Quantifying CRS Fit in the Vehicle Seat Environment

Child Occupant Protection: Latest Knowledge & Future Opportunities

John H Bolte IV, PhD

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INJURY BIOMECHANICS RESEARCH CENTER

THE OHIO STATE UNIVERSITY

Quantifying CRS Fit in the Vehicle Seat Environment

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Kleinert (GM)

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Project Background

- Misuse of child restraint systems (CRS) is common:
  - 73 - 94% (Eby and Kostyniuk, 1999; Decina and Lococo 2005; Koppel and Charlton, 2009; Lane et al., 2000)
- Majority of misuse is due to installation errors
- How much is due to incompatibility or poor fit?
- Main goal: Determine the most common sources of incompatibility between CRS and vehicles

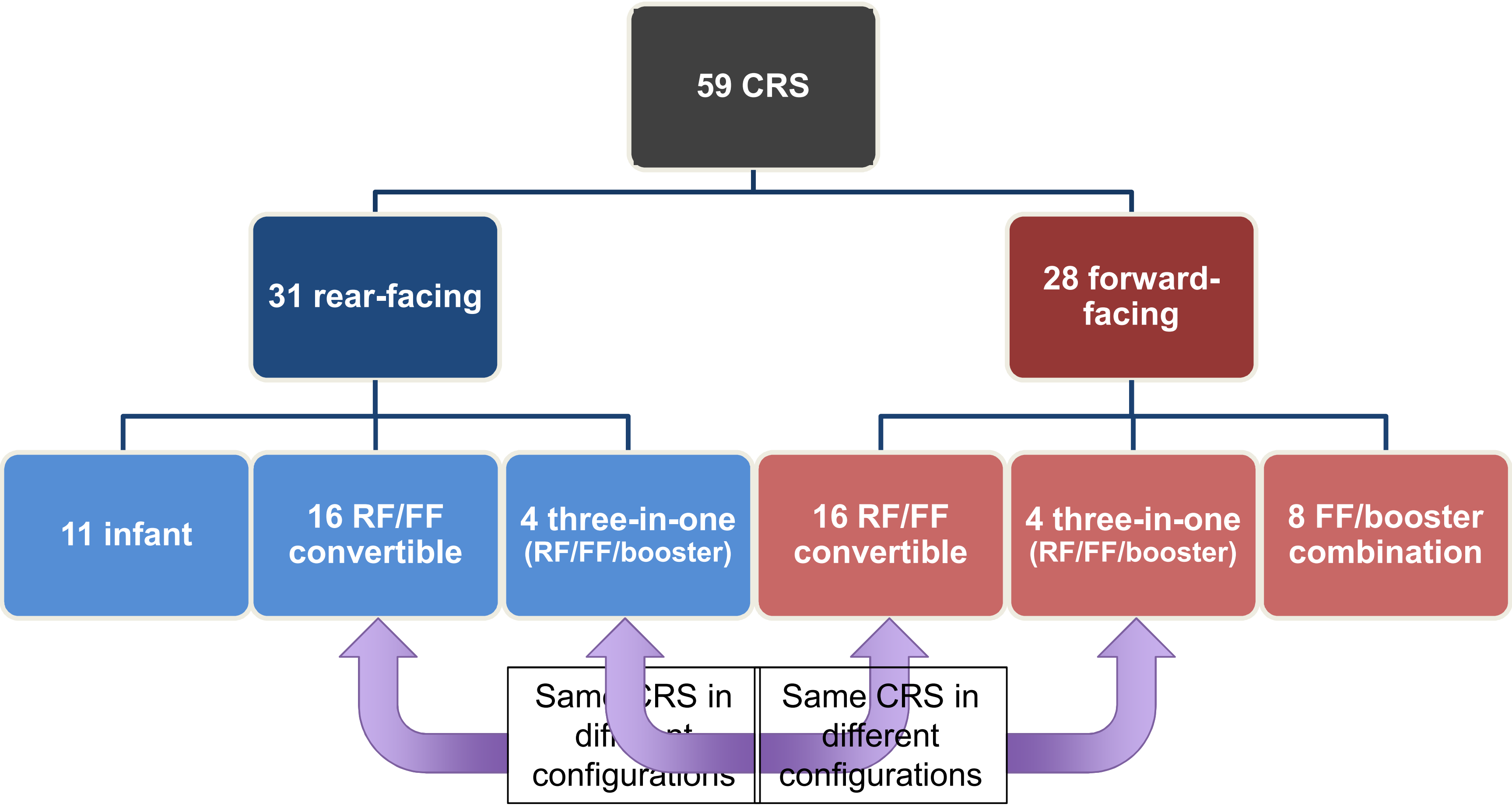
Specific Aims

- Identify and collect dimensional data on large group of CRS and vehicles
- Analyze each aspect of compatibility between groups
- Use information to:
  – Guide consumers in choosing a proper CRS for their vehicle.
  – Identify strong and weak areas of compatibility in CRS and vehicle design.

Cautionary Points

- Avoid ranking system for specific CRS or vehicle models (Ex: “X” fits into “Y”)
  - This type of approach would only be useful for the specific set of CRS and vehicles studied
  - Want overall frequency of each particular problem, so that manufacturers have benchmarks to aim for.
- Avoid “ease-of-use” criteria
  - Would an expert be able to achieve a correct installation?

Methods

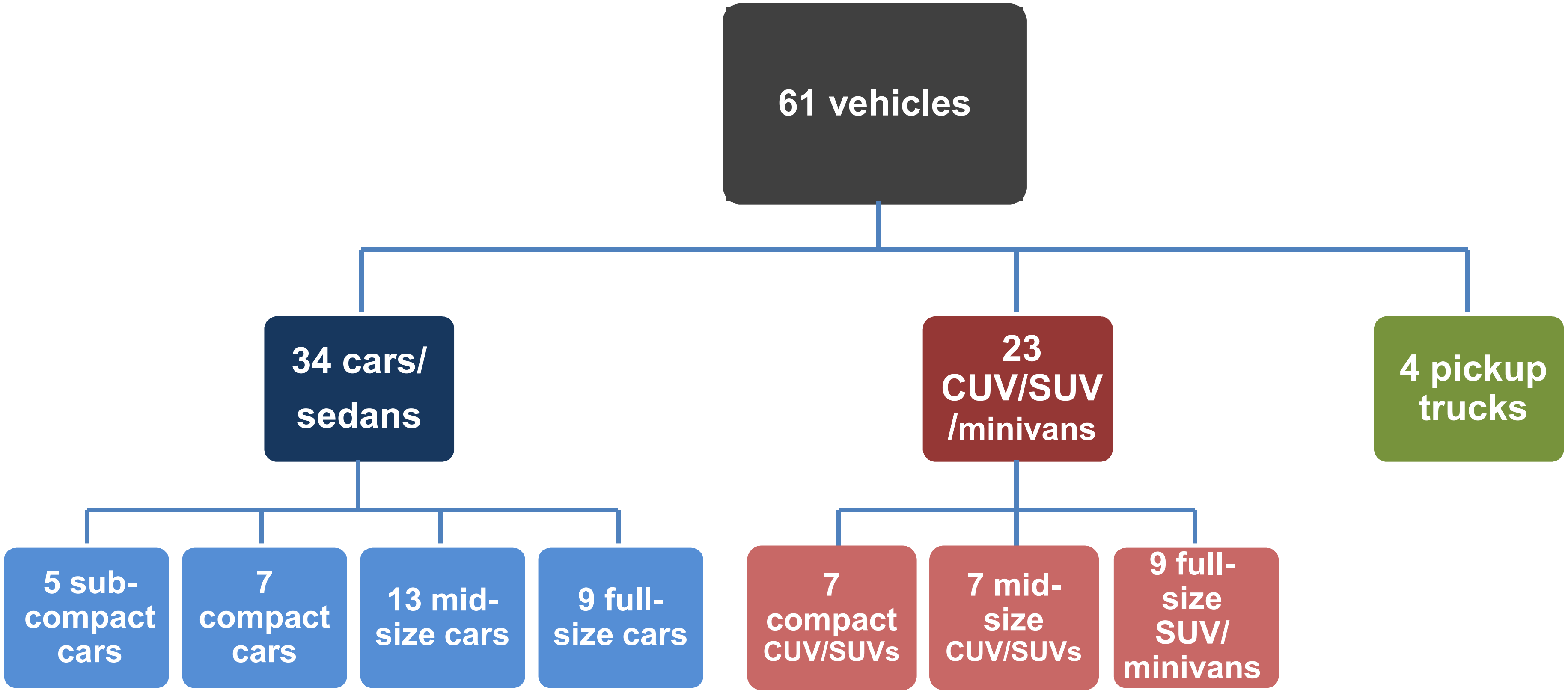

59 CRS
31 rear-facing
28 forward-facing
11 infant
16 RF/FF convertible
4 three-in-one (RF/FF/booster)
16 RF/FF convertible
4 three-in-one (RF/FF/booster)
8 FF/booster combination
Same CRS in different configurations

Methods

- 40 data points collected from each CRS
  - Overall height, width, length at multiple locations
  - Recline angles and base angle settings
  - Belt path features
  - LATCH belt features
  - Top tether information
  - Occupant weight/height information

Hooks Push-button SureLATCH Flex-Loc REMS

Methods


61 vehicles
34 cars/ sedans
23 CUV/SUV /minivans
4 pickup trucks
5 sub-compact cars
7 compact cars
13 mid-size cars
9 full-size cars
7 compact CUV/SUVs
7 mid-size CUV/SUVs
9 full-size SUV/ minivans

Methods

- 94 data points collected from each vehicle
  - Size, shape, contours of seat surfaces at multiple locations
  - Space available in each direction
  - Head rest information
  - Seat belt features
  - Outboard and center position





Methods: Success Rate

- For each fit criterion:

$$\text{Success rate} = \frac{\text{Number of successful combinations}}{\text{Total number of combinations}}$$

- Example: Is the width of the CRS smaller than the width of the vehicle seat along the bight line?

