OCCUPANT KINEMATICS WITH CHILD SAFETY SEATS TESTED UNDER REAL WORLD CONDITIONS

Gary R. Whitman, John Yannacone[1]
Joseph Burton, Paul Lewis Jr.[2]
Dennis F. Shanahan[3]

[1]ARCCA, Inc
[2]Burton Associates
[3]Injury Analysis

Objective: Head impact with the interior surfaces of the vehicle is the leading mechanism of serious injury for restrained children in vehicle crashes. To reduce head impact, head excursion must be minimized. U.S. Federal Motor Vehicle Safety Standard (FMVSS) 213 requires a child safety seat (CSS) to limit head excursion of three and six year old test dummies to less than 81.3 cm (32.0 in) without the use of a top tether, and 72.0 cm (28.3 in) with the use of the tether allowed, when the CSS is subjected to a 48 kph (30 mph) simulated frontal barrier crash. This testing is conducted with the securing vehicle lap belt tightened to 53 to 67 N (12 to 15 lbs) of tension. Prior research has found, however, that the public, when installing child safety seats, rarely achieves 53 to 67 N of seat belt tension. Since FMVSS 213 does not contain any requirements for the performance of child restraints in side impacts, child seat manufacturers seldom assess the performance of CSSs in side impacts. This test program studied the child occupant's kinematics and head excursions with two types of CSSs – a tethered CSS with a 5-point harness and a Booster-With-Shield (BWS). Both CSSs were tested with the securing lap belt tightened to the low tension acquired by the retractor's retraction force. The 5-point CSS was also tested with the lap belt tightened to a higher tension in accordance with its instructions. The CSS with the 5-point harness incorporated side wings that extend 18 cm (7 in) forward of the CSS seat back in the head/shoulder region. This paper presents the findings of frontal and side crash tests, simulated with a horizontal accelerator, to assess the kinematic performance of CSSs and their ability to prevent head impact when secured to the vehicle seat with a seat belt tension commonly achieved by the general public.

Method: The CSSs were restrained in the center of a simulated automobile seat, similar to the FMVSS 213 test seat fixture, with a lap belt incorporating an automatic locking retractor (ALR). The tests were conducted using Hybrid II and III Three-Year-Old test dummies. The securing lap belt was positioned on both CSSs with the tension inherently achieved by the seat belt retractor. The 5-point

CSS was also tested with the lap belt tightened in accordance with the manufacturer's instructions. The simulated frontal crashes were conducted at 48 kph (30 mph) delta-v, the lateral crashes at 32 and 48 kph (20 and 30 mph).

Data: A total of 13 simulated crash tests were conducted, 6 frontals and 7 laterals. In the 48 kph (30 mph) frontal tests with the CSS secured with retractor tension, the average maximum head excursion for the 5-point was 58.0 cm (22.85 in), and the BWS averaged 73.0 cm (28.75 in) (Table 1). The tethered 5-point CSS effectively restrained the upper and lower torso, and there was little movement of the CSS relative to the vehicle seat due to the effectiveness of the top tether. This resulted in early crash ride down for the occupant and low head excursion. The head excursion with the 5-point CSS installed with only retractor tension was one inch greater in the frontal test compared to when it was installed per the manufacturer's instructions. The lack of upper torso restraint with the BWS CSS allowed significantly greater head excursion and reduced crash ride down.

Table 1: Simulated Frontal Crashes

Child Seat Type	Delta-v kph (mph)	Peak Accel (G)	Seat Belt Tension N. (lb.)	Head Excursion cm (in.)
5-point w/tether	49.2 (30.6)	24.6	Retractor 0 to 4.4 (0 to 1)	59.2 (23.3)
5-point w/tether	49.1 (30.5)	24.6	Retractor 0 to 4.4 (0 to 1)	56.9 (22.4)
Booster w/shield	49.1 (30.5)	24.1	Retractor 0 to 4.4 (0 to 1)	73.2 (28.8)
Booster w/shield	49.2 (30.6)	24.4	Retractor 0 to 4.4 (0 to 1)	72.9 (28.7)
5-point w/tether	48.8 (30.3)	24.4	Retractor 0 to 4.4 (0 to1)	59.4 (23.4)
5-point w/tether	48.8 (30.3)	24.0	Per instruction 110 (25)	56.6 (22.3)

