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Assessment of ATD Selection And Use for Dynamic Testing of Rear-Facing Child Restraint Systems for Larger Infants and Toddlers

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16. Abstract

This report documents a test series that explored methods for using currently available child anthropomorphic test devices (ATDs/crash test dummies) to dynamically evaluate child restraint systems (CRS) for children more than 1 year old facing rearward in motor vehicles. These CRS are more typically rear-facing convertible seats but also can be infant-only rear-facing seats. The study evaluated five installation methods using the Hybrid III 3-year-old ATD and the CRABI 18-month-old ATD. Three child restraint system models were evaluated using the current FMVSS No. 213 test bench. None of the ATD conditions produced a systematic change in the dynamic response criteria evaluated by FMVSS No. 213, but some methods were easier to implement in the laboratory. The report documents each method and their potential advantages and disadvantages.

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Background

Federal Motor Vehicle Safety Standard (FMVSS) No. 213 designates the appropriate anthropomorphic test device (ATD) for dynamic testing based on the manufacturer's designated occupant mass and height ranges for each child restraint system (CRS) usage mode (NHTSA, 2013). For rear-facing CRS testing, the newborn is used to represent the smallest CRS occupants, while the Child Restraint Air Bag Interaction (CRABI) 12-month-old (12MO) is used to represent the child for products with maximum occupant weights up to 10 kg and heights up to 850 mm in any orientation. In addition to testing with the CRABI-12MO, the Hybrid III 3-year-old (3YO) is also used for products rated for use with children up to 18 kg and 1,100 mm standing height.

The 2011 American Academy of Pediatrics (AAP) and National Highway Traffic Safety Administration recommendations emphasize keeping children rear-facing beyond 1 year of age, when possible (AAP, 2011; NHTSA, 2014). In response, many rear-facing products are now rated to higher occupant mass capacities of 15-, 18-, or even 20 kg and must be tested using the Hybrid III 3YO. While children typically bend or cross their legs when seated in rear-facing seats, the 3YO dummy's legs cannot always be positioned this way (Ebert et al., 2014). Figure 1 shows the nominal ATD leg posture in a rear-facing (RF) configuration. Sometimes the interaction between the leg and seat back makes installation of the CRS on the FMVSS No. 213 test bench challenging.

Figure 1. Intact Hybrid III 3YO in convertible CRS.

The interaction between the legs and the seat back of the FMVSS No. 213 test bench can affect the installation, particularly the recline angle of the CRS and the lap belt pre-test tension level. An informal survey of child restraint manufacturers and testing facilities identified the common modifications to the ATD leg position to make the ATD easier to use in the RF configuration when problems arise. They include:

- Remove the ATD knee joint stops (basically removing two bolts from the knee joint assembly) to allow the leg to hyperextend at the knee, shown in Figure 2.

Figure 2. Hybrid III 3YO with knee joint stops removed.

- Remove the lower leg completely as shown in Figure 3. This is used for Canadian compliance when a CRS product is labeled for use with children 16 kg or less.

Figure 3. Hybrid III 3YO with lower legs removed.

- Remove the lower leg and attach the shank mass to the sides or top of thigh as shown in Figure 4. This is used for Canadian compliance when a CRS product is labeled for use with children > 16 kg.

Figure 4. Hybrid III 3YO with lower legs attached alongside thighs.

Other approaches that were not reported in the survey but were considered in the initial test series were:

- Bending the leg at the knee as shown in Figure 5. This is considered to be the closest to actual child postures in this situation, although this issue will be addressed in a companion study.

Figure 5. Hybrid III 3YO with bent knees.

- Adding mass to the torso and thigh of the CRABI-18MO to achieve 33 to 35 lb, shown in Figure 6. This approach eliminates the leg-to-vehicle-seat-back interference and might better approximate the shape of a higher mass 2-year-old child, rather than the midsize sized 3-year-old child represented by the 3YO ATD.

Figure 6. Weighted CRABI-18MO.

Appendix A documents related work comparing ATD postures with those of child volunteers measured in RF and FF CRS (Ebert et al., 2015). It also describes some possible changes to the Hybrid III 3YO ATD's lower extremities that were explored to allow more realistic RF postures, but were not pursued because of minimal improvement compared to the postures currently possible with the ATD.

Objective

A pilot test series was conducted to assess the current methods for resolving leg-to-bench interaction issues when testing rear-facing child restraints with ATDs that represent children over 1 year old.

Methods

The current test series used three convertible CRS: a Graco Comfort Sport (GCS), a Cosco Scenera (CS), and a Cosco Scenera 40RF (CS40). These models were selected because they have fairly large market share and relatively upright back support angles when installed on the FMVSS No. 213 test bench (about 33 to 35 degrees from vertical). An upright installation creates a more challenging environment for ATD fit.

Table 1 lists the test conditions used for testing. With the exception of the "no leg" condition, each CRS was tested once in each ATD configuration (no modification, no knee joint stop, no shank, relocated shank, bent knee and weighted 18MO) to determine the effect of different installation methods on the FMVSS No. 213-specified CRS and ATD responses.

Table 1. Test Conditions

Condition	ATD	Description
A - baseline	3YO	ATD intact
B - knee stop	3YO	Knee joint stops removed
C - no leg	3YO	Lower legs removed (ATD mass reduced 2.2 kg)
D - shank	3YO	Lower legs taped to upper thighs
E - bent	3YO	Legs bent
F - CRABI	CRABI-18MO	Mass added to torso+ thighs to reach 15 kg

The tests were performed using the FMVSS No. 213 test bench on the impact sled at the University of Michigan Transportation Research Institute (UMTRI). The CRS were secured to the FMVSS No. 213 test bench with a lap belt. A piece of lightweight string was used to maintain the position of rear-facing restraints during sled launch. The string broke at low tension when loaded during the primary impact.

The ATDs were positioned generally following the laboratory test procedure for FMVSS No. 213 (TP-213-09) with the small modifications noted in Table 2 and illustrated in Figures 1 to 6. Appendix B contains excerpts from TP-213-09 and shows the text changes that would be needed if each method was used.

Table 2. ATD Installation Methods

Condition	Changes to Dummy Preparation (TP-213-09, 12D.4)	Changes to Dummy Installation (TP-213-09, 12D.5.2)
A – baseline (see Fig 1)	No change	No change
B – knee stop (see Fig 2)	Knee stop bolts removed from each knee	No change
C - no leg (see Fig 3)	Lower shank of leg removed from each leg.	No change
D – shank (see Fig 4)	Lower shank of leg removed and taped/tie-wrapped to upper leg	No change
E – bent (see Fig 5)	No change	Legs bent at knee as far as possible without significant interaction with the CRS. Then, feet of ATD oriented to achieve full contact between sole of shoe and seat back of FMVSS No. 213 test bench.
F – CRABI (see Fig 6)	Mass of ATD increased to 15 kg by wrapping lead sheeting around torso and upper leg of ATD	No change

The test data were digitized in real time and filtered according to the requirements of SAE J211. Signals in this report conform to the SAE J1733 sign convention. Photographic data were collected with high-speed digital video cameras at 1000 frames per second from both side and overhead or forward directions. The videos are marked by a strobe flash at the onset of impact that corresponds to time zero on the data plots.

For the rear-facing test configuration, the primary FMVSS No. 213 dynamic response variables are: CRS structural integrity, CRS maximum rotation angle, HIC (36), chest acceleration 3ms clip and ATD containment inside the CRS. The structural integrity was assessed by visual inspection of the samples. Initial and maximum CRS back support angle was measured from the high-speed video frames. In one of the tests (run NT1243) the CRS moved out of position on sled start-up, invalidating the results. The conditions of this run were correctly tested in test NT1245.

Results

Observations on feasibility of each approach – Removing the joint stops and bending the legs at the knees were methods that were easy to accomplish and added little time to the test process. Removing the legs and attaching them to the upper legs was not as simple and the reattached segments were not sufficiently rigidly coupled with a straightforward taping method. Additionally, the added bulk of the ATD thigh showed potential for interfering with CRS lateral features in an unrealistic way. In one test (not reported), the tape broke and the leg became detached, which necessitated discarding the test and repeating the condition. Adding mass to the CRABI-18MO was not difficult but since the ATD does not have large interior cavities, it was accomplished by wrapping flexible weights around the torso and thighs, thus changing the ATD exterior shape.

