# Integrated Booster Seats: Crash Protection, Ease of Use and Errors in Use

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**Abstract**

Integrated boosters are approved restraints and have potential to provide superior performance than add-on boosters. However, no comparative data is available. This paper presents a program of work examining comparative crash protection, ease of use and likelihood of misuse between integrated and add-on boosters. The results reveal few differences in crash protection. However, good side impact protection in the integrated booster requires the presence of a side curtain, and better lateral support for non-struck side occupants. The integrated booster was easier for parents to install but did not demonstrate any benefit in reducing errors in use introduced by child passengers.

## Background

Optimal crash protection requires correct use of size-appropriate restraints (Du et al., 2010; Du et al., 2008; Durbin, Elliott & Winston, 2003). Errors in how a child restraint is used increases the risk of injury in a crash because an error may loosen the restraint's link with the vehicle and allow greater motion of the child and/or alter the way crash forces are distributed over the body (Bilston, Yuen & Brown, 2007). Child restraints integrated (i.e. built-in) into vehicles could reduce the frequency of errors by removing the need for installation and increasing user-friendliness. They could improve restraint fit over a range of child sizes, as well as solve problems with child occupant travel posture. Through their inherent design they could theoretically provide better crash protection by more tightly coupling the child to vehicle. In non-frontal impact directions, they could theoretically provide better crash protection through better optimisation of the whole occupant restraint system e.g. side curtains, belt geometry and other vehicle technologies, but this theoretical benefit has not been proven. Historically, two types of booster seat have been available in Australia; one with a high back and side wings, and the (backless) booster cushion. All add-on restraints used in Australia must meet the mandatory Australian Standard covering their design and performance (AS 1754:2013). Due to the increasing stringency of this Australian Standard, booster cushions no longer meet the crash performance requirements and therefore all add-on boosters currently sold in Australia are high-back boosters. Unlike international regulatory regimes, the Australian Standard does not cover restraints integrated into a vehicle as the child restraint standard is separate to the vehicle standards system. In Australia, integrated restraints fall under the Australian Design Rules (ADR). While there is no ADR specifically covering integrated child restraints, ADR 34/01 requires any integrated booster seat in cars sold in Australia to comply with the specifications of the European Standard (ECE R44). All integrated booster seats currently available in Australia are effectively booster cushions. Furthermore, while the number of vehicles in the Australian fleet offering integrated boosters is currently relatively small, this number may increase in future years as new car assessmnet programs begin to award bonus points for the inclusion of this feature. This commenced in EuroNCAP (2016) in 2017.

As integrated restraints have historically been relatively rare in Australia, little is known about their real world crash performance, or whether or not they do effectively reduce errors in use. This body of work aims to examine the potential of integrated booster seats to provide an improved alternative to ‘add-on’ child restraints, and to assess the adequacy of current Australian regulations and policy surrounding their use. Specifically this study aimed to:-

(i) Assess the real-world crash performance of integrated child restraint systems, by reviewing crash outcomes of children using these systems in North America

(ii) Compare the performance of integrated child restraint systems with conventional ‘add-on’ child restraints using simulated laboratory and full-scale crash impacts by assessing their ability to comply with the mandatory Australian Standard for child restraint systems and comparing their dynamic performance with ‘add-on’ booster seats currently available in Australia

(iii) Identify the barriers and challenges faced by families trying to comply with current Australian restraint use legislation, and assess the potential of integrated systems to ameliorate these, by undertaking a survey to identify these challenges, and comparing the user-friendliness of integrated child restraint systems to traditional ‘add-on’ child restraint systems using human factor assessment tools

(iv) Evaluate the ergonomics of integrated child restraint systems through novel laboratory and field experiments to establish potential for improved restraint fit, and in-vehicle posture in integrated systems compared to conventional ‘add-on’ systems by comparing the ergonomics, comfort, ease of use and propensity for errors in use in integrated booster systems and currently available ‘add-on’ booster seats.

