Comparison of the 6YO ATD kinematics restrained in Booster CRSs – Sled Experiments in frontal, oblique and side impacts

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ABSTRACT

Unintentional injuries, like transportation accidents, pose a threat to children and their parents alike. Researchers have been trying to better understand what happens during a crash in order to prevent and protect this age group from fatal injuries, especially now with a few different types of CRS available on the market. In this sled study, a dummy was tested using six different child seats in seven seating conditions. There were three principal directions of force: 0°, 30°, and 80°; full on frontal impact is 0° while almost side impact is 80°. Cameras were placed all around the testing bench to capture dummy kinematics. The videos collected were then prepared in Meta, a post processor, to trace the kinematics of the dummy's head and other body parts. Because the cameras were only capable of capturing in 2D, usually, two separate views (overhead and side views) are necessary to re-create the kinematic in 3D. Using Meta and its functions allows for an easy adjustment to the rotated angle in 30° and 80°. MATLAB and Excel were used to convert units, adjust for sled's movement, scale videos size, and overlay tracings. Statistical data such as body angle vs. time and maximum excursions were also produced. The resulting data suggest that different types of child seats and PDOF do, in fact, affect excursions differently. High back seats, especially the HBB Best Bet, tend to produce longer head excursions than the other seats. However, most seats like the other HBB and the LBBs are not far away from the HBB Best Bet. Other seat types like the Heightless and Inflatable produce unique excursions and patterns that traces the pattern of the No_CRS condition. These results question the performance and benefits of the Heightless and Inflatable. More research is still needed to draw any firm decision on these new seats, but for now, remaining with the classical designs of child seats is the better choice.

INTRODUCTION

Motor vehicle crashes persist as the leading cause of death for all children over age 3 years (CDC 2006). Worldwide, road traffic was the leading cause of death or injury in 2015 (WHO, 2016). For protection of children in crashes, belt restraints are provided at all seating positions for children who are anthropometrically large enough to fit the adult seat belt (typically above age 8 to 10 years).

There is ample evidence from real world crashes that belt-positioning booster seats reduce injury risk. Durbin et al. (2003) published the first real-world study to quantify the benefit of booster seats over seat belts for the young school age child. Using the Partners for Child Passenger Safety (PCPS) database, they estimated that the odds of injury after adjusting for child, crash, driver and vehicle characteristics were 59% lower for 4-7 year olds in belt-positioning booster seats than 3-point seat belts. There are primarily two types of belt positioning booster seats, high back and backless, or low back which raises the child up so that the lap and shoulder belts fit properly. The lap belt should fit low across the child's hips or upper thighs and the shoulder belt should cross the center of the child's shoulder and chest. A third category is emerging in the market: Heightless booster seats. These seats do not provide a raised seating surface, but rather route the belt such that the child is seated essentially on a surface that is similar to the vehicle seat but has proper belt fit.

Therefore, the goal of the project is to study the performance of the different types of booster seats currently available. Sled tests re-create crash scenarios with the different booster seats at different crash angles. Data collected will allow for quantitative evaluation and will provide a better understanding of the different crash situations.

METHODS

Sled Test

In this sled study, a Q6 6YO ATD was tested using six different child seats in seven seating conditions: No CRS, LBB Best bet, LBB Check Fit, HBB Check Fit, HBB Best bet, Inflatable and Heightless. The best bet and check fit seats were chosen based on the Insurance Institute for Highway Safety's ratings. The tests were performed at Calspan's facility. Each of the seating conditions were tested in three principal directions of force: 0°, 30°, and 80°; full on frontal impact is 0° while almost side impact is 80°. A seating condition and an angle together create a test condition. There were 7 seating conditions and 3 PDOF totalling up to 21 different test conditions that were tested. To ensure that the results from each test conditions were consistence and correct, each test condition was run twice with exceptions of three conditions in 80° due to time constraint. High-speed cameras were placed all around the testing bench to capture dummy kinematics.