Observations on installation – The baseline installation condition and the legs bent installation condition created the most bracing of the ATD between the occupant CRS and the seat back of the FMVSS No. 213 test bench. The bracing occurred when the ATD posture required the hip or knee joints to be positioned at the joint stops and thus created a separating force between the back support of the CRS and the seat back of the FMVSS No. 213 test bench that tended to recline the CRS. The only reactive force available was contact with the seat and the tension of the lap belt. Achieving the correct installation angle and the correct lap belt tension under the bracing condition increased the difficulty proper test set-up. That bracing, combined with the required lap belt tension, also created a very tightly coupled restraint system before the test. In contrast, in the configurations where the ATD legs did not touch the FMVSS No. 213 test bench, the installation was stable but there was more potential movement in the installation. Removing the knee joint stops created an intermediate level of bracing. The CRABI-18MO was easier to install than the larger, bulkier 3YO and despite the added exterior weight and the feet did not reach the seat back of the FMVSS No. 213 test bench.

Response data - The key FMVSS No. 213 dynamic performance measures for each test are summarized in Table 3. On these key variables, all the relevant FMVSS No. 213 criteria were met and few large changes in the data were observed. None of the CRS showed any signs of structural failure. In every configuration, the ATD head and torso were fully contained within the restraint throughout the test, meeting requirements of FMVSS No. 213, S5.1.3.2.

Table 3. FMVSS No. 213 Response Measures

# NT12	*CRS*	*CONFIG*	*Dummy*	*Initial SB Angle*	*Max SB Angle*	*HIC (36)*	*3ms Clipped Chest (g)*	*ATD Contained per S5.1.3.2*
53	CS	A- baseline	3YO	46	57	342	39	yes
54	CS	B – knee stop	3YO	44	59	293	38	yes
55	CS	D - shank	3YO	45	56	296	39	yes
52	CS	E - bent	3YO	45	57	334	37	yes
57	CS	F - CRABI	18MO@33lb	44	54	279	39	yes
50	CS40	A- baseline	3YO	45	55	383	38	yes
49	CS40	B – knee stop	3YO	44	55	359	40	yes
48	CS40	D - shank	3YO	44	54	361	40	yes
51	CS40	E - bent	3YO	47	55	337	37	yes
56	CS40	F - CRABI	18MO@33lb	44	53	320	40	yes
41	GCS	A- baseline	3YO	32	54	358	41	yes
42	GCS	B – knee stop	3YO	34	54	350	45	yes
45	GCS	C – no leg	3YO	32	51	364	41	yes
46	GCS	D - shank	3YO	29	51	436	35	yes
44	GCS	E - bent	3YO	33	55	334	40	yes
47	GCS	F - CRABI	18MO@33lb	32	48	324	41	yes

Maximum back support angle – Figure 7 shows the difference between the maximum back support rotation angle for different configurations compared with the baseline configuration performance. In this data, a 1- to 2-degree difference is not practically of consequence and is within the expected test-to-test variation level. Removing the knee stops and bending the legs had little effect on the maximum CRS rotation. Tests with the CRABI-18MO showed slightly less maximum CRS rotation.

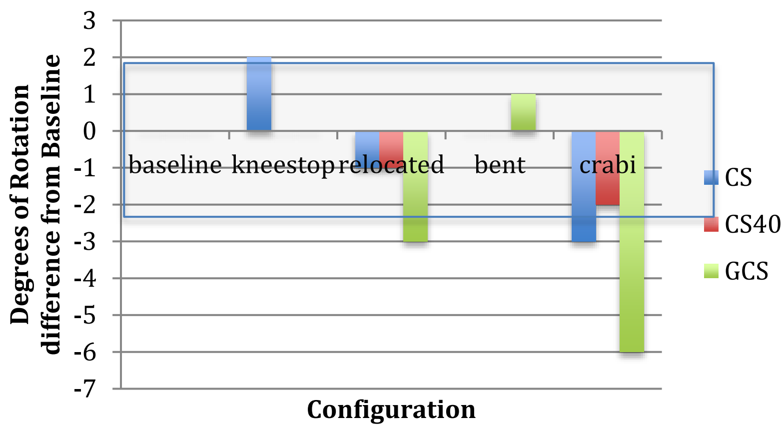

Figure 7. Differences in CRS maximum rotation from baseline condition for each model (gray box shows normal range of repeatability).

HIC(36) – Figure 8 shows the differences in HIC observed between the baseline conditions and the configurations tested. In these data, differences of 50 points in HIC are within the range of expected repeatability of the metric. These data show a somewhat lower HIC in all but one of the configurations. The test with the lower legs removed and reattached along the sides of the thigh produced a higher HIC in the GCS.

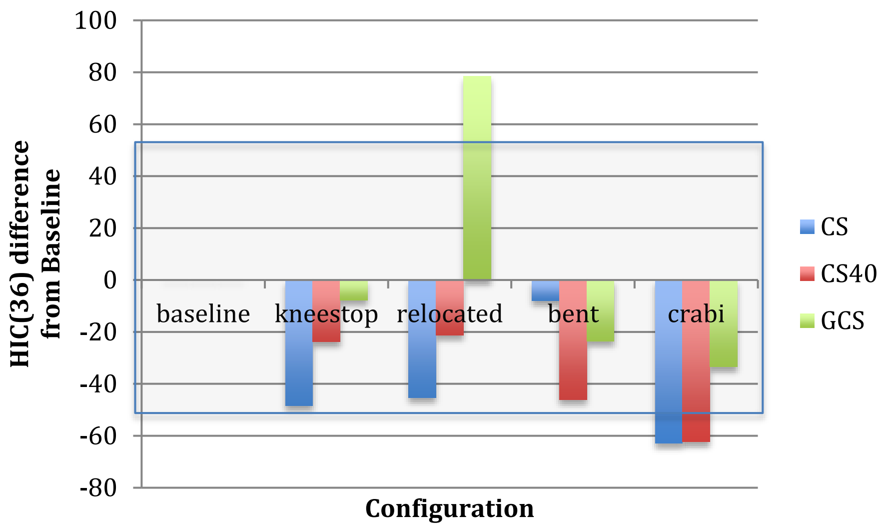

Figure 8. Differences in HIC between baseline and alternative ATD configurations (gray box shows normal range of repeatability).

3ms Chest Clip – Figure 9 shows the difference between the resultant chest acceleration 3ms clip for different ATD configurations compared with the baseline configuration performance. In these data, a 2- to 3 *g* difference is within the expected test-to-test repeatability variation level. The GCS showed a small increase in chest clip with the knee stops removed and a decrease in chest clip with the ATD shank relocated.

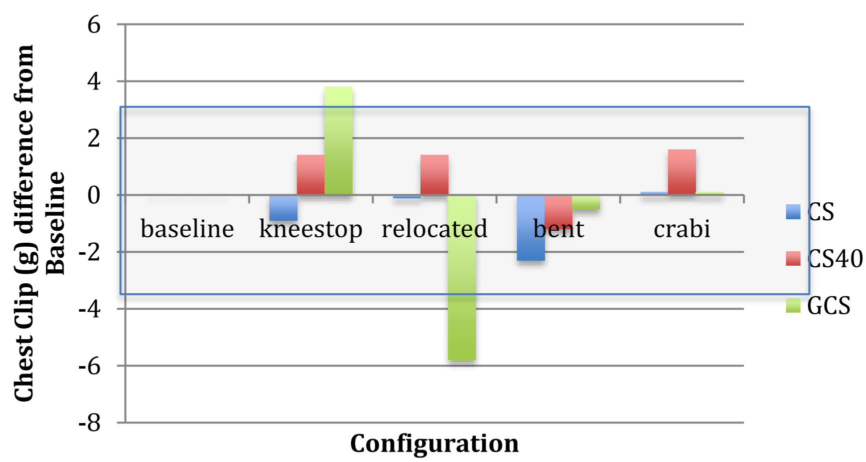

Figure 9. Differences in chest clip between baseline and alternative ATD configurations (gray box shows normal range of repeatability).

