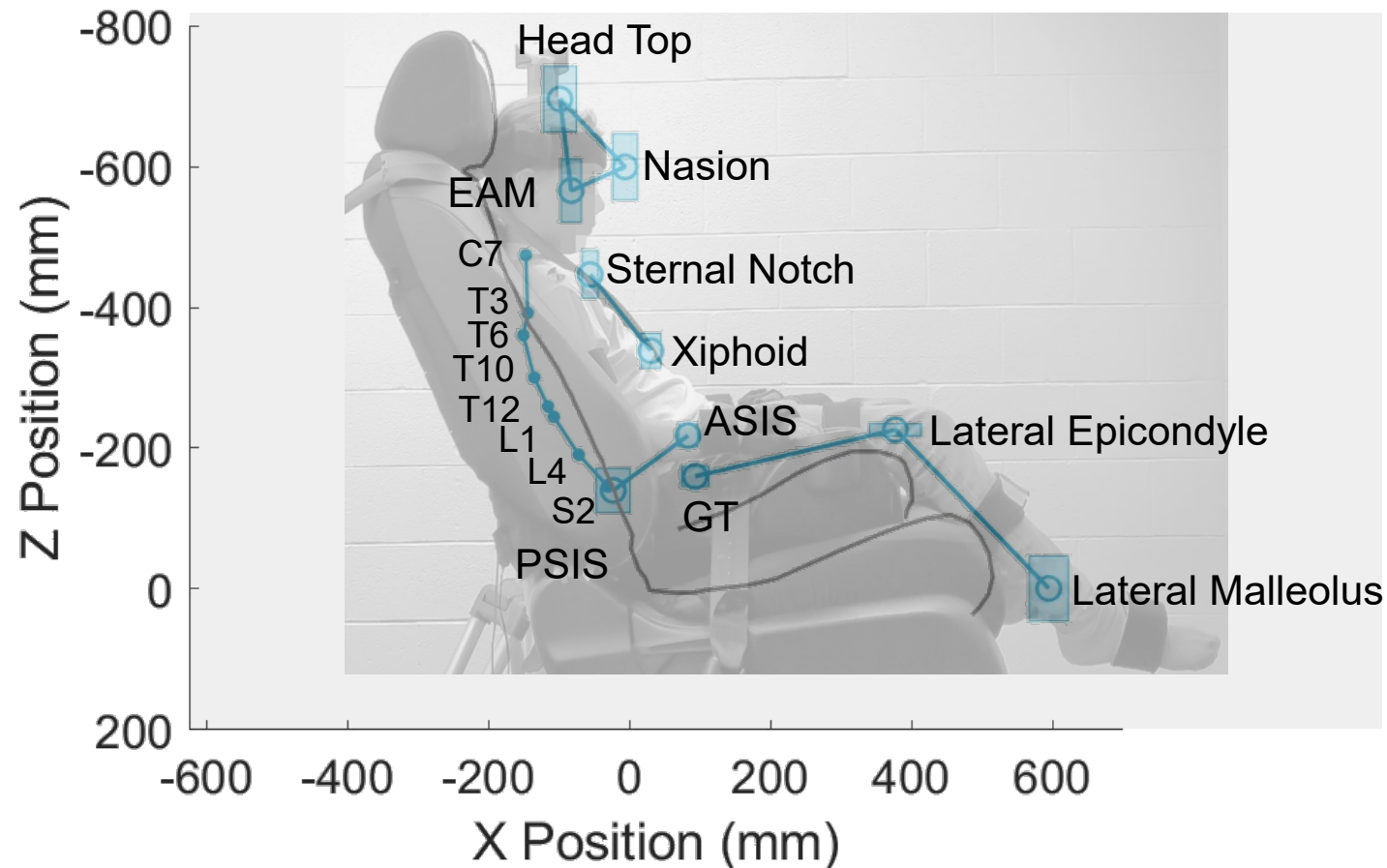
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RESULTS POSTURE