		VEH001	VEH002	VEH003	VEH004
		34.0	36.9	31.2	29.5
CRS001	30.2	1	1	1	0
CRS002	33.8	1	1	0	0
CRS003	27.9	1	1	1	1
CRS004	26.1	1	1	1	1

Width of seat bight

Width of CRS along seat bight edge

Total: $\frac{13}{16} = 81.3\%$

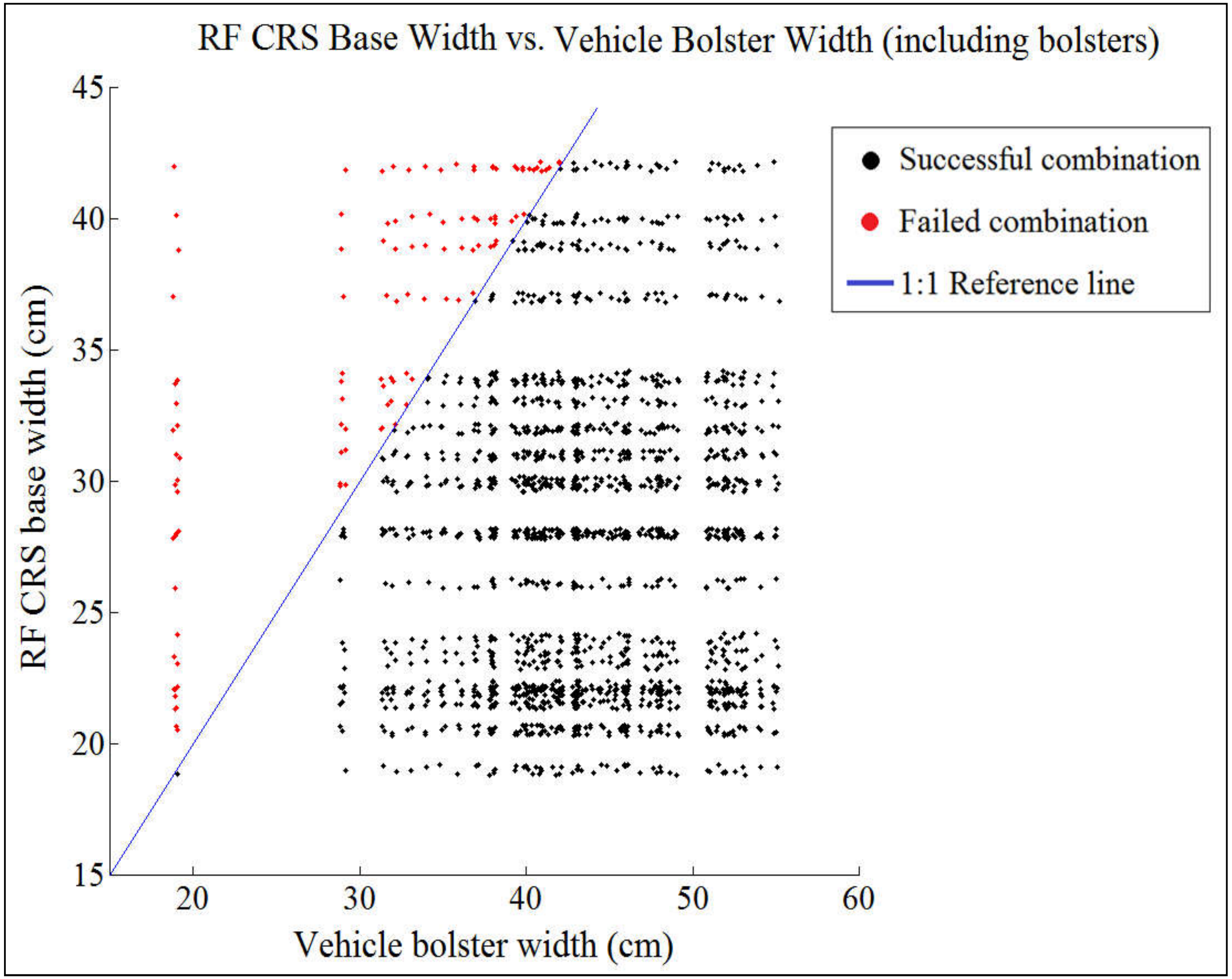
Bight Width, RF CRS

Width of edge of CRS which would be installed in the seat bight

Width of vehicle seat bight, including side bolsters

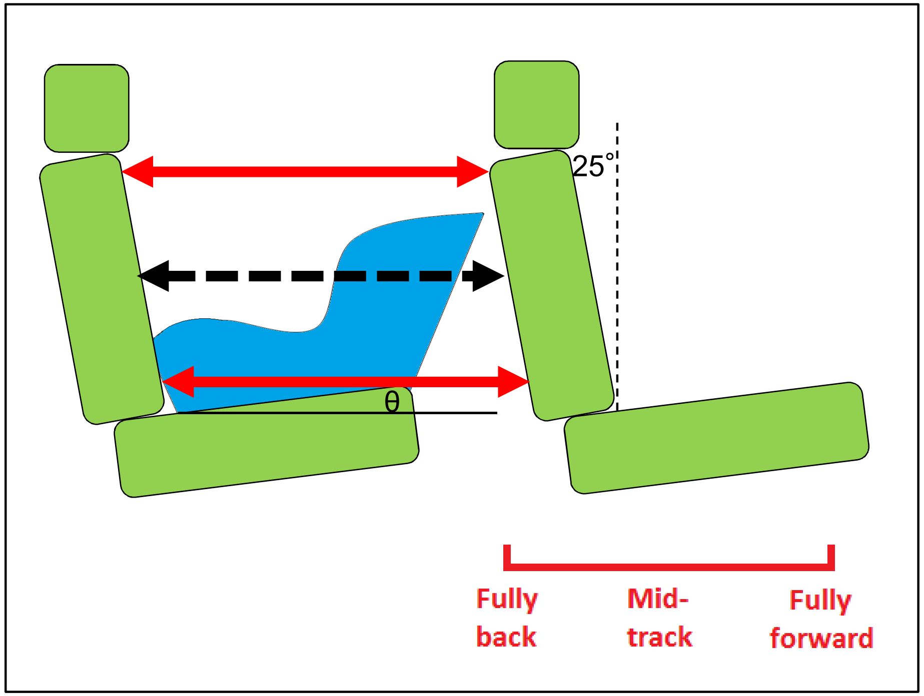
Bight Width Results, RF CRS

Success rate: 93.4% (considers all 1,891 combinations)



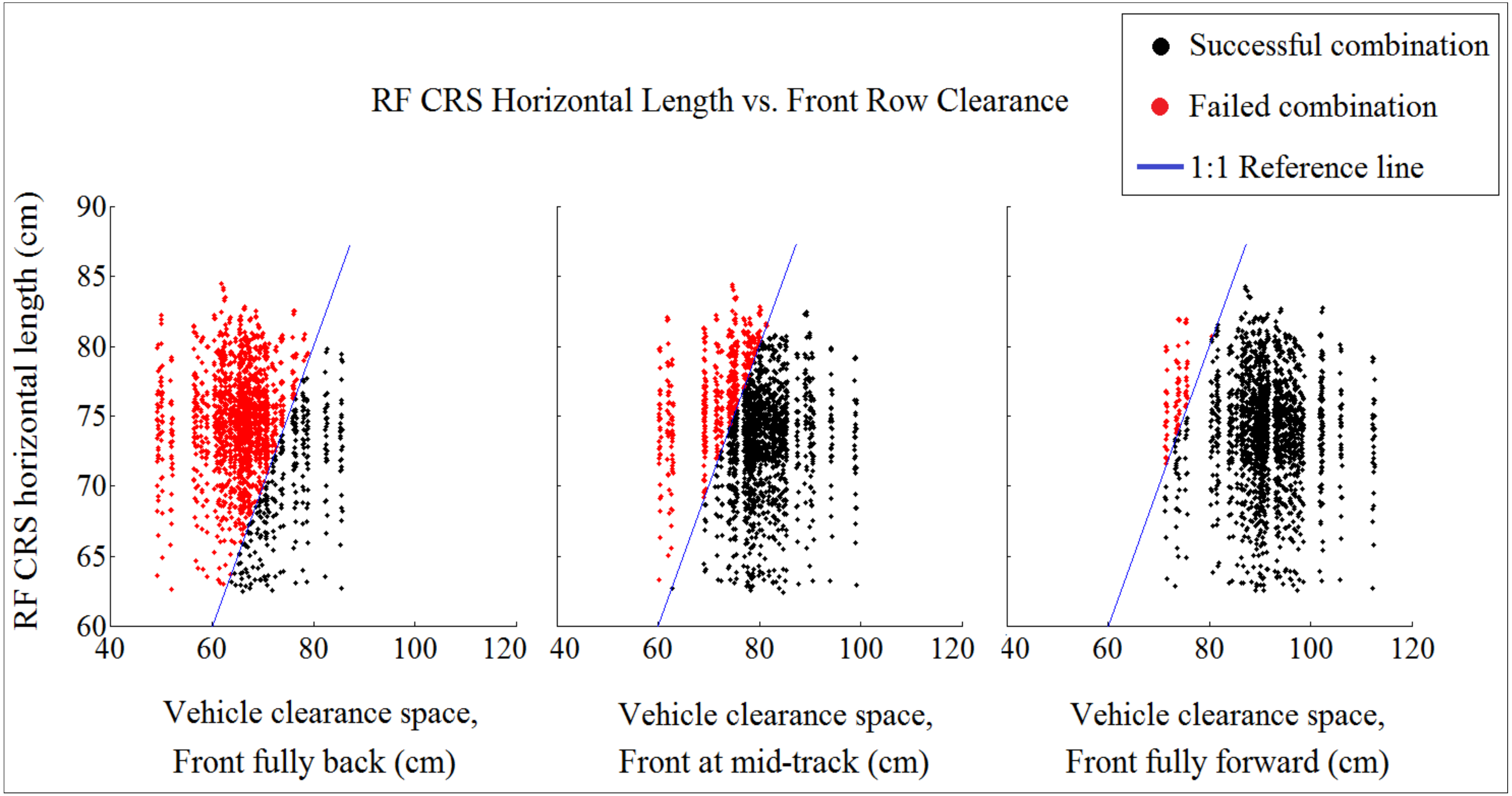
Front Row Clearance, RF CRS

Horizontal distance from plane to plane



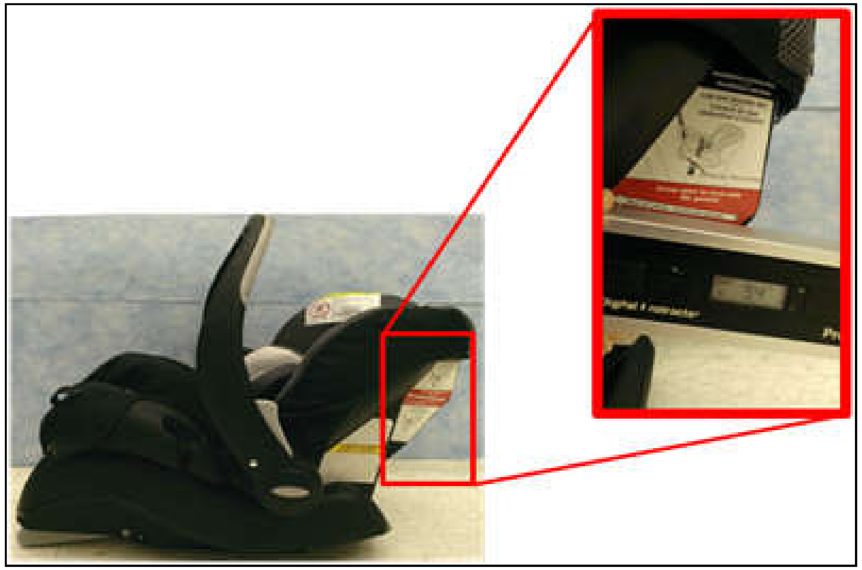
- Front seat recline angle: 25° from vertical
- Used average of high and low clearance
- Analyzed front row fully back, mid-track, and forward