## Method

### *Crash data*

Existing crash data from North America and Sweden was reviewed and results synthesized. This was the only available data reporting real world crashes involving integrated restraints. Firstly, a previous analysis of NASS-CDS (North American Sampling System Crashworthiness Data System) crash data and data collected by researchers at the Children’s Hospital of Philadelphia (CHOP) was reviewed. Secondly, a search of more recent data from the US crash database, NASS-CDS, was undertaken, and thirdly, previously reported data from Volvo in Sweden was reviewed

### *Crash performance*

Crash performance was examined using raw data from four frontal sled impact tests and two full scale vehicle side impact tests conducted at Crashlab, NSW.

<u>Frontal tests:</u> Each booster configuration was tested to the parameters specified in the AS/NZS 1754 and the Child Restraint Evaluation Program (CREP) test procedure. See Table 1. Seatbelt pretensioners were triggered manually at 16ms post initial impact in each test.

Head and knee excursion was also assessed using the CREP protocol. Head and chest acceleration were measured using accelerometers within the test dummies, and the Head Injury Criteria (HIC) was calculated. Dummy excursions and head accelerations in the integrated booster seats in Test 3 and 4 (conducted using CREP protocol test pulses) were compared to best and worst measures obtained from ‘add-on’ boosters tested in CREP. The integrated booster performance was also assessed using the seat belt position requirements of AS1754:2013.

<u>Side impact tests:</u> Two full scale side impact tests using a Volvo XC60 incorporating a second row integrated booster seat system were conducted as detailed in Table 2.

***Ease of use***

Ease of use was examined using raw data collected in the laboratory and through a national family survey.Both studies were approved by UNSW Human Research Ethics Committees (HREA 08/2014/72 & HREA 09/14/010)

Laboratory trials: The integrated booster seat was assessed using the Ease of Use Protocol of the Australian Child Restraint Evaluation Program (CREP). Secondly, parents were asked to evaluate the ease of use of integrated restraints and add-on boosters using a modified version of CREP ease of use protocols, and a trio of Likert scale questions asking the parent to rate difficulty of installation, seating and securing the child, and overall difficulty of the entire process.

For the laboratory study, parents/guardians and their children were recruited between January 2015 and October 2015 and were required to be >18yrs, Australian residents, and routinely transporting a child aged 4-8 years in a restraint. Consent was obtained from the parent and the child. Participants were reimbursed with a payment of AUD 50.

A seating buck constructed from a 2005 Volvo V50 station wagon incorporating a single stage integrated booster was used as the integrated restraint. A booster meeting the Australian Standard (AS/NZS1754:2013) with highest ease of use rating from CREP (2009-2016) was used as the add-on restraint (Safe-N-Sound Hi-Liner SG Series)

***Table 1. Test matrix for frontal impacts***

| | **Test 1** | **Test 2** | **Test 3** | **Test 4** |
|---|---|---|---|---|
| **Test Type** | **AS/NZS 1754** | **AS/NZS 1754** | **CREP** | **CREP** |
| **Dummy Type** | P6 | P10 | P6 | P10 |
| **Dummy Mass** | Nominal 22kg | Nominal 32kg | Ballasted to 26kg | Ballasted to 36kg |
| **Δ Velocity** | 49km/h | 49km/h | 56km/h | 56km/h |
| **Peak Deceleration** | 24g – 34g | 24g – 34g | 33g – 34g | 33g – 34g |
| **Seating Position** | RHS | LHS | RHS | LHS |
| **Booster Configuration** | Stage 2 (higher) | Stage 1 (lower) | Stage 2 (higher) | Stage 1 (lower) |

***Table 2. Test matrix for Part 2 of the integrated booster seat test program (HIII dummy was used on the struck side & TNO P10 on the non-struck side in each test)***

| | **Test 1** | **Test 2** |
|---|---|---|
| **Test Type** | Moveable Deformable Barrier Side Impact (Left Side) | Moveable Deformable Barrier Side Impact (Right Side) |
| **Test Speed (nominal)** | 50km/h ± 1km/h | 50km/h ± 1km/h |
| **Test Mass** | Match EuroNCAP test mass (1961kg) | Match EuroNCAP test mass (1961kg) |
| **Vehicle Instrumentation** | Left and right acceleration Ay at B pillar base | Left and right acceleration Ay at B pillar base |
| **Impact Position** | Vehicle seating reference point (SgRP/R-point) | Vehicle seating reference point (SgRP/R-point) |