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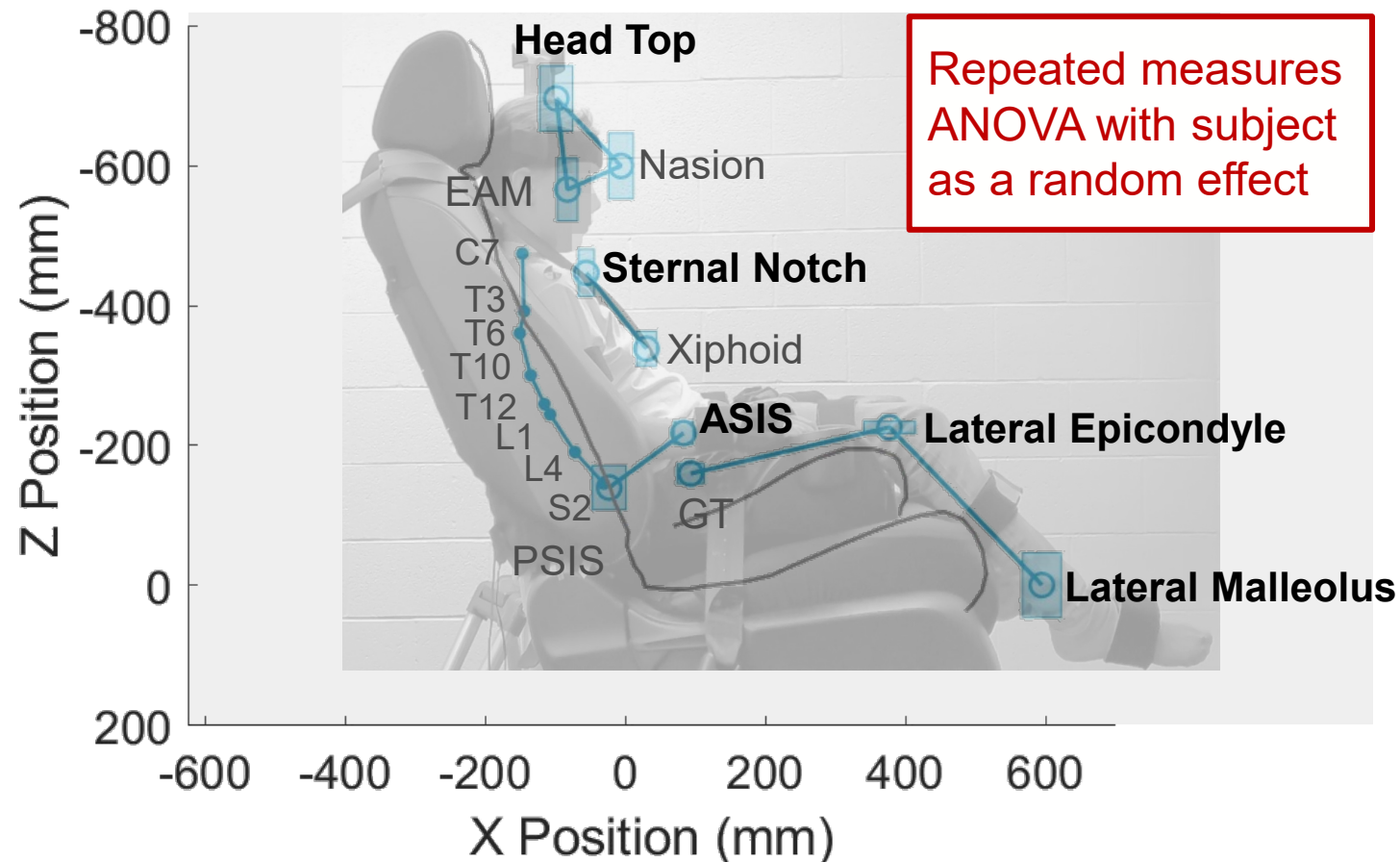
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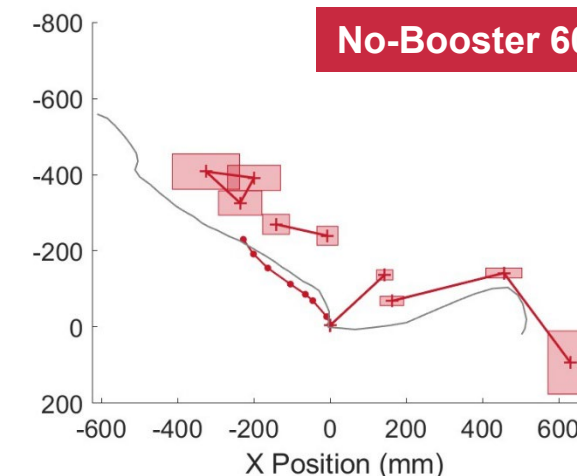
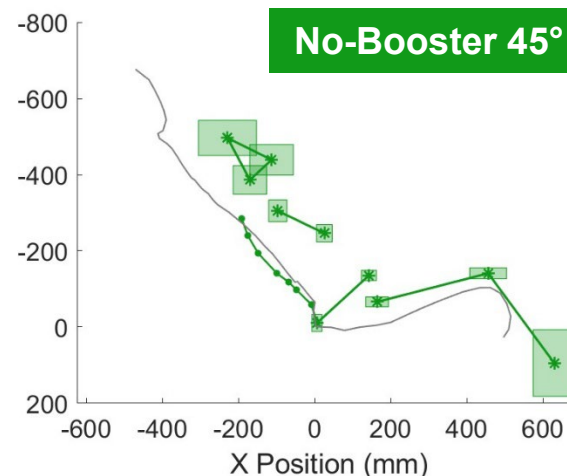
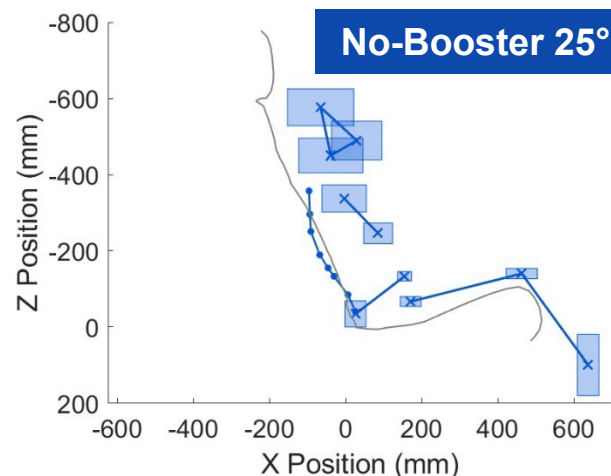
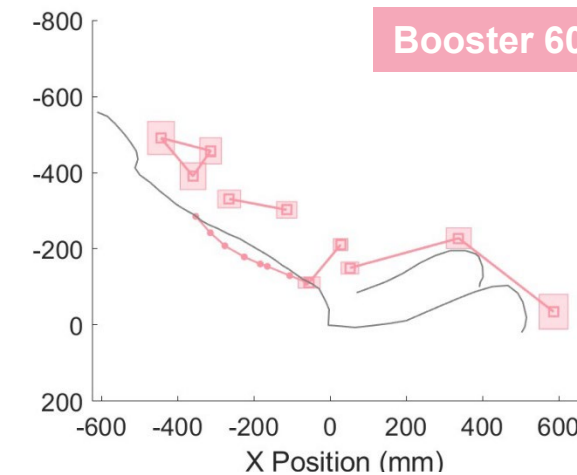
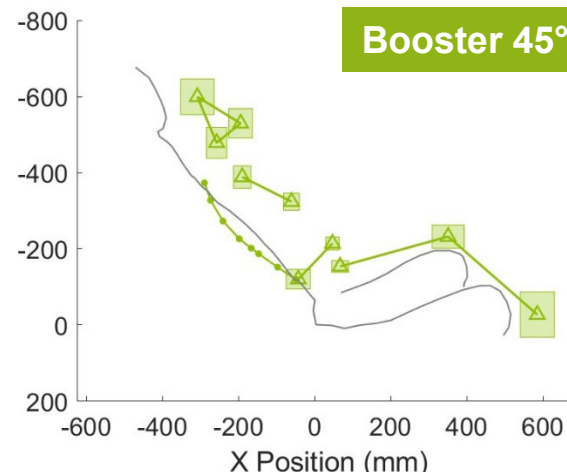
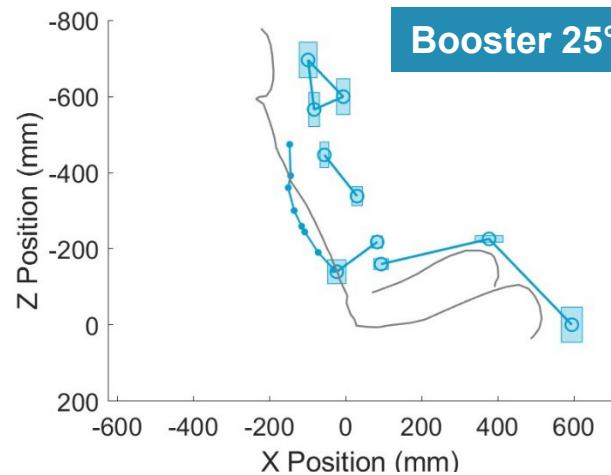
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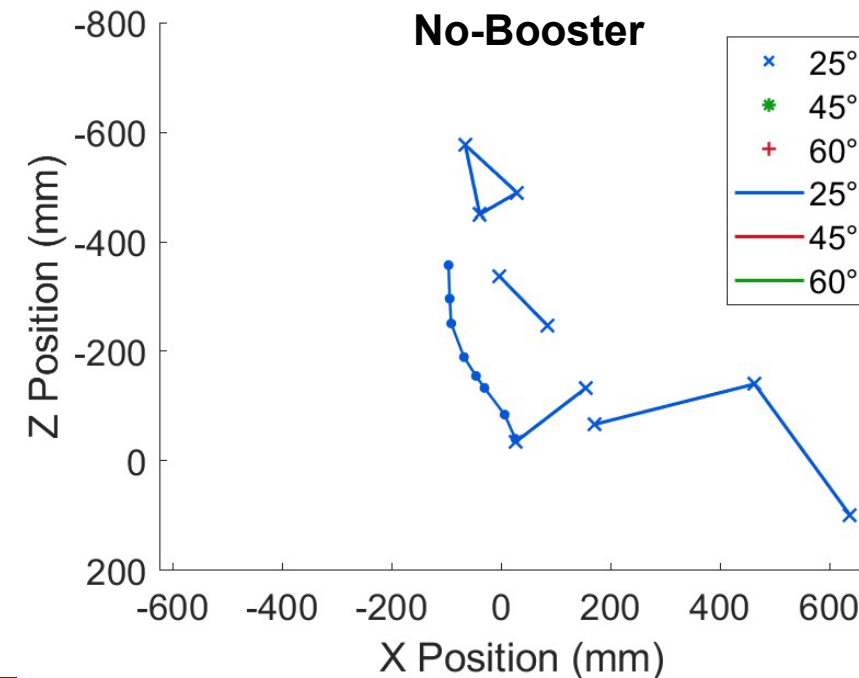
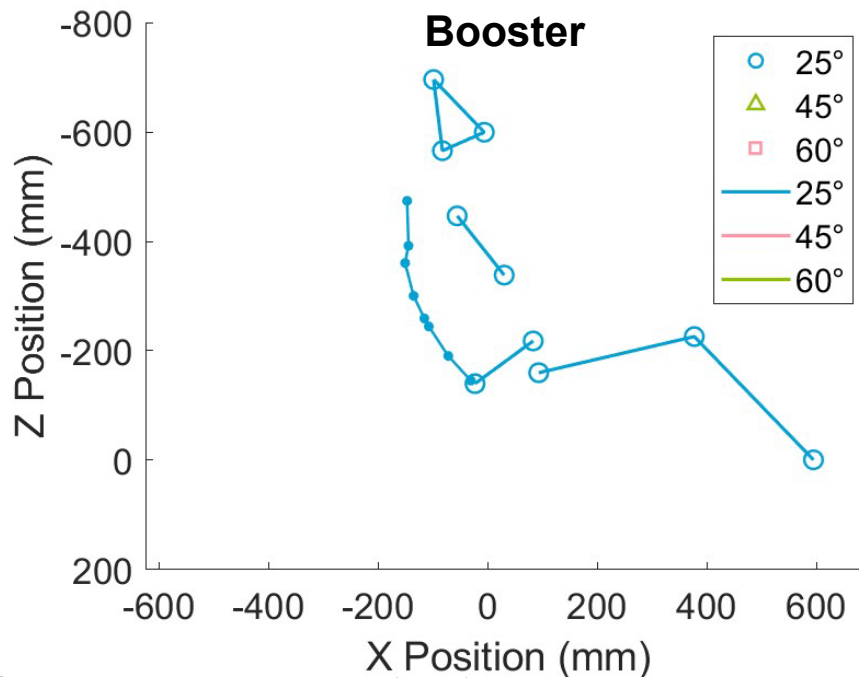