Discussion

This pilot study tested the various approaches used to adapt the Hybrid III 3YO for use in FMVSS No. 213 testing. Some had differences in terms of practical consideration, but any approach based on the 3YO did not show a systematic effect on dynamic performance measures of the FMVSS No. 213 test. Using the weighted CRABI-18MO tended to reduce the maximum CRS rotation angle and the HIC measures, although adding mass to the ATD compromises use of the acceleration based measurements. (Use of a weighted 6YO for higher weight harness testing does not consider acceleration measures for this reason.)

The initial concern that motivated this effort, focused on some of the conflicts between the legs and FMVSS No. 213 test bench when using the 3YO in rear-facing CRS. Since the 2011 NHTSA and AAP recommendations to keep children rear-facing past 1 year old when feasible, more consumers have been seeking products that accommodate larger children. As manufacturers try to meet this need without making CRS that are hard to fit in vehicles, a conflict between the FMVSS No. 213-required head containment requirement and the seated height of the 3YO ATD has arisen for many rear-facing CRS products, including both rear-facing-only and rear-facing convertibles. Table 4 compares the seated height and mass of the 3YO, CRABI-18MO, weighted CRABI-18MO, and the corresponding U.S. anthropometry data from the Centers for Disease Control and Prevention (CDC) and the UMTRI anthropometry of infants and children study (Kuczmarski, 2002; Snyder, 1977). These data suggest that the Hybrid III 3YO is the closest match in seated height and total mass to a large 2-year-old.

Table 4. Comparison of Seated Height and Body Mass for ATDs and U.S. Toddlers

	Seated Height (mm)	Total Mass (kg)
CRABI-18MO	500	11.2
CRABI-18MO - weighted	500	15.0
Hybrid III 3YO	546	16.3
95% 2 YO (UMTRI)	552	13.8
99% 2YO MALE (CDC)	--	15.6

During the informal survey of the child restraint manufacturers, some offered opinions on their internal approaches and preferences to testing for larger child occupants in rear-facing CRS. Table 5 summarizes the potential advantages and disadvantages of each configuration from these conversations and the experience from the pilot testing process.

Based on the relatively small variation in dynamic response data among the configurations, none of the rear-facing configurations are expected to change the performance of a child restraint from passing to failing FMVSS No. 213 requirements. Nor would any products shift from "barely passing" to passing. The configuration with the lower leg of the 3YO removed is probably the least desirable configuration, since it reduced the overall mass of the ATD and is therefore less suitable to represent higher mass rear-facing occupants. However, this method is used by Transport Canada. It would be difficult to specify a method of taping the lower legs to the thighs in a manner that is repeatable across labs; we had to discard one test because the leg became detached during our first attempt. In addition, the lower legs can shift even when taped. Again, this method was considered because it is used by Transport Canada. The method of removing the knee stops is the easiest-to-implement method that is already in use by test laboratories and CRS manufacturers.

Table 5. Advantages and Disadvantages of Each Installation Approach

Configuration	Advantages	Disadvantages
Removing 3YO knee stops	• Easy to accomplish quickly in laboratory setting. • Many child restraint manufacturers and test labs report using this approach. • Minimal change to ATD • Has little effect on FMVSS No. 213 response data.	• Does not fully solve conflicts of fitting ATD in smaller convertible or RF-only CRS due to seated height of ATD. • Although greatly eased, there can still be leg-to-bench issues.
Removing 3YO lower leg and leaving it off	• Completely solves leg-to-bench issue • Used by Canada for products rated for children under 16 kg • Has little effect on FMVSS No. 213 response data.	• Reduces ATD mass by 2.2 kg • Does not fully solve conflicts of fitting ATD in smaller convertible or RF-only CRS due to seated height of ATD.
Removing 3YO lower leg and attaching it to thigh	• Completely solves leg-to-bench issue. • Used by Canada for products rated for children over 16 kg • Has little effect on FMVSS No. 213 response data.	• Shanks need to be tightly fastened to the thigh or there is relative movement between the two elements during the test. • The added bulk of the reattached shank can create fit issues in CRS with narrower spaces to the sides of the occupant upper leg. • Does not fully solve conflicts of fitting ATD in smaller convertible or RF-only CRS due to seated height of ATD.
Bending the 3YO legs	• Easy to accomplish quickly in laboratory setting. • No change to ATD • Has little effect on FMVSS No. 213 response data. • Closest approximation (that is possible with this ATD) to how larger children sit rear-facing based on anecdotal observation • Likely the closest approximation to how a modified Hybrid III 3YO would be positioned	• Creates the maximum amount of bracing between the CRS and bench. • May increase leg-to-bench conflicts. • Some CRs have shorter seated area that may not have enough space for this approach. • Does not fully solve conflicts of fitting ATD in smaller convertible or RF-only CRS due to seated height of ATD • To our knowledge, method not used previously by CRS manufacturers
Adding mass to the CRABI 18MO to reach 15 kg.	• ATD has shorter seated height and may better represent toddlers who are heavy for their height. • Completely solves leg-to-bench issue.	• Current FMVSS No. 213 acceleration based criteria not relevant. • Need to develop a weight kit/procedure compatible with ATD • CRABI 18MO not a part 572 ATD

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Appendix A: Exploration of Alternate Rear-Facing Postures and Lower Extremity Modifications for the Hybrid III 3YO

Initial assessment of different rear-facing lower extremity postures for the Hybrid III 3YO

The lower extremities were positioned in five different postures currently being used by child restraint manufacturers and test labs. Overall, none of the postures led to different outcomes relevant to the child restraints meeting regulatory standards. The posture suggested in the report for future use is shown in Figure A1. This posture removes the knee stop from the lower extremities and places the lower extremities so they are elevated up on the seatback.

Figure A1. Elevated leg posture used with standard 3YO ATD, with knee stops removed.

Another “bent leg” posture was also evaluated in the initial test series as shown in Figure A2. This posture was anticipated to be one of the more common postures chosen by rear-facing children based on anecdotal experience. A potential issue with this posture was that it caused the dummy’s feet to put pressure on the buck seatback. This interaction made it challenging to achieve the correct pretest belt tension and child restraint seatback angle.

Figure A2. Bent leg posture evaluated in initial test series.

Modifying the 3YO ATD

After reviewing the volunteer data and identifying the most common postures, the 3YO ATD was placed in a rear-facing child restraint on the FMVSS No. 213 buck and an attempt was made to replicate these postures with the standard ATD. The "elevated" condition was not evaluated, as we had already tested this posture in the initial testing.

The main issue with the "relaxed" posture was that when the feet were placed against the bench seatback and knees bent, there was substantial force against the bench seatback. This could potentially affect the child restraint seatback angle during test setup, and this posture also made it difficult to achieve and maintain the correct belt tension with the child restraint installation. With the current ATD, installation was easier (and led to less force against the seatback) when the ATD legs were placed in an approximation of the frog leg (with knees drawn back to chest) or feet together (with knees pointing outwards) postures.

When considering potential modifications to the 3YO lower extremities to allow a more realistic rear-facing posture, we applied the following criteria:

- Avoid modifying the pelvis/thorax flesh if possible;
- Change as few parts as possible;
- Avoid flesh modifications near the top front of the thigh where the harness straps interact with the dummy if possible; and
- Avoid changes to improve rear-facing posture that affect response in forward-facing testing.

To explore possible changes to the 3YO ATD that might allow it to be positioned in one of these common postures seen in child volunteers more easily, the upper leg-form was scanned and a model made using a 3-D printer. This strategy was pursued because it is substantially less expensive and quicker than purchasing and modifying a standard dummy upper leg. Two different strategies were considered for increasing the range of motion of the 3YO thigh. One was to try modifying the contour of the flesh near the joint. Figure A3 shows how the thigh mold was tapered to allow greater range of motion.