Data Generation

The videos collected were then prepared in Meta, a post processor, to trace the kinematics of the heads, shoulders (chest), elbows, and knees. Because the cameras were only capable of capturing in 2D, usually two separate views (overhead and side views) were necessary to re-create the kinematic in 3D which allowed for better visualization of the data. Meta splits each 36 second video up and record a coordinate for each of the 900 frames it created. These coordinates were exported for data refinement. MATLAB and Excel imported these data. They helped to convert units, adjust for the sled's movement, scale videos size, and overlay tracings.

Because each test condition was tested twice, the two runs for each test condition were averaged to prevent the graph from being overcrowded with information. In every test condition, because not all initial dummy positions were the same, the delta position was graphed to put all test conditions at the same starting baseline.

Body angle vs. time and were also extracted, graphed and compared. The body angle is measured using three points on the dummy: chest, pelvis and knee. These three points were chosen because they most closely represent the dummy's body angle throughout each sled test. Like the position graphs, the delta angle was plotted to establish a common baseline.

RESULTS

Impact Excursions

One of the two methods of representing the data entails graphing the XY position to show excursion through time. Excursion data do, as expected, vary from one seating condition to another as shown in Figure 1 below

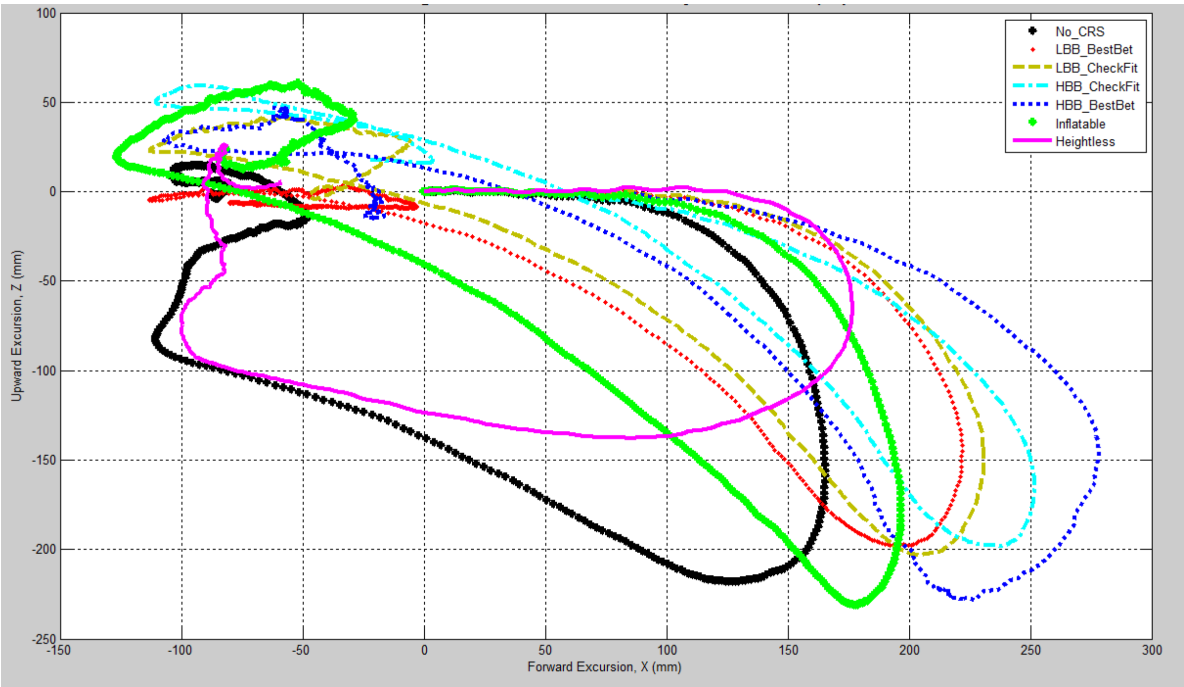

Figure 1: Average Delta Head Excursion at 0° (side view).