Front Row Clearance Results, RF CRS



Success rates: 15.3%, 73.2%, 95.8% respectively

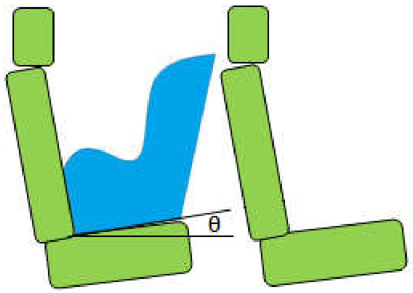
Base Angle, RF CRS



Using a digital inclinometer and the angle indicators on the side of the CRS, determine base angle range necessary for proper installation.

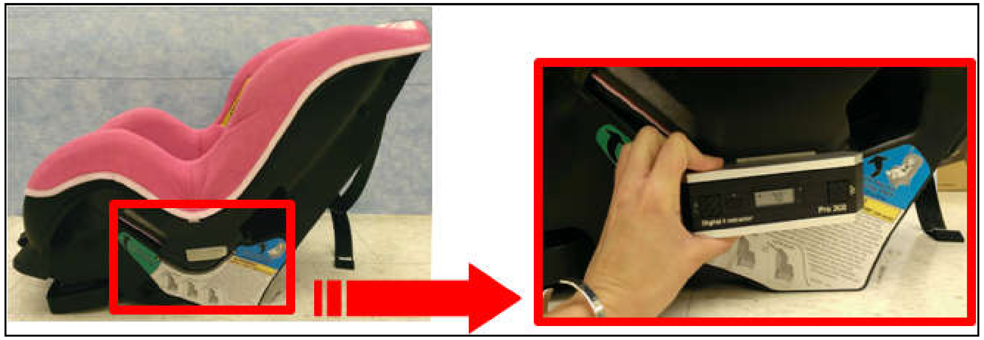
Measure seat pan angles of vehicles, using rigid stick and digital inclinometer.

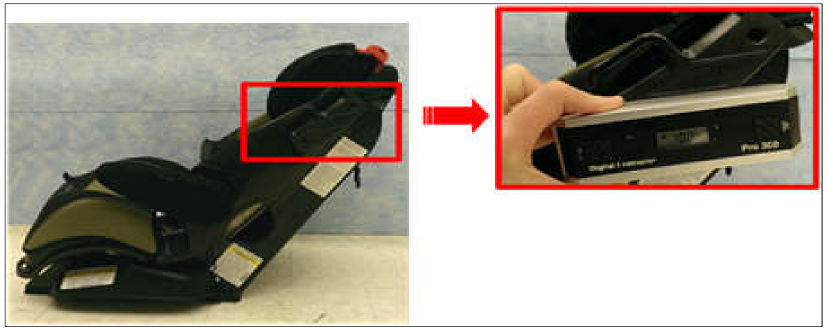
Base Angle, RF CRS



	Vehicle Seat Pan Angles (deg)
Minimum	7.1
Average	13.4
Maximum	22.0

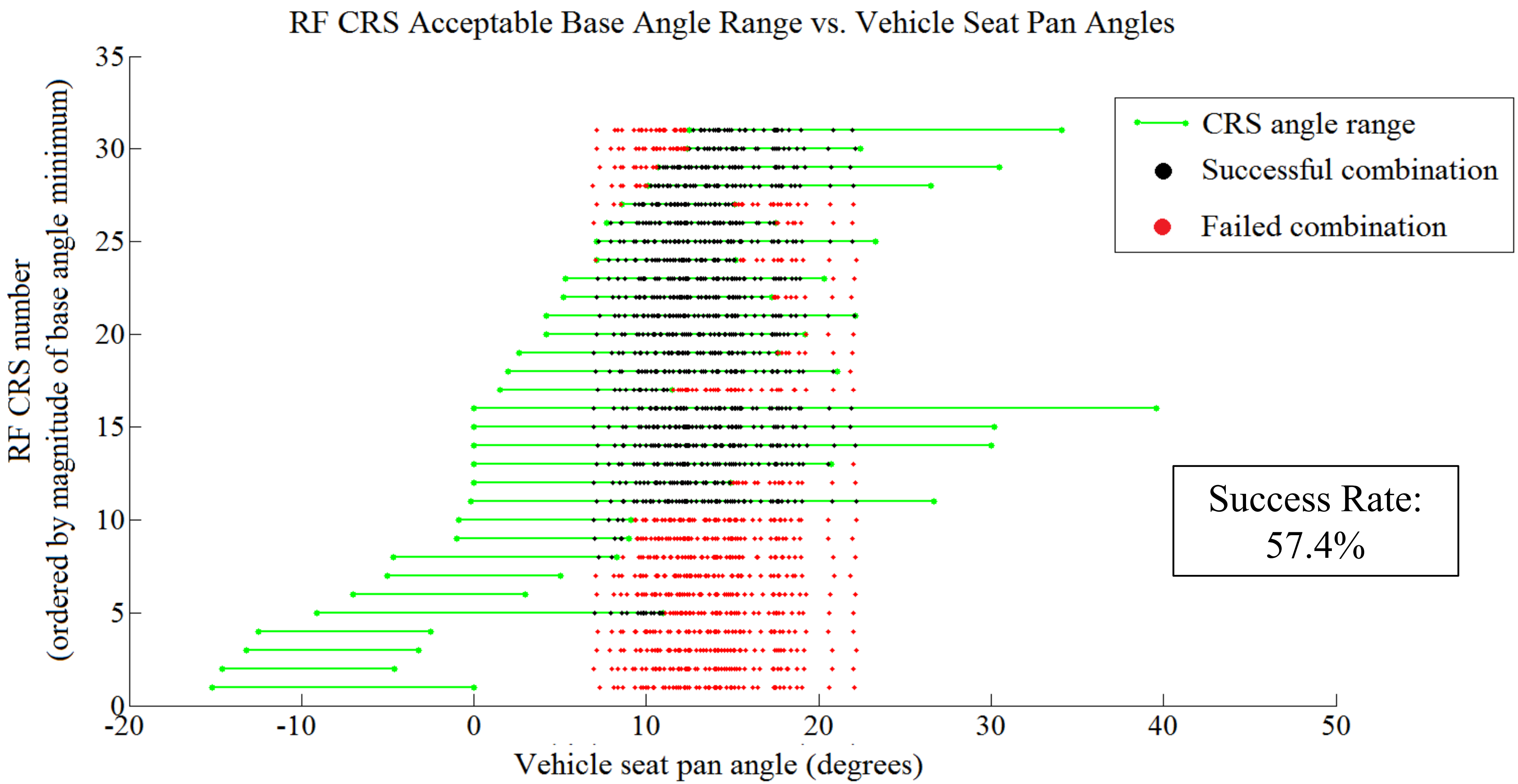
- 7 CRS required seat pan angles of 5º or less.
- These would not fit in <u>any</u> vehicle.





In order for their level-to-ground lines to be horizontal, both of these RF CRS must be rotated the opposite direction of any seat pan angle (clockwise as shown).

Base Angle Results, RF CRS



Back Height, FF CRS

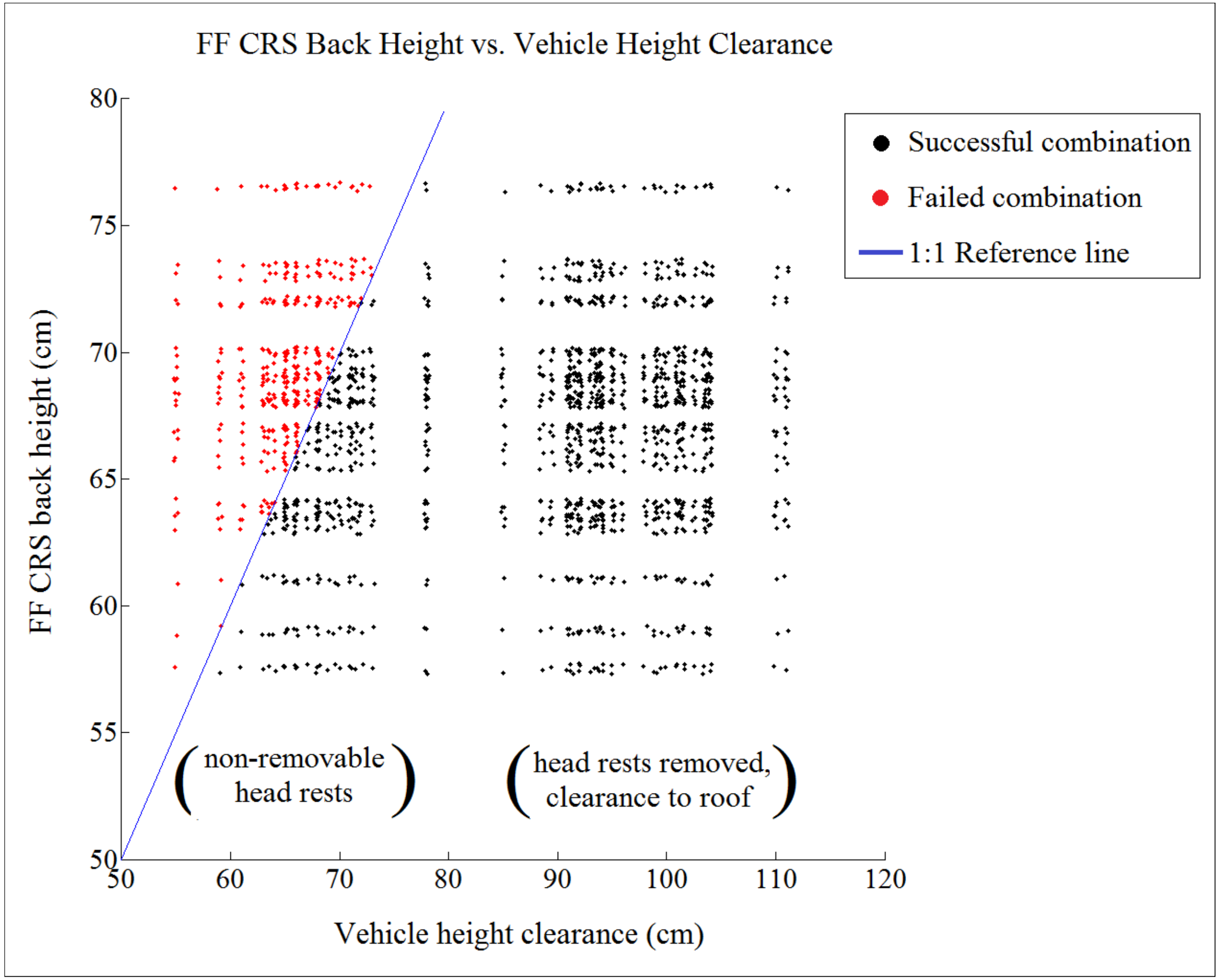
FF CRS:
Measure height of back along flat plane.