| | | |
|---|---|---|
| | Crashlab to determine | Crashlab to determine |
| **Trolley Instrumentation** | Acceleration Ax, Ay, Az at CoG | Acceleration Ax, Ay, Az at CoG |
| **Dummy Type** | HIII 6yo and a TNO P6 | HIII 6yo and a TNO P6 |
| **Seating Position** | LHS and RHS | RHS and LHS |
| **Seating Configuration** | Integrated booster seat Stage 2 (highest setting) | Type E 'add-on' booster |
| **ATD Mass** | HIII 6yo: Nominal 23.41kg<br>P6: 22kg | HIII 6yo: Nominal 23.41kg<br>P6: 22kg |
| **ATD Instrumentation** | Head Gx, Gy, Gz (both ATDs)<br>Chest Gx, Gy, Gz (both ATDs)<br>Neck upper Fx, Fy, Fz, My, Mz (HIII 6yo only) | Head Gx, Gy, Gz (both ATDs)<br>Chest Gx, Gy, Gz (both ATDs)<br>Neck upper Fx, Fy, Fz, My, Mz (HIII 6yo only) |
| **SRS Trigger/Fire** | External trigger (Crashlab)<br>Impact side curtain airbag only | External trigger (Crashlab)<br>Impact side curtain airbag only |
| **High Speed Camera Views** | Three onboard high speed cameras (500fps)<br>Front ¾ view of vehicle and trolley (offboard view 1000fps)<br>Overhead (1000fps) | Three onboard high speed cameras (500fps)<br>Front ¾ view of vehicle and trolley (offboard view 1000fps)<br>Overhead (1000fps) |

The parent was first asked to install the add-on child restraint via the drivers' side rear door. The parent was then asked to adjust the restraint for the child and secure the child into the restraint and then fill out of the ease of use evaluation survey. The survey consisted of a modified version of the CREP protocol and a set of Likert scale questions asking about their perception on ease of installing and securing the child in the restraint and the overall ease of use. Paired sample t-tests were used to examine differences in the parents' evaluation of the integrated and add-on booster seats.

<u>National survey:</u> The NRMA Motoring and Services distributed a link to the online survey through their nationwide electronic mail distribution list in May-August 2014. The survey asked parents/carers of children aged 0-7 about problems they had in using child restraints, features of the car that impact on the installation, and the room available to install restraints. A mix of open ended and fixed response questions were used. All statistical analysis was completed using SPSS (IBM Corp. Released 2013.

### *Errors in use*

Errors in use were investigated using data collected during a laboratory observation study. The participants, recruitment and equipment used were the same as those described above. Any errors in installation and securing the child made by the parents were noted and corrected. The child was then video recorded whilst secured in the restraint for 10 minutes, and any errors introduced by the child were captured, and then scored from the video at a later time. Errors introduced by the child were defined as any active mis-positioning of the seat belt or extreme postural shifts such as leaning forwards or sideways beyond the natural confines of the restraint system during the 10 minutes of observation.

## Results

### *Crash data*

North American Data Analysis: In December 2004, the National Highway Traffic Safety Administration (NHTSA) prepared a report to congress that included a section evaluating integrated child safety systems (NHTSA, 2003). This included an analysis of NASS data for 1992 to 2001 as well as data collected by CHOP in their studies prior to 2004. The CHOP data is based on customers of a large North American insurance company that covers 38 million vehicles and reportedly provides a crash sample representative of the American vehicle population for model year 1990 and newer vehicles.

In the NASS data, NHTSA identified 18 children using an integrated system. These children were aged 1 to 7 years, and 12/18 had no injury, one child whose injury outcome was unknown, four with minor AIS 1 injuries and one with a serious (AIS 3) injury. This was a femur fracture.

The CHOP data included all children under 9 years restrained in rear seating positions in integrated and add-on child restraints. Restraint type was identified through parental survey. This sample consisted of 100 children in integrated systems, 2350 children in forward facing child restraints, 340 in belt positioning boosters, and 278 in shield boosters (not available in Australia). A check of parental reports of integrated system use was made by comparing the parental report with vehicle details, and only those children reported to be using an integrated system in a vehicle known to provide integrated systems were used in the analysis. It is important to note that the definition of integrated systems used by NHTSA included both integrated forward facing child restraints suitable for children aged 1-3 years and integrated booster seats.

