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Performance of Harnessed Child Restraints on Vehicle Seats With Modified Cushion Lengths and Variable Belt Geometry

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16. Abstract

The current series of tests was conducted to identify potential negative outcomes on child restraint performance if recommendations to shorten cushion length and use belt geometry optimized for older child occupants would be implemented. Forty frontal impact tests with four different forward-facing child restraints and 47 tests with five different rear-facing child restraints were performed. Some tests were run using the FMVSS No. 213 bench to establish baseline conditions, but most were run using real vehicle seats with the cushion length set to 350 mm, 400 mm, or 450 mm. Lap belt anchorage locations were set to match the FMVSS No. 213 locations or the locations optimized for the 6YO ATD crash test dummies (Hu, Wu, Reed, Klinich, & Cao, 2013). Some tests attached the child restraint using the lower anchors rather than the lap+shoulder belt. Forward-facing tests were run with and without tethers. Under most testing conditions, the child restraints met applicable FMVSS No. 213 requirements and kinematics appeared reasonable. Among the forward-facing tests, two child restraints with a recline foot slipped off the front edge of the seat, but still met relevant head excursion criteria. Among rear-facing tests, one child restraint exceeded the allowable chest acceleration criteria under most conditions. Overall, the results suggest that shortening seat cushion length to provide a better restraint environment for children using the vehicle seat and belt alone would not adversely affect the performance of most child restraints. Modifications to the lap belt anchorages would also not have a substantial adverse effect.

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Introduction

As of January 2013, 48 states require children to use a harnessed child restraints or booster seats through 5 years old, and 42 require their use beyond 6 years old. While use of a booster seat has been demonstrated to reduce the likelihood of serious injury in a motor-vehicle crash (Arbogast, Jermakian, Kallan, & Durbin, 2009), only about half of restrained children 4 to 8 years old use boosters (NHTSA, 2009), and children 8 to 12, who may also benefit from boosters, have even lower use rates of only 6 percent (NHTSA, 2009).

To address the issue of how to improve occupant protection for children not using boosters who are still too small to obtain good fit from vehicle seatbelts, we have performed a series of research projects to explore the effects of vehicle cushion length and belt geometry on the kinematics of rear-seat occupants in frontal crashes, using several sizes of anthropomorphic test devices (ATDs). We hypothesized that shortening the vehicle seat cushion and increasing the lap belt angle (closer to vertical in side view) could achieve improvements in occupant kinematics in frontal crashes that are similar to those provided by boosters.

A series of sled tests was conducted to examine the effect of using real vehicle seats, rather than the test bench specified in Federal Motor Vehicle Safety Standard (FMVSS) No. 213 on the kinematics of the Hybrid III 6-year-old (6YO) and 10-year-old (10YO) ATDs (Klinich, Reed, Ebert, & Rupp, 2011). Cushion length was tested at 450 mm (close to production length) and shortened to 350 mm (Huang & Reed, 2006). Lap belt anchorage locations were varied to span the range of lap belt angles permitted in FMVSS No. 210, which also matches the range measured in outboard second-row seating positions of production vehicles (Reed, 2013). Shortening the seat cushion improved kinematic outcomes, particularly for the 10YO. Lap belt geometry had a greater effect on kinematics with the longer cushion length, with mid and forward belt anchorage locations producing better kinematics than the rearward belt geometry. The worst kinematics for both ATDs occurred with the long cushion length and rearward lap belt anchorages, which produced relatively flat lap belt angles. This initial test series showed potential benefits in child occupant protection from shortening vehicle cushion length and increasing lap belt angle, particularly for children the size of the 10YO, although the improvements in kinematics were smaller than those provided by a booster seat.

Wu, Hu, Reed, Klinich, & Cao (2012) used the data from the 2011 test series to validate a parametric ATD MADYMO model capable of representing children ranging in age from 6 to 12 years old. The validated model was used to estimate optimal vehicle seat cushion length, vehicle seat stiffness, and belt geometry for occupants the size of the 6YO and 10YO who are sitting on the vehicle seat without a booster (Hu, Wu, Reed, Klinich, & Cao, 2013). The shortest cushion length, and belt anchorages closer to the dummy (at an angle between the mid and forward test conditions) were predicted to improve protection over the baseline for 6-to-10-year-old children.

Additional research was needed to ensure that potential vehicle design modifications would not produce adverse outcomes for other rear seat occupants (Klinich, Reed, Wu, & Rupp, 2014). Tests were conducted with a Hybrid III midsize (50th percentile) male ATD and a 12-month-old child restraint/air bag interaction (CRABI) ATD (hereafter called 12MO) seated in a Graco

SnugRide rear-facing infant restraint. Seat cushion length was set to 450 mm, 400 mm, and 350 mm. Lap belt anchorages included one representing the mid-range of lap belt angles permissible under FMVSS No. 210 as well as one more forward but closer to the vehicle seat H-point that was estimated to be optimal for a 6-year-old occupant. Shoulder belt conditions included the standard FMVSS No. 213 shoulder belt anchorage as well as one positioned closer to the adult male shoulder (also designed to be optimal for a 6-year-old occupant). The tests with the adult male dummy showed no negative consequences from design changes intended to improve protection for children. Kinematics were similar among all conditions tested. For the rear-facing infant restraint, none of the tests exceeded the 70° rotation angle limit in FMVSS No. 213, although shorter cushion length and more-forward belt locations produced larger rotations. The three tests with the more-forward lap belt geometry slightly exceeded the 3-ms-chest clip acceleration limit of 60 *g*, but review of all chest acceleration curves suggests that the vehicle seat may produce higher chest accelerations than the FMVSS No. 213 bench with this child restraint. In tests with the shortest seat cushion length, the infant seat showed acceptable kinematics even though less than 80 percent of the child restraint base was initially supported on the vehicle seat.

The current series of tests was conducted to further assess potential negative outcomes on child restraint performance if recommendations to shorten cushion length and to use belt geometry designed for older child occupants would be implemented. A shorter cushion length decreases the amount of surface available to support the child restraint, while different belt anchorage locations change the angle of loading through the belt path. Forward-facing and rear-facing child restraints, selected to span a range of sizes, weights, and belt path geometries, were tested with either the Hybrid III 3-year-old (3YO) or 12MO using either the FMVSS No. 213 bench or real vehicle seats with modified cushion lengths and belt geometries.

Methods

Child Restraint Selection

Forward-facing restraints

To choose child restraints for testing, we examined the geometry of sixteen convertible child restraint models, reviewing both the side profile and base footprint, and grouped them based on some key features into four categories as shown in Table 1. The first type of product has a stand or foot to change the recline angle. Three convertibles had designs with this feature, and the Scenera was selected because it has the least amount of base surface in contact with the vehicle seat. The second type of product has a forward-facing recline position, which gives it a longer footprint. Three convertibles had this feature. The Symphony was chosen because it was the heaviest of the three products. The third type of product has a larger than typical base; the Compass True Fit was selected to represent these three products. The remaining six products had medium-sized bases. None of these were tested because the expected effect of shortening the seat cushion or changing the belt geometry was expected to be smaller compared to the other three categories of products. After testing with the Scenera, which produced the most interesting results, a second product within this category, the Graco ComfortSport, was obtained for additional testing. These four products also have variation in their belt path locations as indicated in Figure 1.

Table 1. Convertibles considered for forward-facing testing

Child Restraint Category	Products	Weight (kg)
Recline stand or foot	**Graco ComfortSport**	7.8
	Cosco Scenera	5.4
	Evenflo Titan Elite	6.6
Forward-facing recline & longer footprint	**Evenflo Symphony**	11.2
	Alpha Omega Elite	9.5
	Eddie Bauer Deluxe 3-in-1	9.4
Large base	Combi Zeus Turn	15.6
	Compass True Fit	13.6
	Dorel Maxi-Cosi Priori	8.8
Medium base	Orbit Baby TCS	16.4
	Recaro Como	9.3
	Recaro Signo	9.3
	Britax Boulevard	10.3
	Britax Diplomat	10.4
	Evenflo Triumph Advanced deluxe	10.7

Cosco Scenera

Evenflo Symphony

Compass True Fit

Graco ComfortSport

Figure 1. Side-view photos of child restraints selected for forward-facing tests

The right-side profiles, belt path locations and footprints on the vehicle seat of the four selected CRS were compared using digitized data from a previous study. Figure 2 shows the right-side profiles and the forward-facing belt paths of the CRS when the seats are aligned in the fore-aft direction so that the rearmost points on the seat are at the same position. These products provide a range of belt path locations, with the Scenera providing the highest and rearmost path, and the Symphony providing a more forward and slightly lower belt path. The Scenera seat is the most upright so that the initial location of the child's center of gravity will likely be more rearward than in the other FF configurations. The True Fit is the longest and most reclined seat. The ComfortSport has a similar sideview profile compared to the Scenera but a more forward belt path.

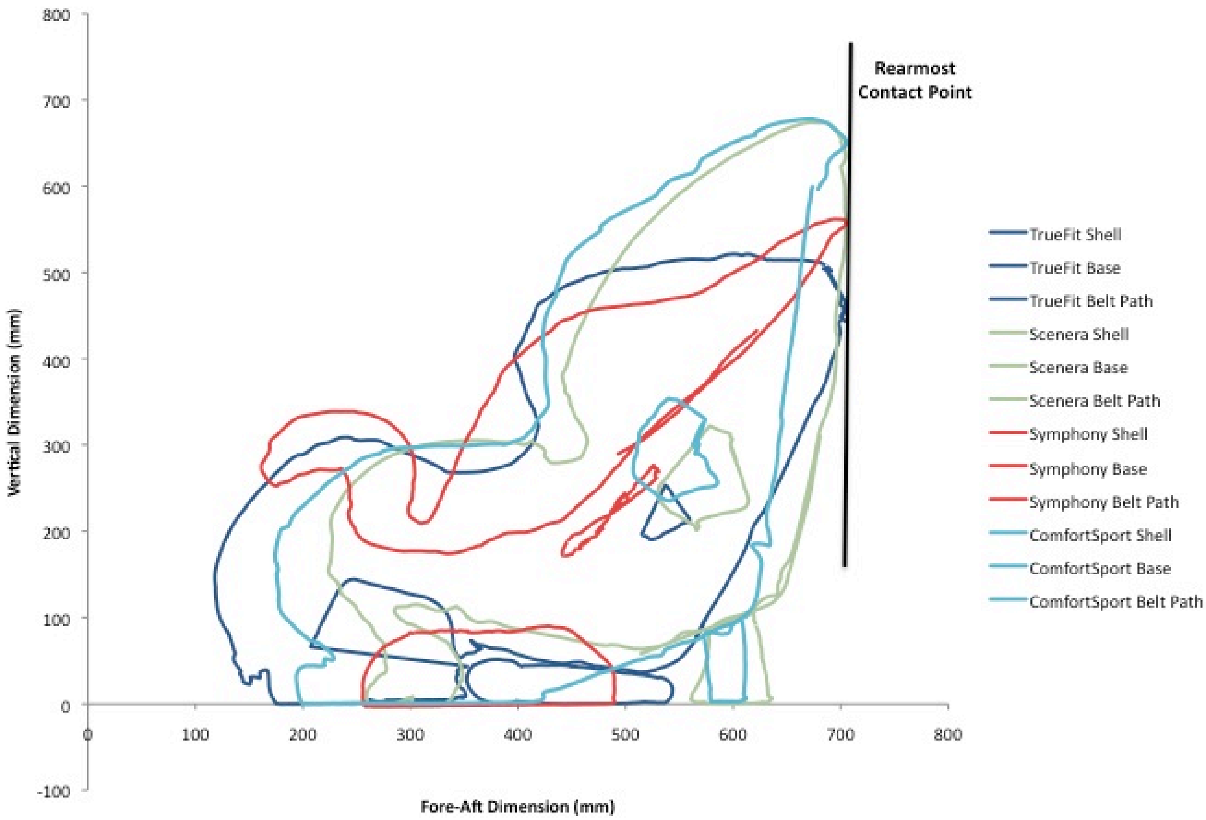


Figure 2. Right-side profile and belt paths of selected CRS

Figure 3 shows the overlaid footprints of the four child restraints they would contact the vehicle seat with the rearmost points aligned. The Symphony and the True Fit have the largest footprints and each footprint differs markedly from the others.