Non-removable head rest:
Measure from seat pan to bottom of head rest.

Removable head rest:
Measure from seat pan to roof.

Back Height Results, FF CRS

Success rate:
70.0%



Summary

Forward-Facing

- Height of back
  - Interference with non-removable head rests
- Tether could not be tightened
  - Small vehicles and trucks with short tether route

Rear-Facing

- Wide base
  - Large vehicles, bucket seats with hinges
- Front row clearance space
- Base angle
  - Convertible and 3-in-1 CRS

Conclusions

- Assembled robust, detailed database of CRS and vehicle dimensions
  - Benchmark for manufacturers
  - Reference for creating models
- Identified several common areas of incompatibility
  - Advise parents to focus on these areas when purchasing a CRS

- Future work: Determine the consequences of each of these incompatibilities.

CRS Compatibility in the vehicle seat environment, Year 2: Focusing on Incompatibilities

PIs: ***Julie Bing, MS***; Amanda Agnew, PhD

Mentors: Drew Kitchens (Graco), William Conway (Graco), Mark LaPlante (Graco), Julie Kleinert (GM), Eric Dahle (Evenflo), Keith Nagelski (Britax), Uwe Meissner (CRA)

Observers: Doug Longhitano (Honda), Suzanne Miller (Honda), Tanji Hiromasa (TK), Linda McCray (NHTSA), Audrey Eagle (FCA US LLC), Agnes Kim (Ford), Ron Burton (TRC), Angela Manning (Honda)

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Project Aims: Year 2

1. Document a large number of physical installations to further define common CRS/vehicle incompatibilities

2. Perform sled tests to investigate the consequences of the most common incompatibilities on safety

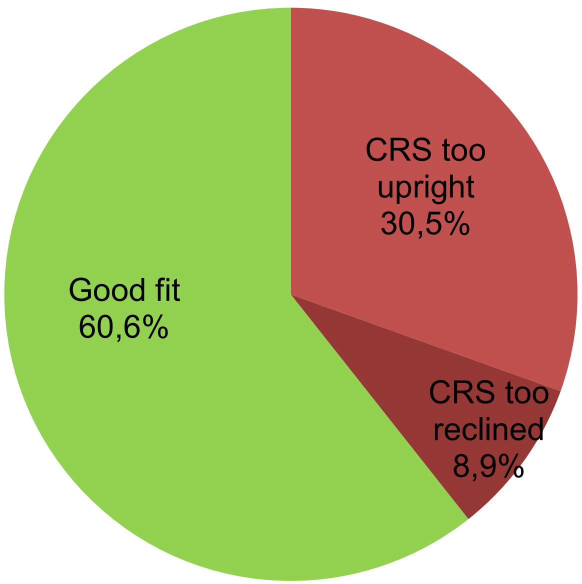
Aim 1: Physical Installations

- 632 installations
  - 315 rear-facing (RF)
    - 100 outboard seat belt
    - 100 outboard LATCH
    - 98 center seat belt
    - 17 center LATCH
  - 317 forward-facing (FF)
    - 100 outboard seat belt
    - 100 outboard LATCH
    - 100 center seat belt
    - 17 center LATCH

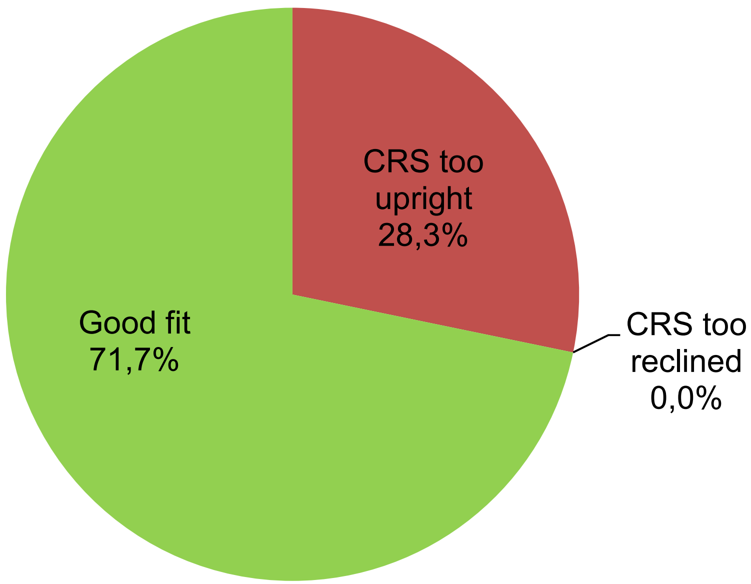
RF CRS: Base Angle

RF CRS: Base Angle Results

<u>Predictions</u> of RF CRS base angle compatibility (n=315)

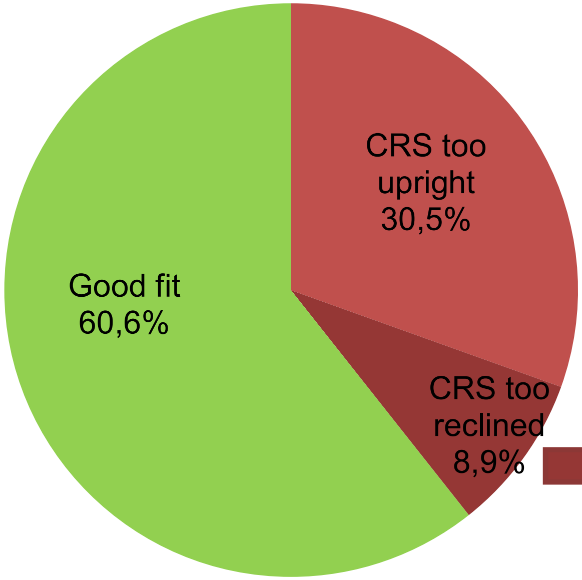


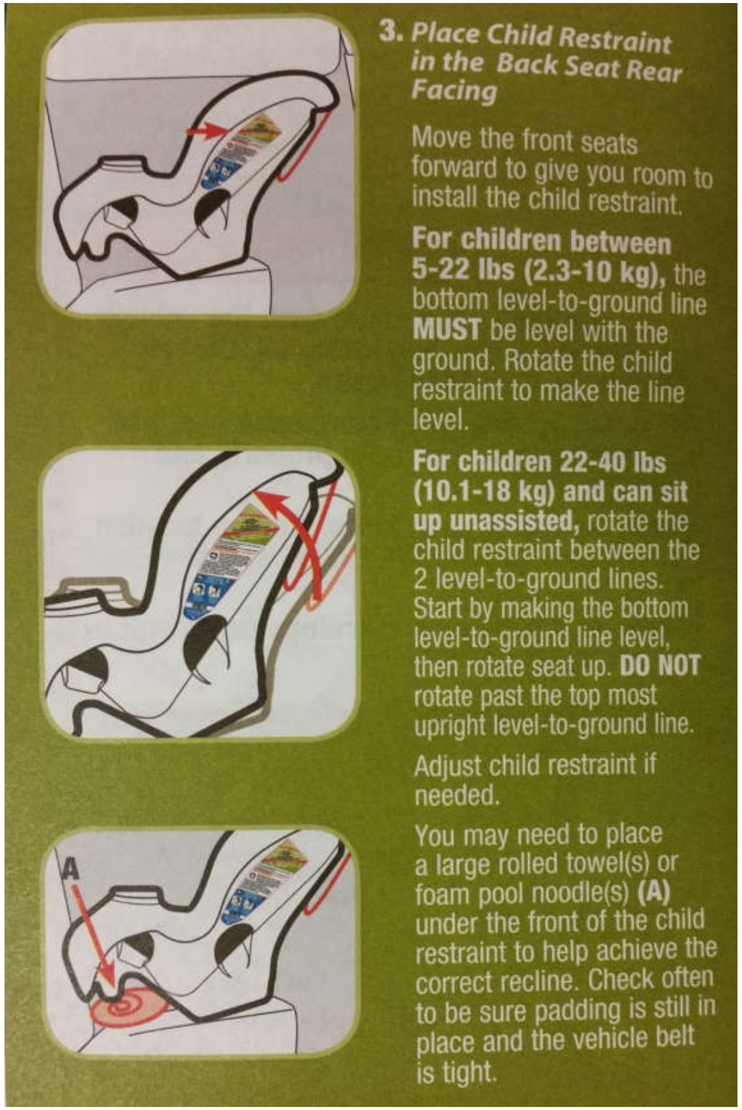
<u>Actual</u> RF CRS base angle compatibility (n=315)



RF CRS:
Base Angle Results

<u>Predictions</u> of RF CRS base angle compatibility (n=315)





RF CRS: Base Angle Results

		Actual results (installations)	
		Incompatible ("positive" result)	Fit ("negative" result)
Predicted results (dimensions)	Incompatible ("positive" result)	True positive (incompatible) **85/315**	False positive **39/315**
	Fit ("negative" result)	False negative **4/315**	True negative (fit) **187/315**

Indicates that we are predicting incompatibilities where there are none.

Indicates that we are predicting good fit when there is actually a problem.