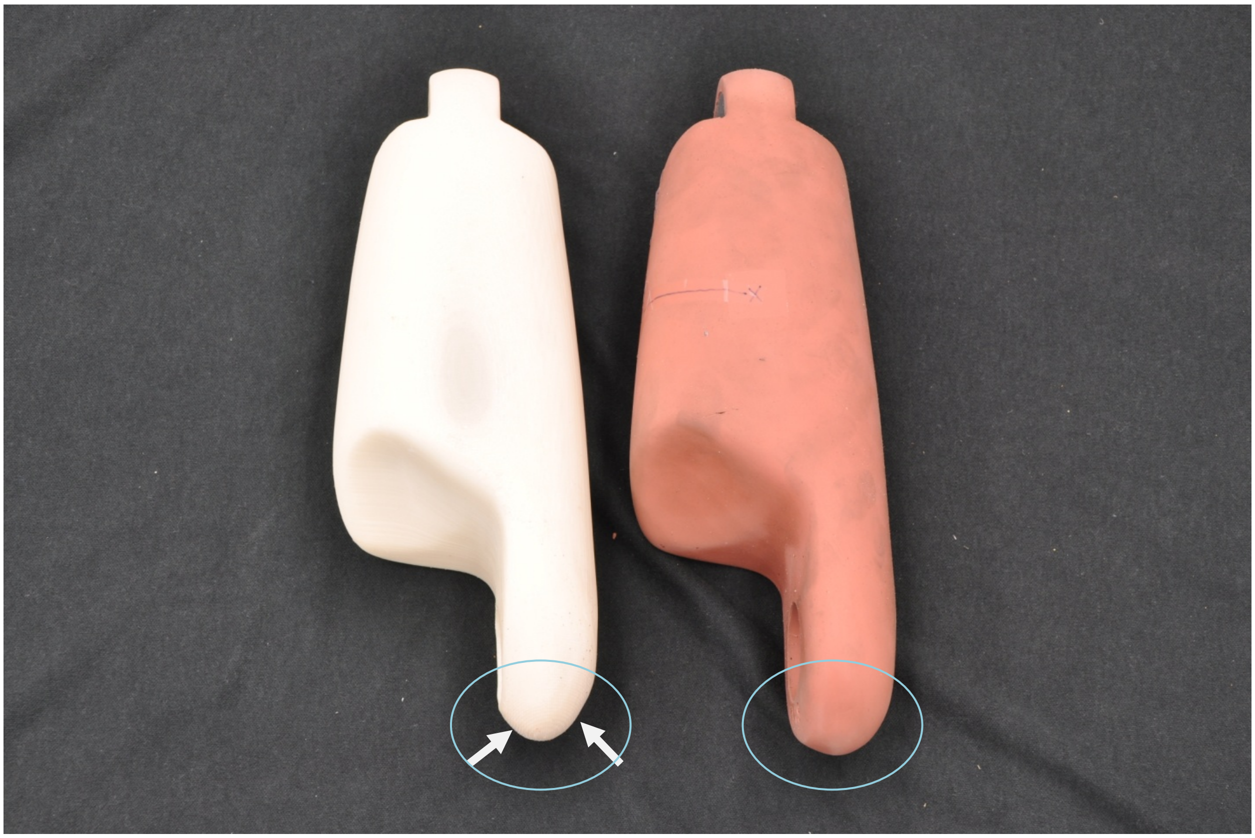


Figure A3. Modified thigh model (left) is more tapered than normal flesh on right.

The other strategy was replacing the hip joint consisting of a rubber cylinder with an off-the-shelf ball joint. Figure A4 shows exploded views of each joint.

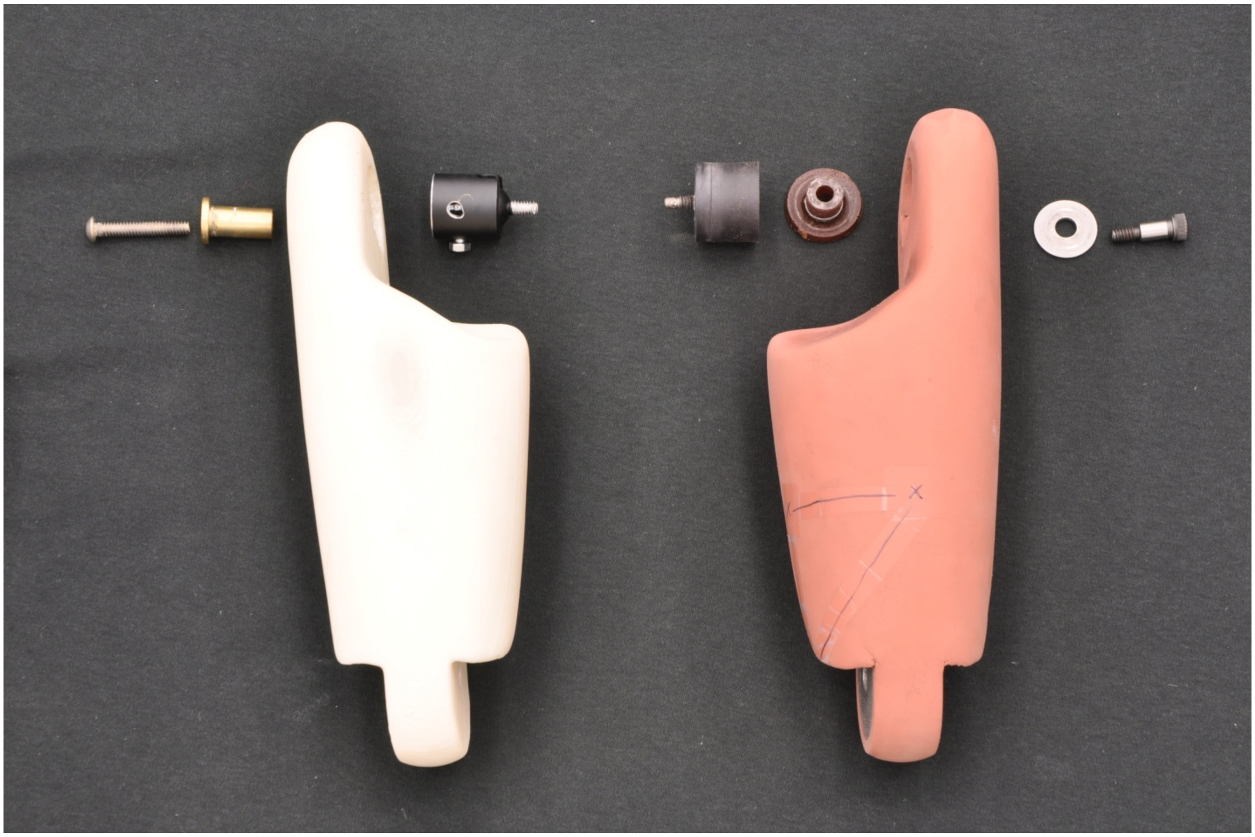


Figure A4. Ball joint (left) and standard joint (right).

Figure A5 shows the normal flesh and joint on the right, plus the normal joint and modified thigh model on the left. The additional range of motion from just reshaping the flesh is small. Figure A6 compares the modified thigh model used with a ball joint to the standard thigh and joint. The combined changes appear to allow greater potential for positioning the ATD's lower extremities in a more splayed posture. However, most of the increased range of motion came from the ball joint substitution rather than the flesh change.