The above figure shows that for 0° the HBBs produce the longer forward excursions as compared to all the other seats. Other than the No CRS condition, the Heightless produced the shortest forward excursions of all the seats. The Heightless seat also produced the shortest downward excursion of all the seating conditions. The longest forward excursion, produced by HHB Best Bet, is 278 mm compared to the shortest which is 166 mm (No CRS) or 177 for the Heightless seat. This trend also holds true across all the seating conditions for the 30° impact as shown in Figure 2.

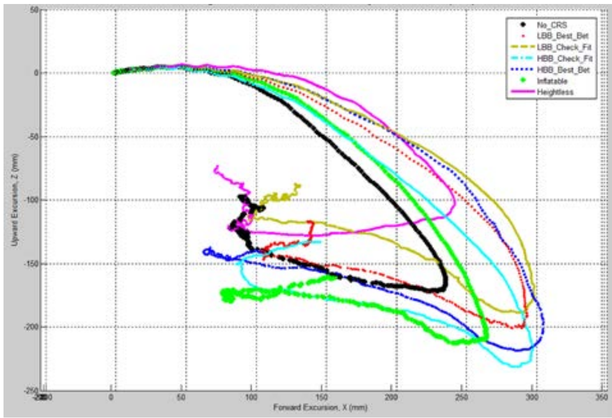

Figure 2: Average Delta Head Excursion at 30° (side view).

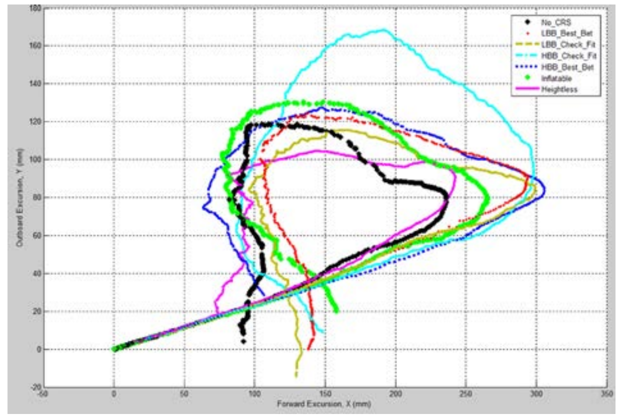

Figure 3: Average Delta Head Excursion at 30° (top view).

HBB Best Bet remains with the longest forward excursion scoring at 307 mm. No CRS has the shortest excursion of 236 mm and next in line is the Heightless seat, scoring at 243 mm. With 30°, also comes the lateral or outboard excursion (Figure 3) which has HBB Check Fit as the longest outboard excursion at 169 mm. The Heightless has shortest outboard excursion of 106 mm with LBB Check Fit at 117 mm and No CRS at 123 mm. For 80°, the differences in forward excursion is lessened with the Heightless as the longest at 20 mm, No CRS as the shortest at 10 mm and the rest of the seats scoring between the two extremes. Outboard excursion for 80° has HBB Best Bet as the longest at 206 mm and No CRS as the shortest at 144 mm.