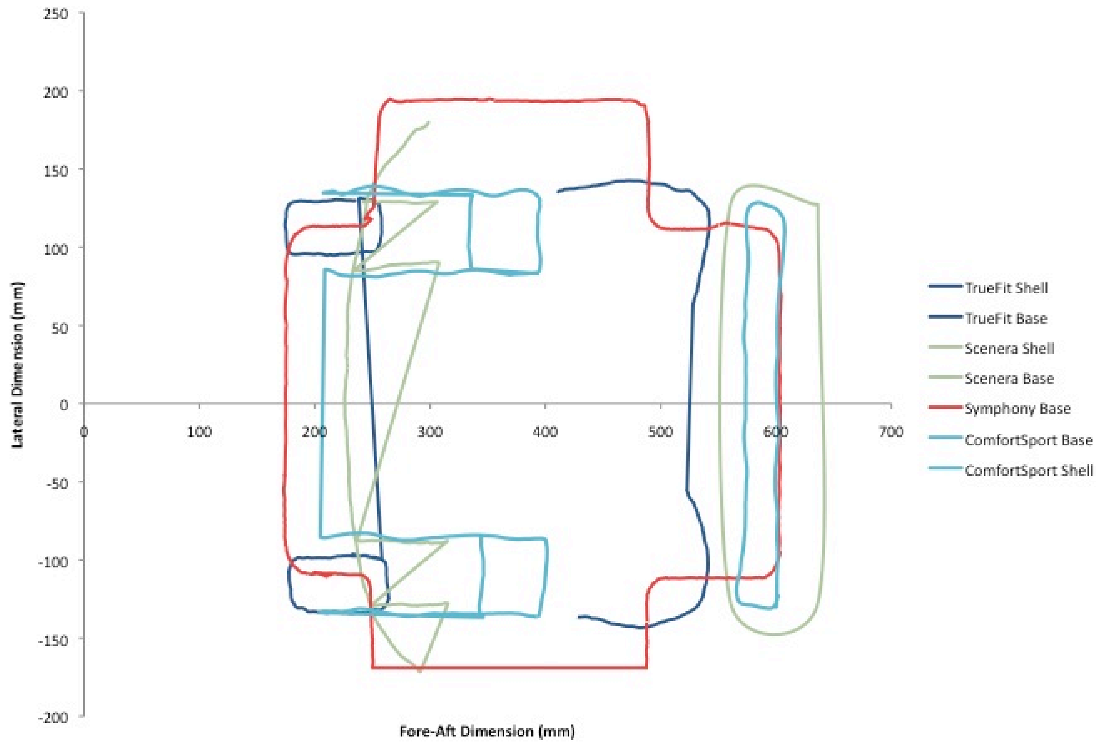


Figure 3. Footprints of the forward-facing convertibles on the vehicle seat

Rear-facing restraints

Three of the convertible child restraints models tested in the forward-facing test series were also selected for rear-facing testing (Evenflo Symphony 65, Cosco Scenera and First Years True Fit). Two additional rear-facing restraints were selected to provide additional variety among the base footprints on the vehicle seat and the weight of the restraint. Since the Graco Snugride was used in the original No Harm test series, products were selected to differ from it, as well as the three convertibles used in forward-facing tests.

Eight rear-facing infant restraint models listed in Table 2 were considered for testing. Figure 4 shows the outlines of the bases of the child restraints compared to the Symphony in rear-facing mode relative to seat cushion lengths of 350 and 450 mm that were used during testing. The two seats with the longest footprints were the Britax Chaperone and the Orbit Baby infant car seat, which also were the two heaviest infant car seats evaluated. With the 350 mm vehicle seat length, only about 65 percent of the bottom surface of these two bases would be supported. Just over 80 percent of the base bottom surface would be supported by the 450 mm vehicle seat length. The Britax Chaperone was selected for use in this study because of its lower price (and higher market share), its high weight, and the long base footprint.

Table 2. Rear-facing infant seats with bases

Child Restraint System Name	Length (mm)	Weight (kg)
Britax B-Safe 30	445	9.0
Lamaze/First Years Via	470	12.5
BabyTrend Flex Loc	480	9.0
Summer Infant Prodigy	510	8.6
Safety 1st Onboard Air 35	510	9.0
Chicco KeyFit 30	515	10.0
Britax Chaperone	545	11.3
Orbit Baby ICS	545	16.8

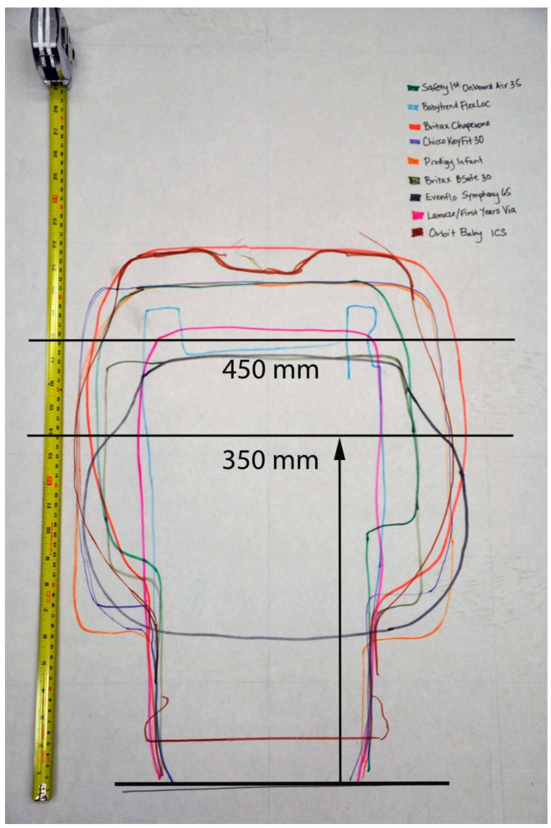


Figure 4. Rear-facing infant seat base footprints

Tests with two rear-facing-only products were originally planned, but the similarities between the Chaperone and SnugRide and the other products instead led to consideration of other convertible products used rear-facing. The Graco Signature Smart Seat all-in-one car seat was selected for inclusion in the test matrix as well, after considering several other convertible and all-in-one car seats. The Graco Smart Seat has a large base (length of 480 mm) that is used when in the rear-facing configuration and it has a very high weight of 15 kg (33 lb).

The right-side profiles, belt path locations and footprints on the vehicle seat of the three selected convertible CRS and two infant seats (including the Graco Snugride which was previously tested) were compared using digitized data. Figure 5 and Figure 6 show the right-side profiles and the rearward-facing belt paths of the CRS when the seats are aligned in the fore-aft direction so that the rearmost point on the seat are at the same position.

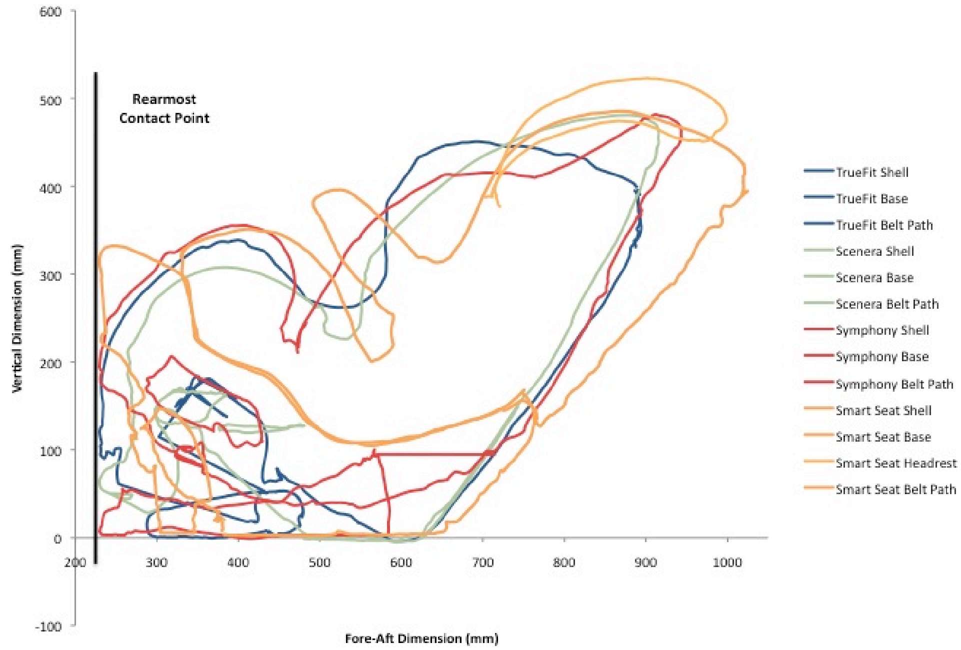


Figure 5. Right-side profile and belt paths of rear-facing convertible CRS

Figure 6. Right-side profile and belt paths of rear-facing infant seats with bases

Figure 7 shows the overlaid footprints of the five rear-facing child restraints as they would be placed on the vehicle seat with the rearmost point on the CRS' aligned.

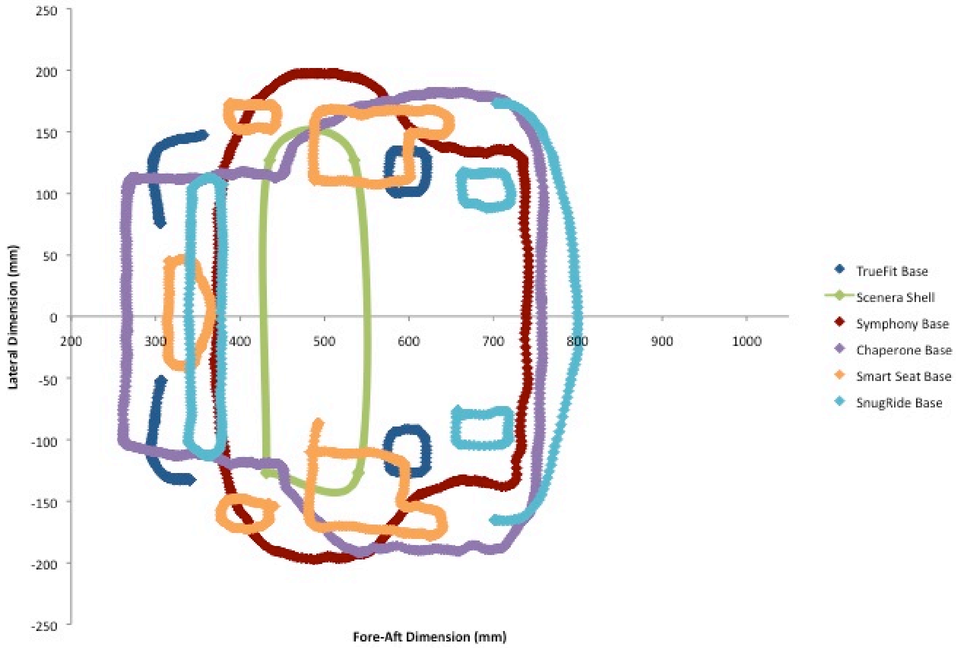


Figure 7. Footprints of the rear-facing CRS on the vehicle seat

Test Condition Overview

The test matrices for the forward-facing and rear-facing tests are listed in Table 3 and Table 4. Each color represents a different test condition, and bold text shows the tests that were run under the same conditions to check repeatability.

The Hybrid III 3-year-old dummy (3YO) was used to conduct 40 tests using four forward-facing convertible models. The CRABI 12-month-old dummy was used to run 47 tests using four different rear-facing convertibles and one rear-facing only child restraint. Some tests were run using the FMVSS No. 213 bench to establish baseline conditions, but most were run using real vehicle seats with the cushion length set to 350 mm, 400 mm, or 450 mm. Lap belt anchorage locations were set to match the FMVSS No. 213 locations or the locations optimized for the 6YO ATD (Hu, Wu, Reed, Klinich, & Cao, 2013). Some tests attached the child restraint using the lower anchors rather than the belt. Forward-facing tests were run with and without tethers.