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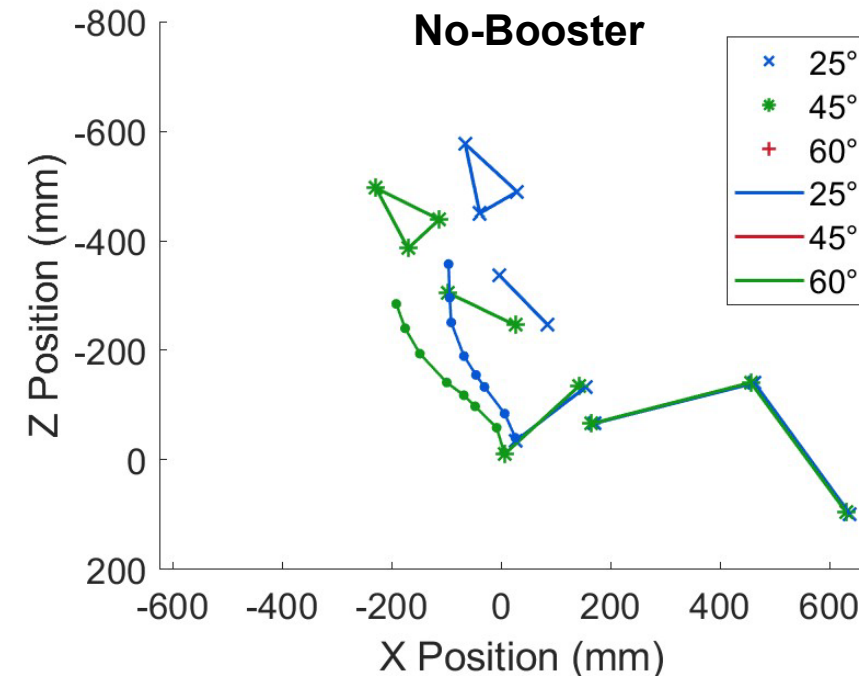
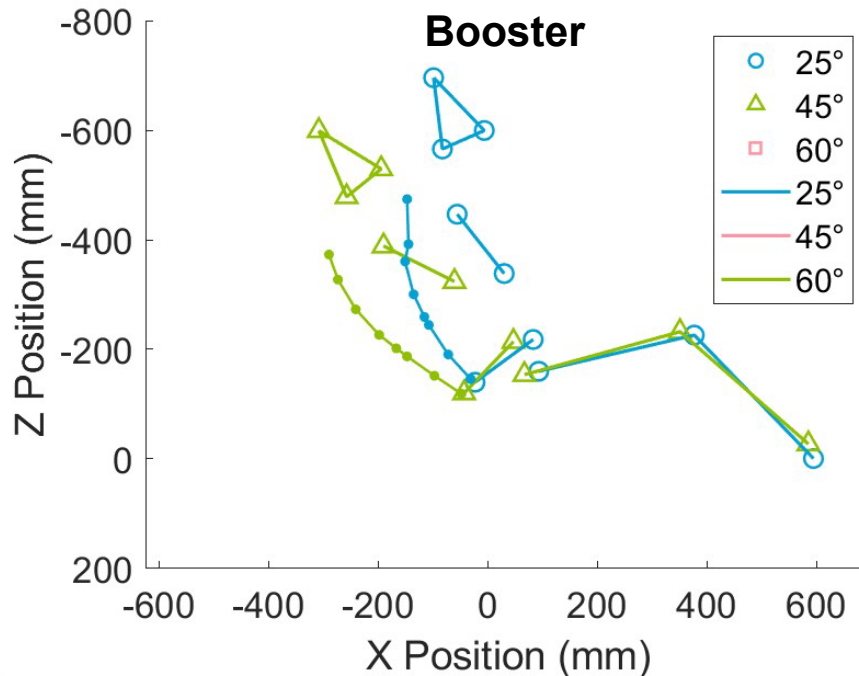
RESULTS