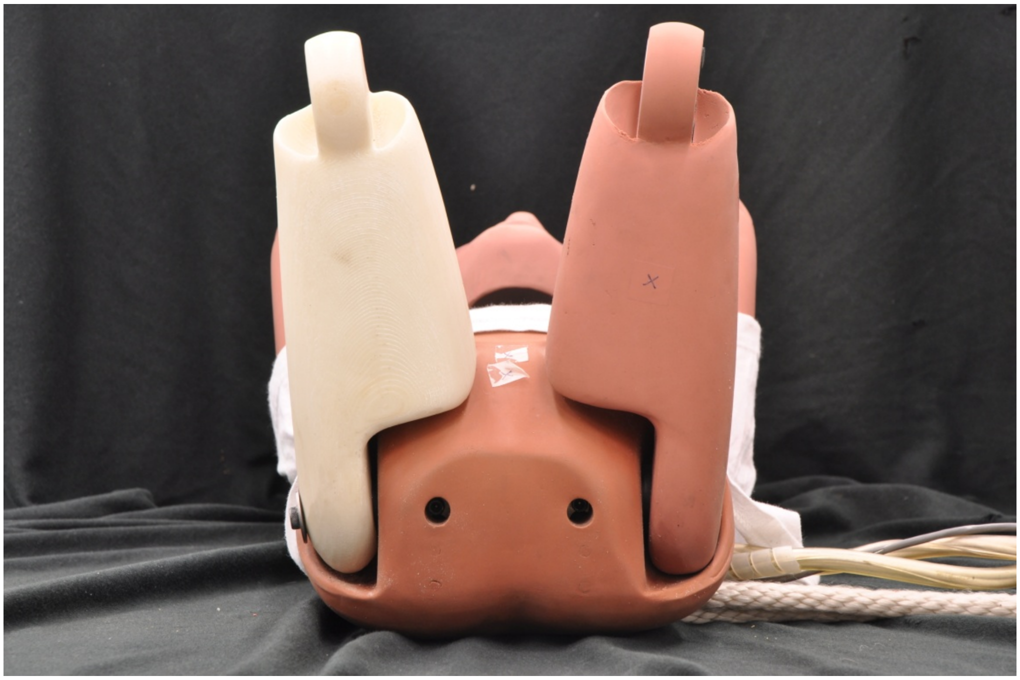


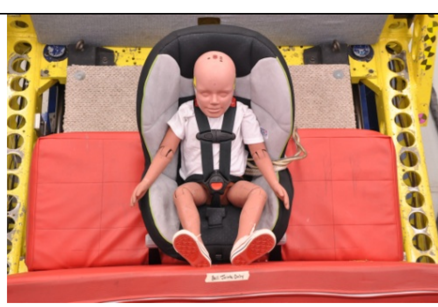
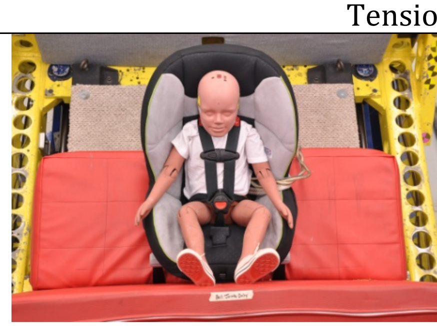
Figure A5. Modified thigh model compared to standard thigh, with standard joint used for each.

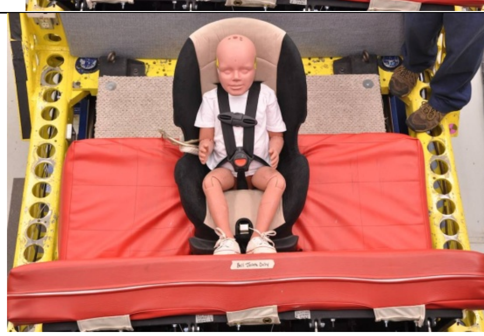
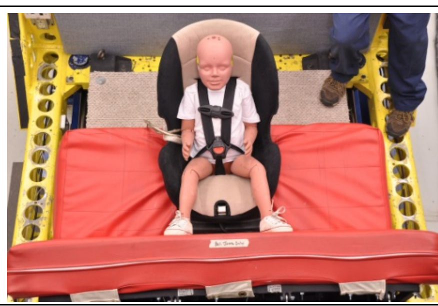
Figure A6. Modified thigh model with ball joint compared to standard thigh and standard joint.

Since changing the characteristics of the ATD joint rather than the leg flesh would be a much simpler, straightforward, and less expensive modification than redesigning the thigh flesh, the next step involved comparing the postures that could be achieved with the standard lower extremity joint to those that could be achieved with the ball joint. We tried to position the dummy in the most common postures seen in the children. Table A1 illustrates the postures with the modified joint on the left side and the standard joint on the right side, using three different child restraints and the FMVSS No. 213 sled buck. We were not able to position the ATD with feet together like the children commonly do, and the degree of splay seen in children was not possible with either type of hip joint.

When positioning the dummy on the FMVSS No. 213 buck, we first tightened the belt to 65 N to achieve an allowable angle. Then we placed the lower extremities in one of the trial postures. The belt tension in the trial posture was recorded. In many conditions, the belt tension was close to double. It would be possible to loosen the belt, achieve the correct tension, and probably still achieve the correct angle. However, loosening the belt to accommodate a new lower extremity position means that the child restraint installation would effectively be looser than testing performed with the 12MO, which has potential to affect relevant 213 outcomes.

Table A1. Summary of postures with ball joints and standard hip joints.

CRS 1 With proposed ball joints	**CRS 1 With standard hip joints**
Elevated Posture Could achieve 213 tensions of 65 N 	 Elevated Posture Could achieve 213 tensions of 65 N
Relaxed , Straight Belt Tensions up to 150 N 	 Relaxed, straight Belt Tensions up to 150 N
Relaxed, splayed Belt Tensions up to 120 N 	 Relaxed Splayed, Belt Tensions up to 120 N
Knees Out Belt Tensions up to 80 N. 	 Knees out Belt Tensions up to 75 N.
Knees out, feet apart Could achieve 213 belt tensions of 65 N. 	 Knees out, Feet apart Could achieve 213 belt tensions of 65 N.

CRS 2 With proposed ball joints	CRS 2 With standard hip joints
Elevated Posture Could achieve 213 tensions of 65 N 	 Elevated Posture Could achieve 213 belt tensions of 65 N.
Relaxed, straight, Belt Tensions up to 115 N 	 Relaxed, straight Belt Tensions up to 80 N
Relaxed, splayed Belt Tensions up to 110 N 	 Relaxed, splayed Belt Tensions up to 70 N
Knees out Belt Tensions up to 90 N. 	 Knees out Belt Tensions up to 75 N.
Knees out, feet apart Belt Tensions up to 90 N. 	 Knees out, feet apart Could achieve 213 tensions of 65 N.

CRS 3 With proposed ball joints	CRS 3 With standard hip joints
Elevated Could achieve 213 Tensions of 65 	 Elevated Could achieve 213 Tensions of 65
Relaxed, straight Belt Tensions up to 115 N 	 Relaxed, straight Belt Tensions up to 130 N
Relaxed, splayed Belt Tensions up to 80 N 	 Relaxed, splayed Belt Tensions up to 100 N
Knees out Belt  Tensions up to 75 N.	 Knees out Belt Tensions up to 75 N.
Knees out, feet apart. Could achieve 213 belt tension of 65 N. 	 Knees out, feet apart. Could achieve 213 belt tension of 65 N.

Performing this exercise led to the following conclusions:

- When seated rear-facing in a child restraint, there was not a noticeable difference in the amount of splay achieved with the standard hip joint or the proposed ball hip joint, even though there was a considerable difference observed in the lab on a tabletop. The shape of the child restraint does not allow greater motion in the direction the ball joint allows.
- When comparing different postures, the legs elevated or the knees out, feet apart conditions cause the fewest problems in achieving the belt tension specified in FMVSS No. 213.

The elevated legs posture was evaluated in the initial test series (Manary et al. 2013). Compared to the bent leg posture evaluated in the initial test series, the *knees out, feet apart* (KOFA) condition has the knees somewhat more splayed and the feet farther apart.

Comparison to Child Postures

The KOFA posture could be achieved with the current dummy and would fall within the general category of "relaxed" used to describe rear-facing child volunteer postures. However, we wanted to confirm that the particular orientation of lower extremities that could be achieved with the current dummy was selected by some of the child volunteers. The time-lapse video was reviewed to compare to the KOFA posture used with the dummies. As shown in Figure A7, we could identify a posture resembling the KOFA posture sometime throughout the session for at least 18 of the 29 subjects. Reviewing the previously categorized data indicates that 18 subjects chose the legs elevated posture during the course of the rear-facing test session.

