Child Passenger Safety Issues Arising from Research Findings

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I. Introduction

This paper describes several child passenger safety issues arising from research findings:

a) The National Highway Traffic Safety Administration (NHTSA) is aware of and has reviewed research reports on certain kinds of child restraints systems (CRSs), CRSs not yet widely available in the U.S., that raise concerns about the ability of these CRSs to effectively protect children in real world situations. The CRSs in question are inflatable booster seats and “shield-type” child restraints emerging in markets overseas.

b) Some infant carriers are marketed as suitable for children up to 13.6 kilograms (kg) (30 pounds (lb)), which is greater than the weight of a 95th percentile 1-year-old (YO) and an -average 1.5 YO, but many of these carriers cannot “fit” the height of a 95th percentile 1 YO or an average 1.5 YO.[1]

c) NHTSA has supported the development of computer models of children of different weights and heights to assist CRS manufacturers in designing child restraints that better fit the children for whom the CRS is recommended.[2] These virtual models are available to the public to improve the fit of CRSs to children.[3]

II. Issues Arising from Research Findings

a. Inflatable Boosters and “Shield-Only” CRSs

The performance of inflatable boosters and “shield-only” CRSs in research settings has raised NHTSA’s concerns about the satisfactory performance of these CRSs in real world situations.

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[1] Field experience indicates that children at the higher end of growth charts typically outgrow the carriers by height at around 9-10 months.

[2] NHTSA has sponsored an UMTRI project developing toddler virtual dummies for use in improving of the fit of CRSs to child passengers. Information on a 2015 UMTRI workshop describing development of the toddler virtual fit dummies can be found at: http://umtri.umich.edu/our-results/projects/umtri-workshop-new-tools-child-occupant-protection.

[3] Toddler virtual models available for download at: http://childshape.org/toddler/manikins/

1. Inflatable Boosters

Inflatable boosters entered the U.S. market in 2011 with the “Bubble Bum,” later with the “Go Booster,[4]” and more recently the Hiccapop UberBoost which, to NHTSA’s knowledge, are the only inflatable CRSs in the U.S. Inflatable boosters are marketed as CRSs that are foldable, portable, and convenient for short-term and temporary trips involving touring, carpooling and taxi rides. Inflatable booster seats met Federal Motor Vehicle Safety Standards (FMVSS) No. 213, “Child restraint systems,” requirements when tested by NHTSA on the current standard seat assembly and the proposed updated standard seat assembly.[5]

However, safety concerns associated with the boosters have been raised in areas not regulated by FMVSS No. 213. Tests conducted by Transport Canada revealed significant submarining of the Hybrid III (HIII)-6YO and HIII-10YO test dummies in 40 – 48 kilometers per hour (km/h) (25-30 miles per hour (mph)) frontal impact vehicle crash tests.[6] The inflatable boosters excessively compressed when subjected to the forces generated by the restrained HIII-6YO dummy, shifting the dummy’s pelvis forward and under the lap belt portion of the seat belt and lodging the lap belt high into the abdomen of the dummy.[7]

Transport Canada has a quasi-static compression test for evaluating the firmness of the seating surface of booster seats. The test ensures that a child seated on a booster seat would be sufficiently elevated in a crash to enable an adequate fit of the vehicle seat belts. According to this Canada Motor Vehicle Safety Standard (CMVSS) No. 213, “Child restraint systems,” requirement, the seating surface of a booster seat must not deflect more than 25 mm when subjected to a 2,250 N quasi static force with a displacement rate between 50 and 500 mm/s. The load is applied with a flat circular contact area with a 203-mm diameter on the upper seating surface of the booster seats. Inflatable booster seats have not been introduced into the Canadian market, because they do not meet the quasi-static compression test specified in CMVSS No. 213.

[4] No longer available for sale in the U.S.

[5] The Insurance Institute for Highway Safety (IIHS) also rates the Bubble Bum booster seat as a “Best Bet” in IIHS’s booster evaluations for 2015. A “Best Bet” rating by IIHS means that the booster seat provides good shoulder belt fit for typical 4- to 8-year-olds in almost any car, minivan or SUV. IIHS’s booster evaluations only evaluate belt fit in a static environment, not in a dynamic environment.