Table 3. Matrix of forward-facing tests

TestID	Vehicle Seat	Belt geometry	Tether	Child Restraint
NT1201	213 buck	213 geometry	None	C: Scenera
NT1202	213 buck	213 geometry	None	D:TrueFit
NT1204	**213 buck**	**213 geometry**	**None**	**E:Symphony**
NT1203	**213 buck**	**213 geometry**	**None**	**E:Symphony**
NT1209	350 mm	213 geometry	None	C: Scenera
NT1211	**350 mm**	**213 geometry**	**None**	**D:TrueFit**
NT1210	**350 mm**	**213 geometry**	**None**	**D:TrueFit**
NT1212	350 mm	213 geometry	None	E:Symphony
NT1239	350 mm	213 geometry	None	F:ComfortSport
NT1213	350 mm	6YO Optimal	None	C: Scenera
NT1214	350 mm	6YO Optimal	None	D:TrueFit
NT1216	**350 mm**	**6YO Optimal**	**None**	**E:Symphony**
NT1215	**350 mm**	**6YO Optimal**	**None**	**E:Symphony**
NT1235	350 mm	6YO Optimal	None	F:ComfortSport
NT1218	**350 mm**	**6YO Optimal**	**Tether**	**C: Scenera**
NT1236	**350 mm**	**6YO Optimal**	**Tether**	**C:Scenera**
NT1219	350 mm	Lower anchors	None	C: Scenera
NT1220	**350 mm**	**Lower anchors**	**None**	**D:TrueFit**
NT1221	**350 mm**	**Lower anchors**	**None**	**D:TrueFit**
NT1222	350 mm	Lower anchors	None	E:Symphony
NT1233	350 mm	Lower Anchors	None	F:ComfortSport
NT1225	350 mm	LATCH	Tether	D:TrueFit
NT1226	350 mm	LATCH	Tether	E:Symphony
NT1206	**450 mm**	**213 geometry**	**None**	**C: Scenera**
NT1205	**450 mm**	**213 geometry**	**None**	**C: Scenera**
NT1207	450 mm	213 geometry	None	D:TrueFit
NT1208	450 mm	213 geometry	None	E:Symphony
NT1238	450 mm	213 geometry	None	F:ComfortSport
NT1217	450 mm	6YO Optimal	None	C: Scenera
NT1234	450 mm	6YO Optimal	None	D:TrueFit
NT1240	450 mm	6YO Optimal	Tether	D:TrueFit
NT1237	450 mm	6YO Optimal	Tether	E:Symphony
NT1223	450 mm	LATCH	None	C: Scenera
NT1224	**450 mm**	**LATCH**	**None**	**E:Symphony**
NT1232	**450 mm**	**LATCH**	**None**	**E:Symphony**
NT1228	**450 mm**	**LATCH**	**Tether**	**C: Scenera**
NT1229	**450 mm**	**LATCH**	**Tether**	**C: Scenera**
NT1230	450 mm	LATCH	Tether	D:TrueFit
NT1231	450 mm	LATCH	Tether	D:TrueFit
NT1227	450 mm	LATCH	Tether	E:Symphony

Table 4. Test matrix for rear-facing conditions

TestID	Vehicle Seat	Belts	Child Restraint
NT1258	**213 buck**	**213 geometry**	**A: Chaperone**
NT1259	**213 buck**	**213 geometry**	**A: Chaperone**
NT1260	**213 buck**	**213 geometry**	**B: SmartSeat**
NT1261	213 buck	213 geometry	C:Scenera
NT1262	213 buck	213 geometry	D:TrueFit
NT1263	213 buck	213 geometry	E:Symphony
NT1264	**213 buck**	**213 geometry**	**B: SmartSeat**
NT1265	450 mm	213 geometry	A: Chaperone
NT1266	**450 mm**	**213 geometry**	**B: SmartSeat**
NT1267	**450 mm**	**213 geometry**	**B: SmartSeat**
NT1268	**450 mm**	**213 geometry**	**C:Scenera**
NT1269	**450 mm**	**213 geometry**	**C:Scenera**
NT1270	450 mm	213 geometry	D:TrueFit
NT1271	450 mm	213 geometry	E:Symphony
NT1272	350 mm	213 geometry	A: Chaperone
NT1273	350 mm	213 geometry	B: SmartSeat
NT1274	350 mm	213 geometry	C:Scenera
NT1275	**350 mm**	**213 geometry**	**D:TrueFit**
NT1276	**350 mm**	**213 geometry**	**D:TrueFit**
NT1277	**350 mm**	**213 geometry**	**E:Symphony**
NT1278	350 mm	6YO Optimal	A: Chaperone
NT1279	350 mm	6YO Optimal	B: SmartSeat
NT1280	**350 mm**	**6YO Optimal**	**C:Scenera**
NT1281	350 mm	6YO Optimal	D:TrueFit
NT1282	**350 mm**	**6YO Optimal**	**E:Symphony**
NT1283	**350 mm**	**6YO Optimal**	**E:Symphony**
NT1284	**350 mm**	**Lower anchors**	**A: Chaperone**
NT1285	**350 mm**	**Lower anchors**	**A: Chaperone**
NT1286	350 mm	Lower anchors	B: SmartSeat
NT1287	350 mm	Lower anchors	C:Scenera
NT1288	350 mm	Lower anchors	D:TrueFit
NT1289	350 mm	Lower anchors	E:Symphony
NT1290	**400 mm**	**6YO Optimal**	**A: Chaperone**
NT1291	400 mm	6YO Optimal	B: SmartSeat
NT1292	400 mm	6YO Optimal	C:Scenera
NT1293	**400 mm**	**6YO Optimal**	**D:TrueFit**
NT1294	**400 mm**	**6YO Optimal**	**D:TrueFit**
NT1295	400 mm	6YO Optimal	E:Symphony
NT1296	**400 mm**	**6YO Optimal**	**A: Chaperone**
NT1297	**350 mm**	**6YO Optimal**	**C:Scenera**
NT1298	**350 mm**	**213 Optimal**	**E:Symphony**
NT1299	400 mm	213 Optimal	C:Scenera
NT12100	400 mm	213 Optimal	B: SmartSeat

TestID	Vehicle Seat	Belts	Child Restraint
NT12101	400 mm	213 Optimal	D:TrueFit
NT12102	400 mm	Lower anchors	B: SmartSeat
NT12103	400 mm	Lower anchors	D:TrueFit
NT12104	400 mm	Lower anchors	E:Symphony

Figure 8 shows the lap belt anchorage locations relative to the seat H-point and FMVSS No. 210 corridors. As in the preceding test series (Klinich, Reed, Hu, & Rupp, 2014), a belt-shortening clip was used to simulate an inboard belt stalk length of 150 mm. With the tests run using the FMVSS No. 213 buck, the three-point belt configuration was used to provide consistency with the tests using the three-point belt on the vehicle seats, but the buckle stalk was not simulated.

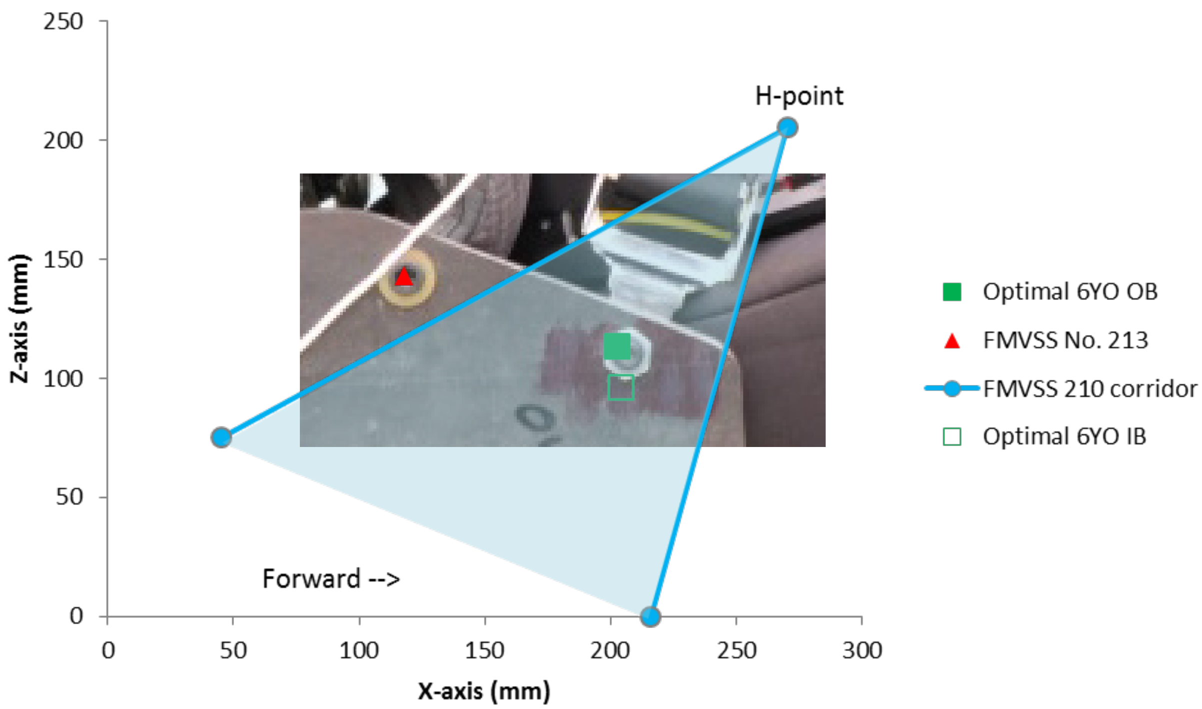


Figure 8. Lap belt anchor locations used during testing relative to FMVSS No. 210 corridor (OB=outboard; IB=inboard)

The vehicle seat conditions were the same as those run in two previous test series (Klinich, Reed, Ebert, & Rupp, 2011, Klinich, Reed, Hu, & Rupp, 2014). Second-row captain's chairs from 2008 and later Dodge Caravans (all with the same design) were obtained from vehicle recyclers and adapted for mounting on the UMTRI sled. None of the test seats showed any unusual damage or wear on visual inspection. The vehicle seats were positioned on the sled such that the fore-aft location of the H-point of the vehicle seat matched the fore-aft H-point of the FMVSS No. 213 bench to facilitate visual comparison between these tests and comparable tests run on the FMVSS 213 No. bench. The seat back angle (SAE J826) was 22.5° and cushion angle was 18.5°, which matches those measured in an exemplar vehicle second-row when set to the design seatback angle. The cushion length of the production vehicle seat is 450 mm, 5 mm less than the median second-row, outboard seat cushion length (Huang and Reed, 2006). The seats were disassembled and mounted such that the seatback and seat cushion were attached separately. Cushion length was adjusted by shifting the seat pan rearward relative to the seat back. Examples of forward-facing and rear-facing configurations are shown in Figure 9 and Figure 10.

Figure 9. Pretest photo of TrueFit test with FMVSS No. 213 belt geometry and 350-mm cushion length

Figure 10. Pretest photo of Britax Chaperone tested with 400-mm cushion length and 6YO-Optimal belt locations

With this vehicle seat, hardware was fabricated to place the lower anchors of the LATCH system in the same location found in the production vehicle, while allowing the cushion to be shifted rearward to simulate a shorter cushion length. The left part of Figure 11 shows the production lower anchors, while the right side shows the hardware used for the lower anchorage test conditions. For the tether, the tether anchor used with the FMVSS No. 213 buck was used.

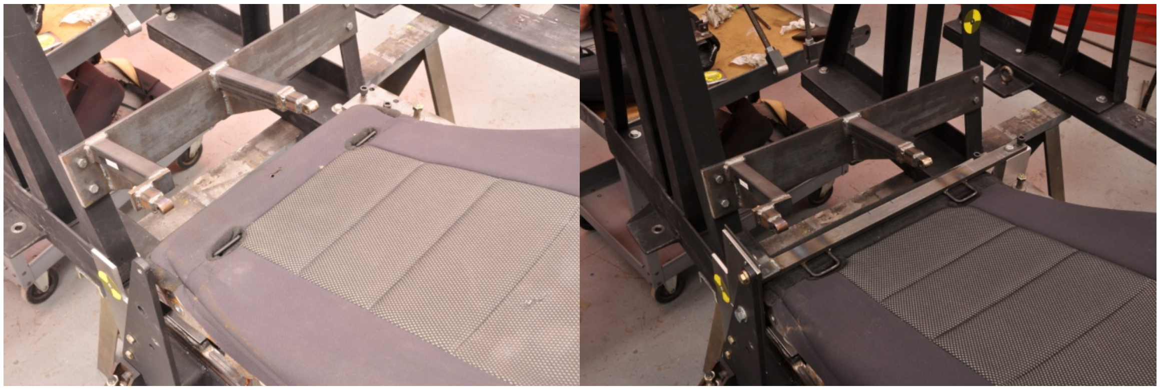


Figure 11. Production lower anchors (left) and modified lower anchor hardware (right) that allows use with different cushion lengths

For the vehicle seat tests, the head restraint hampered installation of the child restraints in the full-down and full-up positions as shown in Figure 12. Since the owner's manual for this vehicle allows removal of the head restraint when using child restraints, the head restraint was removed for all tests.

Figure 12. Head restraint interfered with child restraint installation in both the full up (left column) and full down (right column) positions

Results

Forward-facing

Table 5 compares peak head excursion, HIC, and 3-ms-clip chest acceleration results among test conditions run using the same child restraint model. Color shadings represent test conditions. Bold text indicates a failure relative to FMVSS No. 213 injury measures.