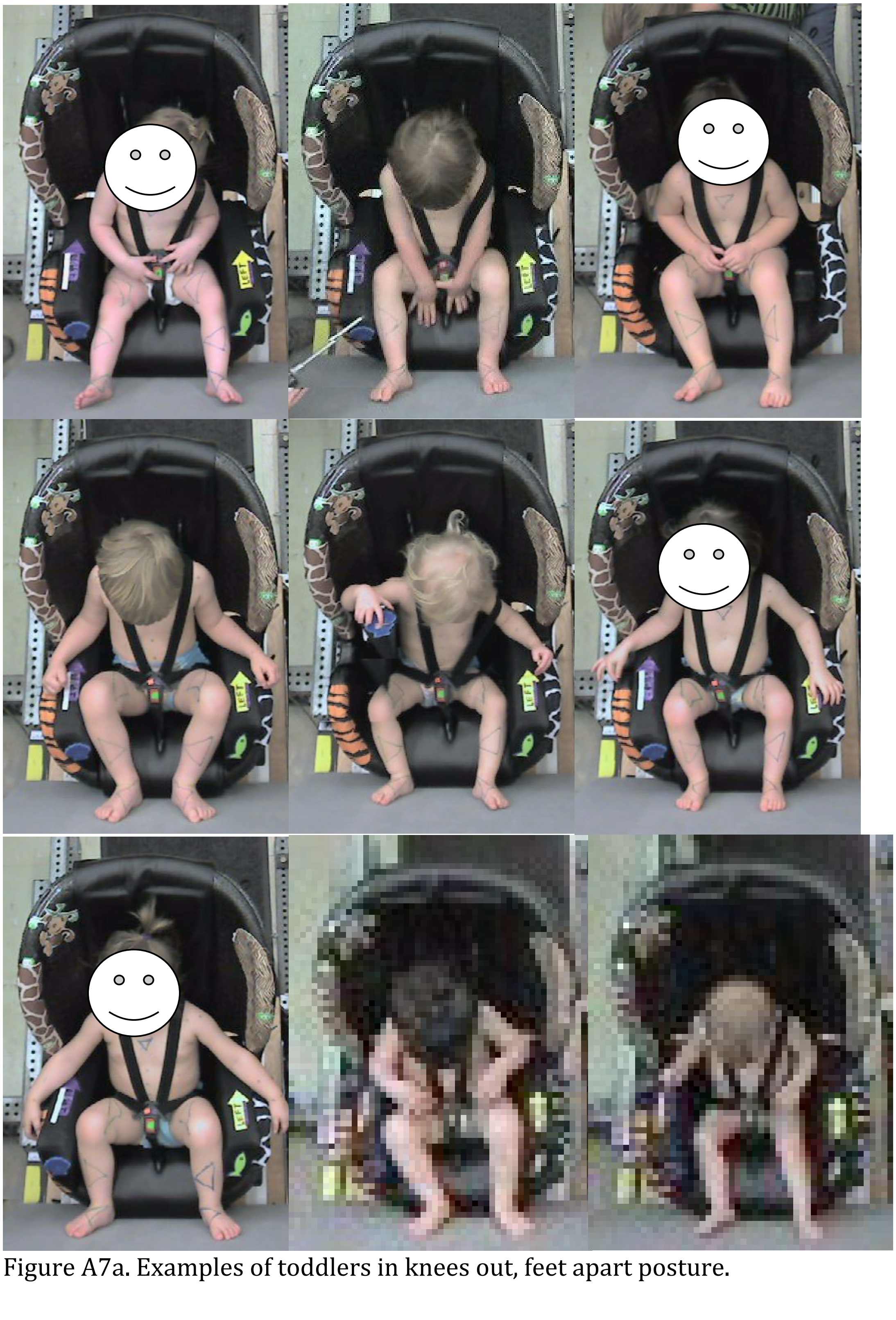


Figure A7a. Examples of toddlers in knees out, feet apart posture.

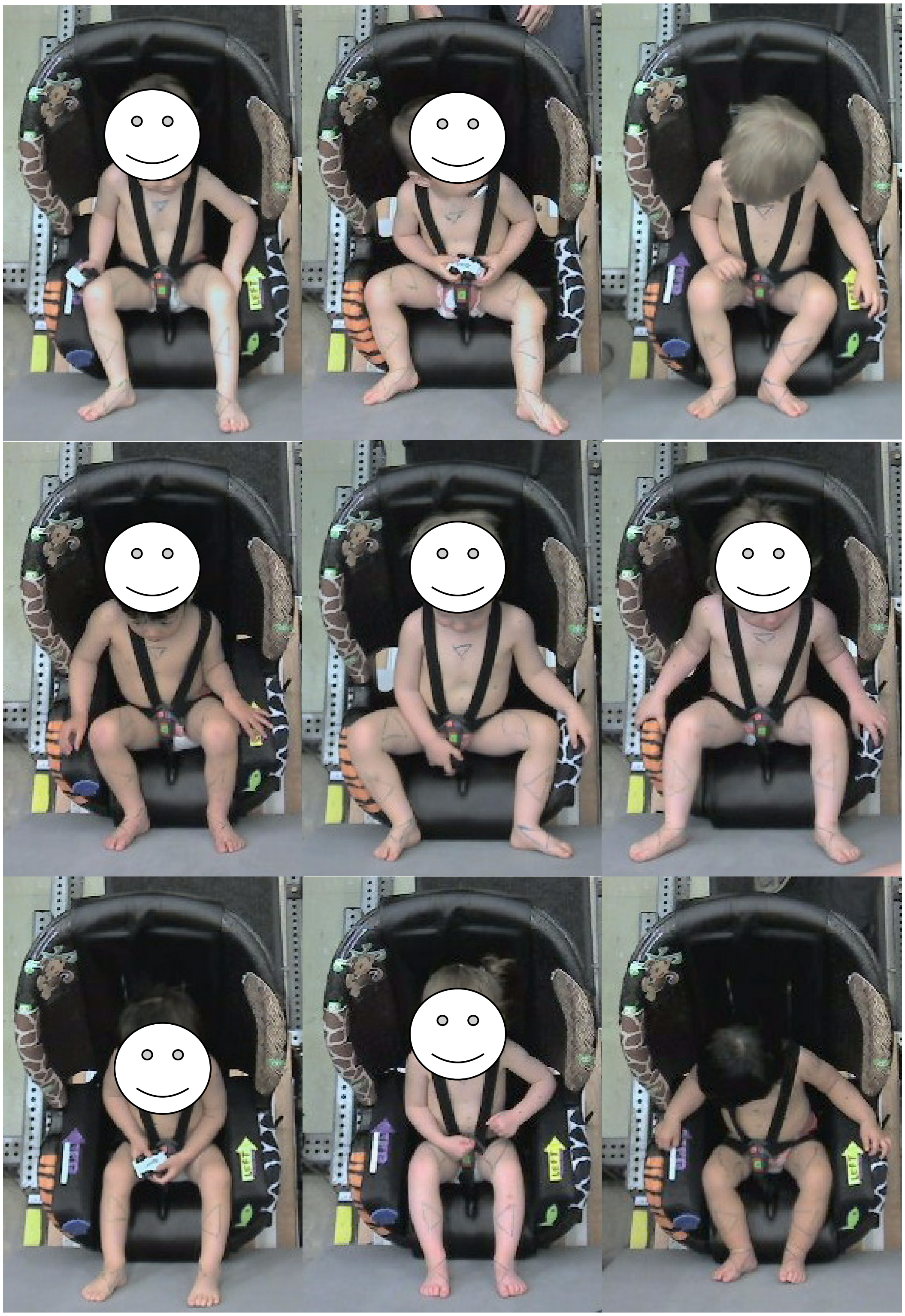


Figure A7b. Examples of toddlers in knees out, feet apart posture.

Decisions about possible modifications to 3YO

The lower extremity postures that can be achieved with the current 3YO dummies do not exhibit the range of motion seen in toddler volunteers. However, some of the postures that can be achieved with the current dummy are reasonable compared to postures seen in the child volunteers.

In discussions with NHTSA that occurred in September 2013, we recommended against pursuing further changes to the 3YO ATD to increase the range of motion of its hip joints. Achieving greater range of motion would require modifications to the pelvis/torso flesh, and additional testing to determine the effect of changes on evaluating forward-facing harnessed child restraints. Given that some of the postures that can be achieved with the current dummy are realistic, we do not think this endeavor would be worth the additional time and expense needed. During the discussions, the consensus was to propose that rear-facing child restraints be tested using the elevated leg position evaluated in the earlier series of tests performed for this project.

Appendix B: Modifications in TP-213-09 Associated With Each Test Condition

Condition A – Baseline - No Changes.