[6] “Submarining” refers to the tendency for a restrained occupant to slide forward feet first under the lap belt during a vehicle crash, which could result in serious abdominal, pelvic, and spinal injuries.

[7] NHTSA has docketed the reports documenting Transport Canada’s vehicle crash tests using the Bubble Bum and Go Booster inflatable models with the HIII-6YO and -10YO. The reports show how the booster seats are compressed by the weight of the dummy during the crash. Most of the tests with inflatable boosters show excessive forward shifting of the pelvis and a lap belt riding up into the abdomen of the dummy. The reports are available in the docket NHTSA-2020-0093 for the 2020 NPRM to update FMVSS No. 213.

NHTSA seeks comment on the performance of the inflatable booster seats in the research tests conducted in Canada. NHTSA is concerned that FMVSS No. 213's current child dummies and performance criteria are unable to detect the submarining and risk of abdominal injury exhibited in the Transport Canada vehicle tests. NHTSA seeks comment on the quasi-static compression test requirements for booster seats in Canada as an alternative approach to mitigate submarining of children restrained in booster seats.

2. Shield-Only CRSs

The U.S. currently has no CRSs that use only a shield to restrain a young child's upper torso, lower torso and crotch.[8] We refer to these as "shield-only CRSs". In the 1990s, prior to the emergence of Type 2 (lap/shoulder) belts in vehicle rear seating positions and of belt-positioning boosters specially designed for Type 2 belts, booster seats with shields were common. They were made for use with a vehicle lap belt that the parent would route over and around the shield in front of the child.[9] Yet, even when shield boosters were popular, the agency prevented the boosters from being sold for children weighing under 13.6 kg (30 lb) (S5.5.2(f)).

Today, the European market has a wide variety of shield-only CRS models for children weighing less than 13.6 kg (30 lb) and the CRSs are gaining in popularity. One reason for the popularity of this type of CRSs may result from their "good" ratings in consumer ratings programs (e.g., those of Stiftung Warentest and the German Automobile Club (ADAC)).[10] ADAC performs simulated 64 km/h frontal and 50 km/h side impacts in a four-door vehicle bodyshell mounted to a test sled using different sized dummies in CRSs. The CRSs are also relatively less expensive than harnessed-CRSs. While shield-only CRS models have good ratings in the ADAC rating system, ADAC test configurations do not replicate an environment

[8] NHTSA knows of only the Kiddy World Plus produced by Kiddy USA, Inc. which was available in the U.S. market from 2013-2016, http://www.kiddyusa.com/kiddy-seats/kiddy-world-plus.html . Kiddy recommends the child restraint be used with its "protection shield" with children 10 to 18 kg (22 to 40 lb).

[9] In the 2000s shield boosters were replaced in the market by belt-positioning boosters, which were believed to be more protective than shield boosters. Belt-positioning boosters were found to be capable of accommodating a wider range of child sizes than shield boosters, and performed better with a Type 2 belt than shield boosters with a Type 2 belt.

[10] Visvikis, C., et al., "Evaluation of shield and harness systems in frontal impact sled experiments," TRL, UK. Johannsen, H., Beillas, P., Lesire, P. "Analysis of the performance of different architectures of forward facing CRSs with integral restraint system," International Technical Conference on the Enhanced Safety of Vehicles Conference, Seoul, Republic of Korea, 2013, Paper 13-0226.

where shield-only CRSs are more prone to have ejections, such as rollover tests and frontal offset tests.

Several studies conducted to evaluate the performance of shield-only CRSs found evidence of an ejection risk in some moderate-to-severe crash scenarios when used with ATDs representing small children.