Table 5. Summary of results from forward-facing tests

TestID	Vehicle Seat	Belt geom	Tether	CRS	Head Exc (mm)	Knee Exc (mm)	HIC 36	Chest Acc. *(g)*
NT1201	213 buck	213 geom	None	C:	689	711	681	42.7
NT1209	350 mm	213 geom	None	C:	677	689	843	39.1
NT1213	350 mm	6YO Opt	None	C:	771	744	946	46.5
NT1218	350 mm	6YO Opt	Tether	C:	636	694	499	41.4
NT1219	350 mm	LA	None	C:	778	747	**1138**	45.1
NT1206	450 mm	213 geom	None	C:	573	665	544	51.8
NT1205	450 mm	213 geom	None	C:	554	683	409	46.2
NT1217	450 mm	6YO Opt	None	C:	668	727	588	39.0
NT1223	450 mm	LA	None	C:	663	730	415	36.5
NT1228	450 mm	LATCH	Tether	C:	537	647	384	41.5
NT1229	450 mm	LATCH	Tether	C:	527	651	376	49.4
NT1236	350 mm	6YO Opt	Tether	C:	540	662	413	45.5
NT1202	213 buck	213 geom	None	D:	720	756	638	46.1
NT1211	350 mm	213 geom	None	D:	653	735	687	57.2
NT1210	350 mm	213 geom	None	D:	650	742	589	55.5
NT1214	350 mm	6YO Opt	None	D:	744	799	934	59.9
NT1220	350 mm	LA	None	D:	713	770	528	44.3
NT1221	350 mm	LA	None	D:	661	735	583	45.8
NT1225	350 mm	LATCH	Tether	D:	573	690	364	54.6
NT1207	450 mm	213 geom	None	D:	599	730	450	**63.4**
NT1234	450 mm	6YO Opt	None	D:	638	785	691	55.5
NT1240	450 mm	6YO Opt	Tether	D:	622	740	454	57.9
NT1230	450 mm	LATCH	Tether	D:	592	697	362	**64.4**
NT1231	450 mm	LATCH	Tether	D:	589	725	334	55.2
NT1204	213 buck	213 geom	None	E:	699	811	423	41.1
NT1203	213 buck	213 geom	None	E:	694	811	451	40.5
NT1212	350 mm	213 geom	None	E:	620	801	390	51.6
NT1216	350 mm	6YO Opt	None	E:	695	825	480	46.0
NT1215	350 mm	6YO Opt	None	E:	692	837	443	48.4
NT1222	350 mm	LA	None	E:	761	844	402	41.7
NT1226	350 mm	LATCH	Tether	E:	594	782	381	57.7
NT1208	450 mm	213 geom	None	E:	571	764	354	**60.1**
NT1237	450 mm	6YO Opt	Tether	E:	588	738	376	57.9
NT1224	450 mm	LA	None	E:	615	778	405	55.0

TestID	Vehicle Seat	Belt geom	Tether	CRS	Head Exc (mm)	Knee Exc (mm)	HIC 36	Chest Acc. *(g)*
NT1232	450 mm	LA	None	E:	594	768	359	50.1
NT1227	450 mm	LATCH	Tether	E:	521	744	320	**62.9**
NT1239	350 mm	213 geom	None	F:	645	674	682	41.4
NT1235	350 mm	6YO Opt	None	F:	732	763	715	39.6
NT1233	350 mm	LA	None	F:	806	780	496	35.2
NT1238	450 mm	213 geom	None	F:	622	668	655	51.9

Figure 13 shows the peak head excursions for each test condition, with the red line showing the limit without tether use and the dashed line showing the limit with tether use. All CRS met the applicable excursion limit under all conditions. For all four CRS, the 350 mm seat cushion led to the highest excursion, but it occurred during the test with lower anchor attachment for the Symphony, Scenera, and ComfortSport and the 6YO-optimal anchors for the TrueFit. Table 6 illustrates the peak head excursion for the FMVSS 213 condition and the condition tested with vehicle seats that resulted in the highest head excursion. The last row shows the improvement in head excursion for the Symphony when the tether was used. (The ComfortSport is not included in the table because it was not tested under baseline conditions.) The data show that use of a tether reduces peak head excursion between 15 and 167 mm under paired test conditions, with the larger changes when using the 350-mm seat compared to the 450-mm seat.

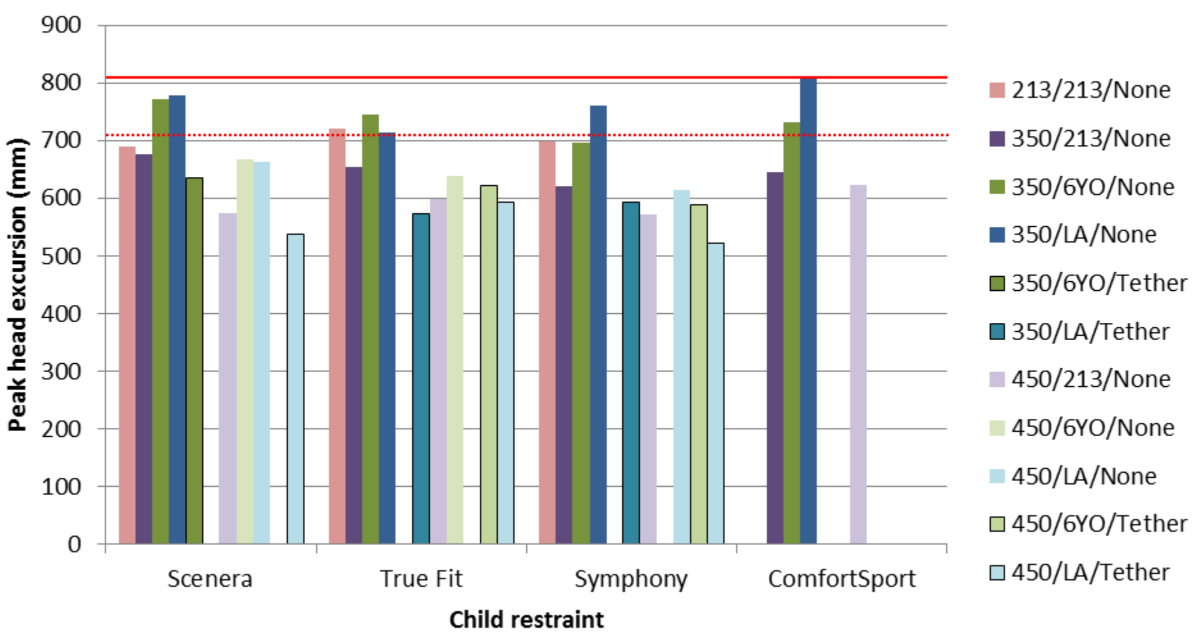
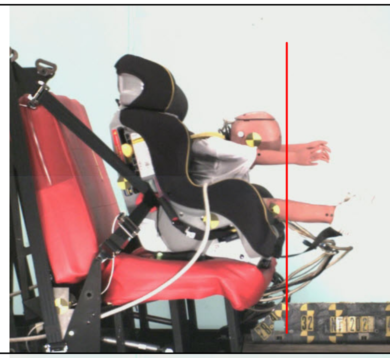
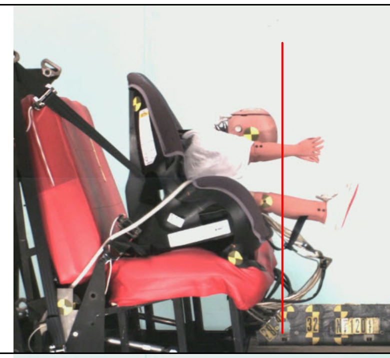
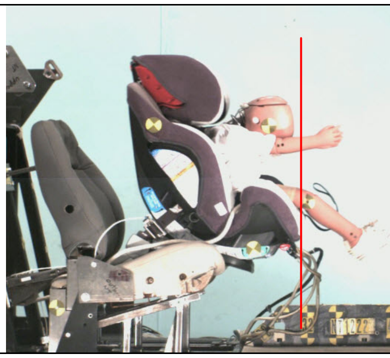
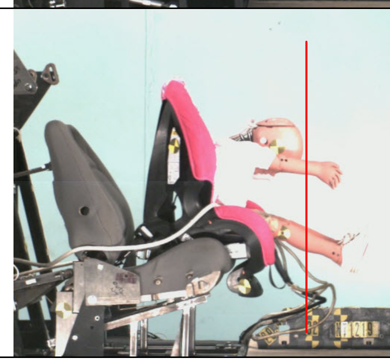
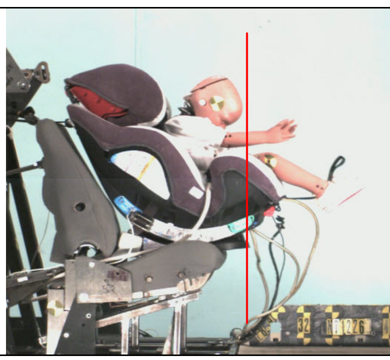


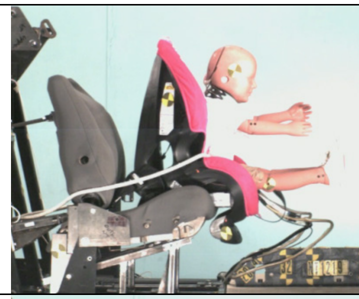
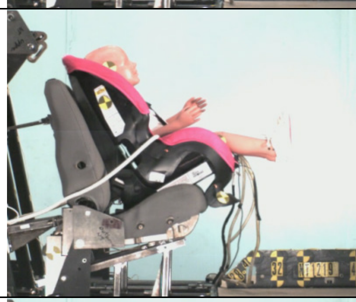
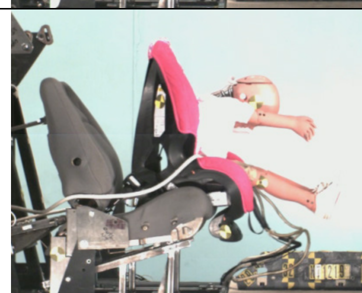
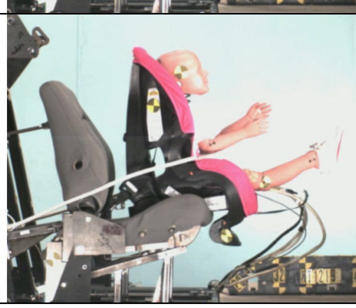
Figure 13. Peak head excursions for each test condition

Table 6. Peak head excursion for three forward-facing products under baseline, worst case, and worst case condition with tether. (Reference targets near floor indicate 711 mm and 813 mm allowable excursion limits with and without tether).

	Symphony	True Fit	Scenera
213 (Baseline)			
Worst case			
	NT1222, 350 mm, lower anchors	NT1214, 350 mm, 6YO optimal	NT1219, 350 mm, lower anchors
Add tether			
	NT1226, 350 mm, lower anchors plus tether		

The kinematics of the Symphony and TrueFit appeared reasonable in all conditions. In contrast, the front part of the Scenera slipped off the front edge of the seat in all conditions run with the 350 mm seat. An example is shown in Table 7. With the 450-mm seat, it slipped off the front when the 6YO-optimal belt anchorages were used and when the lower anchors were used, but remained in contact with the seat surface when the FMVSS No. 213 belt anchorages were used and when the tether was used with the lower anchors. Although the resulting kinematics were atypical, the excursions were similar to those seen in the test run on the FMVSS No. 213 bench.

Table 7. Kinematics of Scenera slipping off the front edge of the seat producing worst-case excursion

Time (ms)		Time (ms)	
0		75	
30		90	
45		105	
60			

Additional tests were run with another product that had a recline foot to see if these kinematics were unique to the Scenera. The Graco ComfortSport remained on the seat cushion in the tests run with the FMVSS No. 213 anchorages and the 350 mm and 450 mm cushion lengths, but slipped off the front in the 350 mm/6YO optimal and 350 mm/lower anchor test conditions.

One test condition (Scenera on 350-mm seat with lower anchors only) failed the HIC criteria of 1000. Three conditions failed the 3-ms-clip chest acceleration criteria. All were on the 450-mm vehicle cushion length, two with the 6YO-optimal belt geometry and one with lower anchors and tether, one with the True Fit and two with the Symphony.

Rear-facing

Results for the rear-facing tests are summarized in Table 8, grouped by each child restraint tested. Colors represent test conditions. For most combinations of seat and belt, at least one pair of tests was a repeat condition. Bold indicates a failure relative to FMVSS 213 criteria.