12.D.4.2 PRETEST CONDITIONING - THREE-YEAR-OLD DUMMY (S213, S9)

Calibrate the three-year-old dummy according to the requirements of 49 CFR Part 572, Subpart P as described in Appendix D of this procedure. Calibrations are performed prior to the start of the compliance test program, after an apparent noncompliance (as described by the COTR), after 30 tests, or if the dummy has been in storage for thirty days or more during the testing program.

Prior to testing, condition the three-year-old dummy at any ambient temperature from 20.6°C to 22.2°C and at any relative humidity from 10 percent to 70 percent, for at least 4 hours.

…

12.D.5.12 DUMMY INSTALLATION

THREE-YEAR-OLD AND SIX-YEAR-OLD DUMMY (S213, S10.2.2)

Position the test dummy according to the instructions for child positioning that the restraint manufacturer provided with the system.

. (1) Holding the test dummy torso upright until it contacts the system’s design seating surface, place the test dummy in the seated position within the system with the midsagittal plane of the test dummy head—

. (A) Coincident with the center SORL of the standard seating assembly, in the case of the add-on child restraint system, or

. (B) Vertical and parallel to the longitudinal centerline of the specific vehicle, in the case of a built-in child restraint system.

. (2) Extend the arms of the test dummy as far as possible in the upward vertical direction. Extend the legs of the dummy as far as possible in the forward horizontal direction, with the dummy feet perpendicular to the centerline of the lower legs.

. (3) Using a flat square surface with an area of 2580 square millimeters (4 square inches), apply a force of 178 N (40 lbs), perpendicular to:

. (A) The plane of the back of the standard seat assembly, in the case of an add-on system, or

. (B) The back of the vehicle seat in the specific vehicle shell or the specific vehicle, in the case of a built-in system, first against the dummy crotch and then at the dummy thorax in the midsagittal plane of the dummy. For a child restraint system with a fixed or movable surface, which is being tested under the conditions of test configuration II, do not attach any of the child restraint belts unless they are an integral part of the fixed or movable surface. For all other child restraint systems and for a child restraint system with a fixed or movable surface, which is being, tested under the conditions of test configuration I, attach all appropriate child restraint belts and tighten them as specified in S6.1.2. Attach all appropriate vehicle belts and tighten them as specified in S6.1.2. Position each movable surface in accordance with the instructions that the manufacturer provided.

Condition B – Knee Joint-Stops Removed - Changes underlined

12.D.4.2 PRETEST CONDITIONING THREE -YEAR-OLD DUMMY (S213, S9)

Calibrate the three-year-old dummy according to the requirements of 49 CFR Part 572, Subpart P as described in Appendix D of this procedure. Calibrations are performed prior to the start of the compliance test program, after an apparent noncompliance (as described by the COTR), after 30 tests, or if the dummy has been in storage for thirty days or more during the testing program.

Prior to testing, condition the three-year-old dummy at any ambient temperature from 20.6°C to 22.2°C and at any relative humidity from 10 percent to 70 percent, for at least 4 hours. When ATD will be used to test a rear-facing child restraint, remove knee stop bolts in each knee.

12.D.5.12 DUMMY INSTALLATION - RESTRAINTS OTHER THAN CAR BEDS

THREE-YEAR-OLD AND SIX-YEAR-OLD DUMMY (S213, S10.2.2)

Position the test dummy according to the instructions for child positioning that the restraint manufacturer provided with the system.

. (1) Holding the test dummy torso upright until it contacts the system's design seating surface, place the test dummy in the seated position within the system with the midsagittal plane of the test dummy head—

. (A) Coincident with the center SORL of the standard seating assembly, in the case of the add-on child restraint system, or

. (B) Vertical and parallel to the longitudinal centerline of the specific vehicle, in the case of a built-in child restraint system.

. (2) Extend the arms of the test dummy as far as possible in the upward vertical direction. Extend the legs of the dummy as far as possible in the forward horizontal direction, with the dummy feet perpendicular to the centerline of the lower legs.

. (3) Using a flat square surface with an area of 2580 square millimeters (4 square inches), apply a force of 178 N (40 lbs), perpendicular to:

. (A) The plane of the back of the standard seat assembly, in the case of an add-on system, or

. (B) The back of the vehicle seat in the specific vehicle shell or the specific vehicle, in the case of a built-in system, first against the dummy crotch and then at the dummy thorax in the midsagittal plane of the dummy. For a child restraint system with a fixed or movable surface, which is being tested under the conditions of test configuration II, do not attach any of the child restraint belts unless they are an integral part of the fixed or movable surface. For all other child restraint systems and for a child restraint system with a fixed or movable surface, which is being, tested under the conditions of test configuration I, attach all appropriate child restraint belts and tighten them as specified in S6.1.2. Attach all appropriate vehicle belts and tighten them as specified in S6.1.2. Position each movable surface in accordance with the instructions that the manufacturer provided.

Condition C – Shank Removed - Changes underlined

12.D.4.2 PRETEST CONDITIONING THREE -YEAR-OLD DUMMY (S213, S9)

Calibrate the three-year-old dummy according to the requirements of 49 CFR Part 572, Subpart P as described in Appendix D of this procedure. Calibrations are performed prior to the start of the compliance test program, after an apparent noncompliance (as described by the COTR), after 30 tests, or if the dummy has been in storage for thirty days or more during the testing program.

Prior to testing, condition the three-year-old dummy at any ambient temperature from 20.6°C to 22.2°C and at any relative humidity from 10 percent to 70 percent, for at least 4 hours. When ATD will be used to test a rear-facing child restraint, remove lower leg at the ATD knee.

12.D.5.12 DUMMY INSTALLATION - RESTRAINTS OTHER THAN CAR BEDS

THREE-YEAR-OLD AND SIX-YEAR-OLD DUMMY (S213, S10.2.2)

Position the test dummy according to the instructions for child positioning that the restraint manufacturer provided with the system.

. (1) Holding the test dummy torso upright until it contacts the system's design seating surface, place the test dummy in the seated position within the system with the midsagittal plane of the test dummy head—

. (A) Coincident with the center SORL of the standard seating assembly, in the case of the add-on child restraint system, or

. (B) Vertical and parallel to the longitudinal centerline of the specific vehicle, in the case of a built-in child restraint system.

. (2) Extend the arms of the test dummy as far as possible in the upward vertical direction. Extend the legs of the dummy as far as possible in the forward horizontal direction, with the dummy feet perpendicular to the centerline of the lower legs.

. (3) Using a flat square surface with an area of 2580 square millimeters (4 square inches), apply a force of 178 N (40 lbs), perpendicular to:

. (A) The plane of the back of the standard seat assembly, in the case of an add-on system, or

. (B) The back of the vehicle seat in the specific vehicle shell or the specific vehicle, in the case of a built-in system, first against the dummy crotch and then at the dummy thorax in the midsagittal plane of the dummy. For a child restraint system with a fixed or movable surface, which is being tested under the conditions of test configuration II, do not attach any of the child restraint belts unless they are an integral part of the fixed or movable surface. For all other child restraint systems and for a child restraint system with a fixed or movable surface, which is being, tested under the conditions of test configuration I, attach all appropriate child restraint belts and tighten them as specified in S6.1.2. Attach all appropriate vehicle belts and tighten them as specified in S6.1.2. Position each movable surface in accordance with the instructions that the manufacturer provided.

Condition D– Shank Removed and Attached to Upper Leg - Changes underlined

12.D.4.2 PRETEST CONDITIONING THREE -YEAR-OLD DUMMY (S213, S9)

Calibrate the three-year-old dummy according to the requirements of 49 CFR Part 572, Subpart P as described in Appendix D of this procedure. Calibrations are performed prior to the start of the compliance test program, after an apparent noncompliance (as described by the COTR), after 30 tests, or if the dummy has been in storage for thirty days or more during the testing program.

Prior to testing, condition the three-year-old dummy at any ambient temperature from 20.6°C to 22.2°C and at any relative humidity from 10 percent to 70 percent, for at least 4 hours. When ATD will be used to test a rear-facing child restraint, remove lower leg at the ATD knee and tape lengthwise to the anterior surface of the ATD thigh/upper leg.

12.D.5.12 DUMMY INSTALLATION - RESTRAINTS OTHER THAN CAR BEDS

THREE-YEAR-OLD AND SIX-YEAR-OLD DUMMY (S213, S10.2.2)

Position the test dummy according to the instructions for child positioning that the restraint manufacturer provided with the system.