According to the NHTSA document, the CHOP data demonstrated that less than 5% of children used integrated restraints, and that the typical child using an integrated system was < 3 years of age.

From the CHOP data, NHTSA reports that injury rates among the three types of restraints were very low and not statistically different from one another. Furthermore, review of the children seriously injured in a crash while using each restraint type revealed similar patterns of injury between each restraint type. In the six children identified as being seriously injured while using an integrated system, four sustained head injuries and two sustained lower extremity injury. CHOP researchers ascertained this was a similar distribution across body regions as seen in other restraint types.

NHTSA concluded that the CHOP data did not indicate that integrated child restraints provide enhanced safety over add-on child restraint systems. However, it is important to keep in mind this conclusion is based largely on integrated forward facing child restraint data.

Researchers at NeuRA conducted a search of NASS data spanning 2006-2014 to identify children using integrated booster seat systems. No cases were identified.

Swedish data: In 2009, Jakobsson et al. (2009) presented data on booster seat use among children in crashes in Sweden between 1987 and 2008 from the Volvo crash database. This dataset contained records for 2626 children aged 4 to 12 years, with 10% of boosters being integrated boosters. Jakobsson et al noted the integrated booster was particularly popular with booster seated children >7 years.

In a more recent, similar analysis, Jakobsson et al. (2015) presented the proportion of all children 4 to 12 years using integrated booster seats during the years 2001-13. They noted an increase in integrated booster seat use from 10% to 15%. In a personal communication, Jakobsson reported examining differences in injury among children in different restraint types using the 2000-2013 data, and the earlier 1987-2008 data. She reported no statistical difference in injury outcomes between integrated booster seats and add-on or accessory boosters. She also noted the overall number of children injured was very low and that only two cases of AIS2+ injury in children using an integrated booster were identified. Both involved older vehicles and the first generation of integrated boosters incorporating a booster seat that folded down from the backrest in the centre rear position. One of these sustained an MAIS 2 injury in a frontal impact and the other sustained a MAIS 3 injury in a side impact. In her personal communication, Jakobsson concluded that their data confirmed that children using a booster of any type in a Volvo car are provided with 'efficient protection' and they cannot find any difference in crash protection between boosters of different types.

***Crash protection***

<u>Frontal impact:</u> Testing to AS/NZS 1754 conditions led to the seat base dislodging. Crashlab's attempts to secure the seat base in further testing proved successful, however the seat base still showed a tendency to dislodge, as the mounting points bent following impact.

Head and knee excursion throughout the four sled tests were similar to the best scores as measured during add-on booster seat testing. The seat belt's performance in frontal impact showed good restraint of the dummy throughout the entirety of the crash event. Based on the observed performance, the integrated booster appears to behave as well as the best performing add-on boosters available in Australia, and demonstratescomparable performance to add-on restraint that have been shown to meet the requirements of AS/NZ 1754 . See Figure 1-8

<u>Side impact:</u> While the integrated restraint in combination with the side curtains demonstrated adequate head protection during the impact, the overall restraint was compromised due to the lack of lateral support. Both dummies slid on the seat base towards the impact side of the vehicle before rebounding back. The seat belt on the struck side had little effect on restraining the lateral motion of the HIII 6yo. The HIII 6yo's head, left shoulder, arms, hips and legs all contacted the side door trim and rebounded following impact. Similarly, the lack of lateral restraint provided by the sash belt in the integrated child restraint allowed both sideways and forward excursion of the P6 upper torso. The HIII 6yo's head contacted the back of the TNO P6 upon rebound of the side door trim.