In the side tests with the CSS secured with retractor tension, the maximum head excursion for the 5-point CSS in the 32 kph (20 mph) tests averaged 58.2 cm) (22.9 in), the BWS 83.12 cm (32.75 in) (Table 2). In the 48 kph (30 mph) lateral tests with retractor tension, the maximum head excursions were 25.3 and 35.3 inches for the 5-point and BWS, respectively. The head excursion with the 5-point CSS installed with only retractor tension was less than one inch greater in the lateral tests compared to when it was installed per the manufacturer's instructions. The 5-point CSS and side wings combined to limit head excursion and provides early crash ride down in the lateral tests. The BWS's lack of upper torso restraint and side wings combined with limited lower torso restraint allowed the test dummy's torso to rotate to a horizontal orientation across the seat with the dummy only restrained by its legs. This resulted in high head excursion, poor crash ride down, and risk of ejection.

Table 2: Simulated Side Crashes

Child Seat Type	Delta-v kph (mph)	Peak Accel (G)	Seat Belt Tension N. (lb.)	Head Excursion cm. (in.)
Booster w/shield	32.0 (19.9)	18.1	Retractor 0 to 4.4 (0 to 1)	83.6 (32.9)
Booster w/shield	31.9 (19.8)	17.8	Retractor 0 to 4.4 (0 to 1)	82.8 (32.6)
5-point w/tether	32.2 (20.0)	18.0	Retractor 0 to 4.4 (0 to 1)	57.7 (22.7)
5-point w/tether	31.9 (19.8)	17.8	Retractor 0 to 4.4 (0 to 1)	58.7 (23.1)
5-point w/tether	31.9 (19.8)	17.8	Per instruction 110 (25)	56.4 (22.2)
Booster w/shield	47.2 (29.3)	23.6	Retractor 0 to 4.4 (0 to 1)	89.7 (35.3)
5-point w/tether	48.4 (30.1)	23.5	Retractor 0 to 4.4 (0 to 1)	64.3 (25.3)

Frontal head clearance in the rear seat of passenger vehicles ranges from 45.0 cm (17.7 in) to 91.9 cm (36.2 in) and averages 73.4 cm (28.9 in) with the front seat full rearward. The distance from the centerline of the vehicle to the side interior panel ranges from 58.4 cm (23 in) to 85.7 cm (33.8 in) and averages 71.3 cm (28.1 in). Based upon these dimensions, head impact would only occur with a child of the size of the test dummy in frontal crashes of the severity simulated with the 5-point CSS when the frontal head clearance is well below the average vehicle. In side crashes of the severity simulated in these tests, a child the size of the test dummy restrained by the 5-point CSS will not sustain a head impact unless seated on the impacted side during the side impact. The same child in the BWS will be at risk of head impact in the side crash even when not seated on the impact side and in the frontal crash in the majority of passenger vehicles.

Conclusions: The tethered 5-point CSS effectively limits head excursion and provides early crash ride down in both frontal and side impacts and is not significantly affected by lower seat belt tension. Its kinematic performance is significantly superior to the BWS. Occupants restrained by the BWS experienced reduced crash ride down and increased risk of head impact and the associated injuries and ejection. The torso of an actual child is much more flexible and compliant than current child dummies. This will result in even greater body excursion in real crashes with the BWS due to its lack of upper torso restraint.

Discussion and Limitations: A vehicle interior was not represented in the testing. This would have visually demonstrated the head impact potential, but would have prevented identifying maximum head excursion. Given the measured head excursions and occupant kinematics, potential head impacts with any given vehicle interior can be readily identified.