POSTURE



RESULTS

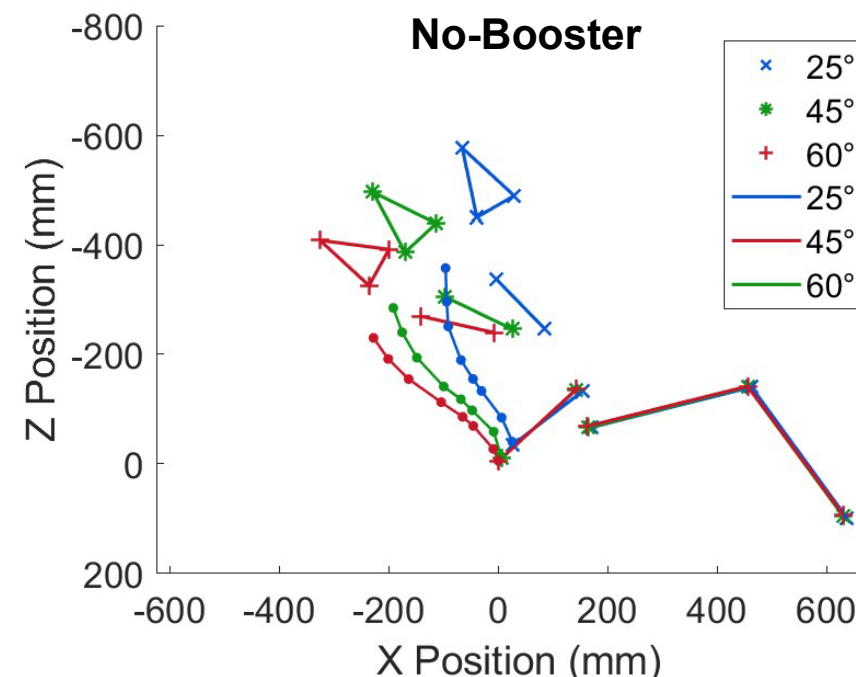
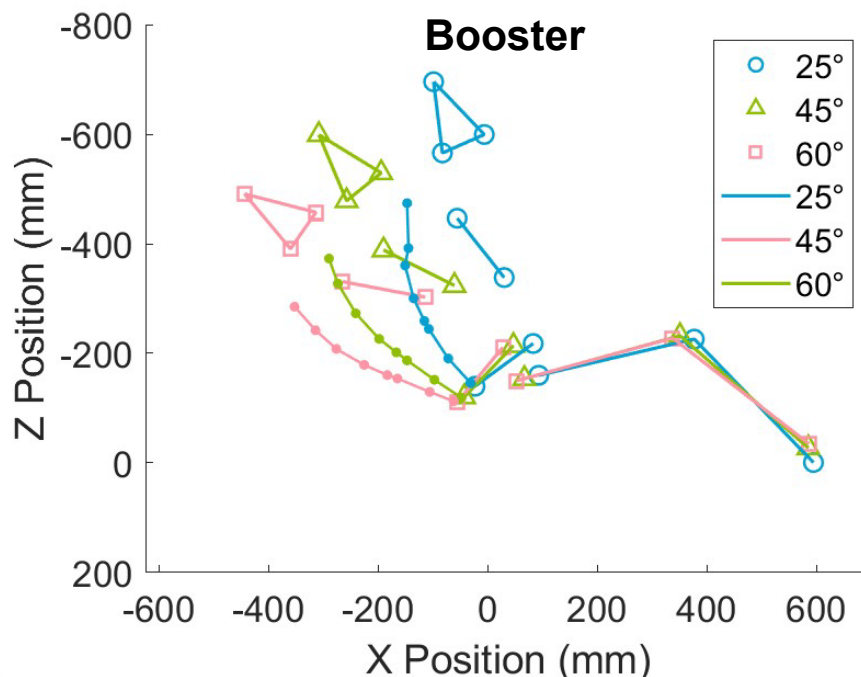
POSTURE



RESULTS POSTURE



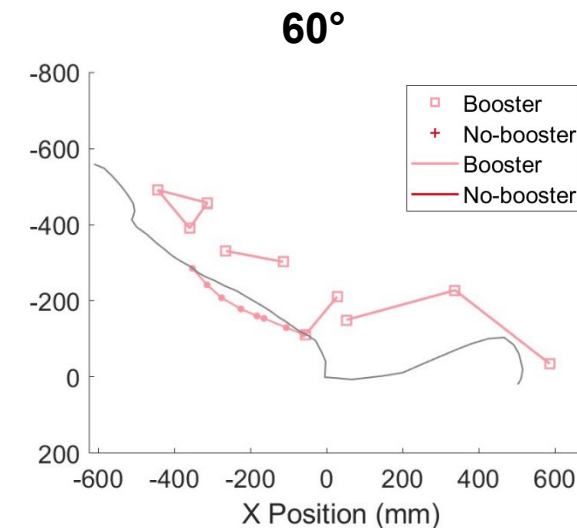
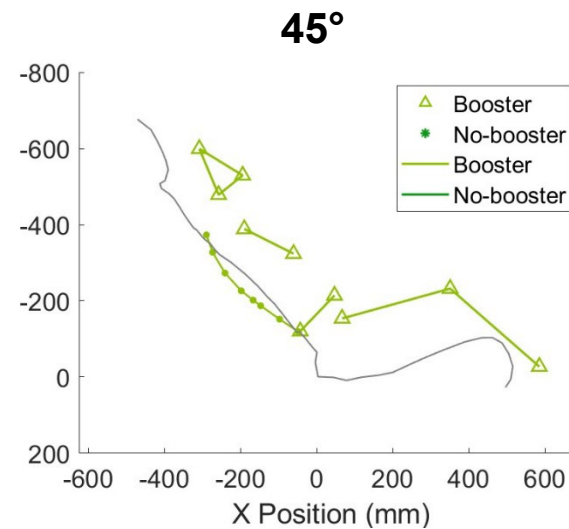
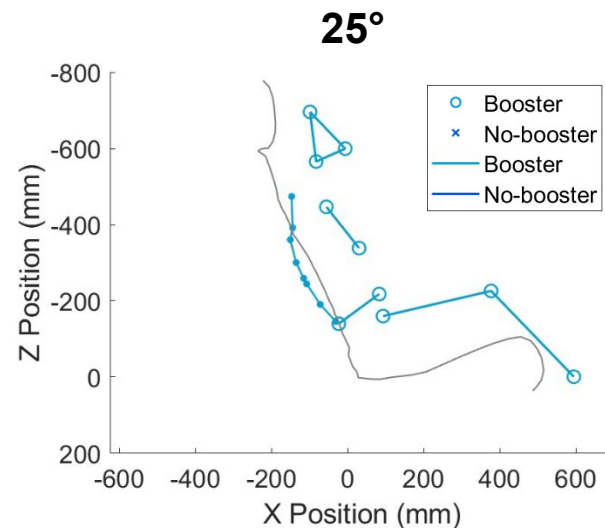
- Seating condition, recline condition, and seating*recline condition ($p < 0.05$)
 - Except recline: ASIS Z, Lateral Epicondyle Z, Lateral Malleolus X
- More reclined postures with increasing recline angle