Table 8. Summary of rear-facing test results

TestID	CRS	Seat	Belts	Head RG	HIC36	Chest Acc. (*g*)	Angle0	Angle Peak	Angle Diff
NT1258	A	213	213	47	308	44	38	67	29
NT1259	A	213	213	46	288	42	37.5	67.6	30.1
NT1265	A	450 mm	213	60	550	47	38	56	18
NT1296	A	400 mm	6YO	59	425	48	36	56	20
NT1290	A	400 mm	6YO	50	342	53	38	58	20
NT1272	A	350 mm	213	48	366	50	42	63	21
NT1278	A	350 mm	6YO	56	413	59	42	68	26
NT1285	A	350 mm	LATCH	60	376	40	38	58	20
NT1284	A	350 mm	LATCH	47	294	39	37	62	25
NT1264	B	213	213	72	492	**76**	48	68.4	20.4
NT1260	B	213	213	72	466	**76**	48.5	69.1	20.6
NT1266	B	450 mm	213	73	605	**74**	39	47.2	8.2
NT1267	B	450 mm	213	52	304	51	49	60	11
NT12100	B	400 mm	213	76	578	**75**	47	62	15
NT1291	B	400 mm	6YO	91	689	**97**	45	61	16
NT12102	B	400 mm	LATCH	60	468	**64**	46	56	10
NT1273	B	350 mm	213	60	475	**73**	49.5	66	16.5
NT1279	B	350 mm	6YO	86	632	**86**	44	68	24
NT1286	B	350 mm	LATCH	53	420	**61**	45	57	12
NT1261	C	213	213	48	291	43	43	59.4	16.4
NT1269	C	450 mm	213	58	327	45	45	52	7
NT1268	C	450 mm	213	52	349	44	46	54	8
NT1299	C	400 mm	213	56	389	49	44	49	5
NT1292	C	400 mm	6YO	58	442	54	45	51	6
NT1274	C	350 mm	213	57	417	44	46	53	7
NT1297	C	350 mm	6YO	51	343	45	47	56	9
NT1280	C	350 mm	6YO	49	349	52	45	57	12
NT1287	C	350 mm	LATCH	51	363	44	45	53	8
NT1262	D	213	213	57	463	46	45	52	7
NT1270	D	450 mm	213	65	469	57	47	50	3
NT12101	D	400 mm	213	54	406	55	45	45	0
NT1294	D	400 mm	6YO	46	289	54	41	42	1
NT1293	D	400 mm	6YO	56	433	**64**	45	47	2
NT12103	D	400 mm	LATCH	48	375	53	45	47	2
NT1275	D	350 mm	213	67	463	**60.2**	47	52.5	5.5
NT1276	D	350 mm	213	63	480	**60.8**	46	54	8
NT1281	D	350 mm	6YO	72	643	**83**	46	56	10

TestID	CRS	Seat	Belts	Head RG	HIC36	Chest Acc. (*g*)	Angle0	Angle Peak	Angle Diff
NT1288	D	350 mm	LATCH	51	397	55	48	58	10
NT1263	E	213	213	59	503	46	42.6	59	16.4
NT1271	E	450 mm	213	76	591	50	40	48	8
NT1295	E	400 mm	6YO	74	617	54	40	56	16
NT12104	E	400 mm	LATCH	65	514	46	39	50	11
NT1277	E	350 mm	213	61	492	55	40	52	12
NT1298	E	350 mm	213	69	544	48	43	53	10
NT1283	E	350 mm	6YO	63	547	**61**	40	61	21
NT1282	E	350 mm	6YO	57	509	58	42	63	21
NT1289	E	350 mm	LATCH	73	542	47	40	55	15

All of the rear-facing tests met the requirement that maximum rotation does not exceed 70°. Peak rotations are shown in Figure 14 for one test in each condition; when two tests were run under the same condition the higher value is shown. For the Chaperone, SmartSeat, and Scenera, the largest rotation occurred in the baseline condition using the FMVSS No. 213 bench and belt geometry. For the Symphony, the condition with the 350 mm seat length and the 6YO optimal belt anchors had a higher rotation than the baseline FMVSS No. 213 condition, but the baseline test had the second highest rotation. For the TrueFit, the three tests with the 350 mm cushion length had higher rotations than the baseline FMVSS No. 213 condition. Overall, each product had higher rotations with the 350-mm cushion length compared to the 450-mm cushion length. Most products also had higher rotations with the 6YO optimal belt geometry compared to the FMVSS No. 213 belt geometry.

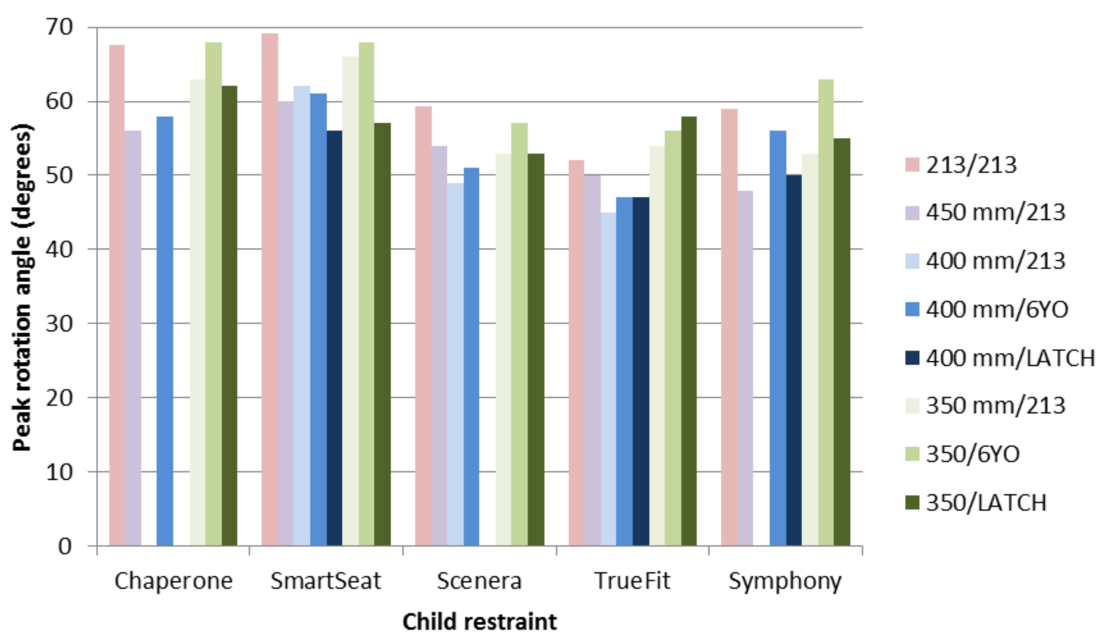


Figure 14. Peak rotations for each rear-facing test condition

The 3-ms-clip chest acceleration values are shown in Figure 15. All but one of the tests with the Graco SmartSeat failed the chest-acceleration criterion, with values ranging from 61 to 97 relative to the 60 *g* limit. (In test NT1267 with chest acceleration of 51 *g*, the test failed because the adjustable head restraint/harness shifted during the test, which is not allowed according to FMVSS No. 213 specifications.) Four tests with child restraint D (TrueFit) and one test with child restraint E (Symphony) also failed the chest-acceleration criterion, but the values in four of those tests were just over the 60 *g* limit. With the TrueFit, the chest acceleration failures usually occurred when the 6YO-optimal belt geometry was used, suggesting that the TrueFit belt path may be less compatible with this belt geometry.

Most of the tests with the vehicle seats and belt attachment of the child restraint produced higher chest accelerations than in the baseline FMVSS No. 213 test condition. But for four of the CRS, relatively lower chest accelerations were also measured in the condition with the 350-mm cushion length and attachment with lower anchors. For a particular seat condition, chest acceleration values were often 10-20 *g* lower using lower anchors rather than either lap belt configuration.

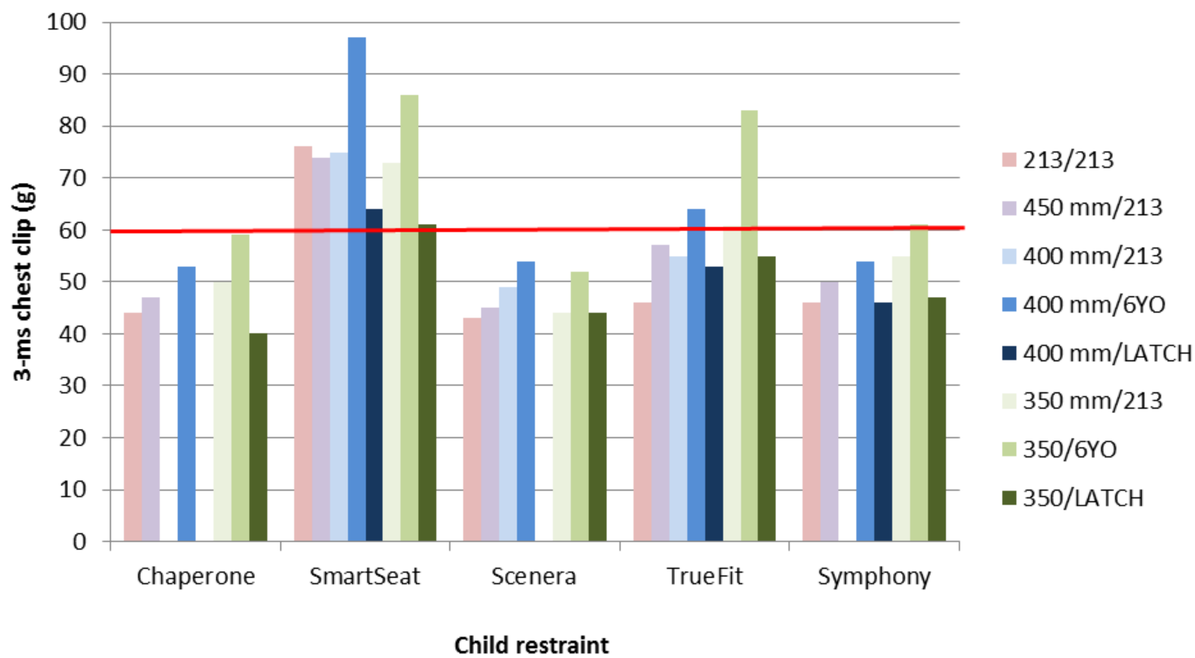


Figure 15. Values of chest acceleration (3-ms-clip) for each rear-facing test condition

In test NT1290, the Chaperone shell detached from the base on one side, but the shell remained attached in the repeat test (NT1296). Also, the base of the Chaperone cracked in test NT1284 but not in the retest (NT1285).

Repeatability

Forward-facing tests

The peak head excursions for nine paired test conditions are shown in Figure 16. Of the nine tests, seven had differences in head excursions less than 25 mm. The Scenera and TrueFit each had a test condition with the 350 mm cushion length with larger differences in head excursion between the paired tests (96 and 52 mm, respectively.) Comparison of knee excursions for paired test conditions are in Figure 17. The difference between tests was 35 mm or less for all conditions.