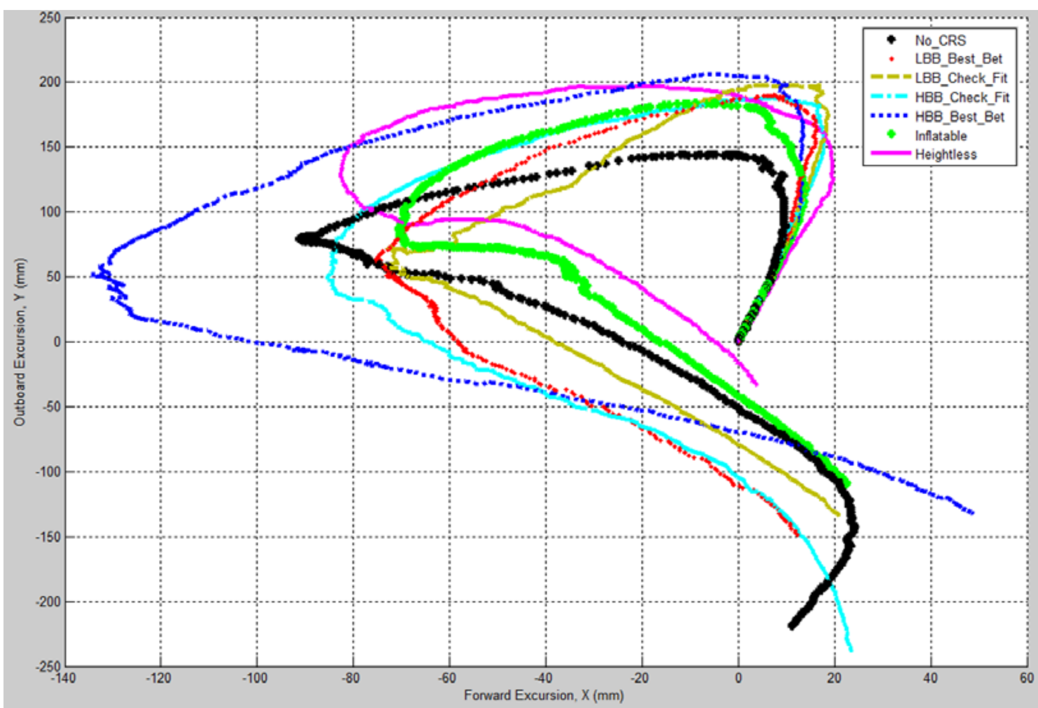

Figure 4: Average Delta Head Excursion at 80° (top view).

To more accurately compare these data, the maximum delta excursions at all three PDOF were extracted; such data are represented in the table below. At 0° the out and inboard excursion are minimal thus could be ignored.

Table 1: Maximum Forward (X) and Outboard (Y) Head Excursion.

All measurements here are in respect to (0,0,0)	0°		30°		80°	
Seat	**Head X**	**Head Y**	**Head X**	**Head Y**	**Head X**	**Head Y**
No_CRS	166	N/A	236	123	10	144
LBB_BestBet	222	N/A	294	125	16	190
LBB_CheckFit	231	N/A	300	117	19	198
HBB_CheckFit	252	N/A	299	169	18	188
HBB_BestBet	278	N/A	307	130	14	206
Inflatable	197	N/A	267	133	14	184
Heightless	177	N/A	243	106	20	198

Impact Body Angles

The other method of representing the data calculates the body angle of the dummy to compare performance and determine submarining. The body angle graphs like Figure 5 below show similar patterns between 0°, 30°, and 80°.