RESULTS POSTURE



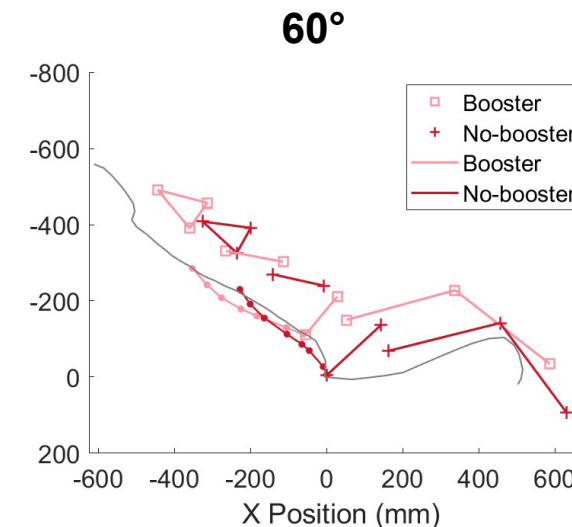
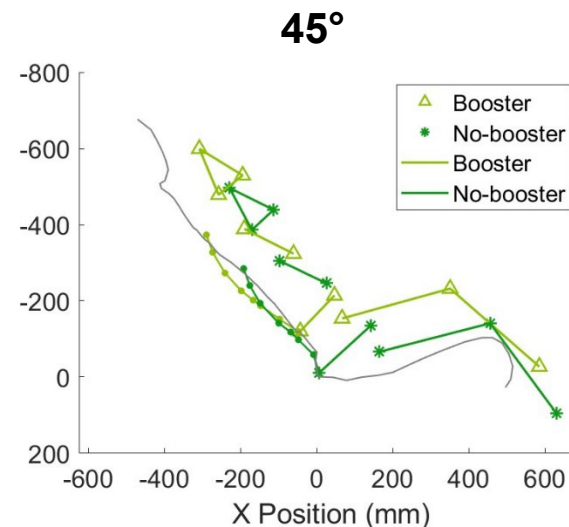
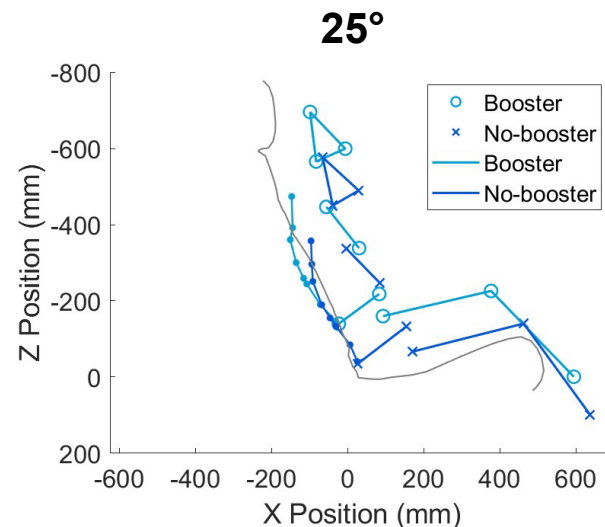
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RESULTS POSTURE



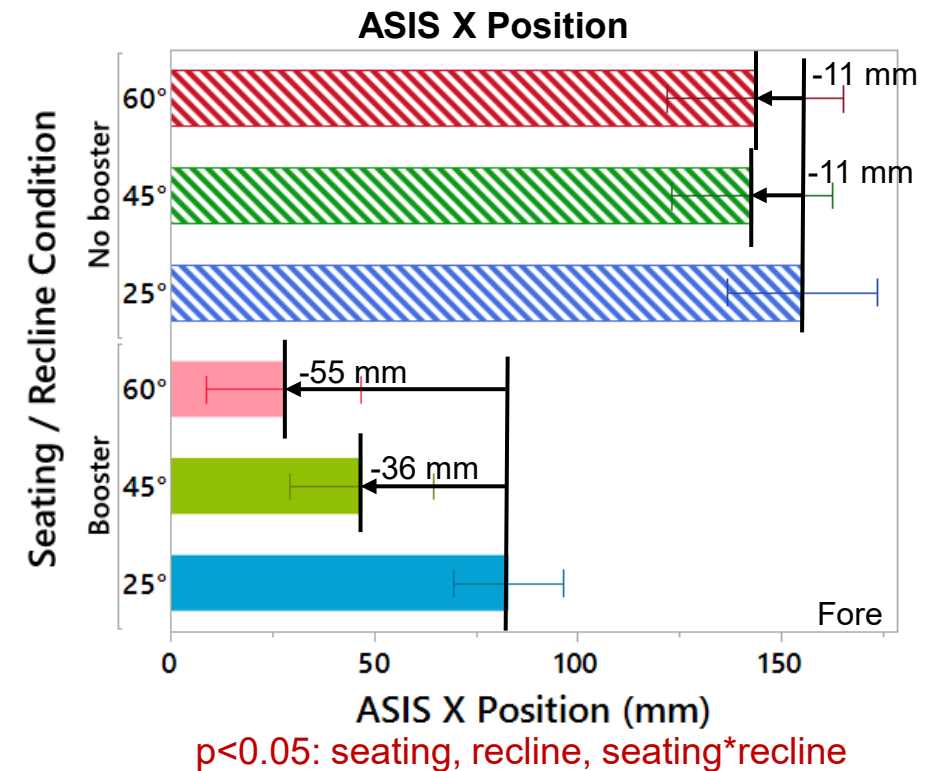
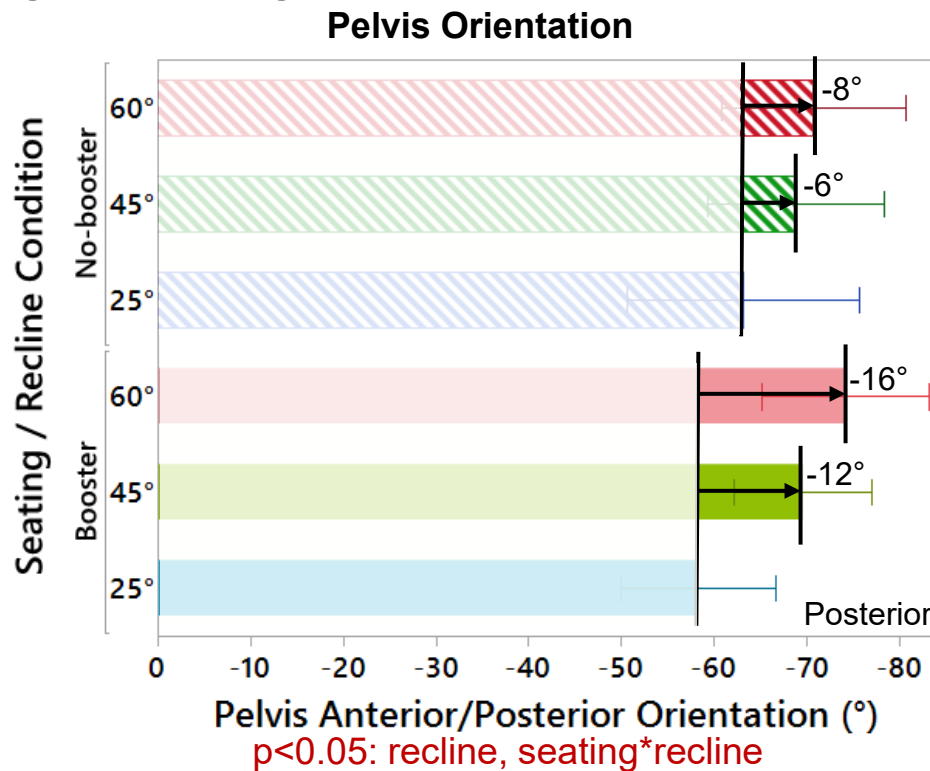
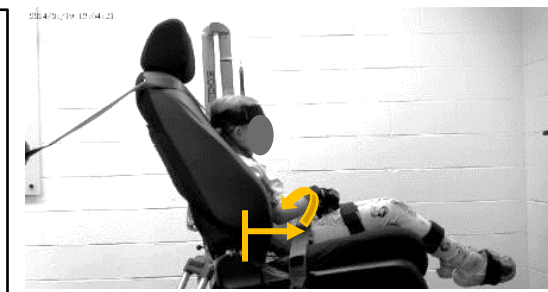
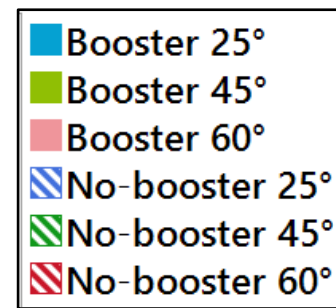
- Seating condition, recline condition, and seating*recline condition ($p < 0.05$)
 - Except recline: ASIS Z, Lateral Epicondyle Z, Lateral Malleolus X
- Booster: positions more superior
- No-booster: more forward ASIS, knee positions