UTAC CERAM[11] and Transport Canada collaborated to investigate the performance of shield-only CRSs in tests simulating rollover and frontal crashes using the HIII-3YO dummy and a European Q series 3YO child (Q3) dummy.[12] The UTAC tests, simulating a rollover crash, consisted of a moving floor tilted at 23 degrees and the vehicle on the floor with its longitudinal axis perpendicular to the direction of motion of the floor. The floor was accelerated to 48 km/h (30 mph) prior to being quickly decelerated from 48 km/h (30 mph) to 0 km/h, resulting in the vehicle rolling off the tilted floor. Two vehicles were tested. Vehicle 1 had a Q3 dummy restrained on the left rear seating position in a shield-only CRS and a Q3 dummy restrained on the right rear position with a harnessed-CRS. Vehicle 2 had an HIII-3YO dummy in the left rear seating position in a shield-only CRS and a Q3 dummy in the right rear position in a shield-only CRS. All the CRSs in both vehicles were attached to the vehicle using a seat belt and tether. Vehicle 1 had two full rotations (8 quarter-turns) and Vehicle 2 had two and a half rotations (10 quarter-turns) during the test.[13]

The shield-only CRSs could not retain the dummies. In the rollover test with Vehicle 1, the Q3 dummy in the shield-only CRS partially ejected from the child restraint while the Q3 dummy in the harnessed-CRS was well restrained in its CRS. In the Vehicle 2 rollover test, the HIII-3YO dummy in the shield-only CRS partially ejected from the CRS and the Q3 in the shield-only CRS fully ejected from the child restraint. In both vehicle tests, the ejections occurred during the second revolution of the rollover sequence.

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[11] UTAC CERAM is a private, independent group providing services in all areas of land transport, including regulation and approval, testing and technical expertise (environment, safety, durability and reliability), certification, and driver training.
[12] Tylko, S., Bussières, A., Lepretre, J.P. "Comparison of Hybrid III and Q series Child ATDs for the Evaluation of Child Restraint Performance During Dynamic Rollovers." The Protection of Children in Cars, Munich, Germany, December 2013, available in the docket for the 2020 NPRM to upgrade FMVSS No. 213.
[13] While the crashes were severe, they were representative of a deadly rollover crash. According to NASS Crashworthiness Data System data of occupants exposed to a rollover crash from 2000 to 2009, half of all fatal complete ejections occurred in crashes with 6 or more quarter-turns.

In the Transport Canada tests, Transport Canada observed ejections of dummies restrained in shield boosters in two 40 percent frontal offset crash tests conducted at a 48 km/h (30 mph) impact speed which imposed both longitudinal and lateral accelerations on the dummy. One test involved a Q series 18-month-old child (Q1.5) dummy[14] restrained in a shield-only CRS, while the other involved a CRABI-18MO in a shield-only CRS. Both dummies were partially ejected from the child restraint towards the inboard side of the vehicle.

NHTSA is also aware of a study by the United Kingdom's Transportation Research Laboratory (TRL) (Visvikis et al.[15]) that found evidence of ejection risk associated with shield-only CRSs. TRL conducted eighteen frontal impact sled tests using the ECE R.44/R.129 standard seat assembly and test conditions replicating an ADAC child restraint sled test.[16] The change in velocity of the sled was 64 km/h (40 mph) with a 40 g peak acceleration. Three harnessed-CRSs and five shield-only CRSs were tested with the Q1.5 dummy. Five harnessed-CRSs and five shield-only CRSs were tested with the Q3 dummy.

TRL found that the kinematics of ATDs in the harnessed-CRSs and shield-only CRSs were similar during the loading phase but not in the rebound phase of the test. During rebound the dummy tended to ride up the back of the CRS. The shoulder belts of the harnessed-CRS limited this ride up and adequately restrained the dummy, but for shield-only CRSs, the ride up was constrained by the top of the dummy's legs contacting the underside of the shield component. One shield-only CRS partially ejected the Q1.5 and Q3 dummies in the tests. A full ejection of the Q1.5 dummy was prevented only by the ATD's feet engaging the shield of the CRS. Since the dummies' legs are stiffer than a child's, it is unlikely that a child's legs would be able to constrain the ride-up and prevent ejection, nor would be able to withstand the crash forces without serious injury. In contrast, in the research tests, harnessed-CRSs (with upper and lower torso restraints and crotch restraint) performed well in restraining the child dummy.