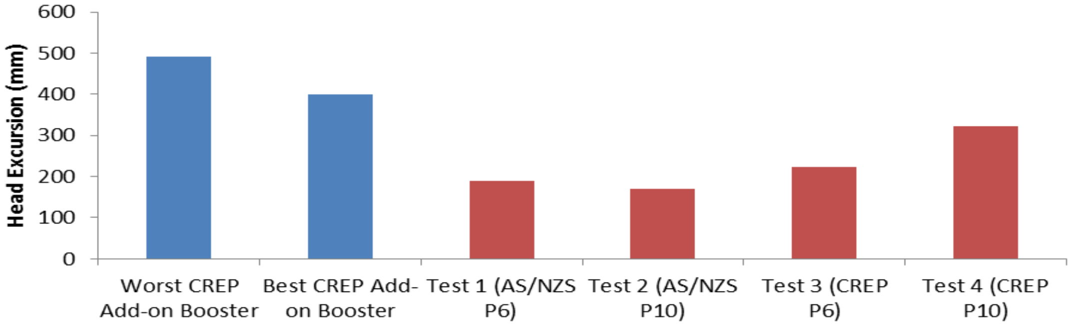


***Figure 1: Comparison of head excursion between add-on boosters and integrated child restraints (blue bars extracted from Australian CREP data, red bars measured in current test program)***

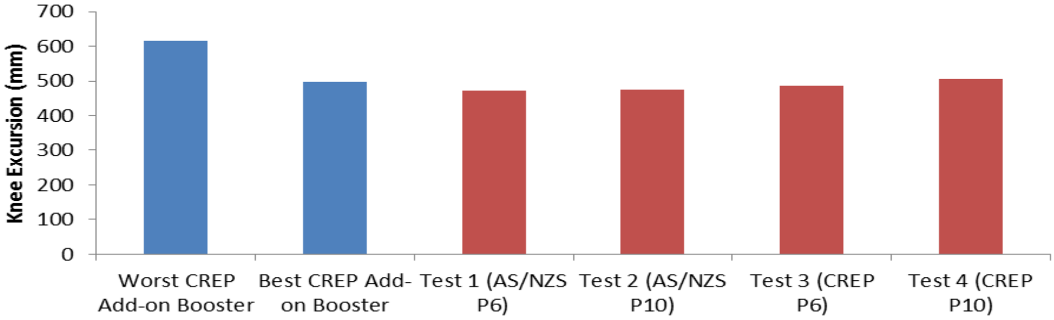


***Figure 2: Comparison of knee excursion between add-on boosters and integrated boosters (blue bars extracted from Australian CREP data, red bars measured in current test program)***

***Figure 3: Sash belt remains in contact with the shoulder at point of maximum forward excursion, TNO P6, Stage 2 integrated booster, CREP pulse***

***Figure 4: Sash belt slips from the shoulder at point of maximum forward excursion, TNO P10, Stage 1 integrated booster, CREP pulse***

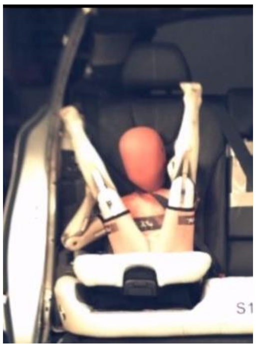

***Figure 5: Sash belt remains in contact with the shoulder during rebound, TNO P6, Stage 2 integrated booster, CREP pulse***

***Figure 6: Sash belt remains in contact with the shoulder during rebound, TNO P10, Stage 1 integrated booster, CREP pulse***

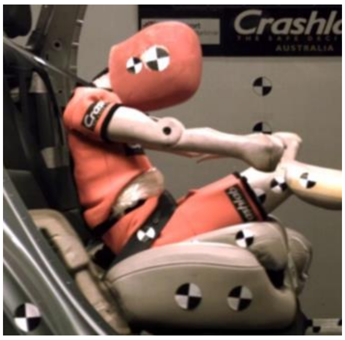

*Figure 7: Lap belt position during impact phase, TNO P6, Stage 2 integrated booster, CREP pulse*

*Figure 8: Lap belt position during the impact phase, TNO P10, Stage 1 integrated booster, CREP pulse*

The add-on booster also demonstrated adequate protection of the head during the impact phase, and superior control of the overall dummy motion due to the lateral support of the dummy provided by the side wings. During Test 2, both the dummies on the struck and non-struck side remained within their restraint during and after impact, however the TNO P6's head rotated past the add-on booster's head rest and consequently contacted the window sill on rebound.