RESULTS

POSTURE

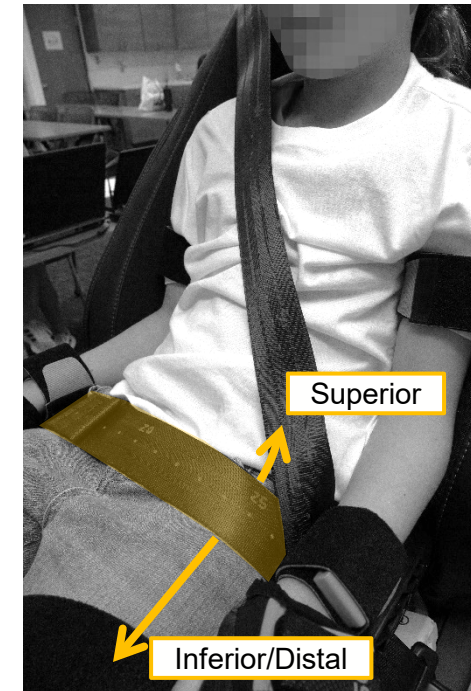
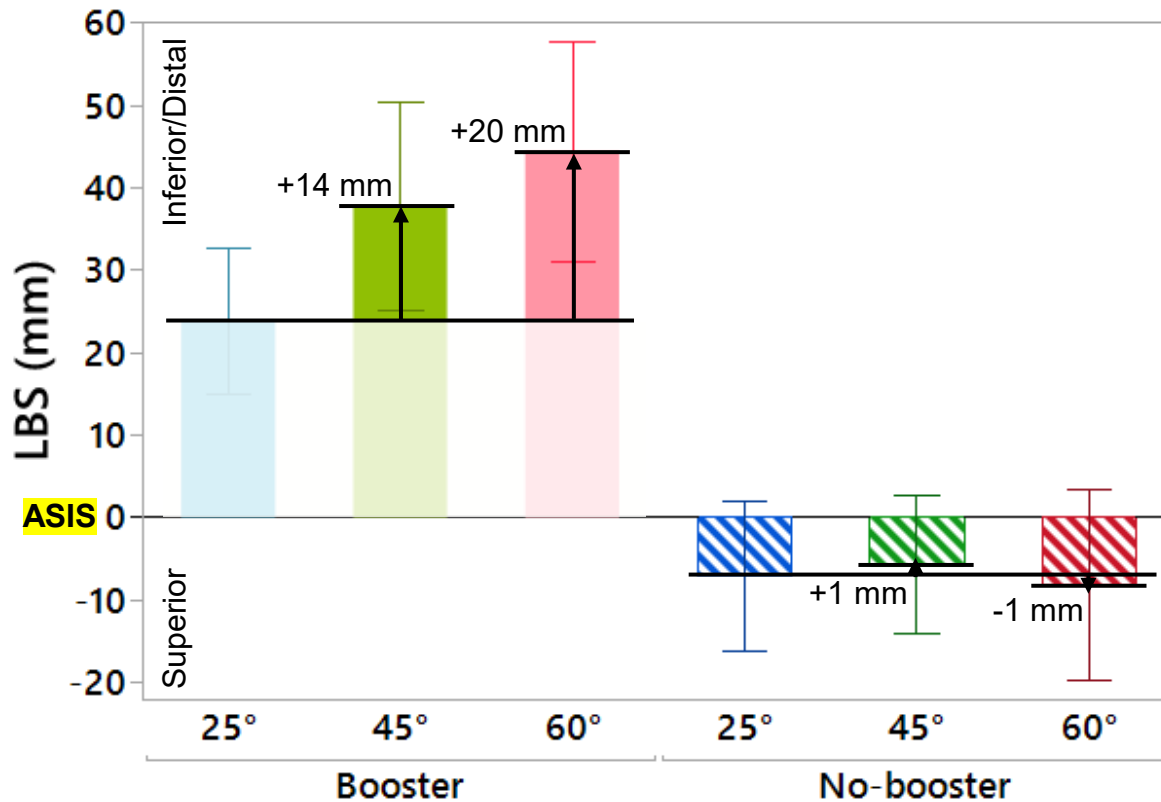
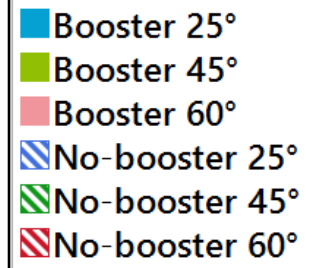
- Pelvis rotates posteriorly (ASIS moves rearward) with increasing recline
- Larger change on booster vs. no-booster