The above data raise concerns about the ability of a shield-only design to retain small children in the CRS in certain moderate-to-severe crashes involving an angular component or a rollover. While the crashes replicated in the research settings are less common than most, they

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[14] Q1.5 and Q3 are dummies used in ECE Regulation No. 44, Child Restraint Systems, and Regulation No. 129, Enhanced Child Restraint Systems (ECRS).

[15] Visvikis, C., Pitcher, M., Carroll, J. "Evaluation of shield and harness systems in frontal impact sled experiments," TRL, UK. The Protection of Children in Cars, Munich, Germany, December 2013.

[16] ADAC procedures are not public, but TRL obtained a sample test pulse from a CRS manufacturer.

are not rare events. NHTSA is concerned that shield-only designs are not as protective of small children as designs that use shoulder belts and a crotch belt.

NHTSA seeks comment on the findings in these research tests regarding shield-only-CRSs. Comments are sought on any field data on shield only CRSs.

b. On Infant Carriers Better Accommodating the Height of Children Recommended for the Restraint

Some infant carriers are marketed as suitable for children up to 13.6 kg (30 lb), which is greater than the weight of a 95th percentile 1 YO and an average 1.5 YO, but many of these carriers cannot "fit" the height of a 95th percentile 1 YO or an average 1.5 YO. Field experience indicates that children at the higher end of growth charts typically outgrow the carriers by height at around 9-10 months. NHTSA believes that infant carriers' height and weight recommendations should better match up to better accommodate the children for whom the CRS is recommended.

By "fit," the agency means the accommodation of the child such that, statically measured there is at least a 25 mm (1 inch) space between the top of the child's head and the top of the infant carrier shell. Most CRS instruction manuals[17] specify a 25 mm (1 inch) spacing between the top of the child's head and the top of the infant carrier shell, as do best practice recommendations.[18] FMVSS No. 213 does not have such a clearance specification. Instead, S5.1.3.2 has dynamic test provisions to counter the risk of excessive excursion, stating that target points at the dummy's head center of mass, which is around the ear area, must be contained within the CRS shell during the test. The test is conducted with a test dummy representing a 50th percentile 12-month-old.

To study concerns about how some infant carriers fit children, NHTSA contracted with the University of Michigan Transportation Research Institute (UMTRI) to evaluate 19 infant

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[17] For example, the Britax B Safe and Chaperone CRS user manuals provide the following height recommendation: 32 inches in height (81.3 cm) or less and when the top of the head is one inch or more below the top of the child seat shell (http://www.britaxusa.com/uploads/cms/file/p469000_r3_b-safe_us.pdf and http://www.britaxusa.com/uploads/products/user-guides/84.pdf).

[18] E.g., the Safe Kids Worldwide/National Child Passenger Safety Board Child Passenger Safety Technician Certification Training Program curriculum states: "In general, the top of the child's head should be well contained within the shell and at least 1 inch from top of shell. Some manufacturer instructions state otherwise so be sure to check the car seat manual." http://cpsboard.org/cps/wp-content/uploads/2014/01/Technician-Guide_March2014_Module-8.pdf

carriers.[19] Six (6) of the carriers were sold with the manufacturer's recommending the CRS as appropriate for children weighing up to 10 kg (22 lb), 6 were recommended for children weighing up to 13.6 kg (30 lb), 1 was recommended for children weighing up to 14.5 kg (32 lb), 5 were recommended for children weighting up to 15.8 kg (35 lb) and 1 was recommended for children weighing up to 18 kg (40 lb). To assess fit, the study used the CRABI-12MO and, for the infant carriers for heavier children, the CRABI 18-month-old dummy (CRABI-18MO). The CRABI-18MO was used because its weight and height are representative of children at the upper range of children for whom the carriers were recommended. I.e., the CRABI-18MO's weight and height are very close to those of an average 95th percentile 1-year-old, as shown in Table 1 below.

Table 1. Weight and standing height of the CRABI-18MO and 95th percentile 1YO male child

	Weight	Height
CRABI-18MO	11.3 kg (25 lb)	812 mm (32 inch)
95th Percentile 1YO	12 kg (26.4 lb)	800 mm (31.5 inch)

UMTRI found that all the infant carriers recommended for children weighing up to 10 kg (22 lb) could fit the CRABI-12MO (representing a 50th percentile 1YO).