RF CRS: Base Angle Results

		Actual results (installations)	
		Incompatible (“positive” result)	Fit (“negative” result)
Predicted results (dimensions)	Incompatible (“positive” result)	True positive (incompatible) **85/315**	False positive **39/315**
	Fit (“negative” result)	False negative **4/315**	True negative (fit) **187/315**

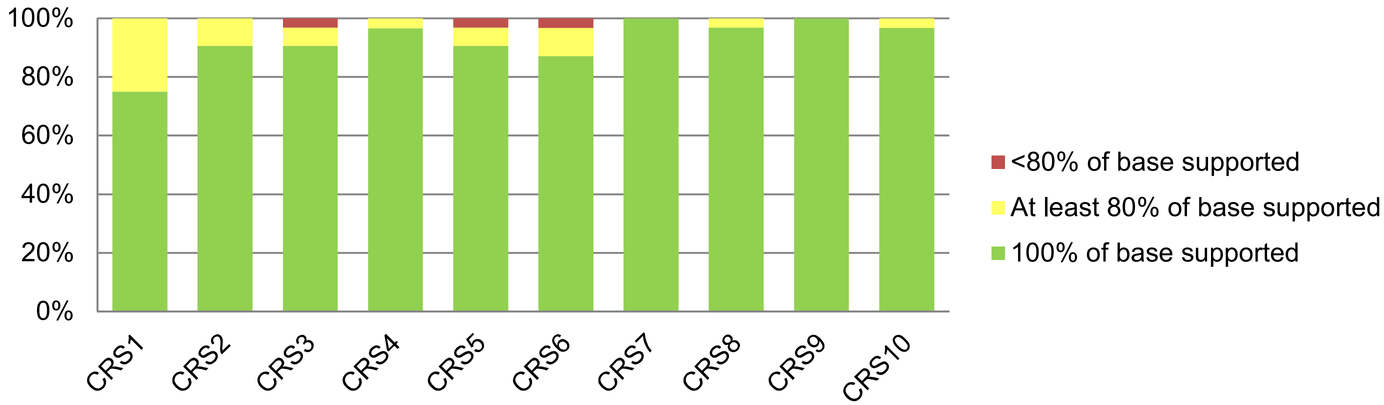
Sensitivity = **95.5%** = proportion of positives correctly identified = TP/(TP+FN)

Specificity = **82.7%** = proportion of negatives correctly identified = TN/(TN+FP)

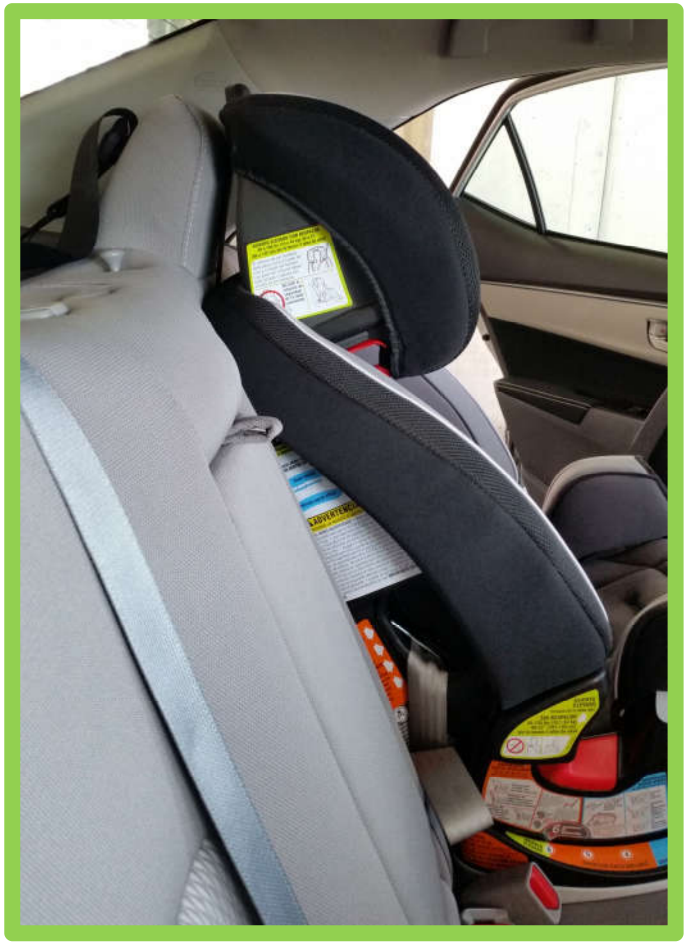
Accuracy = **86.4%** = proportion of true results = (TP+TN)/(TP+FP+TN+FN)

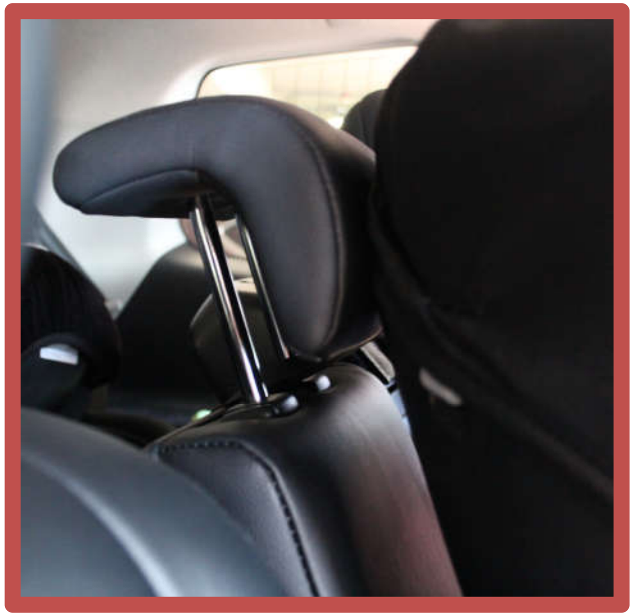
Results:
RF CRS front edge overhang

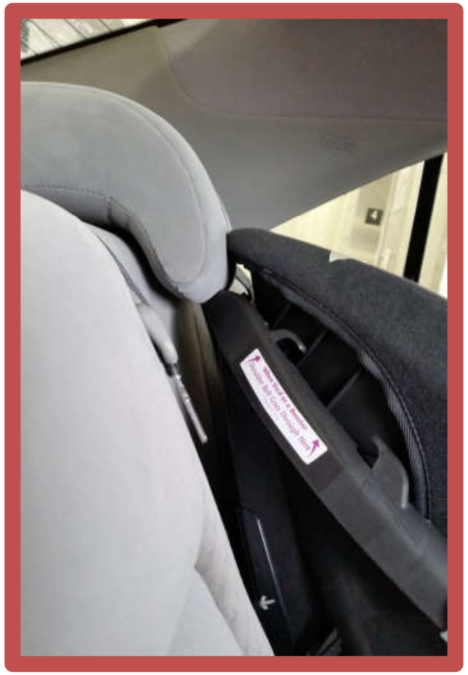
Front edge overhang (all positions, by CRS) (n=315)



Results:
FF CRS head restraint interaction

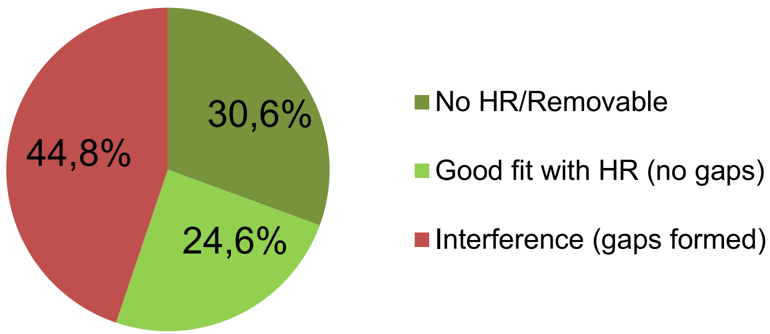




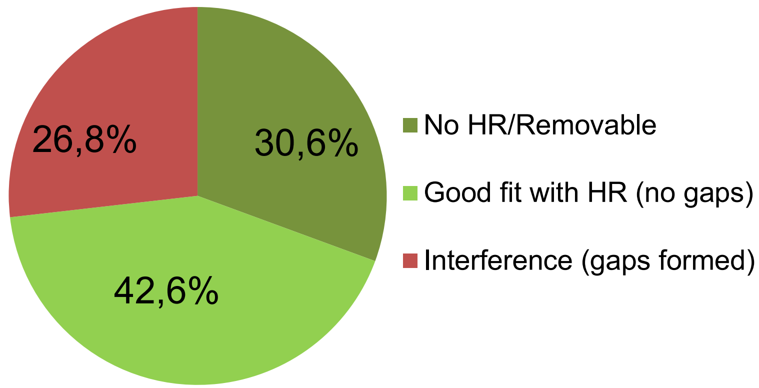


Results:
FF CRS head restraint interaction

Predictions of FF CRS interference with head restraint (5 cm tolerance) (n=317)