Post impact head contacts therefore occurred in both restraints. In the integrated system, the head contact occurred between the two test dummies, and in the add-on restraint, the head contact occurred only in the dummy seated on the non-struck side and this involved the side door. However both head contacts were relatively 'soft' having no impact on the overall HIC measurement, which remained well below levels associated with high risk of serious head injury.

From the perspective of AS1754 compliance, it should be noted that the integrated system would not meet the requirements in the absence of side curtain airbags, but with airbags may provide good head protection to a child on the struck side in the real world.

Finally, it is important to highlight that seatbelt pre-tensioners were not fired in the full-scale side impact tests, as we were unable to confirm whether or not these pre-tensioners are set to fire in side impact collisions in the real world. It is possible that, had these been fired (and if they fired in real world side impacts), this might better control the lateral motion observed in the non-struck side dummy in the integrated restraint. However, this remains unknown.

***Ease of use***

In the laboratory evaluations using CREP ease of use protocols for booster seats the integrated booster acheived four stars. The add-on booster acheived three stars. Parents rated the integrated booster significantly easier to use than the add-on booster in terms of seating the child and overall (Fig 9).

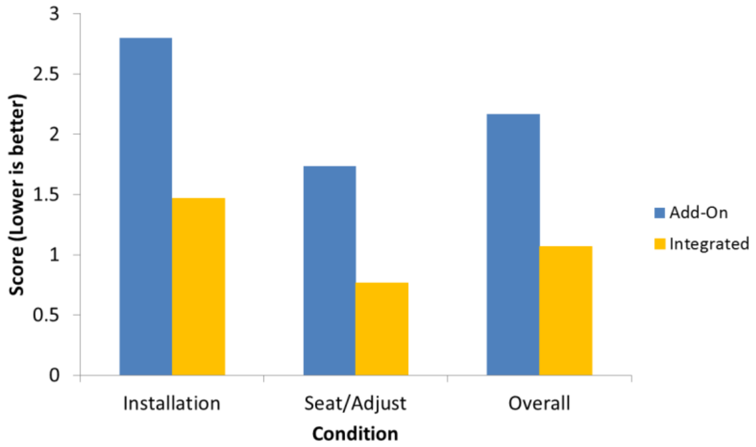


***Figure 9: Average parent-rated ease of use (Likert scale of 1-5 with 1 being easiest to use)***

National Survey: 470 respondents with at least one child aged 0-7 years completed the survey, 430 (91.5%) respondents were female and 40 (8.5%) male. 35% reported having only one child, 42% reported having two children, 15% reported having three children and 8% reported having more than 3 children. Almost three quarters (74%) had more than one car in the household. Almost a third (30%) reported their primary vehicle was a small/medium car.

More than half (53.3%) reported sometimes moving the child's restraint between vehicles (50% less than once a week, 2% once a week, 1.1% several times a week, and 0.2% daily), and most (84.8%) reported that they or another adult normally secure their child in the restraint. However, 14% reported that the child normally buckles themselves into the restraint.

Over a quarter of respondents (26.4%) reported difficulties installing child restraints in their vehicle. The most common problems reported related to the space available in the car (17.9%), problems fitting multiple restraints (11.7%) and difficulties with hardware such as seatbelts, tethers etc (8.5%). More than a third of participants (35.5%) reported features of the vehicle that impacted the fitment of restraints. These included issues related to the width of the rear seat (11.7%), the shape of the rear seat (7.9%) and the top tether anchor position (7.4%).

Among those whose sampled child used a booster, only 4% reported that there were issues with fitting the restraint into their vehicle, compared with 6% of those using forward facing restraints, and 3.5% of those using rearward facing restraints. Among those whose children were using boosters, the most commonly reported difficulties were accessing top tether anchorage locations, need to install anchorages in third row positions, the width of the rear seat, as well as the shape of both the seat back and the seat cushion. A number also raised issues with the use of the centre seat; these included difficulties associated with top tethers and split back seats, as well as the booster seat obstructing the driver's rear view when installed in this position. Other booster specific issues raised included difficulties using locking clips, side wings of the booster making it difficult to install adjacent seats, difficulties accessing the seat belt buckle – both because of interference from the booster and the position of the buckle with respect to kerbside. A number also mentioned issues with booster height relative to the rear seat back height. Interestingly a number also talked about specifically choosing their vehicle to overcome problems fitting three restraints in rear seat.