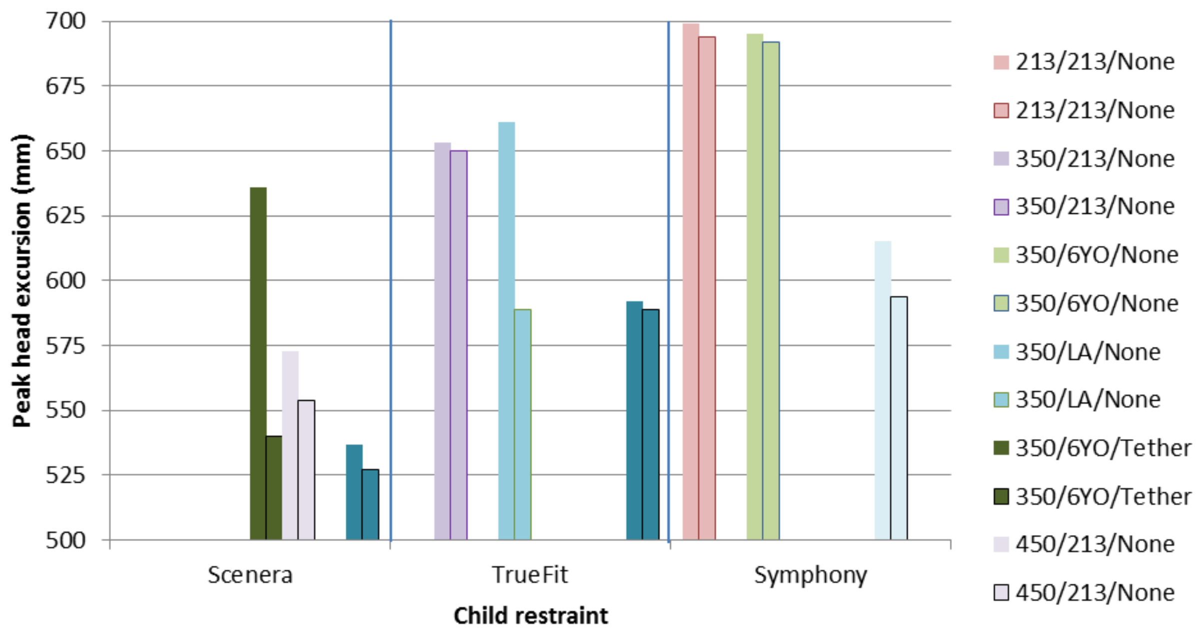


Figure 16. Peak head excursion values for paired test conditions

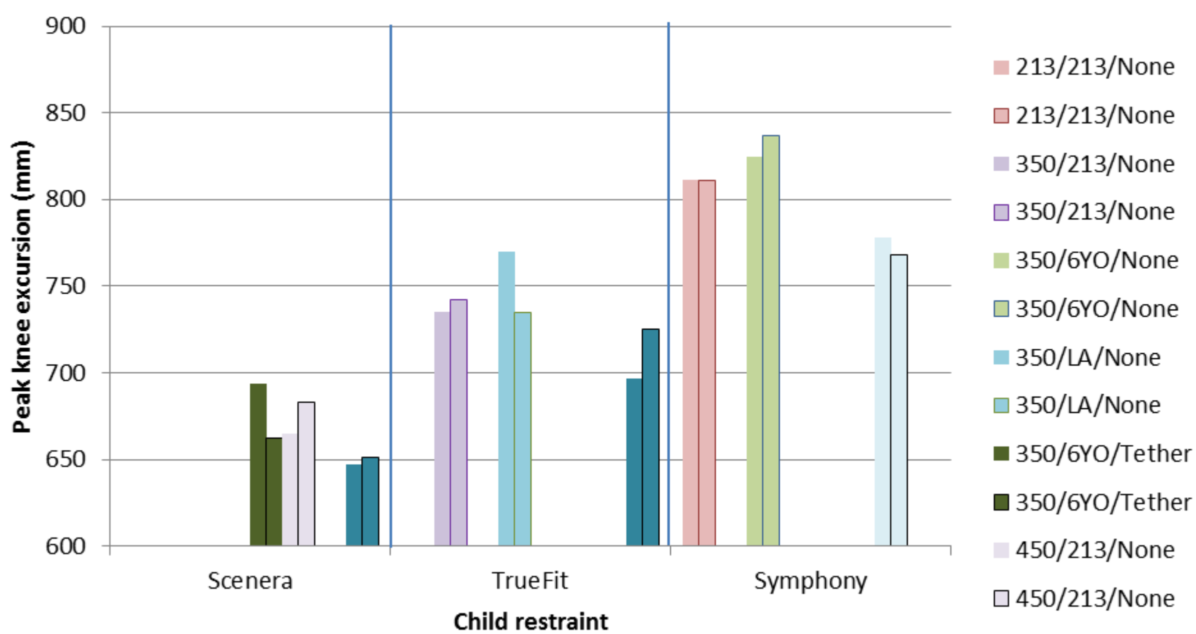


Figure 17. Peak knee excursion values for paired test conditions

Figure 18 and Figure 19 show the values of HIC (36 ms) and 3-ms chest clip *(g)* for paired forward-facing test conditions. In five test conditions, the difference in HIC between paired tests was 50 or less, between 50 and 100 in three tests, and 136 in one test. In six test conditions, the maximum HIC value was less than half the threshold. For the 3-ms chest clip, four tests had differences of less than 3 *g*, while the other five had differences between 4 and 10 *g*.

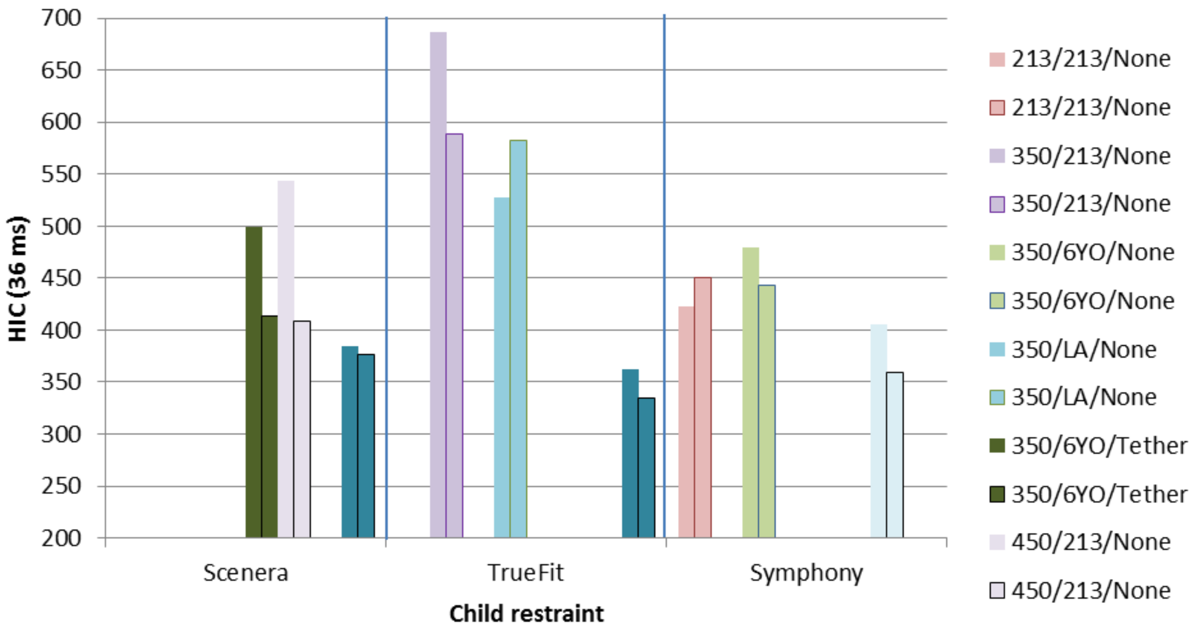


Figure 18. HIC (36 ms) values for paired test conditions

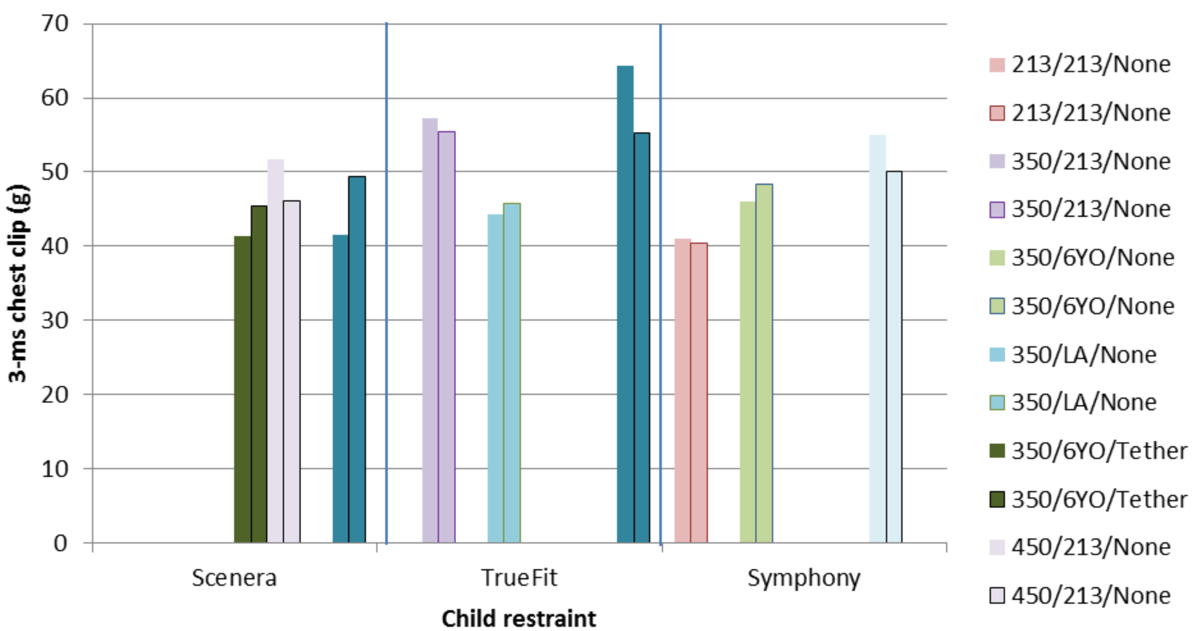


Figure 19. 3-ms chest clip *(g)* values for paired test conditions

Rear-facing tests

Figure 20 shows the values of peak rotations for eleven paired test conditions. Of the eleven paired test conditions, ten of them had differences of peak rotation of 5° or less and eight had differences of 2° or less. In the test condition with the SmartSeat with the largest variation of 12°, the head restraint shifted during one of the tests so it does not represent the same test condition. Repeatability in peak rotation was similar across all test conditions and products. Typical maximum rotation repeatability in FMVSS No. 213 testing is 2° or less.

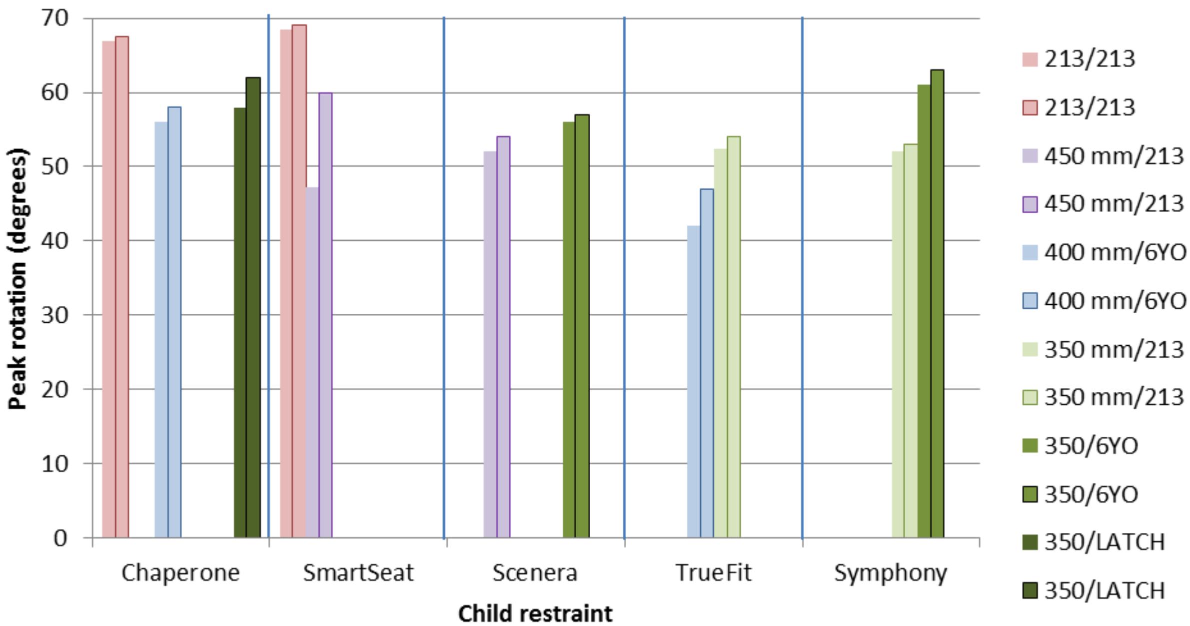


Figure 20. Peak rotations in paired rear-facing tests

Rear-facing HIC (36 ms) values are plotted in Figure 21 for paired test conditions. Six tests had differences in HIC (36 ms) between 6 and 38, while the difference between paired tests was between 52 and 144 in the other four tests. (The largest difference of 301 occurred with the SmartSeat where the head restraint shifted in one test). Typical HIC repeatability in FMVSS 213 testing is 40 or less.

The 3-ms chest clip values are shown in Figure 22 for 11 test conditions. The largest difference occurred with the Smart Seat when the head restraint shifted during the test. For the other cases, the difference in was 0 to 3 *g*'s in six conditions and 4 to 10 *g* in four conditions.