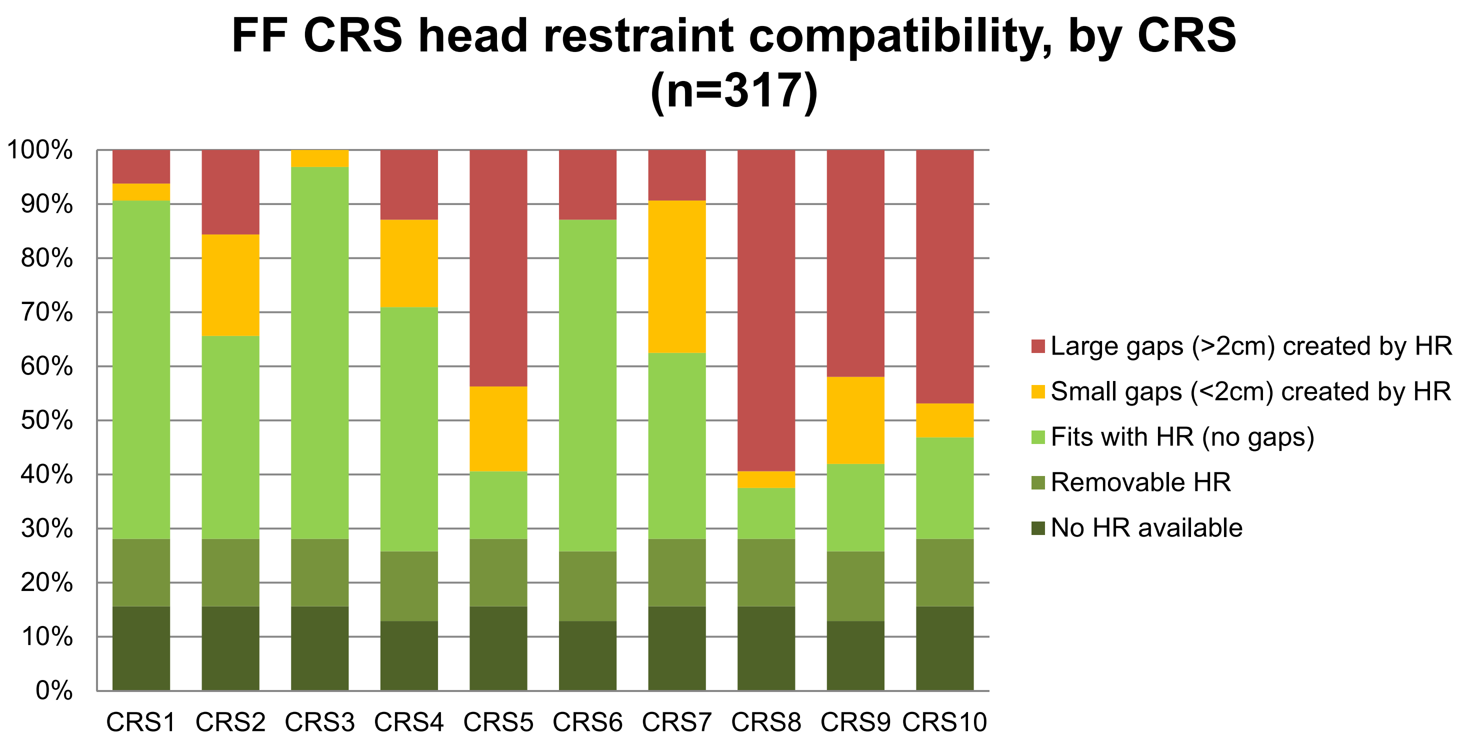


Actual FF CRS interference with head restraint (n=317)



Sensitivity = **97.4%**
Specificity = **69.5%**
Accuracy = **79.5%**

Results:
FF CRS head restraint interaction

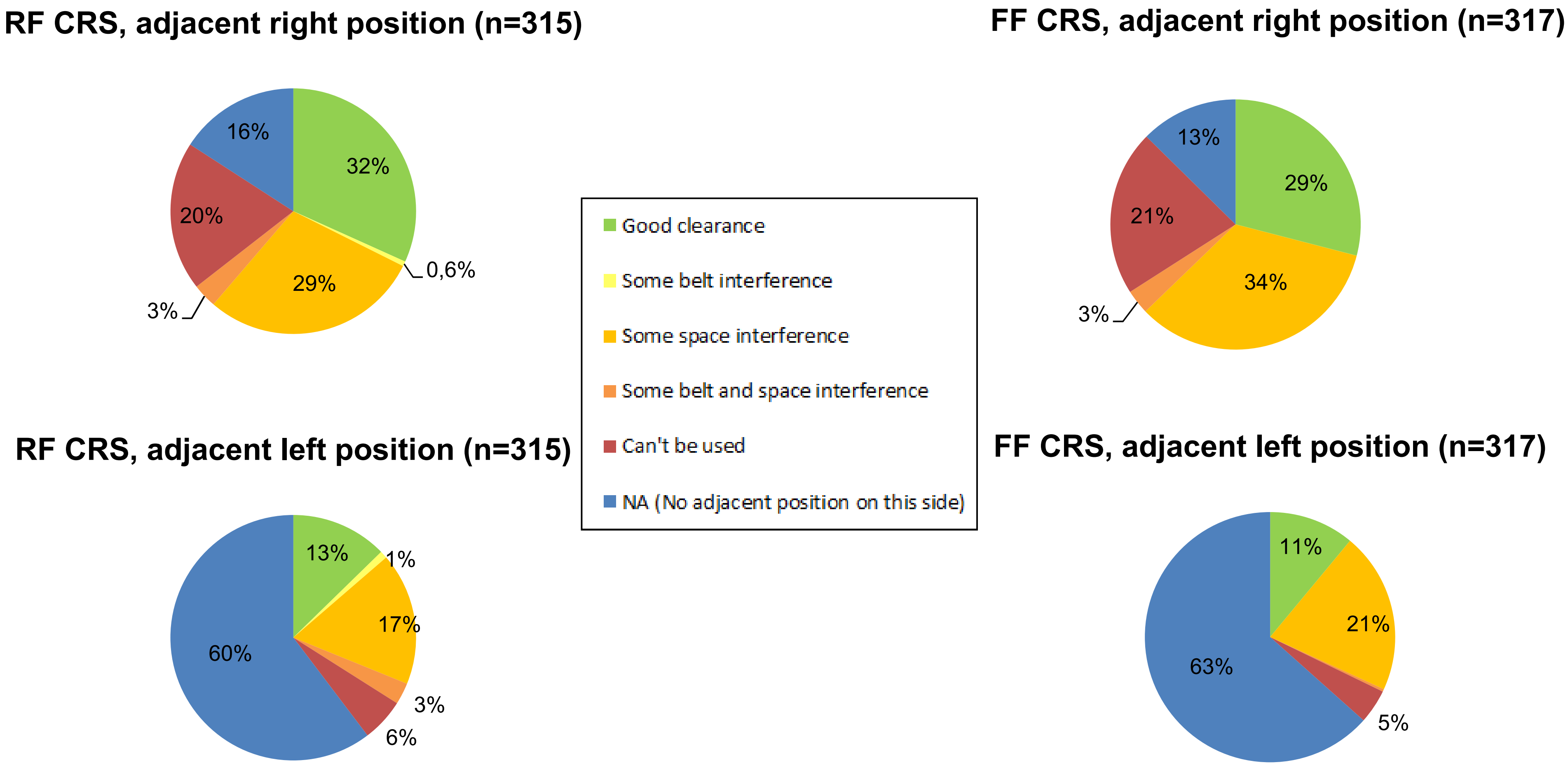


Aim 1: Other Findings

Does the CRS interfere with the adjacent seating positions?

Aim 1: Other Findings

- Does the CRS interfere with the adjacent seating positions?



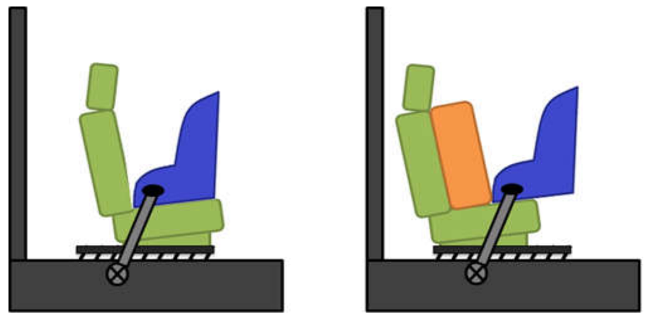
Aim1: Summary

- Installations which could not be completed according to manufacturers' instructions
    - n=315 RF and n = 317 FF
  - Too much front edge overhang (3 RF and 6 FF)
  - Tether could not be used correctly (7 FF)
  - Seat belt too short (2 RF: excluded from analysis)

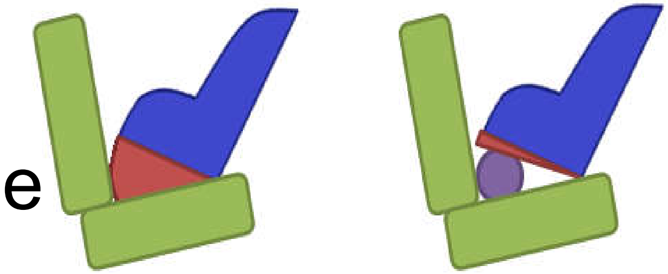
- Other difficulties:
  - Base angle requires pool noodle (57 RF)
  - Front row seat must be forward of midtrack position (73 RF)
  - Large gaps behind CRS created by head restraint (79 FF)

Aim 2: Sled Testing Objectives

- Front Edge Overhang



- Initial Base Angle
  - Spacers (pool noodles, towels) to achieve proper base angle for RF CRS



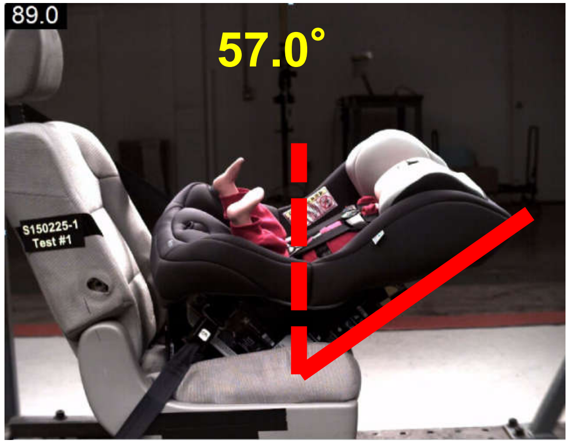
Front Edge Overhang

Control (n=3)

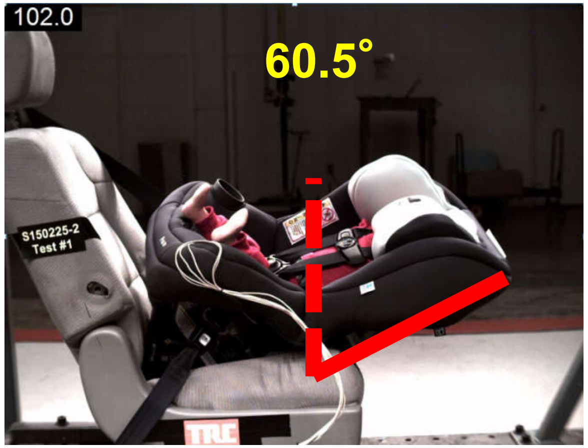
Overhang (n=2)