. (1) Holding the test dummy torso upright until it contacts the system's design seating surface, place the test dummy in the seated position within the system with the midsagittal plane of the test dummy head—

. (A) Coincident with the center SORL of the standard seating assembly, in the case of the add-on child restraint system, or

. (B) Vertical and parallel to the longitudinal centerline of the specific vehicle, in the case of a built-in child restraint system.

. (2) Extend the arms of the test dummy as far as possible in the upward vertical direction. Extend the legs of the dummy as far as possible in the forward horizontal direction, with the dummy feet perpendicular to the centerline of the lower legs.

. (3) Using a flat square surface with an area of 2580 square millimeters (4 square inches), apply a force of 178 N (40 lbs), perpendicular to:

. (A) The plane of the back of the standard seat assembly, in the case of an add-on system, or

. (B) The back of the vehicle seat in the specific vehicle shell or the specific vehicle, in the case of a built-in system, first against the dummy crotch and then at the dummy thorax in the midsagittal plane of the dummy. For a child restraint system with a fixed or movable surface, which is being tested under the conditions of test configuration II, do not attach any of the child restraint belts unless they are an integral part of the fixed or movable surface. For all other child restraint systems and for a child restraint system with a fixed or movable surface, which is being, tested under the conditions of test configuration I, attach all appropriate child restraint belts and tighten them as specified in S6.1.2. Attach all appropriate vehicle belts and tighten them as specified in S6.1.2. Position each movable surface in accordance with the instructions that the manufacturer provided.

Condition E– Bent knee posture- Changes underlined

12.D.4.2 PRETEST CONDITIONING THREE-YEAR-OLD DUMMY (S213, S9)

Calibrate the three-year-old dummy according to the requirements of 49 CFR Part 572, Subpart P as described in Appendix D of this procedure. Calibrations are performed prior to the start of the compliance test program, after an apparent noncompliance (as described by the COTR), after 30 tests, or if the dummy has been in storage for thirty days or more during the testing program.

Prior to testing, condition the three-year-old dummy at any ambient temperature from 20.6°C to 22.2°C and at any relative humidity from 10 percent to 70 percent, for at least 4 hours

12.D.5.12 DUMMY INSTALLATION - RESTRAINTS OTHER THAN CAR BEDS

THREE-YEAR-OLD AND SIX-YEAR-OLD DUMMY (S213, S10.2.2)

Position the test dummy according to the instructions for child positioning that the restraint manufacturer provided with the system.

. (1) Holding the test dummy torso upright until it contacts the system's design seating surface, place the test dummy in the seated position within the system with the midsagittal plane of the test dummy head—

. (A) Coincident with the center SORL of the standard seating assembly, in the case of the add-on child restraint system, or

. (B) Vertical and parallel to the longitudinal centerline of the specific vehicle, in the case of a built-in child restraint system.

. (2) Extend the arms of the test dummy as far as possible in the upward vertical direction. Extend the legs of the dummy as far as possible in the forward horizontal direction, with the dummy feet perpendicular to the centerline of the lower legs. <u>Bend the legs of the ATD at the knee as far as possible without incurring significant interaction with the CRS. Then orient the ATD feet to fully contact the seatback of the 213 bench.</u>

. (3) Using a flat square surface with an area of 2580 square millimeters (4 square inches), apply a force of 178 N (40 lbs), perpendicular to:

. (A) The plane of the back of the standard seat assembly, in the case of an add-on system, or

. (B) The back of the vehicle seat in the specific vehicle shell or the specific vehicle, in the case of a built-in system, first against the dummy crotch and then at the dummy thorax in the midsagittal plane of the dummy. For a child restraint system with a fixed or movable surface, which is being tested under the conditions of test configuration II, do not attach any of the child restraint belts unless they are an integral part of the fixed or movable surface. For all other child restraint systems and for a child restraint system with a fixed or movable surface, which is being, tested under the conditions of test configuration I, attach all appropriate child restraint belts and tighten them as specified in S6.1.2. Attach all appropriate vehicle belts and tighten them as specified in S6.1.2. Position each movable surface in accordance with the instructions that the manufacturer provided.

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Condition F– Weighted CRABI 18 Month – Followed CRABI-12

12.D.4.2 PRETEST CONDITIONING TWELVE-MONTH-OLD DUMMY (S213, S9)

Calibrate the twelve-month-old dummy according to the requirements of 49 CFR Part 572, Subpart R as described in Appendix E of this procedure. Calibrations are performed prior to the start of the compliance test program, after an apparent noncompliance (as described by the COTR), after 30 tests, or if the dummy has been in storage for thirty days or more during the testing program.

Prior to testing, condition the twelve-month-old dummy at any ambient temperature from 20.6°C to 22.2°C and at any relative humidity from 10 percent to 70 percent, for at least 4 hours.

Wrap and tape lead sheets to the ATD torso to add mass symmetrically to reach 15 kg

12.D.5.12 DUMMY INSTALLATION - RESTRAINTS OTHER THAN CAR BEDS

NEWBORN DUMMY AND TWELVE-MONTH-OLD DUMMY (S213, S10.2.1)

Position the test dummy according to the instruction for child positioning that the manufacturer provided with the system.

When testing forward-facing child restraint systems, holding the twelve-month- old test dummy torso upright until it contacts the system's design seating surface, place the twelve-month-old test dummy in the seated position within the system with the midsagittal plane of the dummy head:

(1) Coincident with the center SORL of the standard seating assembly, in the case of the add-on child restraint system, or

(2) Vertical and parallel to the longitudinal centerline of the specific vehicle shell or the specific vehicle, in the case of a built-in child restraint system.

When testing rear-facing child restraint systems, place the newborn or twelve- month-old dummy in the child restraint system so that the back of the dummy torso contacts the back support surface of the system. For a child restraint system which is equipped with a fixed or movable surface and which is being tested under the conditions of test configuration II, do not attach any of the child restraint belts unless they are an integral part of the fixed or movable surface. For all other child restraint systems and for a child restraint system with a fixed or movable surface which is being tested under the conditions of Test Configuration I, attach all appropriate child restraint belts and tighten them as specified in S6.1.2. Attach all appropriate vehicle belts and tighten them as specified in S6.1.2. Position each movable surface in accordance with the instruction that the manufacturer provided under S5.6.1 or S5.6.2. If the dummy's head does not remain in the proper position, it shall be taped against the front of the seat back surface of the system by means of a single thickness of 6 mm (1/4 inch) wide paper masking tape placed across the center of the dummy's face.

When testing forward-facing child restraint systems, extend the arms of the twelve-month-old test dummy as far as possible in the upward vertical direction. Extend the legs of the twelve-month-old dummy as far as possible in the forward horizontal direction, with the dummy feet perpendicular to the centerline of the lower legs. Using a flat surface with an area of 2580 square mm (4 square in), apply a force of 178 N (40 lbs), perpendicular to:

. (1) The plane of the back of the standard seat assembly, in the case of an add-on system, or

. (2) The back of the vehicle seat in the specific vehicle shell or the specific vehicle, in the case of a built-in system.

Apply the force first against the dummy crotch and then at the dummy thorax in the midsagittal plane of the dummy.

For a child restraint system with a fixed or movable surface, which is being tested under the conditions of test configuration II, do not attach any of the child restraint belts unless they are an integral part of the fixed or movable surface.

For all other child restraint systems and for a child restraint system with a fixed or movable surface, which is being, tested under the conditions of test configuration I, attach all appropriate child restraint belts and tighten them as specified in S6.1.2. Attach all appropriate vehicle belts and tighten them as specified in S6.1.2. Position each movable surface in accordance with the instructions that the manufacturer provided.

When testing rear-facing child restraints, extend the dummy's arms vertically upwards and then rotate each arm downward toward the dummy's lower body until the arm contacts a surface of the child restraint system or the standard seat assembly in the case of an add-on child restraint system, or the specific vehicle shell or the specific vehicle, in the case of a built-in child restraint system. Ensure that no arm is restrained from movement in other than the downward direction, by any part of the system or the belts used to anchor the system to the standard seat assembly, the specific shell, or the specific vehicle.

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