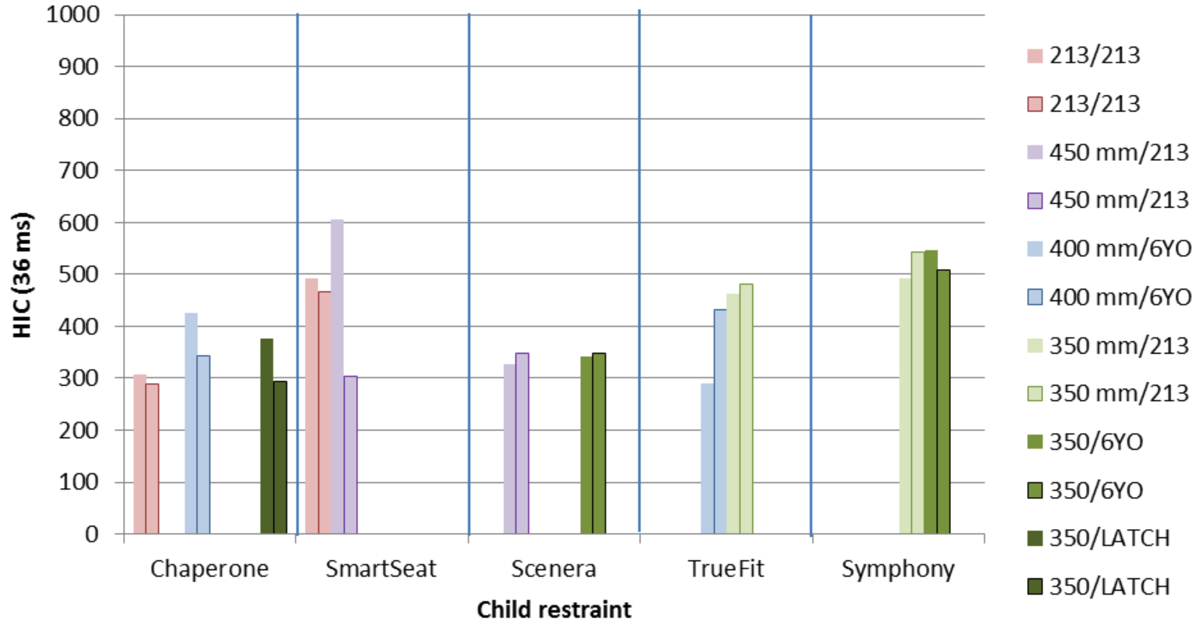


Figure 21. HIC (36 ms) in paired rear-facing tests

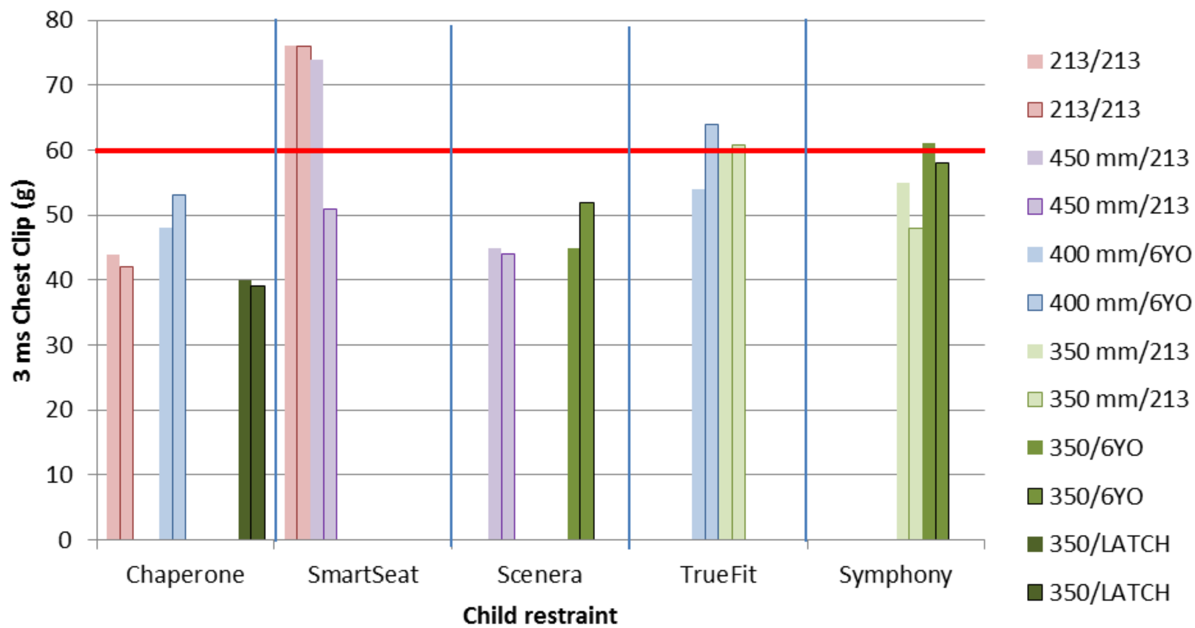


Figure 22. 3-ms clip chest acceleration for paired rear-facing test conditions

Discussion

Overall, the kinematics and dummy measurements from the forward-facing tests did not change adversely when tested on a real vehicle seat using either the 450 mm or 350 mm cushion length or the alternate belt anchorage location or LATCH when compared to test results using the FMVSS No. 213 bench. Two products with a recline foot slipped off the front of the vehicle seat when it was adjusted to the 350 mm condition. However, the tests still met the excursion requirements. For most of the products tested, the 350 mm cushion did not have higher head excursions compared to baseline when using the same belt anchorage, but did have increases in head excursion when LATCH or the more forward belt anchorages were used.

Three of the forward-facing tests failed the 3-ms chest clip measurement when tested using the 450 mm vehicle cushion length. This is thought to result from the higher stiffness of the vehicle seat compared to the FMVSS No. 213 cushion stiffness. Although the other tests met the chest acceleration requirement, peak chest *g*'s were usually higher on the 450 mm vehicle seat with FMVSS No. 213 anchors compared to the FMVSS No. 213 bench.

For the rear-facing tests, all of the test conditions met the 70° maximum rotation angle, even though rotations tended to increase with shorter cushion length and more forward belt anchorage location. One product, the Graco SmartSeat, exceeded the chest acceleration criterion under most conditions, sometimes by a substantial amount. The TrueFit also failed when the 6YO-optimal belt anchors were used.

Two of the tests run with the Chaperone and the shorter cushion length resulted in damage to the shell in one test and partial detachment of the shell in the other. These were hypothesized to occur from the flexing of the child restraint over the stiff front edge of the vehicle seat. Repeat tests were performed under the two test conditions resulting in damage and detachment, but the issues did not occur in the repeated tests.

For the rear-facing tests, the initial angle obtained on the FMVSS No. 213 bench was difficult to achieve on the vehicle seat in some tests, particularly when the shorter cushion length was used. An example is shown in Figure 23. For a real in-vehicle installation, a CPS technician would likely suggest using a pool noodle to fill the gap between the product and the vehicle seat. The gap is not present in the FMVSS No. 213 installation because the child restraint can more easily deform the softer foam used in the bench. Because pool noodles are not allowed in FMVSS No. 213 testing, none were used with the vehicle seats.

Figure 23. Child restraint installed with gap to achieve same initial angle achieved under FMVSS No. 213 conditions

These CRS performed well on the FMVSS No. 213 test bench, which has an extremely shallow lap belt angle compared to the range of angles allowed by FMVSS No. 210 and implemented by vehicle manufacturers, but the products sometimes did not perform as well when using more-forward belt anchorage locations. Nonetheless, they still met the relevant excursion or rotation criteria. These results raise the possibility that proposed revisions to the FMVSS No. 213 bench to make it more realistic may decrease discrepancies between test-bench performance and laboratory performance on vehicle seats. Changes should address both cushion length and belt anchorage geometry.

This series of tests included paired tests to assess repeatability. Results were good, particularly considering that most of the tests were conducted on individual vehicle seats rather than a standardized test bench. Some greater variability might be expected since the vehicle seat hardware was switched between each test, and the seats themselves had varying levels of wear, so the minimal variations seen were encouraging.

The results suggest that shortening seat cushion length to provide a better restraint environment for children using the vehicle seat and belt alone would not adversely affect the performance of most child restraints. One concern is that most child restraint manufacturers, and the Child Passenger Safety Technician Curriculum, recommend that child restraints only be used on vehicle seats where 80 percent of the child restraint footprint is supported by the vehicle seat. A cushion length of 350-mm would not provide this level of support for some of the CRS currently available, although we are not aware of any testing that supports this criterion.

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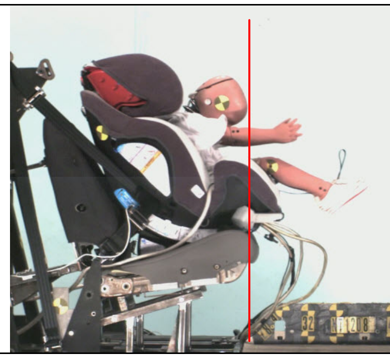
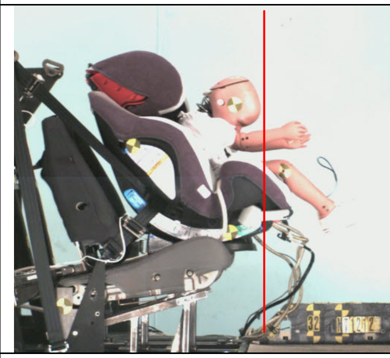
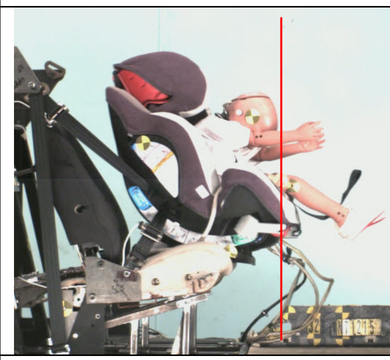
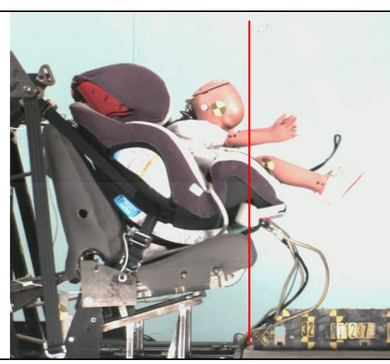
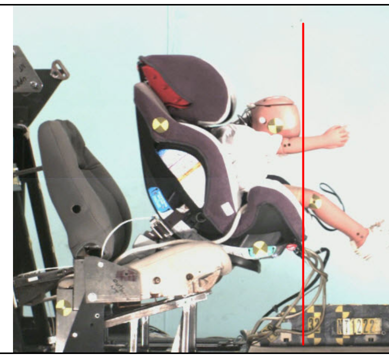
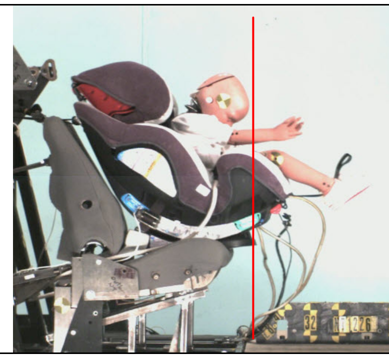
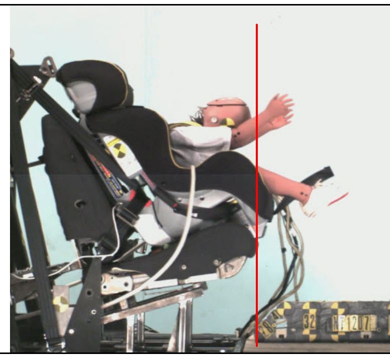
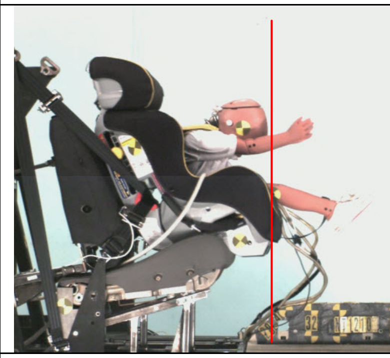
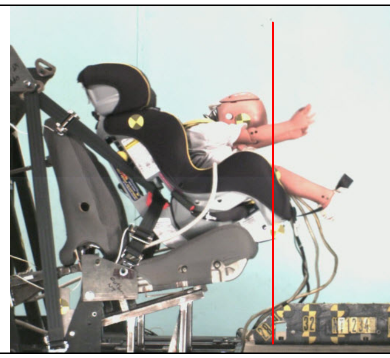
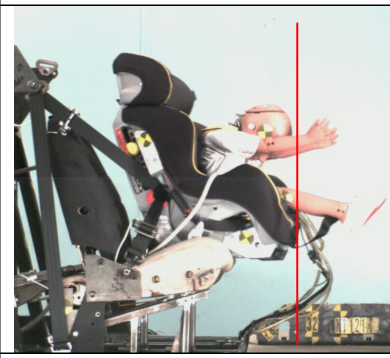
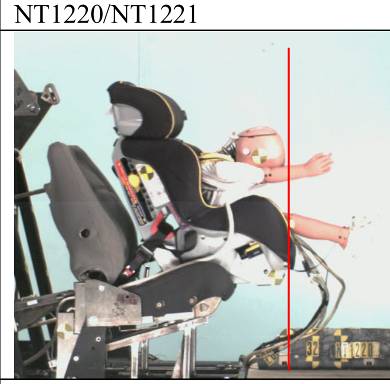
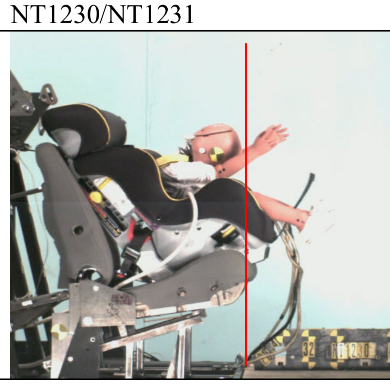
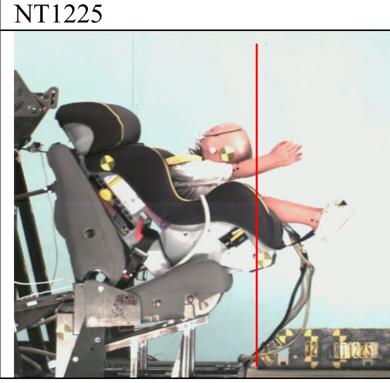
Appendix A: Peak Head Excursion in Forward-Facing Tests