Front Edge Overhang: Max Recline Angles from Vertical

CONTROLS



Initial: 34.9°

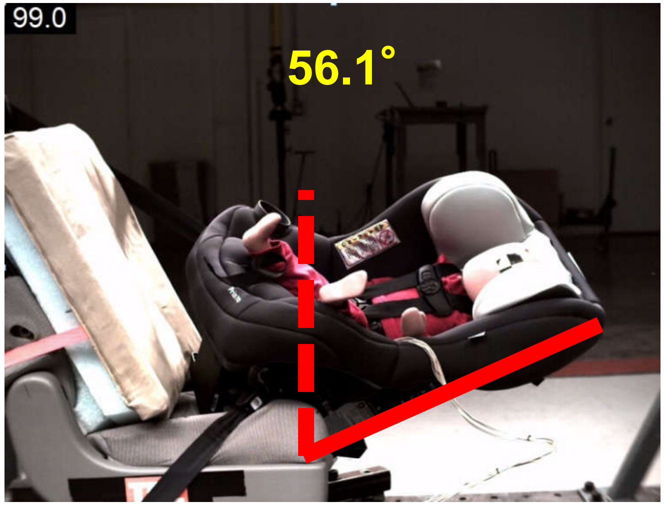


Initial: 35.9°

Initial: 32.7°

OVERHANGS

Initial: 34.2°

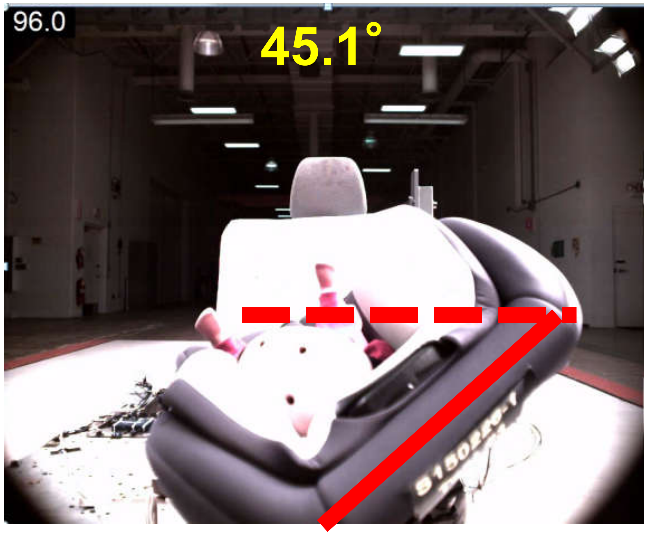


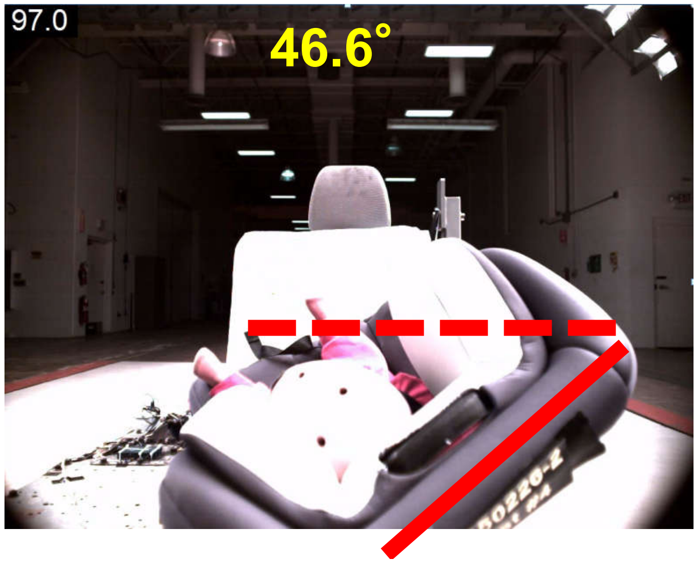
Initial: 34.2°

Front Edge Overhang: Maximum Frontal Rotation

CONTROLS

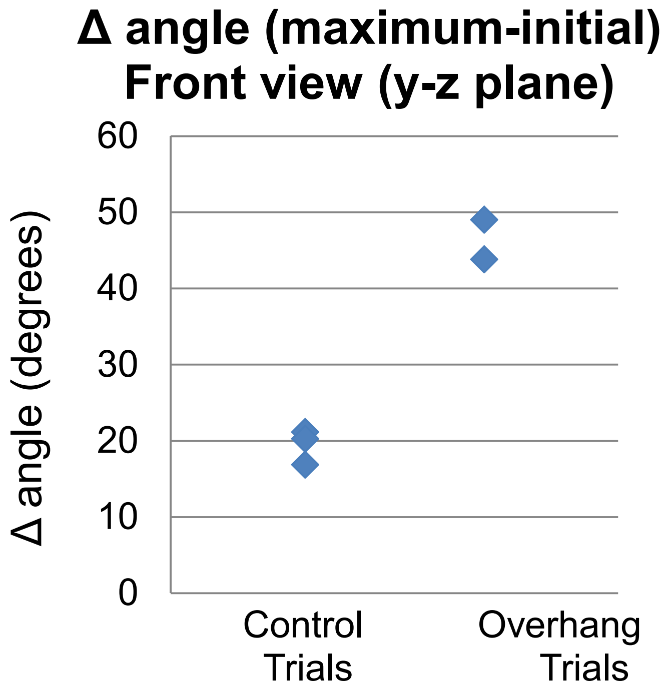
OVERHANGS





Control Trials vs. Front Edge Overhang Trials

Variable	p-value
Initial recline angle	0.837
Maximum recline angle	0.799
Δ recline angle (max-initial)	0.624
Time of max recline	0.090
Forward excursion (cm)	0.491
Initial frontal angle	0.755
Maximum frontal angle	**0.002**
Δ frontal angle (max-initial)	**0.002**
Time of max frontal angle	0.181
HIC36	0.070
Chest resultant acceleration	0.960



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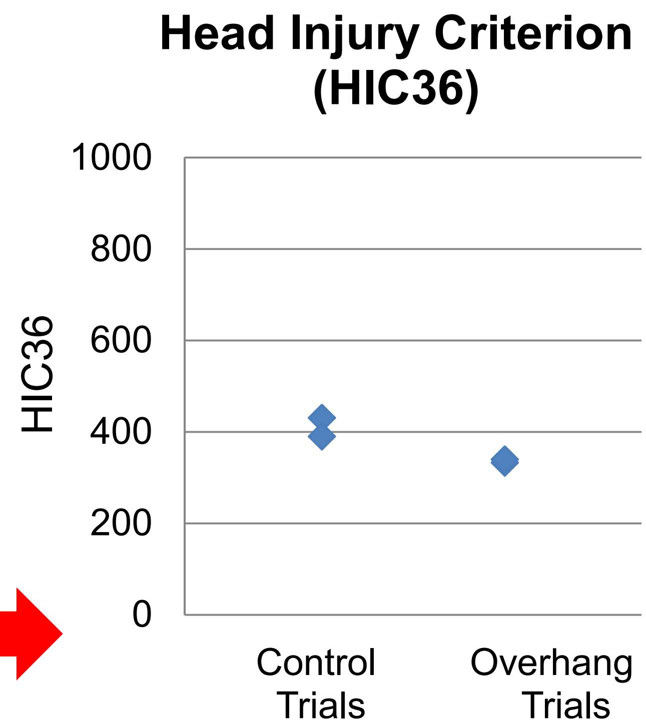