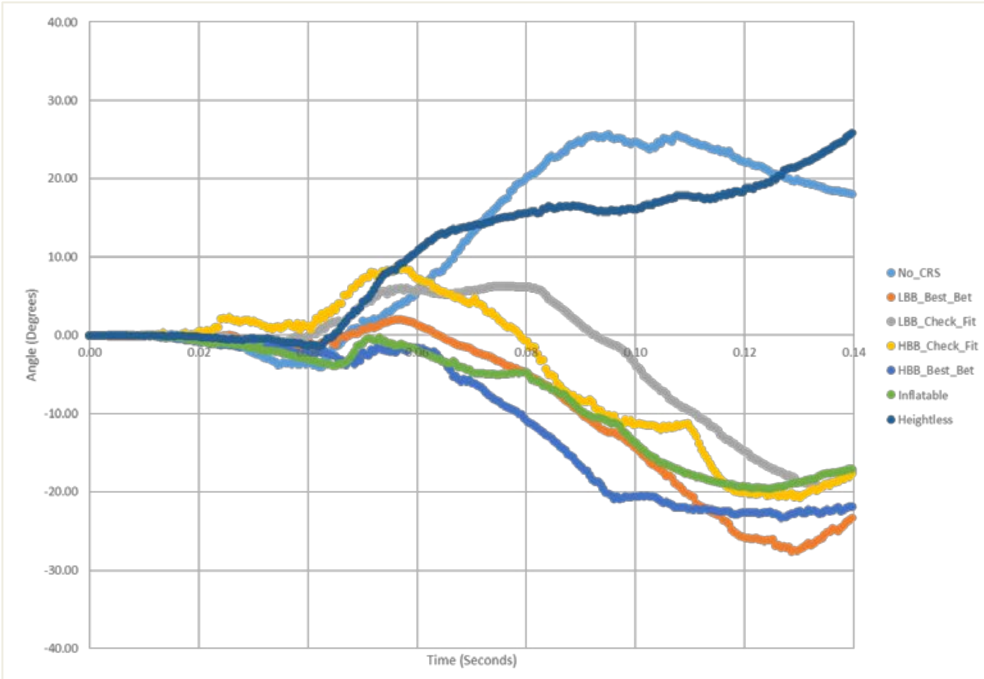

Figure 5: Average Delta Body Angle vs. Time.

For 0° shown in Figure 2 above, all the seats have an overall negative net body angle but the Heightless has a positive net body angle which is like the curve of No CRS condition. It remains similar for 30° but this time the Inflatable joined the No CRS and Heightless in scoring a positive net body angle. The LBB Check Fit is different for its net body angle lies between the two extremes (around net of 0). For 80°, just like in the excursion data, the differences became less distinct and the body angle of all the siting conditions have the same pattern. All the conditions have their lowest change in body angle between 90 to 140 milliseconds and -35° to -48°.

DISCUSSION

The resulting data suggests that different types of child seats and PDOF do, in fact, affect excursions differently. The high back seats, especially its Best Bet, have the longest forward head excursions in 0° and 80°. During the 0° tests, it was noticed that the back of the HBB Best Bet pushed the head forward which could be the reason to it having the longest forward head excursion. This is also an occurrence in the 30° tests but the excursion of HBB is only a tiny bit higher than the others compared to 0°. It is expected because as the PDOF increases, there would be decrease in forward excursions and increase for in and outboard excursions. The 80° reinforced this idea further by showing a max difference of 10 mm between seats in forward excursion. Despite this forward excursion becoming minimal was the PDOF increases, it is still interesting to see the HBB Best Bet has the tendency to increases head excursions. The HBB Check Fit which is also a high back but does not push the dummy's head forward during the sled tests. The new Heightless type of seat has shorter downward head excursions in all three angles compared to most the other seats but has no trend in forward head excursion. The Inflatable seat produced excursions that are along the line of some of the high back boosters. Some general trends could, however, be concluded. Low back boosters tend to produce shorter head excursions while high back boosters do the opposite. The data for dummy body angles also supports the irregularity of the Inflatable and Heightless seats. Low back and high back seats have similar body angles vs. time. However, the angles of Inflatable and Heightless seats shows similar trend to that of the no CRS condition. This begs the question of whether these Inflatable and Heightless seats are protecting children properly.

When compared to another study that belongs to UMTRI to validate submarining, the data seems to complement each other (Klinich). UMTRI suggests that the change in body angle that is not less than -10° represent submarining. As to this project's data, the No CRS and Heightless conditions both do not have the delta of body angle lower than -10° so they both have submarining. This is true for both situations. From observing the video collected, the dummy did submarine. As for 80°, all the seats produced curves with delta body angle much lower than -10° so the dummy in 80° did not submarine. The impact was an almost side impact so submarining did not happen.

CONCLUSIONS

It can be concluded that low backs and high backs are the safest out of all these seats with an exception of high backs tending to produce longer head excursions. It is probably safer to rely upon the tradition designs of booster seats until the new designs are proven to be safer. Further research is necessary to draw any firm conclusion on the effectiveness of the new seat types.

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