E: Evenflo Symphony

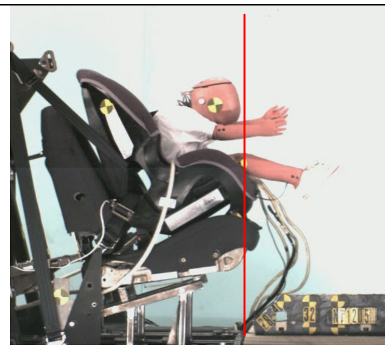
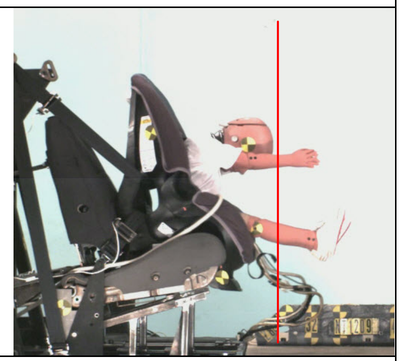
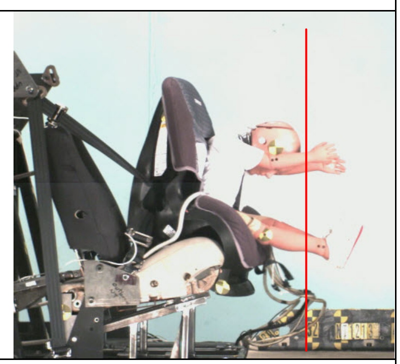
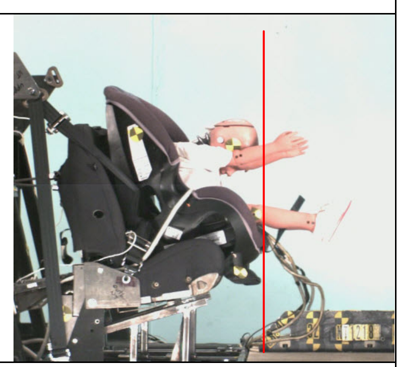
	213	450	350
	NT1203/NT1204	NT1208	NT1212
213			
			NT1215/NT1216
6YO Optimal			
		NT1237	
6YO Opt+tether			
		NT1224/NT1227	NT1222

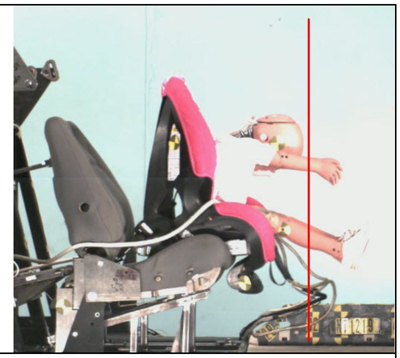
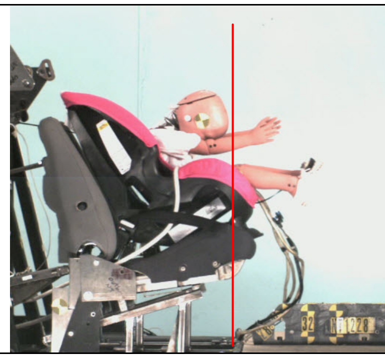
LA			
		NT1232	NT1226
LA+Tether			

D: TrueFit

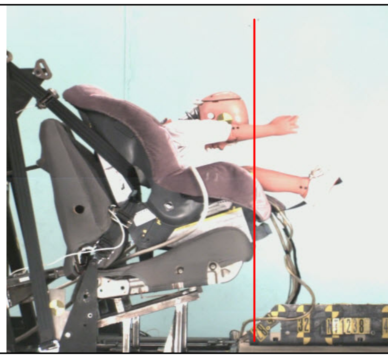
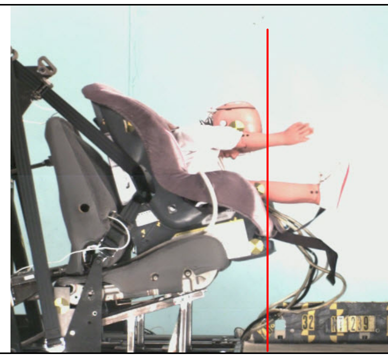
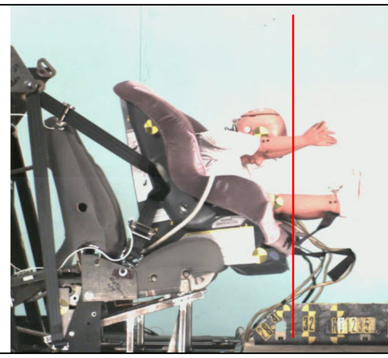
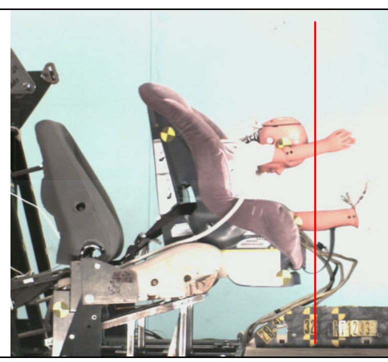
	213	450	350
	NT1202	NT1207	NT1210/NT1211
213			
		NT1234	NT1214
6YO Optimal			
		NT1240	
6YO			
			NT1220/NT1221
LA			
		NT1230/NT1231	NT1225
LA+Tether			

C: Scenera

	213	450	350
	NT1201	NT1205/NT1206	NT1209
213			
		NT1217	NT1213
6YO Optimal			
			NT1218/NT1236
6YO Opt+ tether			
		NT1223	NT1219

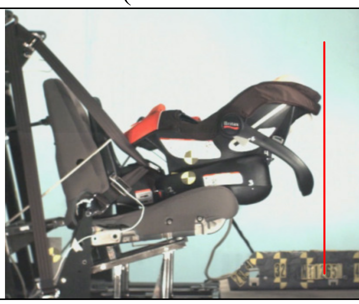
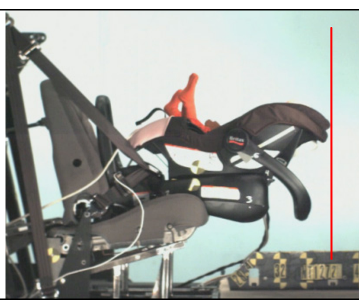
LA			
		NT1228/NT1229	
LA+Tether			

F: ComfortSport

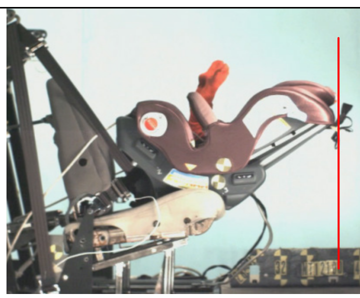
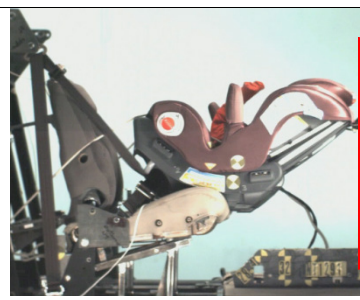
	213	450	350
		NT1238	NT1239
213			
			NT1235
6YO Optimal			
6YO Opt+tether			
			NT1233
LA			
LA+Tether			

Appendix B: Peak Rotation in Rear-Facing Tests

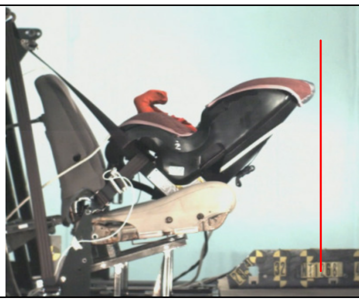
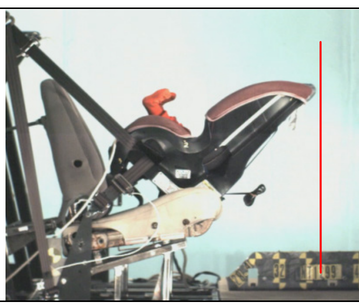
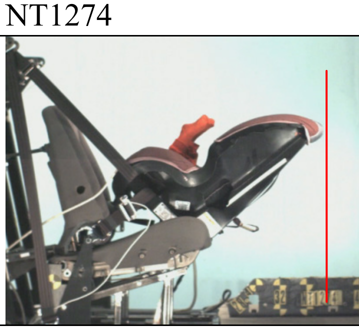
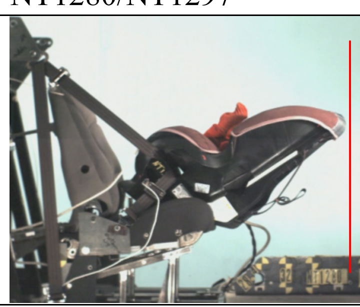
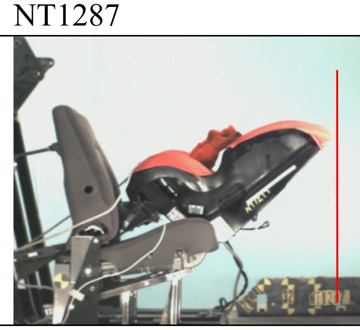
A: Britax Chaperone

A	213	6YO Opt	LA
	NT1258/NT1259		
213			
	NT1265 (		
450			
		NT1290/NT1296	
400			
	NT1272	NT1278	NT1284/N51285
350			

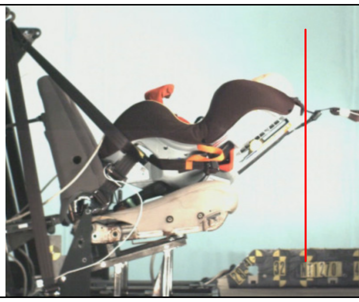
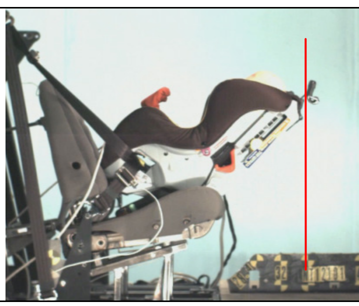
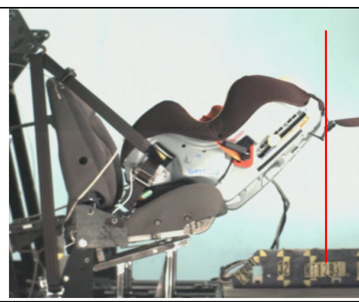
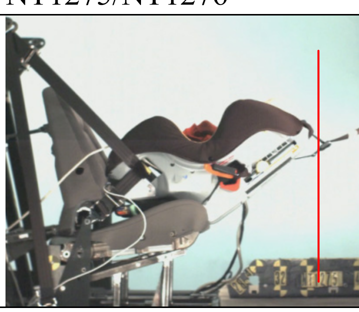
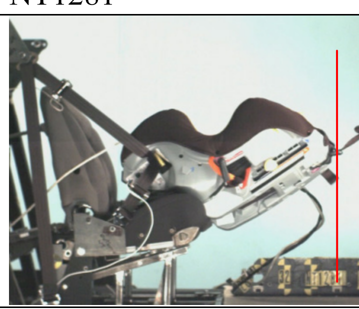
B: Graco SmartSeat

B	213	6YO Opt	LA
	NT1260/NT1264		
213			
	NT1266/NT1267		
450			
	NT12100	NT1291	NT12102
400			
	NT1273	NT1279	NT1286
350			

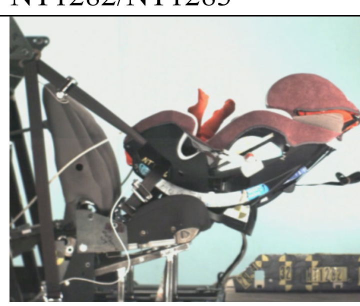
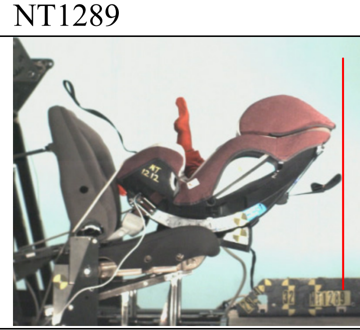
C: Cosco Scenera

A	213	6YO Opt	LA
	NT1261		
213			
	NT1268/NT1269		
450			
	NT1299	NT1292	
400			
	NT1274	NT1280/NT1297	NT1287
350			

D: TrueFit

D	213	6YO Opt	LA
	NT1262		
213			
	NT1270		
450			
	NT12101	NT1293/NT1294	NT12103
400			
	NT1275/NT1276	NT1281	NT1288
350			

E: Evenflo Symphony

E	213	6YO Opt	LA
	NT1263		
213			
	NT1271		
450			
		NT1295	NT12104
400			
	NT1277/NT1298	NT1282/NT1283	NT1289
350			

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