However, 8 out of 13 infant carriers recommended for children weighing more than 13.6 kg (30 lb) could not fit the 11.3 kg (25 lb) CRABI-18MO dummy as the top of the dummy's head was less than an inch from the top of the infant carrier's back.[20] Four (4) of the 8 infant carriers could not fit the CRABI-18MO even though they were labeled with a height recommendation that included children of the height of the CRABI-18MO (and even children taller than the test dummy). Stated differently, these infant carriers marketed for heavier children were not able to fit children with the heights associated with those weights.

As the CRABI-18MO represents a 95th percentile 12MO, NHTSA would like to see more infant carriers with weight recommendations capable of fitting the dummy, since then they would be able to fit a 95th percentile 12MO. The longer a child can use a rear-facing infant

[19] Manary. M., et al.,"Comparing the CRABI-12 and CRABI-18 for Infant Child Restraint System Evaluation." June 2015. DOT HS 812 156. The report is available in the docket for the 2020 NPRM to update FMVSS No. 213.

[20] There is a 30.1 mm (1.2 inch) difference in seated height between the CRABI-12MO (469.9 ±7.6 mm (18.5 ±0.3 inch)) and the CRABI-18MO (500 ±7.6 mm (19.7 ±0.3 inch)). Seated heights were taken from http://www.humaneticsatd.com/crash-test-dummies/children.

carrier without outgrowing it, the less likely a caregiver will transition the child out of it before age 1, possibly to a forward-facing CRS. Also, improving the fit of carriers to make them slightly longer to fit better a large 1YO would provide more clearance between the protective shell of the CRS and the child's head, better protecting the rear-facing infant's head from impacts against the vehicle interior in a frontal crash.

NHTSA believes that infant carriers' height and weight recommendations should better match up to better accommodate the children for whom the CRS is recommended. NHTSA seeks comment on UMTRI's research findings regarding how current infant carriers fit children that they are designed for.

c. Availability of Computer Models to Assist Fit

NHTSA has also observed other kinds of fit problems using various test dummies. UMTRI's fit evaluations with the CRABI-18MO dummy (25 lb) showed problems fitting the dummy around the shoulder area.[21] Most of the 13 infant carriers recommended for children of a weight range that included the dummy's weight had a tight fit in the shoulder area or had the shoulders of the dummy touching the head restraint. In a separate evaluation, NHTSA tried to position a HIII-3YO dummy (35 lb, 37 inches) in a Graco SnugRide 40, which is sold for newborns to 2-year-olds and is recommended for children weighing up to 40 lb.[22] The HIII-3YO has the weight and height of a 95th percentile two-year-old. NHTSA found poor fit of the dummy in the head, shoulder, pelvis and back area.

NHTSA has supported the development of computer models of children of different weights and heights to assist CRS manufacturers in designing child restraints that better fit the children for whom the CRS is recommended.[23] These virtual models are available to the public to improve the fit of CRSs to children.[24] NHTSA requests comments from manufacturers and other parties on whether they used the models and whether the models were helpful.

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[21] Manary. M., et al.,"Comparing the CRABI-12 and CRABI-18 for Infant Child Restraint System Evaluation," supra.

[22] http://www.gracobaby.com/products/pages/snugride-click-connect-40-infant-car-seat-mena.aspx GRACO states: "SnugRide® Click Connect™ 40 is the ONLY newborn to 2-year infant car seat. SnugRide® Click Connect™ 40 provides comfort and protection for babies from 4-40lbs." Last accessed July 20, 2016.

[23] NHTSA has sponsored an UMTRI project developing toddler virtual dummies for use in improving of the fit of CRSs to child passengers. Information on a 2015 UMTRI workshop describing development of the toddler virtual fit dummies can be found at: http://umtri.umich.edu/our-results/projects/umtri-workshop-new-tools-child-occupant-protection.

[24] Toddler virtual models available for download at: http://childshape.org/toddler/manikins/