Taking these findings into consideration, it would appear the greatest practical barriers to compliance with the law for booster seat users is the fitment of three restraints across the rear seat and the compatibility between the restraint and the geometry of the rear seat and top tether anchorage position. Integrated restraints completely negate the compatibility issues. However integrating a booster into the rear seat will not necessarily address issues with fitting three restraints across the seat as this depends on the overall width of the rear seat and the types of all restraints required. The vehicle/integrated system studied in this program of work included integrated boosters in both the outboard seating positions and there was not enough room for three restraints to be installed across the rear seat. Another issue identified in the survey was the frequency with which restraints are moved between vehicles, and integrated restraint systems would also address this – if integrated systems were available in all vehicles within the household. Finally, as well as removing compatibility issues related to top tether access anchorage point, the fact that no top tether is required with an integrated system also removes problems associated with split seats and provision of anchorage points in third row seats.

***Errors in use***

A total of 15 parent and child pairs participated in this study (Table 5). This sample consisted of 8 male and 7 female children (age Mean=5.6 years, SD=1.3 years, height Mean=119.0cm, SD=10.5cm, weight Mean=21.9kg, SD=4.6kg) accompanied by their parents (6 Male, 9 Female). All but one parent reported English to be the language spoken at home.

The integrated booster restraint was correctly installed and adjusted in every case, however errors in installation and adjustment were observed routinely with the add-on booster (Fig 10). There was an average of 0.73 errors introduced by the parent per installation, adjustment and securing of the child in the add-on booster. There were no observed parent introduced errors in the installation, adjustment and securing of the child in the integrated booster seat.

The most commonly observed parent introduced errors with the add-on booster included; twisted top-tether or seat belt strap, incorrectly or failing to adjust seat back height to suit the child, not using the anti-submarining clip.

Both the integrated booster and add-on booster seat were actively misused by the child (Fig 11). However, there were a significantly larger number of use errors in the integrated booster seat (Mean=5.40, SD=4.79) than the add-on booster (Mean=1.20, SD=1.32), ($t(14)=4.2$, $p<0.01$).

The types of use errors that were observed included; child leaning sideways heavily enough for the sash belt to slide off the shoulder, leaning forwards enough for the sash belt to slide off the shoulder, unbuckling the seat belt, placing the sash belt under the arm, and holding the sash belt away from the body.

There were two cases where the child removed the lap belt from the anti-submarining clip whilst in the add-on booster seat. One child lowered the integrated booster from the booster position to the closed position whilst secured in the integrated booster.