RESULTS

LAP BELT FIT

- Booster: lap belt becomes more inferior/distal with increasing recline
- No-booster: lap belt is more superior, minimal change with recline

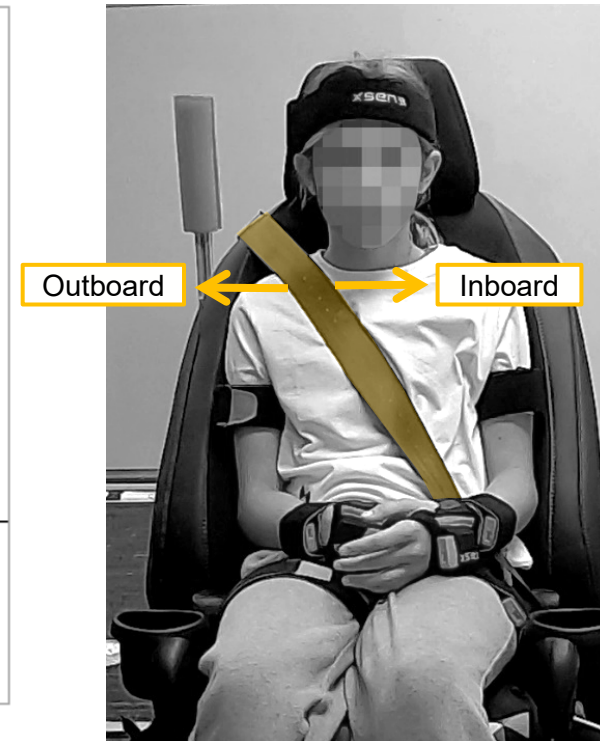
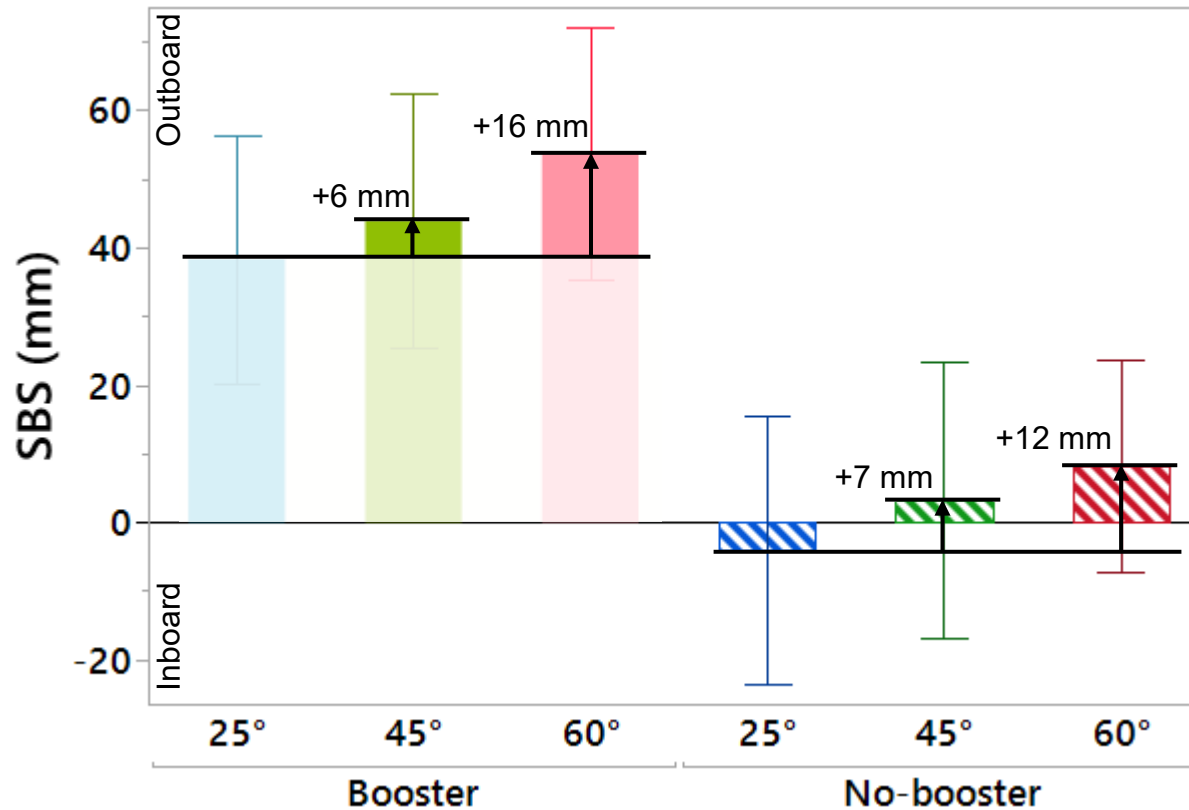
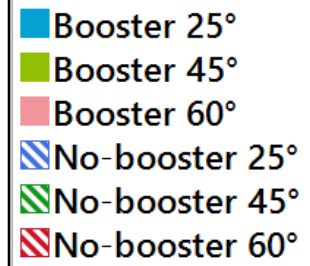


$p < 0.05$: seating, recline, seating*recline

RESULTS

SHOULDER BELT FIT

- No-booster: shoulder belt more inboard
- Shoulder belt becomes more outboard with increasing recline



$p < 0.05$: seating, recline

DISCUSSION

- **Children adapted their posture to reclined seatback angles**
 - More posterior pelvis orientation and ASIS X position
 - Greater changes observed on booster vs. no-booster



DISCUSSION

- **Booster provided improved posture and belt fit**
- **No-booster**
 - More slouched postures
 - Shoulder belt more inboard
 - Lap belt more superior