Initial Base Angle

CONTROLS

Initial: 37.7°

Initial: 38.0°

POOL NOODLES

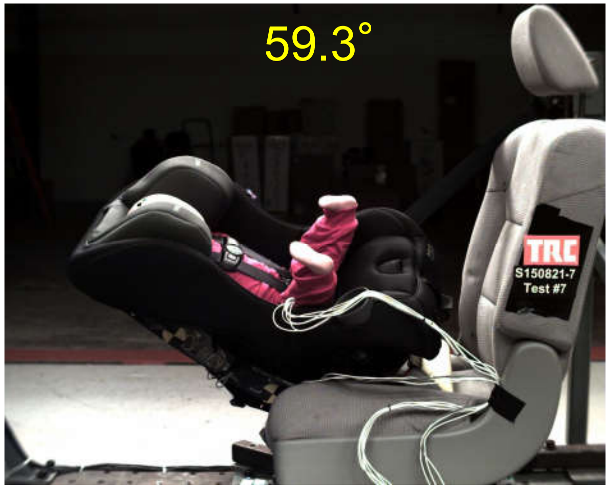
Initial: 37.5°

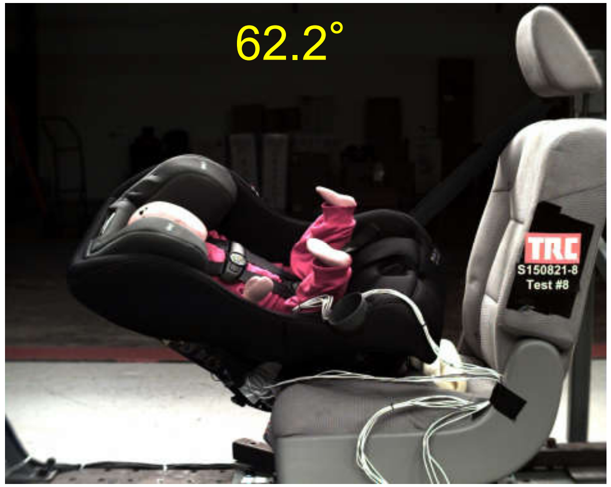
Initial: 37.5°

Initial Base Angle:
Max Recline Angles from Vertical

CONTROLS

POOL NOODLES





Initial Base Angle: Maximum Frontal Rotation

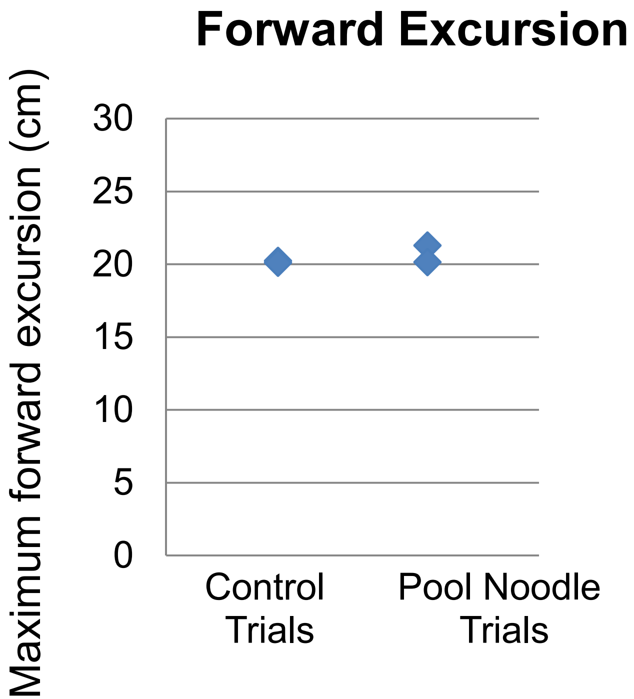
CONTROLS

POOL NOODLES

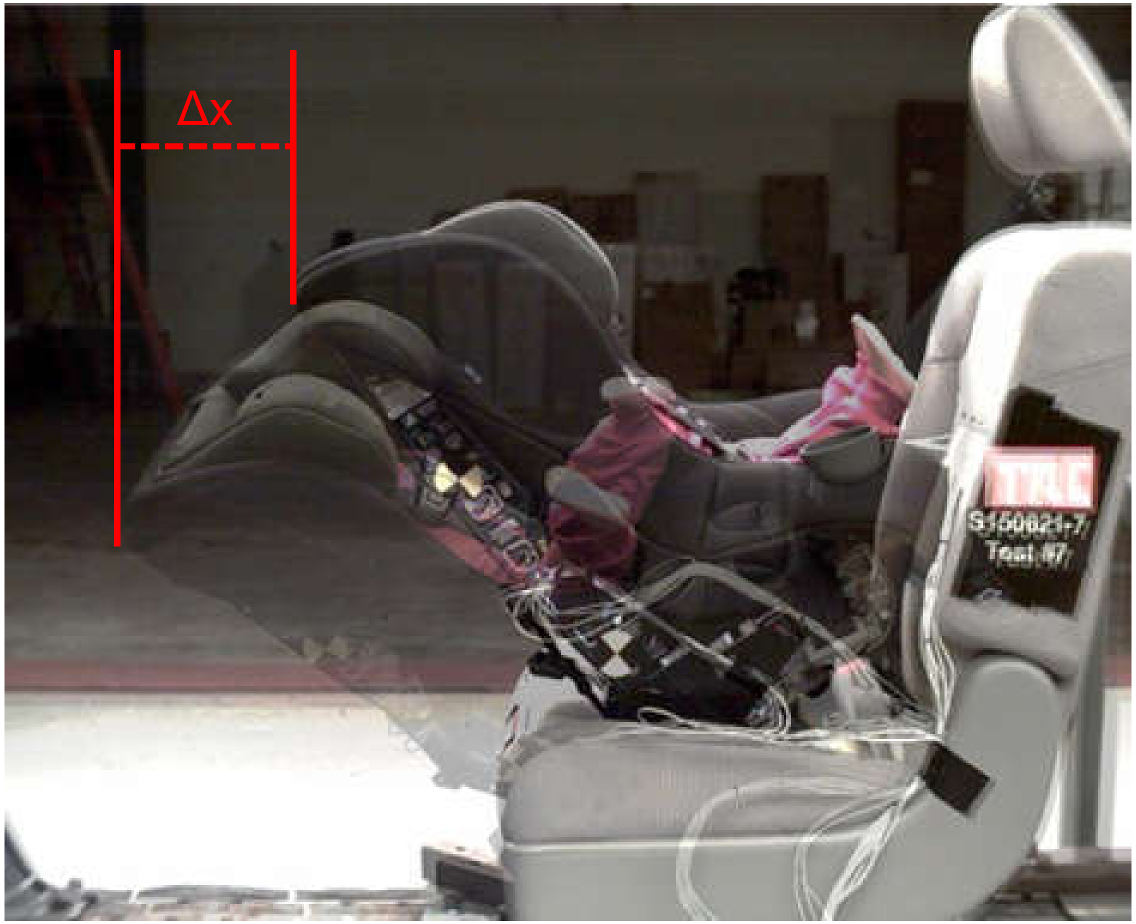
Initial Base Angle Results

Variable	p-value
Initial recline angle	0.145
Maximum recline angle	0.920
Δ recline angle (max-initial)	0.971
Time of max recline	0.445
Forward excursion (cm)	0.446
Initial frontal angle	0.700
Maximum frontal angle	0.806
Δ frontal angle (max-initial)	0.786
Time of max frontal angle	0.384
HIC36	0.233
Chest resultant acceleration	0.440

Initial Base Angle: Max. Forward Excursion

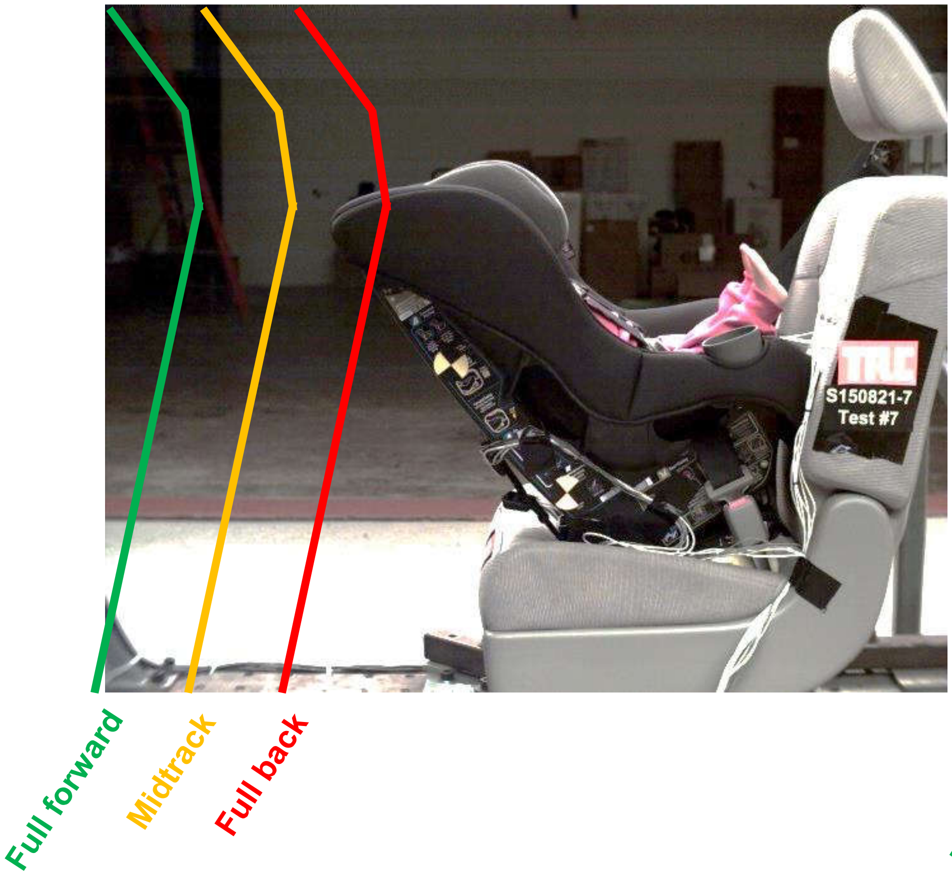


p=0.446

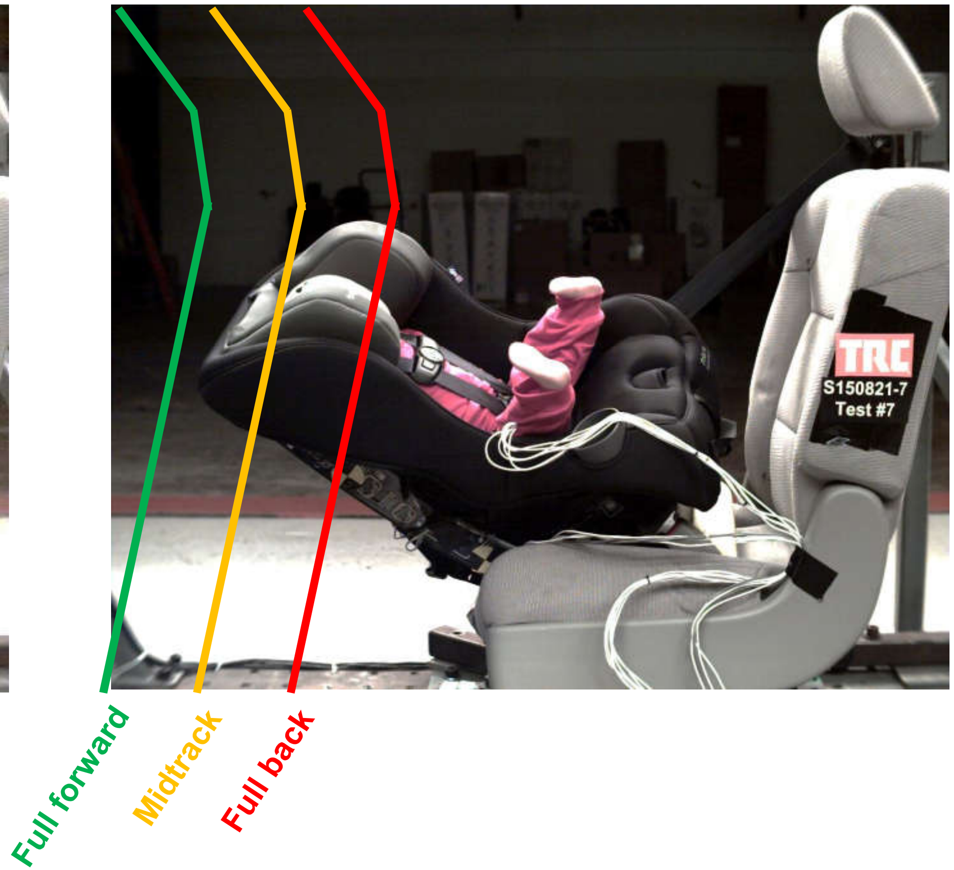


Initial Base Angle: Front Row Interaction

Initial position



Maximum excursion



Interaction expected in most vehicles when front row is not in fully forward position.

Conclusions

- Frequent problems with RF CRS base angle
  - 28% of installations were too upright
  - This condition well predicted by Year 1 methods
- Head restraint interference often causes gaps behind CRS, but tight installation usually possible.
- Limited frontal impact sled testing found:
  - No detrimental effects of using pool noodles
  - Slightly more lateral rotation when CRS hangs over front edge of vehicle seat

Acknowledgements

- CChIPS Industry Advisory Board
- CChIPS Mentors:
  - Ron Burton, TRC, Inc.
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  - Doug Longhitano, Honda
  - Eric Dahle, Evenflo
  - Keith Nagelski, Britax
  - Julie Kleinert, GM
  - Drew Kitchens, Graco
  - William Conway, Graco
  - Mark LaPlant, Graco
  - Uwe Meissner, CRA
  - Angela Manning, Honda
  - Suzanne Miller, Honda
  - Tanji Hiromasa, TK
  - Linda McCray, NHTSA
  - Agnes Kim, Ford
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  - Duey Thomas
  - Josh Hendricks
  - George Saker
- TS Tech
  - Travis Miller
- Aditya Belwadi, CHOP
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  - John Bolte IV
  - Yun Kang
  - Victoria Dominguez
  - Randee Hunter
  - Colleen Mismas
  - Kevin Soong
  - Michelle Murach
  - Allie Guettler

Quantifying CRS Fit in the Vehicle Seat Environment

Child Occupant Protection: Latest Knowledge & Future Opportunities

John H Bolte IV, PhD

September 20, 2017

Injury Biomechanics Research Center

The Ohio State University