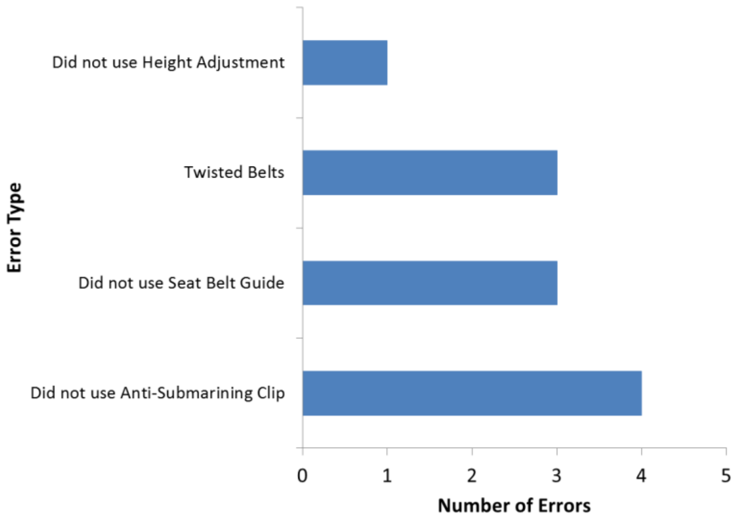


***Figure 10: Types and occurrences of parent introduced errors in add-on booster***

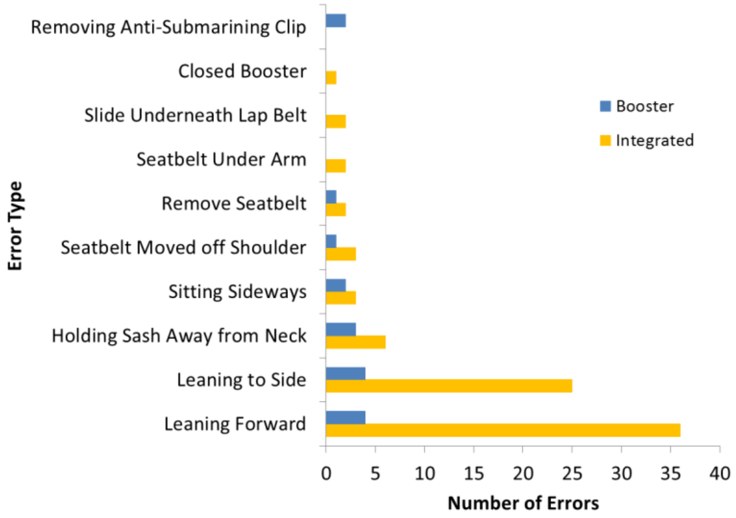


***Figure 11: Types and occurrences of child-introduced use errors observed in both integrated and add-on boosters***

## Discussion

In summary, the findings from this body of work are that;

- There is no evidence of better or worse performance of integrated boosters compared to add-on boosters in the real world, but they are not commonly used, so data is sparse.

- Dynamically, the integrated booster examined was as good as or better than current design high back add-on boosters in frontal impact and for struck side occupants in side impact. However the good performance in side impact is reliant on the outboard seating position and the presence of a side curtain.

- There is an inherent lack of lateral support of the torso and the head in the integrated booster cushion examined compared to the high back add-on booster. Less than optimal control of lateral motion for the non-struck occupant was observed in the integrated booster in side impact. While this may be impacted by pre-tensioners, these were not fired in the tests and it is unknown whether these would fire in the real world in side impact and what difference this would make to occupant kinematics.

- The primary perceived barriers to compliance with legislation among Australian families were issues surrounding compatibility between child restraint and vehicle, and the ability to install three restraints across the rear seat. Integrated restraints can solve the compatibility issues, but will not necessarily make it easier to install three restraints.

- Parents perceive integrated restraints as easier to use than add-on boosters, and the integrated system scored very well using the CREP ease of use evaluation. There were also fewer parent induced errors in installation and securing of the child in the integrated system compared to the add-on booster.

- No benefits for child induced error, posture and improved seat belt fit in the integrated booster system across a range of child sizes were identified and further work is required to confirm optimal design features for these aspects of misuse.

## Limitations

The North American crash data[5] included integrated forward facing child restraints and booster seats in the integrated restraint sample, and there are significant differences in the design of child restraints, particularly of the age included in the CHOP analysis, between North American and Australian child restraints. For the Swedish data, comparison of restraint performance was reported through personal communication with researchers from Volvo.

In the frontal dynamic testing, it should be noted that we observed failure of the seat assembly on the rebound sled when tested using the AS/NZS1754 test pulse. The association between this behavior in this simulated impact environment and the likely behavior of the seat assembly in the real world is unknown. In the side impact testing, seat belt pre-tensioners are provided in the rear seat of the vehicle tested but these were not fired during the test. It is possible the activation of pre-tensioners would alter the lateral motion of the dummy in both restraints, but this is not known.

Participants in the laboratory study of ease of use were exposed to the add-on booster first and the integrated booster second. The failure to randomize the order in which they were exposed may have influenced some results. However, the consistent increase in errors observed among participants installing the add-on restraint, and among children seated within the integrated restraint suggest this effect if present was likely minor.

## Conclusions

Current Australian legislation is adequate but could be strengthened by including requirements in the relevant Australian Design Rules that integrated boosters be supplied in outboard positions in combination with side curtains. Until policies are in place to ensure good side impact protection for all positions, and to minimise child induced errors, there is no evidence to support active encouragement of integrated boosters. The exception may be in commercial vehicles and in aftermarket third row seats where integrated boosters could address barriers to optimal child restraint use in these situations.

## Acknowledgements

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