Booster 25°

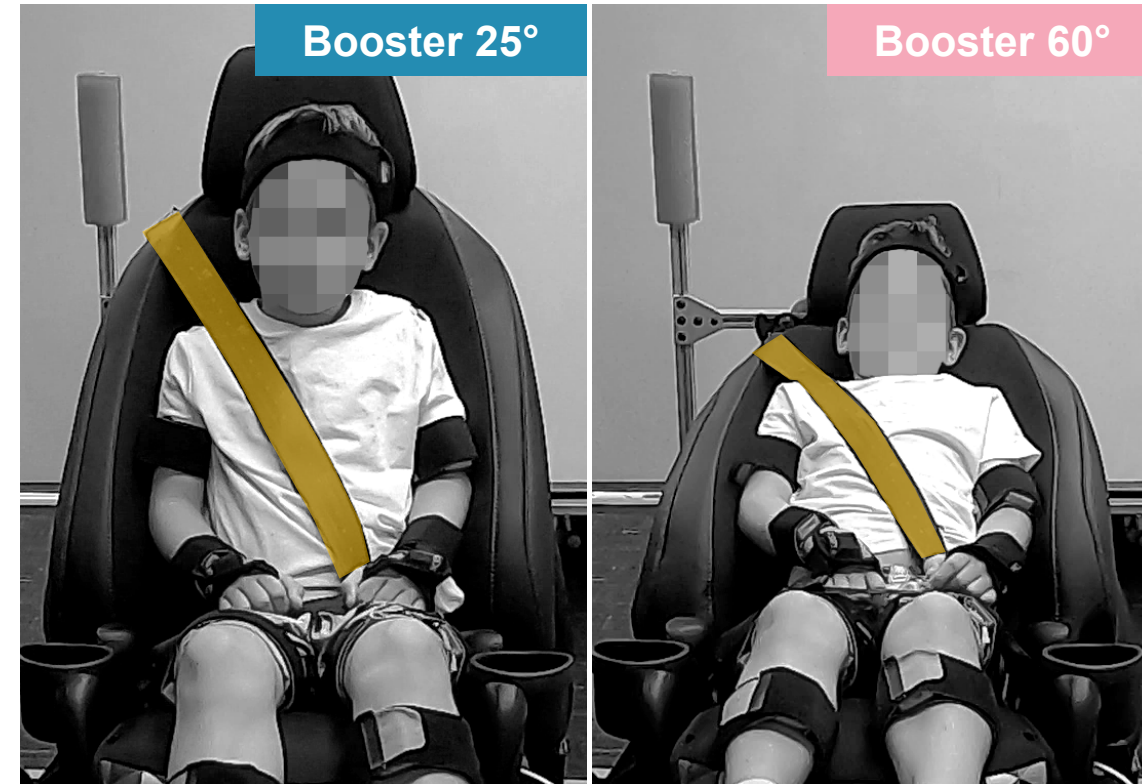


No-Booster 25°

DISCUSSION

- **Shoulder belt → outboard with more recline**

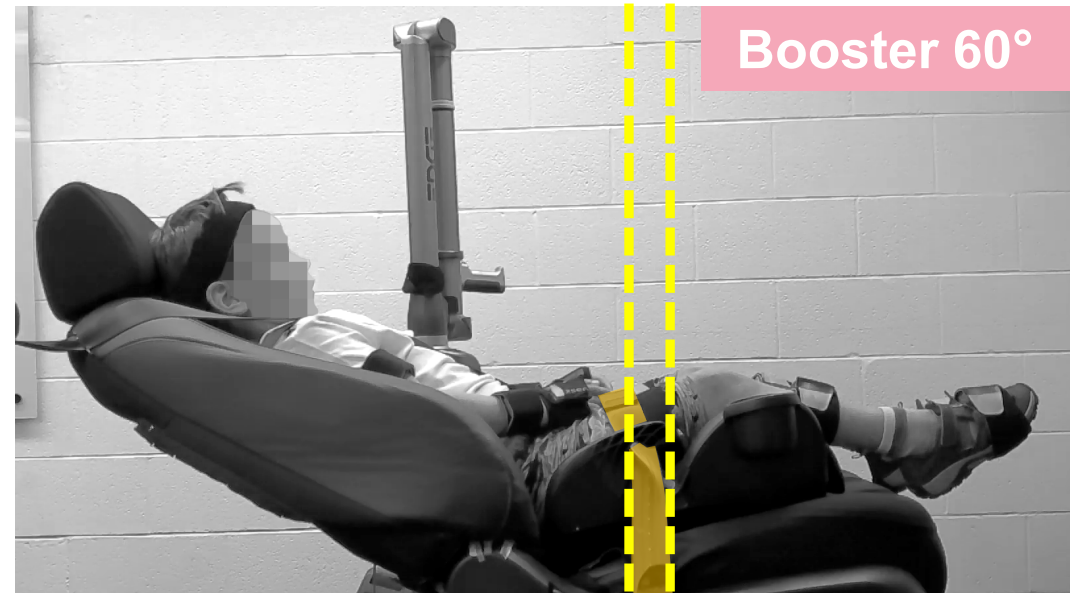
- Implications for slip-off
- Children on boosters
 - 38 mm (25°) → 54 mm (60°) = +16 mm
- Adults [Reed 2019]
 - 40 mm (23°) → -25 mm (53°) = -65 mm
- Opposite trend for children vs. adults
 - Both integrated belt outlet
 - Differences in belt geometry, order of study steps (sit vs. recline first)



• Reed et al. (2019). *Traffic injury prevention*, 20(sup1), S38-S42.

DISCUSSION

- Change in lap belt fit dependent on booster vs. no-booster
 - **Booster:** lap belt → inferior/distal with increasing recline (+20 mm)
 - Held in place by belt guides
 - Pelvis rotates posteriorly
 - May delay pelvis engagement



DISCUSSION

- Change in lap belt fit dependent on booster vs. no-booster
 - **Booster:** lap belt → inferior/distal with increasing recline (+20 mm)
 - Held in place by belt guides
 - Pelvis rotates posteriorly
 - May delay pelvis engagement
 - **No-booster:** no improvement (-1 mm)
 - Lap belt does move rearward with pelvis
 - All positioned more superiorly
 - Implications for submarining
 - **Adults:** lap belt X more rear (-26 mm)
[Reed 2019]



26

• Reed et al. (2019). *Traffic injury prevention*, 20(sup1), S38-S42.

CONCLUSIONS

- Children adapted their posture to reclined seatbacks
- Reclined conditions (45°, 60°): detrimental belt fit outcomes
 - Shoulder belt → outboard
 - Lap belt → inferior/distal (booster) and no improvement of superior positions (no-booster)
- Belt fit changes differed for children vs. adults [Reed 2019]
 - Important to consider child occupants alongside adults



LIMITATIONS

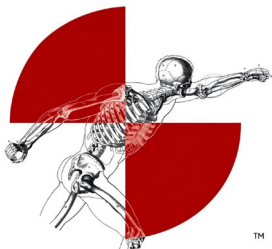
- Short duration (5–10 minutes)
- Not representative of all possible futuristic vehicle environments

FUTURE WORK

- **Use these data to position pediatric crash surrogates** when evaluating reclined scenarios
 - Better assess realistic initial posture and belt fit
- **Caregiver survey: ~25% allowed child to recline on some trips**
 - Further assess reasons and current/future frequency of reclined postures

ACKNOWLEDGEMENTS

The child volunteers and their families



Faculty, staff, and students of the IBRC

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Chloe Schroeder, Ty Bolte, Greta Yugovich, Kelly Labant

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The views presented are those of the authors and not necessarily the views of CHOP, OSU, the NSF, or the IAB members.



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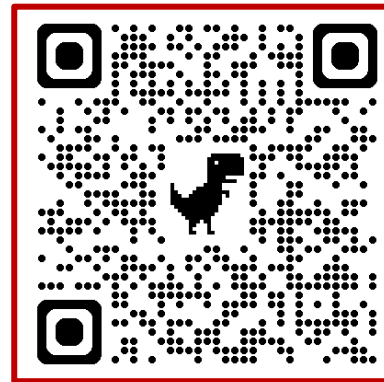
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